# CROSSING THE OSLOFJORD - AN EARLY STRATEGIC ANALYSIS
## - Technical challenges and consideration of Feasible solutions

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## ABSTRACT

*Feasibility studies are in progress for a fixed link across the southern part of the Oslofjord covering an area from Tønsberg in the south to Drøbak in the north. The present Oslofjord tunnel at Drøbak has shown itself not to be a preferred alternative to the ferry between Moss and Horten, which is the ferry link in Norway carrying most vehicles. New potential crossings will be considered including a railway link in combination with the road link. Regional impacts as well as other relevant conditions related to the transport sector will be evaluated. The study is scheduled to be completed by summer 2014. Various combinations of bridge and tunnel solutions will be considered, including the effect of improved ferry connections related to current and predicted traffic volumes. The sailing lane requirements for the Oslofjord will probably be 1500 m wide (alternative: 2 x 750 m) and 75 m high due to the frequent passage of large size ships. At the most relevant sites for future crossing the fjord is 1,8 - 8 km wide and the bedrock has depths down to -400 m.*

*This paper presents a choice of technical alternatives at this very early stage related to the topographic and ground conditions at the various prospective sites.*


## GEOGRAPHY – BACKGROUND

As may be seen in Figure 1, all the roads and railway lines around the Oslofjord are channelled towards the capital Oslo. It follows therefore that the focus of those living west of the fjord naturally is on the capital Oslo, and likewise for those living on the east side of the fjord. The fjord is thus effectively preventing those living close to the fjord from having a mutual labour- and housing market. At present there are also regrettably few social and educational contacts across the fjord. And the industry is not cooperating either. This ought to change.

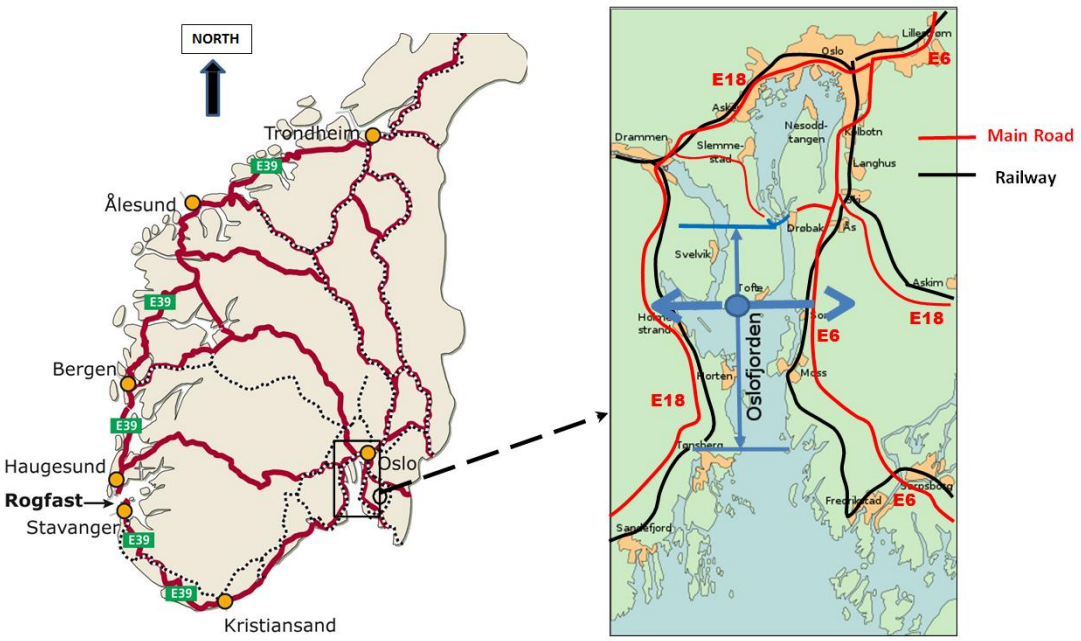


*Figure 1 South of Norway and the Oslofjord*

This feasibility study considers different concepts to substantially improve transport and communications across the Oslofjord south of Drøbak as indicated in Figure 1. The object of the technology part of the present study is to ensure with sufficient certainty that what is proposed as fixed link solutions, can be built, and at a cost the country can afford. Adding to the complexity of this task, a combined crossing for road and rail is also be investigated and developed.

At this point all possible crossing sites and all methods of crossing is to be considered. No concept is at present excluded from the investigations. It will therefore be totally misleading to present any concept, as "a chosen one"!

## HISTORY

The model in Figure 2 is from 1988 and shows a planned road bridge crossing the fjord just north of Drøbak. If having been built, it would have destroyed many summer cottages and reduced the value of scenery and nature in one of the most visited parts of the Oslofjord. The navigational channel is quite narrow at this point.

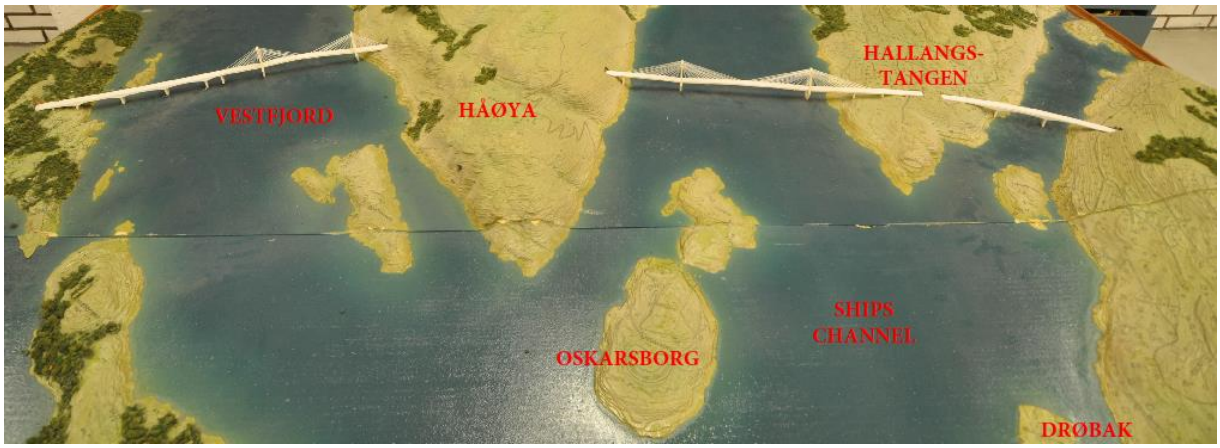


*Figure 2 Model from 1988 showing possible bridge crossings north of Drøbak*

The inhabitants of the area and local politicians reacted strongly against this concept. The minister of Transport and Communication then decided to build a subsea tunnel instead.

The two acoustic profiles shown in Figure 3 was the sole information of bedrock available for the southern part of the Oslofjord when this feasibility study was started. One of them covers the distance from the Bastøy Island to the Jeløy Island, while the other covers the distance from Bastøy to Rygge on the eastern mainland. These profiles were obtained in 1988.
As may be seen, the profiles show sediments having thickness up till 120 m in the deeper parts of the fjord. This strongly indicate that the depths to the bedrock is more than the depths to the sea bed as shown in public seamaps.

A great need for additional data of the bedrock arose, and a seismic exploration program was drawn up trying to take all eventualities into consideration. Interests were focused on rock formations through which drill and blast tunnels could be constructed or upon which bridge foundations could be placed. This program was executed August 2012, and provided some unexpected results.

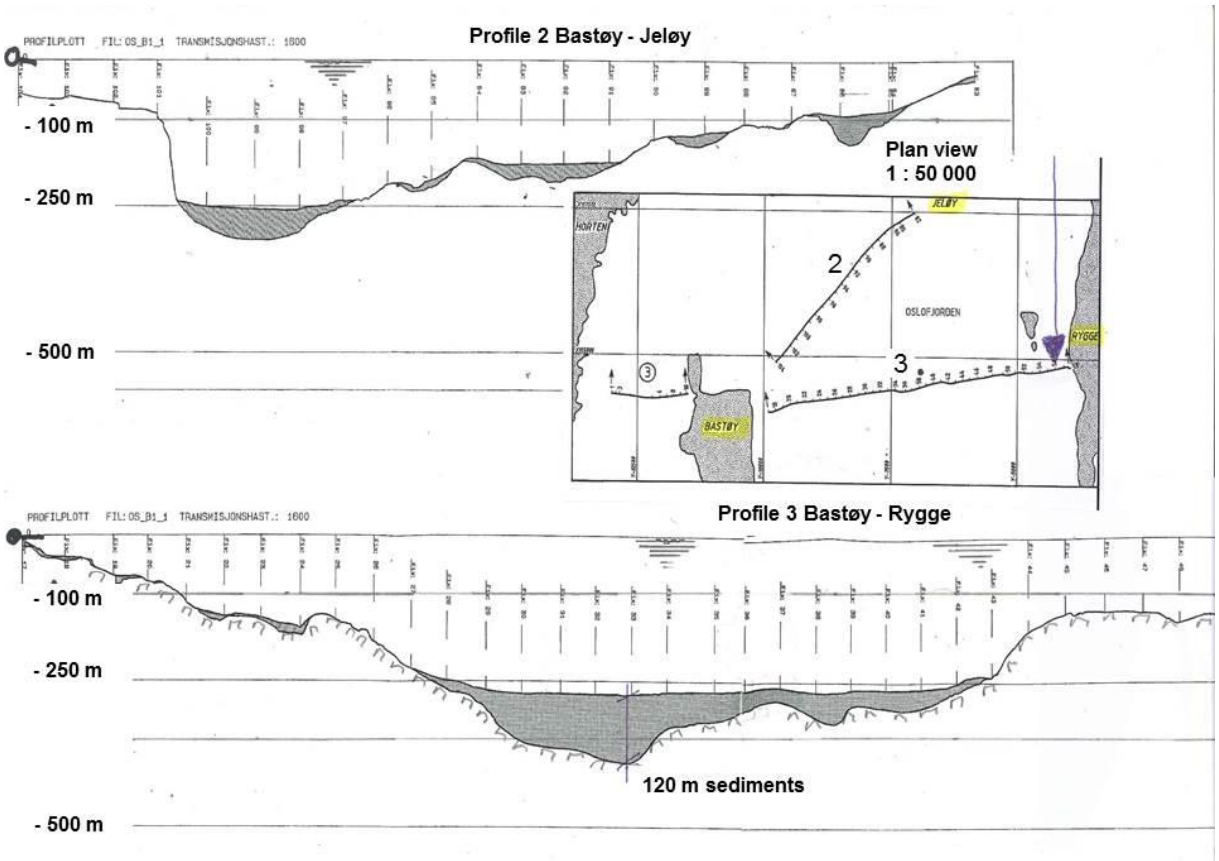


*Figure 3 Showing location and result of two acoustic profiles in the southern part of the fjord*

## CONDITIONS IN THE FJORD - BEDROCK

Figure 4 gives an adequate view of the location of seismic profiles in order to obtain depths to bedrock and the thickness of sediments. Dark red is very deep, red is deep, yellow is still deep and green is less deep, whereas blue represents shallow water or naked rock.
In all 6 narrow corridors and 3 more extensive areas were explored.

The result shows that the Drøbak Channel represents a typical U-shaped valley. Here is mostly naked rock having only small layers of sediments at the bottom. Depths of 200 - 300 m to bedrock prevent solutions like tunnels in this part of the fjord. The fjord in the channel is barely more than 2000 m wide and is therefore favourable to large conventional bridge constructions.

South of the Hurum Peninsula the rock formations in the fjord become more varied and unpredictable. Here great variations occur in the depth to bedrock. In some places gigantic potholes in the rock were found filled with sediments up till two hundred meter in thickness.

The fjord has a general strike north - south.

The resulting bedrock map however has large uncovered areas where additional knowledge is required before rock tunnel alignments or the location of bridge foundations may be recommended. Supplementary seismic exploration is to be carried out this summer ending with a final report in September. Until September this year it is therefore impossible to conclude on or recommend any of the crossing possibilities between Moss and Horten. And it will be a challenge to decide upon a recommendation for the alignment of a subsea tunnel.

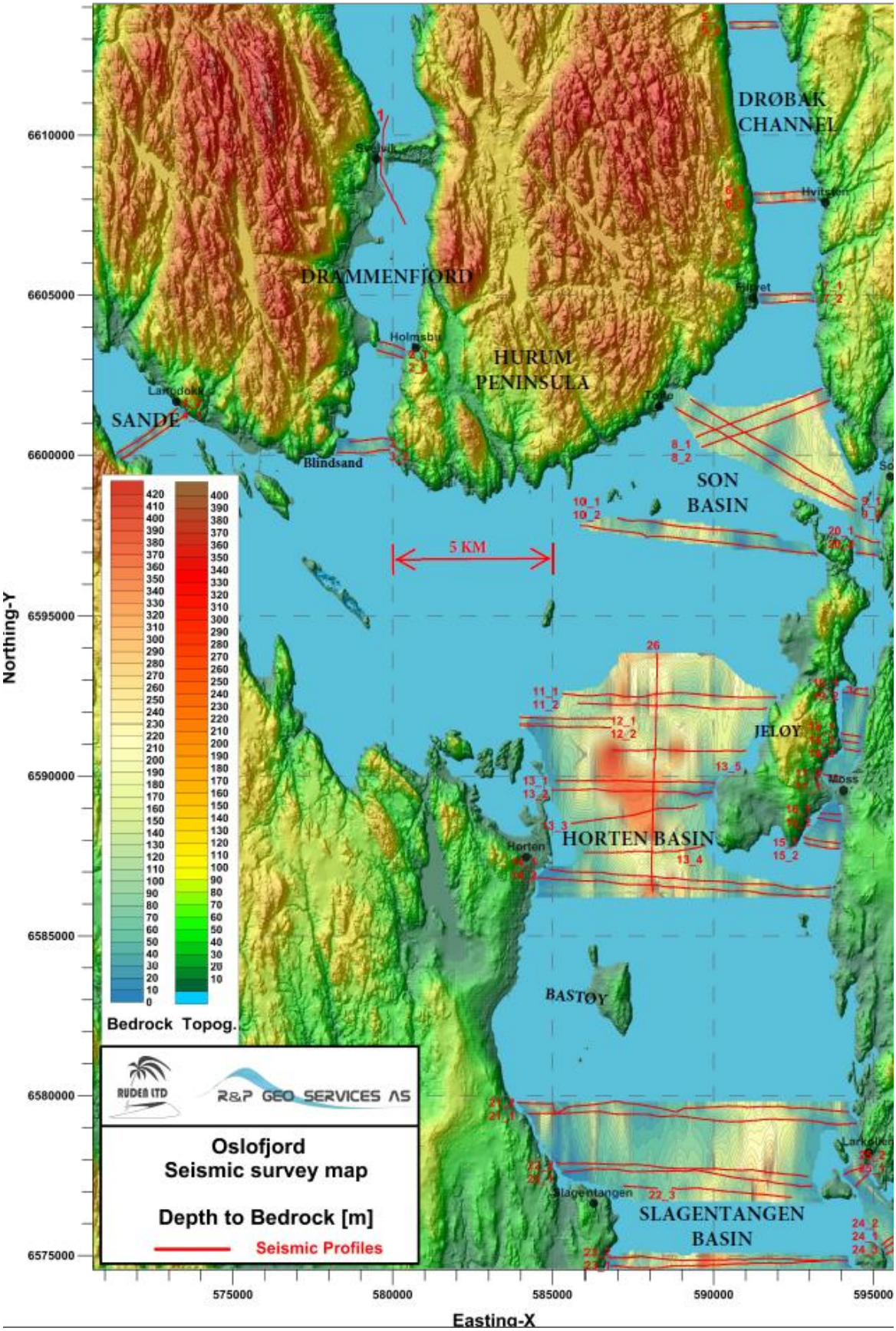


*Figure 4 Showing the location of seismic profiles and bedrock topography in the middle part of the Oslofjord*


*Figure 5 Areal view from the south-east looking north-west towards Moss City and the Jeløy Island*

Figure 5 gives an aerial view to the northwest where the City of Moss and the Jeløy Island can be seen. Further away we can see the Son Basin, the Hurum Peninsula and Drøbak Channel. Observe that the fjord becomes much wider south of Hurum. A ferry can be seen in Moss Harbour.

## A SELECTION OF CROSSINGS OVER THE DØBAK CHANNEL USING HURUM PENINSULA AS A "STEPPING STONE"

The object of the ongoing feasibility study is to find and define favourable places where to cross the fjord. In Figure 6 only some of the considered crossings via the Hurum Peninsula are presented. To obtain the full potential of a crossing of the fjord at Drøbak, it will be necessary to cross the Drammensfjord as well. Drammensfjord is a sidefjord to the Oslofjord.

A is the position of the bridge which nearly was built in 1988 (see Figure 2).

XX is the subsea tunnel which was built with one single tube and opened in the year 2000. This tunnel lies in a rock formation crossing the fjord. It reaches its deepest point at -134 m and has a gradient of 7%. The EU-recommended gradient is maximum 5%. Some serious fire incidents due to overheating of brakes have occurred in this tunnel. At present a tube no. 2 is being planned having the same gradient of 7%. An additional task was added to this feasibility study early this year: to develop and propose a bridge near to the present tunnel as an alternative to building tube no. 2!

The project has also been asked to identify and recommend any feasible combined railway/road crossing. B is a crossing where a foundation can be placed in comparatively shallow water at -35 m depth in the middle of the fjord and thereby cutting the main span in half. B seems therefore to be the “best buy” for a combined rail/road crossing.

C represents a suspension bridge having a main span of 1500-1700 m, see figure 7. This type of bridge can technically be built anywhere across the Drøbak Channel and is an example of a suspension bridge composed of 4 vehicle lanes and a pedestrian/bicycle lane in the middle. This type of bridge can be placed nearly at any crossing in the Drøbak Channel. As the foundations are placed in shallow water, the risk from colliding ships is small.

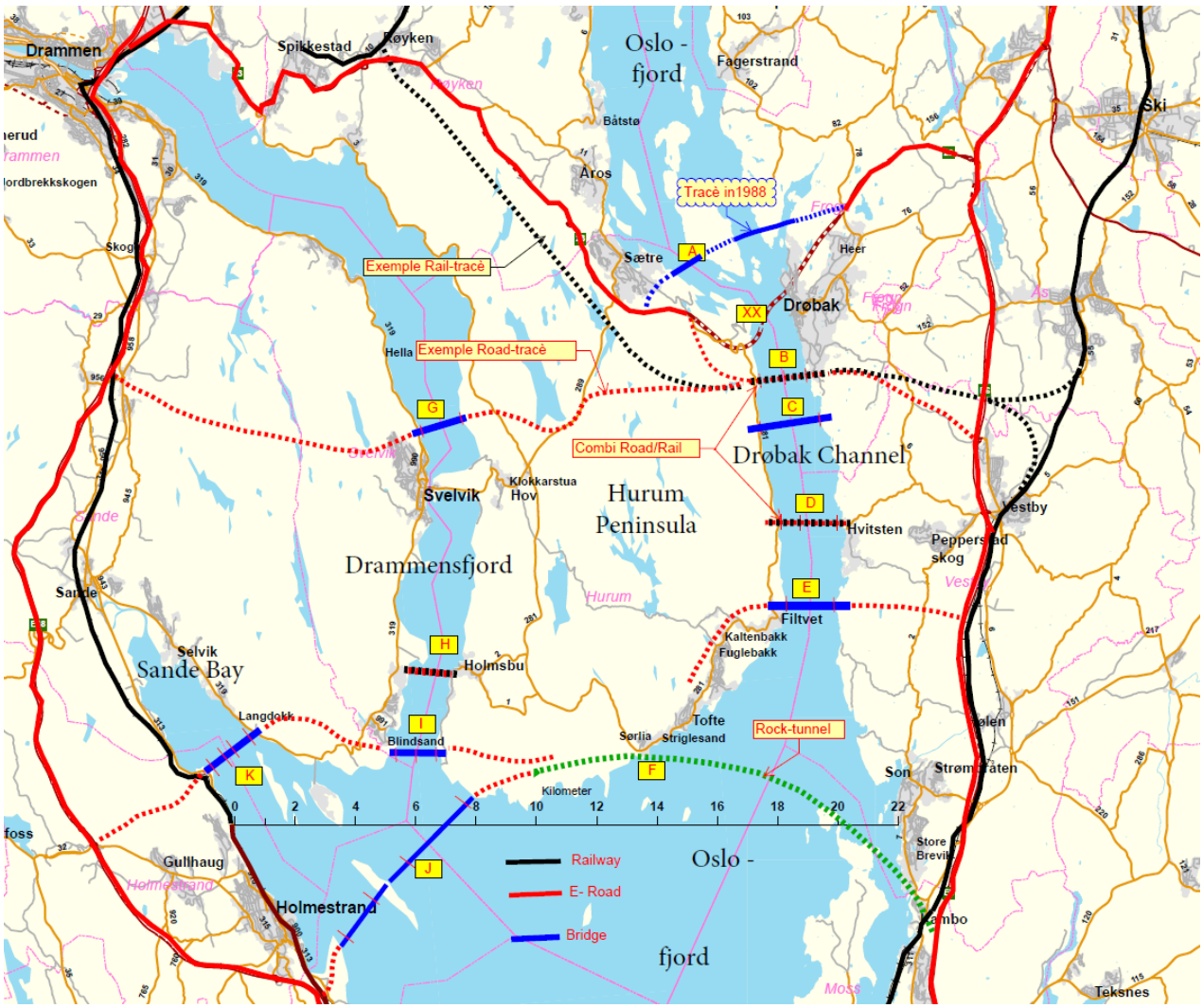


*Figure 6 Alternative potential crossings of the Oslofjord and Drammensfjord. Blue lines represent bridges and dotted lines road/rail on dry land.*

D is located where a shallow foundation site is situated at 1/3rd of the distance which reduces the main span to 1200 m and can perhaps thereby offer another combined rail/road crossing.
E is the most southern crossing for a bridge in this part of the Oslofjord and is a suspension bridge as described in figure 7.
F is a concept unlike the others in the Drøbak Channel. The rocktunnel is very long, and the connecting suspension bridge J over this part of the fjord will probably have a record span of

2000 m. At present it is thought of as being a road concept. It may also be combined with the K bridge.
G and I are places where to cross the Drammensfjord by bridge.
H represents an immersed tunnel for a combined solution with 2 lanes rail/4 lanes road.
K is a bridge spanning the Sande Bay. Here thought of as cable-stayed. It can be combined with the I bridge.

Examples of road connections between E-18 and E-06 are shown. Similar for rail.

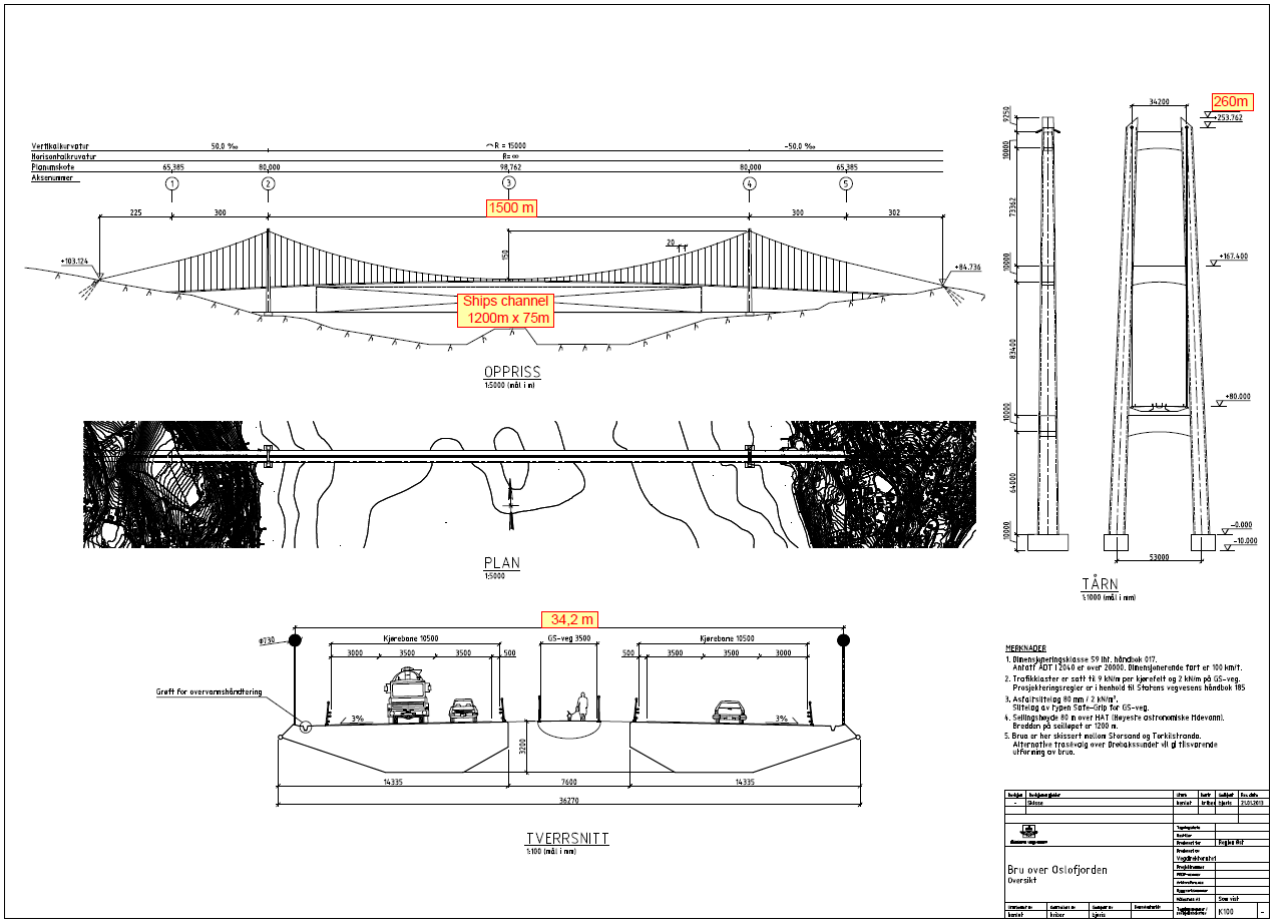


*Figure 7 Example of suspension bridge with 4 vehicle lanes and a pedestrian/cycle lane in the middle.*

The drawing in Figure 8 shows a combined rail/road bridge at crossing B with 2 rail lanes and 4 road lanes. This is a cable stayed bridge 2470 m long having 3 main towers. A cable stayed bridge is sturdier with regard to a fast rail track than that of a suspension bridge.

The free height of the ships channel in the Oslofjord has been generally defined to be 75 m and the ships shall have 2 x 750 m in each direction or a single width of 1500m in which to manoeuvre if geographically possible. In the Drøbak Channel the width is reduced. The superstructure consists of a concrete road deck and a sturdy steel girder beneath. On the south side of the bridge there is a 3.5 m wide pedestrian/bicycle lane.

This bridge has a main foundation placed on a -35 m shallow in the middle of the fjord. Due to the risk of colliding vessels, this foundation has to withstand up to approximately 30-40.000 tons

of impact force. The road and rail continues into a tunnel westward, and to the east it crosses a 500 m viaduct.

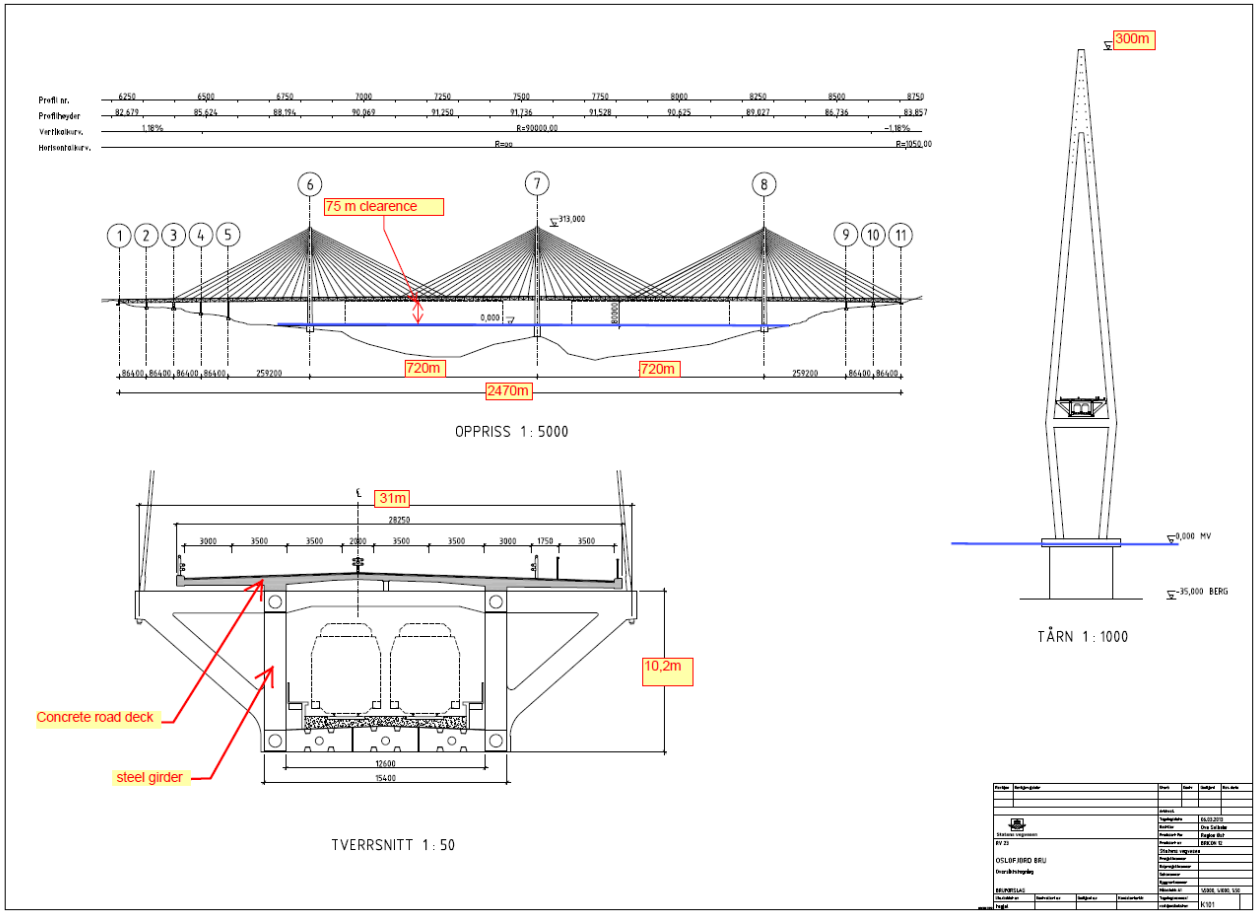


*Figure 8 Example of a combined road and rail bridge at crossing B.*

In Figure 9 the cable stayed bridge is shown in 3D. Multiple cable stayed bridges are usually pleasant to the eye when they are symmetrically built and have the superstructure high up in the air.

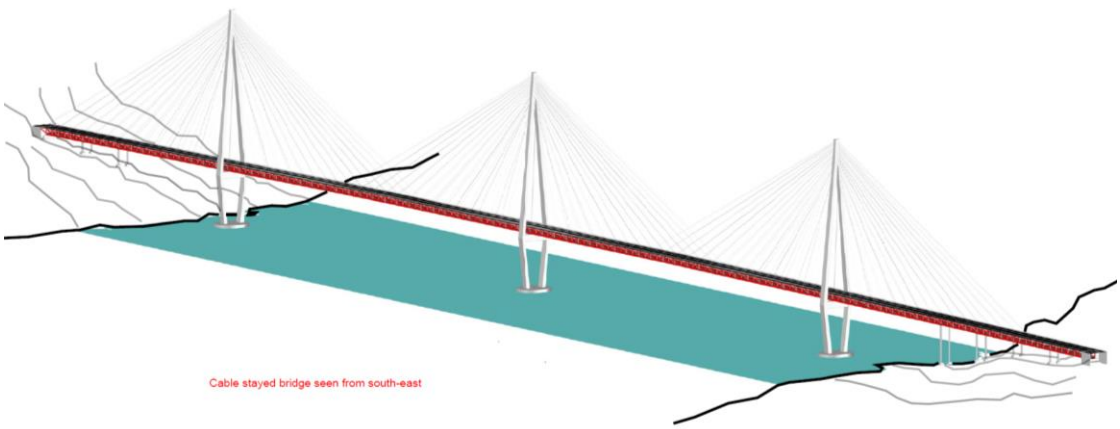


*Figure 9 Three dimensional view of cable stayed bridge.*

As will be apparent from these examples, existing technology is expected to be used when crossing the Drøbak Channel.

## TUNNELS

EU has stated new requirements for the gradient of road tunnels as shown in Figure 10. This gives a subsea road tunnel a length of 16-20 km under the Oslofjord. A rail tunnel can here end up being nearly 50 km long! This makes it near to impossible to combine rail and road when building deep tunnels.

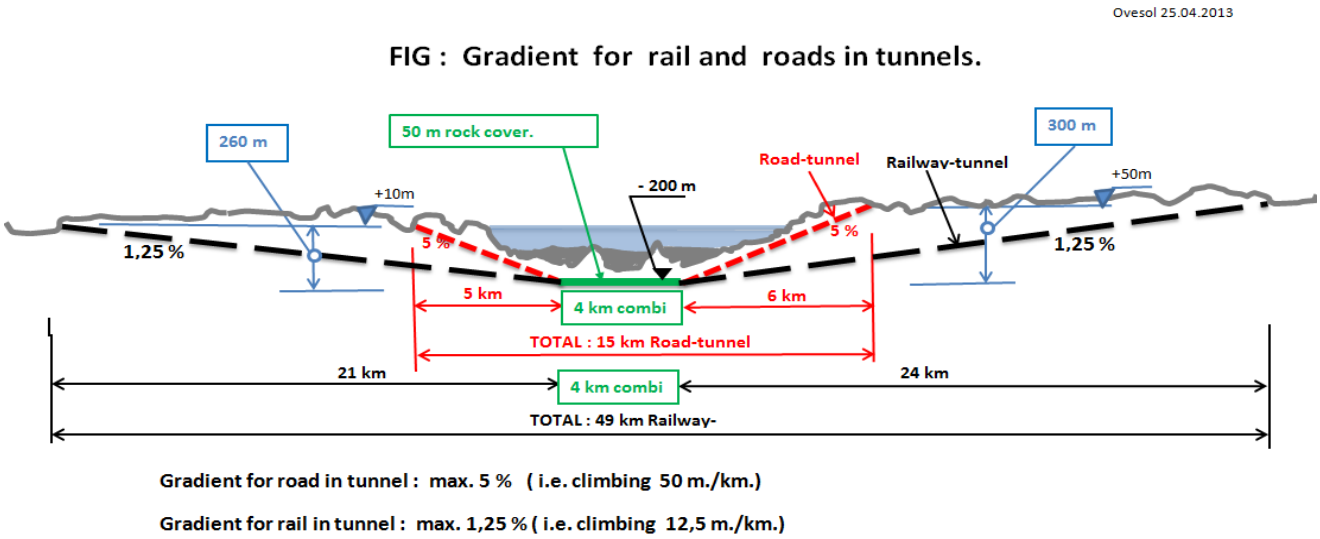


*Figure 10 Example of tunnel lengths with gradients adjusted to EU requirements.*


*Figure 11 Areal view of basin between the Cities of Moss and Horten.*

## CROSSING THE FJORD SOUTH OF THE HURUM PENINSULA

The photo in Figure 11 gives an aerial view over the Horten Basin between the Cities of Moss and Horten. This is the shortest distance over the fjord south of Hurum Peninsula. The forest and agricultural areas which are protected by law, can be clearly seen. If a crossing is proposed which includes the Jeløy Island, a tunnel has to be placed in the rock under the island.

The ferry is the only link at present between the two sides of the fjord and runs between the Cities of Moss and Horten. On workdays as many as 5 ferries will be busy carrying cars and people across the fjord. A ferry can be seen at the quay in Moss.

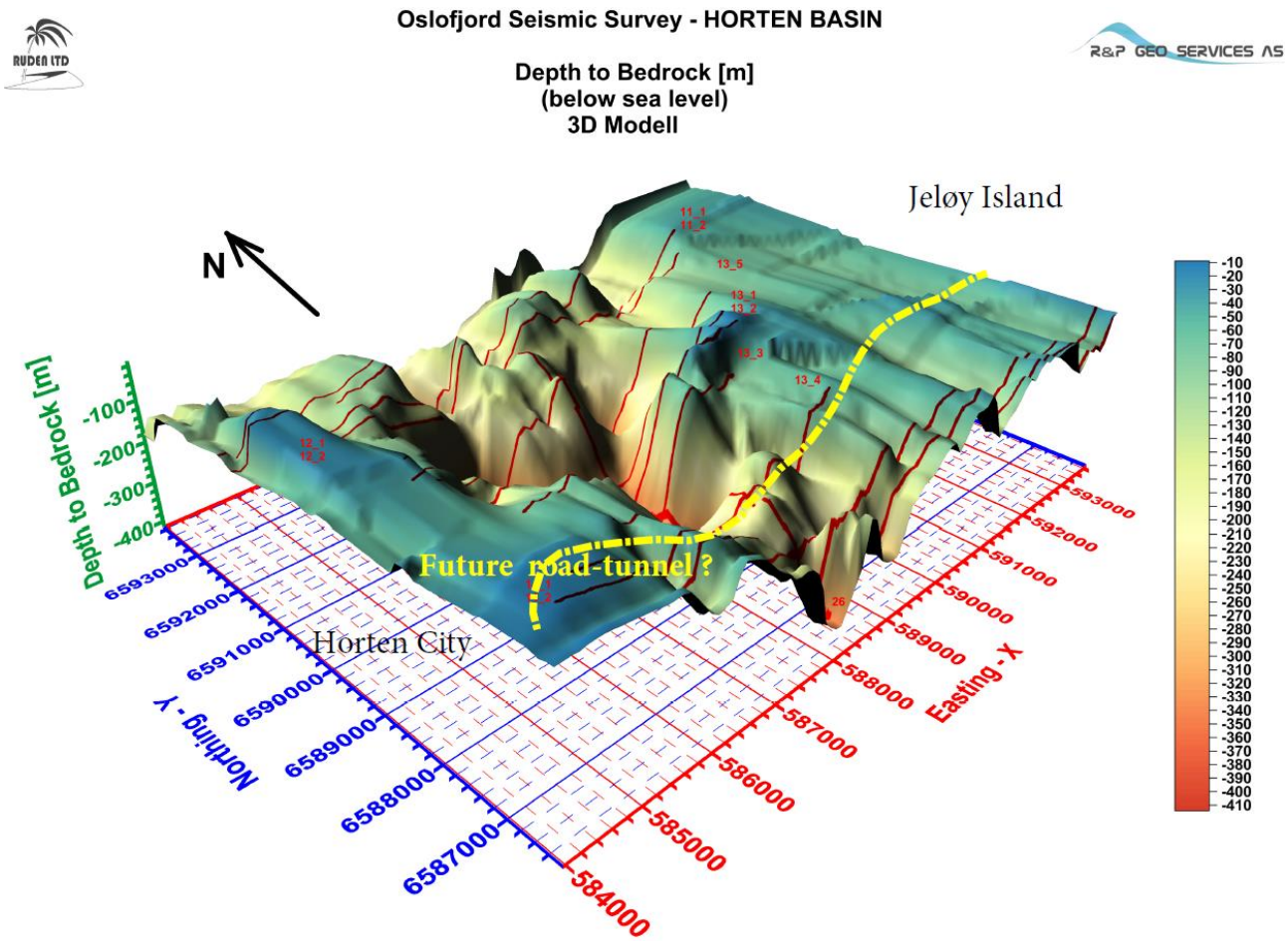


*Figure 12 3D impression of the varying undersea bedrock "landscape" of the Horten Basin.*

The 3D map in Figure 12 gives an impression of the varying bedrock "landscape" in the Horten Basin. It gives an impression of the difficulties that will be met when trying to locate suitable places for the foundations of bridges.

A subsea tunnel must waver its way inside the ridges which crosses the fjord. Here the supplementary seismic exploration being carried out this summer is strongly missed.

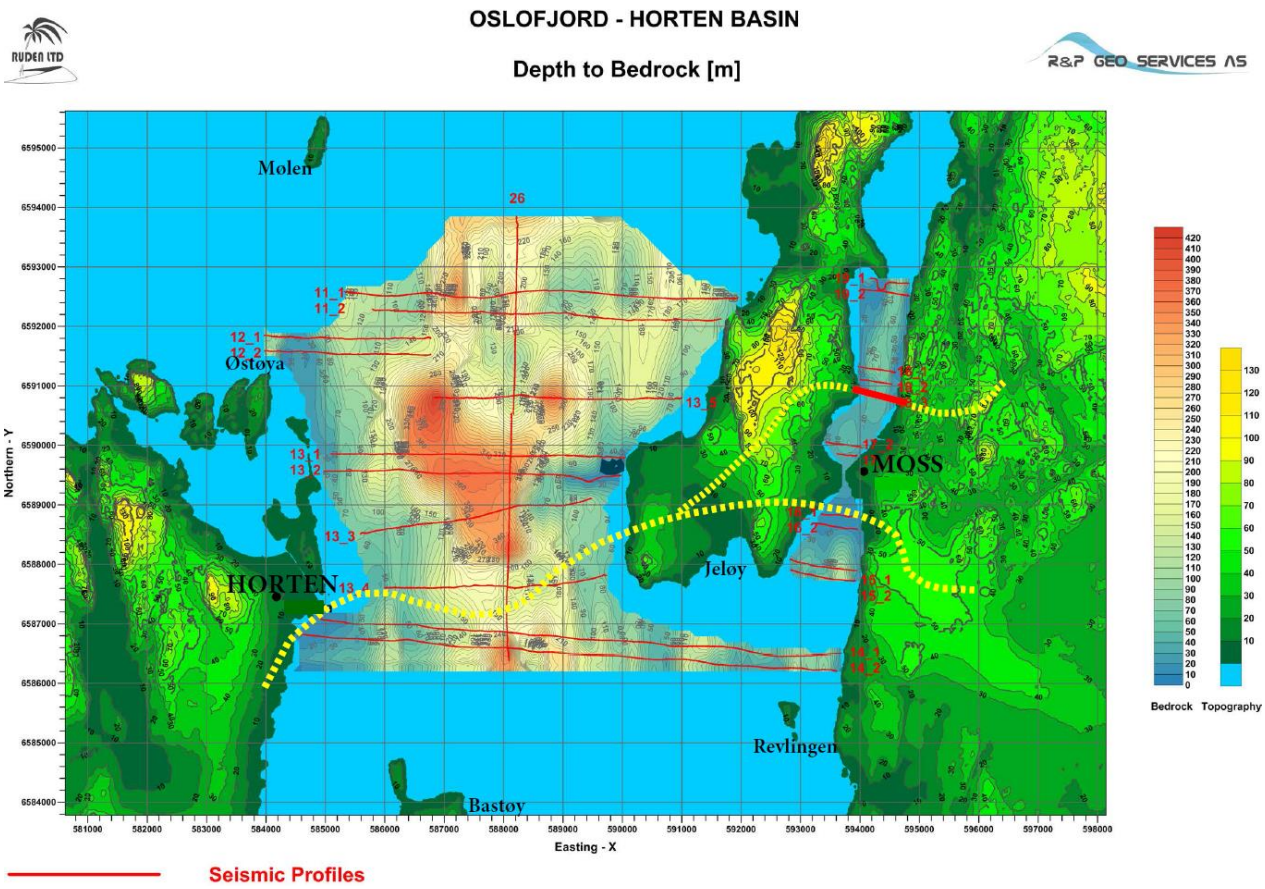


*Figure 13 Map showing bedrock surface in the Horten Basin*

In Figure 13 the bedrock in the Horten Basin is shown on an ordinary underwater map. There is a huge pothole between Horten and the Jeløy Island containing 3 $km^3$ of sediments. And the amount of trapped freshwater in this pothole is estimated to be near 1 $km^3$ - enough to satisfy the total needs for all Norwegians for 1½ year.
Between the Jeløy Island and the mainland the great fault zone in the Oslofjord is situated. This zone can make it necessary to divert a possible rock tunnel under the Jeløy Island and around Moss Bay. The map shows an example of such a road tunnel.
A bridge spanning the Oslofjord at this location will require very deep foundations - or a very long main span or floating foundations, if that is possible. The height over the water and the danger of ship collision can make such a solution near to impossible.
To illustrate the difficulties presented by the subsea terrain, a combination of rock tunnelling, an immersed tunnel and an underwater bridge is shown between Horten and Jeløy.

In Figure 14 alternative crossings between Larkollen and Slagentangen are also shown. These alternatives present similar difficulties as in the Horten Basin, perhaps more so, since the width of the fjord is greater at this location.

In order to consider what sort of crossing is most suitable for this part of the fjord, the results from the further seismic surveys to be performed this summer, is needed.

When considering the crossing possibilities south of the Hurum Peninsula, new technology will have to be implemented to varying degrees. Much of this new technology will come from

concepts developed for the Coastal Highway Route E39 Project along the western coast of Norway.

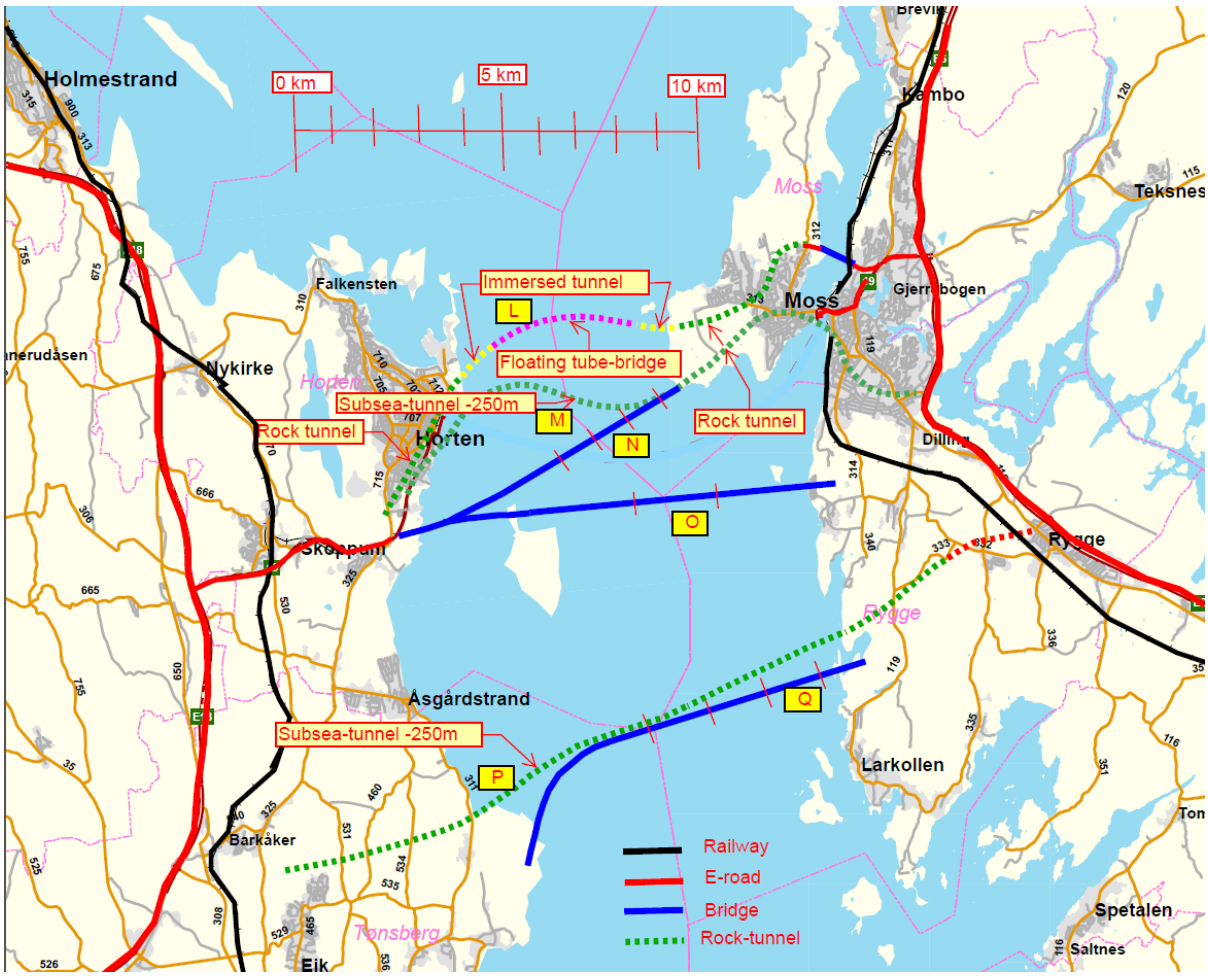


*Figure 14 Alternative crossings between Larkollen and Slagentangen (blue line bridge – dotted line tunnel)*

## CLOSING REMARKS

At the present stage of this preliminary feasibility project for crossing the Oslofjord there is not enough knowledge of the fjord geology and topography to present proper solutions for a crossing south of the Hurum Peninsula. All possible crossing-scenarios are still being considered.

The present Strait Crossings and the request for a technical paper came one year to early. During next spring the feasibility project will hopefully be able to present one or two viable crossing concepts.
And thereafter it will be most interesting to see what the Norwegian government will decide with respect to the submitted concept(s) for a new link across the Oslofjord.