Technical description for the technical dialogue for the
Storstrøm Bridge project

93200 – Storstrøm Bridge

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Revision 1
NEW STORSTRØM BRIDGE
DESCRIPTION
TECHNICAL DIALOGUE
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1 Introduction

In the autumn of 2011, it became clear that the current Storstrømsbro from 1937 would not be able to withstand the increased goods traffic by rail when Fehmarnbelt Fixed Link opens in 2021. Therefore, in 2011, the Danish Parliament initiated a preliminary study of "Scope for action concerning Storstrømsbro" with a view to mapping out how the railway and road traffic across Storstrømmen can be maintained in the most socio-economic cost-effective manner. The preliminary study, completed in 2012, recommended that the further work concentrated on the construction of a new bridge with a twin-track railway and road and that the existing bridge should be demolished.

With the traffic agreement concluded on 21 March 2013 on "A new Storstrømsbro, Holstebro motorway, etc." between the government (the Danish Social Democrats, the Danish Social-Liberal Party and the Socialist People's Party), the Liberal Party, the Danish People's Party, the Liberal Alliance and the Conservative People's Party, it was decided to build a new Storstrømsbro. The bridge shall be a combined road and twin-track railway bridge with a combined bicycle track and footpath across Storstrømmen between Vordingborg and Orehoved. The old bridge will be demolished as part of the work.
Building of a new combined road and twin-track railway bridge across Storstrømmen will ensure the future capacity of this central railway corridor to Europe. A new combined road and railway bridge will ensure local and regional mobility, which is why it is important to maintain a road link across Storstrømmen in the interest of the local traffic between Falster and Southern Zealand.

Before a proposal can be made for a works act to establish a new Storstrømsbro, an assessment needs to be made of the facility's impact on the environment (EIA). The EIA must be carried out in accordance with the EU EIA Directive. The objective of the EIA is to investigate various proposals for a new Storstrømsbro and to shed light on any related environmental impacts. It is also a key objective that the EIA procedure gives the general public and the authorities an opportunity to make proposals or objections in connection with the project. The preparation for the EIA procedure will be completed during October 2014.

The project generally aims to establish a new road and railway bridge in a new joint alignment across Storstrømmen. The new alignment allows for railway operations with line speed up to 200 km/h.

The existing roads on Masnedø and Falster must be re-routed/rebuilt to be able to maintain traffic internally on Masnedø and Falster.

The Danish Road Directorate has decided to conduct a technical dialogue before issuing the invitation to prequalify for the construction of the bridge. This report provides a description of the bridge and technical information to interested contractors and consultants as a basis for the technical dialogue.

This report was prepared on behalf of the Danish Road Directorate by COWI A/S.
2 Background to the report

2.1 Status September 2014

This revision of the report is the final version for the technical dialogue with interested contractors and consultants. However, sketches, calculations, assumptions, specifications and information, etc. in this revision of the report may be further developed or changed. Possible changes under consideration are described in the report.

2.2 Ongoing and completed activities

The following activities have been conducted or are ongoing:

› Preliminary definition of assumptions and requirements.

› Assessment of foundation conditions and choice of possible foundation methods based on available geotechnical data.

› Performance of and reporting from new geotechnical investigations in the selected bridge line.

› Definition of cross section, alignment and longitudinal profile of road, railway and bicycle track. Choice of preferred bridge types.

› Investigation of the measures required to ensure a 120 years design life without repair or replacement of load-carrying structures.

› Sketch designs of the bridge, including description of possible construction methods.

› Description of drainage conditions.

› Risk screening as precursor of actual risk analyses for the construction and operational phase.
› Preparation of preliminary time schedules and construction cost estimates.

› Assessment of operation and maintenance for selected components.

This technical description is structured as follows:

› Section 3 gives a summary of the solution chosen and the derived conclusions.

› Section 4 describes bridge proposals.

› Section 5 describes the mechanical systems.

› Section 6 outlines proposals for traffic management.

› Section 7 outlines main quantities for the bridge structure.

› Section 8 provides a preliminary overall construction time schedule.
3 Summary

On the north side, the bridge abutment is placed approx. 120 meters into Masnedø to minimise the barrier effect in relation to the protected area around Masnedø Fort. Here, the road lies about 10 metres above the existing ground level.

On the south side, the bridge abutment is placed approx. 400 meters from the coastline, as an embankment is expected to optimise the construction costs.

The bridge has a total length of 3,840 m measured between the abutments. The western railway track lies throughout (almost) the entire length of the bridge in a horizontal radius of 6,200 m, which has been found to be optimum for connection to the existing (and the future Masnedsund bridge for the railway) facilities on both Masnedø and Falster.

At the highest point – above the centre of the navigation channel – the railway lies 33.07 m above mean sea level. This bridge height is determined based on the requirement that the bridge should not restrict the height of the ships more than the existing Farø bridge. Even though the existing Farø bridge does not have a remaining lifespan of 120 years, it is expected to be maintained and repaired. Two navigation spans of each 160 (one-way traffic) will be established.

The navigation spans constitute only 10% of the bridge length, so it is financially desirable to optimise the approach spans. This has led to the selection of a girder bridge in prestressed concrete with an 80-m span length during phase 2. Other spans or possible material choices (steel or composite) may be considered later in the process.

The longitudinal profile of the bridge is a vertical radius of 62,000 m, which runs over the majority of the bridge length and ends up with a maximum gradient of 1.25% at the southern bridge end (a little less at the northern bridge end), which is the normal, maximum permissible gradient for freight trains according to the Danish regulations.

Based on the current knowledge of soil conditions, it is expected that soil improvement using piles under stone beds will be necessary for almost 40% of the foundations, meaning that such a solution has also been investigated.
The effective width of the bridge consists of 12.1 m for the railway and its emergency paths, two traffic lanes of 3.5 m each plus central reserve and edge strips for the road and 2.5 m for the two-way bicycle track with the addition of two railing additions of 0.3 m. Moreover, edge beams and crash barriers will be established between the road and track or railway.
4 Bridge proposals

4.1 Assumptions and requirements

4.1.1 Architectural assumptions

The bridge proposals have been prepared in close cooperation with the architect (Dissing + Weitling) and the landscape architect (Haslov & Kjærgaard), which among others means that the first sketches (phase 1, March 2012) with two independent bridges with two rows of bridge piers have been revised, as it is preferred to have only one bridge pier in each bridge support.

The faceted shape of the bridge piers is partly based on aesthetic wishes and partly justified in a wish to minimise the resistance to water flow and ice loads.

The bridge cross section satisfies the architectural wish for optimum vision for the road users, since the road is elevated to above the height of the rails, meaning that only overhead wire masts, crash barriers and trains will impede vision.

The bridge extends so far into Masnedø that the vertical clearance under the bridge at the abutment is roughly equal to the height of the bridge girder, which the architects considered as a suitable minimum height. To ensure a partly unrestricted view from Masnedø Fort an entire bridge span has been placed on land. The coastal cliff on Masnedø will not be permanently affected by bridge piers. Temporary disturbance of the coastal cliff shall be minimised.

The length of the bridge embankment on Falster is determined based on low water depth and an intervention in Storstrømmen that must not exceed that of the embankment of the existing bridge. From a landscaping point of view the height of the embankment is acceptable and has provisionally been found to be economically optimal, since the highest part of the embankment is cheaper than a corresponding length of the bridge. However, a more detailed comparison between bridge and embankment will be made, when the extent of any soft ground
replacement below the embankment is determined through geotechnical drilling and when the general soil conditions are known.

The bridge construction will be tendered as a design and build contract, in which the tenderers are free to choose construction methods and where they are given a certain degree of freedom with regard to designing the bridge while maintaining the overall, aesthetic expression. These degrees of freedom may for example be related to the choice of span of the approach bridges, since a tenderer may have limited lifting capacity or preferred span for launching girder.

4.1.2 Geometric assumptions

The railway section of the bridge has an effective width of 3.8 + 4.5 + 3.8 = 12.1 m between railings. Due to the horizontal radius of 6,200 m, it is optimum to install each track with a cant of 50 mm at a maximum speed of up to 200 km/h mixed with freight trains with an average speed of 120 km/h, so this has been chosen.

The weight of the track base has been minimised by giving the bridge deck below the track the same cross fall as the track cant (3.33%). This means that the right (south going) track is placed 140 mm higher than the left track. This difference is counterbalanced on land by a minor difference in the alignment of the two tracks.

The road width is 9.0 m between crash barriers as there are two lanes of 3.5 m plus central reserve and marginal strips. With the agreed maximum speed of 80 km/h, there is no requirement for superelevation on the road at the current radius. Still, it has been decided to construct the road with a one-sided cross fall of 2.5% as this is considered to provide optimum driving experience and improve the drivers' view over the railway.

The width of the bicycle track is 2.5 m plus 0.3 m railing addition on both sides, i.e. a total of 3.1 m. The bicycle track is made with the same cross fall as the road, so that rainwater only needs to be collected in one gutter line for road + bicycle track.

One of the preferred solutions – a cable stayed bridge – requires increased distance between road and railway at the pylon, since the optimum solution is to have a single pylon located between road and railway. This is achieved by small changes to the horizontal radius of the road (4,700 m over 397 m length at the pylon and then 9,000 m over the next 198.5 m on either side), while the railway has a 6,200 m radius all the way. The increase of the bridge width will be accommodated in the cantilever under the road, while the box girder and the railway side will remain the same.

The two navigation spans of 160 m each are determined on the basis of available data (AIS data) for ship traffic. They have been verified by simulations of sailing under difficult conditions (wind, current, visibility, other ship traffic). Such simulations have proven highly efficient in the planning of large bridges (Great Belt, Øresund, project for Fehmarn Belt). The simulations have been made using a different type of main spans than those now preferred, meaning that sailing conditions will improve if the cable-stayed bridge is chosen by the Owner, since the
navigation clearance is not reduced towards the piers as was the case in phase 1 and in the simulations.

The northern end of the bridge has been widened slightly since the road and railway are placed in transition curves. The road transition curve goes the furthest into the bridge, approximately 209 m from the bridge end. The bottom and sides of the box girder are unchanged so that the widening is accommodated only in the cantilevered sections.

4.1.3 Load and design assumptions

The bridge will generally be designed in accordance with Eurocodes with corresponding Danish national annexes as well as supplementary rules from the Danish Road Directorate and Rail Net Denmark.

Because of the size of the bridge, a critical review of the entire set of codes of practices is performed as was the case for the Great Belt Bridge, the Oresund Bridge and the project for the Fehmarn Belt bridge. Recommended deviations from the code requirements must be documented but not implemented before they have been approved by the Danish Road Directorate.

A document, “Design Basis - Bridge”, which in its final version will account for all special requirements for the design of the bridge, has been prepared. The document will be prepared in English, as the bridge size requires an international call for tenders. Deviations from Danish and European codes of practice are described in “Background Documents”, which justify the deviations. These documents are recurrently revised when new data become available or the designers find ambiguities.

An example of special requirements is impacts from ships as described in the following, where the codes of practice require a separate investigation for large bridges.

The bridge is designed for ship impacts with magnitude as determined in an ongoing risk analysis. The following preliminary impact forces have been assessed based on general knowledge of ships, sailing the waters and consultant's experience:

- Bridge piers adjacent to navigation spans (3 pcs.): 60 MN (6,000 tonnes)
- Other bridge piers located at a water depth of at least 2 m: 25 MN (2,500 tonnes)
- Bridge superstructure, where the bridge underside is max. 16.00 m: 15 MN (1,500 tonnes)
- Bridge superstructure, where the bridge underside is 16.00 - 20.00 m: 6 MN (600 tonnes)
Bridge superstructure, where the bridge underside is 20.00 - 26.85 m: 1 MN (100 tonnes)

The above-mentioned ship impacts against bridge piers are parallel to the direction of travelling vessels. In the perpendicular direction, half the ship impact is traditionally applied (drifting ship instead of wrongly manoeuvred ship). The 60 MN for the piers of the navigation spans corresponds to collision by one of the largest occurring ships at normal speed.

Acceptance criteria for accident loads in relation to ship impact have yet to be finally settled with the Danish Road Directorate. In the Danish national annex for bridges, the Danish Road Directorate and Rail Net Denmark have initially specified a target safety level of $10^{-7}$ per year, which, in principle, applies to all types of failure, but for accident loads such as ship impacts, other acceptance criteria have been applied so far. During the continued work in phase 3 of the project, this basis will be defined, as it will be of importance for the dimensions of various bridge components.

The different forces against the bridge superstructure are due to the fact that the top of the ships consist of masts with limited strength compared to the strength of the deckhouse, and the top storey of the deckhouse has less strength than two storeys. Above level 26.85, no ship impact against the superstructure is considered, since the ship mast will not be able to pass under the Farø bridge. However, an impact force of 1 MN against the superstructure can under all circumstances be absorbed without problems.

The risk analysis will, among others, include a forecast for the future ship traffic both in regard to size and number.

The assessment of the above ship impact assumes that the sailing direction does not change near the bridge. Any bends will increase the risk of collision with the bridge piers located in continuation of the direction of travel before the bend, since a significant contribution to the risk of collision is due to ships that forget to follow the bend. The greater the risk of collision with a bridge pier, the greater the force it must be designed for.

4.1.4 Environmental assumptions

The environmental conditions to be fulfilled in the construction of the bridge will be determined at the end of the EIA hearing period, January 2015. The material prepared for the EIA procedure will be available shortly in Danish at the home page of the Danish Road Directorate.

4.2 Choice of bridge type

During the initial phase 1 screening of possible links across Storstrømmen, a comparison was made between tunnel and bridge solutions, which clearly was in favour of a bridge solution, meaning that any tunnel proposals will not be considered.
During the early phases, a number of bridge solutions has been investigated, some of which were rejected due to significantly higher construction estimates than the current proposals. This includes a double-deck solution such as the Oresund Bridge and a steel box girder (pure steel solution such as the Great Belt East Bridge).

Some of the reasons why solutions with more or less extensive use of steel were appraised unable to compete are:

› Unfavourable development in the price of steel compared to the price of concrete.

› The foundation conditions in parts of Storstrømmen are considered as reasonably good, yielding that savings in dead weight as rather insignificant. On the contrary, a considerable dead weight is required to be able to withstand ship impacts, meaning that any saved dead weight in the superstructure will in many cases lead to a need for increased weight of foundation or bridge pier.

› Increased spans of approaches that would make steel solutions more competitive do not seem economically advantageous, even where foundation strengthening or actual piled foundations could be used.

4.2.1 Current solutions

The navigation spans constitute only 10% of the bridge length, so it is economically crucial to optimise the approach spans. This led to the selection of a girder bridge in prestressed concrete with a span length of 80 m.

The solutions that have been considered since the beginning of 2014 are:

1 Separate box girders for railway and for road plus bicycle track, one column for each superstructure, but a common foundation (proposal A). This was the solution in phase 1, so it has been used as benchmark, but the other solutions are preferred in terms of aesthetics and price.

2 Separate box girders for railway and for road plus bicycle track, but a joint bridge pier with a pier head (proposal C). Navigation spans with increased girder height towards bridge piers (haunches). Advantages in relation to solution 1: Only one pier that must be designed for ship impact and aesthetically preferred, disadvantage: Complicated tee head.

3 A single box girder under the railway, the carriageway supported on the box and on compression members, struts, from the box bottom (proposal D) or with ribs on the underside of the cantilever (proposal F). Navigation spans with increased girder height at bridge piers (haunches). Advantage in relation to solution 1: Less concrete in the superstructure and bridge piers, disadvantage: Heavier elements.
4. A single box girder with beams under the carriageway. Navigation spans with a constant girder height but supported by stay cables from a centre pylon (proposal E). Advantage and disadvantage in relation to solution 1: As option 3 + aesthetic advantage, but marginally more expensive to construct than 3 + advantage for ship traffic since the navigation clearance is available throughout the span.

The various bridge proposals are described and compared in the report: "Broarkitektur. Fagnotat fase 2" (in Danish), which is available.

4.2.2 Choice of solution
Proposal E can be selected based on:

› Aesthetic considerations.

› Construction costs: Cheaper than proposals A and C and only marginally more expensive than proposals D and F.

Proposal F or D may, however, be preferred based on economic considerations. Both proposals E and F are described in the following. The final choice between these solutions will be made by the bridge Owner, before the start of the tender process.

4.3 Description of the bridge

4.3.1 Bridge design
For reference to drawings, see document 93200-3.10-DWG-3-GEN-00010, revision 1.0 Technical Dialogue, Sample Drawings.

On the north side, the bridge abutment is placed approx. 120 meters into Masnedø to minimise the barrier effect in relation to the protected area around Masnedø Fort. Here, the road lies about 10 metres above the ground level.

On the south side, the bridge abutment is placed approx. 400 meters from the coastline, as an embankment will be established leeward of the embankment of the existing bridge, which is expected to reduce construction costs. When the old bridge has been removed, the blocking of water flow from bridge piers and embankment will be considerably less than today since the new bridge will have fewer, slimmer and more streamlined bridge piers than the old bridge.

With the specified position of the bridge abutments, the bridge will be 3,840 m long. The superstructure is designed as a closed box girder.
The railway track lies throughout (almost) the entire length of the bridge at a horizontal radius of 6,200 m, which has been found to be optimum for connection to existing facilities on both Masnedø (however, future Masnedsund bridge for the railway) and on Falster.

To the north, the road and the railway will be located in transition curves, which will continue onto the bridge. This means that the distance between road and railway is up to approx. 0.5 m larger than normally, but this extra distance decreases to 0 over approximately 209 m. The extra width is accommodated by increasing the cantilevers, so that the box girder remains unchanged. The extension is almost entirely limited to the first two bridge spans, which may be expected to be cast in situ on scaffolding, and therefore complications are limited. For construction methods involving prefabricated elements or launching in situ on formwork girders, complications are also considered to be limited. The transition curves are due to the fact that the distance between road and railway must be reduced from Masnedsundbroen to Storstrømsbroen, which must be done gently.

At the highest point – above the navigation channel – the railway lies 33.07 m above mean sea level. The bridge height is determined based on the requirement that the bridge should not restrict the height of the ships more than the existing Farø bridge. Even though the existing Farø bridge does not have a remaining lifespan of 120 years, it is expected to be maintained and repaired. The vertical clearance at the highest point of the unloaded Farø bridge is 26.85 m. This has also been achieved for the new Storstrømsbro in both navigation spans.

Two navigation spans of each 160 (one-way traffic) shall be established. Simulations have been carried out of sailing using two different markings of the ship route: One in which bends in the ship route before and after the bridge result in a perpendicular intersection with the bridge, and one in which bends are minimised, but the ship route angle with the bridge axis is approx. 75°. Both solutions appeared acceptable in the simulations, but the latter is recommended as the preferred solution.

Since the navigation spans are thus not completely perpendicular to the navigation channel, the effective width of each navigation channel is approximately 142 m. The existing Storstromsbro also has two navigation spans, but they are only 102 and 136 m, respectively, so conditions for the ships will improve when the new bridge is opened and the existing bridge is removed. The simulations have confirmed that the length of the navigation spans of the new bridge is sufficient.

The navigation spans are placed optimally in relation to the existing, preferred ship route, which is determined on the basis of AIS data for ship passages during the period 2006-2013. The longitudinal profile of the bridge is a vertical circle with a radius of 62,000 m, which runs over the majority of the bridge length and ends up with a gradient of 1.09 % at the northern bridge end, 1.25% at the southern bridge end. The gradient of 1.25% is the normal, permissible gradient for freight trains according to the Danish regulations. According to Danish exception rules, the gradient could be somewhat higher, viz. 1.56%, but that has not proven necessary or aesthetically acceptable.
Outside the navigation spans, the bridge spans are 80 m, which is considered to be approximately the optimum span for the selected bridge type. For comparison, the existing Storstrømsbro has 65 m spans outside the navigation spans, which was probably optimum in the 1930s. The bridge piers will be made hollow in reinforced concrete and are mainly expected to be placed directly on foundations, which are also made of reinforced concrete. If proposal D or F is chosen, the two spans next to the navigation spans may be increased from 80 to 110 m for aesthetic reasons.

The foundation level is expected to be at least 1 m below the seabed. Excavations will go deeper, since the foundations are proposed to be placed on a 1.2 m stone layer. Some of the foundations will not be entirely concealed under the seabed, but this has no impact on the water flow since the bridge site is located far from the critical cross section of Storstrømmen. Foundations protruding from the seabed, will, however, be avoided above level -5.0, which is the largest draught for ships in the area, since Grønsund is kept dredged to level -5.0. Similarly foundations on land which protrude above the ground level will be avoided (aesthetic requirement). The foundations consist of a base plate with ribs on the upper side with a total height of typically 4 m. Protruding foundation parts may give rise to turbulence in the water and a related increased risk of erosion. However, the erosion protection is extended to the entire excavation area and is designed accordingly. Large foundations may alternatively be made as closed caissons.

The distance between the two railway tracks is 4250 mm. Along both tracks, emergency paths will be placed at normal platform height and with a width of 800 mm outside the danger zone, which is the first 3000 mm from the centre of the tracks. This width of the emergency paths is under discussion – may be reduced.

The road will have two 3.5 m lanes, a central reserve and edge strips, i.e. a total width of 9.0 m. The two-way bicycle track on the outside of the road (as far away from the trains as possible) will be 2.5 m wide plus 0.3 m for guard rail addition on each side, i.e. a total of 3.1 m. A CE approved crash barrier, type H4b, will be placed between the road and bicycle track.

The bridge width is determined based on Rail Net Denmark’s requirements for 12.1 m between railings for the railway part and the Danish Road Directorate’s requirements for 9.0 m road width and 3.1 m bicycle track width plus necessary widths for railings and crash barriers.

The necessary bridge length of almost 4 km calls for three expansion sections, meaning that expansion joints will be placed at the two bridge abutments and another two at a suitable distance from the navigation spans. Expansion joints on old bridges often cause discomfort to road users due to unevenness and noise; however, these problems can be solved by using relevant options. Expansion joints for the railway are required to be designed in accordance with the Eurocode and UIC rules, i.e. with rail expansion joints, which ensure railway operations in terms of safety and comfort.

Minimising the number of expansion joints is justified partly by operation and maintenance considerations, partly in response to the requirement for low girder
depth (simple supported spans require greater girder depth to achieve sufficient rigidity).

The bridge girder is supported on two bearings on top of each bridge pier; however, it is cast monolithically with the central pylon or bridge pier between the two navigation spans. On bridge piers with expansion joints, four bearings will be installed, two for each girder, so that the girders can move independently. The pier dimensions must respect the size of the bearings, and they must also be designed so that temporary jacks can be located in such a way that bearing replacement can be carried out from the top of the piers. For aesthetical reasons all pier tops will have the same dimensions even though some reduction was possible for piers without expansion joint.

4.3.2 Foundation

The following describes the foundation types, which are used in the static calculations; however, the contractor may choose other methods. For example, some contractors may prefer to build foundations on moderate water depths in situ within sheet piles and lowered ground water.

Where direct foundation is possible, a 0.8 m thick layer of compacted stone is placed in the excavation for the foundation followed by a 0.4 m un-compacted stone layer (to ensure a close to even distribution of pressure between and foundation and base).

Based on the current knowledge of soil conditions, it is expected that piled foundations are required for almost 40% of the bridge piers, meaning that this solution has also been investigated. The preferred solution is steel or reinforced concrete piles with their top in the stone cushion described above. The piles reduce bridge settlements to the same level as with direct foundation; they contribute to absorbing horizontal forces (ship impacts) and a complicated joint between piles and foundation is avoided.

Depending on the required footprint of the foundation, either a hollow caisson or a solid base plate with ribs will be chosen.

The upper part of a foundation is permitted to protrude above the seabed, but not above the water or ground level. However, it is also a requirement that a ship with maximum draught of 5.0 m must not be able to collide with a protruding foundation.

4.3.3 Bridge piers

On top, the piers are rectangular, but faceted, meaning that they are almost diamond-shaped at the bottom and fixed in the foundations. All bridge piers are hollow with wall thickness of about 500 mm. To the extent found necessary the bridge piers will be filled with sand, mass concrete or other infill material to increase the resistance against ship impact.
4.3.4 Abutments

The design of abutments is currently being considered, since many aspects in respect of adaptation to the surrounding terrain and the bridge main design impact on their design.

4.3.5 Superstructure

The bridge superstructure is expected to be a concrete box with longitudinal prestressing cables. In addition, ribs are expected to be prestressed in the transverse direction.

4.3.6 Bridge equipment

Expansion joints

The bridge will be divided into three expansion sections to absorb movements in the longitudinal direction due to temperature changes, creep and shrinkage in the concrete. The movement of each expansion joint can be up to ±500 mm.

The expansion joints of the railway are combined with rail expansion joints.

The road expansion joints must be constructed using noise reducing measures.

Bridge bearings

The central expansion section will be fixed in the bridge longitudinal direction by casting together with the pylon (proposal E) or the centre pier (proposal D or F), while the two other expansion sections will be held by fixed bearings on one to three bridge piers. All other bearings are sliding bearings in the longitudinal direction, while one bearing per bridge pier is fixed in the transverse direction to absorb wind loads and loads from ship collisions.

The bearings must be POT bearings or spherical bearings.

Buffers

It may be advantageous to place buffers in the two inner expansion joints so that longitudinal forces (braking forces) can be transferred from one expansion section to the next.

Waterproofing and surfacing

The following structure is expected for the road. However, alternatives are being investigated such as e.g. thin pavement with synthetic binder:

- Waterproofing type IVa in accordance with rules of the Danish Road Directorate
- 20 mm drainage course, open graded asphalt concrete (ÅAB)
- 50 mm base course, asphalt concrete (ABM) type c
- 40 mm wearing course, asphalt concrete AB

Total 115 mm.
Asphalt surfacing is made with a noise reducing wearing course.

On the bicycle track, the same structure as above or a thin pavement with synthetic binder, which also serve as waterproofing, will be used.

**Railway tracks**

Below the railway, waterproofing type IVa as above plus 200 mm protective concrete is expected to be used. A slab track solution with the rails fastened in the protective concrete (not in the structural concrete) has been decided.

**Crash barriers and railings**

Between the road and the bicycle track, a CE approved crash barrier, type H4b, possibly with horizontal bars on the side facing the bicycle track, will be placed. The crash barrier can be removed in sections, so that the bicycle track can be used as carriageway during major repair works such as replacement of waterproofing and asphalt. When the track is included, a New Jersey crash barrier will be placed in front of the track railings, an appropriately low speed limit will be introduced and special transports will be prohibited.

A CE approved crash barrier, type H4b, possibly with filling-in on the side facing the railway, will be placed between the road and the railway. At the pylon (proposal E), the crash barrier beams will be placed up against the pylon which prevents the normal deflection of the crash barrier.

In case of a massive collision with one of these crash barriers, their posts and beams will get a permanent deflection which reduces the width of the bicycle track or the railway emergency path. Therefore, additional sections of these crash barriers can be stored next to the bridge to allow deformed crash barriers to be replaced quickly, possibly within one working day.

Railings will be mounted on the outside of the bicycle track and railway emergency path.

All steel for crash barriers and railings is expected to be hot-dip galvanised.

**Lighting**

Lighting of the bicycle track will be installed in the handrail. Any lighting of the railway emergency paths has not been settled. Otherwise, lighting is not provided for the bridge users in accordance with the general practice in Denmark for bridges outside urban areas.

The navigation spans are illuminated due to ship traffic; the proposal must be approved by the Danish Maritime Authority. Aesthetic lighting of bridge piers and bridge superstructure may also be considered.

Inside the box girder, orientation lighting and outlets for floodlights for operation and maintenance will be placed.
Installations
A number of possible installations have been identified and are being discussed. This applies, for instance, to monitoring of the behaviour of the structure, recording of weather data (for e.g. warning of slippery roads) and monorail transport inside the box girder.

4.3.7 Materials
The following material parameters are applied:

Concrete:
- Environmental class: A or E
- Strength class: 40 MPa (however, 50 MPa in pylon and possibly in super structure)
- Control class: Strict
- Aggregate size: Max. 32 mm.

Reinforcement: B500

Cable steel, stay cables and prestressing: Quality 1860 / 1680, low relaxation.

4.3.8 Durability
The bridge must have a design service life of 120 years with normal maintenance, but without replacement of load carrying structures. This requirement necessitates additional measures on top of the normal standard for railway/motorway bridges in Denmark. This requires a carefully considered approach to durability and maintenance strategy for the structure. It may, among other things, be investigated whether it will be advantageous to use stainless steel in particularly exposed structural elements (edge beams and splash zone in bridge piers), increased concrete density, increased concrete cover and / or preparation for cathodic protection.

At a later phase, an Operation and Maintenance Manual will be prepared, which will describe the scope and frequency of inspections and expected design life of components with less than 120 year design service life (mechanical and electrical installations, bearings, expansion joints, crash barriers, railings, waterproofing and surfacing). This manual will also include instructions for replacement of components with less than 120 year design service life, including restrictions for the traffic during their replacement and requirements for access to inspect and repair plus evacuation of personnel. Completion of the manual may require contributions from the suppliers of these components and from the Danish Working Environment Authority and the emergency services.
4.4 Construction methods
The following provides a short description of the construction methods, space requirements and means of access that are expected to be used for the construction of the bridge.

4.4.1 Space requirements
In addition to the areas for the permanent structure, the construction site areas on both sides of Storstrømmen will typically include storage site for materials and equipment, office and crew facilities and possibly a concrete batching plant.

The work sites should be situated in accordance with local conditions; their space requirements depend on the selected construction method.

It is expected that many structural elements will be prefabricated on land at some distance from the bridge site. Ten local authorities have submitted proposals to the Danish Road Directorate on areas that can be made available, and discussions with these local authorities have commenced to find the optimum solutions with respect to environmental approval, price, flexibility, etc. The preferred location is Nakskov harbour.

If both substructure and superstructure for the bridge are prefabricated on such a work site, the space requirement at each bridge end is expected to be limited to 10,000 m². It is expected that parts of the bridge will be cast in situ, including abutments, selected foundations, piers, navigation spans and bridge spans partly or fully on land. Moreover, a further need for a work site of 10,000 m² in the vicinity of the bridge alignment for concrete batching plant, etc. should be expected. This area should be situated next to a quay for shipping of materials and the Contractors work force.

4.4.2 Means of access
It is expected that the contractor will use existing roads to the widest possible extent while observing the general traffic rules, but also construct temporary roads from Masnedundsbroen and from Storstrømsvej, probably within the permanently expropriated areas.

4.4.3 Dredging of temporary channel
Masnedø Kalv is a shallow area in the bridge alignment with a water depth of approx. 2 m, which is insufficient for the excavation for foundations or for transport of bridge elements (foundations, possible pier shafts and possibly superstructure in span long elements). It is therefore expected – depending on the construction method – that a channel must be established along the bridge line with a width of approx. 80-100 meters and to a depth of 3 or 5-6 m depending on whether transport is made using flat-bottomed barges or a floating crane.
The bridge site is located near a Natura 2000 protected area and therefore it is necessary to limit the spill from dredging to avoid adverse effects to the protected area.

### 4.4.4 Foundation and bridge piers

#### General

The foundation dimensions will vary depending on the water depth at their location, since a low water depth results in small forces from ship impact and thus small foundations. The largest foundations for the main bridge are expected to be carried out as hollow caissons, while smaller foundations are expected to be carried out as concrete slabs braced with ribs on the upper side. Most foundations are expected to be prefabricated on land with a sufficient length of the pier shaft to allow the further work with the bridge pier to be carried out under dry conditions in the bridge alignment. This means that the caisson will be too heavy to be able to float. Transport to the bridge site will probably take place on a barge if the casting site is far from the bridge line or with a floating crane if it is located near the bridge site. A solution, in which the foundation is transported suspended between two connected barges, may also be considered.

The foundations are expected to be put in place by a floating crane or, alternatively, lowered from a position between two barges.

The foundations for the main bridge are expected to be prefabricated in a dry dock. The base slab and the walls of the caisson are cast in an existing dry dock followed by erection of a steel cofferdam. The dry dock is then flooded and the caisson is towed to the bridge site where the caisson construction is completed and the lower part of the pylon is cast inside the cofferdam in floating condition. Then the caisson is lowered down to the gravel pad by ballasting and the cofferdam is removed.

All foundations will be placed at a depth to avoid ship impacts on the foundation itself. At moderate water depths this means that the upper side of the foundations cannot exceed level -5m. At shallow water depths, the upper side of the foundations will be placed level with the existing seabed or deeper if this is a better option.

Foundations on land or in less than 1.0 m of water are expected to be cast in situ in a dried excavation pit surrounded by sheet walls, which will require temporary lowering of the groundwater.

#### Direct foundation

In connection with direct foundation, foundations are expected to be placed on competent soil 2-5 m under the seabed. Any related dredging will be carried out to the required level, after which an approx. 1.2 m thick layer of stone bed will be placed. The stone layer will typically be placed in two layers: a lower layer of approx. 0.8 m which is compacted and an upper layer of approx. 0.4 m, which is not compacted. This combination ensures optimum transfer of load to the
underlying competent soil layers, while achieving a certain load distributing effect through compaction of the stone layer.

The upper layer may alternatively be established by injecting mortar.

Foundation strengthening by piled inclusion in the soil strata
For this type of foundations, driven steel piles with a typical diameter of 1.5 to 2.0 m or rectangular concrete piles with side lengths of approx. 400 - 500 mm, will be used. The piles are expected to terminate in the stone layer, meaning that a fixed connection between piles and foundation is avoided; this allows the piling to have similar stiffness as a direct foundation. This solution is known from the Rion-Antirion bridge in Greece and the Izmit bridge in Turkey.

If more detailed knowledge of the geotechnical conditions renders hard piled foundation necessary, the actual pile driving can alternatively be carried out using a template to ensure correct global and mutual location of piles. The foundations are in this case expected to be cast on land as hollow caissons that are lowered on the driven piles. Then, a temporary casing will be installed and fixed to the driven piles. A bottom plug will be cast and the casing will be pumped dry. Then, the rest of the foundation and pier shaft can be established under dry conditions.

Bridge piers
The pier shafts above the waterline can either be prefabricated and transported as above or cast in situ in 4 to 5 m long sections. The suggested time schedule is based on casting in situ, partly because it is the most time-consuming method, partly because the relatively short bridge piers allow rational working routines and prevent a possible quality problem of in situ casting of the gap between the two prefabricated parts.

4.4.5 Superstructure of approach bridges
The following provides a brief description of the most likely methods of constructing the superstructure of the approach bridges if made in post tensioned concrete:

› Prefabrication in span long elements
› Prefabricated segments with launching girder
› In situ casting with launching girder
› Incremental launching from bridge ends

Prefabrication in span long elements
In this case, e.g. 80 m long elements will be cast on land and prestressed (probably with cast in cables) to prevent detrimental cracks in concrete during transport and erection. Casting together with the previously completed part of the bridge is preferably achieved at a distance from the pier (2.5 - 15 m from the pier, 2.5 m is assumed in the following).
Transport to the bridge site may for example take place on a barge. The barge could be equipped with jacking towers for lifting the girder up to the final level at the bridge site for placing the girder on supports on the completed bridge element and on the next bridge pier. See illustration below. Alternatively, the girder could be lifted from the barge and erected with floating cranes.
The construction is preferably started on land, meaning that the first two spans on Masnedø probably is cast on site on conventional scaffolding. On Falster, the first element can be 82.5 m long to achieve the normal location of the casting to the next element. Similarly, the first element after an expansion joint can be 82.5 m long, making the last element up to the joint 77.5 m long.

The casting together of elements is made over a length of approx. 1 m to allow reinforcement to overlap. After hardening of the casting, supplementary prestressing cables will be tensioned.

The method is the fastest of the above-mentioned methods, as – even when taking days lost due to bad weather into account – spans can be erected every third day, or one span per week, if the same equipment is used to place foundations, pier shafts and bridge spans. Foundations and bridge spans are produced at a rate corresponding to one foundation and one bridge span per two weeks, and the erection of the elements is done continuously, meaning that the storage space required for finished elements is limited.

**Prefabricated segments with launching girder**

In this method the bridge girder is made in 3-8 m long segments on a separate work site and is transported to the bridge site on a barge. At the bridge site, the segments are assembled to an 80 m section by gluing, while they are supported by a launching girder. This may either be underslung and supported on two bridge piers or overhead so that it moves forward on the already finished bridge and is supported on a temporary tower on the next bridge pier. After gluing of all segments to form a span, it is prestressed using cast-in or external prestressing cables and the launching girder is pushed one span forward. An 80 m section should normally start and end 10 to 15 m from a bridge pier.

All approach spans are made using this method. Whether it is most expedient that the launching girder is assembled on water or on land is up to the contractor to decide.

Gluing between segments serves only to ensure water tightness of the joint, since the prestressing must ensure that the joint is always under pressure. Transfer of shear forces in the joint is ensured by toothing, since each segment is match-cast against the previous segment (with an appropriate adhesive-breaking layer), so that it is ensured that the toothings match.

The segments are expected to be transported on a barge to the bridge site where they can be hoisted into place on an underslung launching girder by a floating crane or be hoisted into place by a crane on an overhead launching girder. Alternatively, the segments can be transported along the finished part of the bridge to the launching girder.

Following a learning period, it is expected that a span can be made in the course of approx. 2 weeks, so it should be possible to use the same launching girder for the northern and southern approach spans.
In situ casting on movable scaffolding system

In this method, the bridge girder is cast section by section on a scaffolding girder, which is supported by two bridge piers or their foundations. After the completion of a section, including prestressing, the scaffolding girder (which is provided with a long nose that can extend to the next bridge pier) is moved with the external form forward and brought into position for the next section, then reinforcement for the base plate and "vertical" members are put in place before the internal form is moved one section forward. As with the previous method, the section length is 80 m, and each section starts and ends 10 to 15 m from a bridge pier.

Casting of the bridge girder may preferably done in two steps: First the bottom slab and webs are cast, then the top slab is reinforced and cast. Construction is likely to start at the bridge end and work out towards the navigation spans. The materials, i.e. reinforcement and concrete, may in that case be transported from land to the casting site via the completed part of the bridge. All approach spans can be made using this method.

Compared with the other methods, this method is relatively slow since each span is estimated to take 4 - 6 weeks, meaning that work will probably have to be done from both bridge ends at the same time. The significant difference between shortest and longest time per span is due to variations from contractor to contractor with regard to prefabrication of large reinforcement meshes or on-site reinforcement work. It should be mentioned that some contractors will likely be able to accelerate this method further than specified above.

Incremental launching from bridge ends

Incremental launching is performed by establishing a factory like work site behind the abutment. When a suitable long section is complete, the entire superstructure is pushed one section forward so that the next section can be cast in the same place. This launching motion is done using jacks and temporary sliding bearings on all pier tops.

In order to reduce the load in the cantilevered end of the girder during launching, the front of the girder must normally be fitted with a cantilevered, relatively light steel structure, a so-called launching nose. One problem with this method is that the girder is exposed to varying moments during launching, which requires considerable, central prestressing, and probably also a temporary support placed in each span.

This method allows rational and industrialised manufacture without the use of scaffolding, but the temporary measures (increased prestressing and temporary supports) can prove too expensive. Otherwise, the longitudinal profile and alignment of the bridge are suitable for the method, as it becomes complicated without a constant radius (or straight line) throughout the course. With a constant horizontal radius as on Ny Storstrømsbro, a segment fits just as well during launching as in the finished situation. The combination of a straight line (with up to 1.25% gradient) and a vertical radius of 62,000 m offers a minor complication during launching, since the temporary bearings on some of the bridge piers may
need to be adjusted in height to follow the rounding. The method can be applied from both bridge ends, except the navigation spans.

4.4.6 Superstructure of the navigation spans (proposal E)
The superstructure starts at the pylon, and work moves symmetrically to both sides, probably with in situ casting in 4-6 m long segments. Especially if the approach spans are constructed from precast segments, this method can also be applied for the navigation spans. After hardening of a segment, prestressing is applied and a stay cable is fitted to prevent any harmful cracking caused by the weight of the next segments. The segment length will typically equal the distance between anchors of stay cables. However, the half segment length can sometimes be used, meaning that only one stay cable is tensioned for every second segment.

In any case, the pylon must be designed for impacts during the construction phase where it is unavoidable that there is one more segment on one side than on the other. This method has been used in many projects, so rules are set for how to handle the lack of balance and the accident mentioned safely during the project.

Each stay cable ends at a cross beam in the box girder; the vertical component of the cable force is transferred to the two webs in the box through a steel truss (or, alternatively, through a high cross beam in concrete). In the pylon, the horizontal component of the cable forces is transferred through a cast-in steel box (or, alternatively, by means of horizontal prestressing cables or rods).

4.4.7 Superstructure of the navigation spans (proposal D or F)
Work progresses symmetrically from each of the three bridge piers, probably with in-situ casting in 3-6 m long segments. Alternatively, precast segments may be glued together, which is the natural choice, if the approach bridges are made of prefabricated segments; see above. After hardening of a segment, prestressing is applied to prevent any harmful cracking caused by the weight of the next segments.

With regard to lack of balance during launching from a bridge pier and the potential risks of the method, conditions are the same as described above for the cable stayed bridge.

4.5 Operation and maintenance
Access for inspection of bearings and expansion joints at the abutments will be established. From this point, access will be provided to the inside of the box girder through a manhole in the bridge girder end diaphragm.

At the other expansion joints of the bridge, external access is provided for inspection of bearings and expansion joints and to the inside of the box girder.
Above each bridge pier, the box girder is provided with a transverse diaphragm with a manhole.

From the inside of the box girder a manhole is located at each bridge pier in the base slab, which gives access to inspection of the pier top and its bearings. Similarly, a manhole will be located in the pier top, providing access to a ladder with platforms for each 5 m for inspection of the internal surfaces of the bridge pier.

Access to the top of the pylon and cable anchors in the pylon (option E) is expected to be provided by an internal lift.

Access conditions for inspection and maintenance will be further detailed in a manual for operation and maintenance, which will be prepared at a later stage. Details to be agreed with the Danish Working Environment Authority and the emergency services. Reference is also made to section 10, Health and safety at work.
5  Mechanical systems, including drainage

Mechanical systems on the bridge comprise bearings, expansion joints, possible buffers, possible dehumidification systems and drainage system.

Bridge gullies are cast in the bridge deck gutter lines at a spacing adjusted to the width of the catchment area from which they collect water and at a reduced distance in areas where the bridge longitudinal slope (in and around the navigation spans) is less than 0.5%. In such areas, artificial slope is established in the depth lines towards the gullies.

The bridge gullies are fitted with pipes that lead to the underside of the bridge deck and allow discharge into into Storstrømmen. Close to land, it is considered to collect water from the bridge drains in a collector pipe, which is led to a sedimentation basin on land.
6 Traffic management

Traffic management will not be established during the construction phase or at the start of the operational phase.

If it becomes necessary to close the bridge, for example due to high wind speeds, the approach to the bridge will be closed by the police. Alternatively, barriers at the abutments will be established, which can be remotely controlled to stop traffic entering the bridge. The latter solution is currently used at the existing Storstrømsbro.

Simulations of ship traffic in the permanent situation – after demolition of the existing bridge – have been conducted. During the period when both bridges stand in the way of the ships, extra marking of the ship route, compulsory pilotage or requirement for reduced speed are being considered. A VTS (Vessel Traffic Surveillance) system is not expected to be introduced.
7 Main quantities

The following indicative main quantities have been assessed for superstructures, pier shafts and foundations together. Quantities for piles are not included and will be assessed later during phase 3 when the geotechnical studies in the bridge line are complete.

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<th>Unit</th>
<th>Cable-stayed bridge</th>
<th>Girder bridge</th>
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<td>Total concrete</td>
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<tr>
<td>Dredging of access channels</td>
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</table>

Note to quantities as at September 2014

The main quantities are assessed based on relatively detailed calculations for a solution with span elements cast on a launching girder.
8 Construction time schedules

Provisional time schedules for option E and F have been set out below, since a detailed, realistic time schedule for the bridge cannot be prepared at present due to lack of knowledge of:

› Division into lots. It is assumed that the bridge contractor is to complete the road and bicycle track facility but not the railway track system. It is envisaged that other contracts establish the track system, signal and catenary systems.

› Contractor’s preferred working methods. As described in section 4.4, significant differences in the work pace may occur depending on the choice between prefabrication and casting in situ. The current time schedules assume prefabrication of foundations and span long elements for the approach bridges, but in situ casting of the pier shafts and the two navigation spans as well as the two northern spans on Masnedø.

› Choice of work site for prefabrication and scope of preparatory works on this site before the bridge contractor starts work.

› Time of year for the commissioning of works. Downtime due to bad weather mainly occurs during autumn and winter, but has been evened out over the whole year in the time schedules.

› Requirement from Energinet Denmark about late start of activities off Masnedø to allow for the relocation of submarine cables. It has been assumed that Energinet Denmark will need so long a time for this activity so the bridge contractor shall start from the southern end.

The following two pages show a provisional time schedule based on the cable stayed bridge with a high degree of prefabrication, followed by the girder bridge solution.
NEW STORSTRØM BRIDGE – DESCRIPTION - TECHNICAL DIALOGUE

Planning with start on Falster
Cable stayed bridge

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<td>Moving of high voltage cables</td>
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<td>Local roads on Masnedø</td>
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<td>Construction of ramp on Masnedø</td>
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</table>

Masnedø Bridge span

- Construction of temporary access channel
- In-situ casting of bridge girder
- Erection of bridge girder
- Installation of bridge equipment
- Construction of peninsula and driving of sheet piles
- Excavation for foundations and construction of gravel pads
- In-situ casting of foundations and pile shafts/abutments
- Erection of prefabricated foundations
- In-situ casting of pile shafts and pylons
- Backfill and scour protection at foundations
- Construction of containment dike for ramp
- Construction of road to abutment
- New structure, Storstrømvej
- Construction of new Storstrømvej
- Temporary diversion of traffic to new Storstrømvej
- Construction of ramp on Falster

Removal of top soil for new structure
Removal of soft soil near the coast
Removal of soft soil near the coast
Construction of containment dike for ramp

**NEW STORSTRØM BRIDGE – DESCRIPTION - TECHNICAL DIALOGUE**

**Planning with start on Falster**

Haunched girder bridge

**Signing of contract**

Opening of the bridge

- Detailed design. Foundations near Falster and Masnedø.
- Mobilising
- Design and procurement of equipment
- Preparation of production site
- Prefabrication of foundations
- Prefabrication of bridge girder
- Moving of high voltage cables
- Cleaning of the construction site

- Removal of top soil for new structure
- New structure. Viaduktvej
- Local roads on Masnedø

**Temporary diversion of traffic to Viaduktvej**

**Construction of ramp on Masnedø**

- Masnedø Bridge span
  - Span 23 80
  - Span 22 80
  - Span 21 80
  - Span 20 80
  - Span 19 80
  - Span 18 80
  - Span 17 80
  - Span 16 80
  - Span 15 80
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  - Span 11 80
  - Span 10 80
  - Span 9 80
  - Span 8 80
  - Span 7 80
  - Span 6 80
  - Span 5 80
  - Span 4 80
  - Span 3 80
  - Span 2 80
  - Span 1 160

- Falster 3840

- Removal of top soil for new structure
- Removal of fill soil near the coast
- Construction of containment dike for ramp
- Construction of road to abutment

- New structure. Storstrømsvej
- Construction of new Storstrømsvej

**Temporary diversion of traffic to new Storstrømsvej**

**Construction of ramp on Falster**

**Dredging of temporary access channel**

**In-situ casting of bridge girder**

**Erection of bridge girder**

**Installation of bridge equipment**

**Excavation for foundations and construction of gravel pads**

**In-situ casting of foundations and pile shafts/abutments**

**Erection of prefabricated foundations**

**In-situ casting of pile shafts**

**Backfill and scour protection at foundations**

**Construction of peninsula and driving of sheet piles**

**Excavation for foundations and construction of gravel pads**

**In-situ casting of foundations and pile shafts/abutments**

**Erection of prefabricated foundations**

**In-situ casting of pile shafts**

**Backfill and scour protection at foundations**
The time schedules show that:

› a temporary peninsula at Masnedø is expected to be established so that the first bridge foundation on water can be cast in situ and the embankment can be used as foundation for scaffolding for the casting of span no. 22 in the time schedule

› casting of the northernmost bridge spans on the scaffolding is not critical in terms of time since erection of bridge spans from the seaside can be started independently of span no. 23. Only span no. 22 must be completed before erection starts from the seaside

› the time schedule for the land contractor must be incorporated so that the lower part of the embankment on Falster is ready when the bridge contractor is to start making the abutment. The remaining part of the embankment can be carried out while the bridge contractor undertakes erection from the seaside, but if the bridge contractor chooses to use incremental launching from land, the time schedule for the embankment work must be adjusted to this situation

› The time schedules are based on Energinet Denmark relocating their submarine cables before the contractor starts work at the northern end
Vejdirektoratet har lokale kontorer i:

Aalborg, Fløng, Middelfart, Næstved og Skanderborg samt hovedkontor i København

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