SHETLAND ISLANDS COUNCIL

Shetland Islands Fixed Links
Geotechnical Pre-investigations

Report 2484.02 dated 18th of October 2002

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Summary:
The report includes a description of the various elements of a pre-investigation programme based on the normal development of similar projects in Norway. Such pre-investigations involve geological mapping, refraction seismic survey, core drilling and shallow investigation at the portal areas. These investigations will provide information on geology and hydrogeology in the project areas that could form the basis for an appropriate alignment evaluation, cost estimate and detail design of the tunnels.

It is assumed that a pre-investigation programme for the two projects, crossing of Bluemull Sound and Yell Sound, would involve a total cost of approximately 685.000 to 915.000 £. Such an investment is needed before the preparation of detail design and tender documents can be commenced.

The report includes a possible sequence of pre-investigation activities followed by a design period. Given a go-ahead signal during fall 2002 most the pre-investigations can be competed in 2003.

Trondheim, 18. October 2002
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1. Appendix 1, Initial refraction seismic lines Bluemull Sound, Dwg. no. 2484-03
2. Appendix 2, Initial refraction seismic lines Yell Sound, Dwg. no. 2484-04

1 BACKGROUND AND PURPOSE

The Shetland Islands Council is considering establishing fixed links projects connecting the Mainland with the island of Yell across the Yell Sound, and also connecting the islands of Yell and Unst, across the Bluemull Sound, see Figure 1. At present, ferries are operating the crossing of these sounds. One optional solution for fixed links is sub sea rock tunnels.

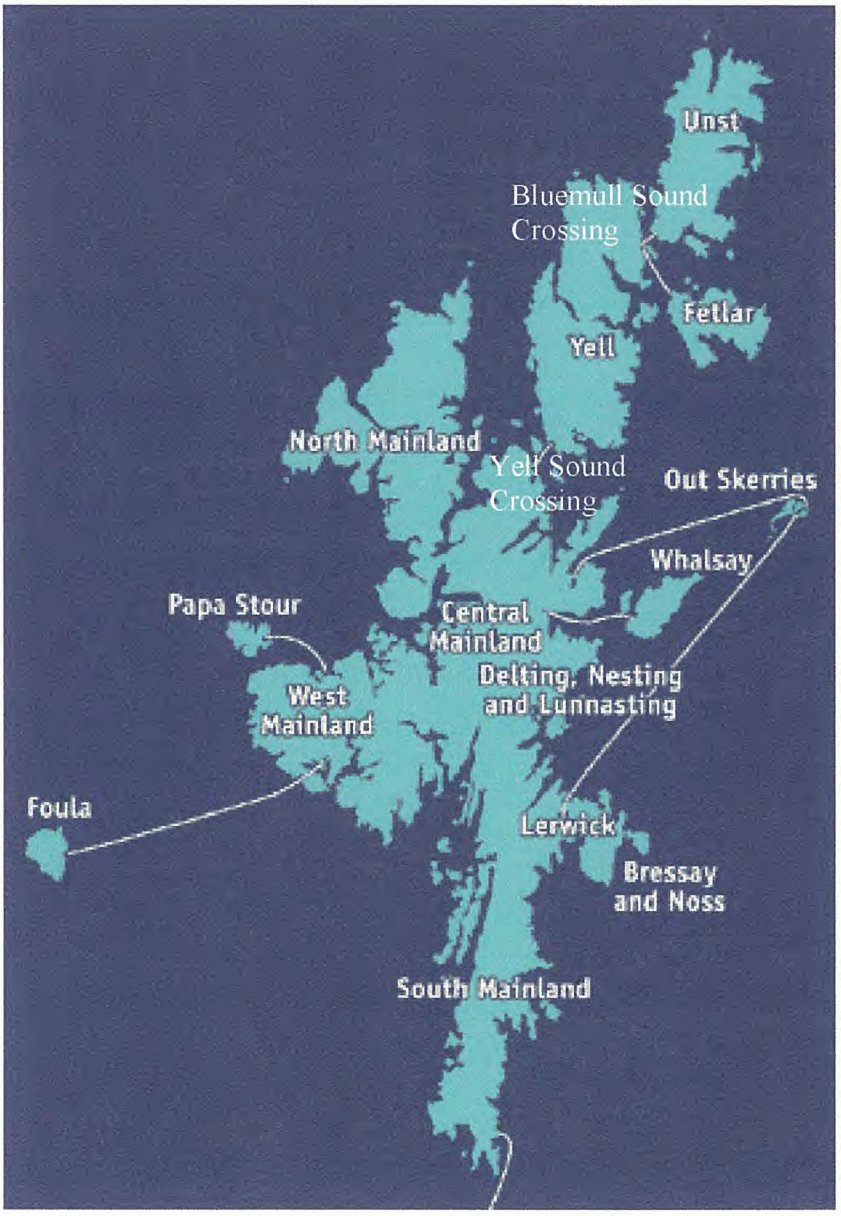

Figure 1. Overview map of Yell Sound and Bluemull Sound crossings

In early 2002 the company O. T. Blindheim AS conducted a technical evaluation and cost estimate for the tunnel links crossing Bluemull Sound and Yell Sound, see [Ref. 1] based on our experience from similar projects in Norway and elsewhere within the Nordic countires. As a separate chapter of this report recommendations were presented on how to proceed with respect to further geotechnical investigations. The report [Ref. 1] included descriptions of the main elements of such geotechnical pre-investigations as well as a rough cost estimate of these investigations.

The company O. T. Blindheim AS has now been asked to provide the Shetland Islands Council with a programme for the pre-investigations that are needed for the safe and successful construction of sub sea rock tunnels crossing the Bluemull and Yell Sounds. This report describes such a programme.

Further, a brief cost estimate of the same pre-investigations is prepared. This report includes also a possible time schedule and an estimate on the duration of each of the proposed elements in the pre-investigation programme.

The pre-investigation programme has been based on the development of similar projects in Norway, as well as the recent projects performed in Iceland and in the Faroe Islands.

2 GEOPHYSICAL INVESTIGATIONS

For the Bluemull Sound a reflection seismic survey has been undertaken in the area for the planned tunnel. The company Caledonian Geotech Ltd. performed the survey in 2000, see [Ref. 2]. The survey included hydrographic survey (echo-sounder), sidescan sonar and sub-buttom surveys using two separate seismic systems (Sparker and Pinger), both based on reflection seismic technique

In May 2002 Caledonian Geotech Ltd. conducted a similar geophysical survey (reflection and acoustic seismics) for the Yell Sound as recommended in [Ref. 1]. See [Ref. 3] for the report from the survey.

The conducted reflection seismic surveys cover the areas for the proposed tunnel alignments in both sounds. A few distinct weakness zones were identified, namely the Nesting Fault Zone and the Bluemull Faulting Zone.

A technical note was prepared by O. T. Blindheim AS for the Shetland Islands Council with an evaluation of the latest works carried out in the Yell Sound, see [Ref. 4]. Quoting [Ref. 4]: "The results from the acoustic seismic survey by Caledonian forms a valuable background for the further developments of the fixed link across the Yell Sound and for the documentation of seabed conditions. The survey covers a wide area which provides a good overview of the seabed conditions in the sound."

For the purpose of obtaining more accurate information of the rock mass quality and the location and conditions of weakness zones, it is necessary to conduct refraction seismic surveys. According to [Ref. 1] the following aspects call for further investigations:

- the rock surface is not accurately defined, and
- the location and condition of weakness zone(s), if any, are not known.

In addition, information on the rock mass quality along the tunnel route must be obtained.

To supplement the existing information obtained during the acoustic surveys, refraction seismic is normally performed. The next chapter describes a programme for refraction seismic profiles.

2.1 Refraction seismic survey Bluemull Sound

2.1.1 Description

A typical refraction seismic survey consists of seismic profiles each having a length of 235 m. The cables that are used have a hydrophone each five meter. The hydrophone cable is placed on the sea floor and sound velocities in the ground caused by small explosives are registered. These refraction seismic profiles shall be used particularly in the central parts of the sound, in areas with low rock cover and where the reflection seismic has identified potential weak zones.

A programme for the initial refraction seismic profiles are presented in appendix 1. This programme includes 10 refraction seismic profiles in the sound, and covers a corridor of approximately 500 meters. These initial lines include six profiles that will cross the sound and have an orientation N60°E. The remaining four profiles will be oriented more or less parallel to the coastline, with two profiles on the vest side of the sound, oriented N-S, and two lines on the east side, oriented N165°E. These are marked on the drawing in appendix 1 as the initial profiles.

The tunnel alignment might be adjusted based on the findings from the different surveys. After analysing the output of the initial lines and before concluding the final tunnel alignment in the sub sea part, it is recommended to include refraction profiles to obtain a more or less full coverage of the sub sea section of the tunnel thus establishing a "describing profile". These will be used to investigate further details if weakness zones if needed. The location of these last profiles will be based on the output from the initial ones. An expected 5 more seismic profiles will be used for completing the survey and to obtain a "describing profile" along the tunnel alignment. In appendix the location of such completing have not been marked.

2.1.2 Time schedule

Since a refraction seismic survey is sensitive to weather conditions and tidal currents, late fall and wintertime are not good periods of the year. In a technical note by O. T. Blindheim AS dated 9th of April 2002, it was indicated, that summer and early fall would be advisable timing of such investigations. The most realistic alternative would probably be to conduct the survey during the summer of 2003.

Even with favourable weather conditions and good timing with respect to tidal currents, two lines a day could be the maximum production rate. With a total of 15 refraction seismic lines, the refraction seismic survey in the Bluemull Sound is expected to have a duration of about two weeks, depending on the weather conditions. In addition the contractor would probably need a total of 1 week for mobilisation and demobilisation.

The contractor shall produce a separate report on the works and some 3 weeks after the completion of the survey the report should be expected to be finalised.

2.1.3 Cost estimate

The companies that could conduct such works are highly specialised. A similar survey in the Faroe Island in 2002 yielded a total cost of appr. 1,5 mill NOK, equivalent to 130.000 £ for a total of 13 refraction lines (conversion rate 11,5 NOK per 1 £). Assuming a similar cost level for the survey in the Shetlands the cost for the Bluemull Sound survey is expected to be in the range of 150.000 £.

2.2 Refraction seismic survey Yell Sound

2.2.1 Description

A refraction seismic program for Yell Sound is naturally divided in two parts; the part of Yell Sound SW of the island Bigga, and the part NE of Bigga. A programme for the initial refraction seismic profiles as well as the ones dedicated for a "describing profile" for these two regions are presented in appendix 2.

Between Bigga and Yell. In this NE-part of the Yell Sound it has been proposed to use 10 refraction profiles in the initial stage of the refraction survey. Out of these 6 profiles are planned with an orientation parallel to the tunnel alignment, that is perpendicular to the orientation of the sound whilst 4 profiles are planned being orientated parallel to the sound, or perpendicular to the tunnel alignment.

Another 5 lines could be optional for further details and for completing a "describing profile".

Between Bigga and Mainland. In this SW-part of the Yell Sound the proposal includes 10 refraction lines in the initial stage. The proposal includes 5 profiles being parallel to the tunnel alignment, that is perpendicular to the sound. Another 5 profiles will be intersecting potential weak zones identified by the acoustic survey and also intersecting some of those lines parallel to the alignment. The orientation of these latter refraction lines will be both NW and NS.

Another 5 profiles could be optional for further details and for completing a "describing profile".

2.2.2 Time schedule

The time schedule for the Yell Sound investigations follow the same general outline as presented above. The survey must be programmed to take place in periods where the tidal currents and weather conditions are favourable. It is assumed that a duration of 3-4 weeks would be required to perform a total of 30 refraction seismic profiles as described above for the Yell Sound. In addition one week for mobilisation/demobilisation must be expected.

The time schedule for the entire ferry replacement program has not been communicated with us, therefore it is impossible to implement the real timing of these investigations. However,

normally in similar projects refraction seismic surveys are conducted prior to the detail design of the projects. Typically, the refraction seismic surveys are used to fix the final tunnel alignment.

2.2.3 Cost estimate

Using the same basis for the estimation of the cost for the refraction seismic survey in the Yell Sound as was used for the Bluemull Sound a total of 30 refraction lines would be required producing a total cost of appr. 300.000 £.

3 GEOLOGICAL MAPPING AND CORE-DRILLING

3.1 Geological mapping

3.1.1 Description

At the present stage of the project some geological mapping has been conducted by various companies in addition to general material from external sources like the British Geological Survey. Both Halcrow and Caledonian Geotech made some surface observations and investigations of rock types, jointing and fault zones, however these were in small number and just locally. In addition some material was collected by O. T. Blindheim AS during our first visit to the project sites.

However, a detailed geological surface mapping is required. Such a mapping programme should include description of rock types, rock boundaries, joint characterisation, identification and description of fault zones and description of sediments (alluvial material and morraine).

It is normal that such a surface geological mapping programme is supported by studies of vertical aerial photos, together with studies of existing publications on the geology in the area. Such studies are normally done at the home office of the consultant.

The material gathered from the geological surface mapping will be presented in a dedicated report with a geological model attached. The geological model is a 2-dimensional model in terms of a plan of the investigated area with cross section along the preferred tunnel alignment. Joint mapping should be presented by graphical joint rosettes showing the statistical distribution of the various joint sets.

At the entrances and at the portal areas a more detailed geological surface mapping is normally performed. These could be conducted as separate investigations at the time the portals and the tunnel alignment has been fixed.

3.1.2 Time schedule

The areas where these crossings are planned have been located. A geological mapping programme would support the reflection seismic survey to form the basis for the design of the next coming investigations, such as refraction seismics and selection of core hole locations.

With the gentle climatic environment in the Islands, it is believed that such a programme can be performed practically all year around, except during shorter periods at mid-winter with snow on the ground.

3.1.3 Cost estimate

The surface mapping would probably take some 2 weeks of field investigations for one geologist. Writing report and doing the necessary desk-studies would probably take another 2-4 weeks. The total cost of such a programme is estimated to approximately 10.000 to 15.000 £. In addition comes direct costs for transportation, lodging etc.

3.2 Core drilling Bluemull Sound and Yell Sound

3.2.1 Description

It has been the recommendation of our report 2484.01 to conduct a core drilling scheme to gain information about quality and hydraulic properties of the rock mass. Such core drilling involves drill holes with an outer diameter of 56 to 76 mm. It also includes sampling of cores and logging. The depth of the drill holes is recommended to reach below the lowest level of the sub crossing. This implies that the length of each hole would be in the range of 100 to 125 m.

The core drilling will take place at selected locations at the shorelines. It is not common in Norwegian sub sea tunnelling practice to perform core drilling from boats within the sounds themselves. The refraction seismics normally provide adequate information. Inclined core holes, or core holes with directional control drilled from the shoreline would be preferred if particular zones call for special drilling.

The cores that have been sampled during the drilling shall be properly stored, numbered and logged. This is a standard procedure for core logging, but must be addressed in the contract with the drilling company.

During drilling, or possibly also after completion of the drilling, each hole shall be tested to obtain information about the hydrogeological conditions of the rock mass.

The core drilling programme will be established based on surface geological mapping. It may also be needed to core drill through particular zones to collect specific data on these zones. Such coring must be decided on a later stage when detailed information is available, particularly from the refraction seismic survey.

It is assumed that the core drilling programme covers both crossings. Although the alignments are not fully detailed or fixed, such core holes can be located within the vicinity of expected tunnel routes. Contractors for core drilling are expected to be available throughout the UK.

It is assessed that a total number of 3 to 6 holes per project would be required. That will make a total of 8 to 12 holes, or 800 to 1500 m.

A separate report from the contractor shall present all the information from the core drilling. The logging of the cores must be undertaken by a trained geologist and should include parameters assigned to a well recognised rock mass classification system. In some cases the drilling contractor can provide such logging.

3.2.2 Time schedule

Core drilling is likely to be conducted year around in the Shetland Islands. The contract can thus be executed during the winter and spring of 2003.

It is assumed that the capacity per drill rig for such drilling would be in the range of an average of 10 m per 10 hours working shift pending of the conditions of the rock mass. Assuming 2-4 drill rigs working simultaneously a duration of 1-3 months for the core drilling scheme should be expected.

3.2.3 Cost estimate

The cost per m of core drilling is assumed to be in the range of 1500 to 2300 NOK including water pressure testing, proper numbering and storing, mobilisation and demobilisation of crew and equipment. This is equivalent to 130 to 200 £ (conversion rate 11.5 NOK per 1 £).

For the core logging approximately 10 to 15 £ per m can be used as a budget price

The total cost of the core drilling would then be 120.000 £ to 325.000 £ with a weighted average of 220.000 £ for the two projects totally.

3.3 Laboratory testing

During the core drilling and also from the geological surface mapping samples can be taken for testing in the laboratory. Such testing would typically included mechanical properties of the rock and also drillability and abrasiveness.

It is assumed that such testing can be performed within a budget of 10.000 £.

4 SHALLOW INVESTIGATIONS AT THE PORTAL AREAS

At the time the tunnel corridor has been established and whilst seeking the detailed locations of the portals, it is necessary to do shallow investigations in the portal areas. These could include refraction seismic as described above, but also percussion (or core) drillings, even trenching could be possible pending on the thickness of soil deposits. Such shallow investigations may also be used in particular areas of low cover in the on-shore sections of the tunnel alignments, or otherwise where found required.

In the cost estimate the following has been included:

Percussion drilling:	30 holes/ 500 £ per hole	15.000 £
Shallow core drilling:	100 m/175 £ per m	17.500 £
Surface refraction seismic:	5 lines/6.500 £ per profile	32.500 £
Total shallow investigations:		65.000 £

5 TOPOGRAPHICAL MAPS (ON SHORE)

It is believed that preparation of new topographical maps are needed. It is not known to us if this is a matter that can be taken care of by the Council itself. Consequently costs for such works have not been included in the cost estimate.

6 TOTAL TIME AND COSTS

In our letter dated 9th of April a ball park figure on the planning and following up of the pre-investigation works was presented. This ball park figure indicated a cost in the range of 40 to 60.000 £. Table 2 below summarises the costs associated with pre-investigations.

Table 2. Summarising the cost estimates for pre-investigation activities for both Yell and Bluemull Sounds

Activity	Bluemull Sound	Yell Sound
Refraction seismic	150.000 £	300.000 £
Geological surface mapping	10.000 - 15.000 £	
Core drilling	120.000 – 325.000 £	
Laboratory testing	10.000	
Shallow investigation portals	65.000 £	
Planning and follow-up	40.000 – 60.000 £	
Total	695.000 – 925.000	

As a comparison, in our report 2484.01 [Ref. 1] an estimate of the geotechnical pre-investigations was provided. This estimate totalled 1.000.000 £ for the pre-investigations including also the costs of the reflection seismic survey conducted this summer.

Based on a go-ahead signal this fall for the pre-investigations for the two projects involved, that is the Yell Sound and Bluemull Sound crossings, a summarised time schedule for these works can be established as given in Table 3 below. This summary is based on that the pre-investigations go simultaneously for the two projects.

It has also been included the timing of the various design tasks in the time schedule aiming at making a realistic overview of the process of the project development.

Table 3. Summarising the time schedule for pre-investigation activities for both Yell and Bluemull Sounds

Activity	Sequence	Timeschedule
Topographical maps on-shore	1	Fall 2002/winter 2003
Geological surface mapping	2	Fall 2002/winter 2003
Alignment evaluation	3	Winter 2003
Detailed planning of pre-investigations	4	Winter 2003
Core drilling	5	Winter/spring 2003
Refraction seismics	6	Summer 2003
Detail design	7	Can not start until the pre-investigations have been concluded
Shallow investigations at the portals	8	To be done when portal locations have been established
Tender preparations	9	

7 REFERENCES

1. Tunnel links Yell Sound and Bluemull Sound
Technical evaluation and cost estimate
Report 2482.01 by O. T. Blindheim AS dated 3rd of May 2002

2. Marine site investigations – Bluemull Sound
Caledonian Geotech Ltd.
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3. Yell Sound tunnel project
Caledonian Geotech Ltd.
Report MM0209 dated June 2002

4. Fixed links Shetland Islands
Evaluating the seismic acoustic survey
O. T. Blindheim AS dated 23. September 2002