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Subject:

Recommendations for ground investigations

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1 GROUND INVESTIGATIONS

1.1 Topographic survey

Detailed information of the sea-bed topography is required for evaluation of possible and suitable methods for anchoring along the tube-bridge alignment. Detailed survey of the sea-bed is easy to perform with a fairly high resolution and degree of accuracy.

A 3-dimensional terrain model of the sea-bed should be established along a corridor below the bridge alignment (all alternative alignments), with special attention to high resolution data at the planned locations of the anchoring points. Such a model will allow for a better understanding of the sea-bed topography, and to a certain extent also the conditions of rock outcrops, and types and expected thickness of sediments. The model may also reveal structures that may influence the stability of the ground at the anchoring points.

Specialists within marine surveying may advise on optimal methods for surveying. It is expected that an advanced multi-beam echo sounding may be a suitable method to obtain or supplement data for a detailed 3D terrain model. A principal sketch of such survey method is shown in Figure 1.

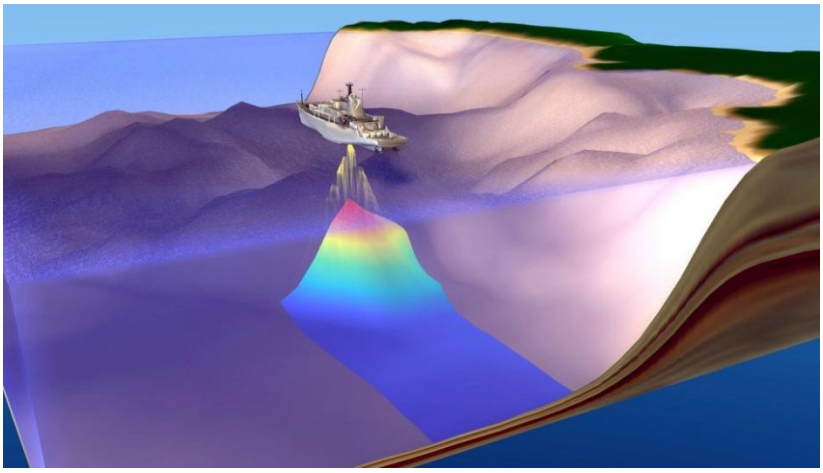

Figure 1 Principle sketch of subsea topographical survey by multi-beam echo sounding.

1.2 Thickness of sediments

Some data on the thickness of sediments exist from preliminary acoustic profiling (reflection seismic survey). These investigations indicate that in the shallow areas close to shore and the steep sections where the water depth increase down to 3-400 m, there are little or no sediments, while in the deep sections in the middle of the strait, the thickness of sediments may in some area be more than 50 m.

This type of acoustic profiling is an efficient way of mapping, as large areas may be covered in relatively short time and at a moderate cost. However, a downside is that the signals for the survey have a relatively large scatter, thus the resolution will suffer in deeper waters, and there are particular challenges related to side reflections in steep terrain. The latter is indeed also the case for the existing survey, as it is indicated on the plots that the data is inaccurate in some areas due to side reflections. The existing mapping is considered very useful for evaluation of concepts and planning of further investigations. For further detailing of the design principles it is recommended to perform more detailed and accurate mapping and investigations along the final alignment(s), particularly at the locations of anchoring.

More detailed survey of the local areas for foundations/anchoring may possibly be done by refraction seismic survey. A limitation for this survey method is however the water depth. It is assumed that practical limitations allow for this type of survey to be performed down to about 300 m. In this case, the northern 1/3 of the alignment may probably be surveyed by this method. In the south the topography is quite steep and the water depth increases to over 300 m after a very short distance from the shore. It is however assumed that the conditions for foundations/anchoring within this steep section, if applicable, may be investigated by refraction seismic. A principal sketch of subsea refraction seismic survey is shown in Figure 2.

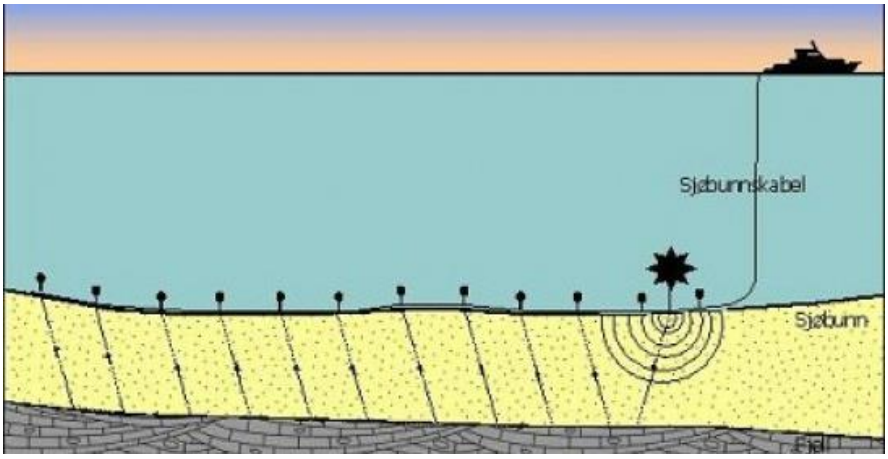

Figure 2 Principle sketch of sea bed refraction seismic survey.

1.3 Rock mass quality

In areas where the anchor point falls in rocky terrain, it will be necessary to collect information on detailed 3D topography. Depending on the topography, it may also be necessary to collect information on geology; rock mass quality and amount and quality of any loose sediments. In particular it is of interest to detect any weakness zones in the rock mass at the anchor point or in the near vicinity where such conditions may affect the stability of the area. This is applicable whether the design includes grouted anchors in rock or gravitational anchors.

Refraction seismic survey, discussed in the previous section, is considered a suitable method to also collect information on rock mass quality and as a tool to detect potential weakness zones in the rock mass. Information on both sediments (type and thickness) and rock mass quality is collected in the same operation by refraction seismic survey.

1.4 ROV video inspection

In due time it will probably be necessary, or at least useful, to perform a "visual" inspection of certain key areas. Such areas may be connection point for tube bridge/rock tunnel, areas for foundation points and particular areas in steep topography where slope stability may be an issue.

In shallow waters such inspection may be performed by divers with video camera, probably down to 20-30 m depth. In deeper water (which will be the major parts of the project) inspection may be performed by ROV. Suitable equipment for such inspections is conventionally available and may be used down to at least 500 m depth.

1.5 Soil investigations

The available information on the soil conditions is limited. Maximum water depth is about 500 m. The near-shore areas are characterized by undulating surface, covered by limited soil. There are steep underwater slopes down to the middle part of the fjord from the shoreline on both sides of the crossing. The slopes are assumed to have outcropping rock. The middle part is covered by varying types of sediments, described as moraine, mixed deposits and clay. In four locations samples of the clay are taken with use of fall-cone sampler. Samples are taken down to 3 - 4 m below sea-bed, showing soft and plastic clay. No information is available at higher depths, nor from other soil types than the clay. Such information is vital to perform more accurate and detailed design of the foundation solutions. In particular more accurate calculations to check stability conditions and to estimate settlements are required.

The location of the investigation should be decided based on existing information and results from surveys described above; more detailed bathymetric investigations and refraction survey. Near-shore areas covered with soil should also be included, but the deep areas in the middle deep part of the fjord must be emphasized.

Preferably all anchoring locations covered with soil, should be investigated. As a minimum the soil investigation should cover all typical soil types and soil thicknesses. The following investigations are recommended:

- **At each location/soil type: Drilling or sounding down and into solid rock, to get information on soil thickness and layering**
- **At each location/soil type: Perform CPT (Cone Penetration Tast) to check soil type, layering and get information on soil parameters**
- **For typical soil types: take undisturbed samples from the soil if possible. Otherwise disturbed samples may be taken. Locations for soil sampling to be based on the results from the drilling, sounding and CPT**
- **Laboratory tests: routine-investigations (unit weight, water content, plasticity, undrained shear strength). In addition more advanced investigations such as triaxial and oedometer tests should be carried out**

As the water depths generally are high, vessels and methods for off-shore sites must be used. For water depths less than 35 – 40 m vessels and methods for near-shore purposes are possible to use.