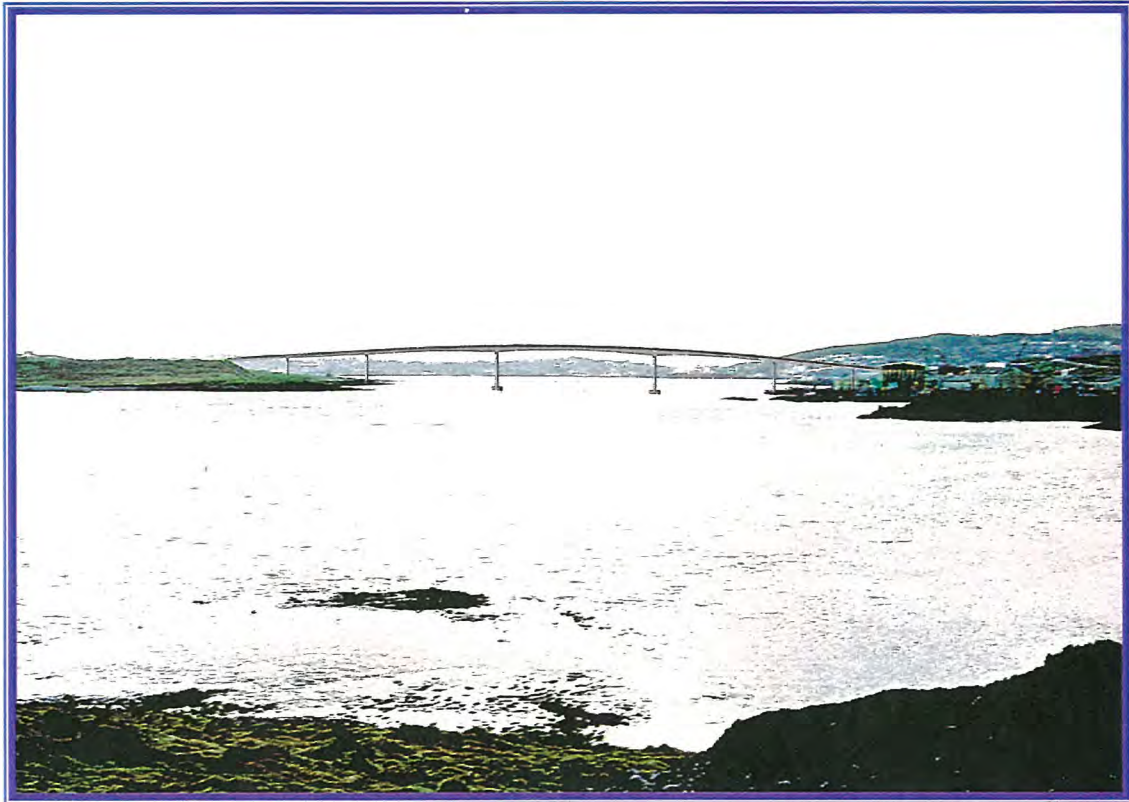


SHETLAND ISLANDS COUNCIL

FIXED LINK TO BRESSAY



**FEASIBILITY STUDY
ABBREVIATED REPORT**

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1

INTRODUCTION

1.1

General

Halcrow Crouch were appointed by Shetland Islands Council in December 1998 to undertake a feasibility study into providing a fixed crossing of the Bressay Sound from Lerwick on the Shetland mainland to the Island of Bressay.

1.2

Brief

The brief for the commission was given in the Shetland Islands Council's letter to Halcrow Crouch dated 27th November 1998. A brief summary of the objectives are reproduced as follows:-

1.2.1

Location

To investigate crossings at Point of Scotland and also at Greenhead and at North Ness.

1.2.2

Options

To identify a number of realistic options at these sites including:-

- High Level Bridges
- Bridges to lesser requirements
- Opening Bridges
- Immersed Tube Tunnels
- Bored Tunnel

For each option, to establish the following:-

- Preparation, design and construction costs
- Operating maintenance and repair costs
- Likely refurbishment intervals and costs
- Design life.

In addition, the brief asked for the following to be addressed:-

- Construction Requirements
- Safety Implications
- Land and Legal Issues
- Environmental Implications
- Availability of Crossing
- Sources and Availability of External Funding

1.3

Site Visit

Representatives from Halcrow Crouch visited the sites twice during the study. The first visit was in mid January and included crossing to Bressay, photographing and reviewing the topography and development at each site in relation to the ordnance survey maps utilised and reviewing the nature and integrity of the outcropping rock. It also included a meeting with the Lerwick Harbour Trust who provided useful information including an inventory on the number and size of vessels visiting Lerwick Harbour during 1997 and 1998 and details of the operating regulations for vessels using the harbour.

The second visit was at the beginning of March and enabled concepts being developed in the office to be verified or otherwise.

1.4

Consultation

Consultation with the large number of interested parties who may have an interest in a fixed link to Bressay was not part of our brief. However in addition to consulting with the Lerwick Harbour Trust, we have also written to the Royal Navy with respect to their interests in navigation through the Sound in relation to a fixed link.

We have also sought information from several departments of the Shetland Islands Council including Marine Operations, Legal and Property Services and Finance and Housing on various aspects of the commission. We have also liaised throughout with the Environment and Transportation Department.

INTRODUCTION

We have also consulted with Herbosche Kiere, the contractor undertaking the contract at the O.I.L. Base at Greenhead in relation to construction matters associated with dredging in and construction adjacent to the north channel.

1.5

Information Utilised

In undertaking this commission we have utilised extracts from ordnance survey maps provided by the Council's Environment and Transportation Department. We have also utilised the Admiralty Chart for the Sound of Bressay and various geological references listed in Section 2.3. In addition Arch Henderson and Partners on behalf of the Lerwick Harbour Trust, graciously provided us with copies of two marine site investigation reports, one for the new quay/dock at Gremista Pier and the other for the refurbishment of the O.I.L. Base at Greenhead.

We obtained statistical data from the Meteorological Office on wind speeds and directions recorded at Lerwick Observatory over a 26 year period from 1970. We also obtained information from the Council's Marine Operations Department on the operating criteria for the existing Bressay Ferry Service and figures on the number of disruptions to this service over the past year. In addition we obtained details of recent road and tunnel projects in Norway from the Norwegian Public Roads Administration.

The Environment and Transportation Department also provided information on recent and proposed planning applications for developments in the vicinity of the three sites.

2

DESCRIPTION OF SITES

2.1

Topography and Development

2.1.1

General

The location of the three sites to be considered is shown in Figure 2.1. Consideration of topography for this study was based on the site visits by representatives of Halcrow Crouch together with a photographic record of these visits. It was also based on the extracts from ordnance survey maps which were updated to take cognisance of recent developments. This information was considered sufficient for this feasibility stage but if the fixed link were to be considered further then a detailed topographic survey at the chosen location should be undertaken.

2.1.2

Point of Scatland

Access to the Point of Scatland site on the Lerwick side is facilitated by a single carriageway road from Lerwick Town Centre. On the Bressay side the existing single track road from the ferry terminals stops at the Heogan Fish Processing Plant some 400 m short of the crossing point. There is an unsurfaced track leading on from this which provides access to the few residential properties.

There has been fairly extensive development along the waterfront on the Lerwick side including a recent office/factory building for Lerwick Fish Traders, a warehouse utilised by a road haulier and a pub/club, as shown on Figure 2.2. There is also a navigation beacon north of the junction between the access road leading to these properties and the main road. Furthermore planning permission has also been granted for a further similar factory/office building between the existing factory/office building and the warehouse.

It should be noted that potential development on the land between the buildings and the main road has been deferred pending the selection of a preferred route for the fixed link.

On Bressay, notwithstanding the fish processing plant, there has been very little development with only a few cottages, some of which are derelict. The land is presently in agricultural use as rough grazing.

On the Lerwick side the land slopes fairly steeply at about 1 in 10 from the main road at a maximum level of 22 m above OD to about +8 m AOD before falling

more gently to the shore. Above the main road, the Hill of Greenhead rises to a maximum level of 75 m AOD. The hardstanding used by the road haulier is land reclaimed from the sea.

On Bressay, the land slopes more gently at a gradient of about 1 in 20 with the property known as Annfield situated at a level of about 16 m AOD. The end of the existing single track road at Heogan is at +10 m AOD.

There are also two undersea cable crossings at the Point of Scatland site. Power cables cross the channel south of the Shetland Fish Traders factory, whereas British Telecom cables cross further north and take a less direct route.

2.1.3

Greenhead

Access to the Greenhead site on the Lerwick side is facilitated by both the high level road which leads on to Rova Head and Dales Voe and a low level road which provides access to the O.I.L. base and the other industrial developments.

On Bressay as with Point of Scatland, there is no existing road beyond Heogan, almost 1 kilometre from the crossing landing point at Turra Taing.

As with Point of Scatland, there has been extensive development along the Lerwick shoreline and the O.I.L. base is presently being refurbished in an £8M contract which comprises new quay walls and dredging to provide deep water access and berthing facilities.

At the north end of the O.I.L. base there are existing industrial buildings and further north still there is a recently completed green industrial building which we understand is a waste processing facility operated by S.O.E.S. Much of the adjacent land is also being cleared for potential development. The land used for this development has been reclaimed from the sea. The new waste incinerator plant has also been built between these buildings and the existing high level road.

In addition to land reclamation, the hillside has been excavated behind the new waste incinerator plant. There is therefore a steep slope between the high level road which follows the 25 m contour and the developed area which is relatively flat at a level of around +5 m AOD. North of the waste incinerator plant however the road level falls and an offshoot provides access to the waterfront developments. It is worth noting that there is also a disused quarry to the north west of this location which is presently used to store scrap.

DESCRIPTION OF SITES

On Bressay there is no existing or recent developments and the land is relatively flat at around +6 m AOD although at the promontory known as Turra Taing it rises up to a maximum level of +10 m AOD.

2.1.4

North Ness

The Lerwick side of this crossing falls on a well established part of Lerwick town with extensive residential, retail and industrial development. Indeed the older industrial units on the promontory are presently being demolished and replaced by road and drainage infrastructure and the establishment of sites for housing and industrial development. Road access to this site is facilitated by the construction of a new roundabout in Commercial Street. The Hays Dock just north of the promontory is one of the original Lerwick Harbours and is a listed structure.

On Bressay there is practically no development and the existing single track road to Heogan is set well back from the coast rising over the Hill of Cruester at a level of 40 m above MHWS. From the road the ground slopes steeply at a gradient of about 1 in 7 down to the high water mark. This contrasts with the Lerwick side where Commercial Street is at a level of 10 m AOD with the north Ness promontory being somewhere lower at around 3-6 m AOD. In land of Commercial Street the topography rises to a maximum level of 30 m AOD but is heavily developed with residential buildings. Being an older part of the town, we also understand that it is a conservation area.

2.2

Hydrography

2.2.1

General

Consideration of the Hydrography for the study was based on the most recent Admiralty Chart for the Sound dated 1995 together with information provided by Lerwick Harbour Trust on both recent dredging works in the north channel and their intentions with respect to future dredging operations.

This information was considered sufficient for this feasibility stage but if a fixed link were to be considered further then a detailed hydrographic survey at the chosen location should be undertaken. As this operation would cause some disruption to navigation through the Sound it should possibly be undertaken in conjunction with a marine geotechnical investigation.

2.2.2

Point of Scotland

The width between high water marks on each side of the Sound is around 385 m and is shown on Figure 2.5. At this location the navigation channel is

approximately 95 m wide and is close to the centre of the waterway being some 125 m from the Lerwick shore and 170 m from the Bressay shore.

The water depth is relatively shallow shelving gently from the shoreline on both sides to 5 m below chart datum at the edge of the navigation channel. It should be noted at this point that mean high water springs is 2.2 m above chart datum and chart datum is 1.22m below Ordnance Datum. The navigation channel is presently dredged to 6 m below CD although the Harbour Trust have stated that it is their intention to dredge the channel to -7.5 m at some date in the future.

2.2.3

Greenhead

This is the shortest crossing with a minimum width between the quay on the Lerwick side and the shoreline on Bressay of some 280 m although to avoid the existing buildings, the crossing length could be up to 320 m. The navigation channel is 100 m wide but is located much closer to the Lerwick shoreline, as shown on figure 2.5. As previously discussed the existing buildings on the Lerwick side have been developed on reclaimed land. The water in front of the quays on the Lerwick side has been dredged to 9 m below chart datum to provide berthing for vessels.

At the north end of the promontory there are rock outcrops in front of the areas of reclaimed land. Beyond these outcrops the seabed slopes very steeply down to a level of -10 m below CD. This level merges with the channel which has been dredged to 9 m below chart datum. On the Bressay side the seabed slopes more gently from the promontory known as Turra Taing and meets the channel at a level of 5 m below CD.

2.2.4

North Ness

The width between high water mark on each side of the Sound at this site is around 610 m although there are rock outcrops at the Loofa Baa and Holm of Cruester which although providing a less direct route would provide founding points for bridge piers or shallower water for a cut and cover tunnel.

The hydrography can therefore be described in three sections:-

- Between the North Ness and the Loofa Baa
- Between the Loofa Baa and Holm of Cruester
- Between Holm of Cruester and the Bressay Shore

DESCRIPTION OF SITES

The waterway between the Loofa Baa and the North Ness is some 260 m wide and incorporates the 100 m wide navigation channel which is dredged to 9 m below CD.

The Loofa Baa is an area of rock rising to 0.7 m below chart datum. The seabed on each side of this waterway slopes down fairly steeply to the edge of the navigation channel particularly on the Loofa Baa side.

The Loofa Baa and Holm of Cruester are some 280 m apart and whereas the Loofa Baa is permanently submerged, Holm of Cruester outcrops above low water. The waterway between has a maximum depth of 6.2 m below chart datum but over 200 m of the width is 2 m below CD or less.

Between Holm of Cruester and the Bressay shoreline, the water is shallow with a maximum depth of just over 1 m below chart datum.

2.3

Geology

2.3.1

General

Consideration of ground conditions at the three sites was based on the following reference documents:-

- Solid and Drift Geological Maps (Sheet 126) for the Shetlands
- Geological Memoir: The Geology of Western Shetland (1976)
- Site Investigation Report for the New Quay/Dock at Shetland Arch
- Marine Site Investigation O.I.L. Base, Lerwick
- British Regional Geology: Orkney and Shetland (1976)

The site investigation reports obtained courtesy of the Harbour Trust relate to the Gremista Quay which is immediate south of the Point of Scatland crossing and the O.I.L. Base which is between Point of Scatland and Greenhead.

The foregoing information was considered sufficient for this feasibility stage but if a fixed link were to be considered further then a detailed site investigation study would be required at the chosen location. The extent of this study would depend on the form of crossing chosen and would obviously be more extensive if a tunnel option was preferred.

DESCRIPTION OF SITES

Transport warehouse at Point of Scotland. The Rova Head conglomerate is a matrix dominated coarse conglomerate with rounded pebbles of granite and quartzite which can locally reach 1 m in diameter.

2.3.3

Point of Scotland

For crossings at this location bridge piers will be founded on or tunnels will be excavated in Lerwick sandstone. A key feature of this rock is the very variable state of weathering and/or alteration which does not show any particular spatial distribution or any pattern in the state of degradation. Rocks at this location are medium to coarse grained sandstones in which the constituent grains are generally poorly sorted and angular. Because of the poor sorting, stratification is not well developed and bedding cannot be identified with confidence. The sandstones contain occasional pebbles, a high proportion of feldspars and appear to have a sparse carbonate cement. The rock mass is assumed to contain steep to vertical planes and smooth discontinuities. The strength of the rock is anticipated to range from moderately weak to moderately strong with an average value of 12 MPa.

2.3.4

Greenhead

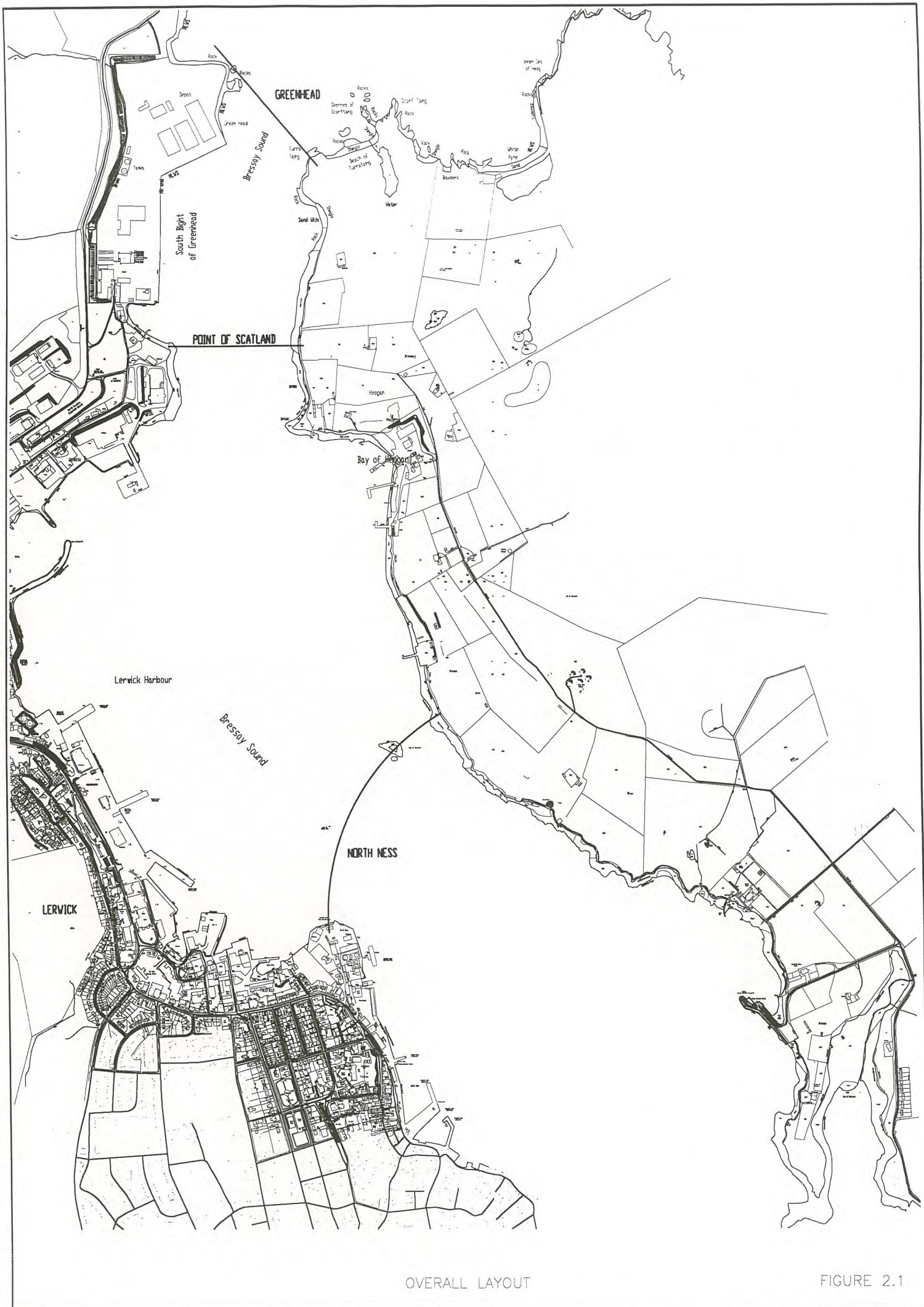
For crossings at this location bridge piers will be founded on or tunnels will be excavated through conglomerate on the Lerwick side changing laterally into pebbly sandstone on the Bressay side.

The sandstone conglomerate is a matrix dominated conglomerate with a coarse reddish brown to grey matrix and clasts ranging from fine gravel to cobble sized, generally sub angular or rounded. The conglomerate has been irregularly weathered showing a weathered horizon towards the upward boundary of the deposit comprised of very dense conglomerate clasts gravel in a sandy matrix. The strength of the rock does not seem to show any correlation with depth ranging generally between moderately strong to strong rocks with unconfined compression strengths of around 40 MPa.

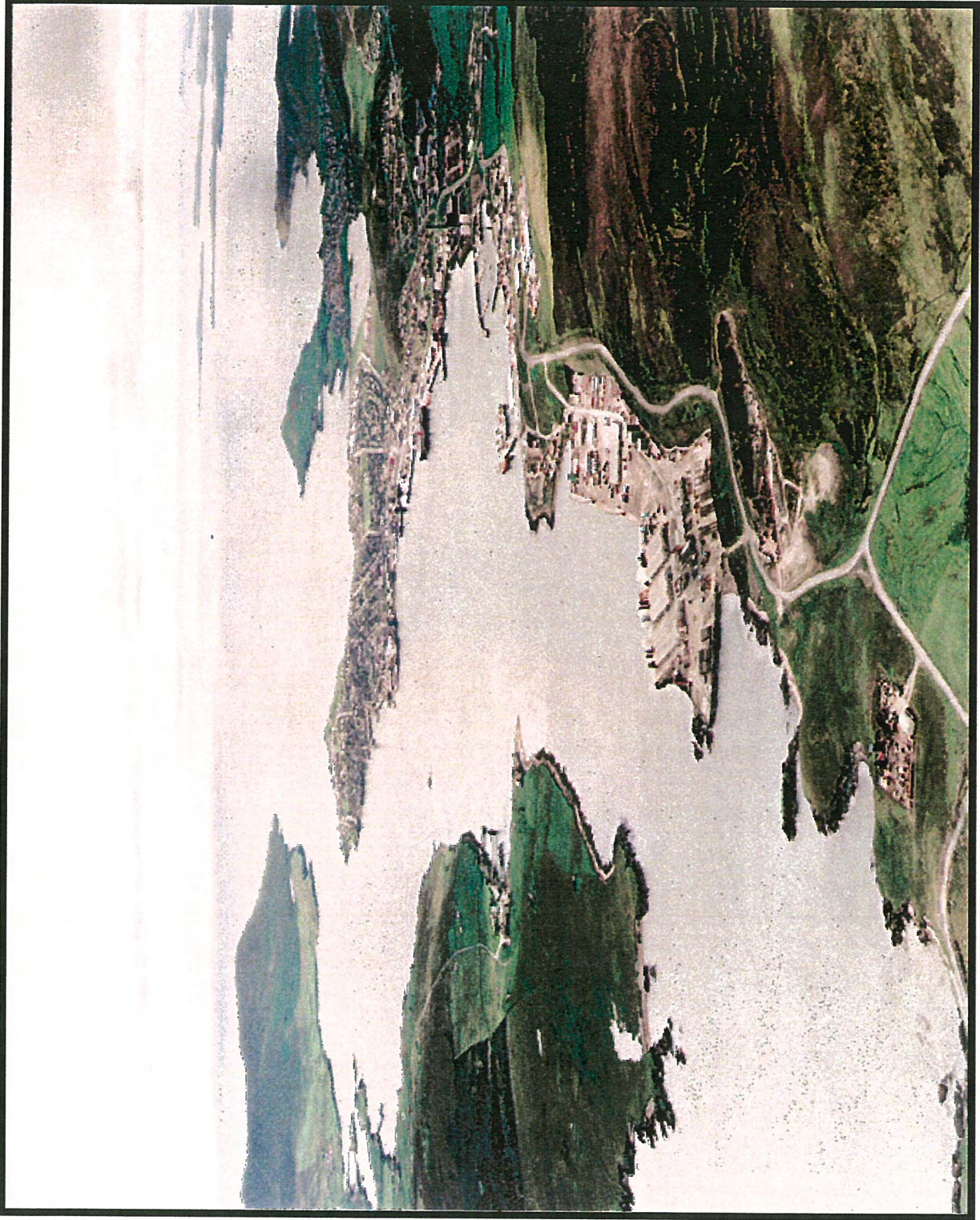
2.3.5

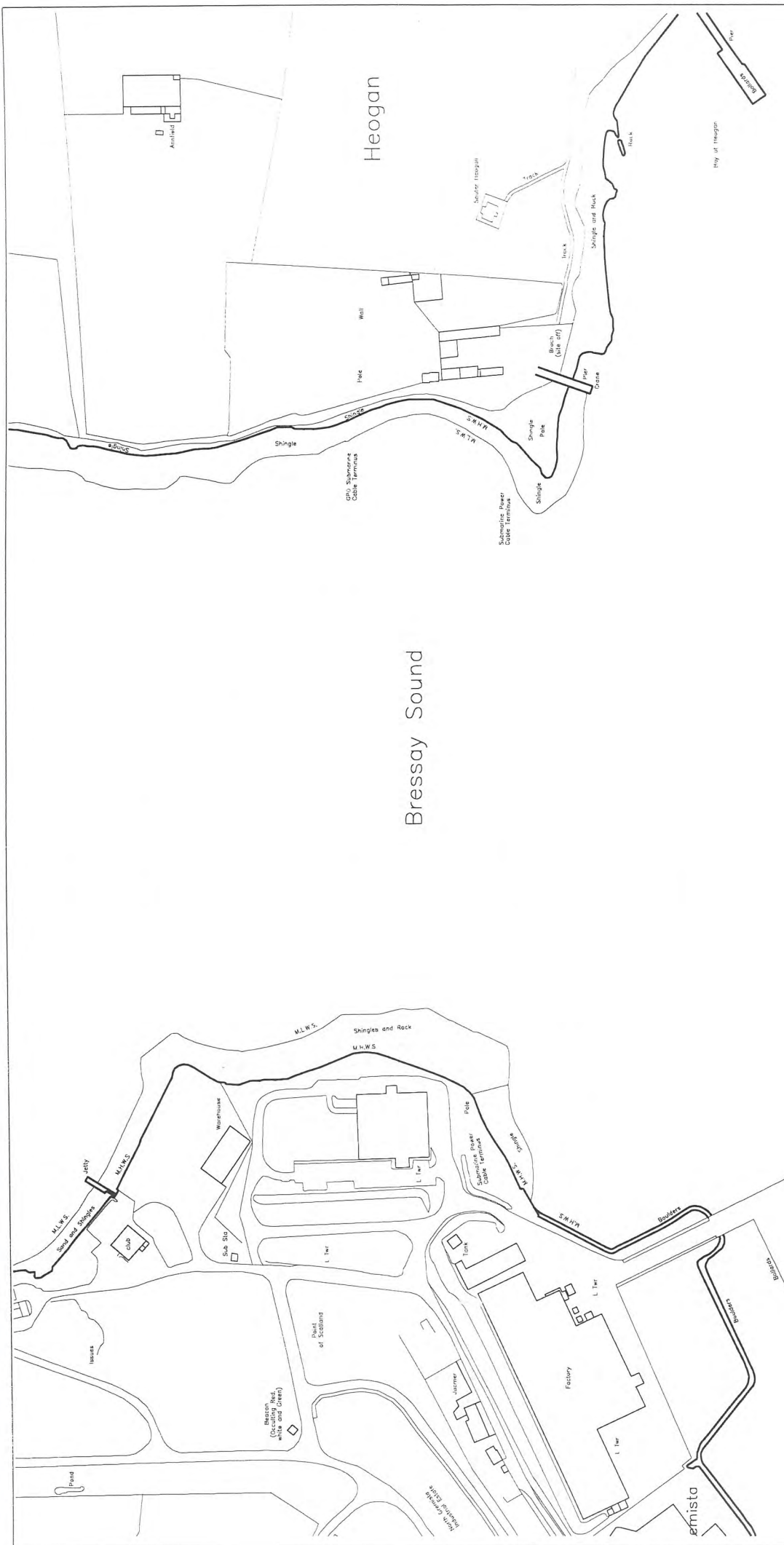
North Ness

Very little information regarding the North Ness crossing at Lerwick is available although it is expected that the approaches at both sides of the channel would have to be excavated entirely through the Lerwick sandstone.

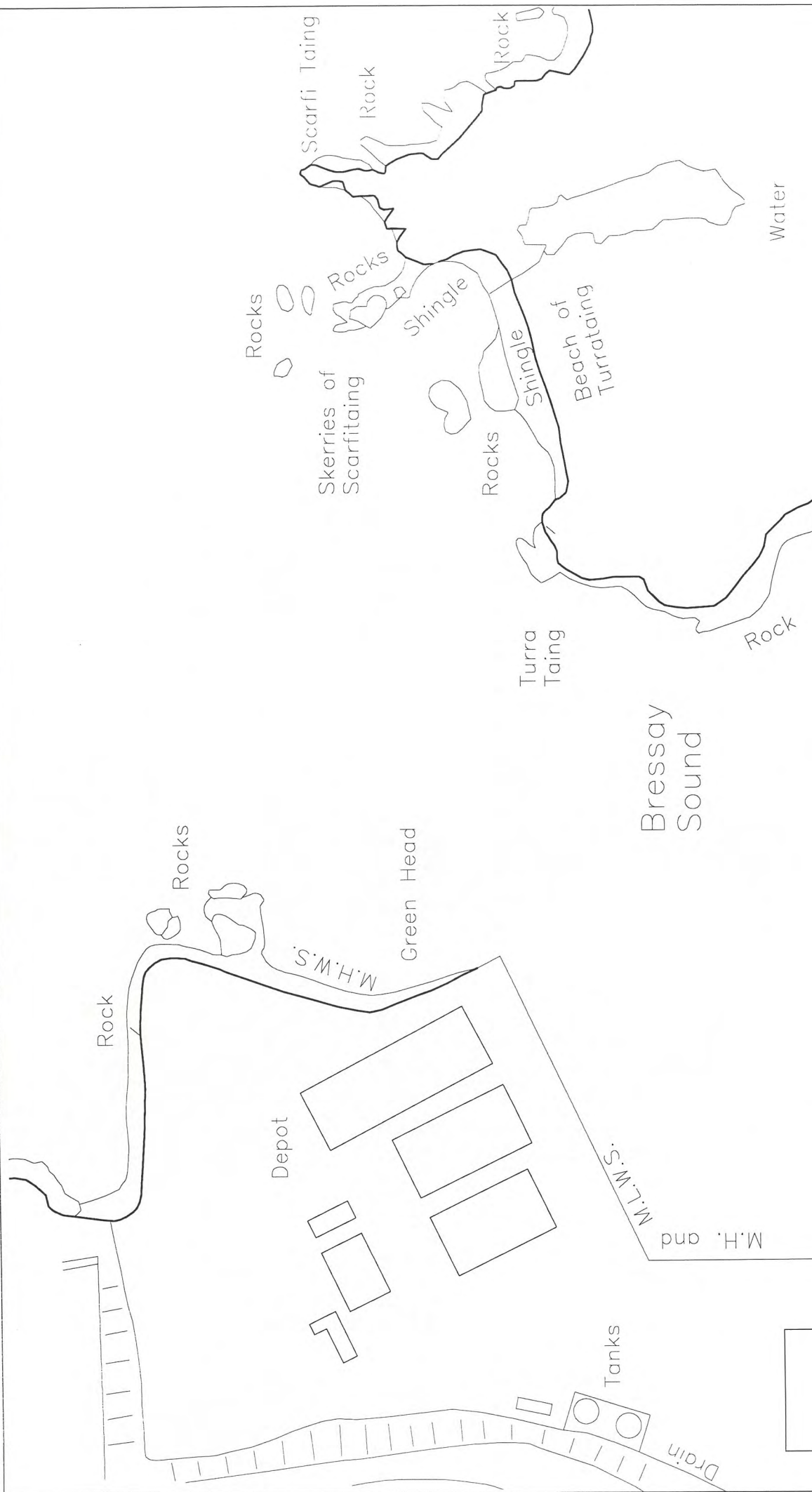


AERIAL VIEW
PLATE 5



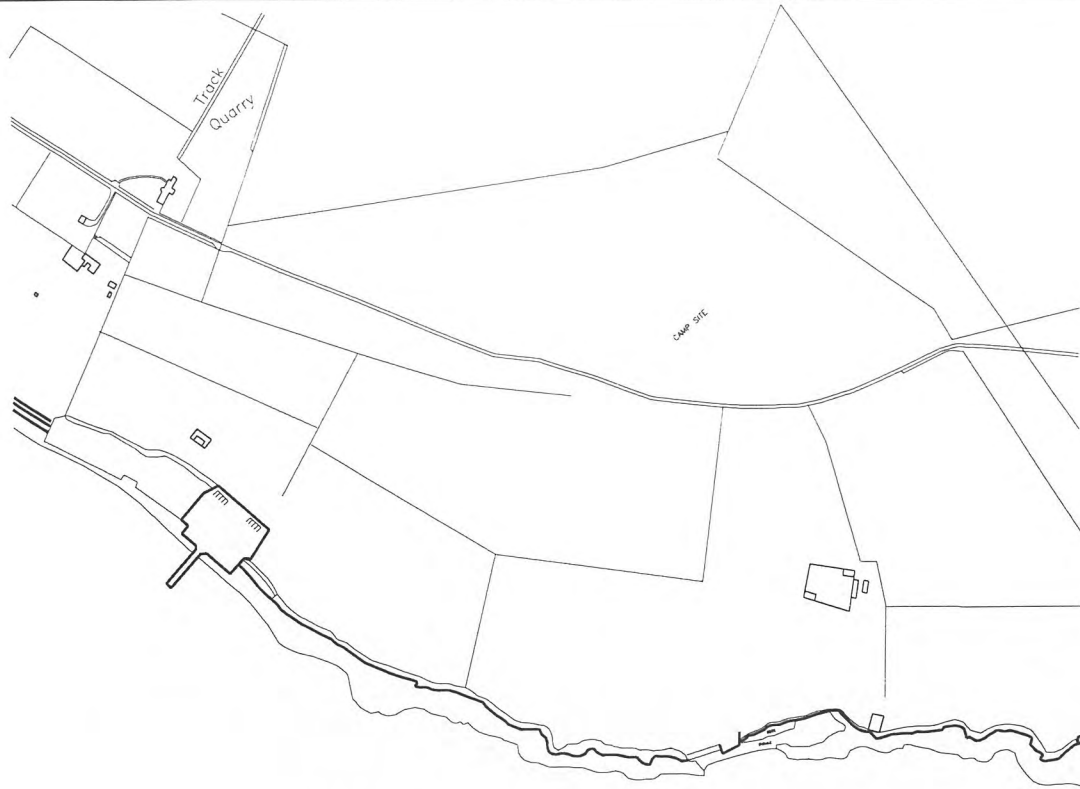


POINT OF SCOTLAND
EXISTING LAYOUT



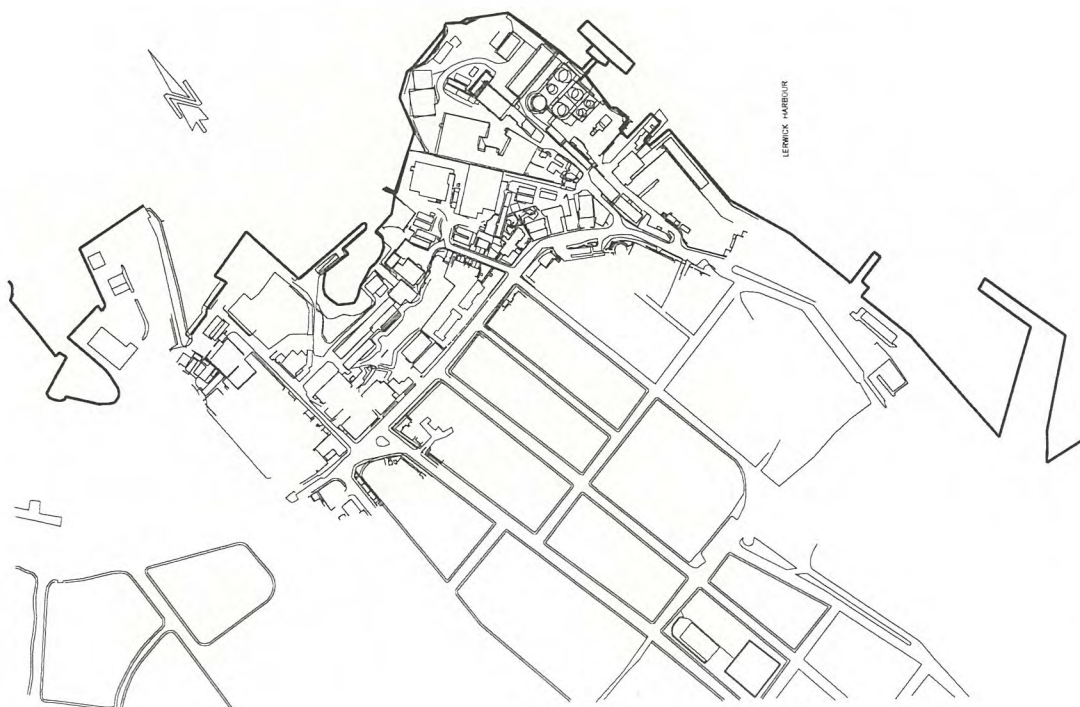
GREENHEAD
EXISTING LAYOUT

FIGURE 2.3



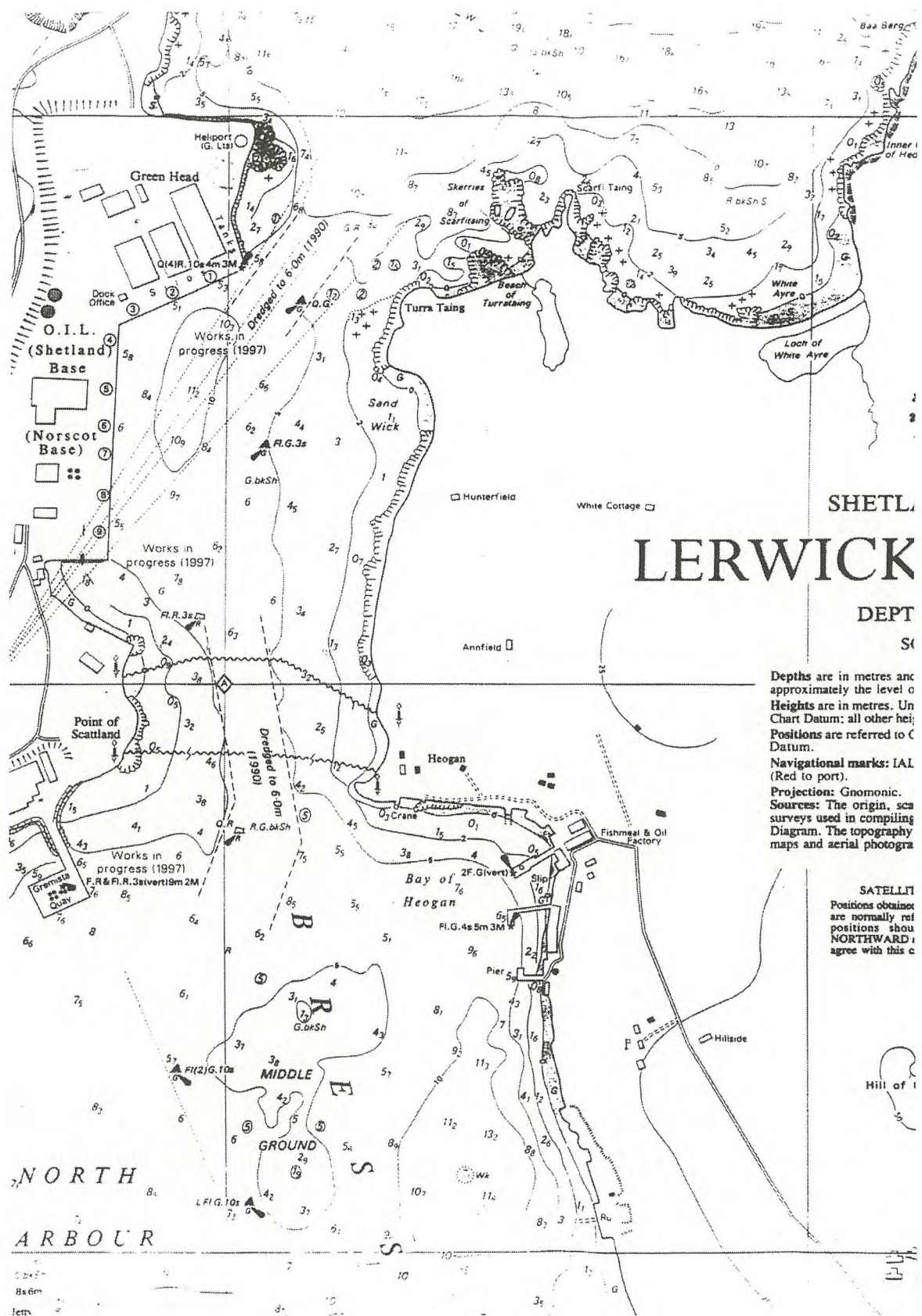
LODGE BAY

Bressay Sound



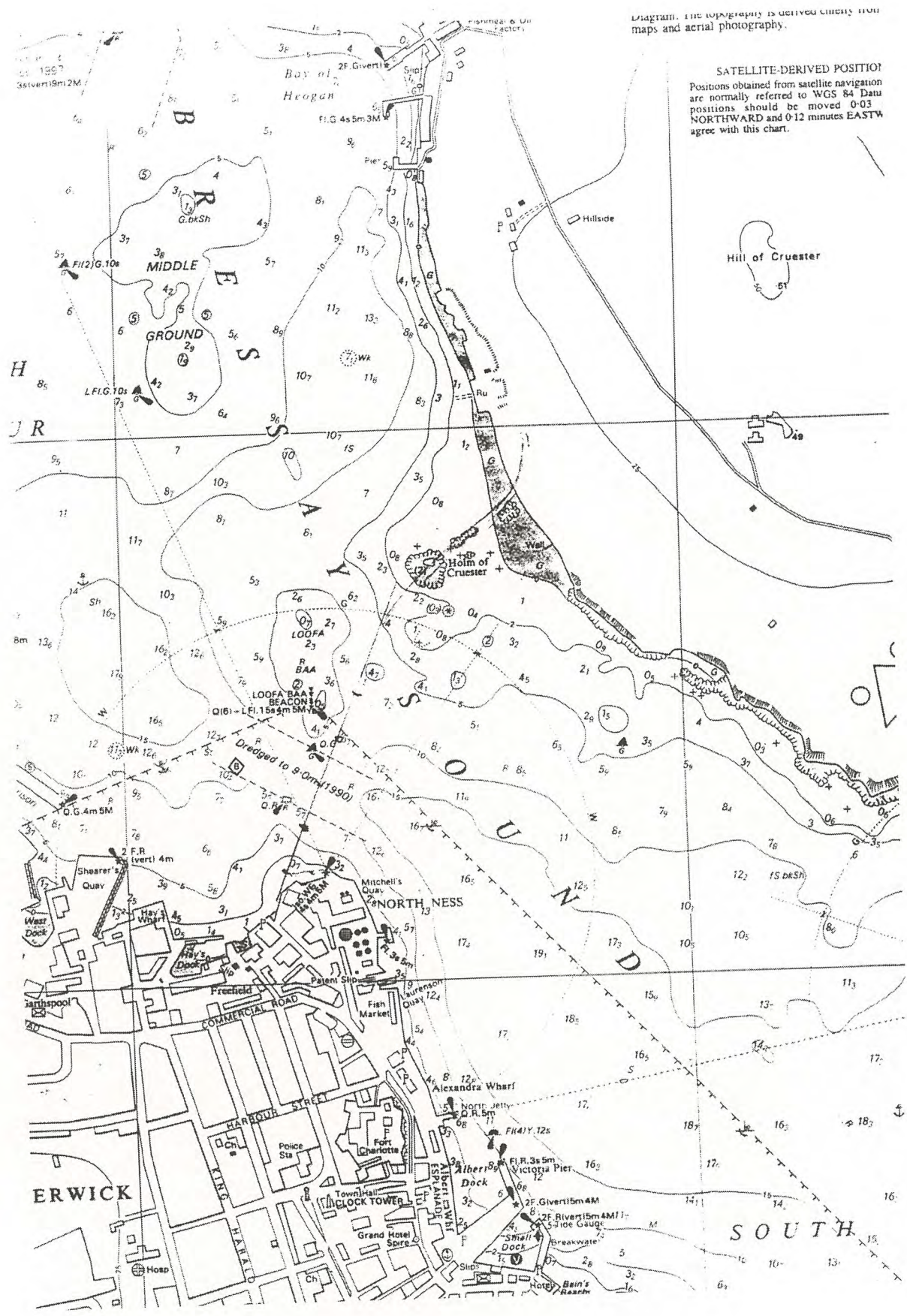
NORTH NESS
EXISTING LAYOUT

FIGURE 2.4



NORTH CHANNEL HYDROLOGY

FIGURE 2.5



NORTH NESS HYDROLOGY

FIGURE 2.6

3

Design Criteria

3.1

General

The brief for the commission required that the consultants establish appropriate design criteria in the consideration of options although the council specified the carriageway and footpath paths.

Two cross sections were stipulated. Firstly a single lane 3.5 m wide with 2 No. 2 m wide footpaths giving an overall width of 7.5 m and secondly a two lane 6.7 m wide carriageway with 2 No. 2 m wide footpaths. Following discussions with the Council, we agreed to also consider a 6 m wide carriageway with 2 No. 1.5 m footpaths to minimise the overall width while maintaining two lanes and footpaths on both sides.

3.2

Roadworks

For preliminary roadworks design was undertaken in accordance with the DMRB. A design speed of 70 kph has been considered and the maximum vertical gradient has been taken as 8%. This gradient exceeds the maximum gradient of 6% for single carriageways from TD9/93 (Highway Link Design) but in hilly terrain steep gradients can be considered provided that a departure from standard is sought. The alignment on many of the bridge options could accommodate a higher design speed but reducing the design speed on the bridge options would not result in any significant cost savings.

For tunnel options the design criteria utilised for alignment was as outlined above in conjunction with consideration of the Highways Agency departmental draft standard BD78 "Design of Road Tunnels".

3.3

Bridgeworks

For preliminary bridgeworks design loads and load combinations have been considered in accordance with BD37/88 "Loads for Highway Bridge". For highway live loading, full HA and 37.5 units of HB have been considered. Abnormal loading has not been considered at this stage but significant abnormal vehicles could be accommodated on the bridge provided that the bridge was temporarily closed to all other traffic and individual axle and wheel loads did not exceed those of normal heavy goods or HB vehicles.

Preliminary design of elements was in accordance with the Design Manual for Roads and bridges and BS 5400.

Particular technical memoranda considered included BD 57/95 "Design for Durability" and BD49/93 "Design Rules for Aerodynamic Effects on Bridges."

3.4

Ship Impact

No specific design standards are available for defining ship impact forces in relation to bridges given the site specific nature of any location considered. As several bridge options at the three sites would have piers and foundations adjacent to the navigation channel, a preliminary study was undertaken to determine impact loads on pier foundations as this loadcase was likely to be critical in sizing these elements. Where the preferred option is to comprise a bridge with foundations adjacent to the navigation channel then a detailed risk assessment and impact study should be undertaken to quantify the risk and consequent impact forces.

No collisions with the superstructure of bridges was considered in that it was assumed that when the bridge was completed vessels with an air draft exceeding that available would be excluded from the channel.

The risk of vessels colliding with bridge foundations is dependent on a number of factors including operating restrictions, environmental conditions, mechanical failure, human error etc. It is obviously also dependent on the depth of water adjacent to the foundations. The impact force with which a vessel is likely to strike a pier is dependent primarily on vessel size and type and speed over the ground.

In determining the ship impact forces applicable to the Bressay crossing, we have based our studies on experience gained on ship impact studies for the Kessock Bridge at Inverness and the Second Severn Crossing in England.

Both these studies considered vessels of around 6,500 tonnes.

Data on vessels visiting Lerwick Harbour were provided by the Harbour Trust. However no information was available for the number and size of vessels using the north channel although vessel size will presently be restricted by the limiting channel depth of 6.5m. As 6,500 tonne vessels have a draft of around 6.5 m, they are therefore unlikely to use the north channel at present. If the channel is dredged in the future to a depth of 7.5 m below CD however then larger vessel could obviously use the channel.

6,500 tonnes was therefore taken as the design vessel in our preliminary studies and a ship impact force of 30 MN was used in the design of the bridge foundations.

In respect of ship impact it is worth noting that the Harbour Trust have full radar surveillance and control the movement of all vessels in and out of the harbour and this will have a significant bearing on any risk assessment.

3.5

Navigational Clearance

As described in the foregoing the navigational channel at all three sites is around 100 m wide and all bridge options would aim to maintain this clear width as a minimum requirement. A potential problem with the Point of Scotland crossing raised by the Harbour Trust was that vessels entering the harbour through the north channel have to swing sharply at this location to avoid the middle ground and berth at the Gremista Quay or other harbour berths. This manoeuvring therefore has a bearing on the clear width of channel required between supports and the Harbour Trust have requested that a clear width of 150 m be provided.

The brief requires that the vertical clearance from high water level to the soffit of any bridge or aircraft is taken as 40 m.

This is in line with the Harbour Trust's requirements and enables vessels such as the 7,700 tonne Maersk Euro Quatero to pass below the bridge.

By way of comparison, a 30 m aircraft has also been considered as this would still enable all but the largest vessels to pass. It is also typical of the aircraft provided at other locations including Kessock and Skye Bridges.

For the swing bridge option, a clearance to the soffit of the bridge of 12 m has been considered. This would enable smaller vessels to pass without the bridge needing to open.

4

OPTIONS

4.1

High Level Bridges

4.1.1

General

As detailed in the foregoing section, high level bridges have been considered for 40 m aircraft over the navigation channel. The overall length of the bridge was then established on the basis of the limiting design criteria most notably an 8% approach gradient. This is considered to be the maximum and a lesser gradient has been adopted where possible, such that for aircrafts less than 40 m the approach gradients have been reduced as opposed to the bridge lengths being shortened. It is worth noting that the Skye Bridge has 8% approach gradients.

Span lengths over the main channel have been considered as detailed in Section 3.4, notably providing a minimum navigation clearance of 100 m, providing the Harbour Trusts desirable minimum clearance of 150 m and also providing a clear span of 250 m to found piers in shallow water and minimise the impact of the bridge structure on navigation.

High level bridges have also been considered in relation to the range of carriageway widths outlined in Section 3.1. It should be noted however that a single carriageway width has not been considered in conjunction with a 260 m mainspan option because of concerns about the stability of the bridge deck in relation to the dynamic effects of wind.

For the required navigational clearance bridges of lengths in excess of 700 m are required and given this factor and the steep approach gradients and their consequent impact on forward visibility, a single lane carriageway is not recommended. A single lane carriageway would also be unable to provide for traffic growth resulting from development on the Island and it would be disproportionately expensive to widen the bridge structure at a later date. A single lane when considered in conjunction with steep approach gradients would also lead to greater congestion and it would be difficult to resurface the carriageway without closing the bridge to traffic.

Given that the bridges are of significant length however, minimising the width of a two lane carriageway option could achieve significant savings in cost over the specified width. Hence a 6m carriageway with 2 No. 1.5m wide footpaths has been considered. Construction and operational maintenance costs are given in

Section 6 and comment on the weather susceptibility of high bridge options is given in Section 7.

4.1.2

Point of Scotland

As described in Section 2.1.2 there has been extensive development on the Lerwick side of the Sound with planning permission granted for an additional factory/office building adjacent to the existing one. Given that ground has been reserved for a possible fixed link behind these buildings it would be feasible to build a high level bridge over the top of the buildings. This is far from ideal from a construction point of view and it would raise a number of significant safety issues with respect to the possibility of vehicles falling off the bridge and is therefore not recommended.

The most suitable line therefore is immediately to the north of the Shetland Transport Warehouse and given that there are no restrictions on the Bressay side crosses directly over the Sound. There would be a pier on the hardstanding utilised by the haulier and significant disruption during construction which may necessitate temporary or permanent relocation of the business. This alignment should also avoid the BT undersea cables crossing the Sound.

As previously described the navigation channel is 100 m wide and is centrally located with respect to the width of the waterway. This is of benefit aesthetically in terms of providing symmetry in the bridge form.

An advantage of locating the crossing point north of the Shetland Transport warehouse is that being further north, vessels entering the harbour will generally clear the bridge before having to swing to avoid the Middle Ground or berth at Gremista Quay. It may be worthwhile to undertake ship simulation studies for the design vessel in conjunction with the Harbour Trust to determine the minimum clear width required at this location. A further advantage of this crossing location is that while it will impose a restriction on aircraft for vessels entering the harbour, it imposes no restriction on access to the O.I.L. base at Greenhead which is currently under re-development. Furthermore, the waters north of the bridge crossing would still provide a haven for large vessels seeking shelter from adverse weather conditions.

Box Girder – 125 m Mainspan – Option 1

The first option considered at this location is a box girder as detailed on Figure 4.1, which could either be steel or concrete and is of variable depth over the mainspan and immediate backspans. The box girder varies in depth from 5.0 m at the main piers to 3 m at the midspan of mainspan and 2.5 m in the approach spans. The

width of the box would vary with carriageway width, sufficient to maintain 2 m wide cantilevers on each side. The minimum mainspan length considered was 125 m to allow for the width of the foundations and fendering and leave some slight margin for error. For a 40 m aircraft, 8% approach gradients are required and the overall bridge length is 770 m. As previously described, for a 30m aircraft as shown on Figure 4.2 it is considered more appropriate to reduce the approach gradients to 5.5% and maintain the overall length as 770 m.

To maintain proportionality, the immediate backspans are shorter than the mainspan and are therefore also founded on the seabed. Given the relatively shallow water depth these piers will not be subject to significant ship impact effects. The approach viaducts then continue on both sides of the Sound supported by piers founded on land until meeting the rising ground on the Lerwick side and a rockfill embankment on the Bressay side.

A new roundabout is shown at the junction with the existing road at the Lerwick end of the fixed link. A 400 m length of new road would connect the Bressay abutment with the existing road at Heogan. Apart from the rockfill embankment adjacent to the bridge abutment, this road would follow the contours of the existing ground.

If a concrete option were utilised then this could take the form of a prestressed concrete box girder as shown on Figure 4.3. Prestressing could either be by internal grouted tendons or external unbonded tendons. The former option is more efficient but as the moratorium on the use of internal grouted tendons has only recently been lifted, great care would be required to ensure the tendon ducts were fully grouted during construction. To ensure durability concrete mixes utilising blended cement and air entrainment would be adopted together with adequate cover to reinforcement.

For a steel option there are two alternatives; a steel box girder with a composite concrete deck slab or a steel box girder with an orthotropic steel deck and mastic asphalt surfacing as shown on Figure 4.4. Given the island location, the mastic asphalt would have to be laid by hand and would be relatively expensive to relay at each 20 year resurfacing cycle. Another disadvantage of an all steel structure would be its susceptibility to dynamic effects induced by wind, and wind tunnel testing may well be required. No such problems would be anticipated with the composite steel and concrete box girder as it has already been proved on the Scalpay Bridge and elsewhere.

To minimise maintenance cycles, a long life paint system would probably be specified on the external surfaces of the steelwork to give a life to first

maintenance of at least 25 years. With respect to protective coating, the advantages of a box girder are that the external surfaces are relatively self-cleansing and are free from ledges and crevices where debris can gather and corrosion can develop. This should therefore ensure against premature failure of the paint system.

Access would be provided throughout the inside of both steel and concrete box girders for maintenance and extensive services could also be accommodated within the box. A gantry together with rails attached to the deck soffit could also be provided for maintenance access to the external surfaces.

A disadvantage of the box girder options and the steel box in particular, would be that it may not be practical to incorporate wind shielding, as this in itself could give rise to instability resulting from dynamic wind effects. Further studies could establish what form of wind shielding if any could be incorporated.

The piers would be in reinforced concrete with their width being slightly greater than the width of the box. The thickness of the piers would vary from 3 m to 1.75 m and the same considerations would be given to durability as the deck in the specification of the concrete as outlined above for the deck.

Bearings would be utilised on each pier top to transfer load from the deck to the piers although with a concrete box the deck could be made integral thus saving on future maintenance costs.

The bridge parapets could be of aluminium for enhanced durability and the deck slab would be waterproofed with a spray applied waterproofing system.

The main piers straddling the navigation channel are supported on reinforced concrete caissons. These are designed for the ship impact loads described in the foregoing sections and would be of the order of 15 m long by 10 m wide. The caissons would be infilled with mass concrete or granular material and would be capped with a structural slab to support the pier shaft.

It is interesting to note that for a 40m aircraft, ship impact loads are only slightly more critical for overturning than load effects such as wind or bearing friction applied at deck level. Therefore there appears to be no significant benefit in using rockfill islands around the caissons as an alternative means of ship impact protection as the caissons without ship impact loads would not significantly reduce in size. Rockfill islands would also have the further disadvantage of reducing the navigation channel and therefore changing the flow characteristics with the consequent adverse environmental impact.

The top of the caissons are set at a level above mean high water springs to prevent a vessel oversailing the caisson on impact and striking the pier.

The caissons will be founded on sound bedrock which will necessitate the removal of overburden and weathered rock. The other marine and land based piers will be supported on reinforced concrete spread foundations which will also be founded on bedrock.

The abutments will be minimal reinforced concrete bankseat type structures. The Bressay abutment may have to be supported on piles extending through the rockfill embankment to prevent excessive differential settlement.

The fixed link will also incorporate variable message signs to give instruction to vehicles in high winds. Appropriate wind thresholds are described in section 7.

Box Girder – 160m Mainspan – Option 2

The next option considered is also a box girder as above with a mainspan of 160 m which when allowing for the width of the piers corresponds with the minimum span requested by the Harbour Trust to allow for vessels manoeuvring. Details are shown of Figure 4.5 and a computer generated impression on Plate 1.

The main pier foundations, although in slightly shallower water, were still designed for the ship impact forces described in Section 3.4. One advantage of this option is that with proportioned backspans all piers other than the main piers would be founded on land, above mean high water springs. Avoiding marine construction for these piers will have the consequent benefits of reducing construction cost and also environmental impact. The box girder would vary in depth from 6.5 m at the main piers to 4 m at the midspan of mainspan and 2.5 m throughout the approaches, but in all other respects this option would be identical to the previous option considered.

Box Girder – 260 m Mainspan – Option 3

A third option considered also utilised the box girder form of construction but had a mainspan of 260 m which ensured that the piers were founded in only 2 m of water with the consequent minimal impact on navigation. Details are shown on Figure 4.6 and a computer generated impression on Plate 2. The piers are not therefore at risk from significant ship impact. The mainspan at 260 m would be 10 m longer than the Skye Bridge. If it were formed in concrete it would equal the Varoddbrau in the Vest-Agder region of Norway in having the longest span of its type in the world. If it were formed in steel then it would be a little way behind the Ponte Coste e Silva in Brazil, which with a mainspan of 300 m is the longest of its

type in the world. The box girder would be 10 m deep at the piers reducing to 6.5 m at the midspan of mainspan and 4.5 m throughout the approaches.

Through Truss – Option 4

An alternative form of construction would be the through girder warren truss, as shown in Figures 4.7 and 4.8 and Plate 3. This form of construction could be utilised in all the span configurations considered for the box girder options but is shown with a 160 m mainspan.

As vehicular and pedestrian traffic pass through the truss the construction depth is less than the box girder options and the approach gradients could be reduced marginally below 8%.

The superstructure consists of a steel truss comprising longitudinal chord members which are shown as box girders but could equally be plate girders. The vertical web members and transverse deck members would be plate girders while the plan wind bracing would be rolled or hollow sections. The deck supporting the roadway would comprise a reinforced concrete slab which would act compositely with steel or concrete precast beams.

The height between top and bottom chords would be 8 m except at the piers where it would be increased to 14 m to resist bending effects and would provide normal headroom clearance for vehicular traffic throughout. It would however impose a restriction on high loads.

Protective coating to the external surfaces of the steelwork would be as for the steel box girder option with the exception that if boxes were used for the chords of the truss then these would have to be sealed as they would be too small for internal access. Because of the configuration the steelwork would also be more susceptible to corrosion than a box girder and would probably require more frequent maintenance cycles.

The main advantage of this through truss option is that the truss is sufficiently stable with respect to aerodynamic effects to facilitate the incorporation of wind shielding to reduce the incidence of bridge closures due to high wind. Being enclosed by the steel frame will also enhance the perception of safety for the bridge user and will prevent vehicles being blown off the bridge.

In all other respects this option will be similar to the box girder options with the exception that the piers will be wider to provide support to the truss chords.

Cable Stayed Bridge - Option 5

A further option comprises a cable stayed bridge as shown on Figure 4.9 and plate 4. This is considered as an alternative to the box girder or truss for a 260 m mainspan only, as it is not considered economic for shorter span lengths. The main piers would also therefore be founded in shallow water only 2 m deep.

The symmetrical cable stayed structure shown has a deck supported by cables arranged symmetrically in fan configuration from two towers projecting 50m above deck level. These towers would be in reinforced concrete and in side elevation would be in A frame or diamond configuration. The cables would be of the parallel wire type enclosed in pvc sheaths for durability. The deck could be either a concrete beam and slab structure prestressed longitudinally or two steel box girders acting compositely with a reinforced concrete slab.

In elevation the structure would therefore be similar to the Helgeland Bridge in the Nordland Region of Norway, albeit with a much shorter mainspan. At 260 m the mainspan is of a similar length to Kessock Bridge. As with both these bridges, scale models of the proposed bridge would have to be wind tunnel tested to ensure that they were stable aerodynamically.

The cables would also be tied to each other to ensure their stability.

The piers other than the main piers would be reinforced concrete leaf walls, as for the box girder option.

A disadvantage of this option would be the height of the towers. Not only would they dominate the surrounding landscape but they would also present a potential hazard to helicopter traffic which, we understand, uses the Shetland coastline for navigation.

A further disadvantage would be maintenance of the towers and cables in that specialist operatives or access plant would be necessary to undertake maintenance.

4.1.3

Greenhead

Box Girder – Line 1 – Option 6

As with Point of Scotland and as described in Section 2.1.3 there has been extensive development on the Lerwick side of the Sound with the most recent building being the Waste Process Facility operated by SOES.

This therefore restricts the options for a possible crossing. As described in Section 2.2.3, the navigation channel, although still 100 m wide is quite close to the Lerwick shore. As a bridge structure at this location would restrict access to the redeveloped O.I.L. base, only a 40 m airdraft was considered at this location.

The most suitable line therefore crosses from the rocks on the shoreline north of the waste process building to the promontory on Bressay known as Turra Taing. As described in Section 2.2.3, the seabed beyond these rocks slopes very steeply down to a level of 10 m below chart datum. Any bridge foundation would therefore have to be founded on these rocks. While this would have the benefit of reducing cost and environmental impact, the next pier would have to be located on the shallower water on the other side of the navigation channel and so the minimum mainspan length would be around 180 m, as shown on Figure 4.10.

To maintain proportionality the immediate backspans are shorter than the mainspan and both are founded on land. Because of the skewed alignment however the bridge line crosses the bay north of the Greenhead promontory and an approach pier will be founded in the water although the water is relatively shallow at 4 mBCD and the foundation would not have to be designed for ship impact. An alternative option would be to reclaim this area of the seabed.

The Lerwick approach viaduct then crosses the northern access road to Greenhead before meeting the rising ground where the abutment would be located. The approach viaduct on Bressay continues beyond the shoreline for a further two spans before being replaced by a rockfill embankment. The overall bridge length is therefore 800 m which is greater than at Point of Scatland.

The deck form would be a box girder or truss as for the Point of Scatland crossings, Figures 4.3, 4.3 and 4.8.

The piers and abutments would also be as for the Point of Scatland Crossings. The caisson on the Bressay side of the navigation channel would be founded on the seabed at 7 m below chart datum and would therefore be larger than the caissons required at Point of Scatland. It would also be designed for ship impact as before. So although only one caisson would be required, with the additional marine foundation on the Lerwick approach there would be no significant savings in substructure costs. An 850 m length of new road would connect the Bressay abutment with the existing road at Heogan. The approach roads would follow the contours of the existing ground before rising on an embankment over the low lying area inland of the Turra Taing promontory.

Box Girder – Line 2 – Option 7

The only other alignment considered as Greenhead utilised the shortest crossing from the quayside in front of the industrial buildings on the Lerwick side to the Turra Taing promontory on Bressay as shown on Figure 4.12. The clear crossing width is 275 m and only one foundation would be required in the water on the Bressay side of the navigation channel. To bridge the navigation channel the minimum main span width would be 170 m. However because of the industrial buildings on the quayside the adjacent span on the Lerwick side would have to be 150 m to straddle these buildings and given the aircraft of 40 m over the navigation channel, the viaduct would have to tie in at a new roundabout on the high level road. This would enable the gradient on the approach viaduct to be reduced to 5.5%.

On the Bressay side the pier adjacent to the main pier would be founded on land and the viaduct would continue for a further three spans before being replaced by a rockfill embankment. The overall length of the viaduct would therefore be 830 m which is greater than any of the Point of Scatland crossings. All the other details would be as for the Point of Scatland and other Greenhead crossings.

As described for the Point of Scatland site, building over the existing industrial buildings is far from ideal in that it would make the installation of the deck over the buildings difficult and would raise a number of safety issues with respect to the implications of vehicles falling off the bridge. This would probably necessitate the use of high containment parapets. Construction of the pier on the quayside would also cause significant disruption to harbour activities.

4.1.4

North Ness

At this location 40 m aircraft would be required as a minimum for passage of the Ro-Ro ferry and other vessels. The navigation channel is also close to the Lerwick shore hence there is very little room to incorporate an approach viaduct to get the road back down to the low lying ground behind the Lerwick waterfront. The only possible options would be to either incorporate some form of spiral structure as in a multi-storey car park or to carry the viaduct over existing buildings and land further back. Either option would dominate Lerwick town centre and would involve significant disruption and demolition and they have therefore not been considered further.

would bridge the navigation channel and extend a good way to the shore on each side, as shown on Figure 4.12. The abutment structures at each shore end would provide a transition between the swing bridge and a causeway extending out 35 m from the high water mark on the Lerwick side and 50 m on the Bressay side.

The form of bridge structure is a balanced cantilever steel trough truss which would have sufficient stiffness to cantilever 80m. The cross section would therefore be similar to the high level truss option with the exception that an orthotropic steel deck may well be used in lieu of a reinforced concrete steel deck to reduce weight. This would have the disadvantage of requiring a mastic asphalt surfacing which would be hand laid and would be relatively expensive to relay in each maintenance cycle.

The causeways on each side of the Sound would extend as nominal embankments over land and would quickly meet the rising ground on both sides. On Lerwick, the fixed link would extend to a new roundabout at the existing junction, and on Bressay, the 400 m approach road would tie in with the existing road at Heogan.

A 12 m aircraft would be provided to enable smaller fishing vessels and pleasure craft to pass without the bridge opening. Dolphins would also be provided along the edge of the navigation channel. These would secure the bridge in the open position and would act as fenders to prevent vessels colliding with the superstructure and could enable vessels to moor while waiting for the bridge to open. It would be possible to mount the plant and control room for the operation of the bridge on one of these dolphins but this could equally be accommodated in the pier shaft supporting the swing bridge. The operator would have to have adequate visibility of traffic and shipping before operating the bridge however.

Operation of the swing span could be facilitated by a pair of hydraulic cylinders mounted horizontally. It is anticipated that rotation would be facilitated by a slewing ring of significant diameter. Locking dowels, cylinders and wedges would also be provided at the ends of each swing span to lock the bridge in the closed position and ensure positive reactions at the supports to prevent “chattering”.

In addition to using robust mechanical and electrical components, back up systems would also be utilised. Other mechanical and electrical devices would include the road barriers and wig wags together with advance warning signs.

Appropriate telemetry could also be installed to link the bridge controls to the Harbour Trust’s control centre which provides for continuous radar surveillance of the harbour.

OPTIONS

The pier shafts would be in reinforced concrete and could be hollow as described above to incorporate plant and control rooms as described above. They would be made continuous with the reinforced concrete caissons extending from seabed to above high water level.

These caissons would be designed for ship impact loads together with momentum effects and out of balance loads resulting from the operation of the bridge.

The steelwork for the trusses would be as for the fixed truss option.

4.2.3

Greenhead

An opening structure was not considered feasible at this location partly because of the proximity of the navigation channel to the Lerwick shoreline, but also due to the greater depth of water and the greater length of viaduct required on the Bressay side. The arc scribed by the swing span would also blight a significant area of land on the Lerwick side.

4.2.4

North Ness – Option 9

The alignment is shown on figure 4.12. A balanced cantilever double swing bridge identical to that utilised at Point of Scatland would span the navigation channel between North Ness and a point south of the Loofa Baa. On the Lerwick side a fairly steep ramp would be required to take the approach from the existing ground level of +4 m AOD to the swing bridge deck of +13 m AOD and this will inevitably interfere with the new infrastructure, pumping station and SLAP development sites. At the Loofa Baa the swing bridge will interface with an approach viaduct bridging the channel between the Loofa Baa and the rock outcrop known as Holm of Cruester. Beyond Holm of Cruester a causeway will carry the road over the shallow water to the Bressay shoreline. Given the alignment of the crossing it may be more appropriate to connect the existing approach road to Heogan by construction of a new carriageway along the shoreline.

The swing bridge will be identical to that described at Point of Scatland. The low level bridge between Holm of Cruester and the Loofa Baa would be a low level bridge with spans of an appropriate length.

Given that this crossing is much longer than that at Point of Scatland and will involve greater disruption on the Lerwick side it has little merit.

4.3

Bored Tunnels

4.3.1

General

The alternatives for a bored tunnel crossing include

- Excavation by TBM and lining by precast concrete segmental lining
- Excavation by road header and primary support provided by shotcrete, rock dowels and lattice girders with a permanent insitu concrete lining.

The topography and hydrography at each crossing location is the principal influence on the vertical alignment of the tunnel options. While the land at the Lerwick side of the sound is quite hilly at the northern sites increasing in steepness rapidly from the coastline, the topography at the Bressay side is more gentle at the northern sites but quite hilly at North Ness. The sea bed within the Bressay sound is known to be quite irregular changing in depth from 10.5 m BCD at the Greenhead crossing to 7.5 m BCD at the Point of Scatland crossing and to 16.2 m BCD at the North Ness Crossing.

For this study 8% has also been adopted as a maximum gradient when determining the alignment of the tunnel.

The proposed bored tunnel alignment assumes that a minimum of one tunnel diameter should be left between the tunnel crown and the rockhead below the sound. A minimum of half a tunnel diameter between the tunnel crown and the rockhead has been assumed for the remainder of the alignment. In order to achieve the required depth at a maximum of 8% gradient the tunnel approaches will have to extend some distance in land. At the Greenhead and Scatland crossings the tunnel approaches will need to start at a level of approximately 10 m above CD to be able to descend down to a tunnel diameter below the sea bed level. The tunnel approaches will be particularly long at the North Ness crossing due to the depth of the sound at that location (16.2 m BCD).

The vertical curvature of the alignment has been defined by a minimum desirable sag K value of 17 for the required design speed of 70 kph.

The horizontal alignment has been determined according to the following constraints:

- Existing buildings and services
- Connection with existing roads

- The minimum horizontal curvature allowed according to the Highways Agency Departmental Standard TD9/93.

For the bored tunnel the rectangular structure gauge is located within the circular tunnel profile as shown on Figure 4.13. This provides space above and below the structure gauge that can be utilised to locate tunnel services such as the ventilation fans, power and communication cables and drainage facilities. The cross sections proposed are detailed as follows:

Carriageway Arrangement	Internal Diameter
Single lane carriageway – 3.5m	9.2 m
Two lane carriageway – 6m	10.5 m

Normal headroom clearance of 5.5m is provided. It is worth noting that most road tunnels in Norway have a headroom clearance of less than 4.6m.

Frequently cladding is installed on the inside of segmentally lined road tunnels. The cladding serves three purposes:

- It provides a better surface for tunnel cleaning.
- It improves the aesthetics of the tunnel.
- It covers cables supplying services located in the tunnel crown.

For a bored tunnel the method of ground support is dependant on the method of excavation. If the tunnel is to be excavated by tunnel boring machine (TBM) then the tunnel will have a circular cross section and ground support will be provided by precast concrete segments. For excavation by road header the tunnel cross section need not be circular, as shown in Figure 4.14, and ground support is provided in the temporary condition with shotcrete and rock dowels. Permanent support would be provided with an in situ concrete secondary lining.

The water tightness of the segmental lining would be ensured by a rubber compression gasket around each segment. The annulus around the lining would be filled with cement grout.

Where ground support is provided with sprayed shotcrete and rock dowels the sprayed concrete would be reinforced with steel mesh or steel fibres. The permanent in situ concrete lining is likely to be unreinforced. To waterproof the tunnel a waterproof membrane would be installed between the primary and secondary linings.

The approaches to the bored tunnel will be excavated in an open cutting through peat deposits and into the sandstone. The side slopes of the cutting in sandstone may require some rock bolting and localised shotcrete to ensure long term stability. The bored tunnel portals have been located to provide half a tunnel diameter cover to rockhead.

4.3.2

Mechanical and Electrical Services

Within the tunnel structure various mechanical and electrical services are required. These include ventilation fans, power supply, lighting and drainage. The tunnel has to be sized to accommodate these services and the required structure gauge. The major components of the mechanical and electrical services are discussed in the following sections.

Monitoring and control of the mechanical and electrical services usually takes place at a central location and normally a purpose made tunnel services building is provided for this.

The most common form of ventilation for this length of tunnel is longitudinal ventilation with jet fans located in the tunnel crown. Exhaust fumes from the vehicles is carried along the tunnel by the airflow created by the fans and exhausted at the tunnel portals.

Tunnel Drainage

Water will be present inside the tunnel from sources such as tunnel washing, leakage through the lining or fire fighting, to collect the water, drainage sumps are usually provided at the following locations:

- Tunnel portals.
- Tunnel low point.

Associated with these sumps will be sump pumps, water level monitoring equipment, atmosphere monitoring equipment and where necessary a fire safety provision. The drainage requirements are common to both the immersed tube and the bored tunnel.

Interceptor Sumps

These sumps are located at the extremities of the tunnel and help reduce the water flowing into the tunnel from the access ramps and tunnel approaches and hence will reduce the quantities of water to be accommodated by the low point sump.

Low Point Sump

The low point sump, as its name suggests, is located at the lowest point on the tunnel alignment. The sump houses pumps, which transfer the water back to the tunnel portal for disposal. The pumping main, typically ductile iron pipe, would be located under the carriageway.

Sources of water (or other fluids) will include water from tunnel washing, leakage through the lining and fire-fighting water. Apart from allowances for water in the tunnel the drainage sump has to be sized to accommodate the contents of one cell of a petrol tanker.

As the drainage sump is an enclosed space with the possibility of containing petrol spills then some significant safety provisions have to be met. These provisions will be common to the immersed tunnel. Adequate space has to be provided for the M&E facilities associated with the sump including:

- Duty and stand-by pumps.
- Automatic water level monitoring - typically a robust and simple float system.
- Low oxygen monitoring equipment to allow for man-entry.
- Hydrocarbon monitoring equipment to sense petrol in the sump.
- Fire suppression equipment, which neutralises the petrol in the event of a spillage and allows for safe access to the sump chamber by the fire service. Typically a nitrogen foam system is employed.

Frequently oil and petrol skimmers are provided to facilitate separation from the drainage water, and collection of oil and petrol to a separate sump.

It is imperative that if a petrol spill is collected in the sump the drainage pumps are automatically stopped to prevent them pumping petrol out of the tunnel. A specialist contractor should remove any petrol, which has collected in the low point sump.

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Frequently oil and petrol skimmers are provided to facilitate separation from the drainage water, and collection of oil and petrol to a separate sump.

It is imperative that if a petrol spill is collected in the sump the drainage pumps are automatically stopped to prevent them pumping petrol out of the tunnel. A specialist contractor should remove any petrol, which has collected in the low point sump.

All safety systems should have the facility to be monitored locally and remotely in the tunnel services building. Similarly the pump controls should be local and remote, automatic operation and manual. Apart from the pumps and the safety system sensors all other equipment should be located outside the sump enclosure in the tunnel cross-passage located adjacent to the sump location.

Tunnel Lighting

Typically tunnel lighting is provided with high-pressure sodium luminaries. These are fixed to the walls of the tunnel. It is normal to light the tunnel in zones where the lighting intensity varies along the length of the tunnel. The highest lighting intensity being provided at the portals to allow for drivers to become gradually accustomed to the lighting in the tunnel.

Power Supply

The main power supply for tunnel services is normally 11kv and it is prudent to provide dual supply so that in the event of one supply cable being disrupted the other cable maintains the electricity supply to the tunnel. Under certain circumstances it is prudent to provide stand-by generation facilities.

Fire Fighting Main

At regular intervals along the tunnel it is normal practice to provide emergency points. These consist of:

- Emergency telephone
- Fire hose and extinguishers
- Fire hydrant

The emergency points are also convenient for locating electrical systems distribution panels e.g. lighting distribution panels.

Frequently CCTV cameras are installed in the tunnel to allow remote monitoring of the tunnel.

4.3.3

Point of Scatland

A suitable tunnel alignment at this location is made more difficult by the rising ground on both sides of the Sound and the fairly extensive development on the Lerwick side as previously described.

The most suitable route is therefore to follow the line taken by the bridge in crossing the Sound, but at the Lerwick landfall to swing northwards to run parallel with the contours whilst keeping, if possible, to low ground as shown on Figure 4.15.

On the Lerwick side the crossing will tie into the road providing access to the OIL base at a level of about +10 m AOD but considerable realignment of to the existing road layout will be required to facilitate this including the construction of a new roundabout.

The minimum horizontal curve on the Lerwick side is 260 m for which a superelevation of 7% will be required. On Bressay the tunnel approaches would tie into the existing road at Heogan.

The approaches to the tunnel will be constructed as open cut with structural support to the sides as necessary and as previously described.

The tunnel approaches will be excavated through the peat and boulder clay into the conglomerate sandstone on the Lerwick side and through the boulder clay into the Lerwick sandstone on the Bressay side.

The maximum depth of the seabed at this crossing is approximately central to the channel and with future dredging will reach a value of 7.5 m BCD. Thickness of the seabed gravel may vary considerably.

4.3.4

Greenhead

The suitable tunnel alignment at this location is also affected by the rising ground and waterfront development on Lerwick. On Bressay however, the topography is relatively flat, thus foreshortening the tunnel length. The most suitable alignment is therefore to follow the alignment for bridge option 6 in crossing the Sound but at landfall on the Greenhead promontory to turn away northwards to run parallel with the contours whilst keeping if possible to low ground as shown on Figure 4.17.

On Lerwick the tunnel would tie in with the existing road to Rova Head and Dales Voe with the construction of a new roundabout. Some realignment of this road would be required. The minimum horizontal curve on the Lerwick side is 260m for which a superelevation of 7% is required.

On Bressay the approach road would connect with the existing road at Heogan.

The approaches to the tunnel will be constructed as open cut except through the bay north of the Greenhead promontory where cut and cover techniques may be required. Alternatively this area could be reclaimed using tunnel arisings and an open cut approach maintained.

For the Greenhead crossing a bored tunnel excavation would be in the conglomerate sandstone at the Lerwick side changing laterally into the pebbly sandstone towards Bressay.

A disadvantage of this location compared to Point of Scatland is that the seabed has a maximum depth of 10.5 m and is located asymmetrically in the channel towards the Lerwick coastline. Seabed gravels will be found across the channel up to 8-10 m in depth. There is nothing therefore to commend this option in preference to Point of Scatland.

4.3.5

North Ness

On the Lerwick side the approaches to the crossing will have to be constructed through a built-up area affecting several houses and premises located along Commercial Road together with the new development site at North Ness itself. The approaches to the tunnel would follow Commercial Road as shown on Figure 4.18. The radius of curvature required for this alignment is approximately 255 m and therefore a minimum superelevation of 7% will be required. On Bressay the alignment could follow the contours along the coastline again requiring a horizontal curve of radius 260 m.

Very little information regarding the ground conditions at the North Ness Crossing is available although it is expected that the tunnel and the approaches at both sides of the channel would have to be excavated entirely through the Lerwick Sandstone. Some boulder clay deposits may appear at the Bressay approach.

The maximum depth of the sea bed at this crossing is asymmetrically located towards Lerwick and reaching a maximum value of 16.2 m. Sea bed deposits are also expected to be quite thick although the potential maximum is at present unknown. Given the greater depth of the seabed and the considerable disruption in Lerwick, this option has not been considered further.

4.4

Immersed Tube Tunnels

4.4.1

General

The immersed tube only requires a minimum of one metre cover to the seabed above the tunnel soffit. However due to the depth of the sound and to the size of

the box, similar constraints to those affecting the alignment of the bored tunnel will apply. However a maximum gradient of 6% can be employed on both sides of an immersed tube crossing.

The tunnel profile has been established according to the client requirements described in the foregoing and considering the Highways Agency departmental draft standard BD78; “Design of Road Tunnels”. The minimum internal dimensions of tunnel required to accommodate the carriageway width, both cycle lanes, minimum kerb, verge and height clearance requirements for the single and two lane carriageway would be as follows and as shown on Figure 4.19:

Carriageway Arrangement	Internal Dimensions of Tunnel	
	Width	Height
Single lane carriageway – 3.5m	7.5m	5.5m
Two lane carriageway – 6m	10m	5.5m

The height of the immersed tube elements can be minimised by locating the tunnel ventilation fans in the roof of the cut and cover tunnel approaches.

The cross section dimensions proposed above assume that the immersed tube would be single cell. An alternative to this would be to provide two cells thereby separating the cyclists from the car traffic. The “cyclist tunnel” would also provide a means of escape from the main tunnel in the event of an emergency.

Cladding to offer the required fire resistance would protect the roof of the immersed tube elements and the cut and cover approaches. For aesthetics the sidewalls may be also be covered with cladding.

Excavation for the immersed tube at the seabed level will require consideration of the strength of the rock mass in order to determine the optimum method of dredging. The structural and frictional properties of the rock mass at sea bed level will determine the appropriate slopes to be adopted for the cuttings to ensure their stability. Excessive silting up of the excavated trench could take place if strong currents exists within the channel but will depend on the nature of the seabed deposits. As these appear to be granular in composition silting should not be a significant problem

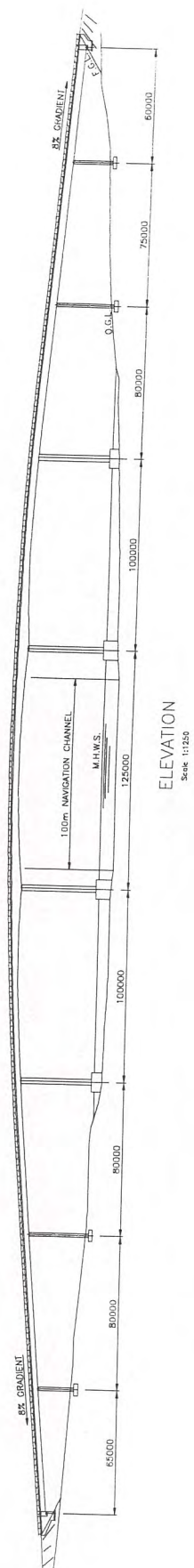
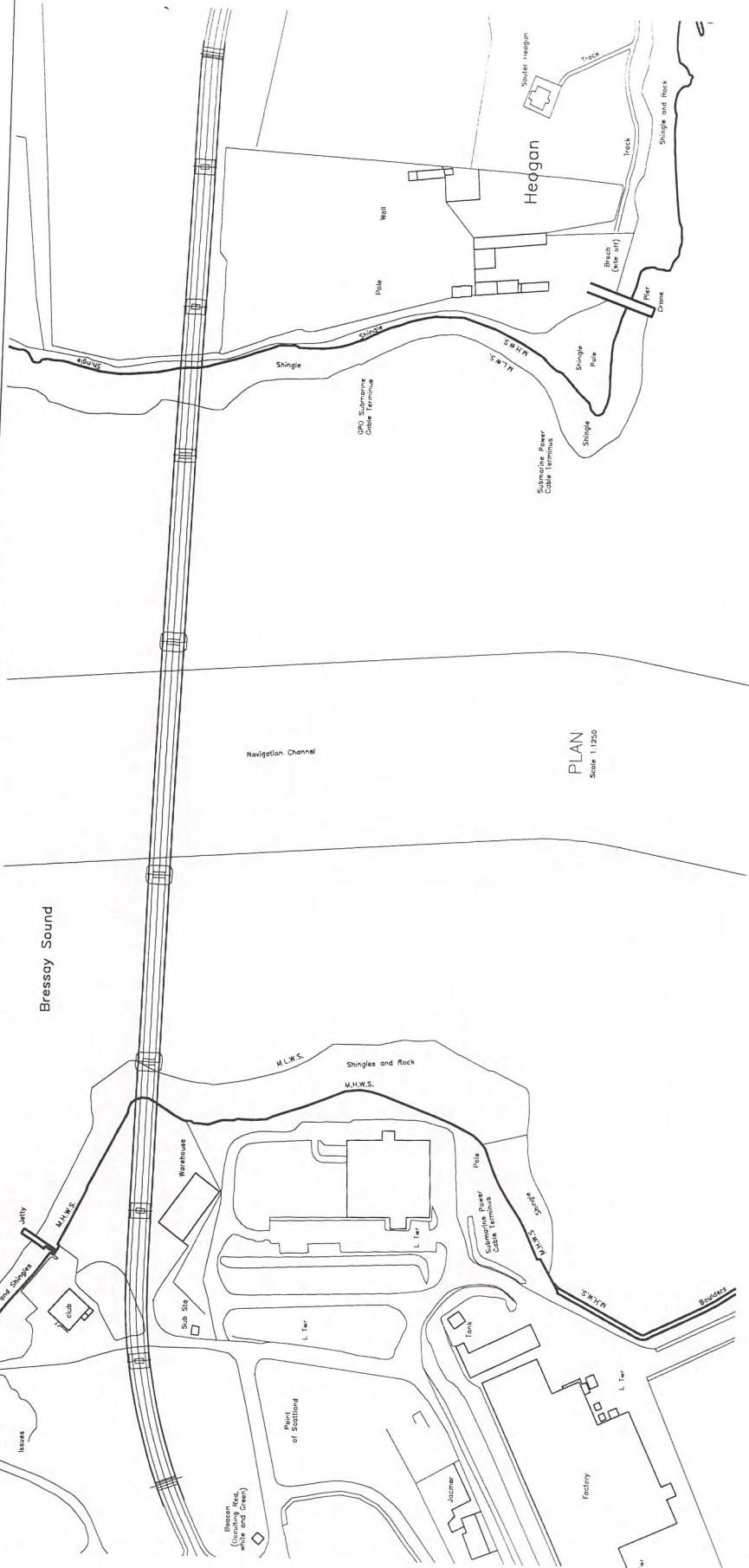
The optimum alignment at the Point of Scotland has been defined on the basis of the considerations described previously for the bored tunnel.

At the Lerwick side the preferred alignment will follow that proposed for the bored tunnel, as shown on Figure 4.20. While the maximum depth of the tunnel is less, as the approach gradients are also flatter, the overall tunnel length is only marginally shorter.

The tunnel approaches will descend below the watertable through made ground and seabed gravels. The final structure has to be watertight and impervious to the surrounding groundwater.

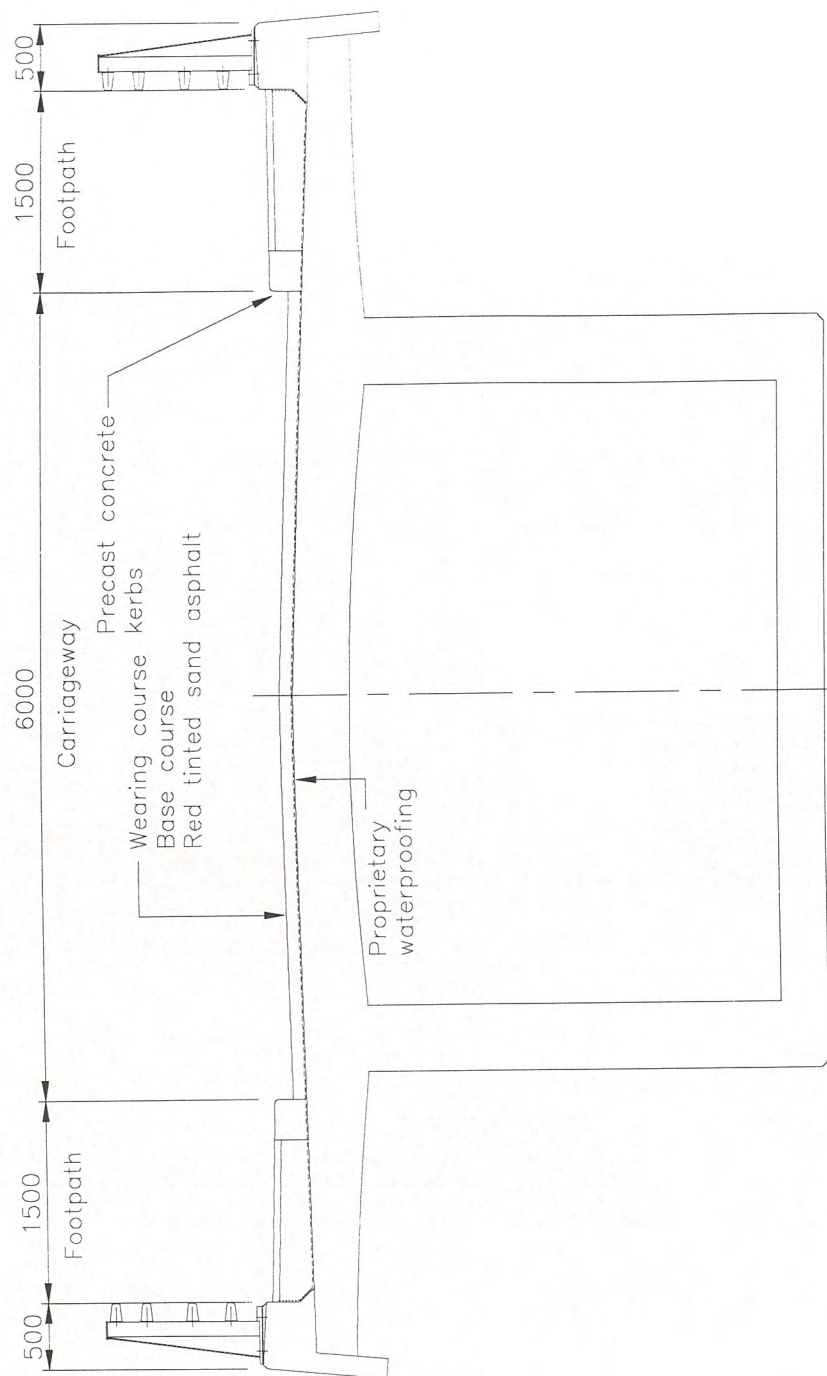
In order to construct the approaches, a cutting has to be excavated to well below groundwater level, which has to be kept dry during construction. It is proposed to excavate the cutting within temporarily reclaimed areas of land. On both sides a reclaimed spur would extend from the shoreline. For construction the reclaimed platform would extend to a level above highest tide level. On completion the platform would be lowered, where possible, to reinstate the existing sea bed profile.

Having reclaimed land on both sides of the crossing diaphragm walls could be employed to form the sidewalls of a retained cutting. Access for the construction plant being provided by the reclaimed platforms. The walls would toe in to the sandstone to provide a groundwater cut-off. It is proposed that the diaphragm walls would form part of the finished cut and cover approaches.

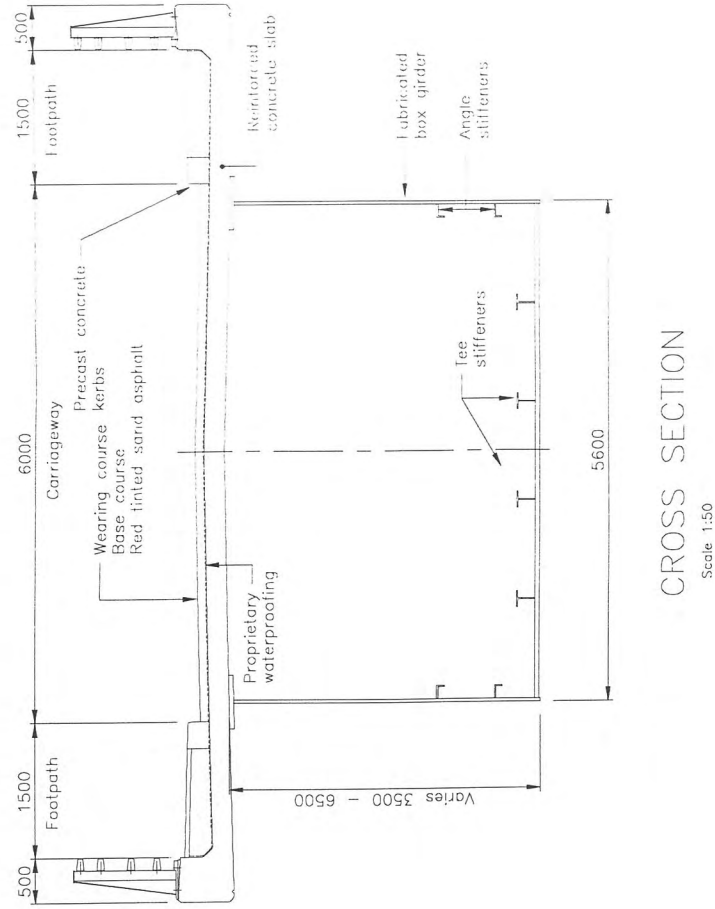
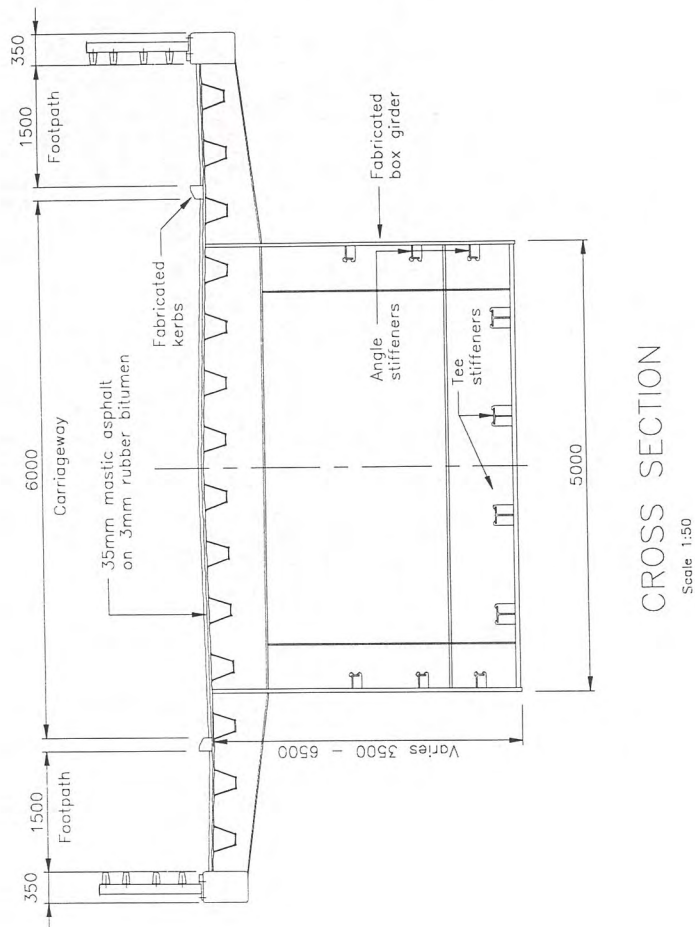


POINT OF SCOTLAND
BOX GIRDER
125m MAINSPAN - 40m AIRDRIFT

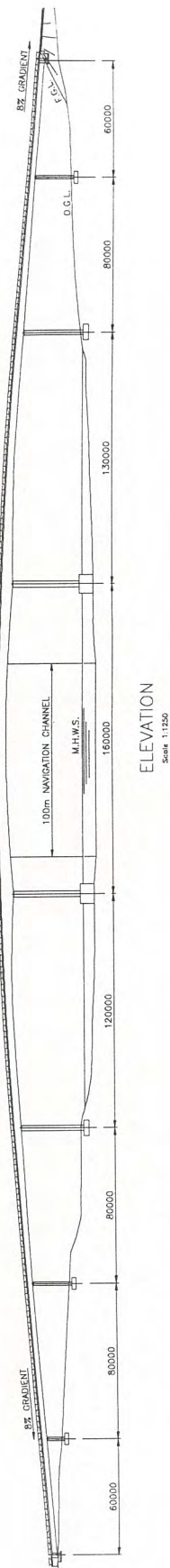
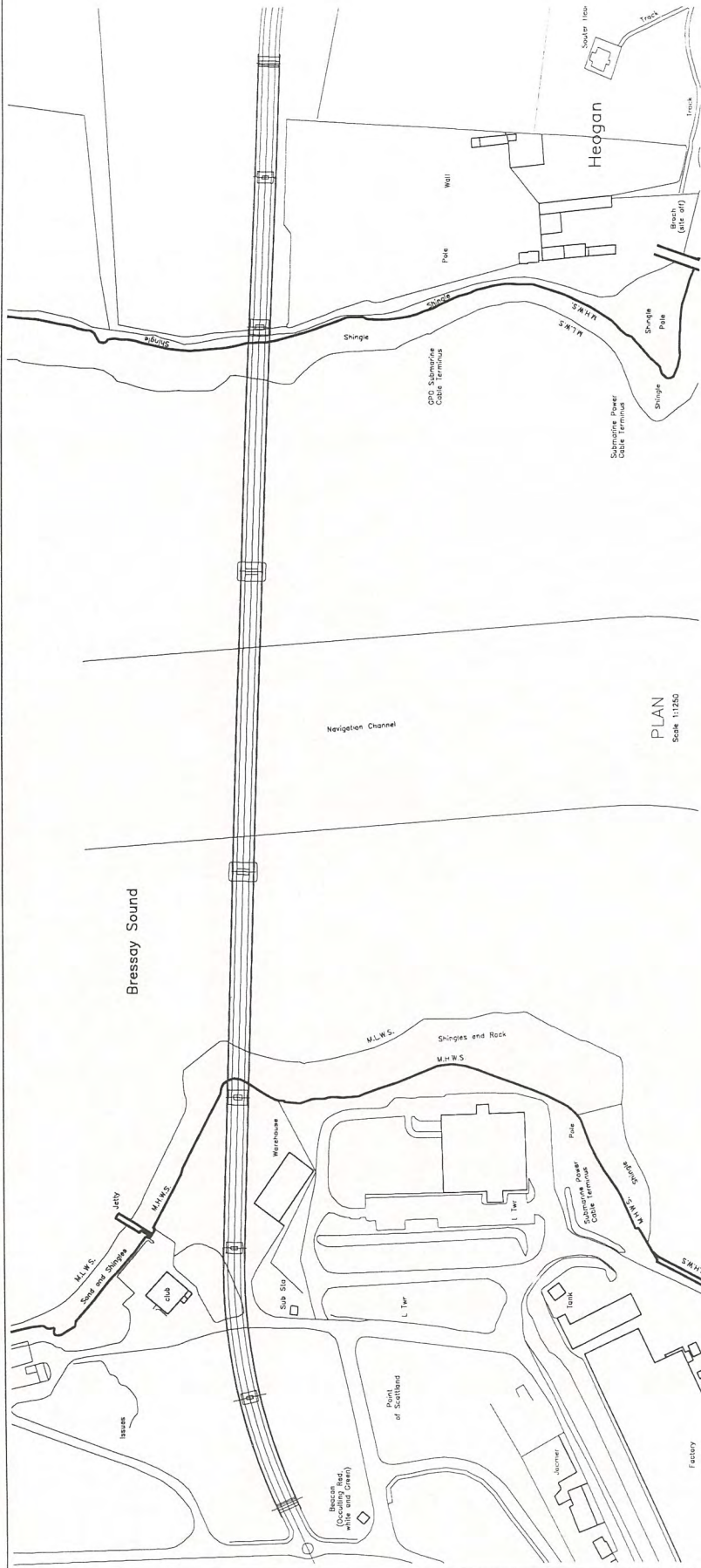
FIGURE 4.1



CONCRETE BOX GIRDER
CROSS SECTION

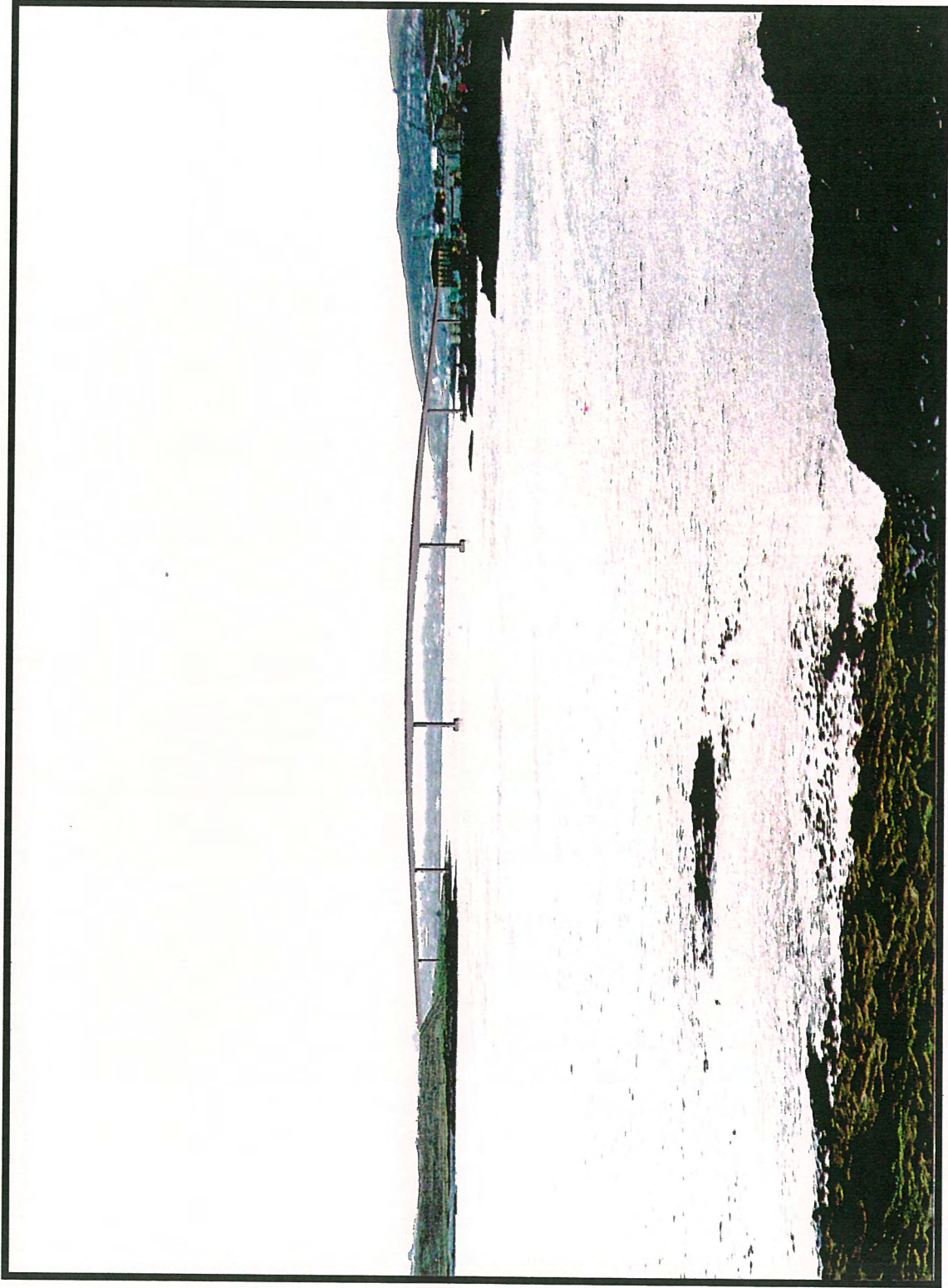


STEEL BOX GIRDER
ALTERNATIVE CROSS SECTIONS

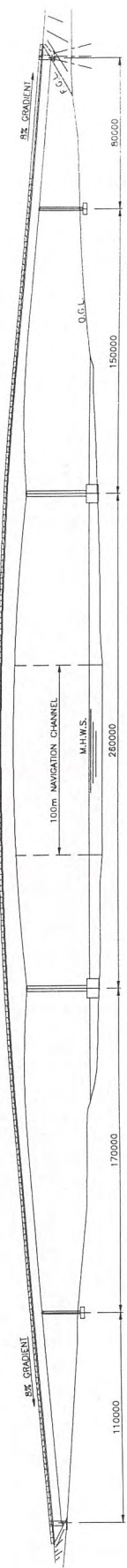
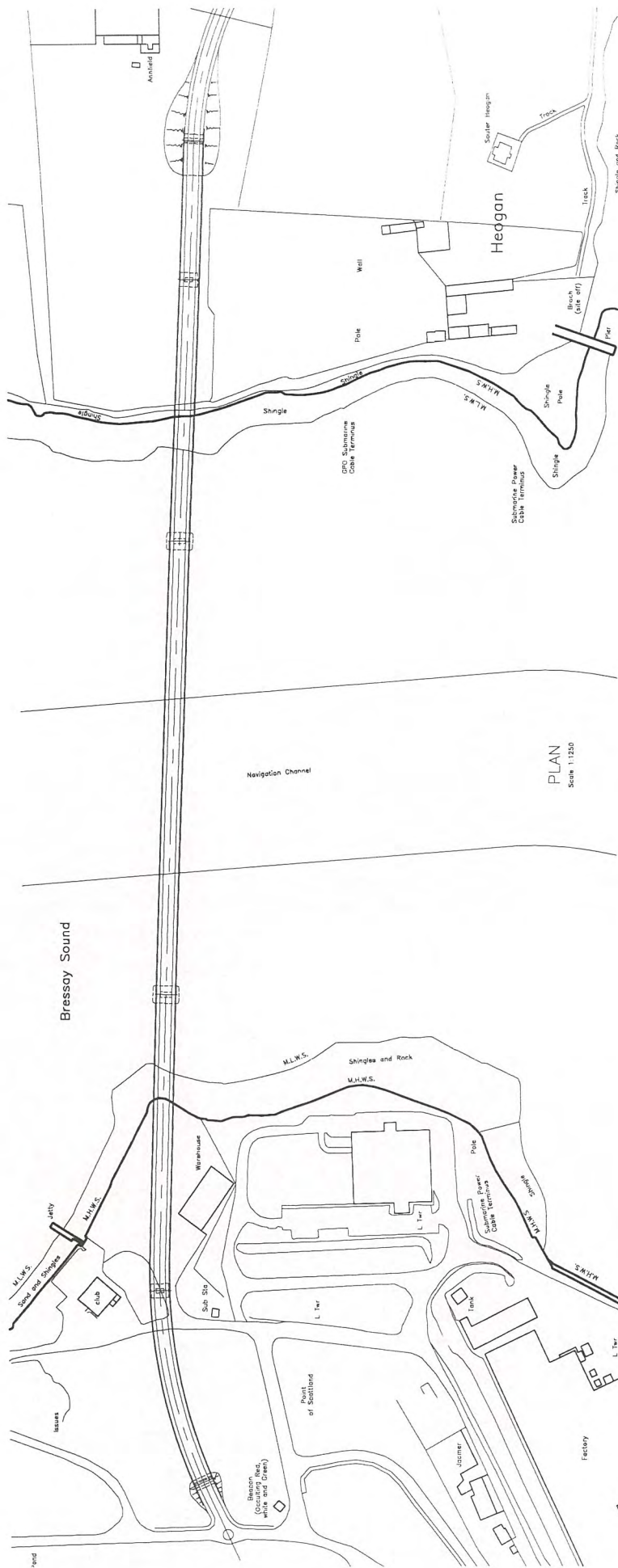


POINT OF SCOTLAND
BOX GIRDER
160m MAINSPAN - 40m AIRDRAFT

FIGURE 4.5

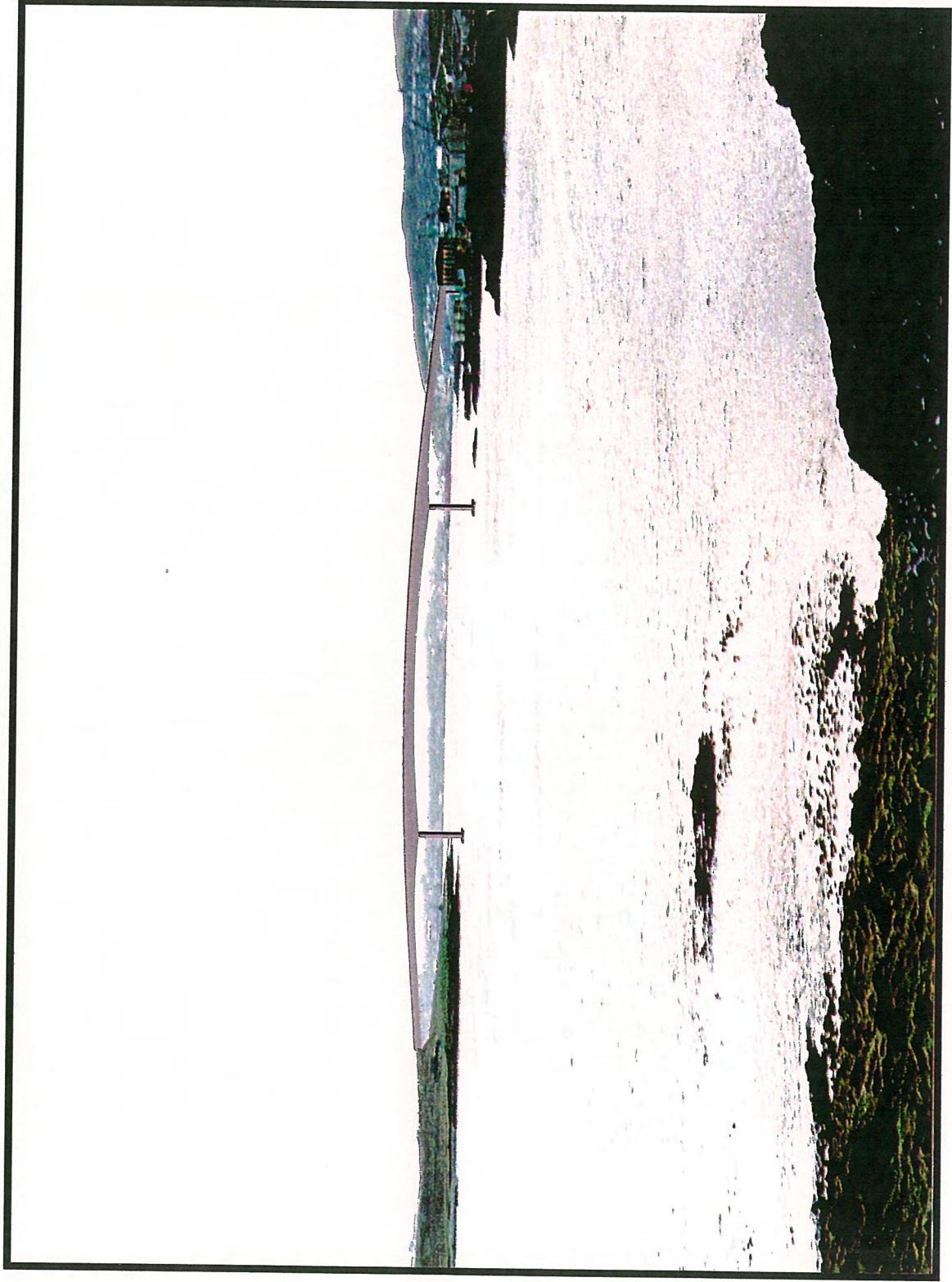


POINT OF SCOTLAND
BOX GIRDER - 160m MAINSPAN
PLATE 1

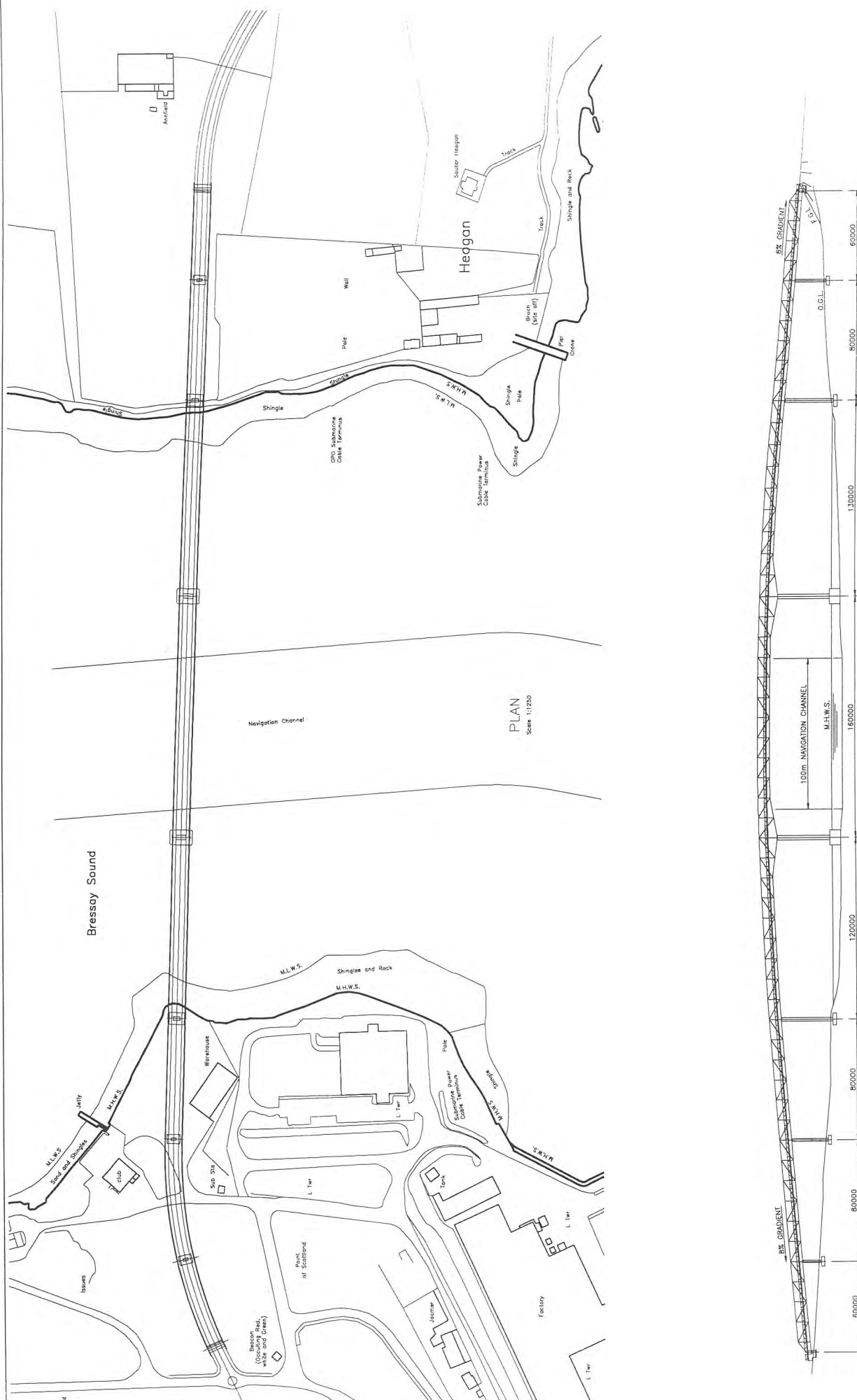


POINT OF SCOTLAND
BOX GIRDER
260m MAINSPAN

FIGURE 4.6



POINT OF SCATLAND
BOX GIRDER - 260m MAINSPAN
PLATE 2



POINT OF SCATLAND
THROUGH TRUSS
160m MAINSPAN

ELEVATION
Scale: 1:1250

FIGURE 4.7

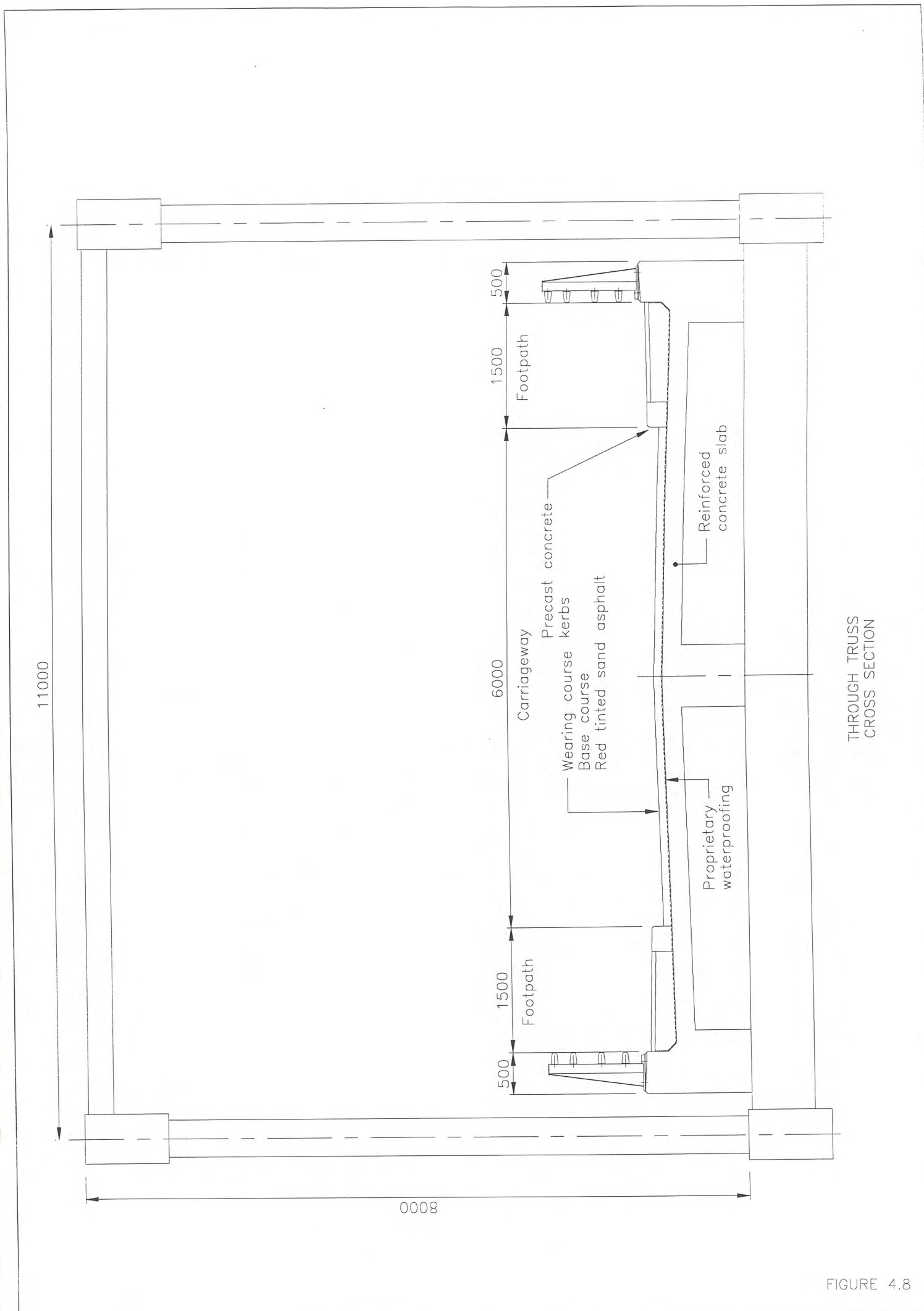
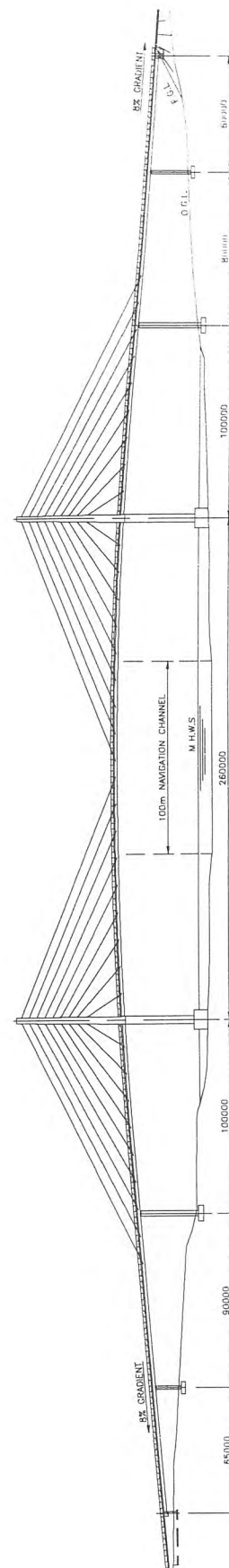
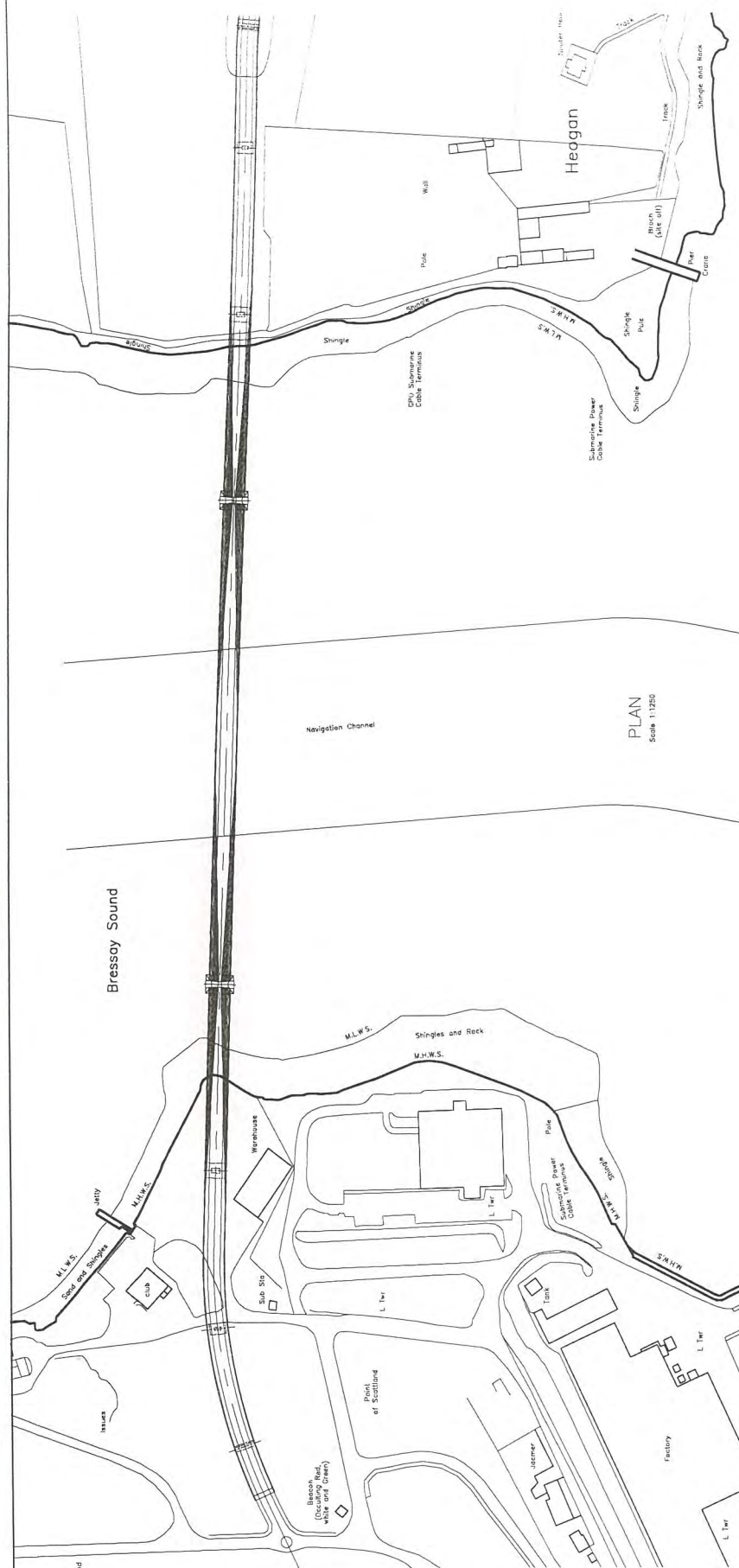


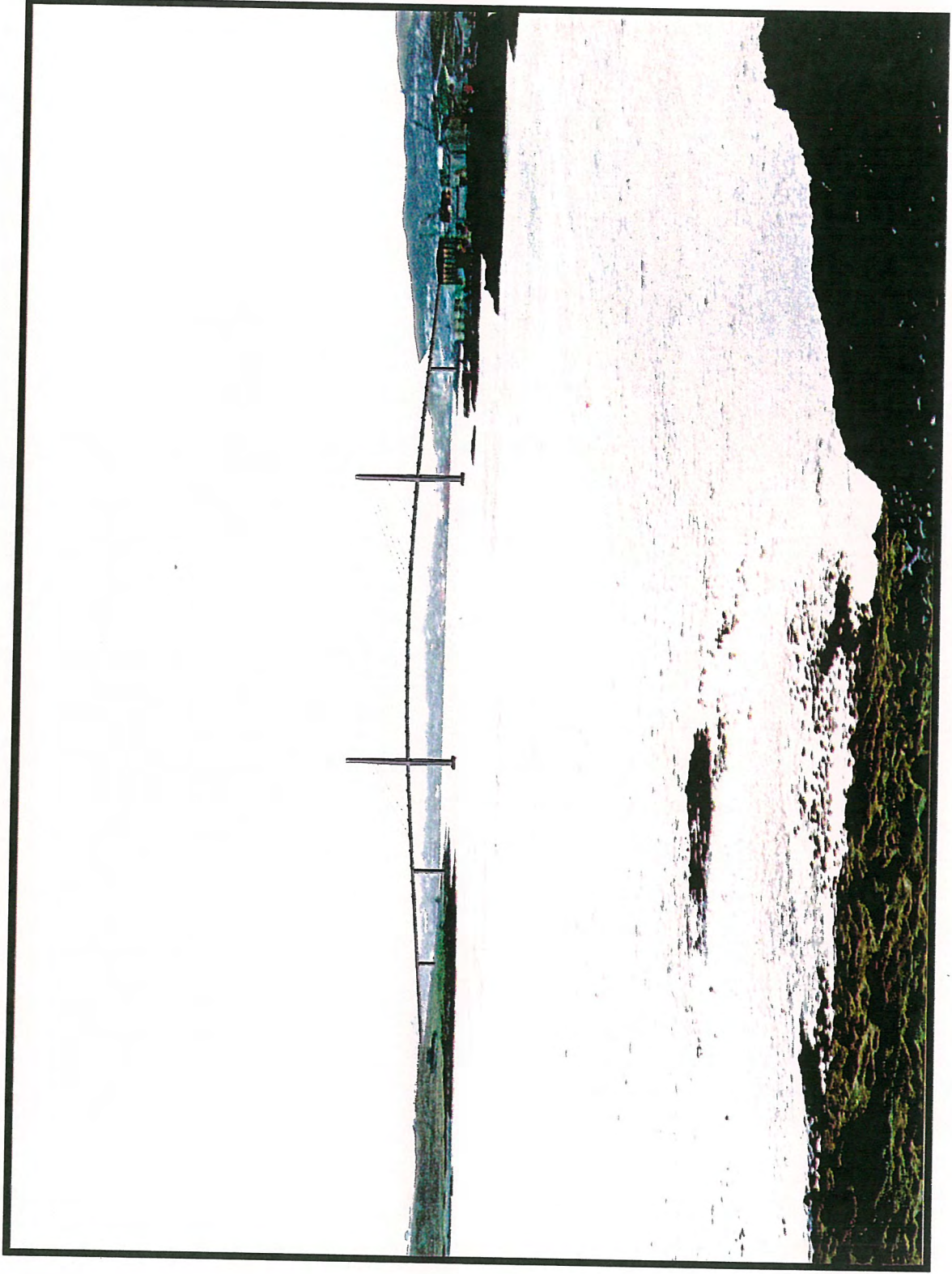
FIGURE 4.8



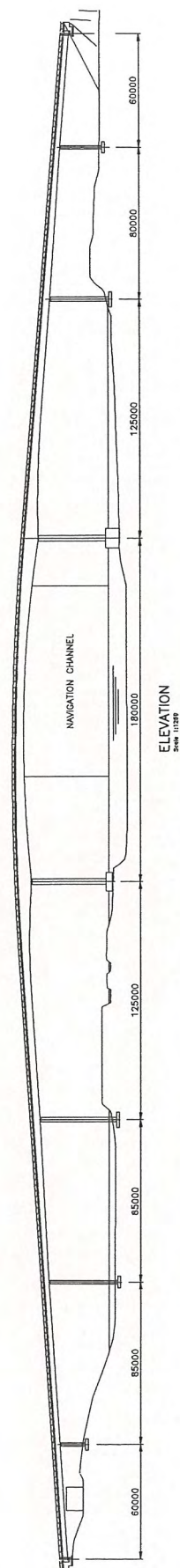
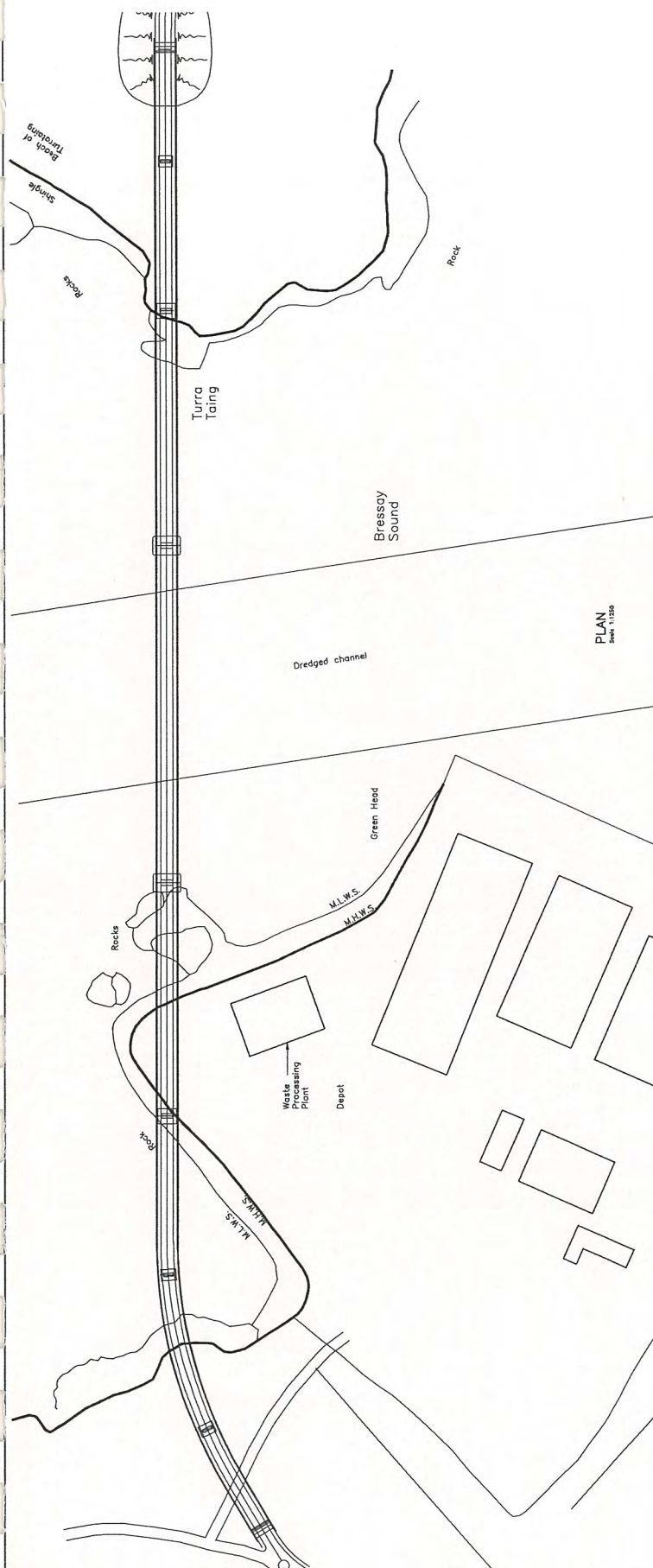
POINT OF SCATLAND
THROUGH TRUSS
PLATE 3



POINT OF SCOTLAND
CABLE STAYED BRIDGE
260m MAINSPAN

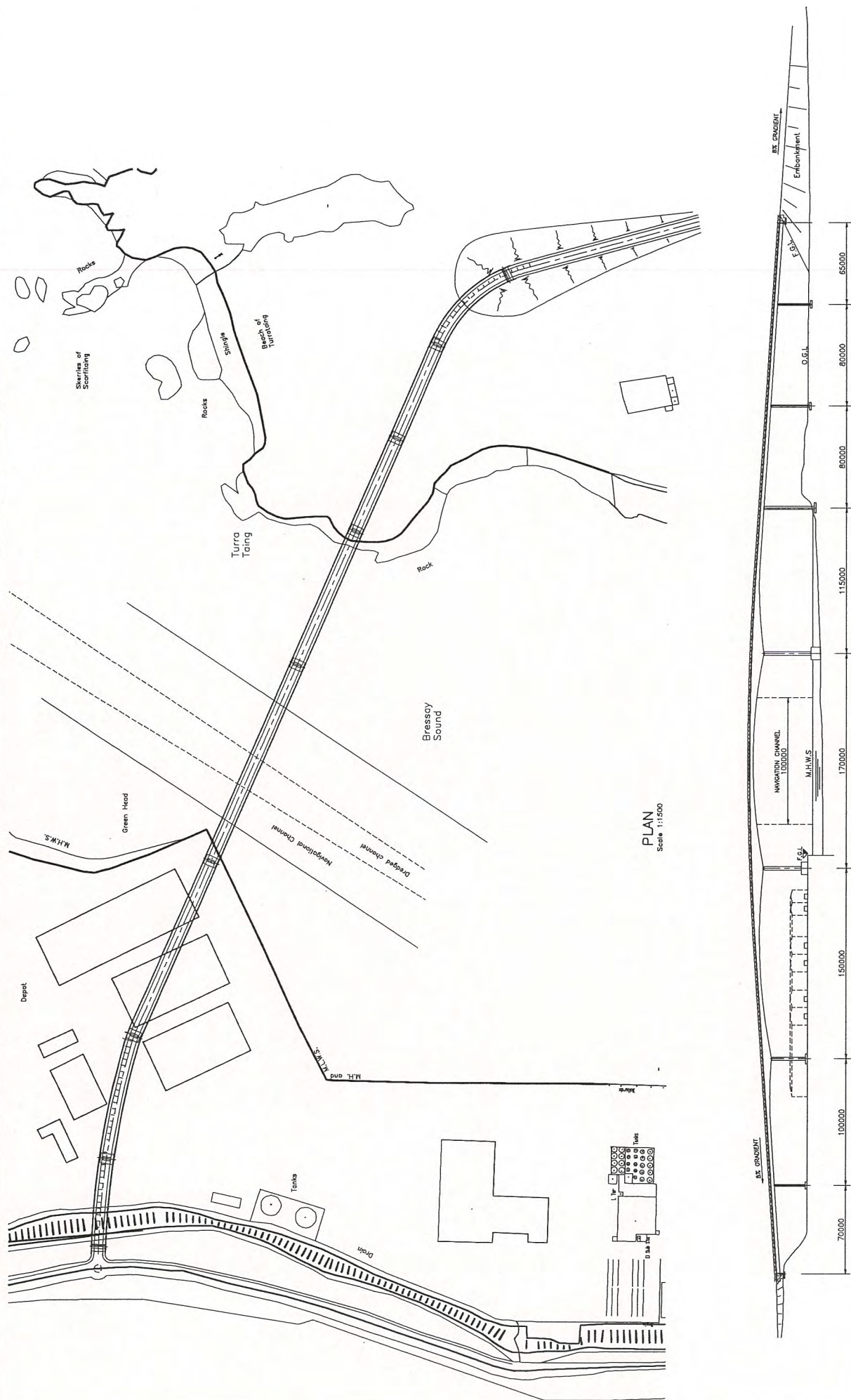


POINT OF SCATLAND
CABLE STAYED BRIDGE
PLATE 4



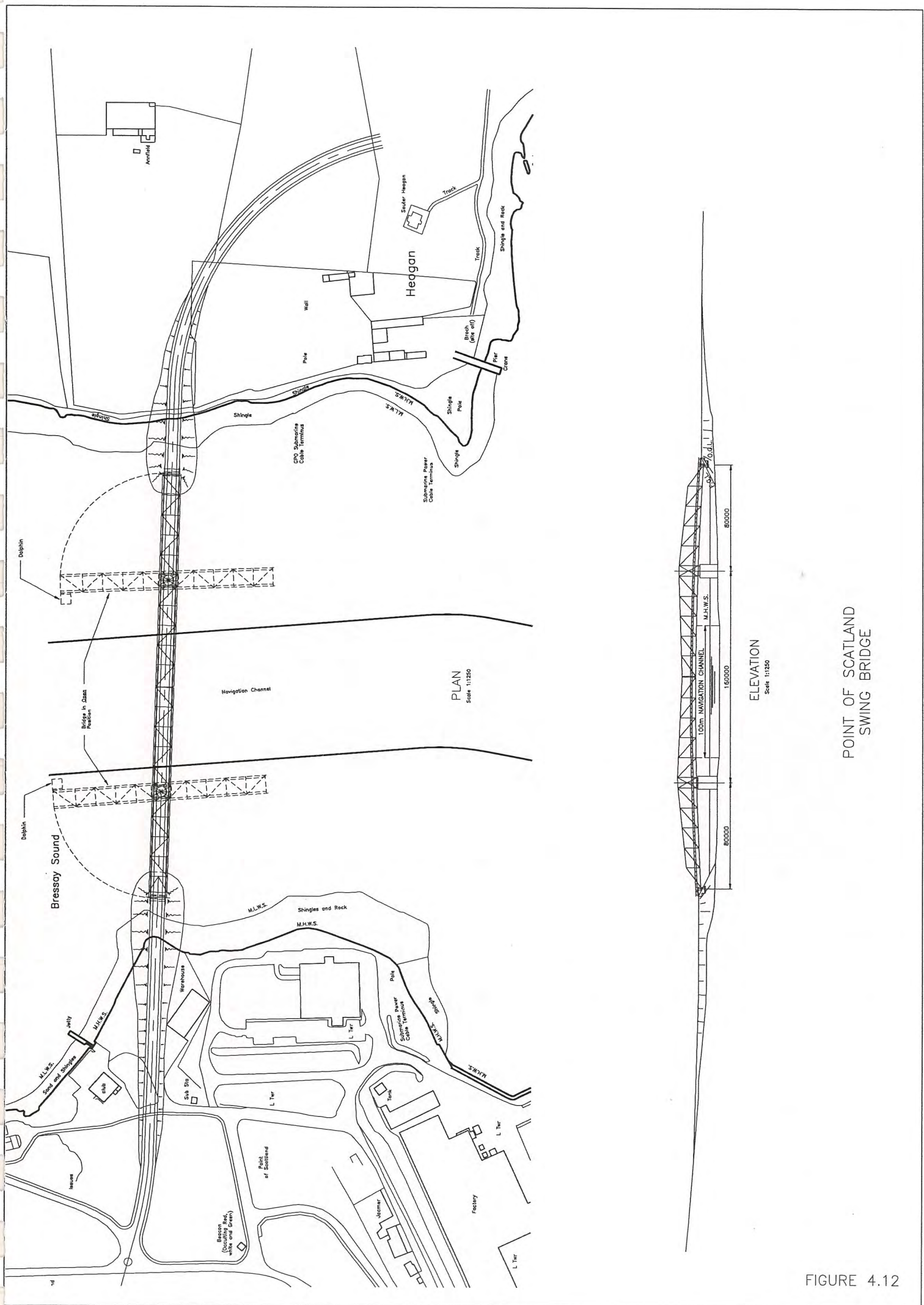
GREENHEAD
BOX GIRDER
OPTION 1

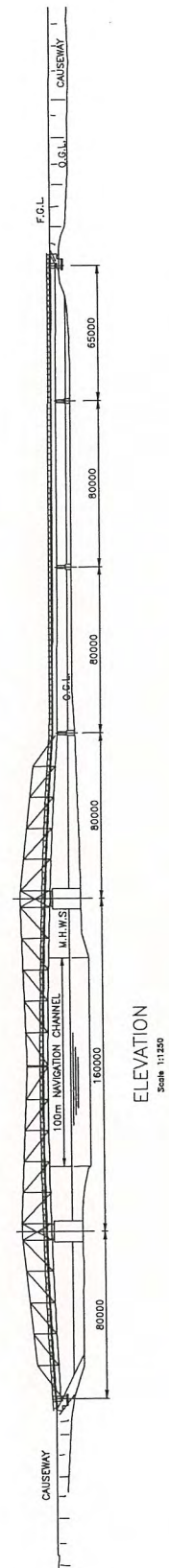
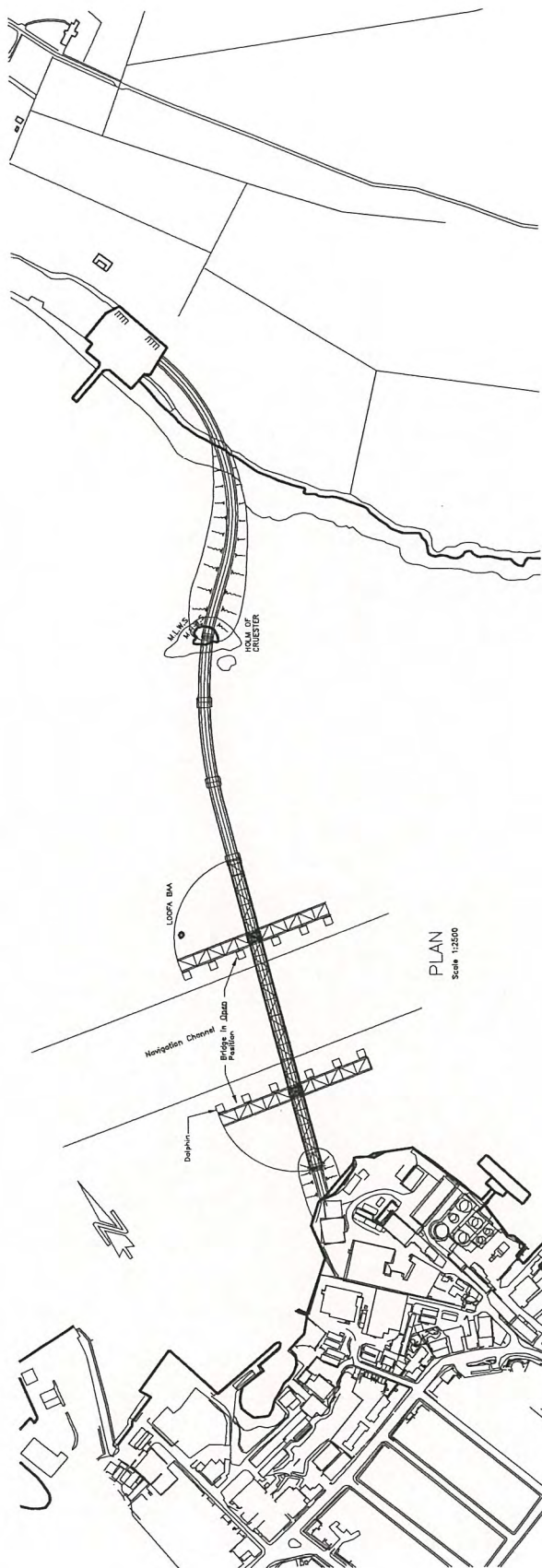
FIGURE 4.10



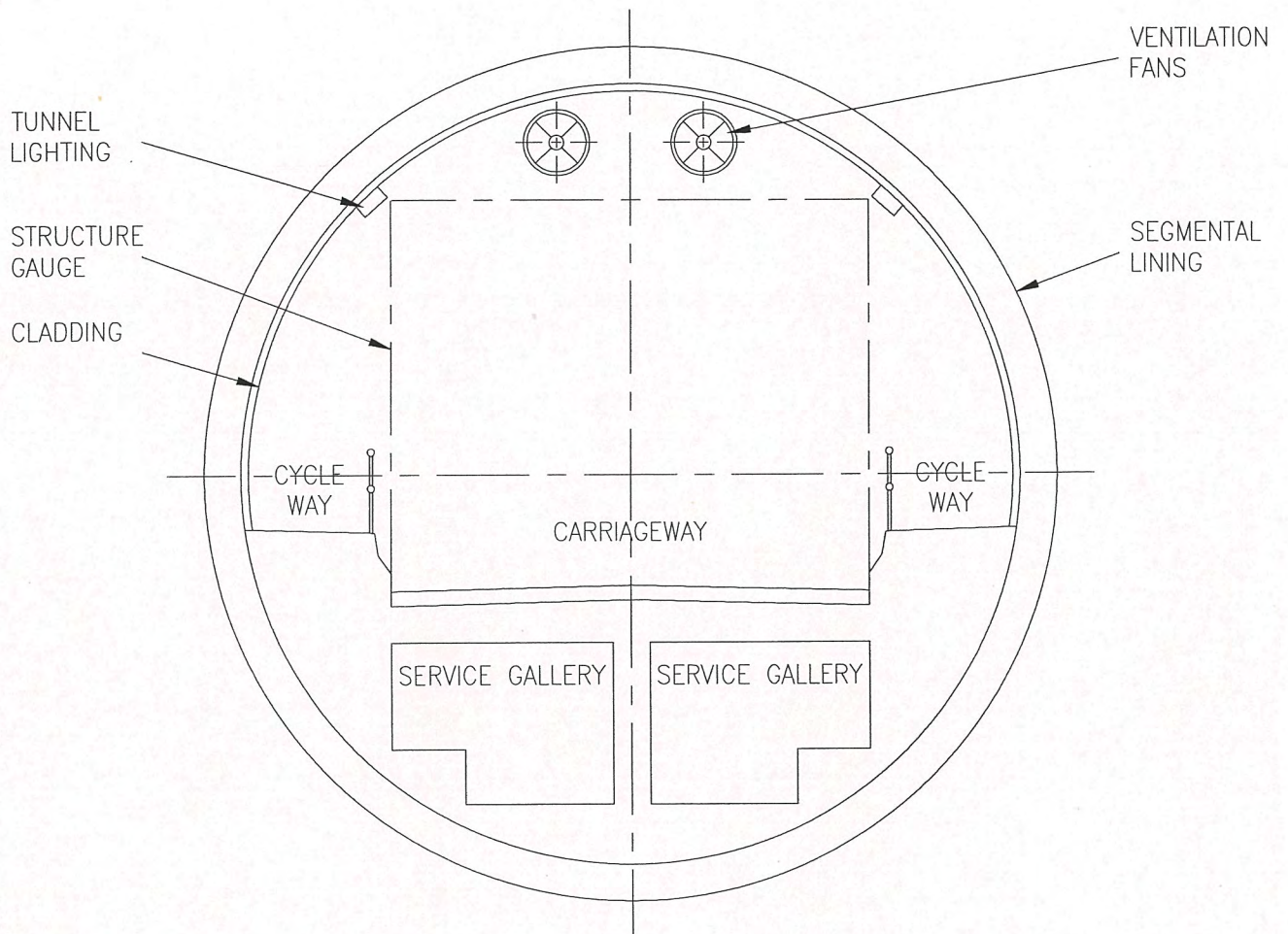
GREENHEAD
BOX GIRDER
OPTION 2

FIGURE 4.11



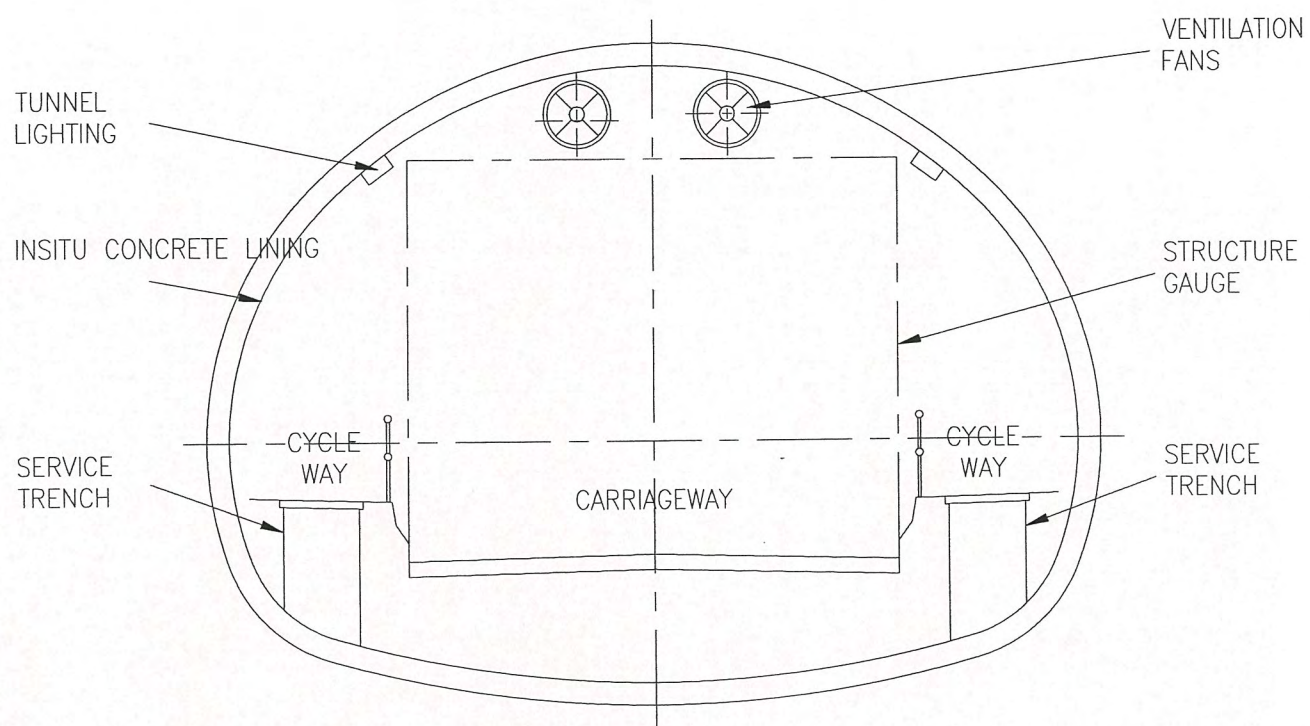


NORTH NESS
SWING BRIDGE



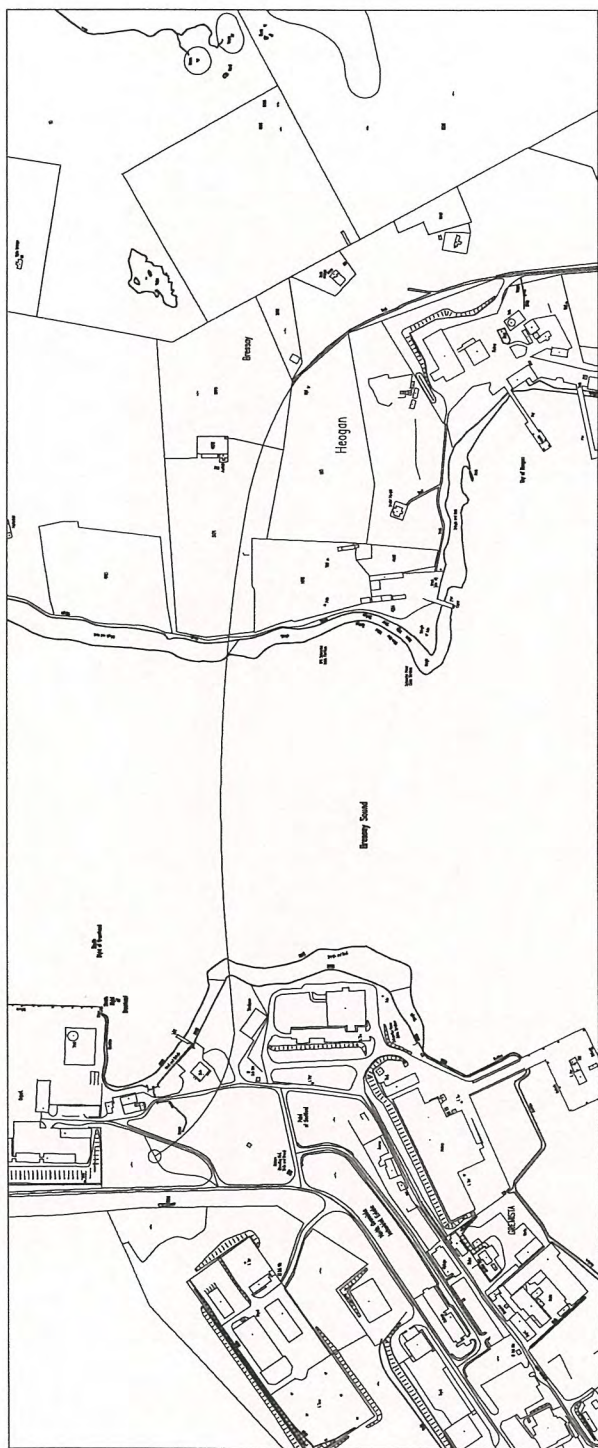
BORED TUNNEL – TBM – TYPICAL CROSS SECTION

FIGURE 4.14

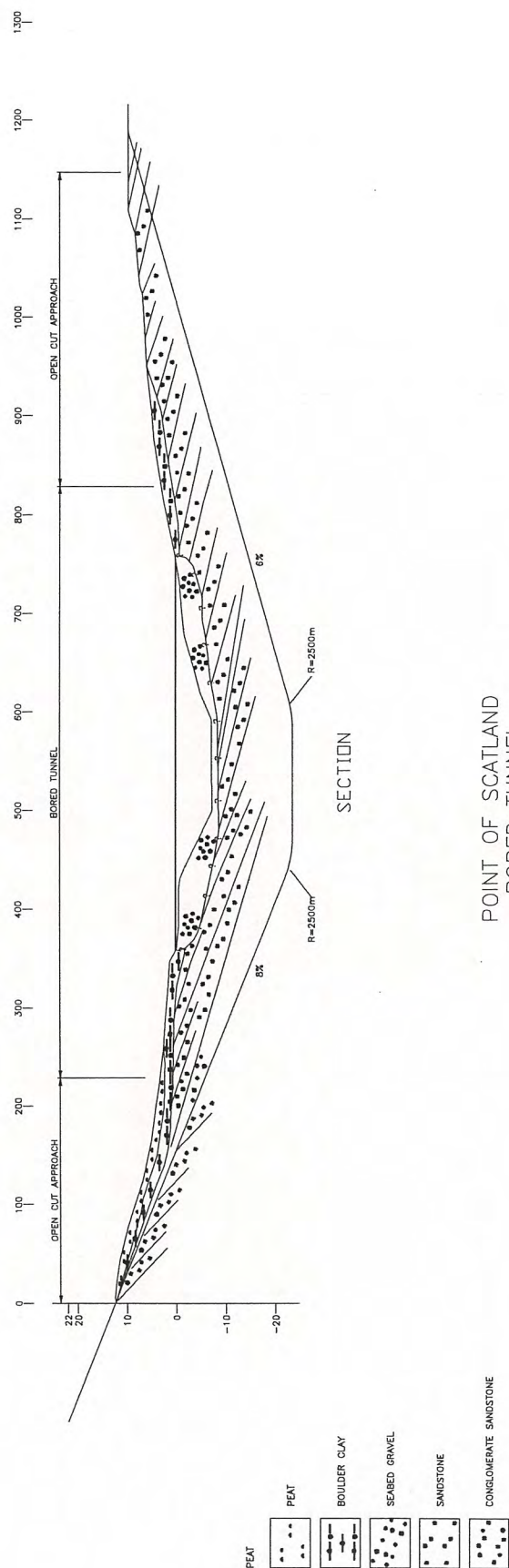


BORED TUNNEL – ROAD HEADER – TYPICAL CROSS SECTION

FIGURE 4.15



LOCATION PLAN
SCALE 1:2500



POINT OF SCOTLAND
BORED TUNNEL

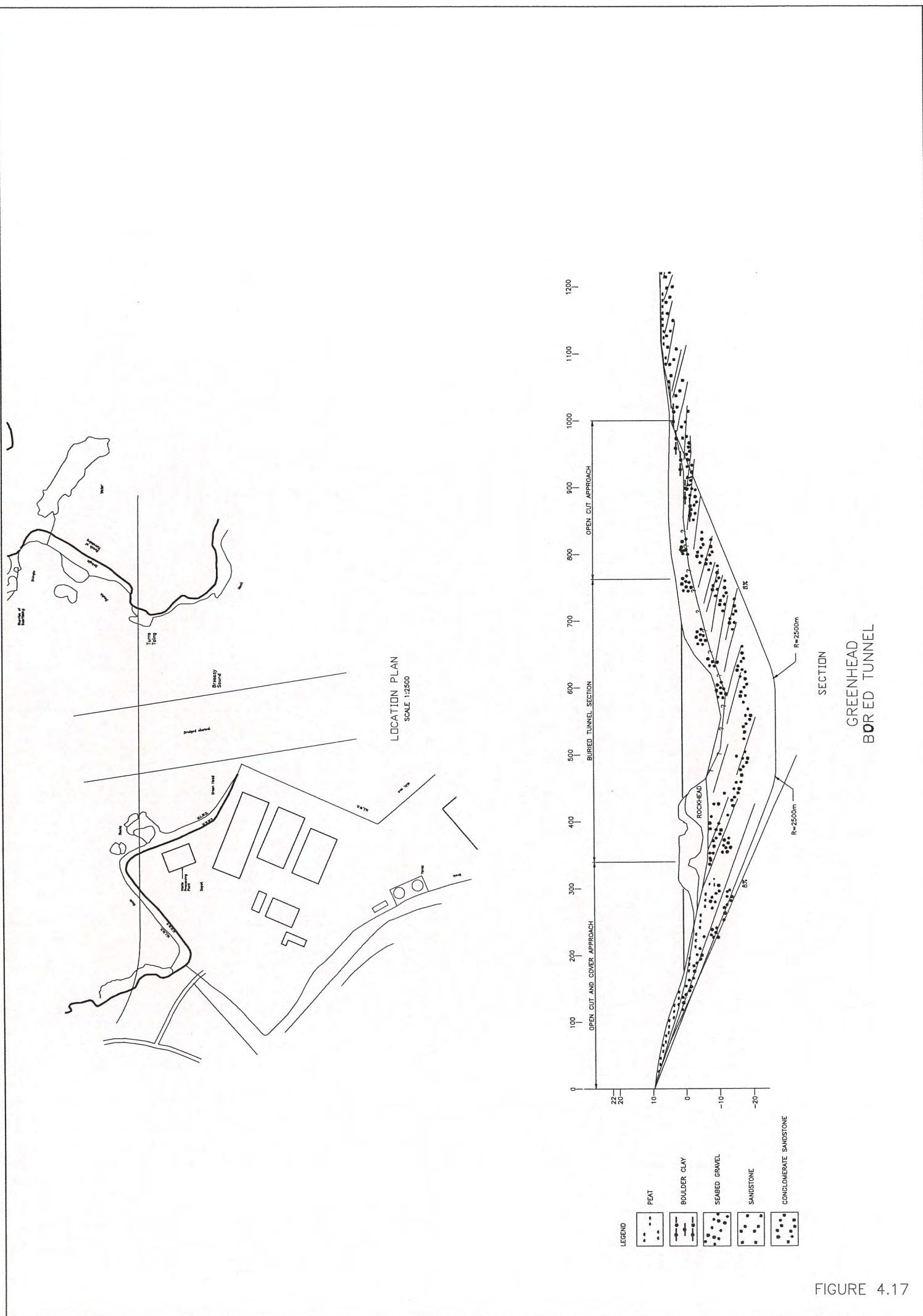
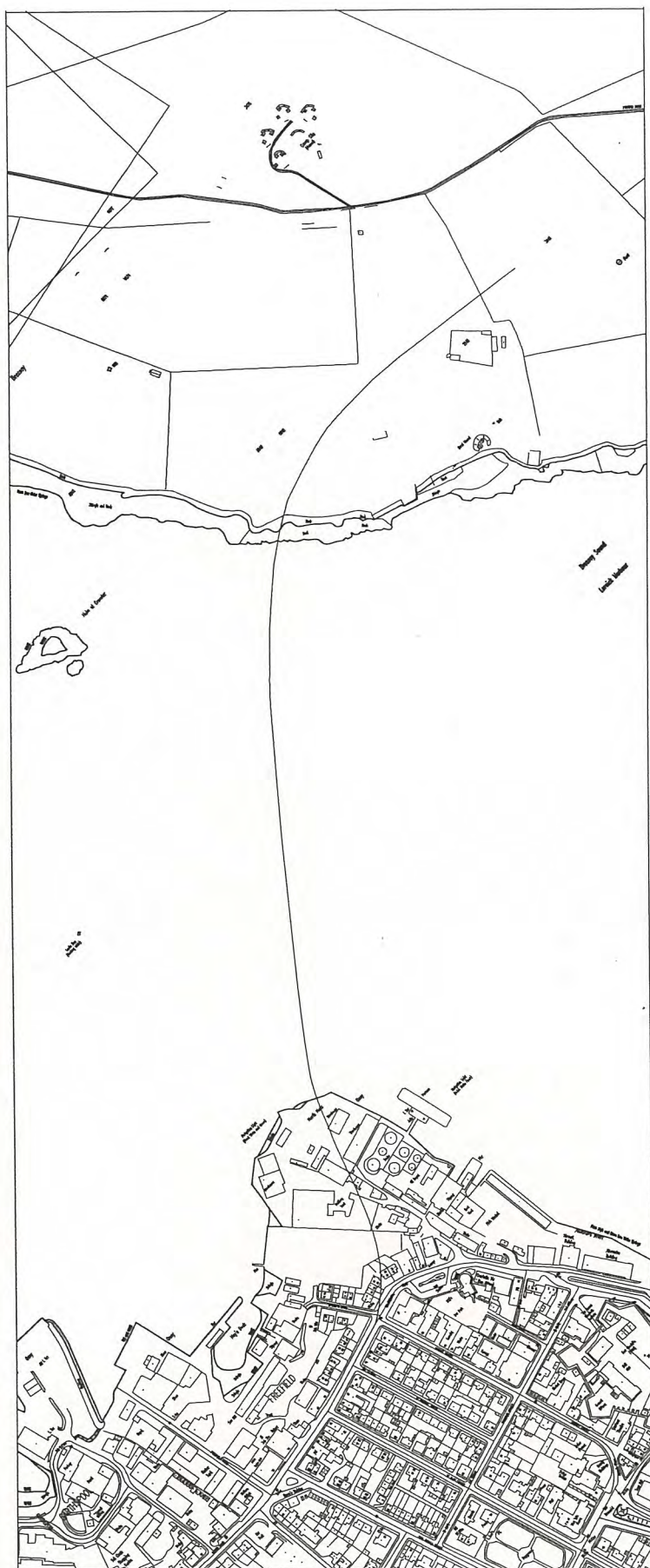
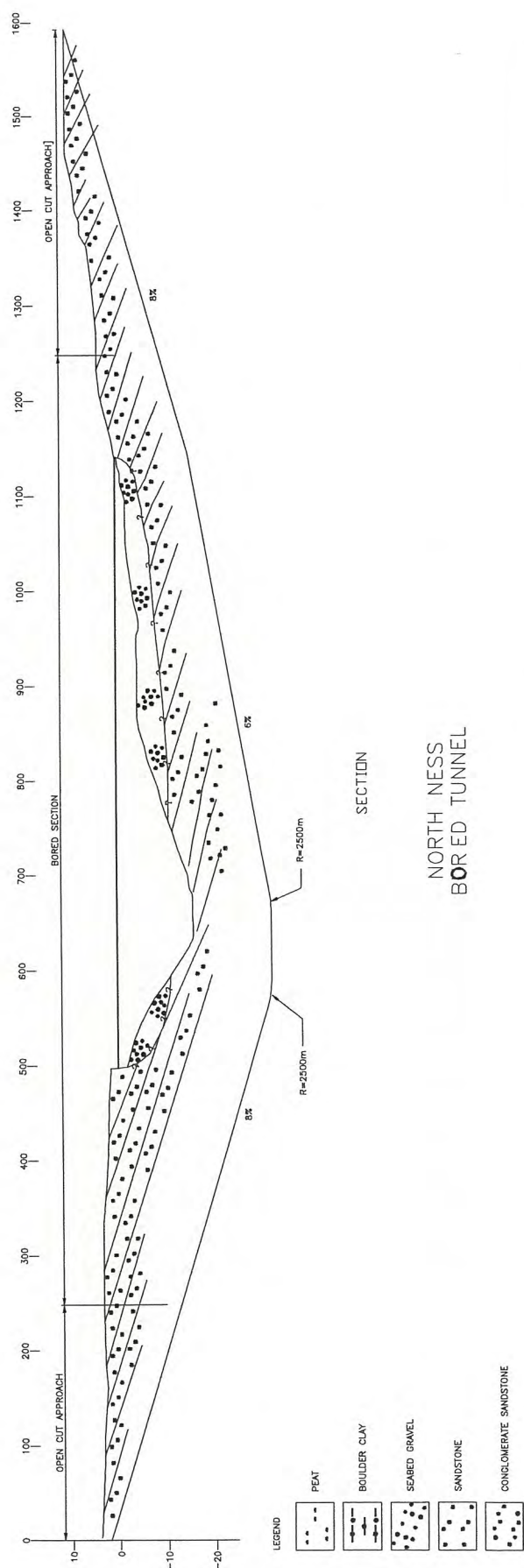


FIGURE 4.17



LOCATION PLAN
SCALE 1:2500



SECTION

NORTH NESS
BORED TUNNEL

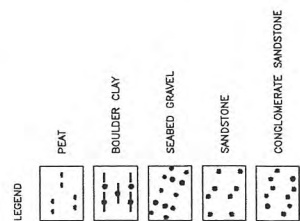
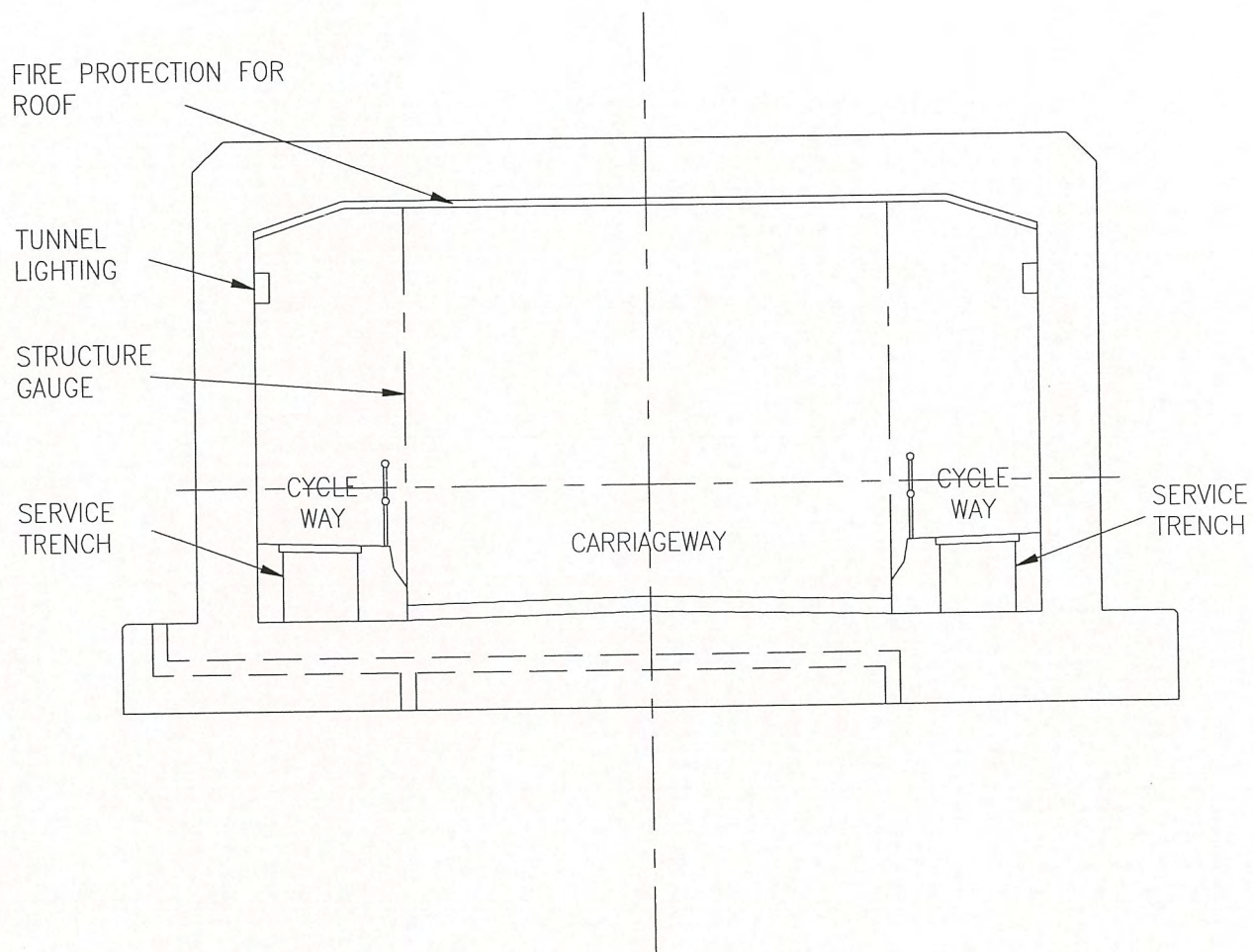
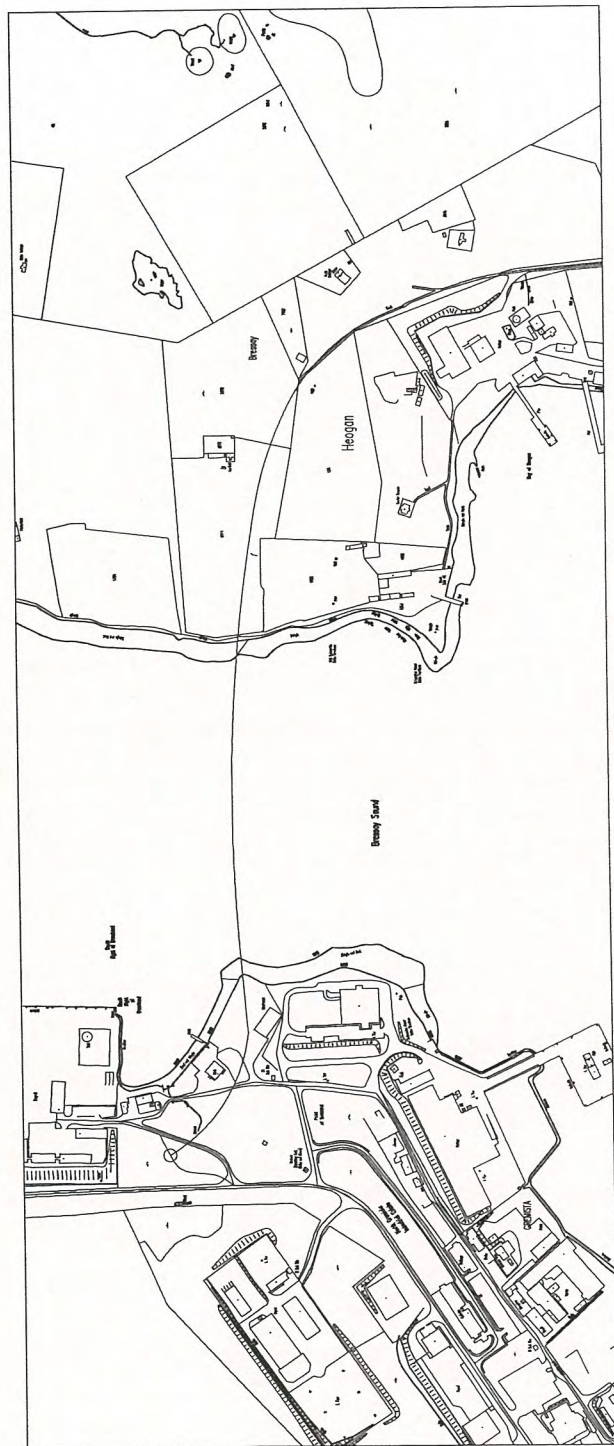


FIGURE 4.18

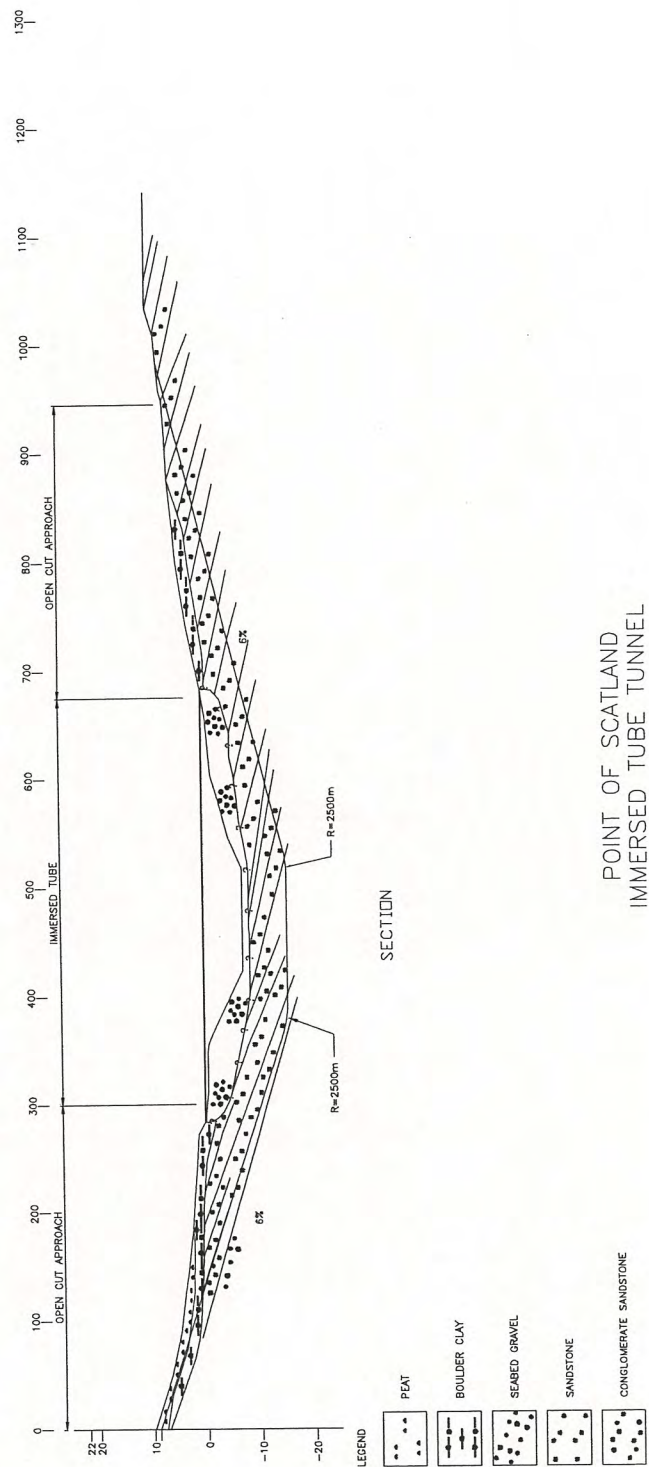


IMMERSED TUBE – TYPICAL CROSS SECTION

FIGURE 4.19



LOCATION PLAN
SCALE 1:2500



POINT OF SCOTLAND
IMMERSED TUBE TUNNEL

5

CONSTRUCTION TECHNIQUES

5.1

General

The techniques employed in the construction of a fixed link to Bressay will depend on a much fuller investigation of aspects such as the ground conditions, weather conditions and the successful contractors chosen preferences etc. However the following presents a synopsis of the possible techniques which will be employed.

5.2

Bridges

Starting with the foundations, the first aspect will be the form of construction for the main piers. Given that on the seabed the granular deposits overlying bedrock are on average only 2 m thick, precast concrete caissons may be preferred to form these foundations in preference to sheet piled cofferdams. These caissons would be precast in an appropriate casting yard, towed to site and lowered into position. Prior to installation the seabed would be prepared by the removal of overburden and weathered rock and the preparation of a level platform.

It may be possible to use the floating dry dock in Lerwick Harbour to form the caissons but this would be dependent on availability and caisson size. Using this facility would also have implications on programme as only one caisson could be constructed at any time. An alternative would be to temporarily dam and dewater a suitable inlet on the coastline adjacent to the site with sufficient water depth to facilitate flotation of the caisson. This site would have to be restored to its original condition on completion.

When the caisson has been installed a tremie concrete plug would be formed in the base and ground anchors may be required to ensure its location. Ballast would then be added in the form of mass concrete or granular material before being topped off with a structural concrete slab to disperse the loads from the pier stem.

Any marine foundations in shallow water would be constructed by forming a temporary bund accessed from the shore, dewatering within the bund and constructing the base in the dry.

If the piers were of regular cross section then they would be cast by slip or jump forming to the requisite height. Given the significant concrete volumes for all the options considered it is likely that a batching plant would be established on site for concrete production to ensure continuity of supply. This could be supplemented by ready mixed concrete from local suppliers. If the batching plant was located on

the Bressay side then ready mixed concrete could be used for the concrete structures on the Lerwick side.

Alternatively workboats would be used to ship concrete across the Sound and workboats would be required in any case to provide concrete to the marine piers. The infrastructure for these workboats could include temporary slipways on each shoreline.

Concrete for the substructure could be placed using pumps although for the marine piers, tower cranes may be required.

Aggregates could be won locally by opening up new quarries or using existing quarries. Alternatively aggregates along with other construction materials such as cement and rebar could be imported by sea. In this respect construction costs would be minimised by bringing a large quantity of material on a specially chartered vessel.

Superstructure construction would be dependent on the deck type and particular location. For the concrete box girder options, balanced cantilever techniques could be utilised for the main over water spans. Travelling forms would be used on both sides of the main piers to facilitate progressive casting of the cantilevers. Additional temporary piers would be provided on the backspan side of the main piers to provide restraint against rotation.

The approach spans of the concrete options could be constructed by staging out using falsework and casting the deck in situ. Alternatively the cast push technique could be utilised. This latter option would have the advantage that the deck construction could proceed in environmentally controlled conditions in a casting shed.

For the steel box girders installation would be by crane. Large crawler cranes would be used to install the land spans. Temporary piers may be required to enable installation in manageable pieces. Alternatively, as with the concrete option the deck could be launched from each abutment. For the over water sections installation would be by large floating crane. Lifts could be up to several hundred tonnes in weight, which is relatively insignificant by offshore standards. Installation of the through truss would be as for the box girder with subsequent casting of the deck slab being facilitated by the use of steel or precast concrete beams and permanent formwork.

For the cable stayed option construction of the deck would also utilise cantilever methods. Either balanced cantilever techniques would be utilised or the backspans

would be constructed first using temporary staging. For the concrete deck option, travelling formwork would be utilised as for the box girder option. For the steel composite option a derrick crane would be utilised to install the girders and permanent formwork. Support to the advancing cantilever would be provided by the progressive installation and tensioning of stay cables.

Whatever option is chosen, cognisance would have to be taken of the potentially severe weather conditions and the consequent adverse impact on quality of workmanship, downtime and productivity.

Overcoming these problems could be facilitated by maximising off site prefabrication and precasting and maximising the use of weather windows and increased daylight hours in the summer months to install bridge elements.

If work does proceed throughout the year then environmental conditions could be controlled through the use of; for example, a cast push technique with the concrete being cast inside a purpose built structure. Some of the industrial buildings along the harbour could also be utilised to house construction operations and it is highly likely that the existing quays and harbour frontage will be utilised in the construction process.

Some construction operations will inevitably cause disruption to navigation. Installing large sections of the deck using a crane barge may well required the channel to be closed for a period of up to six hours, although as this operation would only proceed under fair weather conditions, there will be no safety implications in vessels having to divert around the island. Similarly for cantilever construction of a concrete deck the travelling forms could temporarily reduce the navigation clearance.

5.3

Bored Tunnels

Tunnelling operations would be carried out from the open cut approach on Bressay to minimise disruption on the Lerwick side of the crossing.

Space would have to be provided adjacent to one of the approach cuttings for locating the tunnels services building.

The method of bored tunnel construction to be used for the Fixed Link will depend on the ground conditions and these can only be confirmed after a more detailed site investigation.

The ground investigation information available at this stage suggests that the sandstone varies considerably in strength and that the potential groundwater flow

in to the tunnel excavation is not known. The necessity of controlling the groundwater inflow and the strength variability of the deposits suggests that a full face TBM is the most suitable method of tunnel excavation. However the use of a road header in an open tunnel excavation should not be discounted until more detailed geological information is available.

Whatever method of tunnel excavation is adopted it should be able to deal with big boulders, locally recorded up to 1 m diameter within the conglomerate sandstone.

According to the assumed ground conditions it is expected that the bored tunnel will have to be excavated through conglomerate sandstone and sandstone of variable degrees of weathering. However since the position of rockhead is uncertain and channels and troughs are known to be present at the interface the possibility of mixed ground at the tunnel face should also be considered.

The use of a road header would only be feasible if the rock is proved to have sufficient strength and be impermeable enough as to undertake the excavation under relatively dry conditions. The construction of this option will be carried out using sprayed concrete as the primary means of support.

Sprayed concrete is the most flexible form of ground support and is suited to construct any shape of underground structures. Ground support is provided by a combination of sprayed concrete, mesh, rock bolts, rock dowels and lattice girders or arches. Dry conditions are essential to ensure that the sprayed concrete adheres to the sandstone. The lattice girders serve little structural function but allow the profile of the excavation to be maintained.

5.4

Immersed Tube Tunnels

For this study it has been assumed that the immersed tube elements would be cast on or adjacent to the crossing location. If the elements were cast remote from the site then the cost of the tunnel would increase significantly.

Construction of the immersed tube elements will require a casting basin which will present the same problems of dealing with groundwater as the cutting for the approaches. The casting basin will have to be flooded and opened to the sound a number of times to allow finished immersed tube elements to be removed and floated in to position. It is proposed that the approach cutting on the Bressay side is used as the casting basin for the immersed tube elements. This introduces the efficiencies of using part of the permanent works to house production of the tube elements thereby avoiding an additional temporary casting basin.

The actual immersed tube section of the crossing will be relatively small in comparison to the approaches and therefore the fabrication will not require extensive areas of land.

The penalty of not having a casting basin is that the immersed tube elements may have to be shorter.

The sea bed trench for the immersed tube elements will be excavated by dredging or any other method considered as optimum for the excavation of the particular materials. The trenching calls for the highest precision that can be achieved in dredging and therefore this requirement will determine the type of equipment best suited for the job. In view of the keen positioning tolerances anchored dredgers will be preferred. As a consequence they could not move about freely and may present significant hindrance to shipping traffic. The time lag between trenching and tunnel installation must be minimal to avoid excessive siltation of the excavated trench.

For the seabed deposits a cutter suction dredging system could be utilised but this dredger type could not remove boulders or hard rock, and blasting of these areas may be required.

Disposals of the excavated material will also form a primary consideration although the Harbour Trust have confirmed that they would consider taking rockfill for land reclamation projects.

Material from other dredging operations in the north channel has also be dumped at sea in a designated spoil dumping ground just north of the Island of Bressay.

Immediately prior to the units being placed, a layer of sand is placed on the seabed using precision placing equipment.

Installation of the units will be facilitated by ballasting tanks inside the sealed tunnel unit. The tunnel unit will be placed sufficiently close to the previous unit such that they are in contact through a rubber gasket.

Dewatering the gap between the bulkheads of adjacent units will create a vacuum which will be sufficient to pull the units together and compress the gasket.

Thereafter the trench will be backfilled and an anti-scour layer placed over the top of the tunnel units. This layer will also protect the tunnel units from damage from dropping anchors etc.

CONSTRUCTION TECHNIQUES

Hindrance to shipping will occur, as vessels will operate over the tunnel but the disturbance can be reduced by means of equipment attached to the tunnel elements.

6

COST ESTIMATES

6.1

Preparation Costs

Preparation cost estimates have been listed in the following table. This list includes design costs but if the fixed link were procured by the design and construct route then these costs would be lumped in with construction, although studies may still be required to formulate design criteria incorporated in the contract document.

Item	Cost (£)
(i) Topographic Survey	10,000
(ii) Hydrographic Survey	20,000
(iii) Site Investigation	160,000
(iv) Professional Input to i, ii and iii	15,000
(v) Environmental Assessment	30,000
(vi) Scheme Promotion and Consultation	40,000
(vii) Detailed Design	200,000 *
(viii) Contract Documentation	20,000
(ix) Site Supervision	200,000
Total	495,000

- The figure listed is for the design of a bridge and would be of the order of £400,000 for a tunnel structure.

6.2

Construction Costs

Preliminary designs for the options listed in section 4 have been undertaken to establish the cost estimates listed below. Rates were then applied to these quantities on the basis of our experience and a contingency sum added to allow for all other items not directly considered.

The cost estimates include for all bridge or tunnel works and for the associated roadworks to connect with the existing road network including a new roundabout on the Lerwick side. They do not include for upgrading of the existing road network. The cost estimates for bridge options are firstly given as:-

Option	Location	Description	Mainspan Length	Air draft (m)	Deck Width		Cost (£Million)
					Carriageway	Footpath	
1A	Point of Scotland	Box girder	125	30	3.5	2.0	11.0
1B	Point of Scotland	Box Girder	125	40	6.7	2.0	14.0
1C	Point of Scotland	Box Girder	125	40	6.0	1.5	12.3
2A	Point of Scotland	Box Girder	160	30	6.7	2.0	14.5
2B	Point of Scotland	Box Girder	160	40	3.5	2.0	12.0
2C	Point of Scotland	Box Girder	160	40	6.7	2.0	15.0
2D	Point of Scotland	Box Girder	160	40	6.0	1.5	13.3
3	Point of Scotland	Box Girder	260	40	6.7	2.0	20.0
4	Point of	Through	160	40	6.0	1.5	14.0

COST ESTIMATES

	Scatland	Truss					
5	Point of Scatland	Cable Stayed	200	40	6.0	1.5	18.5
6	Greenhead	Box Girder	180	40	6.0	1.5	14.5
7	Greenhead	Box Girder	170	40	6.0	1.5	15.0
8	Point of Scatland	Swing Bridge	160	12	6.0	1.5	13.3
9	North Ness	Swing Bridge	160	12	6.0	1.5	17.0

Cost estimates for tunnel options have been prepared to provide upper and lower bound order of magnitude costs for the bored tunnel and immersed tube options. As described in previous sections the study has concentrated on the preferred location for a tunnelled crossing at Point of Scatland.

The cost estimates for tunnel options are as follows:-

Description	Lower Bound	Upper Bound
Immersed tube	£25 M	£34 M
Bored Tunnel – TBM	£39 M	£46 M
Bored Tunnel – Road Header	£36 M	£43 M

6.3

Operational and Maintenance Costs

BD36/42 and BA28/92 “The Evaluation of Maintenance Costs in Comparing Alternative Designs for Highway Structures” set out the basis for the evaluation of commuted maintenance costs. In this study all items requiring maintenance or replacement are considered and not just those which differ between options. The costs are based on a 120 year design life for all structures. Assumptions have been made with respect to the design life of components and these assumptions would include the following:-

COST ESTIMATES

- That the carriageway be resurfaced after 20 years
- That external steelwork surfaces be blast cleaned and repainted after 25 years
- That internal steelwork surfaces be blast cleaned and repainted after 35 years
- That joints and bearings be replaced after 30 years
- That stay cables be replaced after 40 years
- That certain mechanical components on opening bridges be replaced after 30 years

The commuted sums however exclude traffic delay costs. In addition for opening bridges it is assumed that given the frequency of opening these bridges would be manned on a full time basis. The maintenance costs thus calculated for each cycle were discounted to present day values using an annual rate of 8% and taking no account of inflation. The figures are not therefore directly additional to construction costs.

Bridge Options	Discounted Maintenance Costs £
1A	250,000
1B	318,000
1C	280,000
2A	355,000
2B	278,000
2C	360,000
2D	315,000
3	400,000
4	395,000

Bridge Options	Discounted Maintenance Costs
5	400,000
6	330,000
7	340,000
8	1,145,000
9	1,220,000

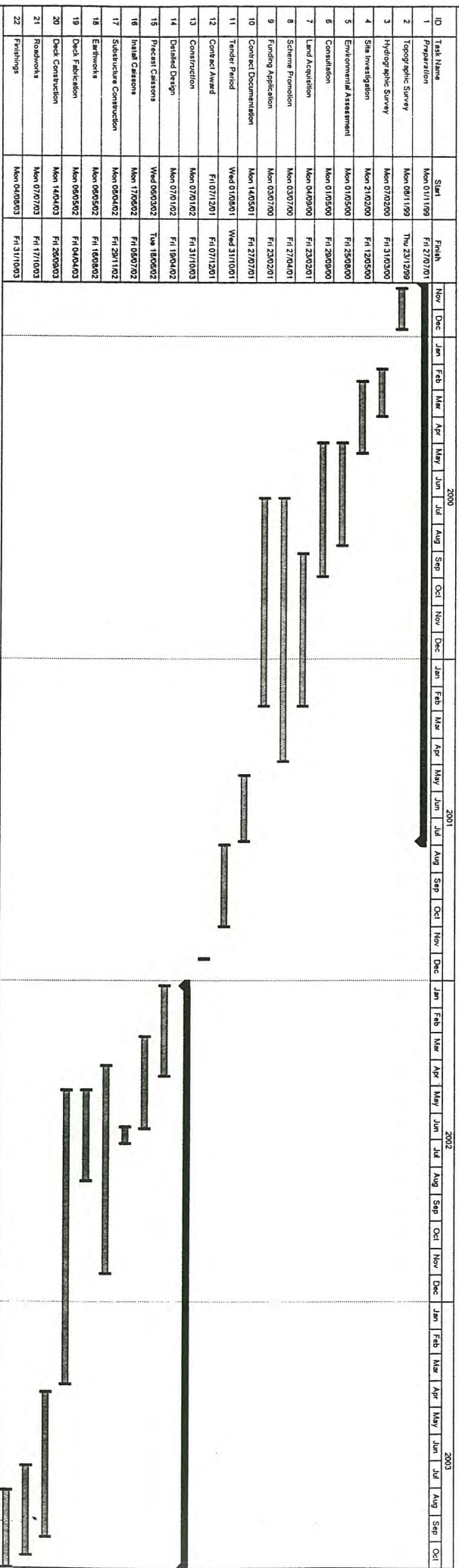
6.4

Programme

An outline programme for scheme preparation and construction is given in Figure 6.1 on the basis of a bridge option being promoted. The programme assumes that there are no delays in acquiring external funding and that a public inquiry is not required.

The programme also assumes that the scheme will proceed as a design and build contract. The overall timescale for the promotion of the scheme is therefore 18 months and for construction 2 years.

**SHELLAND ISLANDS COUNCIL
BRESSAY FIXED LINK
FEASIBILITY STUDY**



OUTLINE PROGRAMME

FIGURE 6.1

7 AVAILABILITY OF CROSSING

7.1

General

In this section we have set out to establish the length of time that a fixed link would be unusable for various reasons and to compare this with the performance of and operating restrictions applicable to the existing ferry crossing.

Reasons for the fixed link being out of use would relate primarily to high winds in the case of a high level bridge and opening to permit vessel navigation in the case of a swing bridge.

We did not consider closures of the fixed link to undertake maintenance as these operations could be undertaken when they will cause least inconvenience, adequate warning could also be provided and alternative provision can be made if necessary.

7.2

High winds

We obtained from the Meteorological Office wind frequency analysis data covering wind speed and direction measurements at Lerwick Observatory. The period covered by the analysis is the 26 years between 1970 and 1995. The winds are presented as hourly average speeds corresponding to each increment of the Beaufort scale with direction given in 30 degree sectors of the compass.

The first task was to convert the mean hourly wind speed at 10 metres above ground level to a maximum gust speed averaged over 10 seconds at 40 m above ground level.

This was achieved using the factors in BD37/88 "Loads for Highway Bridges". In this regard it should be noted that the maximum wind gust speed at 40m above ground level exceeds the maximum wind gust speed at 10m above ground level by around 12%.

The figures were then compared with the operating criteria used for both the Skye and Scalpay Bridges which are reproduced as follows in relation to wind speed.

- With wind speed gusting above 85 mph the bridge is closed to all traffic. This equates to Force 9 on the Beaufort scale and above.
- With wind speeds gusting above 50 mph the bridge is closed to high sided and light vehicles such as lorries and caravans. This equates to Force 7 and above.

- with wind speeds gusting above 35 mph the high wind warning signs would be illuminated. This equates to Force 5 and above.

In relation to direction winds within an angle of 60° to a line perpendicular to the bridge axis were included in the thresholds for activation of these messages. This allows for some variability in the wind direction and for the fact that the bridge axis is not straight.

For the Point of Scotland site, the principal bridge axis runs almost due east-west although there are curves at the end. Thus the bridge is primarily susceptible to southerly and northerly winds.

At Greenhead the principle bridge axis considered runs west north west - east south east thus the bridge is susceptible to south westerly and north easterly winds which are most common.

As high bridge options were not considered feasible at the North Ness site no high wind assessment was undertaken.

From the assessment carried out on the basis that the average results for the 26 years from 1970 are typical, it was established that:

- A high bridge would be completely closed for 21 hours per year;
- It would be closed to high sided vehicles for 34 days per year; and
- The high wind warning signs would be illuminated for 95 days per year.

The above results were similar for both the Point of Scotland and Greenhead sites.

It should be noted that the Lerwick observatory is situated on top of a hill some 300m above sea level and so the wind speeds recorded will be subject to some acceleration.

The figures listed above can therefore be considered as an upper bound.

For the ferry service between Bressay and Lerwick information was provided by the Marine Operations Department on recorded service disruptions and the limiting operating criteria.

From the vessels logbook, over the period between 2 March 1998 and 18 March 1999 there were two whole days and two half days lost due to inclement weather, in each case high winds.

The limiting operating restrictions for the vessel are firstly a steady wind speed of 40 knots in either a west south west or north north east direction and 45 knots in all other directions. In addition the minimum visibility for operation of the vessel is 50m.

A steady wind speed of 45 knots equates to Force 9 which, as described above, is the threshold for closure of the bridge, however with the ferry this can be in any direction. From the Met Office data therefore the wind speed would be Force 9 and above for an average of 26 hours per year. This could equate to four or five storm events and so the disruption over the past year could be considered to be in line with or a little below the average.

7.3

Swing Bridge Opening

The only information available on shipping movements in and out of the harbour is the data provided by Lerwick Harbour Trust on the number, classification and tonnage of vessels visiting the harbour in 1997 and 1998. These figures established that in both years, in excess of 6,000 vessels visited the harbour. The figures did not however differentiate between vessels using the north and south channels nor was there any information available on vessel heights other than correlating this with tonnage. The Harbour Trust were unable to provide further information but suggested that a significant percentage of vessels do use the north channel.

As described in Section 4.2 an aircraft of 12m was considered with the swing bridge options to enable smaller vessels to pass without the bridge being opened. In addition only the Point of Scotland and North Ness sites were considered.

From the data available an estimate was therefore made of the number of vessels with an aircraft exceeding 12m passing each site. This was based purely on size and type of vessel and its likely origin and destination. At Point of Scotland, cognisance was taken of vessels berthing at the O.I.L. base which would not need to pass through the bridge.

From this exercise the number of bridge openings at Point of Scotland was calculated as 4,000 while the number at North Ness was calculated as 5,300. This corresponds to 11 openings per day at Point of Scotland and 16 openings per day at North Ness. As the tidal range in the sound is not particularly large bridge opening would not necessarily have to correspond with high tides.

From data on actual opening bridges and other feasibility studies it was established that an opening cycle would be around 15 minutes although this figure is more dependent on shipping movements than on the mechanical operation of the bridge.

On this basis at the Point of Scotland the bridge would be closed to traffic for just under three hours per day whereas at North Ness the bridge would be closed to traffic for just under four hours per day.

Although the swing bridge and the operating machinery could be designed for opening in extreme winds it is very unlikely that the bridge would open in such conditions.

Setting the threshold for Force 9 and above would therefore close the channel to navigation for 26 hours each year, although the number of vessels entering or leaving the harbour in such conditions would be relatively small.

Failure of the operating machinery on an opening bridge will be largely dependent on the form of machinery utilised. It is recommended that simple robust systems are utilised and that some form of back up system is provided for the event of failure. A regular maintenance regime including keeping a stock of principal components should also minimise the incidence of failure. If the two halves of the swing bridge were operated independently then it is unlikely that they would both fail simultaneously thus enabling navigation over at least half the channel.

7.4

Traffic Accidents

Given that variable message signs are provided at either end of a bridge to give some instruction to vehicles in the event of high winds, the accident rate on the fixed link should be similar to another section of road of similar alignment. The proximity of the fixed link to Lerwick should also enable the prompt recovery of vehicles.

The accident rate in a tunnel option however is likely to be higher primarily because of the sudden transition for the motorist from daylight to a much lower value of luminance.

Figures for accident rates on Norwegian tunnels are given in Section 8.5.

The recovery of vehicles in tunnels will also be more difficult given the limited headroom.

Other disruption to a tunnel could result from water inundation or fire.

AVAILABILITY OF CROSSING

We are not aware of any recent incidences of water inundation in tunnels in service, although the failure of water mains or drainage piping has led to flooding.

There have however been a number of incidences of fire in tunnels and figures for Norwegian tunnels are given in Section 8.5.

The disruption caused by fires will depend primarily on the damage to the tunnel but is likely to result in the complete closure of the tunnel for several weeks.

8

ENVIRONMENTAL IMPACT AND SAFETY ISSUES

8.1

General

Assessing the environmental impact of a fixed link will require a more detailed study of the existing conditions at the respective sites in relation to aspects such as flora and fauna, tidal flows and currents in the Sound, background noise etc. However the following presents a synopsis of the impacts for each form of fixed link crossing.

8.2

Bridges

Bridge options will obviously have the greatest visual impact. High level options have not been considered at North Ness partly because of their dominance over the town centre. With an aircraft of 40m high level bridges at Greenhead or Point of Scotland will also be visible from most areas of the town and will project well above the surrounding landscape particularly on the Bressay side. The “hump-backed” nature of the bridge and the steep gradients of the approaches will also be very noticeable and will detract from the aesthetic appearance of the structure. Being relatively remote from the town centre and given the expansive backdrop they should not however be dominant visually. The Lerwick side of the Sound is heavily industrialised and the surrounding landscape is of limited natural beauty and so such a bridge structure would not significantly detract from the visual quality of the environs.

Bridges with an aircraft of 30m or less will obviously be less intrusive visually and will form a much better fit with the surrounding landscape and in particular the landing points on each side.

Visual impact will also be dependent on the form of superstructure adopted. A through truss option will have the greatest impact and can look particularly utilitarian unless care is utilised in the detailing.

The box girder deck will also have a significant impact although the visual quality can be enhanced by varying the depth of the box by, for example, make a feature of the mainspan proportioning the box depth to span length and also ensuring symmetry.

The cable stayed option has a mixed impact. The towers at 50m above deck level will be visible from a significant distance whereas the deck will have a slender appearance.

In terms of the flow characteristics in the Sound the impact of a bridge will depend on the number and form of bridge foundations. If only two caissons 10m wide are utilised then these will have limited impact in a 400m wide waterway. If rock islands are also incorporated to provide protection from ship impact however then these will obviously have a greater impact on flow. Excavation of the seabed for these caissons will also have an impact in terms of water quality and turbidity but this should be minimal and appropriate procedures could be utilised by way of mitigation.

A detailed study of marine life in the Sound would be required to establish the impact of construction and the permanent works on the habitat.

The fixed link at Point of Scotland and Greenhead will pass very close to existing industrial premises and significant disruption will be inevitable during construction.

A bridge would also have an adverse impact on noise levels, particularly given the height of the bridge above ground level. Noise levels would also be exacerbated by the steep approach gradients and the consequent need for vehicles particularly HGVs to engage low gears. On the Lerwick side there is already a significant noise level emanating from the industrial sites and so the impact would not be so great. On Bressay noise levels from vehicles using the bridge would have a greater impact but, at present, as there are few inhabited buildings the impact would be limited. The location of the north channel bridges will also ensure that the prevailing winds carry noise away from Lerwick Town Centre.

On Bressay a new embankment and approach road will be required to connect the bridge with the existing road. This will be built over agricultural ground which is presently utilised as rough grazing. No existing buildings need be demolished and there does not appear to be any significant flora growing on this land but a site survey would be required to confirm this.

Extending the bridge structure in from the shoreline will also avoid creating a barrier to the migration of animals such as otters.

The construction of a bridge structure at Point of Scotland or Greenhead will increase the volume of traffic in the single track road on Bressay from the Ferry Terminal to Heogan. The main industrial plant on Bressay, the Heogan fish processing facility, however would no longer need to use this road and this would

obviously be beneficial. A fixed link will also increase the volume of traffic entering Lerwick but as the crossings are remote from the Town Centre traffic can to some extent be controlled.

The swing bridge options considered, being at a lower level, would obviously reduce the visual intrusion in comparison to a high level bridge. Noise levels would also be reduced.

Causeways extending out into the Sound however would have a greater impact on the flow characteristics and marine flora and fauna.

A swing bridge option at the North Ness site would also increase traffic volumes at the new roundabout on Commercial Street and in Lerwick Town Centre generally with the consequent adverse impacts on noise and congestion.

8.3

Bored Tunnel

The impacts of a bored tunnel option on completion would relate primarily to the open cut land sections of the link together with the tunnel portals and buildings required to house services, and the increased noise and traffic congestion generated by the fixed link.

A bored tunnel option at North Ness was rejected because of the disruption and demolition required during its construction. At the other two sites the impact of noise and congestion will not be as significant.

The waterfront on Lerwick at Point of Scatland and Greenhead is industrialised. Any building housing services would not therefore require to be of any great visual quality. The open cut approaches and tunnel portals would also be hardly seen.

If necessary, these approaches could be covered and built upon or landscaped to enhance their visual quality.

There would be an adverse impact on air pollution through exhaust fumes being concentrated at the tunnel portals. The extent of this problem would depend on traffic usage but as the sites lie to the north of the Town Centre the prevailing south westerly winds would tend to carry any fumes away from the town.

The higher incidence of wind in Shetland would also help to disperse these fumes more quickly.

Another impact may result from the water collected in the tunnel drainage system and its discharge. Contamination of this water may necessitate treatment before discharging to the sea.

The primary impacts of a bored tunnel option arise during construction in terms of noise and more importantly the handling and disposal of excavated material and the storage of tunnel linings if these are precast. The excavated material could possibly be dumped at sea but this would depend on the nature of the excavated material in terms of the extent of the fines content and whether any contaminants had been introduced in the tunnel boring process.

If the tunnel is formed by a boring machine then the resulting fineness of the excavated material may result in problems of sedimentation and turbidity if dumped at sea. Similarly if conditioning agents were used then this could result in contamination. Other impacts on flora and fauna and traffic volumes would be as for the bridge options.

8.4

Immersed Tube Tunnel

The impact of an immersed tube tunnel on completion would be identical to that of a bored tunnel as already described. The impacts during construction would be of somewhat greater significance however.

Excavation of the trench on the seabed would have significant impact including problems of siltation and turbidity. Disposal of the excavated material would also have a major impact, although the appropriate dredging method could be utilised to recover material of an appropriate size to facilitate dumping at sea or adjacent to the coast of former areas of reclaimed land.

The excavated trench would also have an impact on the hydraulics although as there is no great tidal energy in the Sound these effects should not be significant.

A further impact for an immersed tube option would be the need to create a casting basin for the construction of the immersed tunnel units. As outlined in the foregoing this could be facilitated by using the open cut section of the works thus minimising the impact. If programme constraints precluded this option however then a temporary casting basin would have to be formed at a location on the coastline suitably close to the site and this basin would have to be removed and restored to its original state on completion.

Immersed tube tunnels would also require large volumes of concrete in their construction with the consequent need for the establishment of a batching plant and the supply and storage of materials.

If aggregates were won from new quarries then there would be significant impacts associated with the location and treatment of these quarries.

8.5

Safety Implications

Safety implications during construction would relate both to construction operations and the impact of these operations on third parties including existing premises and marine, vehicular and pedestrian traffic.

Safety of construction operations would be controlled by normal procedures including the use of properly trained staff, the preparation of method statements and risk assessments resulting in the use of safe techniques, equipment and materials, appropriate safety inspection and reporting procedures and compliance with all current legislation etc.

In use, safety implications for a bridge would relate to the potential for vehicles to be blown over or blown off the bridge deck. This risk could be minimised by the use of variable message signs linked to a weather station to give instructions to vehicles. The steep approach gradients could also give rise to an increased risk of accidents resulting from skidding or brake failure. Otherwise, provided that the alignment was designed to current standards the risk would not be greater than a normal section of road.

In use, safety implications for a tunnel would be greater than a bridge. The steep gradients would pose similar risks as highlighted for a bridge but a greater risk of accidents result from changes in light levels. While the concentration in lighting provision at the tunnel portal helps drivers to become accustomed the transition from daylight to relative darkness does give rise to an increased number of accidents.

Norway is one of the countries in Europe which has been building the largest number of road tunnels in recent years and they have assessed the number of accidents in their tunnels over a five year period from 1992.

For this assessment they subdivided the tunnels into four zones. Zone 1 is the 50 m outside the tunnel, zone 2 is the first 50 m of the tunnel, zone 3 is the next 100 m of the tunnel and zone 4 is the remainder of the tunnel.

The rate for traffic accidents with personal injury in terms of accidents per year, per one million vehicle kilometres were recorded as:-

Zone 1 – 0.30

Zone 2 – 0.23

Zone 3 – 0.16

Zone 4 – 0.10

These compare with the Norwegian average figure for all roads of 0.10 and hence there is an increased risk of accidents occurring in a tunnel, although it should be noted that a significant number of the Norwegian tunnels have no lighting. It should also be noted that accidents in tunnels tend to be more serious.

The other risks in tunnels are fires and water inundation. There has been no recent recorded incidents of water inundation that we are aware of, but there have been a number of fires. The Norwegian data cited an incidence of 41 fires in their total stock of 702 tunnels over a 7 year period, 8 of which were initiated by collisions. Two other notable tunnel fires included the channel tunnel fire and the very recent Mont Blanc tunnel fire in which a significant number of people lost their lives.

9

LAND ACQUISITION AND LEGAL ISSUES

9.1

Land Acquisition

The extent of land acquisition will obviously depend on the option chosen. With respect to roadworks, the whole area covered by the road, embankments and a strip beyond the embankments for maintenance access would be required.

A grant of servitude may also be required to construct certain elements of the works, for example an outfall pipe. For an immersed tube tunnel the area occupied by the tunnel would also be required. With regard to bored tunnels the necessity of purchasing land is dependent on whether the tunnel would impose any form of planning blight above the line of the tunnel and so in this instance would only affect developed areas over land.

For a bridge structure it is only necessary to purchase the footprint of the bridge foundations and to acquire a grant of servitude over the area formed by the shadow of the structure plus an extra width on either side to allow for future maintenance. If this project were to proceed on a design and construct basis however, merely acquiring the footprint of bridge foundations for a certain bridge configuration would restrict tendering consortias opportunities to consider alternative bridge forms and span configurations without having to acquire additional land at potentially inflated prices.

Some of the options considered would impact on existing dwellings, commercial premises and development sites on the Lerwick side. Scheme costs would also potentially have to cover the relocation of commercial business, loss of business, disruption during construction and noise abatement through for example the provision of double or triple glazing.

Selection of a crossing alignment however would potentially free up development sites at Point of Scatland which have hitherto been reserved pending the selection of a preferred line.

Consideration has been given to the probable procedures for promoting a scheme for the construction of a bridge over or tunnel under the Bressay Sound. As the fixed link is neither a Trunk Road nor Special Road, it would probably be covered by Section 75(3) of the Roads (Scotland) Act 1984. This states the provision which may be made by a scheme promoted by a local roads authority and subsequently confirmed by the Secretary of State in respect of the construction, as part of a public road (other than a special road, of a bridge over or tunnel under any

navigable waters). The navigable waters should be specified in the scheme and before confirming the scheme, the Secretary of State shall take into consideration the reasonable requirements of navigation in the waters affected by the Scheme.

It should also be noted that special provisions relate to swing bridges.

If a navigation authority objects and does not withdraw its objection, the scheme will become subject to special parliamentary procedure.

In considering legal issues affecting the promotion of a fixed link, consideration was given to the influence of the Zetland County Council Act 1974 on the scheme and the Shetland Islands Council legal and Property Services Division was consulted. They advised that although the Act makes special provision for development activities in the coastal area adjacent to the Shetland Islands, the coastal area does not include the area from time to time within the jurisdiction of the Lerwick Harbour Trust and the Act is therefore not valid in this instance.

10

SOURCES AND AVAILABILITY OF EXTERNAL FUNDING

10.1

Introduction

This section briefly outlines the findings of a summary review of the potential funding options for the financing of the Fixed Link between Shetland and the Island of Bressay. It identifies the potential sources of finance and comments on their suitability to Shetland Islands Council and the criteria used by the funders in distributing these resources. The next section will consider funding from the following sources:

- European Regional Development Fund (ERDF)
- European Investment Bank (EIB)
- Private sector funding (PFI, developer contributions)

10.2

Potential Funding Sources

10.2.1

ERDF

As a designated Objective 1 area by the European Union, Shetland qualifies for ERDF grant aid. The current ERDF funding round expires at the end of this year, from which point Shetland will no longer be designated an Objective 1 area. However, a transitional fund believed to be in the region of £200 million (The Herald 26 March 99) will be established and the Shetland Islands will be able to draw upon these funds.

The European Union sets stringent eligibility criteria for applicants to the fund. Four specific areas are of particular relevance to the Bressay Fixed Link Project, a project should be able to demonstrate that:

- The promoters of the scheme could not carry out the investment without recourse to additional support
- There is demand for the project
- There is a significant level of 'additionality' associated with the investment. These should be estimated prior to securing the aid and monitored post

construction. Specific measures might include: (Jobs created/safeguarded, levels of demand, development impacts, journey time reductions etc)

- what environmental impacts of the project will be

10.2.2

EIB

The European Investment Bank supports investment which adheres to community objectives. It can guarantee up to 50% of the loans required to finance infrastructure projects at extremely favourable rates.

To be accepted by the Bank, projects should be able to demonstrate one or more of the following relevant objectives:

- Foster the economic advancement of less favoured regions
- Improve the European transport and communications infrastructure
- Protect the environment and quality of life

Projects are evaluated under the following criteria:

- Investment is appraised thoroughly and monitored through to completion
- The criteria includes, technical, financial and economic viability
- A demonstration of the promoters financial security is essential

The Shetland Islands Council has stated that it is keen to maintain its' current favoured position with the Scottish Office relating to a zero loan requirement. Therefore, prior to proceeding with this line of enquiry the views of the Scottish Office should be sought in respect of loans from European Institutions to determine whether they differ from commercial lending.

10.3

Private Sector Finance

10.3.1

PFI

The principle behind PFI is that private sector capital, management techniques and ingenuity should be harnessed to provide public sector infrastructure. The private sector is re-paid effectively by charging a rent for the provision of the services from the infrastructure. The basis of the payment mechanism in terms of the Bressay link could be traffic levels or link availability (number of operational hours in a year).

The estimated cost of the link at around £13 million is relatively small in PFI terms. This is important as the bidding process associated with this method of procurement can be lengthy, onerous and therefore has its own associated costs. What is important in consideration of procurement methods is that the Council decide, and can demonstrate, the most appropriate method. This may be through PFI, in which case a public sector comparator funding route needs to demonstrate that PFI is optimal.

In principle the provision of funding through PFI should not be viewed by the Scottish Office as contributing to council debt. However, this would need to be discussed with the Scottish Office to confirm their view.

10.4

Developer Contributions

The provision of a fixed link has potential to create activity hubs with associated increases in land values at either side of the crossing. As such potential developers in these areas could be encouraged to contribute to the costs of the link, with their repayment being the realisation of the land value increase.

10.5

Scottish Office Funding

The Scottish Office have initiated a number of programmes for funding local authority infrastructure projects. The Challenge Fund Programme was used to fund a number of infrastructure projects including the Kelso Bypass and the A92 Arbroath - Dundee route but this programme has now expired. The latest programme is the Public Transport Fund which is primarily aimed at public transport schemes but this fund provided £4.1 million towards the new causeway to Eriskay in the Western Isles. This scheme also included slipway improvements which may well have enhanced its integrated transport credentials and contributed to its success. The present round of the PT fund expires in 2000 and so there is likely to be only one more bidding round left.

11

CONCLUSIONS

11.1

Conclusions

The following options have been considered for the Fixed Link:

- High level bridges
- Bridges to lesser requirements
- Swing bridges
- Immersed tube tunnel
- TBM driven bored tunnel with a precast concrete segmental lining
- Bored tunnel excavated by road header with an in situ concrete lining.

These alternatives have all been considered at the three most feasible crossing locations, Point of Scotland, Greenhead and North Ness.

It is suggested that the single lane carriageway arrangement is not a viable or safe option for a bridge or tunnel of this length and that only the two lane carriageway should be considered. It is also suggested that a two lane carriageway of lesser width be considered given the potential economies.

This study concluded that for both bridge and tunnel options, the Point of Scotland site was the preferred location. It also concluded that bridge options were considerably cheaper than tunnel options.

It should be noted however that tunnelled crossings offer some advantages over a bridge notably:

- Tunnel availability is high and is not affected by adverse weather conditions.
- The tunnel offers a means of providing service connections between Lerwick and Bressay.
- Avoids the concern of ship collisions with bridge piers etc.
- Environmental – visual impact is minimal.

CONCLUSIONS

The tunnelled crossing does have some significant disadvantages:

- Operating costs for lighting, drainage and ventilation.
- Safety considerations particularly tunnel fires.
- Environmental – dispersal of exhaust fumes at tunnel portals.

Swing bridges are economical in terms of capital cost but are unlikely to be acceptable given the control they impose on navigation, the length of time they would be unavailable to vehicular and pedestrian traffic and their relatively high operational and maintenance costs.

A fixed bridge is therefore the preferred option. The choice of bridge option will ultimately depend on the navigation clearances agreed with the relevant authorities. We consider that the optimal air draft would be 30m but recognise that this may need to be greater.

The form of bridge structure may depend on contractors preferences if a design and construct method of procurement is utilised, but an exemplar design may have to be presented for consultation with interested parties, including the Royal Fine Art Commission for Scotland. In this respect the box girder viaduct may offer the best solution for mainspan lengths of up to 180 m while the cable stayed option may offer the best solution for longer span lengths.