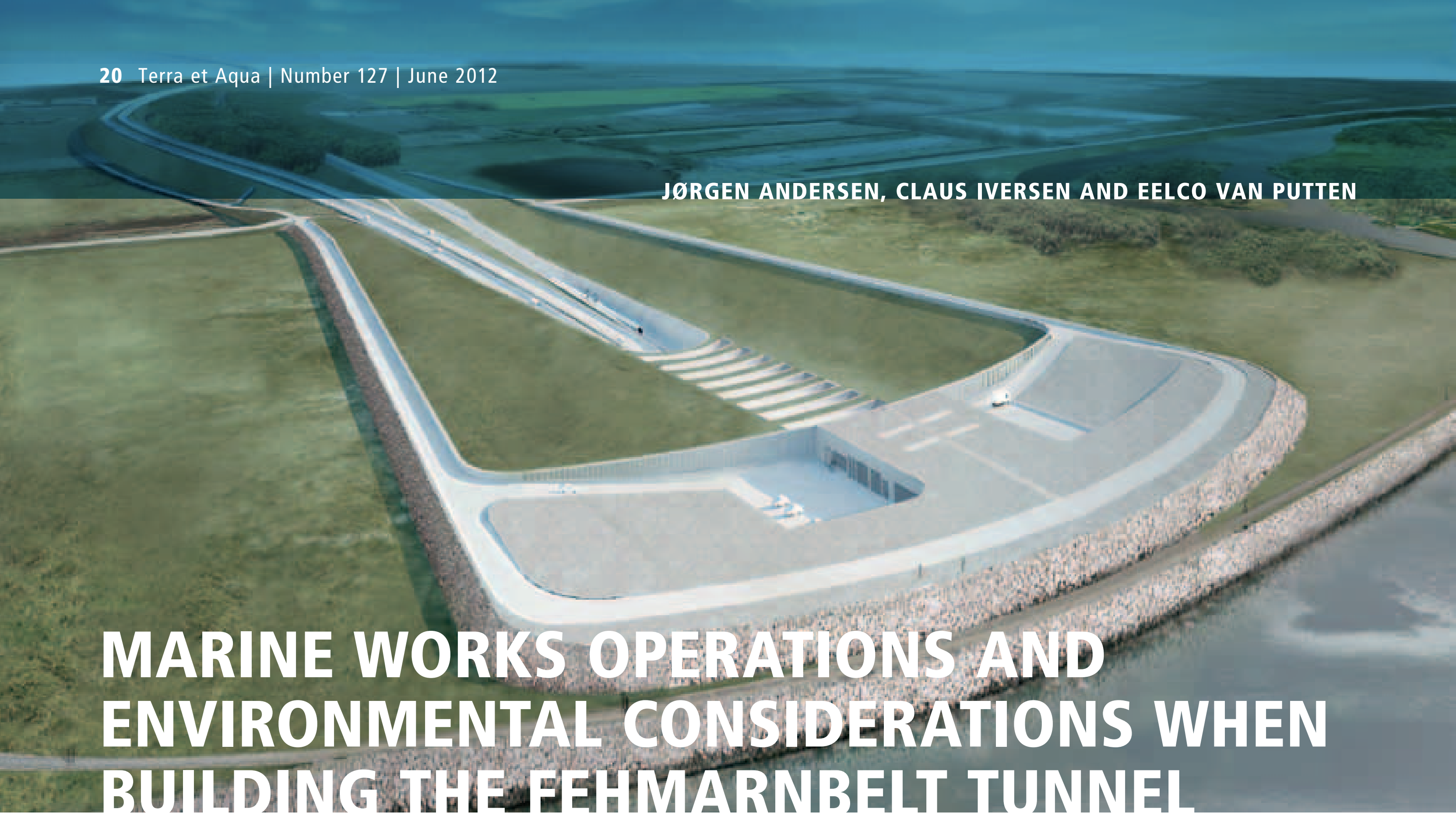

JØRGEN ANDERSEN, CLAUS IVERSEN AND EELCO VAN PUTTEN

MARINE WORKS OPERATIONS AND ENVIRONMENTAL CONSIDERATIONS WHEN BUILDING THE FEHMARNBELT TUNNEL

ABSTRACT

The Fehmarnbelt Fixed Link will connect Scandinavia and continental Europe with a combined rail and road connection between Denmark and Germany. It is planned to cross the Fehmarnbelt between Rødbyhavn, located some 140 km south of Copenhagen on the island of Lolland in Denmark, and Puttgarden, located on the island of Fehmarn on the north coast of Germany.

Important challenges for the realisation of this project are: a world-breaking distance of 18.5 km, a water depth of 30 m and crossing a busy navigational channel.

After a comprehensive comparison between a bridge and an immersed tunnel solution the decision was reached that an immersed tunnel should form the basis for the continuous planning of the project including the environmental impact studies. However, alternative technical solutions are still being considered. The start of the construction is expected to commence in 2015 and the link is scheduled to be opened for traffic in 2021.

This article will present some key points of the conceptual design of the marine works aspects in general, and focus on the dredging process more specifically. The global picture of key dimensions and volumes will be included as well.

INTRODUCTION

Description of the Immersed Tunnel Project

The alignment for the immersed tunnel solution is shown in a plan in Figure 1. The route passes east of Puttgarden, Germany, crosses the Fehmarnbelt in a soft curve and reaches Lolland east of Rødbyhavn in Denmark. The alignment and landfall locations were chosen in a process which considered environmental and technical factors in addition to costs and the practical issues of connecting to the existing infrastructure. A number of alignments were investigated and optimised to fit the spatial resistance factors identified for the project area.

Above: Drawing of the portal building on the Danish island of Lolland, part of the Fehmarnbelt Fixed Link that will connect Scandinavia and continental Europe with a combined rail and road connection. Two tunnel portal buildings, one on Lolland and the other at Puttgarden, Germany, will be located behind newly constructed coastlines.

The major features of the immersed tunnel solution include:

- An immersed tunnel approximately 18 km in length.
- Cut and cover tunnels at each landfall bringing the tunnel up to the surface.
- Portal structures, at the entrances to the tunnel.
- Ramps for the road and rail on the approaches to the tunnel.
- Approach highway and railway linking to existing routes.

Figure 1. Conceptual Design alignment (road shown in blue and rail shown in red).

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graduated in 1989 with an MSc in Civil Engineering from Aalborg University, majoring in marine and off-shore construction. He worked on the Øresund Fixed Link project for eight years; first in the House Consultants organisation during design and tender preparation, then as Engineering Manager for the Dredging & Reclamation contract during the execution phase. After Øresund he worked as consultant on various marine and infrastructure projects, including the Copenhagen Metro and the extension of the M3 motorway around Copenhagen. He joined Femern A/S in June 2009 and is presently Contract Director for Dredging & Reclamation.

CLAUS IVERSEN
is currently employed as Construction Manager, Marine Works at Femern A/S which is tasked with the planning of a fixed link between Denmark and Germany across the Fehmarnbelt. Since his graduation with a MSc in Civil Engineering, specialised in Hydraulic Engineering at the Technical University of Denmark (DTU) in 1972, he has been involved mainly as project manager for a broad spectrum of marine works at an international level – including dredging and reclamation, offshore pipeline projects and immersed tunneling. Recent assignments include Construction Manager responsible for supervision of construction activities for the Bosphorus Immersed Tunnel Project in Istanbul, Turkey.

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studied Civil Engineering at Delft University of Technology (DUT) obtaining his MSc in 2002. He then started as a structural engineer for the Amsterdam Metroline for three years. He has since worked as a consultant for TEC (Tunnel Engineering Consultant) on several tunnel projects, such as the Hubertus tunnel in The Hague, The Netherlands, Oosterweel Connection in Antwerp, Belgium, Limerick tunnel, Ireland and Busan Geoje Fixed Link, South Korea. Since July 2009 he works for the Joint Venture Rambøll, Arup and TEC (JV RAT), the Design Consultant for Femern A/S; he is presently Lead Engineer for the Marine Works, which includes Dredging & Reclamation.

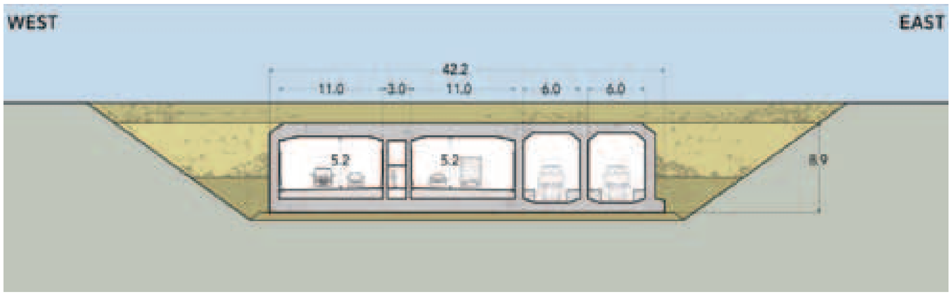

Figure 2. Standard element cross-section with dimensions in metres.

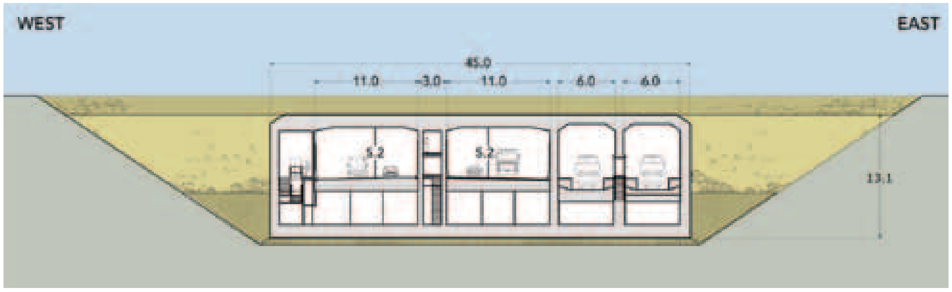

Figure 3. Special element cross section with dimensions in metres.

- Reclamations areas at both coasts (the great majority at the Lolland coast) for the re-use of material dredged from the tunnel trench.

IMMERSED TUNNEL SOLUTION

The tunnel elements consist of a combined road and rail cross-section all at one level, contained within a concrete structure. There are two types of tunnel elements: standard elements and special elements as shown in as shown in Figures 2 and 3. Standard elements represent the cross-section for the majority of the immersed tunnel (79 standard tunnel elements). All standard elements have the same geometric layout and are, to a high degree, interchangeable. Each standard element is approximately 217 m long and is constructed from a chain of smaller segments which, for transportation and immersion, are temporarily connected longitudinally using a post-tensioning system which is cut after the tunnel elements are placed on its foundation.

There are also 10 special elements, one every 1.8 km along the length of the immersed tunnel that provide space within the tunnel to house the mechanical and electrical equipment associated with the tunnel's operations systems. Each special element is unique and cannot be interchanged with other elements. They provide maintenance access via the ground floor to all areas of the tunnel with the minimum of disruption to operation.

Many sorts of tunnel technical installations in the tunnel – such as fire suppression systems, tunnel drainage, lighting, communication system, Intelligent Transportation System and SCADA – will ensure that the future users enjoy a safe journey from coast to coast through the tunnel.

The tunnel elements are placed in a trench dredged into the seabed, as shown in Figure 4. A bedding layer of gravel forms the foundation for the elements. A combination of locking fill and general fill is at the sides, while at the top is a protection layer which is in general 1.2 m thick, but can vary depending on the location on the alignment. The function of the locking fill is to lock the tunnel element into position in the trench and prevent any movement from taking place as a result of hydraulic loads or the placement of the general fill.

The protection layer ensures against any damage from grounded ships or falling and dragging anchors.

The standard tunnel elements are 97% of the total length of the immersed tunnel. In the

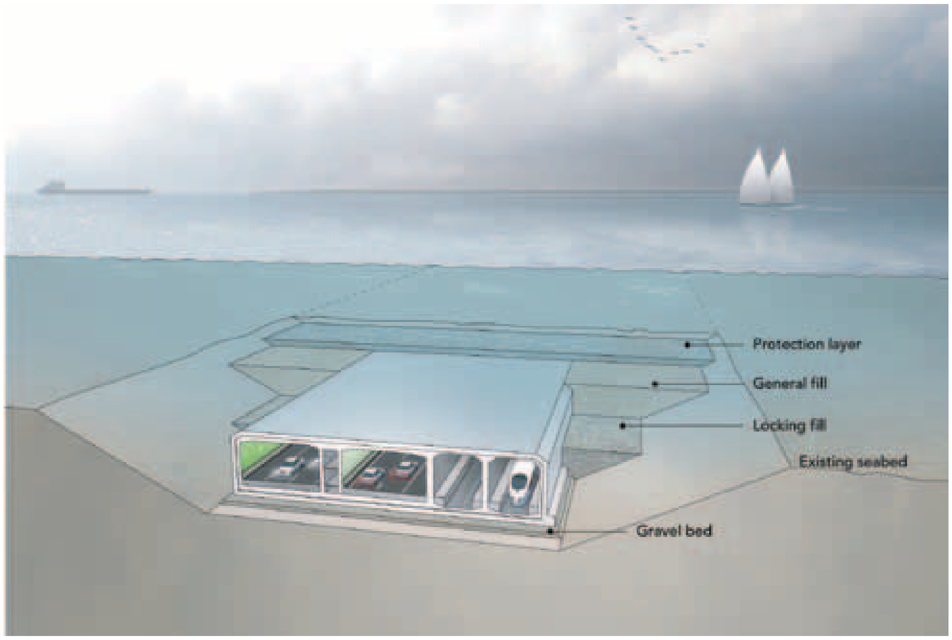

Figure 4. Cross-section of dredged trench with tunnel element and backfilling.

design process the standard tunnel elements have been standardised to allow for an industrialised construction method, which was originally developed for the Øresund project. This site consists of the following main features:
- Construction hall
- Casting and curing hall
- Launching basin
- Work harbour.

To meet the stringent requirement for the opening date, a total of 8 production lines, which will construct 79 tunnel elements, are foreseen. The high production rate for the concrete will result in a high demand for materials to be delivered on site. Deliveries to the site are expected to take place by means of trucks, but the main materials for the concrete production (cement, sand, aggregates and reinforcement) will be delivered by vessels.

The tunnel portal buildings are both located behind the newly constructed coastline and the main features of the portal building and ramp area are as follows:
- Ramps for road and rail
- A cut-and-cover tunnel section including a lightscreen structure
- Portal buildings
- Sea defences.

Table I below gives an approximation for some of the main resources that will be required to construct the Fehmarnbelt Fixed Link tunnel. These quantities are subject to variation at detailed design.

Table I. Resource requirements.

Quantities	
Concrete in tunnel elements	2.5 million m^3
Reinforcement	300,000 tonnes
Ballast concrete, total	0.4 million m^3
Structural concrete, portal buildings, ramps and cut and cover	0.2 million m^3
Total volume dredged from tunnel trench, access channel, harbours	19 million m^3
Trench backfill volume	6.4 million m^3
Total reclamation area	350 ha
Total area Production site	120 ha

Reclamation areas are planned along both the German and Danish coastlines that will accommodate the dredged material from the excavation of the tunnel trench. These areas will be landscaped into green areas. The size of the reclamation area on the German coastline is relative small. Two larger reclamations are planned on the Danish coastline on both sides of the existing harbour which will absorb the majority of the dredged material from the trench excavation.

MARINE CONSTRUCTION WORKS

The marine construction works activities comprise all the coast-to-coast marine construction activities which are needed to create the immersed tunnel for the Fehmarnbelt Fixed Link. The marine construction work phases are described in the following sections.

Phase I: Temporary works

The temporary works comprise the construction of two temporary work harbours (one on the German side at Puttgarden and one on the Danish side at Rødbyhavn), the dredging of the portal areas and the construction of the containment dikes.

The work harbours will be used to provide a safe haven for marine construction equipment, to facilitate the transport of personnel, and to provide facilities for supply, stockpiling, and load-out of materials and equipment. These harbours will be integrated into the planned reclamation areas and upon completion of the tunnel construction works, they will be dismantled/removed, backfilled and landscaped.

The Fehmarn work harbour will be located in front of the reclamation area directly between the existing ferry harbour and the tunnel portal building (as shown in Figure 5). This location has been selected as it removes the need for dredging to provide an access channel to the work harbour.

Likewise, the Lolland work harbour will be located adjacent to the production site which is located in the reclamation area east of the alignment. The landfall of the immersed tunnel passes through the shoreline reclamation areas on both the Danish and German sides and is termed the Portal and

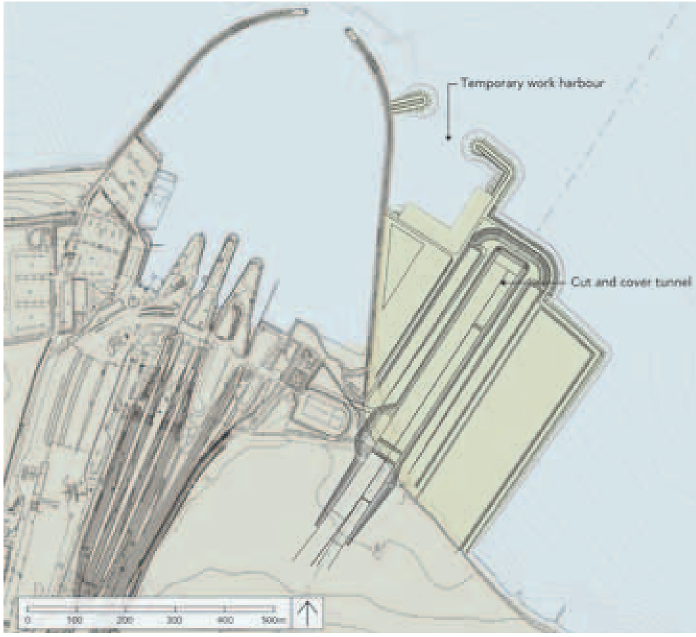

Figure 5. Fehmarn work harbor.

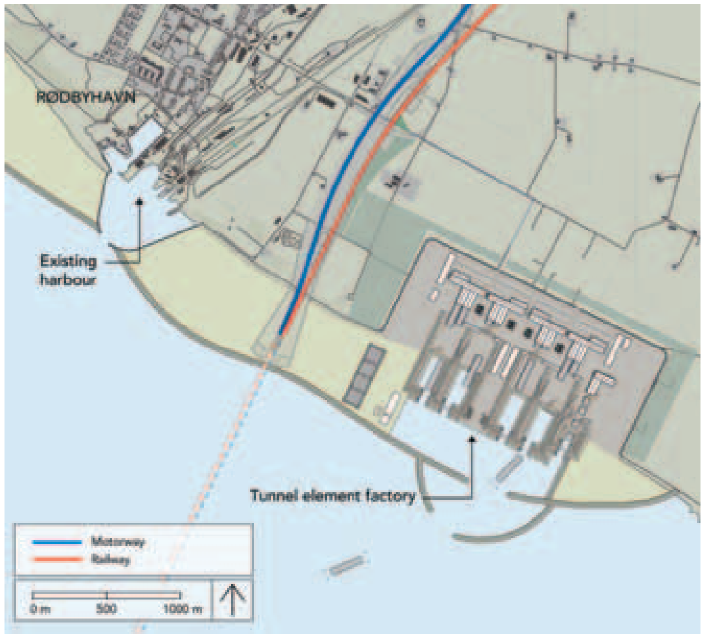

Figure 6. Lolland work harbour with production site.

Ramps section of works. These works comprise the dredging of the ramps and construction of temporary front and lateral dikes.

Before the reclamation takes place, containment dikes are to be constructed some 500 m out from the existing coastline at a depth of approx. MSL-4.5 to MSL-6.5 m (MSL = Mean Sea Level). The dikes will be built to a height of MSL+3m with an extended crest of some 7 m.

Phase II: Dredging and reclamation

A number of different types of dredging works need to be performed:

- Dredging to create the trench where the immersed tunnel can be placed
- Dredging to create sufficient depth for temporary harbours and access channels
- Dredging for the portals and ramps, reducing the need for land-base excavation prior to commencing the structural works.

The excavation of the tunnel trench between Lolland and Fehmarn represents the majority of the dredging works in terms of the quantity of dredged material and the associated construction time. All other dredging works (for work harbours, access channels and ramps) will be completed prior to the start of trench dredging. The total dredging quantity of in-situ soil that will be dredged for different parts of the works is 19 million m^3.

An important goal for the project is to beneficially re-use the majority of the dredged material and at the same time give close attention to environmental issues and safety during the working process.

To prevent blockage of water exchange through the Fehmarnbelt the contours of the reclamation areas do not exceed the boundaries of the existing breakwaters of the ferry terminal.

The production facility is located inside the reclamation area Lolland East, where as a consequence, part of this area will temporarily be unavailable for the storage of dredged material.

The work harbour and basins will result in additional dredging because it will be deepened (and later filled again). This will also lead to a temporary storage of dredged material. Part of the temporary storage of dredged material is done by raising the surface level of the reclamation area Lolland East and the rest is stored on land in earth berms around the production site.

After the construction of the tunnel elements, the stored dredged material will be used to fill the work harbour and then the final landscaping will be done.

Phase III: Installation of the tunnel elements and backfilling the trench

The installation of tunnel elements and the backfilling of the trench is also a sequence of Marine Works activities. As there may be a period of time between dredging of the tunnel trench and immersion of the tunnel structure, the operation will start with a clean sweep operation. Any undesirable sedimentation which has been deposited within the trench can, for instance, be removed with a trailing suction hopper dredger. This will ensure the trench is suitably clean for placing the gravel bed layer and subsequently the immersion of the tunnel elements.

A gravel or rock bedding layer is considered the most likely type of foundation which will be placed within the trench using a pontoon equipped with a fall-pipe and then levelled during placement with the fall-pipe or afterwards using a screeding pontoon.

Crushed rock will need to be delivered from a quarry somewhere in the region.

Expectations are that this will be done by self-unloading carriers which can moor alongside the placing pontoon and unload the rock onto a conveyor belt (via a hopper feeder) and the rock will be subsequently conveyed and fed into the fall-pipe.

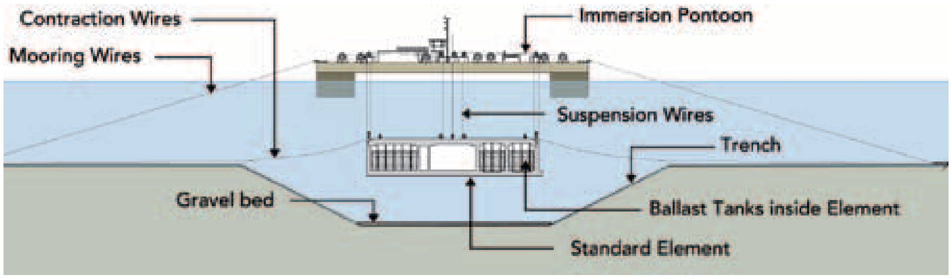

Figure 7. Lowering of an element from an immersion pontoon (cross-section through centre of element).

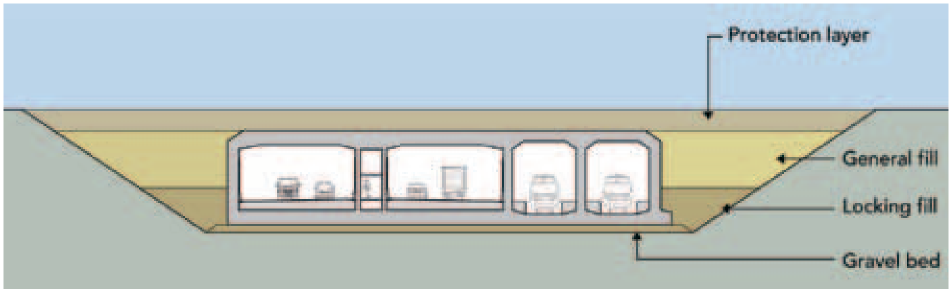

Figure 8. Immersed tunnel backfilling and protection.

The immersion operation involves all activities concerning the preparation, immersion, and connection of the tunnel elements under water. Prior to immersion, the tunnel elements are stored in floatation next to their ultimate location. When ready for immersion the element is winched into position by the immersion pontoons fixed to the element. In near-shore locations tug boats may be used to help guide the elements. The immersion starts by filling the ballast tanks and to create the required negative buoyancy for the element to sink.

During the lowering, the tunnel element is supported from the immersion pontoons on suspension wires, as shown in Figure 7. The position of the pontoons is controlled with mooring wires.

During the immersion the tunnel element is gradually lowered towards the previously immersed element. The horizontal movement of the tunnel element is controlled using contraction wires. When the tunnel element nears its location it will be slowly lowered onto the gravel bed within the trench. The immersed element is pulled against the preceding element and the joint is sealed. Subsequently alignment adjustments are made if needed, with hydraulic jacks inside the immersion joint. Once the tunnel element is correctly positioned, the locking fill is placed.

Once a tunnel element has been installed on the foundation bed it will be necessary to backfill the trench with suitable materials and provide a cover layer for protection. The design of the locking fill, backfill and cover layer is such that it does not extend above the existing seabed level, except in the very near-shore areas.

To create sufficient horizontal stability against wave conditions a locking fill is placed on both side of the tunnel element. Crushed rock or gravel will typically be used for the locking fill, depending on the position along the alignment. The material will be brought from a quarry within the region. The general fill will be sand from a suitable marine source location. A small- to medium-size trailing suction hopper dredger is a likely option which can be used to source the sand and then place the fill via its drag arm into the trench.

For the protection layer, rock will be transported from its source, possibly using a pontoon tugged by a boat, and placed for instance by side stone dumping (pushing rock over the side of the pontoon) or by grabs mounted on the vessel itself.

Phase IV: Landscaping

The expected dredging methodology will be described in the following section, where it is explained why it is most likely that a large part of the dredged material is mechanically excavated and transported with barges to the reclamation areas. Part of the materials (less than half) will need to be placed in the wet areas behind the containment dikes, and the other part is used for dry placement above the water level.

Most of the materials will consist of very hard clay till (approximately 12 million m^3 in-situ values), which will be ideal to form the basis as main fill for the reclamation areas.

It is also expected to be suitable to use as construction material for the containment dikes around the reclamation areas. The rest of the material will consist of mechanically excavated softer soils such as sand, silt and clays (approximately 7 million m^3 in-situ values).

Once dredging and reclamation for the tunnel is complete the reclaimed land are allowed to consolidate and then landscaped into their final design. The main goal for the landscape plans is to use the dredged materials beneficially to create natural landscapes and create added environmental, natural and recreational value to the project as shown in Figures 9 and 12.

This will be achieved with the following landscape elements:

- Beach and dunes at the outer corner of reclamation area Lolland West.
- Artificial pocket beach connected to a lagoon on reclamation area Lolland West which creates a recreational area.
- Armored dikes with higher lying land between the Rødbyhavn and the portal building.
- Coastal lagoons with wetlands on the eastside of the portal building, where the nature is allowed to develop naturally. There are two openings where brackish water can flow in and out of the area.
- A natural cliff on the far east side of reclamation area Lolland East, which is allowed controllably to erode and thereby supply the downstream coastline with sediments.

Figure 9. Final landscape of Lolland Reclamation Area.

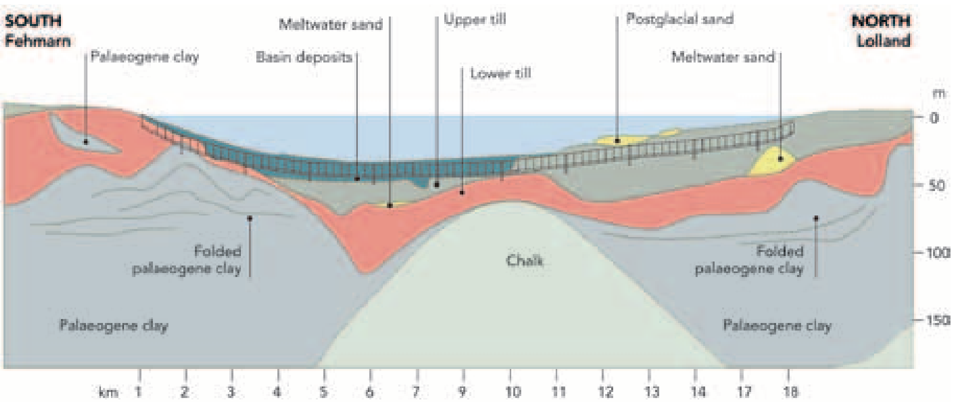

Figure 10. Longitudinal soil profile.

INTEGRATED SOLUTION BETWEEN PROJECT AND ENVIRONMENT

Originally the Fehmarnbelt region is a wetland region but centuries of agriculture and fishery have left their marks on the ecosystem. The main strategy for the project has therefore been to re-use as much as possible of the dredged materials as a resource for reclaiming new land in front of the shorelines of Lolland and Fehmarn, respectively.

The reclaimed areas will create valuable natural and recreational values and will act as an environmental interface between the artificially made landscape and the Fehmarnbelt, while still providing safety against flooding.

In the following sections the main design features of this integrated solution between the project and the environment are elaborated in more detail.

Longitudinal soil profile

The ground investigations were conducted in 1995/1996 and 2009/2010 and based on these investigations several geological units were identified. The youngest of the deposits is the Postglacial marine sand which is characterised as a graded sand without or almost without organic content. The Postglacial marine gyttja is a layer of 6 m and can be found on the southern part of the Fehmarnbelt basin.

The Postglacial/ Lateglacial marine clay and silt and freshwater lake/sea deposits are found in the deeper basin and are layered in parts of the area. The (Upper) Clay-till is a glacial deposit and is characterised as a very hard, low plasticity material, varying from silt, to gravelly clay till (undrained shear strength of 0.7–1.5 MPa). The Palaeogene clay which is the oldest of the excavated materials and is a very high plasticity, fissured clay located directly below the Quaternary deposits and locally as floes within the lower till (Figure 10).

Mechanical dredging

The soils to be dredged on the German side are characterised by paleogene clay and some clay-till with boulders. The central basin comprises gyttja, sands, silts and clays and the soils to be dredged on the Danish side are dominated by thick deposits of clay-till. All dredged material is expected to be classified as clean, unpolluted soil.

From a pure technical point of view all dredging methods are more or less applicable in different parts of the crossing. However, to minimise the impact on the environment mechanical excavation by means of Backhoe Dredgers (BHD) or Grab Dredgers (GD) is expected to be the preferred method. Mechanical dredging will minimise the adverse effects of dredging turbidity on the surrounding environment. The alternative of hydraulic dredging will be associated with relative higher turbidity levels, caused by the suction process or by overflow of a hopper.

The proposed methodology for trench dredging comprises mechanical dredging using Backhoe Dredgers (BHD) to a depth of MSL -25m and Grab Dredgers (GD) below that depth. A Trailing Suction Hopper Dredger (TSHD) is a proposed option to be used to pre-treat (rip) the clay-till below MSL -25m and the pre-treated material will subsequently be dredged by the GDs. The mechanically dredged material (excavated by GD and BHD)

Figure 11. Extent of proposed reclamation on Fehmarn (dashed white line).

is expected to be loaded into barges and transported to the near-shore reclamation areas where the soil will be unloaded from the barges behind the containment dikes by small BHDs. The proposed trench dredging methodology can be summarised as follows:

- Above MSL -25m:
  - All soil types; dredged by BHDs
- Below MSL -25m:
  - All soil types (except clay-till); dredged by GDs
  - Clay-till; ripped by TSHD dredged by GDs.

The main reasons for choosing the mechanical dredging techniques are:

- The spill when dredging especially the clay-till will be minimised. Spill is defined as the material brought into suspension by the dredging activity and leaving the work zone.
- After dredging with a mechanical dredger, the soil can be transported to the reclamation area with only a minimum amount of water in the barge. Emptying those barges with backhoes and transporting the soil by truck into the reclamation area will not result in any significant spill, after initial construction of a containment dike.
- Boulders can be expected in the clay and two boulder fields have been identified east of Puttgarden with many boulders larger than 1m in diameter. Mechanical dredgers, especially large backhoe dredgers, are not troubled by these boulders, whereas hopper suction dredgers (hydraulic dredgers) cannot remove those boulders and the draghead can even be damaged when hitting a big boulder.
- Another advantage of mechanical excavation, as compared to hydraulic excavation (and hydraulic placement of dredged material), is a more effective use of the reclamation area. Mechanical dredging involves disposal of solids which bulk less than hydraulic slurry does and sedimentation basins are not required when the material is dredged mechanically. Besides, it is possible to construct lower containment dikes for the near-shore reclamation areas because they do not have a water retaining function. Furthermore, it creates a "dry" disposal area that will prove easier to manage and be ready for future landscaping within the shortest possible time.

Creating natural reclamation areas

The reclaimed areas are designed and shaped in such a way that sufficient storage capacity is created while maintaining "zero blockage" of the flow of water.

Dredged material will be used to reclaim and create a natural recreational type of landscape with eroding cliffs, wetlands and beaches – each with a different nature and use. The different areas can be expanded or reduced, and the levels can be changed to provide the best conditions for wildlife and recreational activities.

On the Fehmarn coast (Figure 11) the reclaimed land behind the dike will be landscaped to create an enclosed pasture and grassland habitat. New paths will be provided through this area leading to a vantage point at the top of the hill, with views towards the coastline and beyond. The reclaimed land behind the dike will be landscaped to create an enclosed pasture and grassland habitat.

On Lolland (Figure 12), two reclamation areas will be located, one on either side of the existing ferry harbour. The reclamation areas extend approximately 3.7 km east and 3.5 km west of the harbour and project approximately 500 m beyond the existing coastline into the Fehmarnbelt.

The sea dike along the existing coastline will be largely retained and will continue to function as flood protection for the hinterland. A new dike to a level of +3.00 m will protect the reclamation areas against the sea. To the eastern end of the reclamation, this dike rises as a till cliff to level of +7.00 m. The erosion of the cliff will result in sediment releases during severe storms which will feed the beaches with sand on the east of the reclamation area.

Two new beaches are planned within the reclamation areas. There will also be a lagoon with two openings towards Fehmarnbelt and revetments at the openings to control the amount of wave energy passing into the lagoon area.

Minimising the footprint

The impact on the seabed is minimised by not reclaiming within protected natural habitats.

The reclamation area is designed so that it does not extend beyond the existing ferry harbour at Puttgarden and does not impact the protected area at Grüner Brink. The coast at Marienleuchte to the southeast will be left unaffected. The extent of the proposed reclamation areas at the Lolland coast is shown in Figure 12. Again, these reclamation areas are designed so that they do not extend beyond the existing ferry harbour at Rødbyhavn and do not impact the protected area at Hyllekrog.

Stringent navigational measures

During the construction of the Fehmarnbelt Fixed Link there will be restricted working areas where marine activities will take place. The main offshore construction phases are the dredging of the tunnel trench and the immersion and backfilling operations, and they will be performed in a busy navigation route (T-route), where on an annual basis some 40,000 ships (year 2010) pass through the Fehmarnbelt. Ensuring that the risk of a vessel collision during this temporary situation is reduced to an acceptable minimum is of the utmost importance.

The total period for the dredging operation will be approximately 1.5 years and will take place as a continuous process. One disadvantage of the proposed dredging methodology is that it requires a relatively high number of dredging equipment working in the Fehmarnbelt. Based on the detailed planning of the immersion cycle, the conclusion is that the tunnel elements must be immersed from 2 fronts working from both shore lines towards the inner part of the Fehmarnbelt. The foundation and backfilling operations will run in parallel with the tunnel immersion operations.

The aggregates, sand, gravel and cement, for the concrete production for the tunnel element production site on Lolland will be brought in with 5,000 to 10,000 DWT bulk vessels. Vessels will enter the harbour basin through an access channel.

Measures like a Vessel Traffic System (VTS), well-defined boundaries for working areas, buoys and guard vessel control are included in the design and reduce the risk of a collision to an acceptable level. The channel will be marked by navigation aids. The accessibility of the work harbours is dependent on the weather conditions. Storms will from time to time create downtime for the supply of materials. To improve the accessibility and reduce this downtime temporary breakwaters are foreseen. These breakwaters will be removed after the construction of the tunnel elements.

DESCRIPTION OF ALTERNATIVE DREDGING SOLUTIONS

Although the preferred dredging methodology will be a feasible way to execute the works, it might not be the most economical solution. With an open tender the expectation is that the dredging contractors will also look into other solutions, which might be more economically feasible, taking into consideration the availability of suitable equipment.

Obviously dredging contractors, who avail over backhoe dredgers that can reach a depth of 30 m or more, will only start with ripping after they have reached the maximum depth with their backhoe dredgers. This should be seen as a variation, not an alternative.

Another expectation is that the dredging contractors will look at the expensive elements in the dredging works and try to reduce the costs. The following elements are obviously from that point of view:

- The ripping of the clay till below MSL -25 m with a hopper dredger is a very costly operation, because a hopper dredger is a very expensive piece of equipment and if only used to rip, it is not employed to its full potential. Dredging contractors can be expected to look for ways to either utilise

Figure 12. Extent of the proposed reclamation on Lolland (dashed white lines).

the full potential of the hopper dredger or make a special-built tool to rip the clay-till.
- Monitoring the spill will be a responsibility of the dredging contractor. Lessons learnt from the Øresund Link point out that the monitoring required there led to very high monitoring costs (approximately 10% of the dredging and reclamation project value). Therefore one can anticipate that solutions to reduce the costs of monitoring will be thoroughly considered.

Alternative options for hydraulic dredging

By not only ripping the clay-till but dredging it at the same time as well, hydraulic dredging will make full use of the trailing suction hopper dredger. Transporting this material up through the suction pipe from depths ranging between 25 and 50 m will require a high pumping power and large quantities of water. The fully loaded draft of the hopper dredger (assuming a hopper dredger with a hopper volume in the range of 10,000 – 15,000 m^3) will be in the order of 10 m.

This means that the hopper dredger cannot place its load directly in the reclamation area, but will have to pump it into the reclamation area through a pipeline. A cutter suction dredger is an efficient piece of equipment to dredge harder material like for instance the clay-till. For this project it can only be considered when it can pump the dredged slurry directly into the reclamation area, because hydraulic loading of barges with clay will result in an unacceptably high spill percentage.

If the reclamation area is (partly) filled hydraulically instead of mechanically, measures have to be taken to take care of the discharge water. The fill soil consists mainly of clay with large amounts of silt. As result of the mixing with water, pumping and subsequent transport through a pipeline of several kilometers in length, part of the clay will be dissolved in the water, resulting in very dirty water, with high concentrations of fines.

This discharge water can obviously not be released directly into the surrounding sea, but has to flow through a series of settlement basins in which the fines can be collected.

At the moment the effects of the alternative options for hydraulic dredging and its effects on the environment are under investigation, including the measures which might need to be undertaken for such options.

REMARKS

This article gives an impression of the marine operations and their associated marine equipment spread for the conceptual design of the Fehmarnbelt Fixed Link project. It goes without saying that the contractors are challenged to come with their own construction methods during tendering, of course, within the boundaries which are set in the Contract.

Besides minimising the environmental impact by setting stringent requirements during both construction as well as the operational phase, the project also takes up the opportunity to create added value to the environment.
By using the dredged material from the trench to form and shape reclamation areas, valuable recreational and natural resources will be created.

Coastal zone management is often associated with densely populated areas, but the Fehmarnbelt Fixed Link project will demonstrate the positive contribution of such a large-scale project to the natural system in a rural area.

CONCLUSIONS

The following design features are part of this integrated solution between the project and the environment:
- The reclaimed areas are designed and shaped in such a way that sufficient storage capacity is created while maintaining"zero blockage" of the flow of water in the Fehmarnbelt.
- The impact on the seabed is minimised by not reclaiming within protected natural habitats.
- Dredged material is used to reclaim and create a natural recreational type of landscape with eroding cliffs, wetlands and beaches (building with nature).
- Strict limitations to turbidity caused by dredging activities will be maintained.
- Dredging very hard clay-till will involve some ripping in the deeper parts of the tunnel trench.
- After the dredging activities, the trench will be cleaned from sediments and a gravel bed foundation will be pre-installed using a similar fall-pipe technique as was developed for the Øresund project.
- The tunnel elements will have a length over 200 m and a width of 42.1 m. Two working fronts will immerse 89 tunnel elements in total, which will progress from both shorelines simultaneously towards the central part of the Fehmarnbelt.
- Stringent navigational control will assure safe working areas for the ships to pass through areas where the marine works activities take place.
- The trench will be backfilled with sand and covered up with a rock protection layer up to the current seabed level.

REFERENCES

Lundhus, Peter and Wichmann Matthiessen, Christian (2011). "The Fehmarnbelt Tunnel: Regional Development Perspectives". *Terra et Aqua* 123, June.

"Protocol for the Field Measurement of Sediment Release" (2003). from *Dredgers, Issue 1*, August. Produced for VBKO TASS Project by HR Wallingford Ltd & Dredging Research Ltd.

Van Parys, M. *et al*, (2001). "Environmental monitoring of the dredging and relocation operations in the coastal harbours in Belgium: MOBAG 2000". *Proceedings* WODCON XVI.

Van Putten, E., Andersen, J. and Iversen, C. (2011). "Fehmarnbelt Fixed Link between Continental Europe and Scandinavia – Innovative Technology to Optimise Mechanical Dredging Operations." *Proceedings* CEDA Dredging Days, Rotterdam, The Netherlands.