Expansion of Port Infrastructures

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1. INTRODUCTION

Ports on the Danish North Sea coast were built over the last 150 years to serve as basis for fishery and transport of goods between Denmark and UK and Norway. These ports were all constructed on sandy shores in a dynamic morphological setting. During the recent past the ports have been challenged by new demands for increased activity in other areas than the traditional fishery and related industries. The exploitation of oil and gas resources in the North Sea and development of offshore wind farms require good and safe port infrastructures. Also the increase in handling other commodities and international trade has added to the demand for expansion of the port infrastructures.

The present paper presents the challenges related to expansion of these ports, which were originally planned and constructed for less demanding purposes.

2. COASTAL CHARACTERISTICS OF THE DANISH WEST COAST

This section serves as basis for the descriptions of port infrastructures on the Danish West Coast.

The West Coast of the Danish peninsula Jutland faces the North Sea. The landscape was modelled during the glacial periods when ice covered north Europe. When the ice cover receeded, sand and clay were deposited, and created the low hilly landscape so characteristic for Denmark. Variations of the sea level after the latest glacial period in combination with isostatic rebound formed a number of islands, which today are seen as cliffs at several locations along the coast. Between these, the land increase formed a shallow coastline with bays. Subject to wind, waves and current the coast gradually turned into a mixed littoral cliff and dune coast. Larger bays and lagoons were cut off by naturally formed spits and sandy barriers.

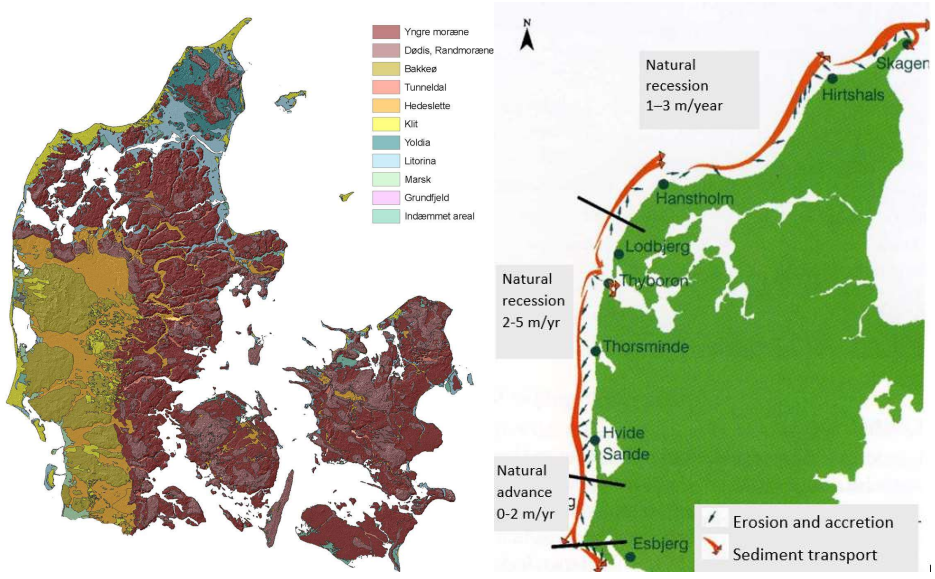

Figure 1: Geological map of Jutland (left) and map of littoral transport along the coast (right)

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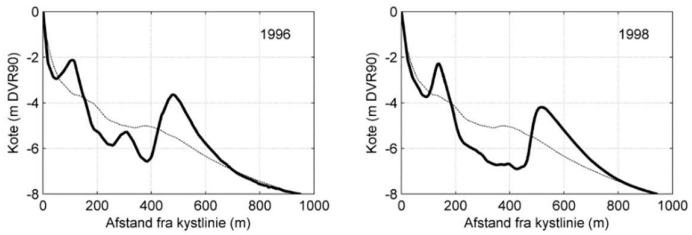

Figure 2: Typical barred profile of the central part of the coast

Over large stretches, the coast is almost linear and due to the strong wave action from the North Sea and resulting littoral transport, there are typically at least two bars along the coast. The 8 m depth contour is typically 900 -1000 m from the shoreline.

The geological map of Denmark, Figure 1, illustrates these features. The coast is in fact suspended between a number of hard points, typically cliffs composed of either hard clay or limestone. Some of the shallow stretches between the cliffs are severely exposed to the dominant west and northwest storms. In one particular location an inlet gives access to a natural waterway, the Limfjord, crossing the northern part of the peninsula.

The southern part of the Danish coast is part of the Wadden Sea, which also covers the coastal zone of Germany and The Netherlands. Here the morphology is governed by high astronomical tides – up to 1.9 m range - and storm surges, whereas the tides at the northern spit of Jutland is only about 0.4 m.

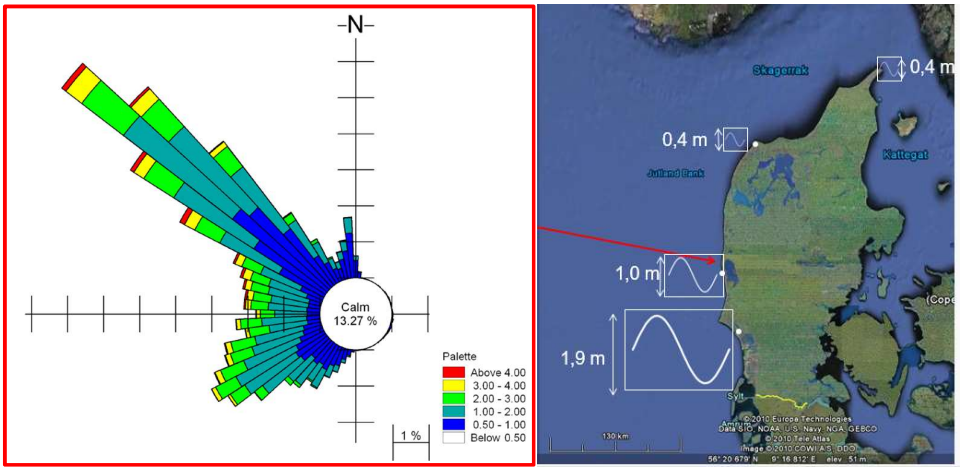

Figure 3: Waves and tides on the Danish West Coast

Winter storms are typically generated by low pressure centers moving over southern Scandinavia and often peaking with waves from northwest as shown by the wave rose above.

3. CHALLENGES FOR PORT DEVELOPMENT ON EXPOSED SANDY COASTS

Planning and construction of ports on exposed sandy coasts must consider the littoral processes, DHI (2017). This is the case for harbours on the open coast as well as for ports in tidal inlets. In most cases the ports and navigation areas need to be protected by breakwaters and sufficient water depths in the port and in the approach area have to be secured by dredging. Dredged channels are subject to sedimentation, thus maintenance dredging will be a continuous effort, FRISCH (1991), MANGOR et al (2010).
Construction of breakwaters impact nearby coastlines. As long as breakwaters are within the littoral zone there is a risk that the port will be buried in sand shortly after its construction. This means that a port needs to have a significant size to be economically viable.

Figure 4: Beach landing of fishing boats at the village of Klitmøller (Cold Hawaii)

It was not – in the first place – a natural consideration for the Danes to build ports on the West Coast. Small fishing communities used to pull their vessels on the beach as seen in Figure 4. Today fishing has ceased in most of these communities. The major part of the population was living on the islands and along the east coast of Jutland. These neighborhoods have good naturally protected sites for ports and harbours to support domestic transport of goods, which to a large extent was by sea. Thus port construction on the West Coast was only considered from late in the19th century as a result of the changed border to Germany after the war in 1864, development of the society and demand for increased international transport of goods, SØRENSEN et al (1996). On the West Coast these challenges were considered and in this paper we will describe how three of the ports were established and developed and how they cope with today's demand for efficient transport infrastructure.

4. OVERVIEW OF DANISH WEST COAST PORTS

The ports on the Danish West Coast can be divided in three types according to the characteristics of the coastal sites – not counting the beach landing places:

- Headland ports, located on the open coast and protected by breakwaters, Hirtshals and Hanstholm.
- Inlet ports at natural inlets or stabilized breaches of lagoon barriers, Thyborøn, Thorsminde and Hvide Sande.
- Tidal region ports, Esbjerg.

Turnover in 2016

Port	Cargo (1000t)	Fish (1000t)
Hirtshals	1718	53
Hanstholm	213	158
Thyborøn	1617	223
Thorsminde	~	1
Hvide Sande	173	43
Esbjerg	4549	~

Figure 5: Ports on the Danish West Coast and their turnover in 2016

The ports of Thorsminde and Hvide Sande are mainly fishing ports whereas the others have a major activity as logistic centres.

All these ports were in 2000-01 transferred from state ownership to independent entities linked to local municipal control. As part of the transfer agreements, the state guarantees minimum depths of approach channels and is responsible for regular maintenance dredging to keep sufficient navigational depth.

Three of the ports are described in details in the following sections as examples of Danish Port expansion over the last century.

5. PORT OF HIRTSHALS

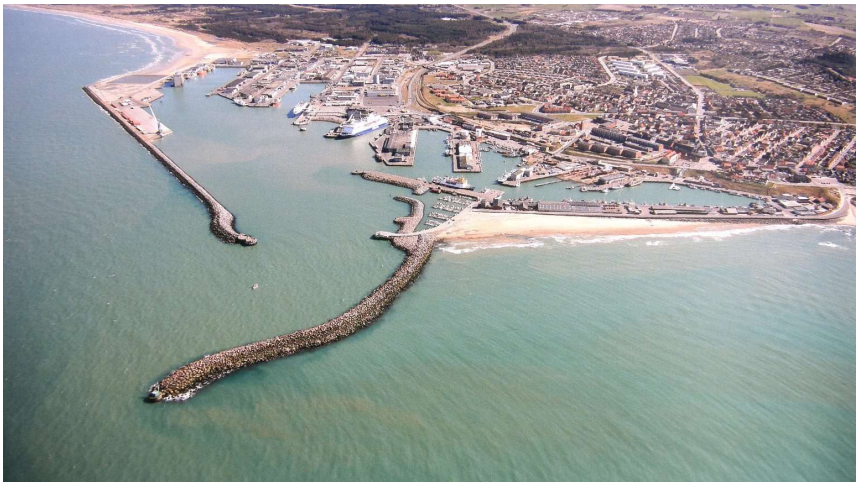

Figure 6: Hirtshals port viewed from the entrance

5.1 The history of Port of Hirtshals

Hirtshals Harbor is built as a fishing port on the shoulder of Jutland, following the thoughts of engineer Jørgen Fibiger's point theory. The harbor is thus built where the coast is strong and not erodible. The original water depth at the entrance was 7 m.

Figure 7: Port of Hirtshals on the northwestern corner of Denmark

Already in 1936, seven years after commissioning in 1929, the first ferry route between Hirtshals and Norway opened, as a number of people saw the possibilities in the port's unique geographic location.

The logical reason for construction of the port when it was planned and built has since evolved into the port's commercial foundation.

From the establishment of the port based on fishing, the port has been through continuous development, and by 2017 transport activities accounted for 70% of the revenue.

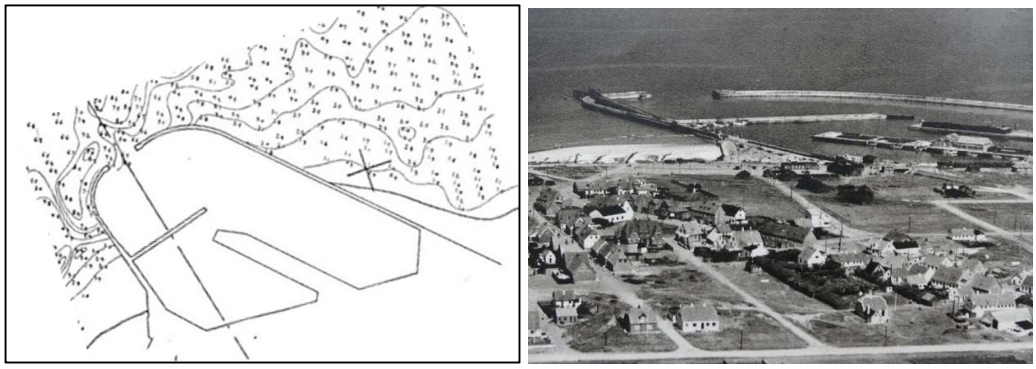

Figure 8: Port of Hirtshals by 1930 – same scale as in Fig. 9

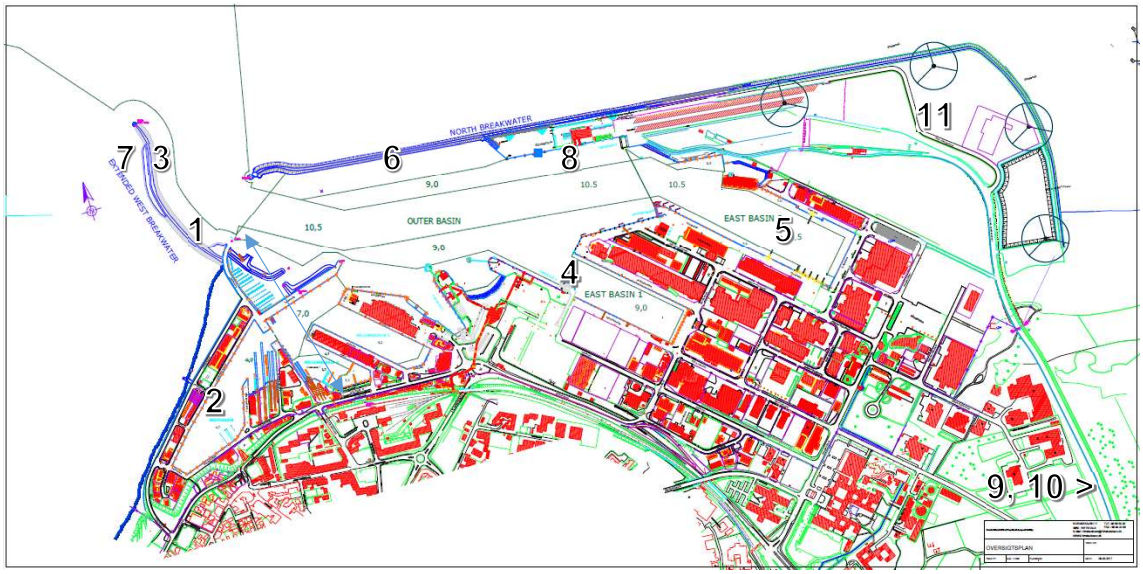

Figure 9: Port of Hirtshals by 2017

Since its inauguration in 1929, the port has been stepwise expanded to keep track of developments. The subsequent developments were typically in response to actual needs of the port. The sedimentation problem in the entrance has been a continuous struggle, BRUUN (1966). To keep the 7 m depth an outer main breakwater extension of 245 m was made and later a further extension to 430 m. Severe storms often result in sudden reductions of the depth, which requires immediate dredging efforts. The relocation of the north breakwater in 1995 was the first strategic move since the building of the port, aiming at a future development towards east.

The following significant construction work has been completed, see Figure 9:

1. The first part of the main breakwater was built in 1937.
2. The first port expansion to the west with a fishery basin in 1959.
3. Extension of the outer breakwater by 185 m in 1974 with the aim to reduce sedimentation in the port entrance.
4. Second expansion was built in 1973 - East Basin 1.
5. Third expansion was built in 1976 - East Basin 2.

6. The north breakwater was relocated in 1995.
7. The outer breakwater has been relocated in 2002-2003 to provide more navigational space.
8. The container berth was built in 2003.
9. New highway connection was built in 2015.
10. Combi-terminal built in 2015.
11. Land expansion established in 2015 - 2017.

Figure 10: The ferry berths in the center of the port area and new combined ferry and container berth along the north breakwater

5.2 Changes of the port use in recent decades

Port of Hirtshals has experienced a continuous development, which means that the activities at the port have increasingly changed the character of fishing towards logistics and transport. Consequently, the port is used by larger ships than originally provided for. The shipping companies that control the regular traffic in the port also adjust to the currently available possibilities, thus approaching the port with as large ships as possible.

Figure 11: Traditional and modern fishing vessels in Port of Hirtshals

With the development that Port of Hirtshals has undergone, there has been a similar investment in infrastructure, while at the same time the perspectives have shifted from the primary port view to a broader perspective focusing on the overall transport system - a multimodal approach that combines all modes of transport.

The port entrance sector was rebuilt in 2002 - 2003 in order to improve the navigational safety.

In 2003 the first new quay (Container wharf) was constructed for about 10 years. The building of the quay opened for container traffic and the traffic has later been shifted to RORO traffic that logically exploits the port's location.

In 2005, the E39 motorway was opened, thus connecting the port to the European motorway network, which strengthened the port's position as a European focal point.

Hirtshals Transport Center was built in the harbor's hinterland in 2011. The transport center operates with the port in relation to road transport services and thus forms a central part of the overall logistics setup in Hirtshals.

The Danish state invested in a combined terminal including railway service in 2015, thus all modalities were connected in Hirtshals and the port position as the intermodal logistics center was finally cemented.

5.3 Challenges and solutions

The challenges relating to ongoing development of the port activities has been the basis for decisions taken about fixed capital investments.

The sedimentation problem traditionally resulting from the port's location on the west coast of Jutland has been solved with traditional maintenance dredging of about 400,000 m^3/year in order to keep a water depth of 10.3 m. So far no initiative has been taken to investigate other methods that can reduce sedimentation significantly. Dredging strategies including proactive dredging on the west side have been tested to counteract sudden water depth reductions during storms.

As a consequence,of the growth of Port of Hirtshals it is necessary to expand the existing port area with emphasis on space for vehicles. Correspondingly, about 10,000 m^2 of fishing industry has been demolished.

Figure 12: All ferry berths in operation

The continued pressure on the need for land and an efficient infrastructure has resulted in an extension of the port with additional land area by 2017.

5.4. The future

Port of Hirtshals and the town of Hirtshals are central to a forward-looking modernization of logistics in Scandinavia, based on efficiency, minimizing climate impact and social impact in Norway by transfer of cargo transport from road to sea. The Port is thus, due to its location, important to the future infrastructure networks in Scandinavia.

The changes that will shape and change logistics in Scandinavia also mean that Port of Hirtshals changes the thinking from "maritime port" to "intermodal logistics center in the heart of Scandinavia". It is a more out-going consideration, and a considerably more complex thinking. To intensify this focus the

Port of Hirtshals has entered collaboration with a number of scandinavian ports, a.o. Kristiansand and Gothenburg, with Zeebrugge in Belgium and with Greenland.

Figure 13: 2017 land reclamation for new marshalling area

The future will lead to construction of local distribution centers and focus on multimodal transport solutions for the industries and logistics companies that will utilize Hirtshals' location in their future developments.

The future will also require improvements of the port access area, so the navigational safety is further improved and the port is accessible for larger vessels under tougher weather conditions. This in order to safeguard the port for future development. This improvement will also be planned with a view to further reduce the sedimentation as much as possible.

Figure 14: Ferry from Norway enters the port

Over the past few years, Port of Hirtshals has increasingly focused on renewable energy and limiting resource consumption. The port has installed solar cells for the production of electricity for the service yard and corresponding measures will be taken in the future.

Within a shorter time horizon the port will initiate actions to obtain an ISO certification in the environmental field in order to optimize resource utilization while implementing an efficiency consideration.

6. PORT OF THYBORØN

Figure 15: Port of Thyborøn

6.1 The history of Port of Thyborøn

Thyborøn Channel was created by a violent breakthrough of the isthmus in 1862, where the North Sea and the Limfjord were connected. Extension of the channel and construction of a port at Thyborøn was decided by the Civil Planning Act in 1914, thus creating the foundation for establishing the port in Thyborøn.

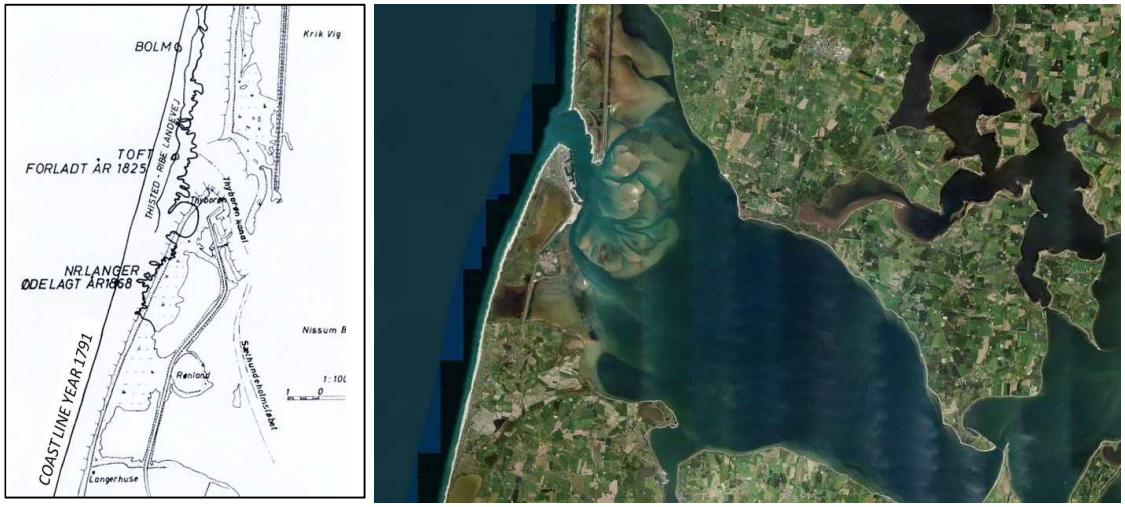

Figure 16: The isthmus at Thyborøn before and after the breakthrough in 1862.

Port of Thyborøn celebrated its 100 years anniversary in 2014. The harbour was founded with a wooden pier and a small wooden breakwater. The basis for the decision was a work carried out by the Third District of the State Coastal Authority. The harbour grew strongly from the start and through the 30's and 40's based on fishing. The development of the harbour remained quiet during the last years of World War II and the following years, as there was doubt about the possibility of keeping the inlet (Thyborøn Canal) open. From the latter half of the 50s and up to 2001, the port had a stable and forward-looking development and is today the third largest fishing port in Denmark

6.2 Changes of port use in recent decades

2001 became a landmark year for Port of Thyborøn. This year, the port went from being a state port to becoming an independent municipal port. Since then, the development has been very fast. The port has grown in turnover, area, water depth and quay structures. Around DKK 400 million has been invested in the port since 2001, and today it is both a fishing and commercial port.

Port of Thyborøn is in a development where other goods than fishing related are becoming more and more important. The harbor is situated with an east-facing entrance to the North Sea, which means that there is good navigational access in all weather conditions.

Port of Thyborøn has several business areas. Fishing still remains a cornerstone. In addition, maritime service companies, sand and gravel and other goods as well as support of offshore activities are important business areas. The port is still expanding with new reclamations and quays, which today allow for a physical separation of the port by business area.

Figure 17: Expansion of Port of Thyborøn towards south 2017.

6.3 Challenges and solutions

The biggest challenge of the port at present is the water depth for access. The guaranteed water depth through the Thyborøn Canal is 8 meters. The Danish state guarantees this depth to the port and 4.5 meters of water depth in the remaining part of the Limfjord until the port of Aalborg. The evolution of the ship tonnage means that the port must increase the water depth to between 9 and 10 meters within a few years.

The inlet is characterized by very dynamic bed conditions. Large sand banks move depending on water level variations and wave directions. In the winter of 2008 waves suddenly reached the port with unusual height as seen in Figure 18. This incident was investigated by DHI using the MIKE21 software tools.

Figure 18: Overtopping of Thyborøn breakwater during northwesterly storm on 06.02.2008.

The investigation demonstrated that a sand bank had developed on the south side of the inlet as shown in Figure 19. This bank caused refraction of the northwesterly waves, which then focused on the port entrance and the outer breakwater as seen Figure 20.

Figure 19: Sand bank development off Thyborøn between 2004 and 2008.

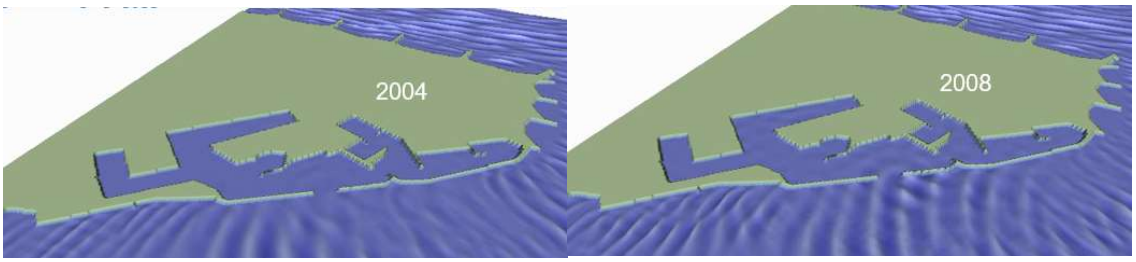

Figure 20: Wave propagation in Thyborøn canal before and after sand bank development.

It is presently expected that the Port of Thyborøn itself will be responsible for the maintenance through the canal to the port entrance. This will provide the basis for deepening to 10 meters of water so that it can be used by larger ships. The limitation of the water depth is a hindrance for both the fishing fleet and the merchant fleet and an increase will be required for the port to maintain its development. By transferring the responsibility of dredging the access, the port will have the opportunity to control the development and is not dependent on the state's desire or priority of maintenance, but can, on the other hand, take action on the problem when it arises. It will be a benefit for the harbour's customers.

This development is of major importance to the whole municipality and region. According to the latest survey, Port of Thyborøn generates 2200 jobs and the revenue from the port of 1.8 billion DKK. Therefore, the whole region takes great interest in the development of the harbor in these years.

6.4 Predicted and planned changes in the future

The Danish ports are still undergoing transformation of both developments in freight routes, ship tonnage development and structural developments throughout the fisheries sector.

Port of Thyborøn continuously works to influence policy makers that set the framework conditions for the sector both nationally and internationally. This effort is through active participation in debates and by inviting politicians to visit the harbour.

In addition, there is a focus on developing both the infrastructure and business processes to meet the customer's needs, driving the development. In the coming years, investments will be in new breakwaters and quays. The port actively engage in quality issues and environmental conditions, for example for unloading protein fish for fish protein industries in Thyborøn and in energy optimisations and digitalisation of many administrative procedures.

The motto in Thyborøn is "we will find out". Customers never get a no, and service companies and other stakeholders around the port cooperate with Port of Thyborøn to solve the wishes and problems to their mutual benefit.

Figure 21: New wind turbines in Thyborøn canal 2017.

7. PORT OF ESBJERG

Figure 22: Port of Esbjerg in 2017. The arrow points at the original triangular dock basin constructed in 1873

7.1 The history of Port of Esbjerg

In 1868 the Danish parliament decided to construct a port at Esbjerg on the west coast of Denmark and at the same time establish a railroad connection between Copenhagen and Esbjerg to meet the demand from the raising agricultural and livestock export to United Kingdom.

The location was selected because of a good natural shelter by the isle of Fanoe, a 4 m deep tidal channel to the sea and the possibility to use high water caused of a tidal range 1.5 m twice a day. At that time there was only a minor village in the neighborhood and a poor road connection.

The local fishermen have until then landed directly on the beaches on the open coast. Shortly after the port was finished in 1874 the fishermen saw the much better opportunities with a harbour and asked for suitable facilities.

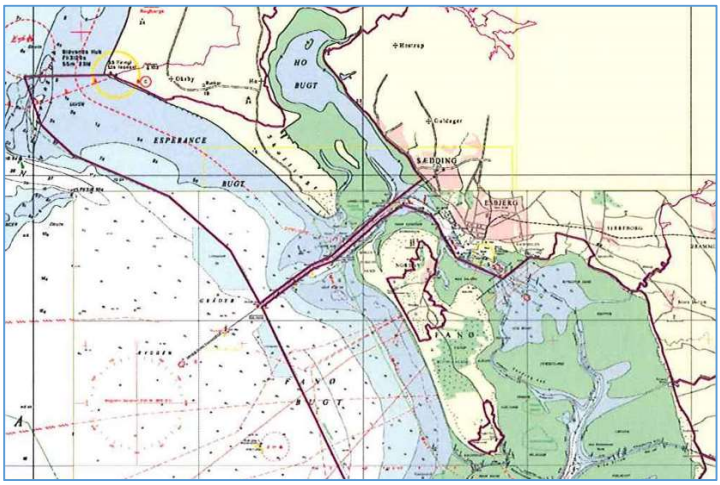

Figure 23: Location of Port of Esbjerg with access channel.
The purple line indicates the NATURA 2000 area of the northern part of Wadden Sea

Since then the port has expanded and has been transformed to suite the demands for general cargo, RO/RO goods, increasing size of fishery vessels (until 2010) and factories, oil and gas activities, export of wind energy components, servicing oil and installations rigs etc.

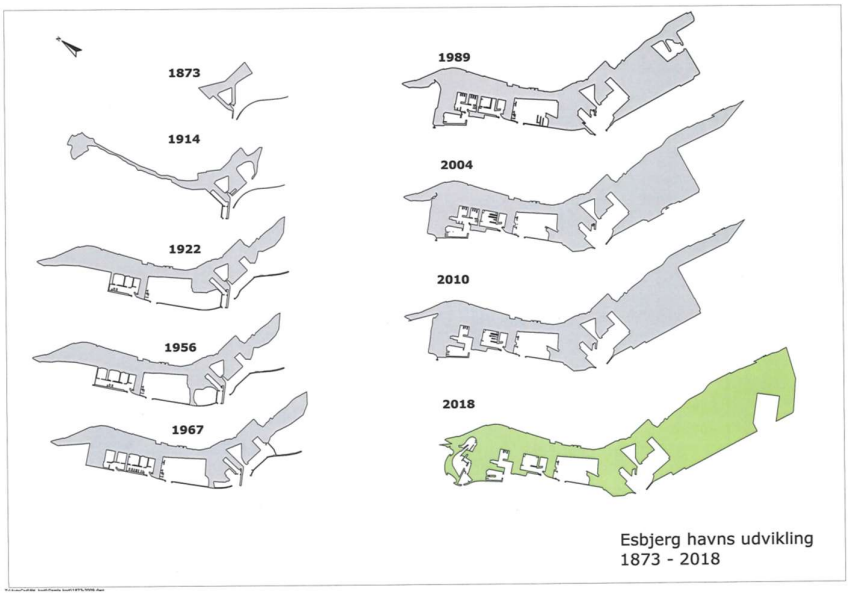

Figure 24: The development of Port of Esbjerg from the initial dock basin in 1873 until today

In 2000 the ownership of the port was transferred from the Danish State to the local Municipality and gave rise to a closer interaction between the city and the port. Anyhow the IMO restrictions (ISPS) in 2004 cut off the easy access to some port areas.

Step-by-step the water depth in the fairway has been increased for accommodation of larger vessels and today a 10 Nm long channel with 10.3 m water depth at Mean Low Water Spring (MLWS) and 200-500 m width leads to 13 km quay side, the harbour area size 4.5 million m^2 and good connection to highway and railroad. The largest vessels arriving in the port today are bulk carriers and RORO vessels with L_{oa} up to 235 m and/or draft 9.5 m and oil rigs and installation vessels with width up to 100 m.
Maintenance dredging is essential and around 1 million m^3 sediment (medium to fine sand from the channel and silt from the basins) must be dredged in the channel and the basins (50/50 distribution) each year to keep the sea chart depths.

The major port activities today are related to RORO import/export of general cargo and servicing offshore oil-, gas- and wind energy installations in the North Sea.

7.2 Changes of port use in recent decades

In 1980 about 700 vessels and the largest fish flour and oil factory in the world was situated in Esbjerg. During the latest 15 years the fishery has stopped in Esbjerg and the fishing fleet and industries have moved to other ports for a number of reasons such as fish quotas, distance to fishing grounds and restructuring of the industries.

Figure 25: Part of the fishing port in 1980

The five former fishing port basins are now used for servicing rigs, shipyard activities, service and crew vessels and as a marina. One basin has been filled to get more berths.

The need for new berths with high carrying capacity and large hinterland areas for the wind turbine industry and RORO handling has increased dramatically. The harbor is extended to the east, the navigation channel is extended, a new turning basin has been established, 1.2 million m^2 hinterland and 3 km new quays have been constructed during the last 10 years.

7.3 Advantages of the location today

The naturally sheltered entrance is still a great advantage, and reduces the need for breakwaters when the port expands.

The connection to the highway system was updated 6 years ago with financial aid from the Trans-European Transport Network (TEN-T) as a Motorway of the Sea project (MoS). The project should and have strengthened and developed a Benelux-Scandinavia short sea connection. As part of the project, the RORO connection between Esbjerg and Zeebrugge was improved by installing a floating RORO ramp and extending the port access road.

Figure 26: Road and railroad connections to Port of Esbjerg

The railroad was electrified from the railway station and a new railway terminal has been located on the port area.

The location of Port of Esbjerg is geographically attractive:

- For servicing the oil- and gas fields in the North Sea
- For export of wind mill components.
- As base for pre-installation and shipping-out of elements for offshore wind parks in the North Sea.

Figure 27: Loading of towers for offshore wind turbines at the new east basin.

During all the years of its existence the port has played a major role for the people of Esbjerg and even today the citizens show a general acceptance, when plans for changes and expansions are in public hearing. More than 10,000 people are employed directly in companies in the port areas. Education can take place on universities and a number of higher education facilities in the city.

7.4 Challenges/ Environmental Concerns:

The expansion possibilities for the Port of Esbjerg are limited, while the port is surrounded by environmentally sensitive areas such as NATURA 2000, a National Park in the Wadden Sea which is

designated as an UNESCO heritage site since 2014, see Figure 23. These environmental restrictions must be taken care of when planning for expansion or change in the activities on land and at sea.

Activities all around the clock sometimes disturb citizens living close to the port. The port captain assigns berths for incoming vessels. Based on expectations and experience specific attention is paid to the impact on neighbourhoods. Since the Port of Esbjerg has avoided residential construction at the port areas, the proximity of the town has not limited the expansion possibilities significantly.

It is difficult to make transport of freight on railroad economically attractive. For environmental reasons the Danish State has decided to improve conditions for transport by rail. However, the size of the country and the flexibility of trucking by road makes railway transport less competitive. This situation may change in the future by introduction of new charges and fees for trucking.

7.5 Ongoing construction works and planning for future demands

Two new ramps for RORO vessels up to 235 m loa and for handling of very long and heavy wind mill components have just been taken in use in the East harbour.

Plans are being implemented for cold ironing (SPS electricity) and more use of renewable energy.

The preparations for a new 1 million m^2 port area and 1 km quay in the east are ongoing. A comprehensive program with hydraulic survey, monitoring and investigations for environmental impact has started and the first phase of the environmental impact assessment is in progress.

In the present planning period (2015-25) it is not intended to deepen the approach channel.

To the North the municipality has taken over a project with marina, a cultural museum and more facilities for the citizens, partly to compensate for the ISPS restrictions in the commercial harbour.

Figure 28: The new marina complex north of the port.

The power plant is using coal today but will change to wood pellets within the coming 7 years. The same quays can be used for unloading, but other cranes and covered silos will be needed.

We try to incorporate much flexibility in our construction, so they can be adapted for future needs.
As an example, the East harbour developed in steps:

- Step 1: Wind mill activities. Strong quays covered with compacted crushed stones.
- Step 2: RORO with hard surface, and possibly
- Step 3: LOLO with mobile or gantry cranes.

To our experience an ongoing revision of a public masterplan is essential, so customers, the local community, etc. are made aware of possibilities and intentions.

To our experience an Environmental Impact Assessment shall be based on a project close in design to the final layout. This process takes time, but a well-prepared plan will usually shorten the time for realization of the project.

The design criteria/parameters increase (e.g. the capacity of the cranes working at the quayside have increased from 80 t in 2004 to 1,000 t today and axel loads on reach stackers from 80 to 160 t), so close contact to users and potential customers is essential during the planning period and detailed design is made “just in time”.

8. CHALLENGES FOR THE FUTURE PORT INFRASTRUCTURES

The ports described above face a number of development challenges due to societal changes and changes in the sectors they are to serve in the future.

- Fishing is concentrated on fewer and larger vessels, which need efficient handling in the ports.
- Increased offshore energy related activities (oil and gas, wind power and other renewables).
- International trade increases with demand for larger ferries and container operations.
- Expanding cruise industry.
- Separation of different port activities.
- Improvements of transport corridors to the hinterland.

The key issue for the ports is to create more space for the operations. This includes i.a. expanding port areas, dredging and reclamation, new and deeper quays and improved navigational access. All of these developments shall respect actual environmental legislation.

References

Bruun, P., (1966). Tidal Inlets and Littoral Drift, University Book Company, Oslo

Frisch, P. Hofmann, (1991). Coastal inlets on the Danish West Coast. PIANC Bulletin 1991, N° 72, pp 52-57

Mangor, Karsten, Brøker, I., Deigaard, R., Grunnet, N., (2010). Bypass Harbours at Littoral Transport Coasts, Paper No.313, PIANC MMX Congress Liverpool 2010.

DHI (2017)., Shoreline Management Guidelines, 4th edition. E-book published by DHI https://www.dhigroup.com/upload/campaigns/shoreline/assets/ShorelineManagementGuidelines_Feb2017-TOC.pdf

Sørensen, T., Fredsøe, J. and Roed Jacobsen, P., (1996). History of coastal engineering in Denmark. *History and heritage of coastal engineering, ASCE*