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STAD SHIP TUNNEL – THE WORLD'S FIRST FULL SCALED SHIP TUNNEL

by

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Background for the Stad Ship Tunnel

Historic

Even the Vikings feared the fairway outside Stad peninsula. There is a pass at Stad peninsula called "Dragseidet", which is English means: "A pass where you pull boats over land". In the Viking age "Dragseidet" was used as an alternative route to avoid the infamous Stad Sea.

In the year of 1874, there was an article in a Norwegian newspaper about the need and possibility of caving a tunnel through the Stad peninsula. The estimated cost at that time was 1.6 million NOK ($200.000)

Johannes Balderhaug, often referred to as the "father" of the Stad Ship Tunnel, was very keen to realize many years of ideas about building Stad Ship Tunnel. In 1984 his efforts resulted in serious conversations with the Mayor of Selje Municipality and, consequently, the concretization of a feasibility study of the project

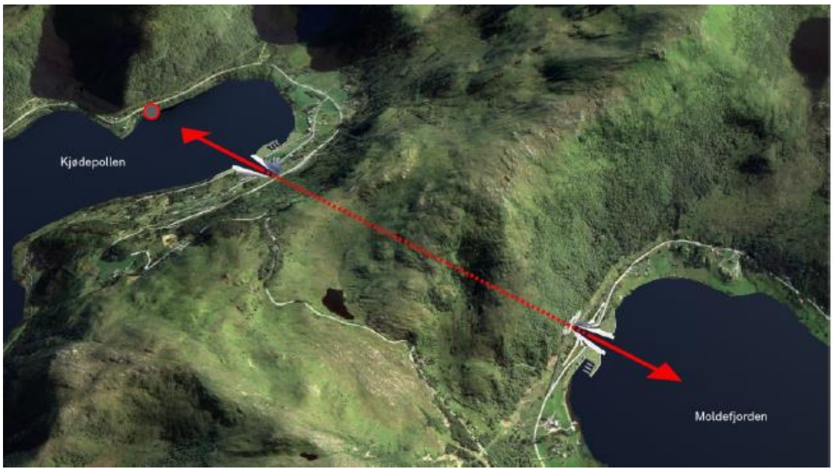
Since then, there have been several studies. The first feasibility study by the NCA (Norwegian Coastal Administration) took place in 2000. This was based on a tunnel with a smaller cross section than the present one.

The 14th of December 2003 there were a serious incident outside Stad peninsula. In stormy weather and with 8 meter waves, the coastal ferry MS Midnatsol got machinery problems which caused a total blackout. The ship was drifting towards land and all passengers were evacuated to the rescue area on deck, waiting for orders to enter the lifeboats. However, only 150 meters from the shore, the captain were able to drop both anchors which enabled the ship to stop drifting.

Because of this incident, suggestions arose about increasing the size of the Stad Ship tunnel to enable coastal ferries to avoid the Stad Sea and sail safe through the tunnel as well. Studies in 2000-2001 and 2007-2008 have analyzed a number of alternative cross sections and routes for the tunnel. The final route has been selected because the Stad Peninsula is at its narrowest point here, and the waters are sufficiently shielded to allow shipping to use the tunnel in most weather conditions.

Picture 1: Trace for Stad Ship Tunnel Studies – as a foundation for the selection of the route and cross section – took place in connection with the concept selection report (KVU) and the subsequent external quality assurance process KS1.

In connection with White Paper 26 (National Transport Plan 2014-2023), the Storting (the Norwegian parliament) opted to proceed with the large tunnel alternative.



Picture 1: Trace for Stad Ship Tunnel

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Navigational conditions

The Stadhavet Sea is the most exposed and dangerous area along the coast of Norway. The Kråkenes lighthouse, just south of Stad, is the meteorological weather station with the most stormy days, which can be anything from 45 to 106 days per year. The combination of wind, currents and waves around this part of the coastline make this section a particularly demanding part of the Norwegian coast.

The combination of sea currents and subsea topography creates particularly complex and unpredictable navigational conditions. Very high waves come from different directions at the same time and can create critical situations. **Picture 2: Challenging navigation outside Stad peninsula**

The conditions also cause heavy waves to continue for a number of days once the wind has died down. This causes difficult sailing conditions even on less windy days.

Picture 2: Challenging navigation outside Stad peninsula

Safety

The aim of the project is to improve accessibility and safety for shipping past Stad**.**

Luckily, there have not been any accidents with loss of life since 1984, but there have been a lot of serious incidents. The last incident was in March last year. The cargo vessel Nyksund was hit by a huge wave, which lead to displacement of cargo and that the vessel become listet at around 20 degrees.

Predictable voyage

The Stad Sea is very unpredictable due to weather conditions and is in a way a barricade for transport of cargo and passengers. Speed ferries do not have permission to sail with passengers past Stad Peninsula. Today many vessels that sail in this area have to wait, several times a year, for weather conditions to improve. When the tunnel is operative, the journey becomes much more predictable so cargo can arrive on time. This is especially important for transport of living fish and transport of caught fish.

To eliminate waiting time for sailing past Stad peninsula will have a huge economic impact. This will also gain the process of transferring more cargo from vehicles to vessels. The Stad Ship Tunnel will also have a social impact as it will make it possible to establish a speed ferry route between two main cities in Norway, Bergen and Ålesund. Also for leisure crafts the tunnel will open for new possibilities. Finally, by establishing a new fairway in a protected area it will become much more comfortable for passengers and crew.

Environmental effects

Sailing distance is 3 nm longer through the tunnel than sailing outside Stad peninsula. Therefore, you gain nothing in good weather conditions. In bad weather conditions vessels often use three times longer time to sail past Stad than in good weather (if they manage to sail at all). That means significant more consumption of fuel and much more exhaust emissions. If vessels wait for weather to improve, their engines are still running and polluting the air.

If an accident should happen, the environmental impact caused by an oil spillage would be tremendous and impossible to handle in such weather conditions. Close by we have the southernmost seabird island in Norway called Runde, also known for having most species of seabirds in all of Scandinavia.

Feasibility study

Traffic situation

Stad Ship Tunnel will be a part of a new main fairway from Ulvesundet to Vanylvsfjorden. **Figure 1: Overview fairway past Stad**

Most of the navigation aids will be concentrated close to and inside the tunnel. There will be one-way traffic through the tunnel, which alternate every hour. All motor-driven vessels may use the tunnel. The maximum speed is 5 knots for all vessels, except speed ferries that are allowed a maximum speed of 8 knots. In the fairway close to the entries of the tunnel, a maximum speed of 8 knots will be allowed. All vessels which intend to sail through the tunnel must apply for a slot-time two hours ahead of ETA. Vessel Traffic Services (CTS) will manage slot-time allotments and vessel monitoring. The capacity will be five large vessels per hour.

West of the tunnel there is a narrow strait called Saltasundet. This strait will be made deeper and wider by underwater dredging.

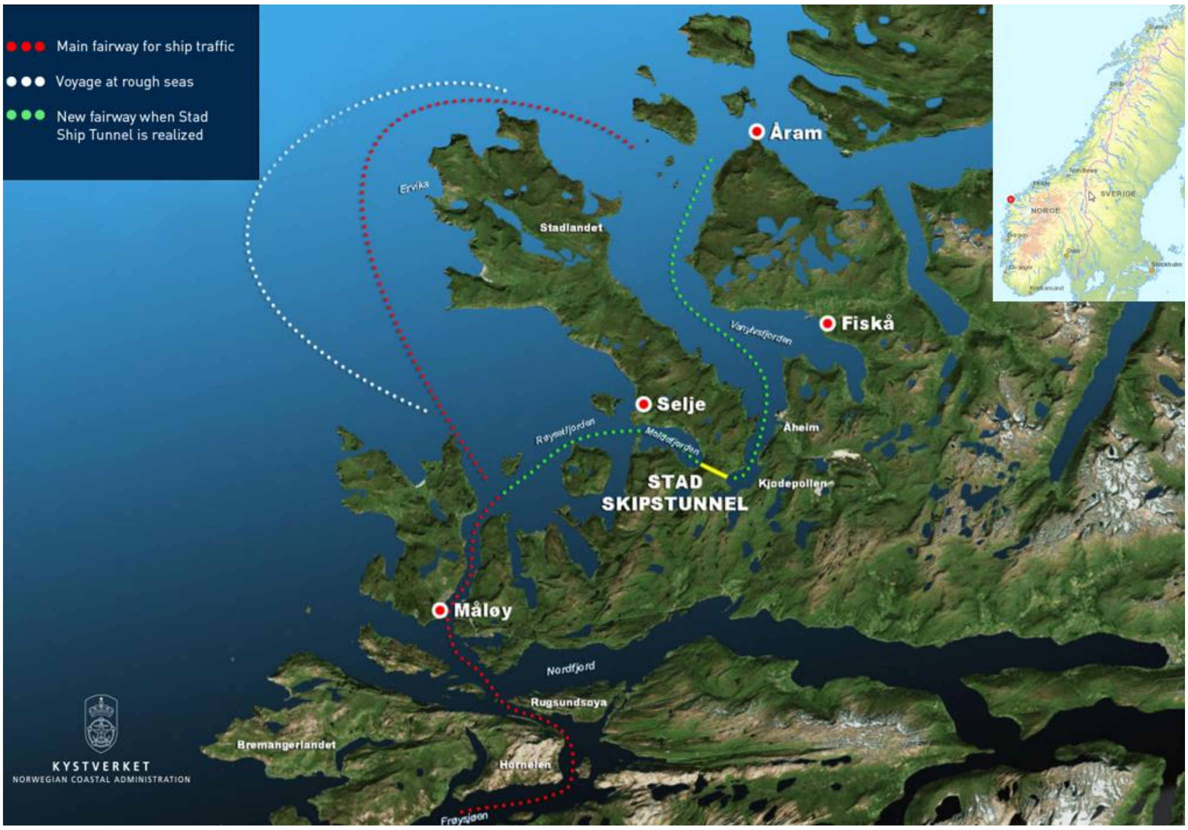

Figure 1: Overview fairway past Stad

Computer simulated voyages

In order for the pre-project to Stad Ship Tunnel to have the best possible basis for describing a project that is "Good", it was decided to carry out a computer simulation in a ship simulator. The ship simulator focused on sailing in areas that would be affected, while testing the effect of necessary safety and navigational measures when approaching and entering the tunnel.

The simulations took place in Copenhagen at Force Technology in 2016 May 30th to June 2th.

In order to make the simulations as realistic as possible, we used navigators who are familiar with the relevant vessel types that would be dimensioning for the tunnel.

Two marine pilots with certificates for the area, a captain at MS Midnatsol, and a navigator from North Sea Container Line navigated vessels in the computer simulation. In addition two nautical experts from the NCA participated. **Picture 3: View inside tunnel from the bridge onboard MS Midnatsol**

We did several simulated voyages with vessels that are most relevant to potential and expected challenges in relation to dimensioning vessels, weather and timing.

The voyage of the largest vessels were carried out by a team of two people from the group of selected pilots, captains and navigators who participated in the simulations. Simulations with smaller vessels were carried out by one navigator only.

Picture 3: View inside tunnel from the bridge onboard MS Midnatsol

The simulator was well equipped, both in relation to optical sailing and instrumental navigation. All exercises were relevant to test challenges in relation to ship dimensions/design, and weather conditions one can expect in this area.

During some voyages, issues and events, such as fire onboard and machine problems,were added to test their effect on other ships in the convoy. Those simulations provided useful information on potential challenges, especially in relation to convoys.

Entering from Vanylvsfjord with large vessels and simple equipment with regard to maneuverability, can be challenging with heavy wind from NNE.

The simulator voyages showed that dimensioned vessels could safely use the tunnel during all relevant weather conditions without excessive risk of accidents. One exception is the maximum size vessel (Container vessel) that has huge drift and limited maneuvering capability. In this case, it will be challenging to enter from Kjødepollen in heavy wind from NNE.

Further studies must be conducted to evaluate fendering; the distance from fender to tunnel wall at the junction where entering construction turns into leading construction.

By convoy, the largest vessels should have priority when entering, either by leading or having more space to the next vessel in the convoy. Otherwise, large vessels should be the last incoming vessel, as it would require more length to stop, hold position and get in position for entry, and thereby more space to do so.

Model test

In the model test, we used the same vessels as in the computer-simulated voyages. However, this time we wanted to study the hydrodynamics inside the tunnel, which, from a maritime point of view, in reality is a channel. **Picture 4: Model test of MS Midnatsol in the tunnel/channel**
In Marintek's harbor basin, we rigged part of the channel to a length corresponding to 1250 meter. The scale of both channel and vessels was 1:27,5.
The tests where done in three different depths of water similar to the tide. There were also arranged currents of one and two knots and we sailed both directions.
The study gave the following observations and conclusions:

- The vessels had a speed equivalent of 5 knots of speed outside the channel, but due to channel effects, the speed was reduced by 20-25% for MS Midnatsol, and 35-45% for the container ship.
- The speed reduction decreases slightly when the water level drops, especially for the container vessel where the channel effects are greatest.
- The efficiency requirement increases by about 10% for MS Midnatsol, while the increase is in the order of 50% for the container vessel, compared to voyages at 5 knots in open water outside the channel.
- None of the regular test conditions gave significant maneuvering problems to any of the vessels.

Picture 4: Model test of MS Midnatsol in the tunnel/channel

CFD study of bank and squat effects

The company Force Technology ran the CFD-study based on the same vessels and scale as the model tests. The study was done with and without currents in two different depths.
The plots clearly show that the speeds around the vessel are significantly reduced when sailing in a current-free environment, compared with voyages with currents in place. The speed range also changes around the ship. In addition, it is clearly seen that the waves generated by the vessel are slightly higher when the vessel is situated close to the fender compared to when the vessel is located in the middle of the channel.
There seems to be a slight increased tendency for the squat as a function of velocity. There is not a big difference between the squat in front and in rear of the vessel, i.e. the vessel gains only a rather weak trim. The deviations in current situations are assumed to be due to the increased cross flow due to the current. However, the real variation is quite small and the vessel does not exhibit the risk of ground impact.

Construction

The construction of the tunnel will be done by traditional drill and blast methods. In the roof of the tunnel, there will be horizontal drilling and blasting. The roof will be secured with bolts, anchors and shotcrete before blasting the nest levels downwards. Those levels will be done by vertical drilling and blasting as in open mining. We will leave a part of the rock in both ends of the tunnel to enable dry conditions down to level -12. **Figure 2: Principle sketch of the construction of the tunnel**

After establishing pillars for the guiding construction, the remaining rock will be blasted so that seawater can flow in.

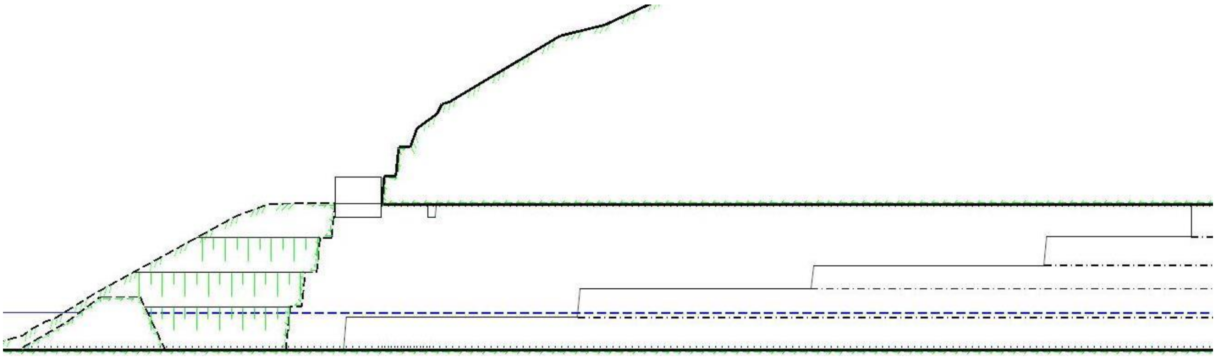

Figure 2: Principle sketch of the construction of the tunnel

On both sides of tunnel, 3 meters above the sea level, there will be a guiding construction applied with fenders. **Figure 3: Principle sketch of guiding construction and roof catwalk**
The main purpose for this guiding construction is to prevent the bridge wing from smashing into the rock. Secondly, this guiding construction can be used as a evacuating path in case of emergencies inside the tunnel. **Figure 4: Principle cross section of quay and friction** There will be established a catwalk up beneath the roof along the whole length of the tunnel in order to do inspections of the tunnel roof.

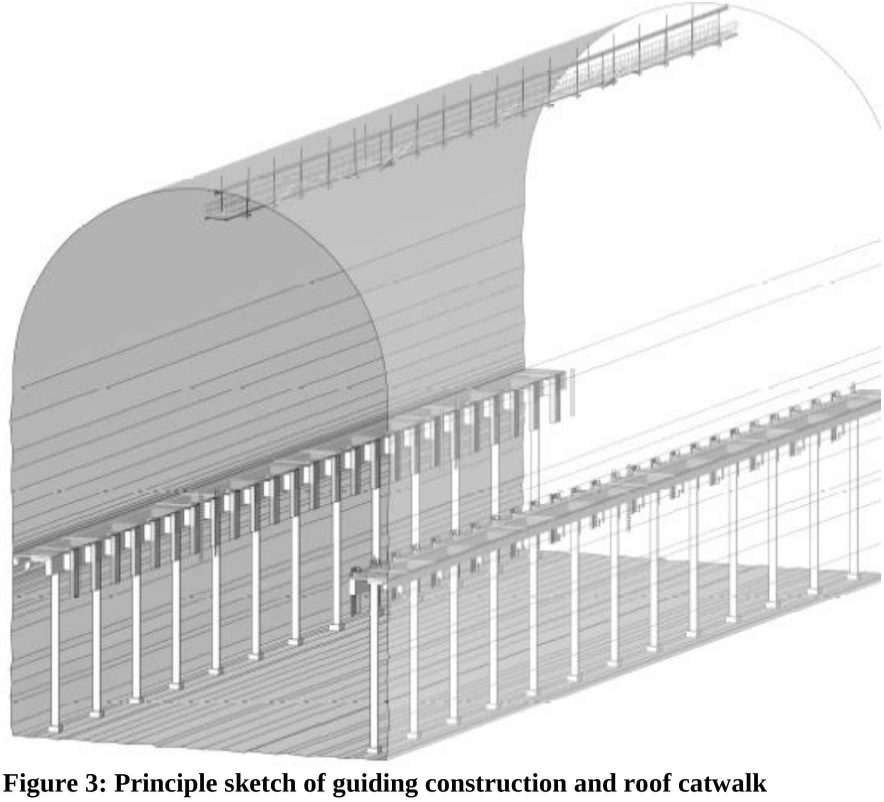

Figure 3: Principle sketch of guiding construction and roof catwalk

Figure 4: Inside tunnel

In both ends of the tunnel, there will be established entrance constructions with an angle of 9 degrees to the centerline. Where the entrance construction meets the guiding construction there will be established three rolling fenders. **Figure 4: Principle sketch of entering construction and rolling fenders**

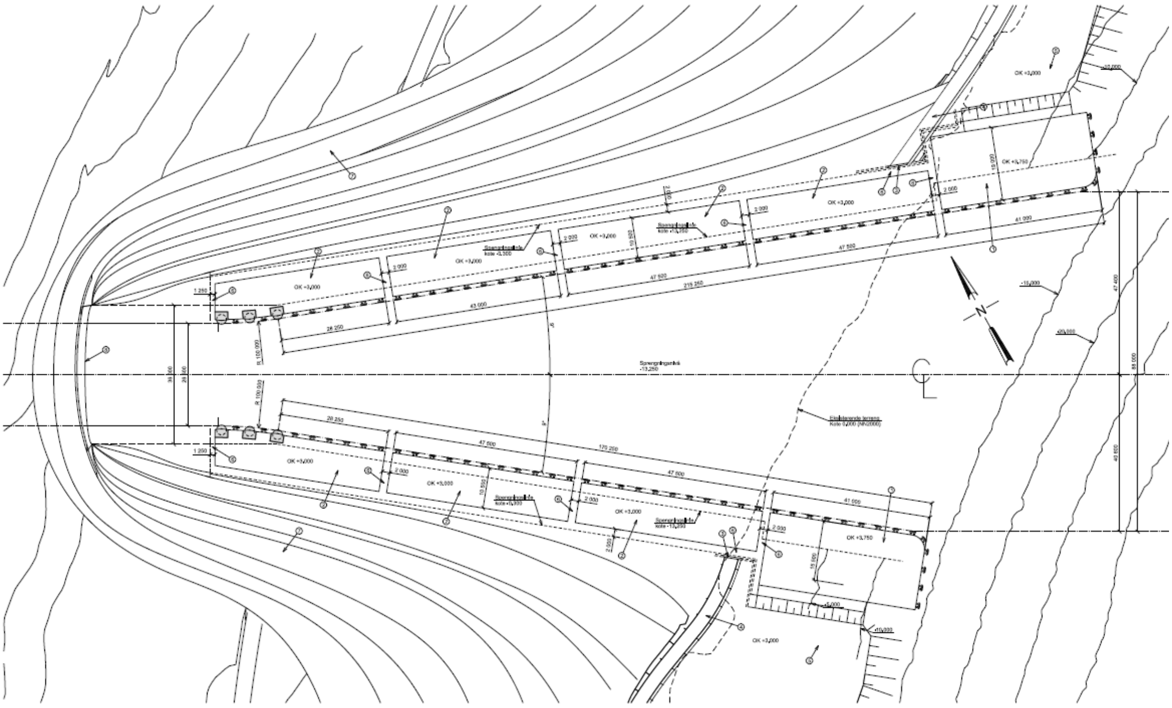

Figure 4: Principle sketch of entering construction and rolling fenders

The idea of the entrance construction is to shield the construction, i.e. in case a vessel unfortunately should crash into the construction. To achieve this, the upper part of the entrance construction is made by frictions boxes with fenders. **Figure 5: Principle cross section of quay and friction** The friction boxes is made of concrete and filled up with ballast of stones. The friction boxes are supported by wire sawed rock in the inner part of the entering construction and by a quay of concrete in the outer part.

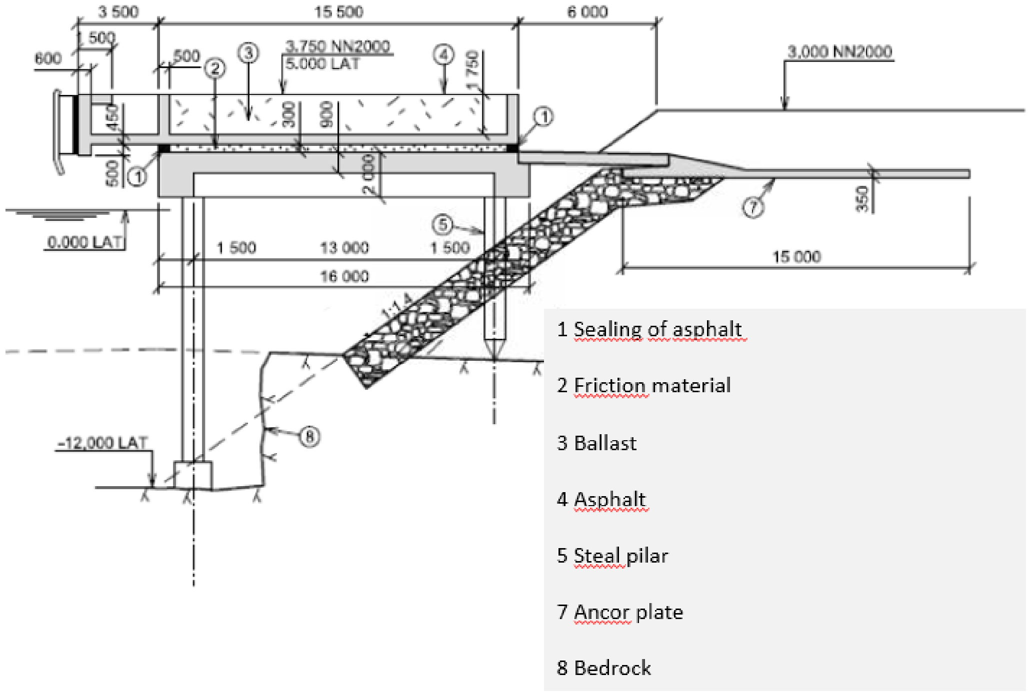

Figure 5: Principle cross section of quay and friction boxes

One of the biggest challenges is to establish a significant infrastructure during the construction time. The landscape is very steep, which forces us to establish an area for rigging in both ends of the tunnel entrances. After the tunnel is caved out, this area must be grabbed and dredged before the construction of entry points can take place. All blasted rock must be transported from the site at huge barges. In addition, there are public roads on both sides that have to be relocated. At the entry in Moldefjorden, a bridge will be made above the tunnel entry. This bridge must have a roof and the area above have to be secured with fences to protect it from landslides and avalanches.

Navigation aids

To help navigation inside the tunnel there will be center marker lights each 50 meters in the roof. In addition, there will be indirect lights at the edge of the guiding construction. **Figure 6: Navigation aids** At the entrances, there will be lateral lights and center lights. Along the fairway to and from the tunnel, there will be some new navigational aids as well.

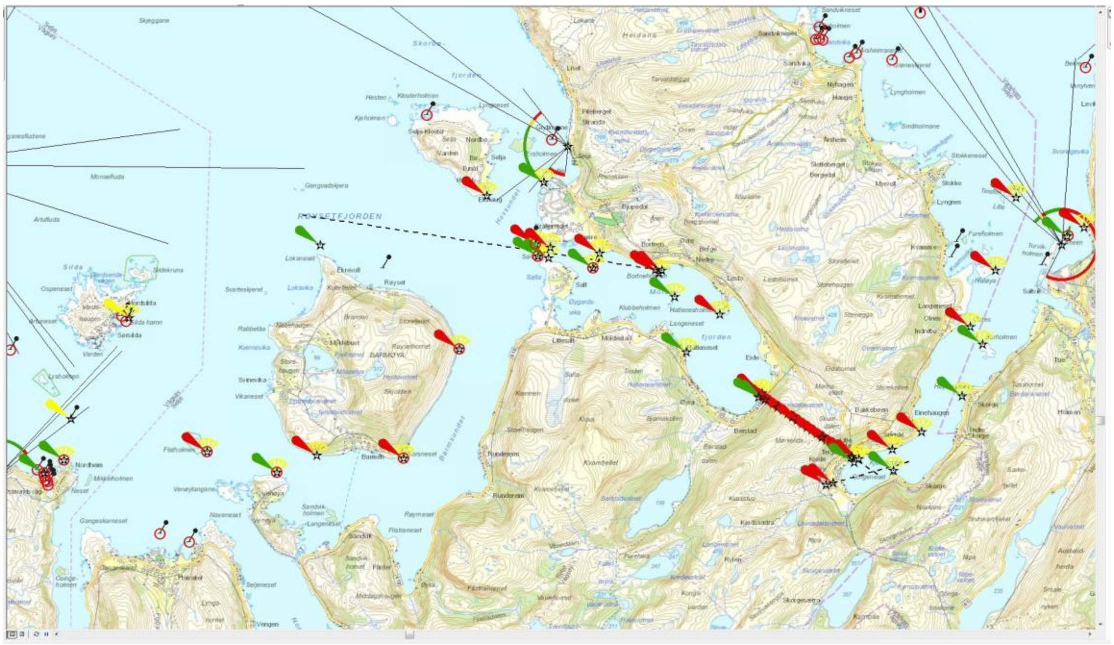

Figure 6: Navigation aids

Landscape and terrain design

Kjødepollen is a small place with characteristic fjord landscape, scattered settlements and smaller farms. The landscape slopes evenly from the wooded mountainside through the open farmland that meets the fjord.

In the transition between the entrance structures and the shoreline, there will be an extensive area affected by fillings during the construction phase. We have looked at the relationship between the construction phase and the finished situation to find a solution that will both work temporarily, and also become part of the new situation for the site. **Picture 4: Entrance Kjødepollen**

At Moldefjorden, the landscape is steeper and therefore also has less agricultural area and fewer dwellings. The landscape is facing west with a great view of the Stad peninsula. No buildings are directly affected by the operation, but in the upper part of the recess, the existing road must be moved and established in an overlying new bridge. The solution has many common features with Kjødepollen, but visually they will appear quite different. The steep terrain in the face of the terraces gives a more close and dramatic impression.

Picture 4: Entrance Kjødepollen

Risk analyses

The risk analysis looks at the effect of Stad Ship Tunnel on collision and ground impact risk in the area from Ålesund to Måløy. The risk analysis consists of a frequency analysis and impact assessment.

The frequency analysis uses the IWRAP navigation risk program to calculate the grounding and collision frequency before and after the action. The measure in this analysis is Stad Ship Tunnel. The frequency analysis has been based on AIS data from 2015, and there are no prognoses for changes in shipping traffic, so the total traffic volume is equal before and after construction. The frequency analysis has included a traffic transfer from the outer fairway to the inner fairway after construction, as it is assumed that the vessels that want to use the tunnel will choose to sail the inner fairway, especially in bad weather.

The frequency analysis shows that there will be a slight decrease in the collision frequency in the area after construction. This is because traffic will be allocated different sailing routes for use of the tunnel. **Figure 7: Different sailing routes**

The grounding frequency will increase after construction, as more vessels will use the internal sailing routes than before construction. As there is risk of more groundings than collisions, the total accident rate will increase. An increase in total accident rate is estimated as 0.23 accidents per year.

The impact analysis has evaluated how the traffic-specific conditions around Stad peninsula will affect the outcome of a grounding or collision. The risk analysis has calculated the potential serious consequences, such as loss of life, personal injuries, serious property damage and emissions based on the frequency analysis and impact assessment. The risk analysis shows that, with the fairway specific assessments, a reduction in the number of deaths, personal injuries and emissions is expected, as well as a marginal increase in serious material damage for utility vessels during ground impact or collision.

For capsizing and stability failure without capsizing, a simplified analysis has been conducted, based on the fact that smaller vessels – that are particularly vulnerable to these types of accidents – are largely transferred to the Stad Ship Tunnel. This will result in a significant risk reduction for the fairway past Stad.

Risk change for the leisure fleet has been considered qualitatively. The main differences between utility vessels and recreational crafts are that sailing distances are not expected to be equally important, and it is assumed that a large proportion will choose to use the Stad Ship Tunnel. The conditions at Stad are considered to increase both the frequency and consequence of a leisure boat accident, and it is therefore considered that the Stad Ship Tunnel will have a major maritime safety effect for the leisure fleet.

The analysis has assessed traffic transfer and fairway-specific conditions on both frequency and impact side. Overall, it is considered that the Stad Ship Tunnel will have a positive marine safety effect for utility vessels for ground impact, collision, capsizing and stability failure without capsizing. In addition, a qualitative assessment of the marine safety effect for recreational crafts has been made, which shows that a major positive impact on the marine environment is assumed.

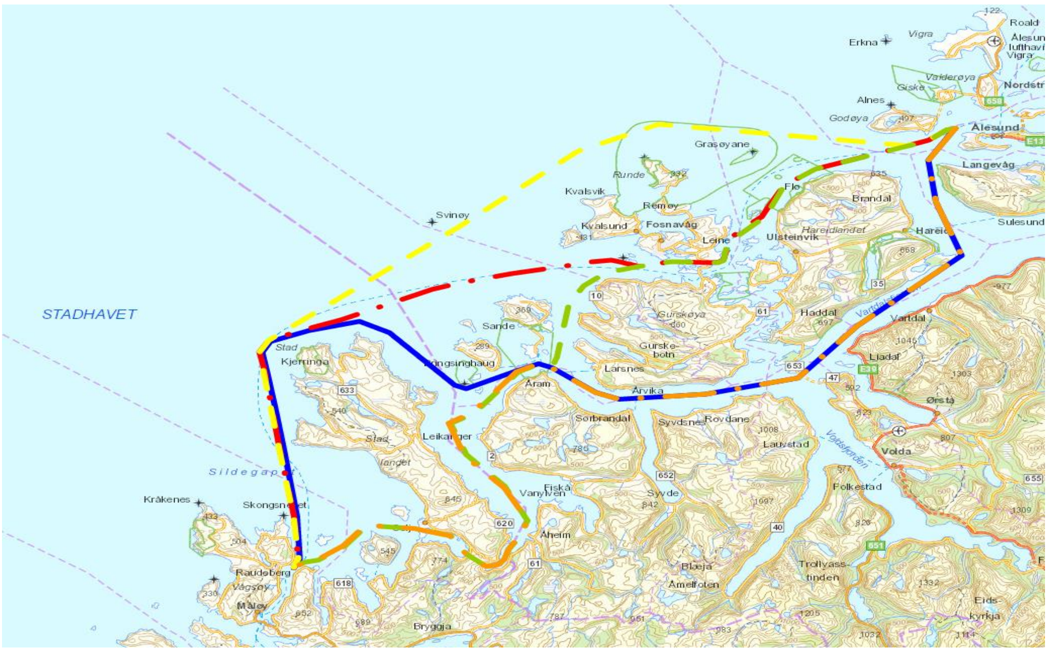

Figure 7: Different sailing routes

Fire protection

The primary contingency concept for the tunnel is that, if possible, the vessel shall attempt to sail out of the tunnel in the event of fire. Evacuation inside the tunnel itself will therefore only happen if the vessel fails to sail out of the tunnel. In the event of an event within the tunnel, the concept is that evacuation should not depend on external resources (self-sufficiency).

Evacuation takes place via gangway / ladder to the lanes that are located on both sides of the tunnel. It should be possible to evacuate in both directions along the lane to the portals. **Figure 8: Illustrating evacuation situation from a coastal ferry to emergency path (Pathfinder)**

The areas outside the portals could be arranged as emergency shelters and are available for emergency services via access routes.

Figure 8: Illustrating evacuation situation from a coastal ferry to emergency path (Pathfinder)

A walkway is facilitated for evacuation by establishing railings, handrails and emergency lights.
The tunnel will not have mechanical ventilation. Mooring possibilities are established for larger vessels in connection with entry construction at each portal to facilitate evacuation of ships at the portals.
There is no need for mooring of larger vessels inside the tunnel.