FEHMARNBELT – A NEW GREEN LINK BETWEEN GERMANY AND DENMARK

by

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The world longest immersed tunnel is to be built in northern Europe and will connect Scandinavia with Germany, thus closing a major gap in the European transport network, reducing the risk of shipping collisions, energy consumption and creating a new region in Europe, while also fostering the development of new nature and recreational landscapes by Working with Nature concepts.

The proposed landscaping is considered a “win-win” situation where the surplus of 19 million m^3 of dredged material will be used to create new landscaping features that will add a positive impact to the project in the form of providing new engineered “natural” landscape elements. This will bring new natural, environmental and recreational values to the area; rehabilitating it to an extent after being blighted by engineering projects in the past.

1. PRESENTATION OF THE PROJECT

The Fehmarnbelt Fixed Link, the proposed eastern route between Germany and Denmark, has been planned for a long time to create a rapid connection between the two countries with a faster and shorter link, see Figure 1. It will also close a major gap in the Scandinavian-Mediterranean corridor, part of the European transport network. Once opened, the journey for freight trains between Hamburg and Scandinavia will reduce by 160 km.

The Fehmarnbelt Fixed Link is a joint Danish and German transport infrastructure project across the Fehmarnbelt. Denmark is responsible for the planning, construction and operation of the Fehmarn Fixed Link. To carry out this task, the government of Denmark has established the company Femern A/S, which is 100% own by the Danish State, represented by the Danish Ministry of Transport.

The initial feasibility studies of the project were already conducted in the mid-90s and eventually followed by the Danish-German treaty signed in 2008. The project was given the go-ahead in Denmark in 2015 and is expected to be approved in Germany by mid-2018. The project includes an immersed tunnel that will run 18 km under the Fehmarnbelt and connect Puttgarden (Fehmarn island, Germany) to Rødby (Lolland island, Denmark). The maximum water depth will be about 30m and the tunnel has an estimated total construction cost of EUR 7 billion.

The design of the link and its land reclamation was developed with the support of both environmental consultants e.g. DHI and COWI, the technical consultants Ramboll-Arup-TEC and the landscape architects Schønherr.

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Figure 1. The upcoming Fehmarnbelt Fixed Link will be the eastern alternative to the western route from Hamburg over Funen and Zealand. The new green link will save time as well as energy.

The Fixed Link is a combined road and railway connection carrying two lanes of road traffic and a single, high speed rail track in each direction. When complete, it will be the third largest marine infrastructure project in southern Scandinavia. It will supplement the first one, the Great Belt Link between the Danish islands of Funen and Zealand, which opened in 1998, and the second, the Øresund Link, which opened in 2000 and connects Denmark's capital, Copenhagen with Sweden's third largest city Malmö. Ten million people will then be brought closer together, enlarging each country's growth region into one major regional centre. This will bring numerous opportunities for development, exchange of culture and business, trade and education etc.

2. THE JOURNEY TO THE IMMERSED TUNNEL

The immersed tunnel will be constructed by placing tunnel elements in a trench dredged in the seabed, see Figure 2. The proposed methodology for trench dredging comprises mechanical dredging using Backhoe Dredgers (BHD) up to 25m and Grab Dredgers (GD) in deeper waters. A Trailing Suction Hopper Dredger (TSHD) will be used to rip the clay before dredging with GD. The excavated material will be loaded into barges and transported for beneficial use to the inshore reclamation areas where it will be unloaded by small BHDs. Some 19 million m^3 of sediment will be handled.

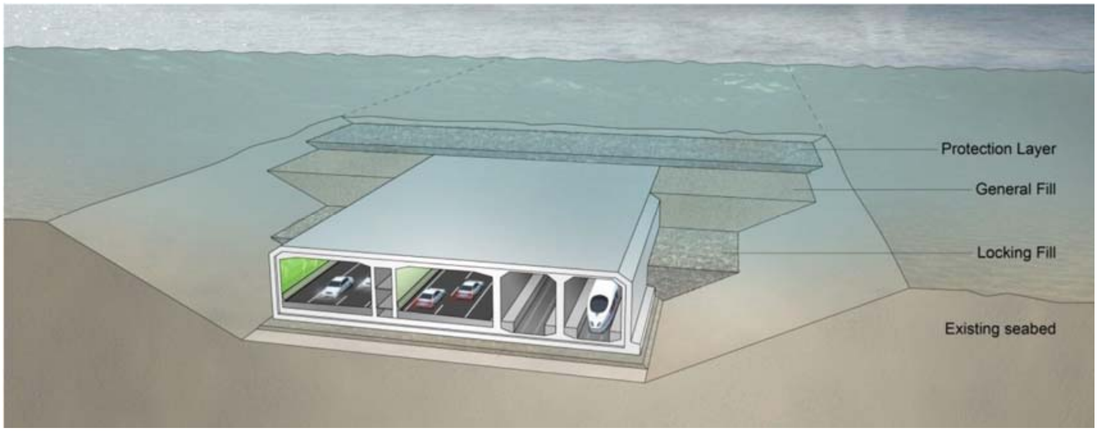

Figure 2. Cross section of dredged trench with tunnel element and backfilling

A bedding layer of gravel will form the foundation of the elements. Each element will initially be kept in place by depositing locking fill followed by general fill. Finally there will be a stone layer on top to protect against damage from grounded ships or dragging anchors. The protection layer and the top of the structure will stay below the existing seabed level, apart from near the shore. However, at the very nearshore area, the seabed will be raised at the coastal locations to incorporate the protection layer over a distance of approx. 500-700m from the proposed coastline. Here the protection layer will be an extended armour rock layer.

Reclamation areas are planned to run along both the German and Danish coastlines to use the dredged material from the excavation of the tunnel trench. The size of the reclamation area on the German coastline has been minimised. Two larger reclaimed areas are planned on the Danish coastline. Before the reclamation takes place, containment dikes are to be constructed some 500m out from the coastline.

The cut & cover sections of the immersed tunnel passes through the shoreline reclamation areas on both the Danish and German sides.

3. KEY REQUIREMENTS

One key requirement of this project is that it has to be designed and constructed in harmony with the landscape and its nature areas, thereby offering the opportunity to:

- Re-establish/re-generate some of the environmental values lost during the construction of major dikes and reclamation works in the early 1900's;
- Use the opportunity to create new landscapes;
- Incorporate the link into the landscape without visual harm;
- Make sustainable options a requirement.

Another requirement was that the Fixed Link poses minimal navigation risks to the important international navigation route connecting the North Sea and Baltic Sea. Finally, that the Fixed Link should have a minimal impact on the environment, particularly the water- and salinity exchange through the project area.

4. UNDERSTANDING THE ENVIRONMENT

To ensure the fulfilment of the above mentioned requirements it is necessary to understand the existing environment, not only to minimise the potential impacts of the project but also to identify win-win opportunities to meet the project requirements.

A detailed two-year survey programme was undertaken using a combination of fixed measurement stations, vessel and air surveys, as well as modelling works to study the important hydraulic and ecosystem components. These included water quality, benthic flora and fauna, fish, marine mammals and seabirds. With this information, it would be possible in the first instance to identify sensitive areas. The understanding of the environment also included analysis of the potential impacts on the sensitive areas.

The effects on higher trophic levels such as birds and marine mammals were assessed based on the outcome of these simulations. Ecological modelling was used to quantify the impacts arising from spilled sediment on water quality and benthic flora. The ecological model describes the relationship between dispersed sediment spill concentrations, light availability and primary producers, between nutrients, as well as the interrelationship and inter-specific competition between three distinct groups of producers: pelagic phytoplankton, benthic macroalgae and rooted vegetation.

The simulation of a realistic construction scenario for the entire construction period and of the permanent operation period of the link demonstrated that the Fixed Link could be built with only minor temporary and permanent impacts. A thorough understanding of the ecological aspects and coastal processes was important in order to identify options to re-generate the environment as well as to define sustainable coastal protection options. Understanding of the environment was a key element for the subsequent stages of the project and for selection of the preferred solution: the immersed tunnel that would provide the option of the beneficial use of dredged material to re-generate the landscape.

Some characteristic elements of the Fehmarnbelt area are described below:

4.1 Geology

The landscape of the area was shaped by the ice masses mainly during the last Ice Age. Since the final retreat of glaciers from the south-western Baltic area, the Fehmarnbelt has been characterised by highly variable sedimentary processes and environments, when the outflow from the Baltic Sea to Kattegat through the Great Belt and Øresund changed position several times. The present day topography and bathymetry was formed by the last Ice Age, which ended about 10,000 Before Present [B.P.], with varying water levels in the period.

The upper subsoils in the Fehmarnbelt consist mainly of glacial meltwater sand covered by clays and topped by post glacial marine sand, gyttja and peat. Beneath these layers are mostly glacial tills (also called boulder clay or moraine clay) of different types with local pockets of meltwater sand and silt, see Figure. 3. Deeper layers are chalk and paleogene clay that are older than the Quaternary period.

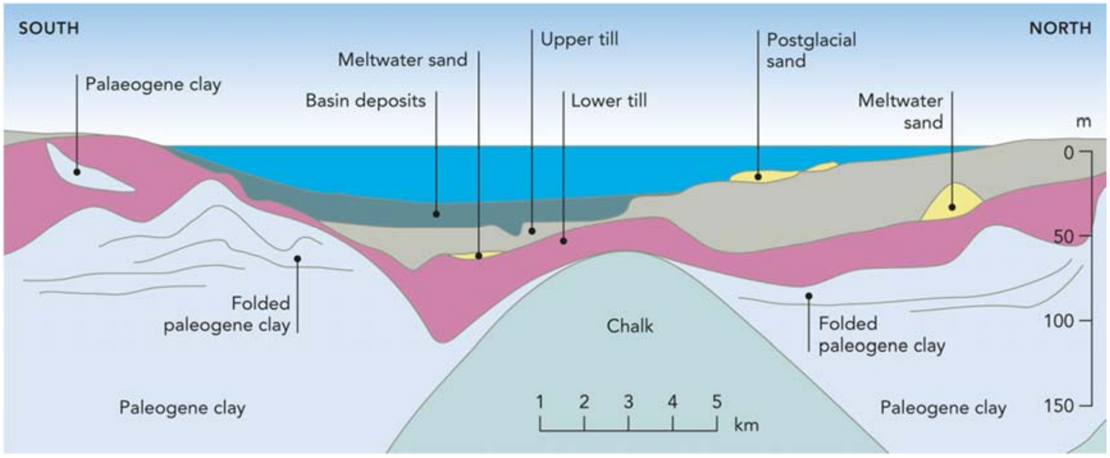

Figure 3. The geology of the Fehmarnbelt

4.2 Hydrography

The Fehmarnbelt is part of the transition area between the central Baltic Sea and the North Sea. The flow and stratification in the Fehmarnbelt is highly related to water exchange between the North Sea and the central Baltic Sea. The upper water strata in the Fehmarnbelt consist of brackish water from the central Baltic Sea, which, close to the surface, flows through the Belt Sea and continues up into Kattegat. A layer of water with higher salinity from the North Sea forms a lower layer.

4.3 Environment and Nature

The Fehmarnbelt is a very dynamic area in terms of water exchange and sediment transport, which forms different types of seabed substrate and forms, as well as coastal features such as cliffs and beaches.

In the shallow areas, the benthic flora is dominated by different flora communities determined by the water depth (light penetration) and substrates (mud, sand, hard bottom). Red algae communities (Fursellaria, Phycodrys, Delesseria species) are replaced in less shallow water by brown algae (Fucus Sp). On water depths over 20m, algae communities are rare. In wave-protected lagoons and bays, red algae are replaced by eelgrass. Blue mussels dominate along the Danish coast and are succeeded by amphipods (Bathyoireia and mussel communities (Corbula, Artcica species) in deeper water.

In terms of fish, the Fehmarnbelt is an important route for migrating cod, herring and silver eel, as well as a spawning area for a number of fish species, including cod and flatfish in general. In the Fehmarnbelt area, three species of marine mammals occur regularly: the harbour porpoise; the harbour seal; and the grey seal. The harbour porpoise use the Fehmarnbelt as a transport corridor whereas the seals do not, although seal haul-out sites are located over 20 km away both west and east of the alignment.

Birds are a special issue as the Fehmarnbelt is an important migration route both for north-south and east-west migration. Many species of water birds use the areas during either winter or summer. For that reason a number of protected habitats and bird areas have been designated. These are the so-called Natura 2000 areas according to EU legislation, see Figure 4.

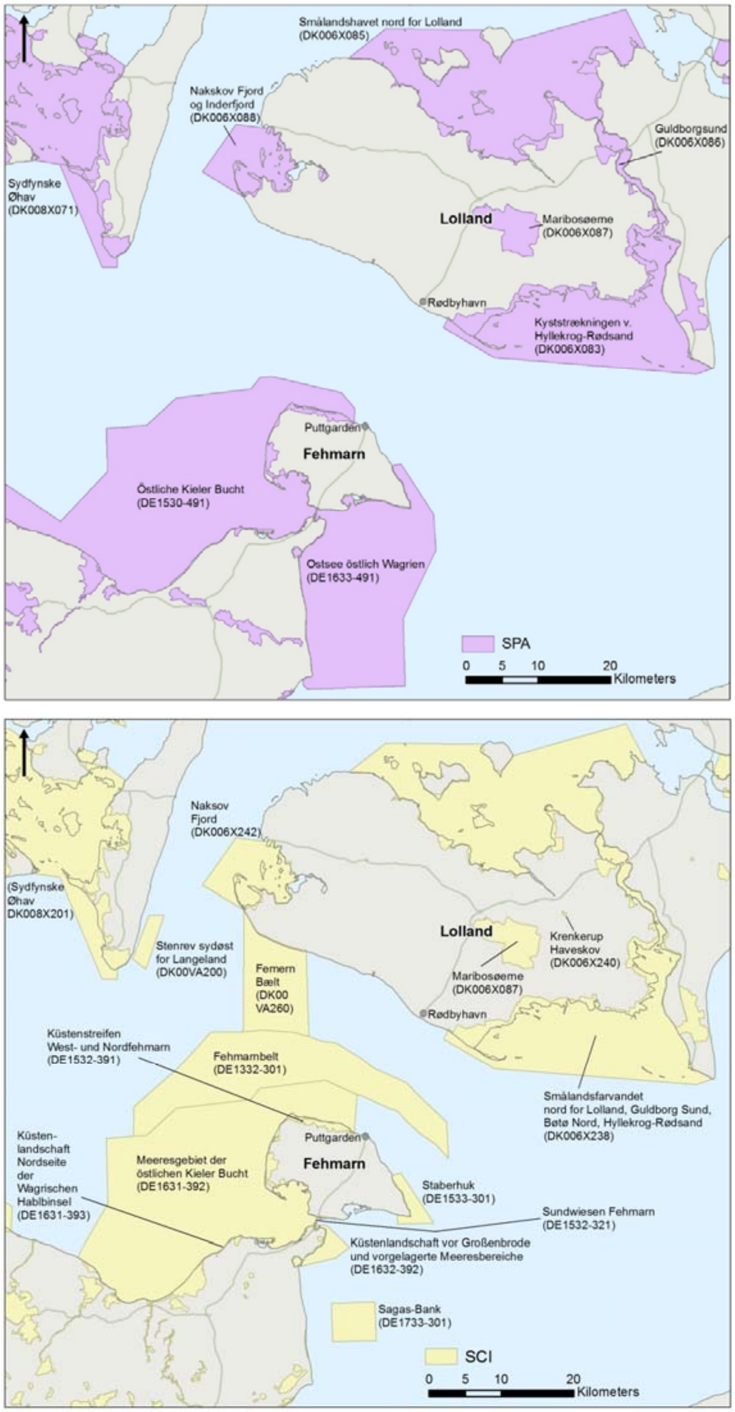

Figure 4. German and Danish Bird (Upper) and Habitat (Lower) areas

4.4 Human activity

Archaeological investigations conducted by the client reveal that the proposed alignment has been a human migration corridor over the last 6,000 years. DNA tests of archaeological finds of goat remains show that ancient human migration from central Europe to Scandinavia used the Fehmarnbelt as the main transport corridor. Today the Fehmarnbelt is one of the heaviest trafficked waters in the world because it is the main entrance to the Baltic Sea. It can be seen from the map (Figure 5) that ferries between Puttgarden and Rødbyhavn contributed with 35,000 crossings in 2013.

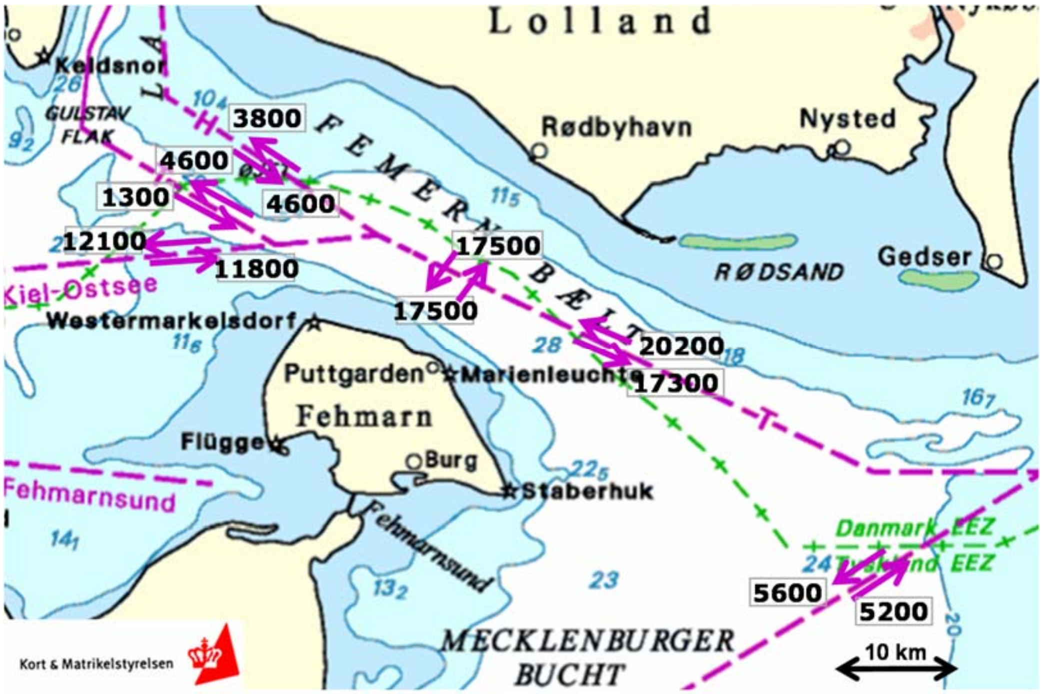

Figure 5. Number of ship movements in 2013 on main sailing routes in the Fehmarnbelt area determined on the basis of AIS data, ref. /20/

5. PROJECT DESIGN TO BENEFIT NAVIGATION AND NATURE

The project was designed by a multidisciplinary team consisting of engineers, architects, biologists, environmental engineers, etc. The design was based on the project objectives defined in early stages of the project and the understanding of the existing environment. These, together with extensive stakeholder engagement, worked towards a design that meets the stakeholder objectives and identifies win-win opportunities. Three options were initially proposed for the link. These were;

- a cable-stayed bridge,
- a bored tunnel, and
- an immersed tunnel.

The immersed tunnel was identified as the preferred option in the light of engineering, environmental, navigational and economic considerations. A tunnel provides safe navigation conditions since it avoids potential damage and associated oil spill resulting from ship collisions with piers and other obstacles.

Figure 6. Left; Cable-stayed bridge with two main spans of 724 m and navigation clearance above the sea of at least 66 m. Middle; Cross section, the bored tunnel consists of three tubes. The railway tube has an internal diameter of 15.2 m, while the two road tubes' diameter are 14.2 m. Right; The immersed tunnel consists of 79 standard elements (approx. 9x42x217 m) and up to 10 special elements (approx. 13x45x39 m).

With respect to the landscape impacts of a tunnel and bridge solution differ. As opposed to the tunnel, which is submerged, a cable-stayed bridge has a clear visual impact on the entire area. On the environmental scale, the bridge would entail permanent barrier effects e.g. on the hydrographical conditions of the Baltic Sea and on bird migration in the area. The impact assessment on the surrounding Natura 2000 areas proved that the tunnel produces significantly fewer environmental conflicts than the bridge.

One reason for deselecting the bored tunnel solution was the uncertain time horizon for the possible re-usage of the bored material for land reclamation purposes, due to its slow dewatering process. Other reasons were that the bored tunnel had a larger (environmental) footprint on Fehmarn and significantly higher greenhouse gas emissions.

The immersed tunnel provided a "win-win" solution because the 19 million m^3 would provide an opportunity for the beneficial use of dredged sea-bed material from the tunnel trench were seen as a great and feasible opportunity to create new landscapes and re-establish some of the historical features that were lost due to coastal protection and flood mitigation works carried out in the past.

5.1 New reclamation areas add nature and recreational values

The new landscape will be shaped as a streamlined area along the existing coast to an extent similar to that of the existing Rødbyhavn harbour. This will ensure that there will be no additional blocking of the flow through the strait.

The new landscape, see Figure 7 will extend approx. 3 km west of the harbour and 3.5 km east of the harbour. The extent of the area is decided mainly by the volume of the surplus sediment that can be absorbed by the landscape. The western part of the reclamation area is designed with the purpose of serving recreational values whereas the eastern part, although it accommodates the tunnel portal, is designed for serving nature values.

Figure 7. Design proposal for a land reclamation area on Lolland in Denmark

These new features will introduce positive aspects by supplying new natural, environmental and recreational values and will partially rehabilitate an area that has suffered severely from past engineering flood protection projects. The use of this surplus sediment will allow the re-creation of features such as those discussed below.

5.2 The landscape

The new landscapes will connect the tunnel portals to the adjacent coastal areas. This will be achieved in a gradual and harmonious way, thus minimising the visual aspects via a green transition zone. On the German side the natural elevation forms a kind of hill, which on one hand will hide the portal structure from the hinterland, and on the other hand secure the tunnel portal against raising sea level and minimizing the scour protection mound. In contrast to a more traditional design, the elevated landscape would probably have been removed and replaced by a rubble revetment mound. Finally, the passengers are allowed to overlook their journey across the sea.

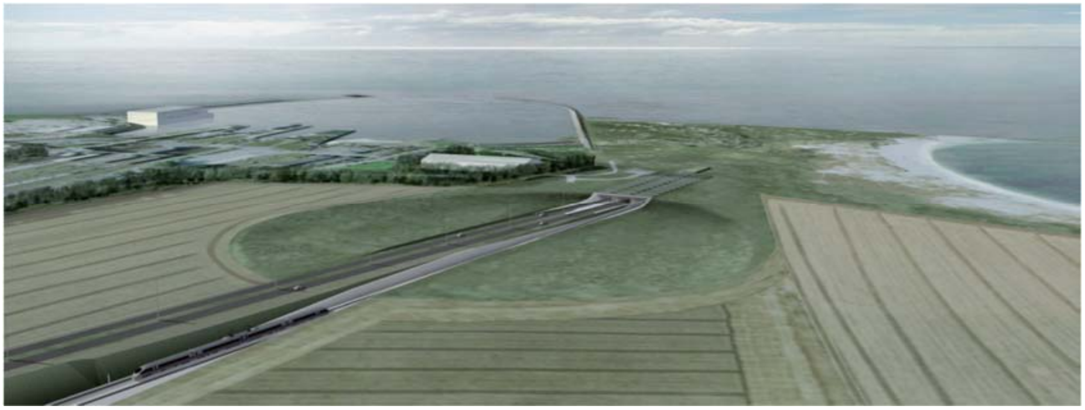

Figure 8. Tunnel portal on Fehmarn. The elevated landscape was retained. No larger revetment was necessary like on the Danish side. (see Figure 9)

5.3 Protected areas

The existing dike on Lolland, which runs along the coast line, is not influenced by the new reclamation areas in front and will consequently still protect the low lying hinterland. The reclaimed areas will be designed with different perimeter types dependent upon the different technical and environmental functions.

Figure 9. View of the portal area at Lolland protected by a revetment

The stretch around the portal at Lolland will be scour protected. The structures are designed to minimise the visual aspects of the tunnel portal but also to protect against possible rising sea levels due to climate change.

5.4 Re-establish previous landscape

Some of the environmental values were lost in connection with the construction of a major dike along the coast in the area following a major flooding event in 1872. The dike cut off the previous shallow archipelago, Rødby Fjord and other shallow areas, which were later reclaimed by the installation of a pumping station. The historical landscape with Rødby Fjord is seen in Figure 10, along with the reclaimed areas

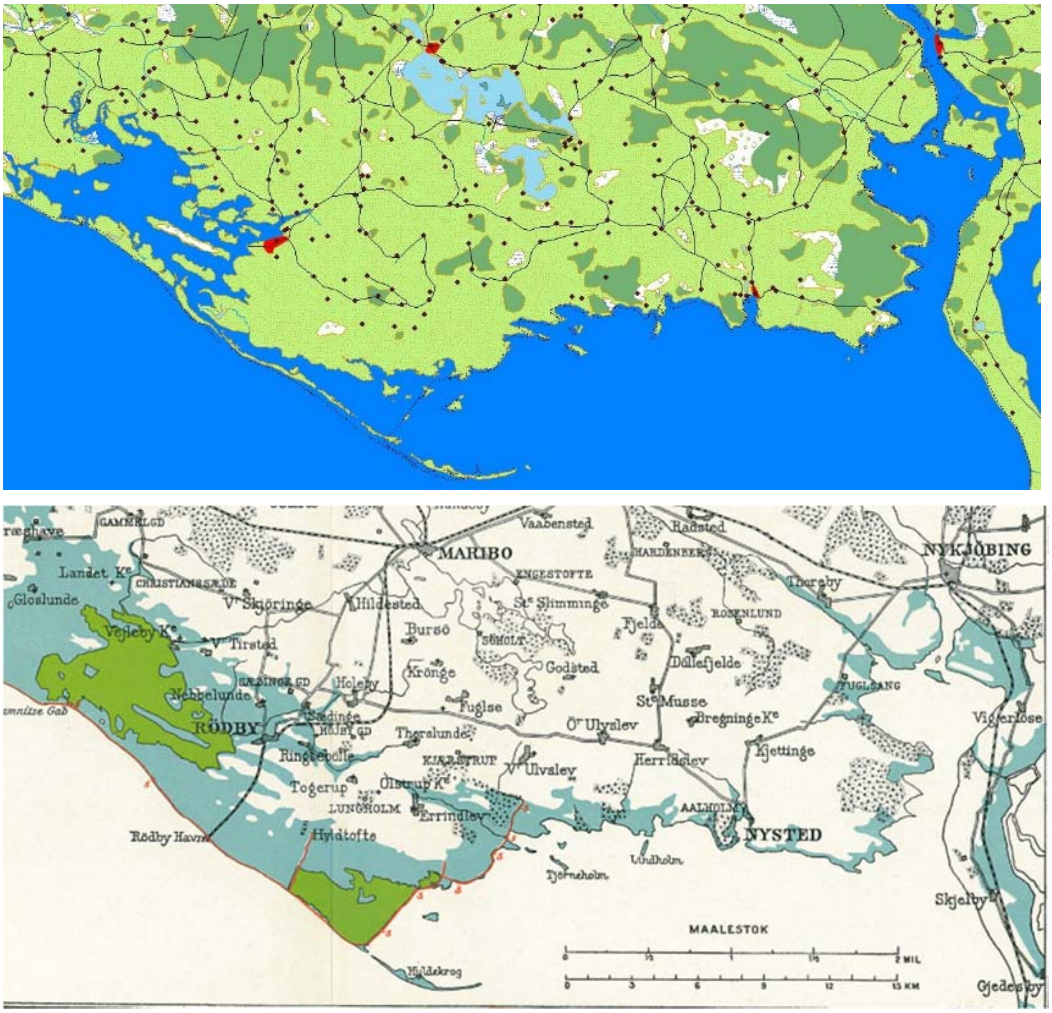

Figure 10. Upper; Historical map for the south coast of Lolland produced by the Scientific Society 1763-1805 – note the large Rødby Fjord. Lower: present condition, the dike (red line), flooded area during the storm event in 1872 (blue area) and dry areas (green). The dike is now protecting the hinterland for flooding and secures with its pumping station and drainage system dry areas for agriculture. With the land reclamation new wetlands are created re-establishing some of the lost previous high environmental values.

5.5 Artificial lagoon

Wetlands, salt meadows and grassland lost due to the construction of the new dike will, to a certain extent, be re-established at the new land reclamation area east of Rødbyhavn, see Figure 11. Overall it will be a 3.7 km long and 0.5 km wide green band featuring an artificial lagoon with two fixed openings east of the tunnel portal. The lagoon includes wetlands, a major recreational island and a small sea bird island. The vegetation in the nature and wetland areas will be allowed to develop naturally, which will enhance the biodiversity of this environment

Figure 11. Visualisation of wetland in the eastern part of the land reclamation area in Denmark on Lolland. The bird island is the small island in the background of the lagoon

5.6 Cliffs

The ferry harbour, Rødbyhavn, was constructed over a century ago and extends 500 meters out from the coast line. This extension has resulted in a beach with sand dunes that has built up west of Rødbyhavn but, on the eastern side of the harbour, the blocking of the littoral transport has resulted in sand erosion along approx. 3.5 km of the coastline, see Figure 12, left.

Figure 12. Left; Protected dike east of the harbour, where beach and environmental values have been lost. Right; Cross section of the cliff section

Most of the eastern area will be filled up to a level of 7m. Natural erosion is allowed here whereby a “natural” cliff will form and the eroded sand will be transported eastward by the predominant littoral transport. This supply of sand will help to stabilise the beaches to the east, following a smooth transition area.

5.7 Artificial beaches

On the western side of the harbour, the area with its beaches will be used for recreational and leisure activities, which feature a major leisure area. The recreational and leisure value will increase with the construction of the beaches and grasslands. Three artificial beaches are planned; on the Danish side, one at the extreme west end of Lolland and one lagoon beach in the middle plus a paddling beach close to the harbour. On the German side a grassland and a beach east of Puttgarden harbour (Figure 8) are planned. The beaches are designed in their equilibrium orientation by fixed structures;

Figure 13. Cross section of the new western beach section with dunes at Lolland

5.8 Reefs

Stones and boulders on the seabed form hard substrate to which sea algae will attach and start to increase the biodiversity, which gradually leads to reef formations. Many of these stones and boulders have been removed for the purpose of constructing harbours, piers, revetments etc. over the last 100 years or more. Stones and boulders large enough to create artificial reef structures will be used for the protection layer on top of the tunnel close to the coast – in shallow water where there will be no barrier effect on the water exchange. If feasible surplus “reef-stone” from the dredging work will be placed at the Natura 2000 area, Sagas Banke, in order to mitigate earlier stone removal over a 25 ha area, see Figure 14.

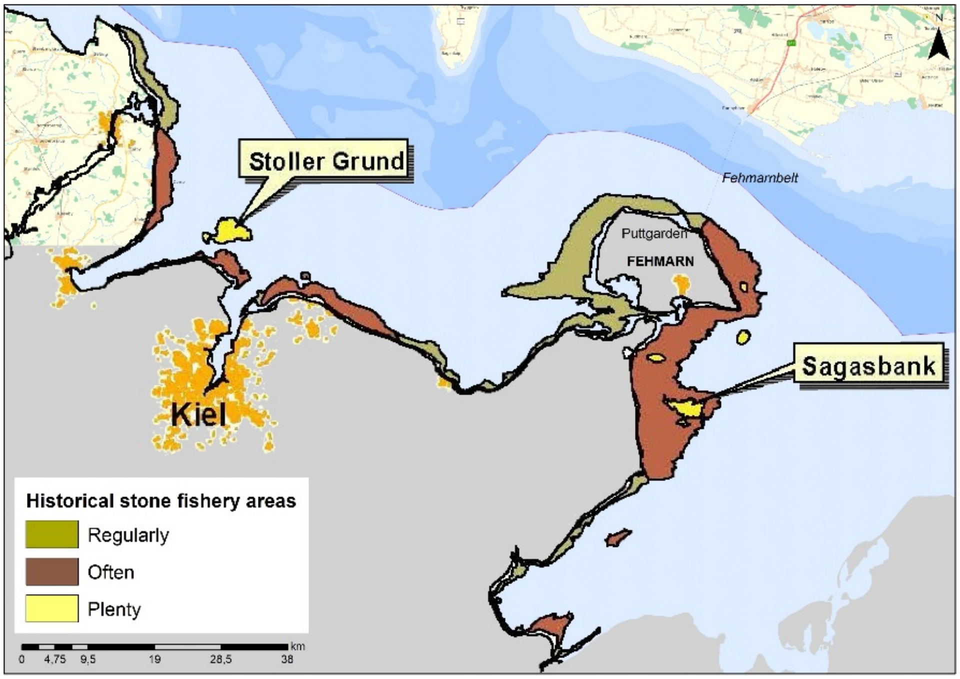

Figure 14. Sagasbank, Germany has suffered for intensive stone fishery and 25 ha will be re-establish

6. STAKEHOLDER ENGAGEMENT TO IDENTIFY POSSIBLE WIN-WIN OPPORTUNITIES

Extensive stakeholder engagement was obtained for this project already from the start. The public, professionals and NGO organisations, as well as authorities were invited to comment on the project. An exhaustive range of consultations (some public) was conducted along the way. This included the scoping process and environmental impact assessments. There were also public plan application document exhibitions.

Cross-border project consultations were conducted in both Germany and Denmark, as well as one involving all the countries around the Baltic Sea (ESPOO hearing).

The outcome of this stakeholder input has had a major influence on the whole project, including the marine area and the new reclamation landscapes; the marine ecosystem's functionality; the bird migration routes; and, of course, the Fehmarnbelt as a transport corridor for other marine life between the North Sea and the Baltic Sea. They are all part of the Danish plan approval already granted and the German plan approval expected in 2018.

7. CONCLUSIONS

This is an outstanding example of the application of the Working with Nature principles for large marine infrastructure projects. The construction of the Fehmarnbelt project is planned to start in 2020. The main features of the project can be summarised as:

- The proposed marine and landscapings are a win-win situation discussed and proposed during the stakeholders engagement
- 19 million m^3 of material will be used to create new landscapes instead of marine dumping
- These will add new nature, environmental and recreational services much to the public needs and requirements
- Understanding and mimicking nature play a key role in the project vision
- Immersed tunnel avoids long-term over-water disturbance of the aquatic environment

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