Ferry free E39 –Fjord crossings Bjørnafjorden	304624

0	15.08.2019	Final issue	JKJ	PNL	SEJ	
0	30.06.2019	Final issue	JKJ	PNL	SEJ	
Rev.	Publish date	Description	Made by	Checked by	Project appro.	Client appro.

Client Statens vegvesen	
Contractor AAS-JAKOBSEN COWI Multiconsult	Contract no.: 18/91094

Document name:

Preferred solution, K12 – Appendix N Construction and marine operations

Document no.:	Rev.:	Pages:
SBJ-33-C5-AMC-28-RE-114	1	190

CONCEPT DEVELOPMENT, FLOATING BRIDGE E39 BJØRNAFJORDEN

Preferred solution, K12

Appendix N – Construction and marine operations

CLIENT

Statens vegvesen

DATE: / REVISION: 15.08.2019 / 1

DOCUMENT CODE: SBJ-33-C5-AMC-28-RE-114

REPORT

PROJECT	Concept development, floating bridge E39 Bjørnafjorden	DOCUMENT CODE	SBJ-33-C5-AMC-28-RE-114
SUBJECT	Appendix N – Construction and marine operations – K12	ACCESSIBILITY	Restricted
CLIENT	Statens vegvesen	PROJECT MANAGER	Svein Erik Jakobsen
CONTACT	Øyvind Kongsvik Nedrebø	PREPARED BY	Jørgen Kjellsen
		RESPONSIBLE UNIT	AMC

Summary

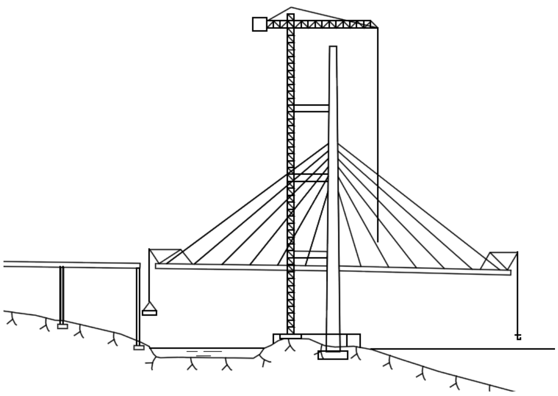
This report describes the construction and installation of the Bjørnafjorden floating bridge.

The bridge consists of a cable stay bridge in the south connected to a 4.5km long floating bridge. The south end of the floating bridge has high columns to attach to the cable stay bridge and is called the “high floating bridge”. The “high floating bridge” transitions to the “low floating bridge” which spans most of the Bjørnafjorden. The floating bridge is moored to the seabed with a total of 12 mooring lines.

The Construction and installation of the bridge is split into sub-operations:

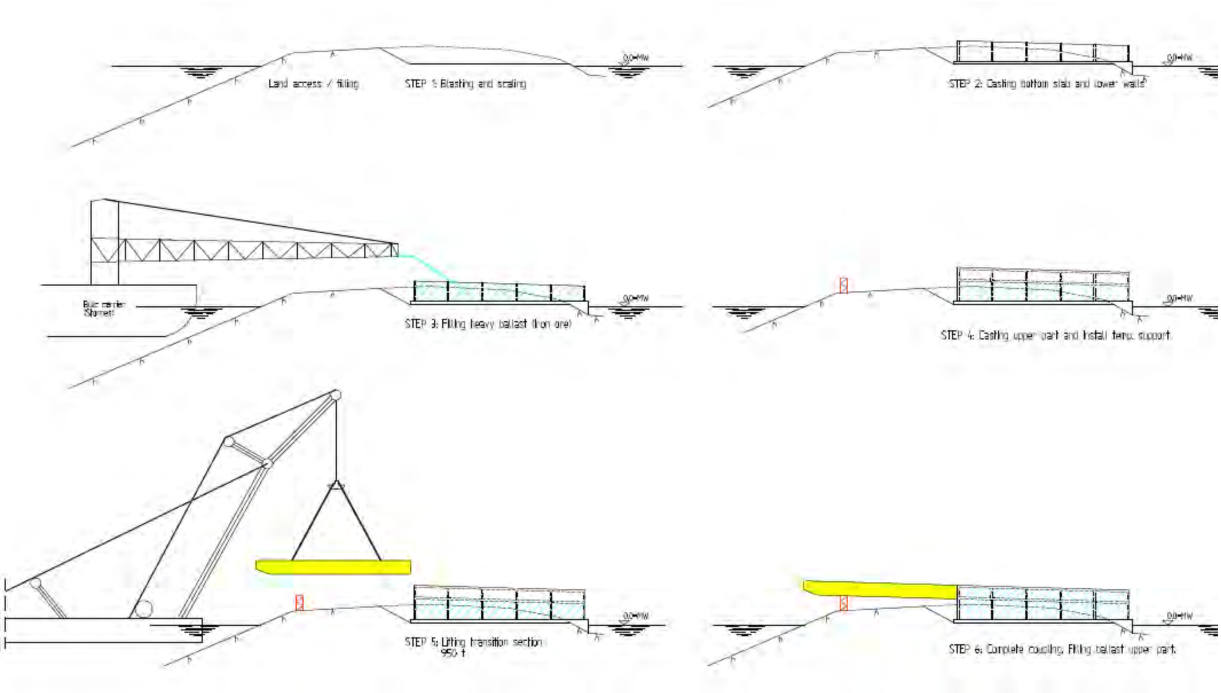
- Construction of the Cable stayed bridge
- Construction of abutments
- Assembly of bridge girder segments and pontoons with columns into high- and low floating bridge sections. This operation takes place in Søreidsvika, a fjordarm of Bjørnafjorden
- Connection of the high and low floating bridge sections in Søreidsvika
- Pre-installation of mooring system
- Installation of the north section which consists of 2 pontoons to the north abutment.
- Towing of floating bridge from Søreidsvika to the final installation location
- Installation of the main floating bridge section including hook up of mooring lines

The piers and the tower of the cable stayed bridge will be constructed using climbing formwork. The bridge concrete box girder is constructed using movable scaffolding. The cable stayed bridge deck is installed using the balanced cantilever method, working out from the tower towards the side span and the main span simultaneously. The sections are lifted from barges by derrick cranes.



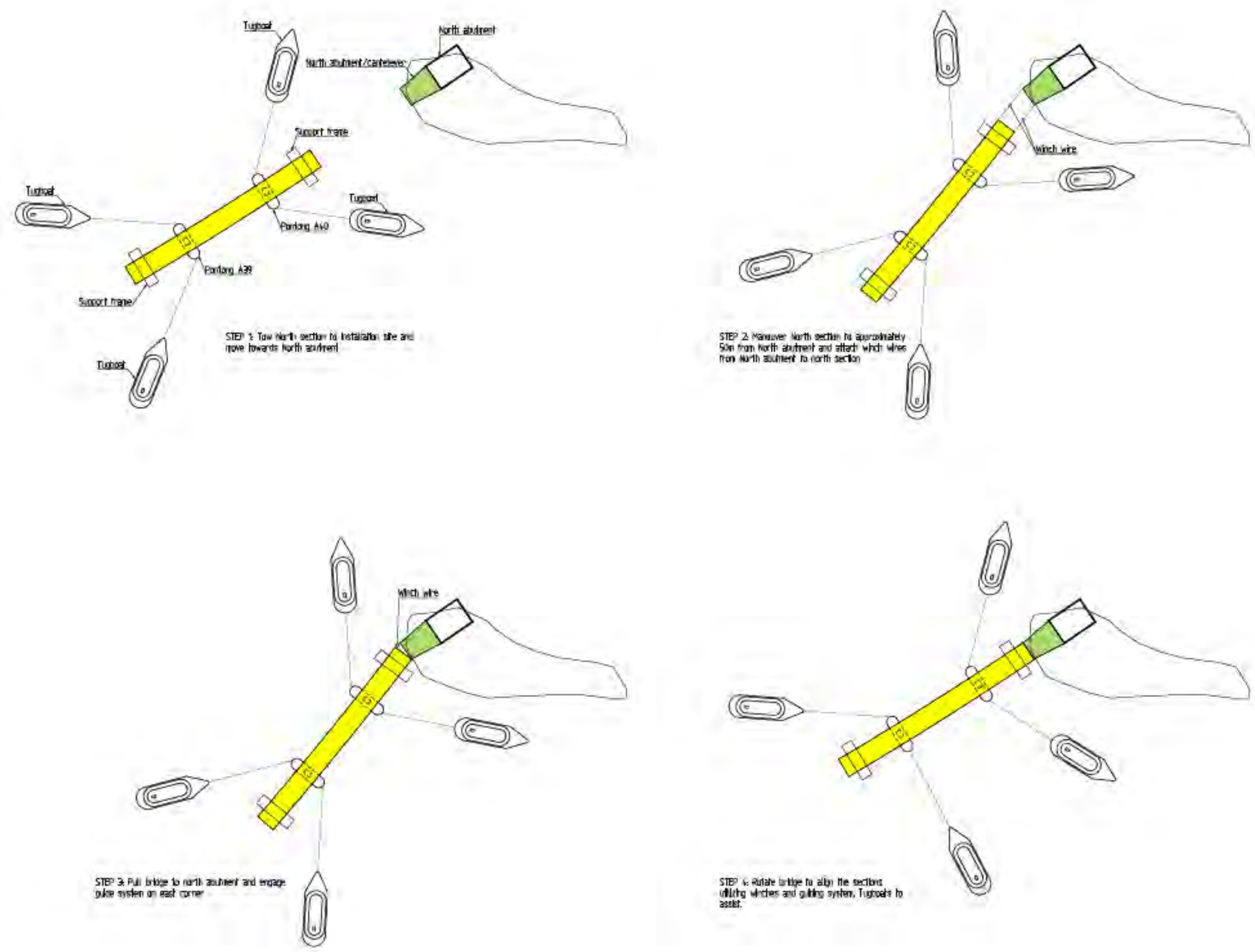
1	15.08.2019	Final Issue	J. Kjellsen	P. N. Larsen	S. E. Jakobsen
0	30.06.2019	Final Issue	J. Kjellsen	P. N. Larsen	S. E. Jakobsen
REV.	DATE	DESCRIPTION	PREPARED BY	CHECKED BY	APPROVED BY

The north abutment is a reinforced concrete box structure. A steel transition structure is connected to the abutment by prestressing tendons. The south end of this structure is coupled to the "standard" floating bridge.

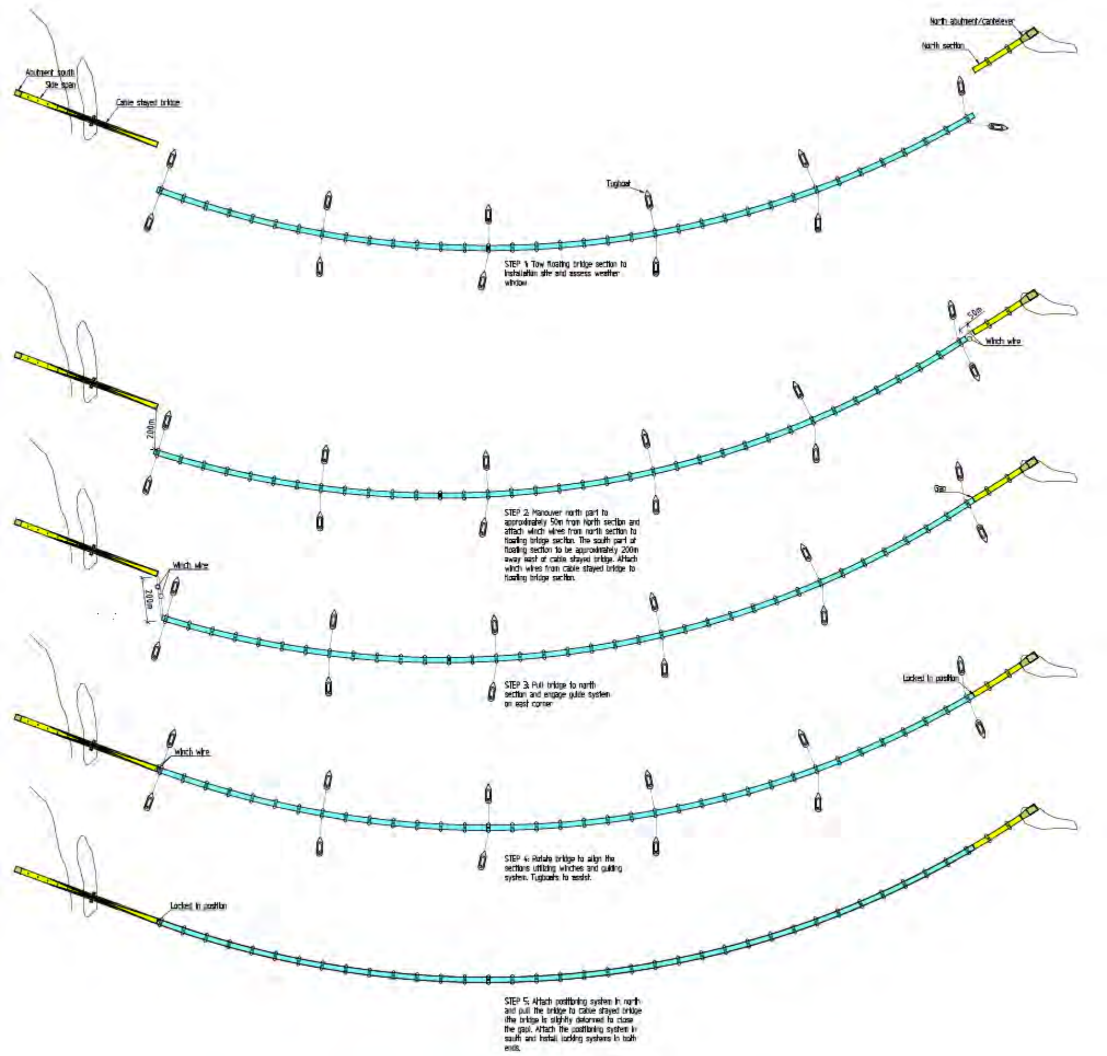


The floating bridge assembly will be performed on barges in a sheltered fjord (Søreidsvika). There bridge sections and pontoons with columns will be combined to form the floating bridge.

A smaller section will be towed to site and connected to the north abutment transition section.



The floating bridge section will be towed to site and connected first to the north t section and then to the cable stayed bridge. Coupling of sections will be performed with 3 different systems. The guiding system will create the initial contact point between two bridge sections. Once the guiding system is engaged, one can connect the “positioning system”. The positioning system enables alignment of the sections and the “locking system” to be installed. The locking system will be able to withstand a summer-storm.



All installation operations are planned as weather restricted operations. The towing operations are planned to have a safe location in Bjørnafjorden, where the tow can survive a seasonal storm. The anchors are installed minimum one year before the bridge sections and mooring lines will be wet stored ready for hook-up when the bridge sections are installed

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1 Introduction

This report describes the construction and installation of the Bjørnafjorden bridge. The report describes the current status of the work for developing robust methods for the constructions and installation.

The report and the final methodologies presented within are the result of numerous iterations which consider the operational feasibility, rules and regulations, engineering considerations, analytical considerations as well as economic factors.

For all sub operations described in this report there are numerous alternatives, which are not described, but which also are feasible.

2 Plan and Overview

The complete Bjørnafjorden bridge consists of many components and sections. The construction and marine operations will partly be dependent on each other and partly take place in parallel.

A high level overview is given below. Each of the elements below is represented by it's own (sub)chapter in this report

- Fabrication of bridge girder
- Construction of cable stay bridge at location
- Construction of north abutment at location
- Construction of north section, high and low floating bridge sections in Søreidsvika (assembly fjord)
- Installation of mooring system (installation of suction anchors and wet-storage of mooring lines is performed one year prior to final installation)
- Connection of high and low floating bridge sections in Søreidsvika.
- Towing and installation of north section from Søreidsvika to final location. Attachment of north section to north abutment.
- Towing of bridge from Søreidsvika to final location
- Mating of bridge to north section, and cable stay bridge. Temporary securing of bridge with a temporary locking system on either end. Hook-up of middle mooring cluster
- Hook-up of remaining mooring clusters
- Welding of final bridge girder section joints (construction joints)

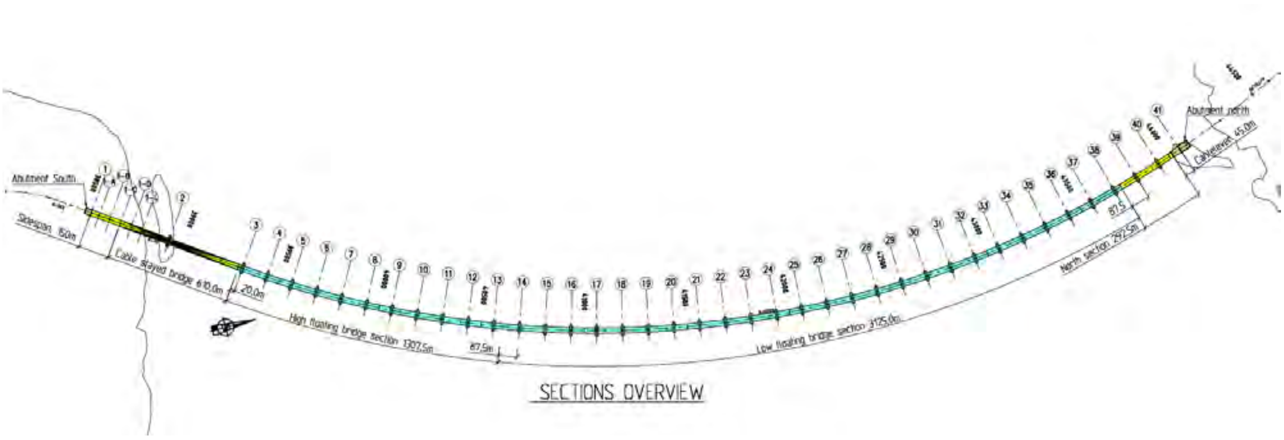


Figure 2-1 Overview of parts and sections

3 Marine Operation Design Premises

Marine operation best practices from the North Sea will be applied during the operation. The planning of the operations shall have a high focus on safety for personnel and assets. The planning is anchored in rules and regulations and recommended practices. There are strict rules about the durations and environmental conditions. The following subchapters investigate some of these areas.

3.1 Rules and Regulations

The rules and regulations applied in the marine operation design are adhering to DNVGL standard (DNVGL-OS-H101 and relevant DNVGL-RP-H documents). For future phases the latest version of these rules, DNVGL-ST-N001 should be adhered to.

3.2 Environmental Conditions

For the marine operations planning phase one considers:

- Unrestricted conditions
- Seasonal unrestricted conditions
- Weather restricted conditions

The unrestricted and seasonal unrestricted conditions are dictated by metocean-data for the relevant locations (Bjørnafjorden and Søreidsvika in this case). For weather restricted operations of limited duration (under 72 hours from safe to safe consition) the engineering and operational team may impose weather restrictions and weather windows.

3.2.1 Unrestricted conditions

Unrestricted conditions for Bjørnafjorden and Søreidsvika are found in the metocean design basis /2/ as well as in eroom correspondence 304624-1-A-0051 / SLA-01-C1-SVV-01-BA-001-A.

Updated information has been received by Statens Vegvesen regarding seasonal unrestricted conditions and this information is found in eroom correspondence 304624-1-A-0063.

The following tables are extracted from DNV-OS-H101 concerning the acceptable return periods for operations of various durations. In all the below seasonal variations may be taken into account.

Table 3.1: Characteristic wind velocities

Table 3-1 Acceptable return periods for (characteristic) wind velocities

Reference Period, T_R	*Return Period, T_d*
$T_R \leq 30$ days	$T_d \geq 10$ years
$T_R > 30$ days	$T_d \geq 100$ years

Table 3.2: Characteristic Hs values

Table 3-3 Acceptable return periods for H_s

Reference Period, T_R	*Return Period, T_d*
$T_R \leq 3$ days	$T_d \geq 1$ month
3 days $< T_R \leq 7$ days	$T_d \geq 3$ months
7 days $< T_R \leq 30$ days	$T_d \geq 1$ year
30 days $< T_R \leq 180$ days	$T_d \geq 10$ years
$T_R > 180$ days	$T_d \geq 100$ years

Table 3.3: Overview of operations and weather criteria

Part of the operation	Criteria			Comment
	Hs	Wind	Current	
Construction of bridge in Søreidsvika	100 year	100 year	10 year	Shorter return values may apply for sub-operations
Towing of Bridge out of Søreidsvika	Weather restricted			
Towing of bridge in Bjørnafjorden	1m	20m/s	1.5m/s	According to DNV towing criteria
Final Positioning, pull-in and initial mating	Weather restricted			
Temporary fixations (Locking system)	1 year seasonal	10 year seasonal	10 year seasonal	
Welding	Weather restricted			
Anchor/Mooring installation and hookup	Weather restricted			This operation is manageable in typical offshore conditions, exceeding the conditions for Bjørnafjorden

3.2.2 *Weather restricted conditions*

Detailed weather restricted conditions are found in the subchapters for each part of the operation. The minimum of the analytical and operational design weather restrictions is going to be governing.

For most of the operations it is assumed that practical operational limitations will be governing, rather than results acquired from analyses

All weather restricted operation must be planned such that a survival/safe condition can be reached within 72 hours.

Weather restricted operations will need to adhere to DNVGL alpha factor calculations. It is assumed that the highest detail of weather monitoring will be available.

4 Fabrication

4.1 General

The focus with regards to fabrication has been on simplifying the the bridge girders fabrication. The first section describes how the bridge girder can be fabricated in a traditional manner with maximizing automatic welding. In section 4.3 a description of newer technology welding robots and how this can be applied to the fabrication of the bridge girder are presented. This technology is significantly less labour intensive and may be implemented for fabrication of bridge girders in a high cost country.

The fabrication of the pontoons and columns have not been presented. The pontoons are designed as a small vessel/barge and hence can be fabricated with traditional shipbuilding techniques.

4.2 Bridge girder fabrication and transportation

4.2.1 Introduction

The bridge cross-section is shown in Figure 4-1. It represents both the low and high parts of the floating bridge in the midspan sections. These sections are called “General Section” hereafter and are characterised by just having the external vertical web plates as vertical shear walls in longitudinal direction. The presence of longitudinal trusses/diaphragms near columns is shown in Figure 4-2.

In the transverse direction trusses are generally used. However, in the vicinity of columns, diaphragms are also used. The spacing between transverse trusses is generally 4.0 m.

There will be some significant differences for assembly of General Sections and other sections near columns, i.e. with increased complexity for the latter types.

The fabrication and assembly at the fabrication yard and the transportation is covered in this section. Assembly at the Bridge Site is covered in Section 5 .

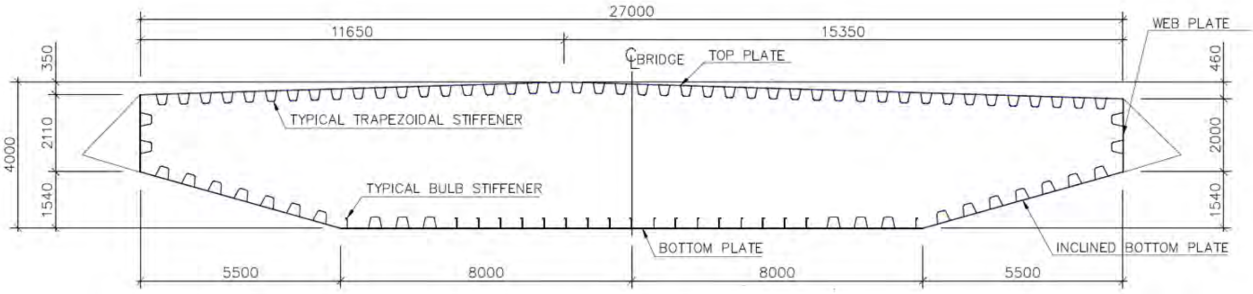


Figure 4-1 General cross-section in mid-span area

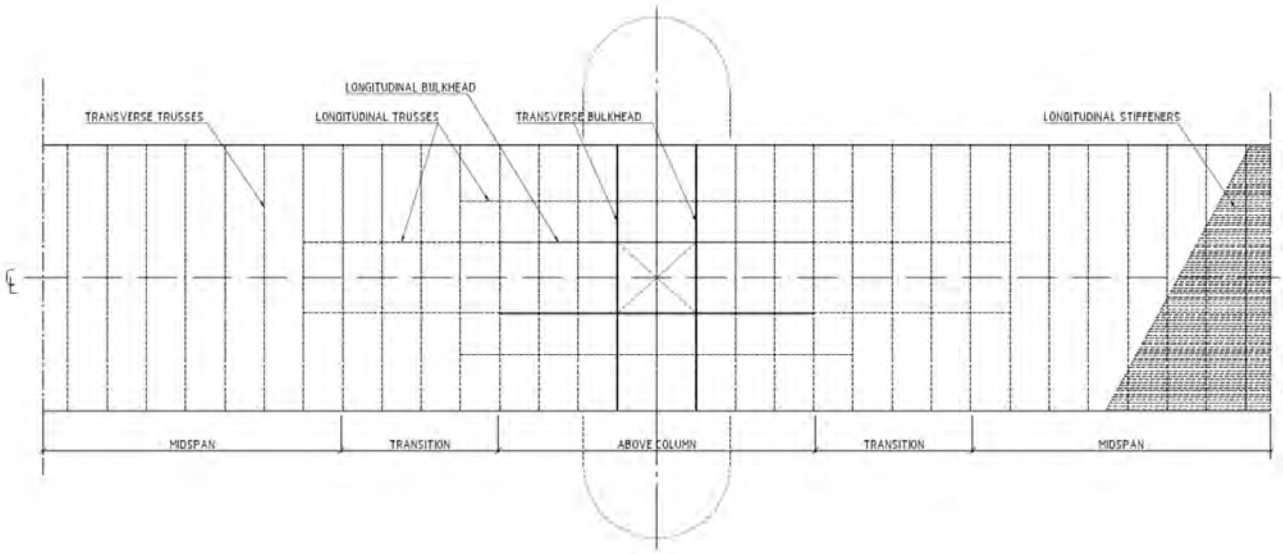


Figure 4-2 Overview of longitudinal trusses and bulkheads

4.2.2 Pre-fabrication

General

Pre-fabrication generally comprises fabrication of stiffeners and panels (i.e. welding on longitudinal stiffeners on to skin plates. Typical stiffeners are shown in Figure 4-3. Trapezoidal stiffeners (U-ribs) are fabricated from steel plates and bent to the specified shape. The ends of the deck U-ribs must be bevelled. The bulb-profiles need no further yard preparations. The spacing between deck U-ribs and bulb profiles is typically 600 mm, whereas for remaining U-ribs 750 mm spacing is used.

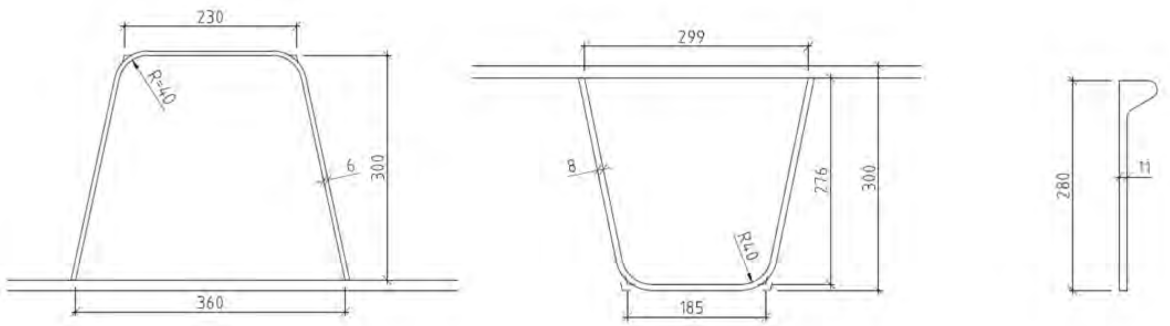


Figure 4-3 Typical stiffener types in longitudinal direction

The longitudinal skin plates for the General Section (midspan at low part of floating bridge) are subdivided into

- 1 deck plate (16 mm)
- 2 vertical plates (12 mm)
- 2 inclined (lower) plates (12 mm)
- 1 bottom plate (12 mm)

For other sections near columns skin plate thicknesses are increased.

The bridge cross-section needs to be subdivided into manageable sizes for panel production and subsequent assembly. In the longitudinal direction a production length of 12.0m is common. It also complies with the need for this length to be multiple of the transverse truss spacing of 4.0 m

In transverse direction, widths will typically be in the range 2.5 m to 3.5 m. This is governed by available sizes from the mill but also handling during fabrication and assembly. This would lead to approx. 18 off such plates per section. The location of panel joints is generally up to the fabricator to choose. The exception to this rule is in the deck structure where direct contact with wheel loads from traffic should be avoided. An acceptable choice is shown in Figure 4-4 ensuring the longitudinal weld seam is close to the centre of the traffic lanes. A width of 3.6 m also ensures joints being in the centre between two adjacent trapezoidal stiffeners (denoted U-ribs in the following). The outlined method adopts an approach where each panel is pre-fabricated with both U-ribs and transverse truss chords necessitates using small width panels.

By this approach, the transverse chords T-beams are also fabricated before panel assembly takes place. This involves cutting webs and flanges in lengths corresponding to the plate widths and making web cut-outs for longitudinal U-ribs and Bulbs. The gusset plates for truss diagonals and verticals are also cut and welded on to the flanges. (Alternatively, for easier intermediate storage by stacking of panels, these items may be welded on just prior to assembly.)

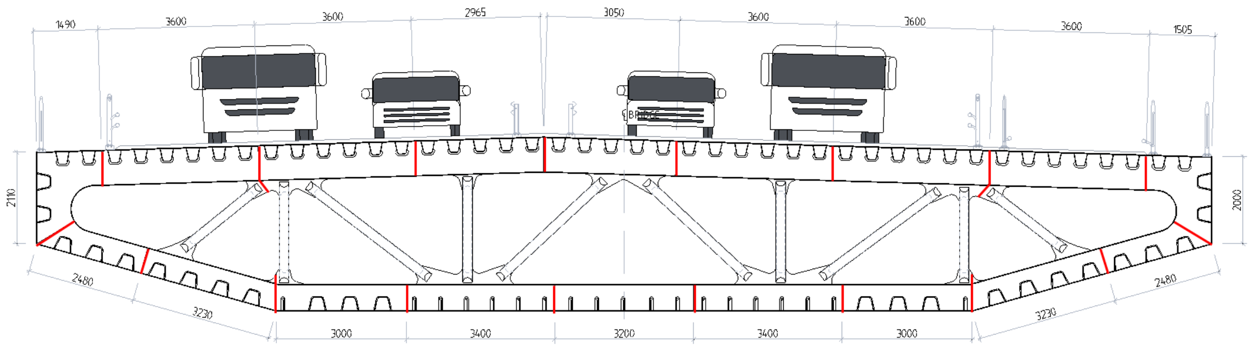


Figure 4-4 Sectioning in transverse direction

U-rib -Truss Chord assembly considerations

The requirements for joining T-beams and skin plate is different for the deck plate exposed to traffic loads and the remaining plates.

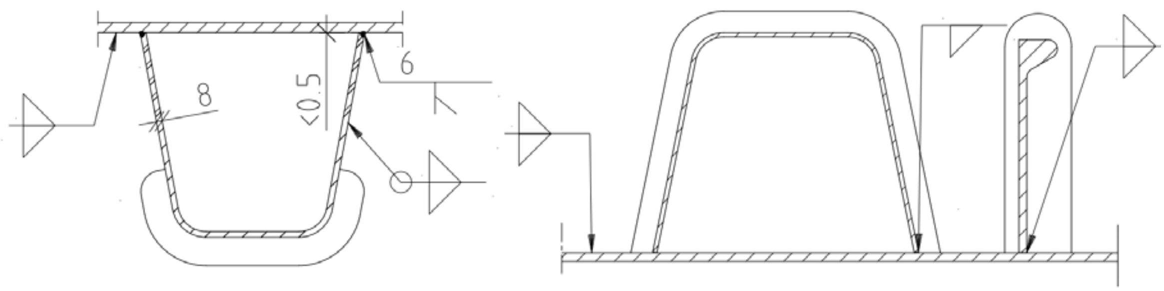


Figure 4-5 Welds between stiffeners, skin plate and T-beam

From Figure 4-5 it can be seen that there is a need for higher accuracy between 3 joining elements for deck plates compared to the other plates. This is dictated by fatigue requirements. In the other plates oversized cut-outs are made to ease the panel fabrication/assembly. The stability of the stiffeners at the T-beam locations are ensured by the solution shown in Figure 4-6, i.e. by small plate pieces.

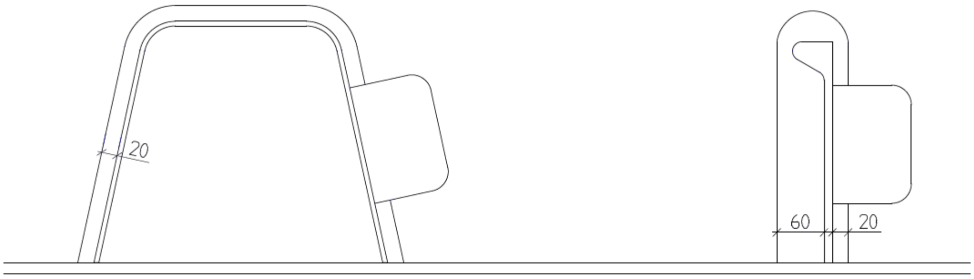


Figure 4-6 Welded-on plate pieces for stabilising stiffeners at transverse trusses

Fabrication of deck panels

The deck plates are placed "face down" on an accurately levelled floor. This is required to meet the need for a maximum gap of 0.5 mm between the U-rib legs and the plate. If this is not satisfied, then the gaps must be reduced to meet the requirements by e.g. adding weights on the plate.

To secure a good fit between the U-ribs and the T-beams, these are used as templates to establish the exact transverse location of the stiffeners. The stiffeners are then tack welded and the T-beams removed. The stiffeners are then welded by use of automatic welding. The welding must be carefully planned and monitored to achieve the intended 75% degree of penetration (min. 70%/max. 80%) whilst avoiding any blow-through and melt-through.

Once the U-ribs have been welded the 3 T-beams can be fitted-up and welded. This can be achieved by robot or manual welding as per fabricators preference. The welding shall be continuous along the deck plate, part of U-rib legs and through the cope hole.

The procedure is shown in Figure 4-7.

Fabrication of other panels

The procedure is similar but with some distinct differences. This is related to the issue that the U-ribs are welded to the plates with a fillet weld rather than a partial penetration weld along with relaxed requirement for the gap between U-rib leg and plate. Furthermore, the cut-outs in the T-beam are made to be oversized to ease assembly.

Thus, the fit-up and welding can be achieved with standard requirements to tolerances. The design does not require direct welding of the T-beams to the U-ribs., i.e. welding of T-beams include just connection to the plate. However, to secure transverse stability of the U-rib, small support plates are welded to connect the T-beam to the U-rib legs.

The procedure is shown in Figure 4-8 for one of the bottom panels.

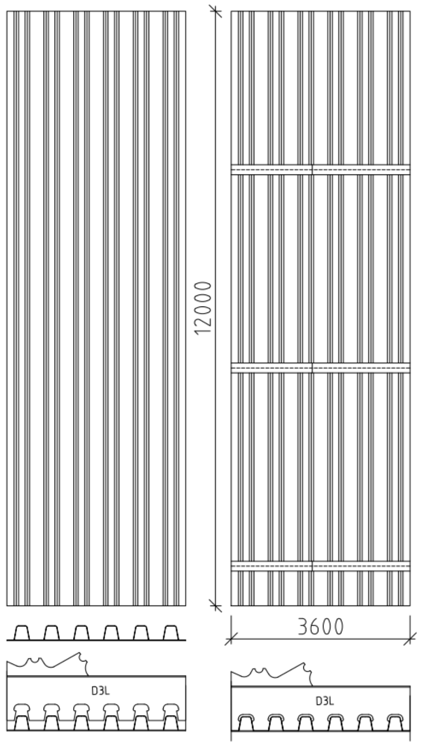


Figure 4-7 Assembly of deck panel

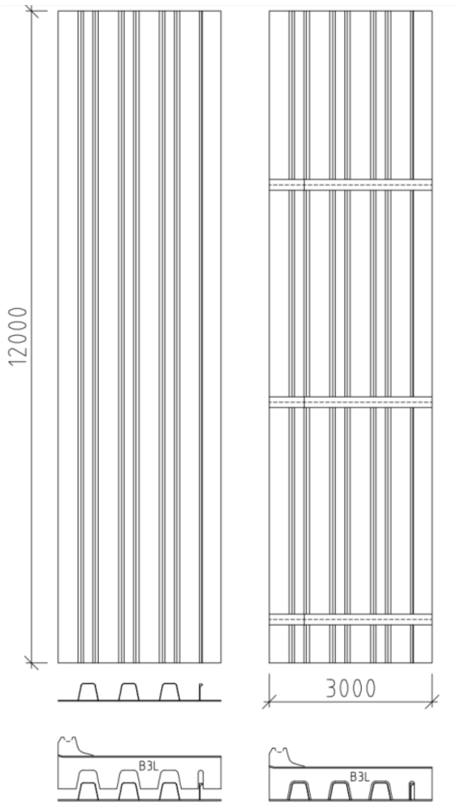


Figure 4-8 Assembly of bottom panel

4.2.3 Assembly of general section (Midspan 1 in Figure 4-2)

There are several possible sequences of assembly. It is foreseen that two possible main approaches could be selected.

1. Assemble all panels to form the box girder in its full width
2. Assemble the box girder in two separate pieces to be joined finally at girder CL when the two halves have been completed.

The welds interconnecting the panels are full penetration welds. Hence, the welding requires either welding from two sides or using a back-strip. In the first case it would be an X-weld or a V-weld requiring gouging and a back weld. In the second case it will require the removal of the back-strip and weld smoothing by means of grinding. In general, for the main welds overhead welding must be avoided but also for the back-weld work this should be avoided.

In the following, an assembly sequence whereby each halve of the bridge girder is assembled separately is described. The welding between each panel is done from above or to the side whilst the girder half is oriented "as-installed". When both halves have been fabricated, they are joined and in order to complete all the back- welds the Bridge Girder is rotated 180 degrees. Alternatively, the rotation for the purpose of back-welding/removal of back-strips is done before joining the two halves. Joining the two halves could then done before or after the section(s) is (are) rotated back.

In the following figures, the assembly of the "left half" and the joining of the two halves is outlined.

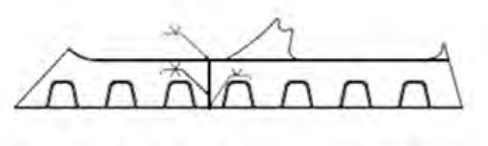


Figure 4-9 Assembly of two inclined bottom panels

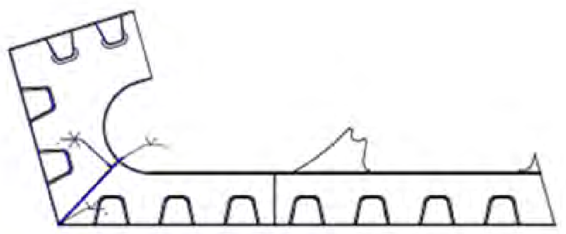


Figure 4-10 Assembly of web panel to the two inclined bottom panels

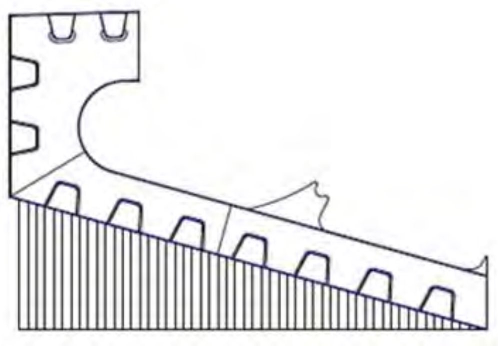


Figure 4-11 Assembly of first top deck panel

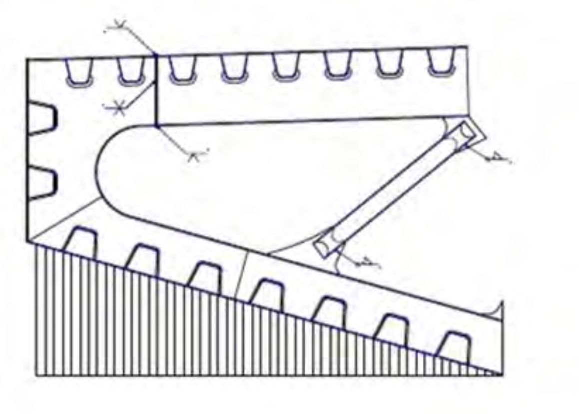


Figure 4-12 Assembly of top deck panel and truss brace

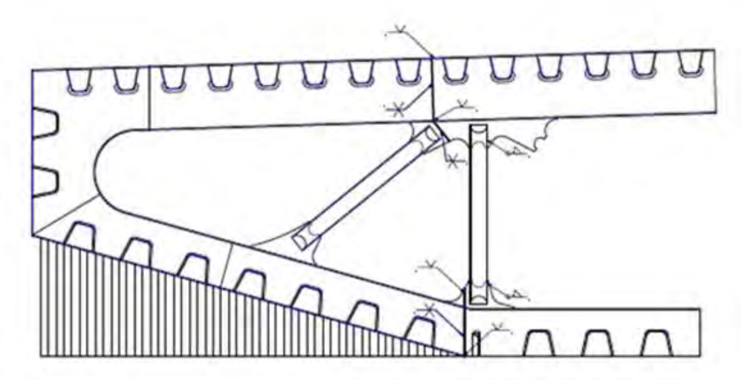


Figure 4-13 Assembly of top and bottom deck panels together with truss column

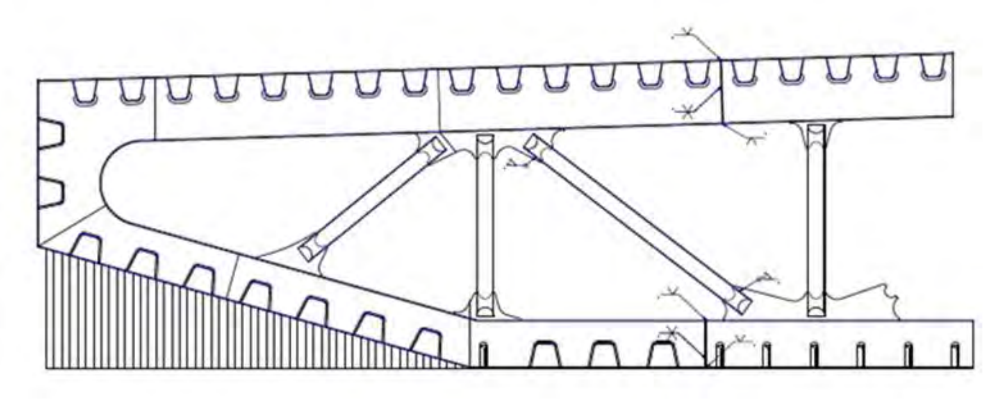


Figure 4-14 Assembly of complete "left half" of Bridge Girder

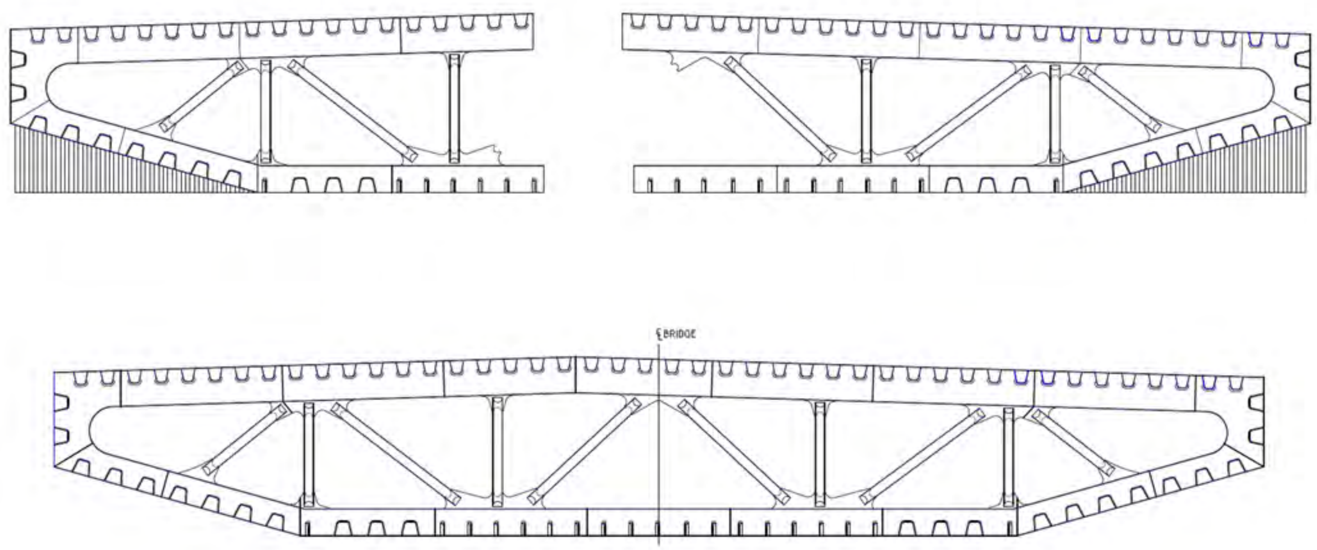


Figure 4-15 Assembly of entire Bridge Girder including back-welding

4.2.4 Assembly of Special Section (Transition in Figure 4-2)

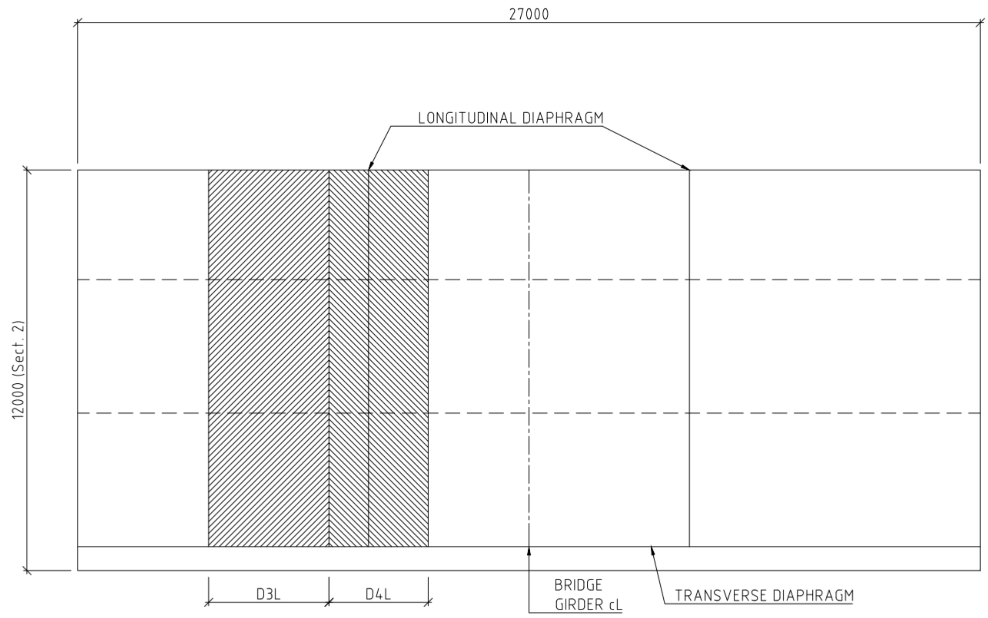


Figure 4-16 Plan of special deck plate section 2

Assembly of special sections, i.e. sections including transverse or longitudinal diaphragms, or both will require an entirely different approach compared to the general section (transverse trusses only). For the general section as outlined in Sect 4.2.3, the panels are successively joined, and the diagonals of the transverse truss joined in the process thus securing the integrity of the bridge girder. In case of sections with diaphragms, this requires earlier fit-up of these. The overall idea of assembling the two halves of the bridge girder separately is maintained. (In Figure 4-16 both halves are shown). Also, the panel prefabrication will be the same with some adjustments, se Figure 4-17. This entails making splits in the transverse truss beams for slotting longitudinal diaphragms.

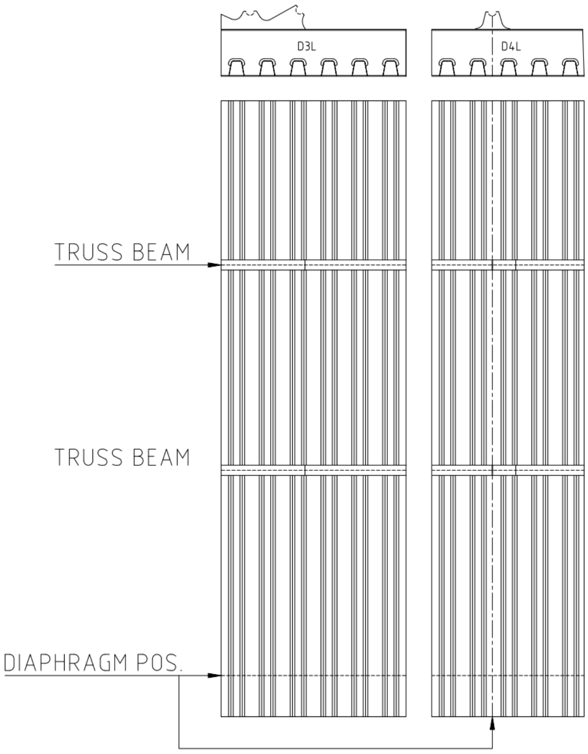


Figure 4-17 Panel prefabrication

The process of Bridge Girder assembly is initiated by assembling the deck panels, see Figure 3-19.

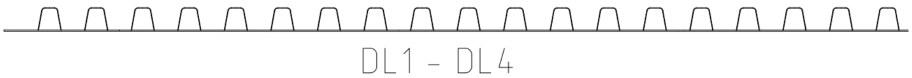


Figure 4-18 Section top panel at position for transverse diaphragm located at levelled workshop floor

At this stage the transverse and the longitudinal diaphragms are slotted into the deck panels as shown in Figure 4-19.

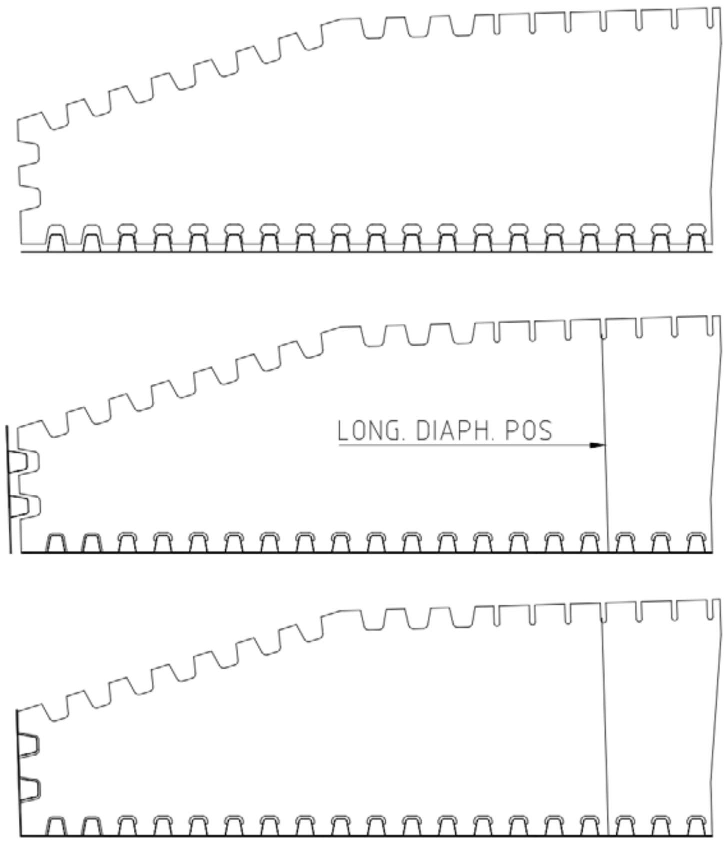


Figure 4-19 Assembly of transverse diaphragm (step 1 -3)

As outlined for the General Section, there is a need for high accuracy when installing the transverse diaphragm onto the deck panels as there is generally a tight fit between U-rib legs and the diaphragm. The tolerances are more relaxed when fitting the remaining panels as shown I step 2 and 3 (and onwards) in Figure 4-19. Following step 1 it is required to also install the longitudinal diaphragm (one per Bridge Girder half section). The installation of panels for the lower inclined and the bottom parts can then be accomplished. The welding work will follow the same principles as for the General Section, i.e. make all “downwards”/”sideways” welds in the initial position and them turn the section 180 degrees to remove backing strips/complete all welds.

4.2.5 Assembly of special section (Above column in Figure 4-2)

Special section 3 differs from section 2 by the fact that there is one additional longitudinal truss per Bridge Girder half section. Assembly of special section 3 is thus similar to section 2 since the deck and floor beams of the longitudinal truss can be pre-installed during panel fabrication/assembly.

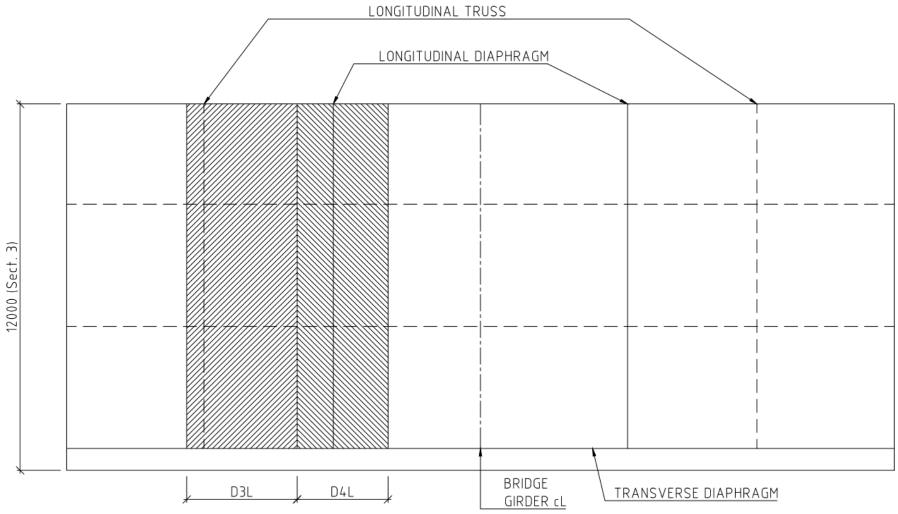


Figure 4-20 Plan of special deck plate section 3

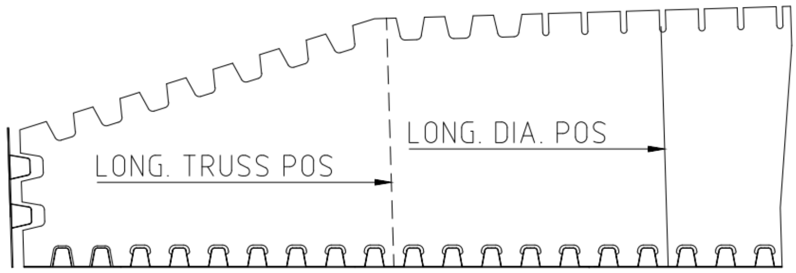


Figure 4-21 Section 3 transverse diaphragm assembly

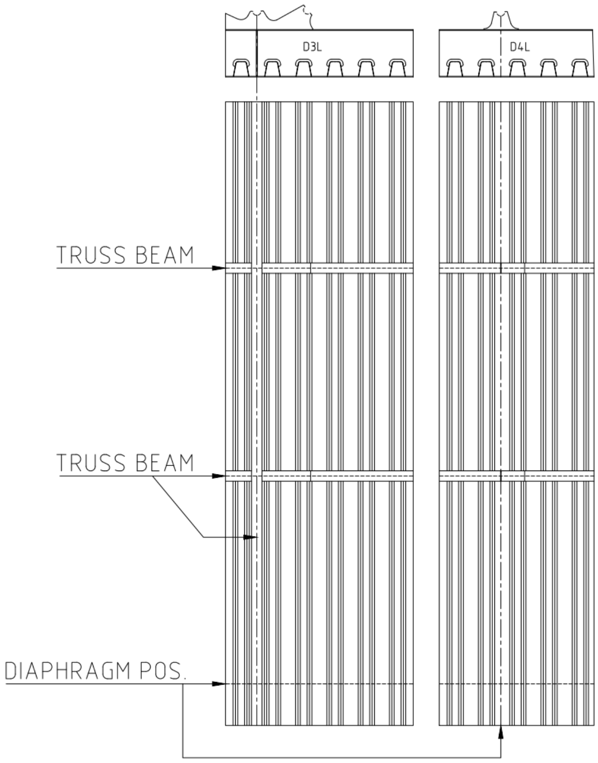


Figure 4-22 Panel fabrication for Section type 3

4.2.6 Fabrication completion and preparations for transport

Once the all the welding works are completed on the 12 m (TBC) long bridge sections, including the welding of small plates (ref. Figure 4-5), the remaining main activities are surface coating and the joining of pairs of 12 m (TBC) sections to form the 24 m (TBC) sections planned for transportation.

Surface Treatment

There will be two systems of surface coating, i.e. all external surfaces will be treated with a duplex system (metallizing plus epoxy/polyurethane) whilst internal surfaces, although being subject to dehumidification during operation, may need a form of temporary protection. The sectioning of bridge parts for metallization and painting will be determined by the fabricator, depending on the yard facilities.

Joining of sections

Joining of two 12 m sections to form a 24m long section comprises welding of skin plates and longitudinal stiffeners. The deck plates are initially aligned and positioned for welding and are temporarily secured. Then, alignment and positioning of the remaining plates is carried out. In order to avoid plate mismatch beyond the tolerances, it may be required to jack the plates on the module with the longest distance to transverse truss/diaphragm into position. The welding is performed with the sections in their normal position, i.e. the main weld (V-weld) is carried out from the top of deck, whereas the welds on the other plates are carried out from the inside. Backing strips are used for all plates. When removed from the bottom panels, the welds must be ground to achieve a smooth surface.

The joining of longitudinal stiffeners needs to be done with use of in-fill pieces. The welds for U-ribs are done using backing strips which will be left in-place.

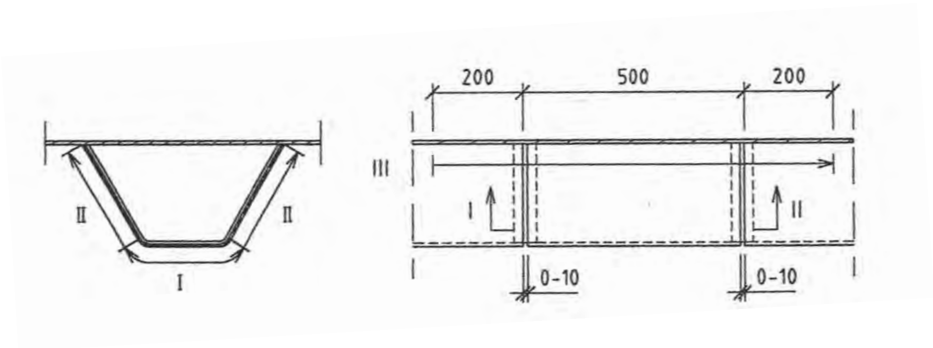


Figure 4-23 Welding details for in-fill member for U-rib (numbers denote weld sequence)

4.2.7 Transportation

It is anticipated that the bulk of Bridge Girder Sections will be fabricated abroad. In the current situation the most probable location in Europe will be Turkey (where the almost 4 km long Bridge Girder for Çanakkale Bridge will be fabricated). Otherwise in recent years, Suspension Bridge Girder type sections have been fabricated in China.

In both cases, there will be a requirement for open sea transportation. This can in principle be by means of a barge using tugs or by a self-propelled special purpose cargo vessel. For transportation within Europe, barges have generally been used in past. For transportation from the Far-East, cargo vessels have typically been used for in order to increase safety and speed. The vessel needs to have a flat deck and be independent of tugs for the voyage. Some of the biggest vessels of this kind may have the option for deck submersion, but this capability is not required for transporting deck sections.

A large self-propelled semi-submersible heavy lift ship vessel of this type is the Blue Marlin. However, as the deck width is 40 m and the sections are 30x24 m, this is not very suitable. Mighty Servant 1 and 2 have a width of 50 m which is ideal, see Figure 4-26 and Figure 4-27.

For the low and high bridge sections, 4 trips will be required. The sea voyage from China to Norway will take about 2 months.

Figure 4-24 Barge used for Hålogaland

The ship of all ships: The largest cargo transport ship in the world, the Blue Marlin of Dockwise, carries four pontoons and 18 hulls on its back from Nantong Port, China

Figure 4-25 Blue Marlin

Figure 4-26 Mighty Servant 2

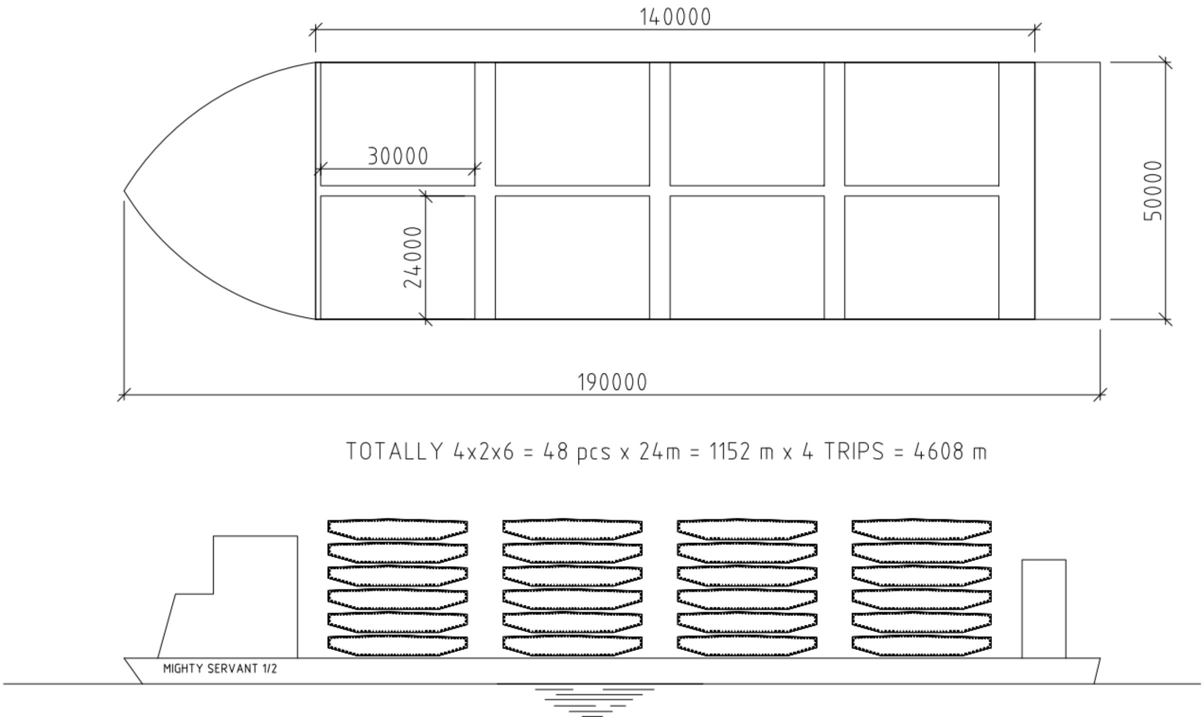


Figure 4-27 Stacking of Bridge Girder Sections on Mighty Servant

It is anticipated that for Bjørnafjorden a similar vessel without the deck submergence capability with a free deck area of abt. 50 by 140 m would be the optimum concept technically and cost-wise.

4.3 Robot welding technology

4.3.1 General advances in welding and robotic technology

Advances within automation of the welding process have during the later years been facilitated by:

- Much more advanced welding power sources and thus better control of the process
- Faster data processing
- Cheaper robots
- More efficient seam tracking systems, enabling compensation for variations/tolerances

The potential of state of the art welding power sources, robots and computer power may be illustrated by the technologically rather spectacular MX3D bridge project, where state-of-the-art weld arc control and robot programming technology are demonstrated, resulting in a footbridge entirely made of weld metal, see Figure 4-28 and Figure 4-29.

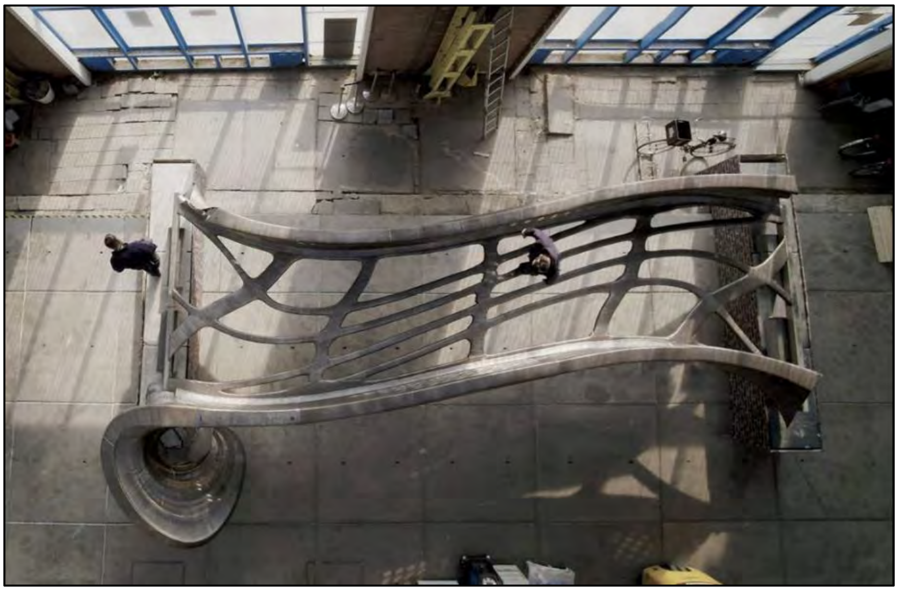


Figure 4-28 Bridge entirely made of weld metal (3-D printed) by means of robotic welding. MX3D project, Amsterdam

Figure 4-29 Welding robot in action during 3-D printing of bridge. MX3D project, Amsterdam

4.3.2 Welding automation for large steel structures

In Denmark, extensive research and development (R&D) efforts have been put into robotization of the welding of large steel structures, with major development being achieved at the OSS Lindø shipyard until it closed (large container ships could still be manufactured cheaper in South Korea at the time, despite Danish efforts, but according to an internal source at OSS, the price difference was only 5%).

Figure 4-30 shows a large welding robot station for fabrication of sub-assemblies ("blocks") at OSS Lindø. Reportedly, 12 robots could produce up to 12 km of weld every day.

Figure 4-30 Large robotic welding station at OSS Lindø shipyard

Figure 4-31 shows the results from a cooperation project between OSS Lindø, Migatronic and FORCE Technology - a self propelled welding tractor travelling on magnetic wheels with a grip force of 0.5 tons. The tractor would follow the wobbling and yawing path of the weld groove, and artificial intelligence based on neural networks would adjust welding parameters as well as weaving pattern, as a function of variations in welding groove geometry – especially varying gap. The welding tractor was at a beta version testing stage when the shipyard closed and the project stopped, but lessons learned persist.

Figure 4-31 Self propelled and self positioning welding tractor for fully automated welding of section joints in the dock of OSS Lindø shipyard, using adaptive control to compensate for variations in groove position and gap

OSS Lindø shipyard may be closed now, but a spin-off from the R&D efforts is now a "Robotic Valley" around Odense on the island of Fyn, with several very successful new companies, the most famous start-up being Universal Robots.

A relevant supplier for the present applications could however be a company like Inrotech, another start-up near Odense. The company spawned from extensive R&D activities at OSS Lindø within welding in confined spaces, where duty cycles are especially low, entailing high costs for manual welding.

The application can be seen on https://www.youtube.com/watch?v=Xe2LKEJxtdM.

Figure 4-32 shows a later solution by Inrotech, robotic welding between webs, stiffeners and deck plate. The robot identifies the structure by itself, and welds automatically. In this case, the robot travels on a modular, lightweight rail system which can be repositioned and extended as needed.

A demonstration of identification of geometry and subsequent welding can be seen on https://www.youtube.com/watch?v=LTU7MTEqX1E.

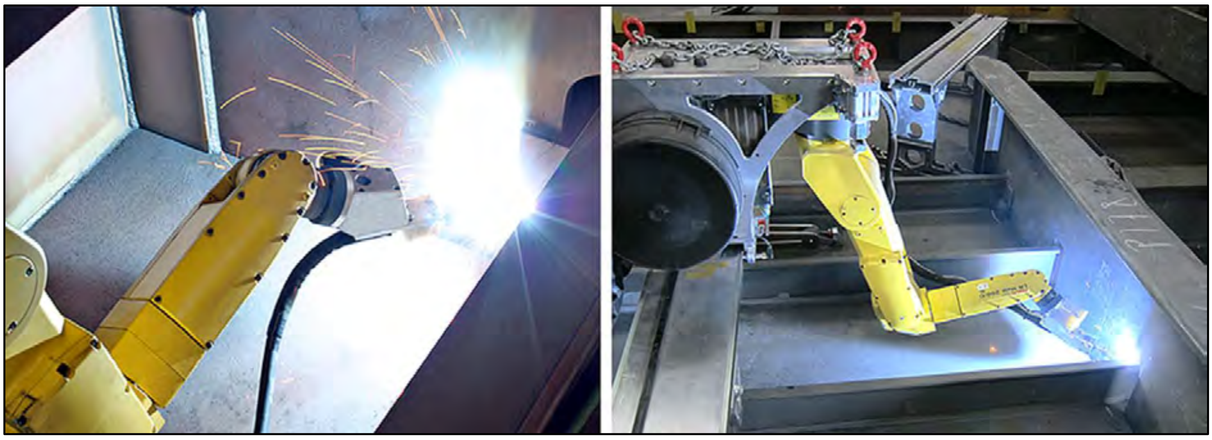


Figure 4-32 Robotic welding between webs, stiffeners and deck plate. The robot identifies the structure and welds automatically. (Source: Inrotech)

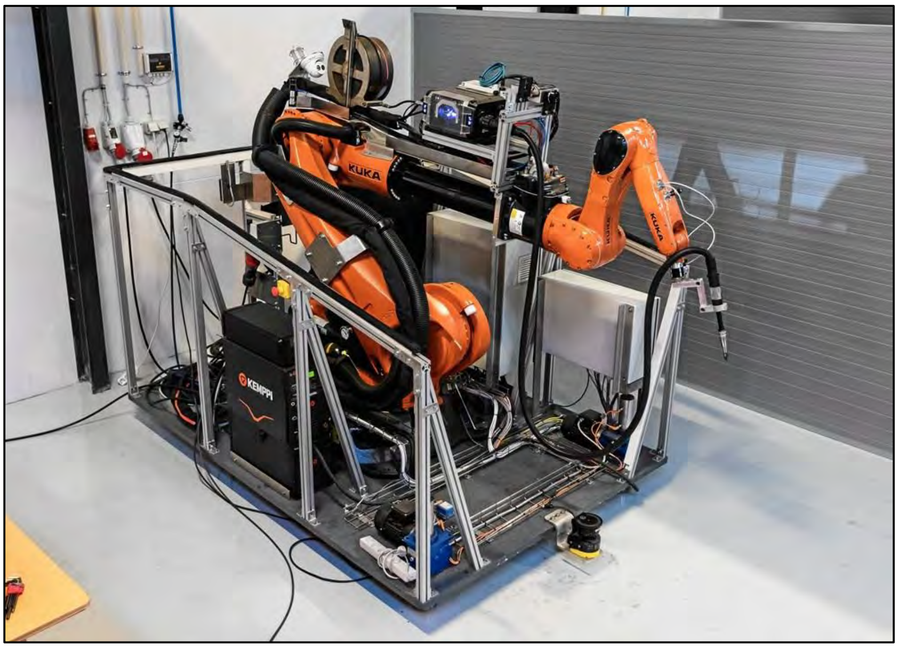


Figure 4-33 Mobile robotic welding unit (Inrotech)

Figure 4-33 shows a mobile, robotic welding unit currently under development, intended for welding of pipe structures like jackets for the off-shore industry - mainly wind turbine jacket foundations. The robot identifies the pipe positions and dimensions (including material thickness). The weld groove is measured by means of a laser line scanner, after which the welding proceeds with fully automated multiple pass welding, until the joint is filled up, taking into account variations in groove position and varying geometry.

A relevant supplier in Norway, could be a company like Kleven, located at Ulsteinsvik outside Ålesund. The company has utilized automat and robots for welding since 2013.

An example of application can be seen on https://www.youtube.com/watch?v=iJDLz8SOJIE.

4.3.3 Welding productivity and welding automation within bridge building

Welding productivity is depending on the deposition rate of the process and the duty cycle i.e., the percentage of available time the welding arc is actually on.

Approximate maximum weld metal deposition rates for different relevant welding processes are shown on Figure 4-34. Please note that the table is indicative, and various preconditions apply.

	Stick electrodes (111)	MAG (135)	Flux cored (136)	Submerged arc (121)
Position				
	1,5 kg/h	3,5 kg/h	5 kg/h	N/A
	7 kg/h	5 kg/h	8 kg/h	22 kg/h single 40 kg/h triple

Figure 4-34 Typical maximum weld metal deposition rate for different weld processes, at 100% duty cycle

Duty cycles vary as a function of the application and the welding process. It will be lowest when using stick electrodes and often highest for submerged arc welding. Duty cycle for manual welding in confined spaces will often be as low as 15%. A normal duty cycle for manual welding will often be around 25-30%. Efficient, automated installations can achieve a duty cycle of 80-90%

Welding fabrication of bridge girders is typically characterised by:

- Semi-automated welding of plate-to-plate for deck, side and bottom panels as well as bulkheads. Process is often submerged arc welding.
- Automated/semi-automated welding of flanges and stiffeners. Process is often flux cored arc welding or welding with metal cored wire.
- All the rest is generally manual welding, including welding of bulkheads and T-profiles against panel plates and other welds characterized by varying positions and short lengths. Process is often flux cored arc welding.

Time consumption for numerous shorter welds tends to add up quite a bit. As automated welding will typically increase the duty cycle significantly, there might be an interesting potential here. If one operator can control several weld arcs/welding stations, which is realistic, the benefit will be even higher.

4.3.4 Selected potential welding automation applications for bridge building

An obvious case for possible robotic welding of shorter welds in varying positions could be the fillet welds between diaphragms/stiffeners, deck plates and troughs, see Figure 4-35.

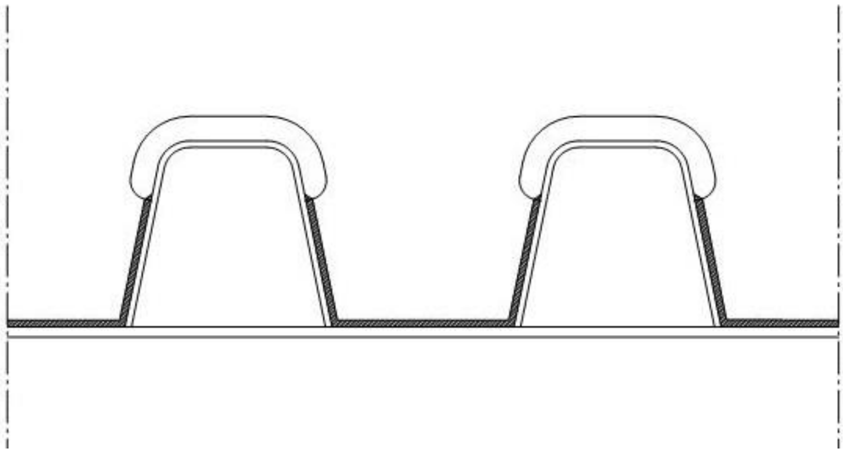


Figure 4-35 Fillet welds between diaphragms/stiffeners, troughs and deck are an obvious case for robotic welding

The recent advances in welding within robotic welding have made it possible to place the robot in roughly correct position, and then let it locate the position of joints to be welded by itself. After some initial measurements by means of a laser sensor, the joints are tack welded and subsequently fully welded. The concept could be as shown in Figure 4-36.

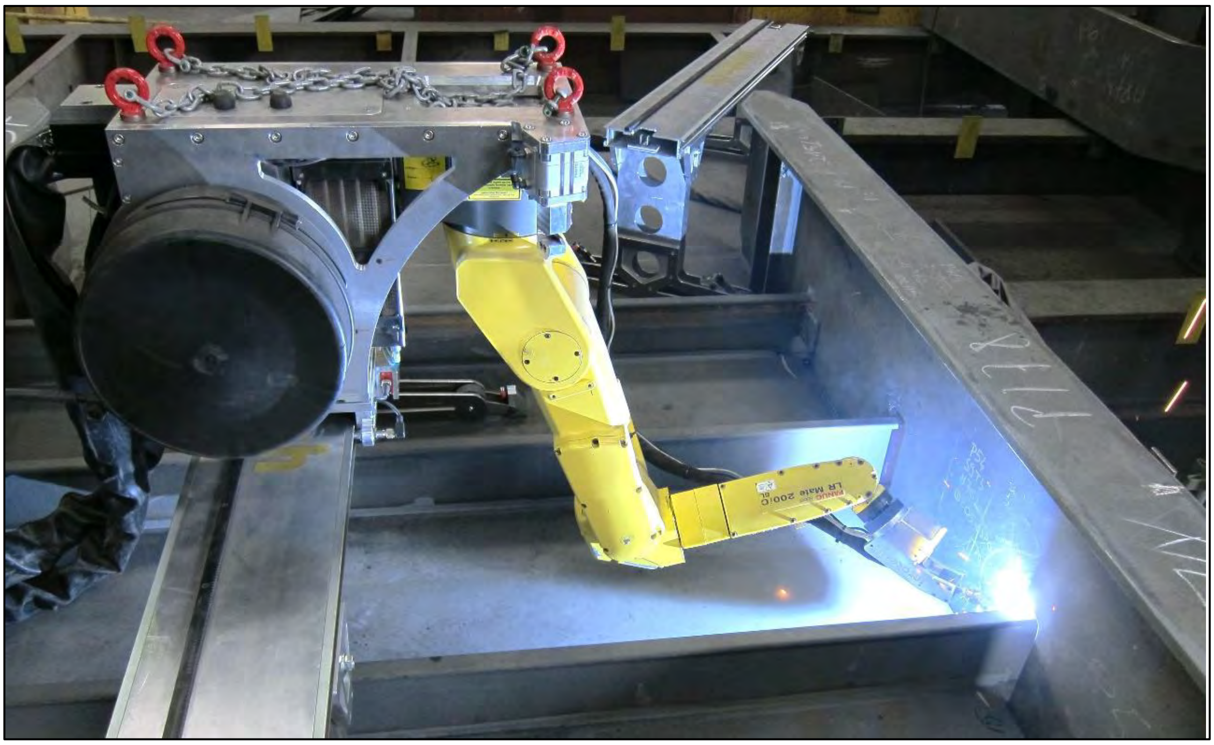


Figure 4-36 Robotic welding concept which might also be used for fillet welds between diaphragms/stiffeners, troughs and deck

Based on experience from shipyard applications, a duty cycle (amount of time the weld arc is actually on) of 60-70% can be expected. A suitable welding process would be flux cored arc welding. It is expected that one operator could control a couple of robots.

Another application could be the welds between diaphragm trusses and flanges, see Figure 4-37.

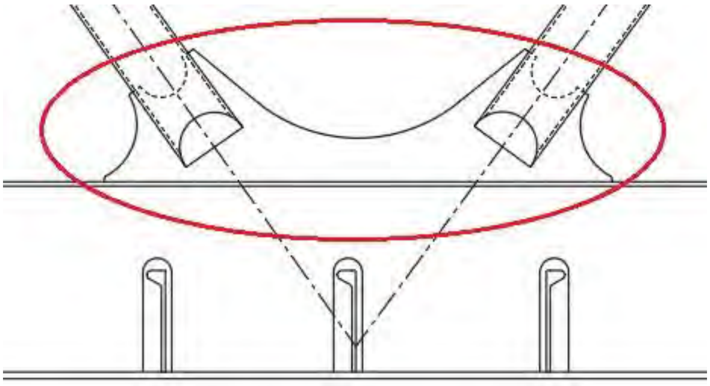


Figure 4-37 Joints between diaphragm trusses and flanges can be another case for robotic welding

4.3.5 Welding of troughs to deck, side, and bottom plates

Welding of troughs to panels is always automated, by means of gantries or welding tractors. The process is typically submerged arc welding (SAW/process 121) or flux cored arc welding (FCAW/process 136), occasionally MAG welding (process 135).

Especially for the deck panels, where tolerances are small, troughs should be positioned for tack welding by means of a template/jig which may basically have the shape of a transverse tooth plate, but with corrections for subsequent transverse weld shrinkages in the panel plate.

Figure 4-38 Gantry for welding on both sides of a trough simultaneously with submerged arc welding on the Pont de Normandie. Some gantries will now be able to weld all troughs on a panel in one take

Figure 4-39 Robotic welding gantry in China. Process could be metal cored wire welding, or possibly MAG/CAW

While transverse weld shrinkages can be compensated for by positioning the troughs slightly further apart when they are tack welded, other measures must be employed to compensate for longitudinal and lateral curvature of the finished panel. This will often be done be means of pre-bending, but application of heat on top of the troughs to counteract longitudinal bending is also an option.

Figure 4-40 Deck panel with troughs on fixture, in China

Welding of trough splices at joints between panels is normally performed manually, with a requirement for full penetration between trough and deck, see Figure 4-41.

Because of tolerances for plate misalignment as well as gap variations due to grinding of the transverse welds, welding automation would require a rather advanced adaptive control of the weld process (open loop or preferably closed loop control).

This could possibly be addressed in e.g., one or two Ph.D. projects.

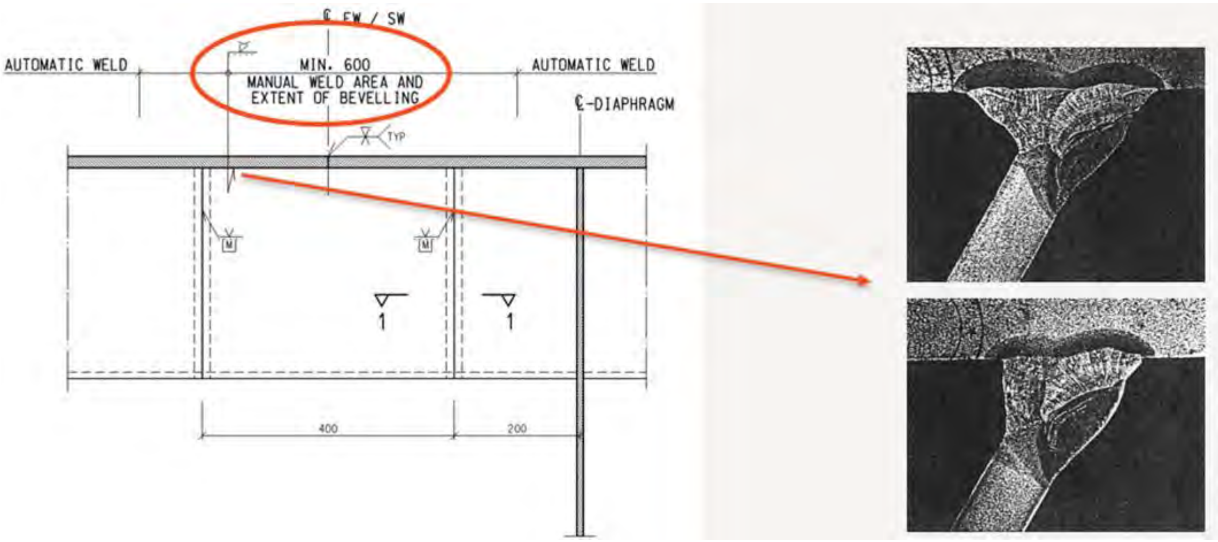


Figure 4-41 Welds between trough splices and deck are normally performed manually, with a requirement for full penetration

5 Construction of Cable Stayed Bridge

5.1 Construction of the approach bridge

The approach bridge comprises a concrete box girder supported on several piers, also constructed in concrete. Several construction methods will be available:

- Traditional scaffolding
- Span-by-span construction using movable scaffolding beam (MSS)
- Balanced cantilever construction from each pier
- Incremental launching

Here the span by span construction using movable scaffolding beam is chosen and described.

5.1.1 Construction of abutment and piers

The works start with access road to the south abutment and ground works for the south abutment, tower foundation and side span piers, with access roads between these sites including a temporary connection to Svanhelleholmen.

The abutment is a reinforced concrete structure, which can be constructed using traditional formwork.

Foundations for piers are constructed in situ.

The piers are assumed to be casted using climbing formwork.

5.1.2 Construction of the tower

After having completed the foundation, a temporary working platform can be installed at the foundation, serving as access and storage area for the construction of the tower.

The tower is constructed using climbing formwork, alternatively by slip forming. Temporary strutting between the tower legs is required due to their inclination. Prefabricated reinforcement cages are transported on barge and loaded onto the working platform for installation by tower crane. Concrete can be provided from an onshore batching plant or directly from a floating plant on a barge.

The tower cross beam is cast supported by temporary scaffolding spanning between the legs.

Construction of the tower can be done simultaneously with the construction of the abutment and approach bridge piers.

When reaching the level of the stay anchorages, steel anchor boxes are installed.

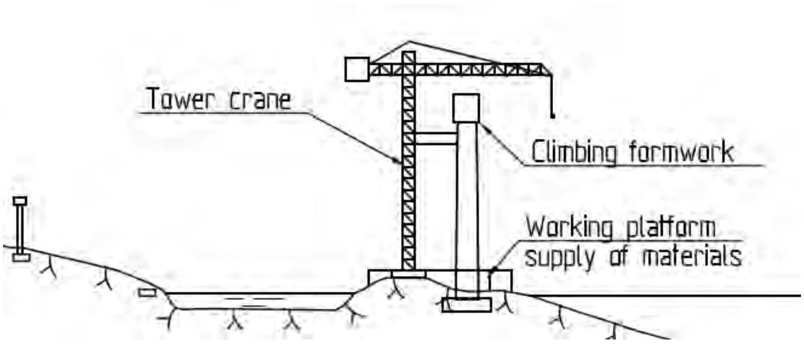


Figure 5-1 Construction of tower

5.1.3 Construction of the concrete bridge deck

After completion of piers, span-by-span construction of the concrete side spans can begin from axis 1. An overhung or underhung moving scaffolding system is shifted along the bridge span by span. The bridge deck is cast monolithically to the pier tops (no bearings). The bridge structure is longitudinally post-tensioned as necessary for the construction stage. Full tensioning can await completion of the concrete works. For an underhung system the reinforcement can easily be prefabricated on land to speed up the construction process. The cross section will normally be casted in two operations, first the trough and then the bridge slab. The construction joint between two spans can be located approximately 0.2*L out in the span. The scaffolding system will be fixed at the construction joint and to a support at the column. Span by span will then be casted with transport of the material on the casted bridge. This is a much used method both on Norwegian and foreign bridges.

5.2 Construction of the cable stayed steel bridge deck

The bridge deck is installed using the balanced cantilever method, working out from the tower towards the side span and the main span simultaneously.

5.2.1 Erection of the pier table

The first two sections closest to the tower are installed, with a floating crane, on temporary supports and skidded into position. The bridge cross section is temporary fixed to the tower for translation in longitudinal and vertical direction and for rotation of bridge deck around all axes. After adjustment of the position the joints between the sections are welded and the corresponding two stay cables are installed.

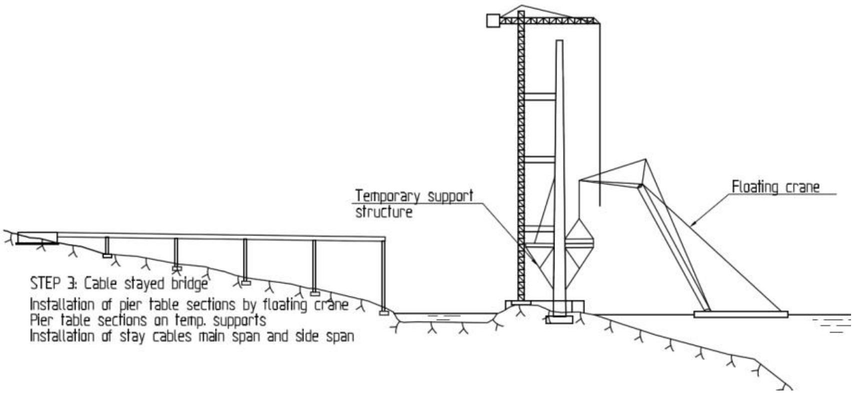


Figure 5-2 Installation of the two first sections to tower

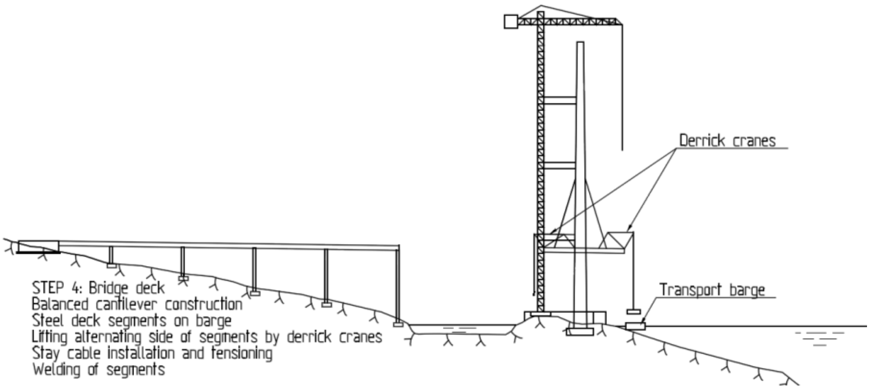


Figure 5-3 Installation of the first cable stays

5.2.2 Balanced cantilever construction

On the tower sections, derrick cranes are installed at the side span side and on the main span side. Installation of the bridge deck is done section by section, alternating between main span and side span and is coordinated with the installation of the corresponding stay cables. A possible construction sequence can be:

- Transport of the deck section on barge to bridge site.
- Lifting of the deck section by the derrick crane located on the previously installed deck sections.
- Attachment of the lifted section to the previous section and adjustment to the correct geometry. The weight of the lifted section remains supported by the derrick crane.
- Start welding of the deck joint.
- When a pre-defined amount of the deck joint is completed, installation of the corresponding stay cable can be commenced.
- Welding of the deck joint is continued and completed.
- Tensioning of the stay cable
- The derrick crane is released and moved forward to the next lift.

The installation sequence can be optimized to reduce the cycle time and is expected to be in the range of 14-21 calendar days.

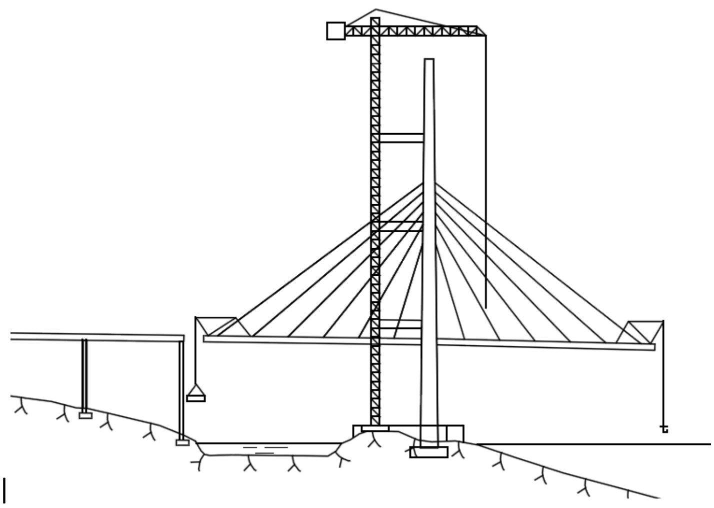


Figure 5-4 Cantilever construction

5.2.3 Closing at the side span

The deck section is lifted and attached to the previous sections according to the sequence mentioned in section 5.2.2.

The correct relative geometry of the joint between the concrete bridge and the cantilevered steel deck can be provided by adjustment of the 1 to 2 outermost stay cables in the side span and/or adjusting the position of the derrick crane.

When the correct position of the steel deck is ensured, the concrete stich is cast, and the prestressing cables connecting the steel section to the concrete section can be stressed. The derrick crane at the side span can be dismantled. The temporary fixations to the tower can be released.

5.2.4 Completion of the main span deck

After having connected the bridge deck to the approach bridge deck at the side span, the balanced cantilever construction is continued in the main span following a similar sequence as described in 5.2.2.

The overall construction sequence could be:

- Installation and tensioning of the corresponding stay cable in the side span
- Lifting of the section in the main span
- Connecting and welding of the deck joint
- Installation of the corresponding stay cable in the main span
- Advance the derrick crane in the main span
- Installation and tensioning of the next stay cable in the side span

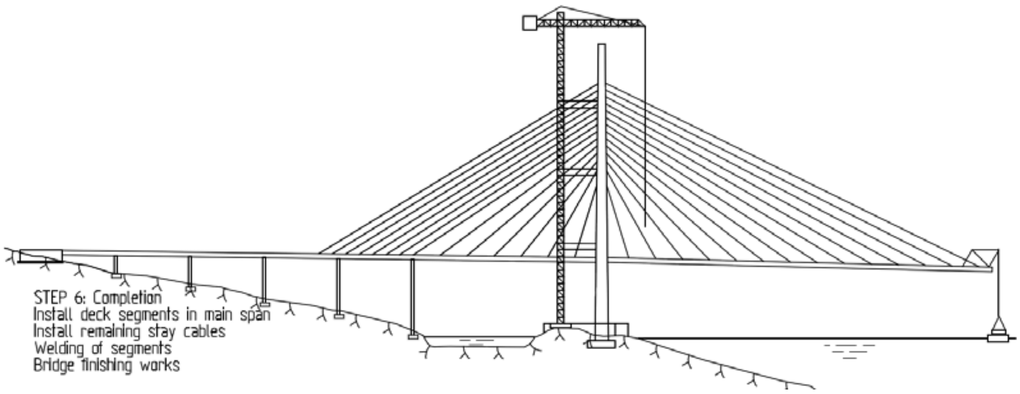


Figure 5-5 Construction of the main span deck

5.3 Installation of stay cables

It has been chosen to use In-situ fabricated cables in this study, (type Freyssinet, VSL and similar). The cable stays are multi-strand type with 31 to 67 numbers of strands, each 15.7mm dia. having an tensile strength of 1860 MPa. The 31 strand cable thus has a breaking load of 8.6 MN, and the 67 strand cable 18.6 MN.

The installation of the stay cables should be done using the length of the stay cable as the primary installation parameter and thus the force as the secondary. Due to the relative flexible steel deck girder, even small variations in the load could result in large deviations in the geometry of the bridge deck.

On the concrete part of the bridge deck, the stay force may be the primary installation parameter

6 Construction of Abutments

6.1 North Abutment.

The abutment is a large concrete box structure with longitudinal walls lining up with the longitudinal bulkheads in the steel floating bridge transition section. The concrete volume is about 8000 m^3, and 140 longitudinal pre-stressing tendons secure the connection to the bridge.

For stability the abutment will be filled with 12000 m^3 iron ore solid ballast.

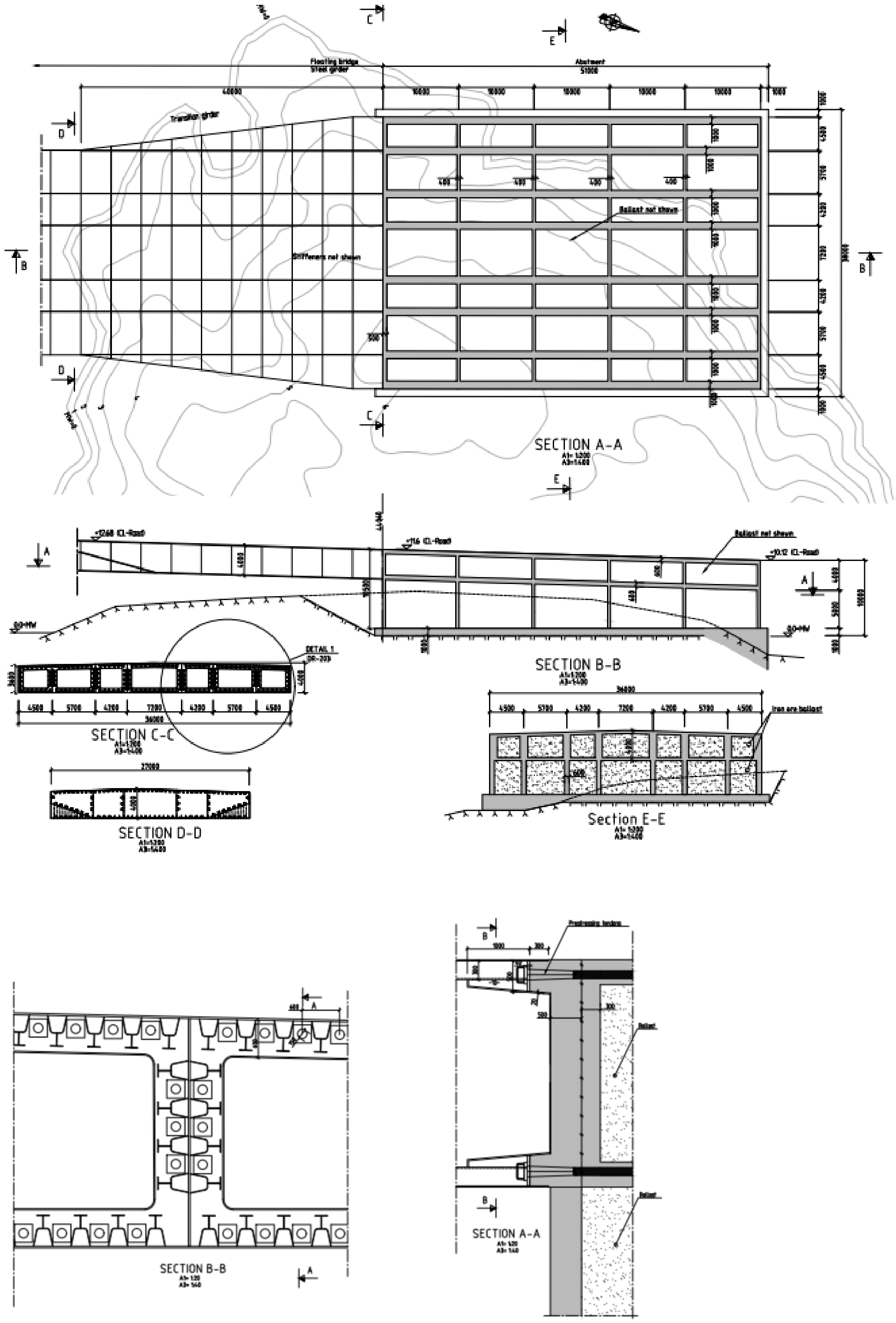


Figure 6-1 Abutment north design layout

The steel transition section is 40 m long with a weight of 950 tons. It should be lifted with a crane vesssel with outreach of approximately 40 m. The sheerleg vessel Taklift 4 has 1100 tons capacity at this outreach.

The following main steps shall be performed for the construction of the north abutment, see Figure 6-2.:

- Establish access from shore.
- Perform blasting and scaling.
- Cast bottom slab and lower walls.
- Fill iron ore heavy ballast into lower compartments utilizing a self unloading bulk carrier, e.g. Nordnes.
- Cast upper part of the abutment and complete ballast filling.
- Construct a temporary support for the steel transition section.
- Lift the transition section with a floating sheer leg, e.g. Taklift 4, onto the support at the abutment and the temporary support.
- Install prestressing tendons, cast the gap between the abutment and the transition section, and stress the tendons.

If the connection between the north short section and the transition sections (Joint 1, ref. section 9.4) show high stresses due to tide variation, an additional girder segment could be installed in the similar way on fixed supports and welded to the transition section. This give one additional lifting operation during this part of the installation.

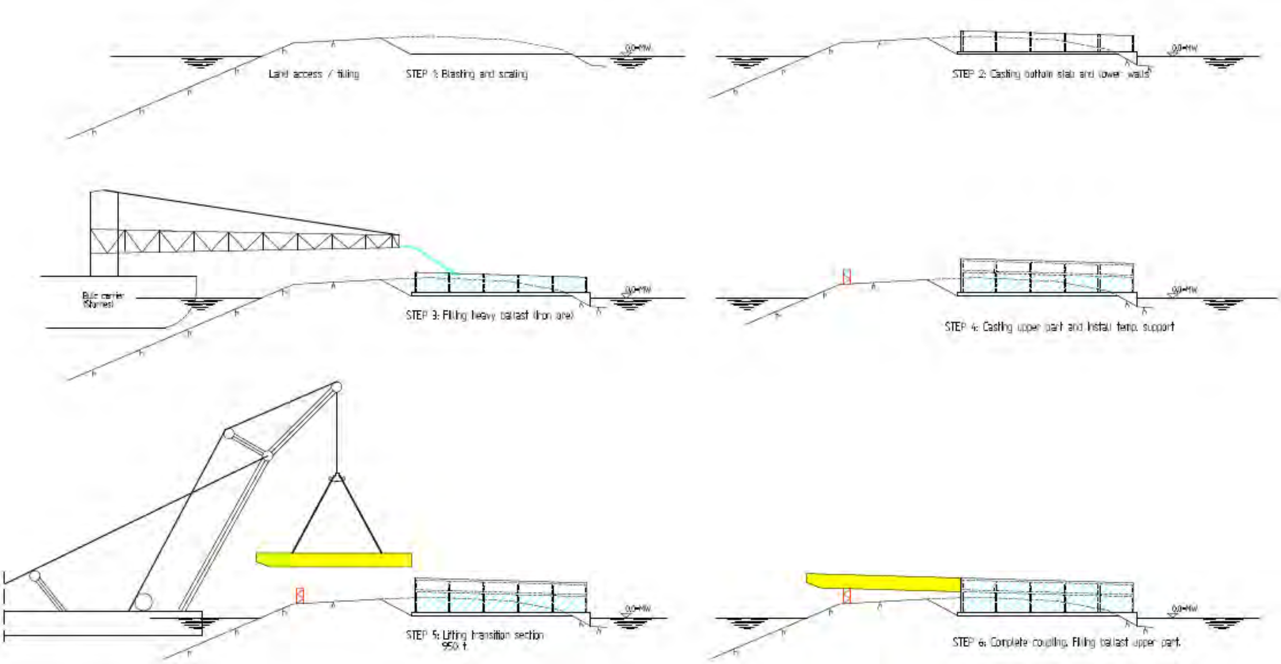


Figure 6-2 Construction of north abutment

Figure 6-3 Taklift4 crane vessel (© Boskalis)

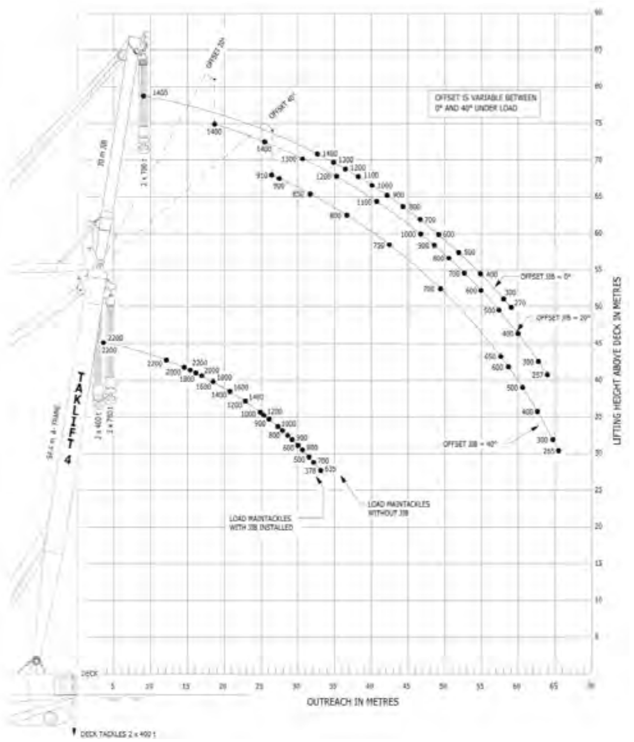


Figure 6-4 Crane curve Taklift4 (© Boskalis)

6.2 South abutment

The south abutment needs a length of 30 m with width equal the bridge width of 28 m. The height 9.5 m is chosen as it fits well with the terrain and gravel ballast can be used. The concrete volume is about 4000 m3.

The abutment is connected to a concrete bridge to which it will have a monolithic connection.

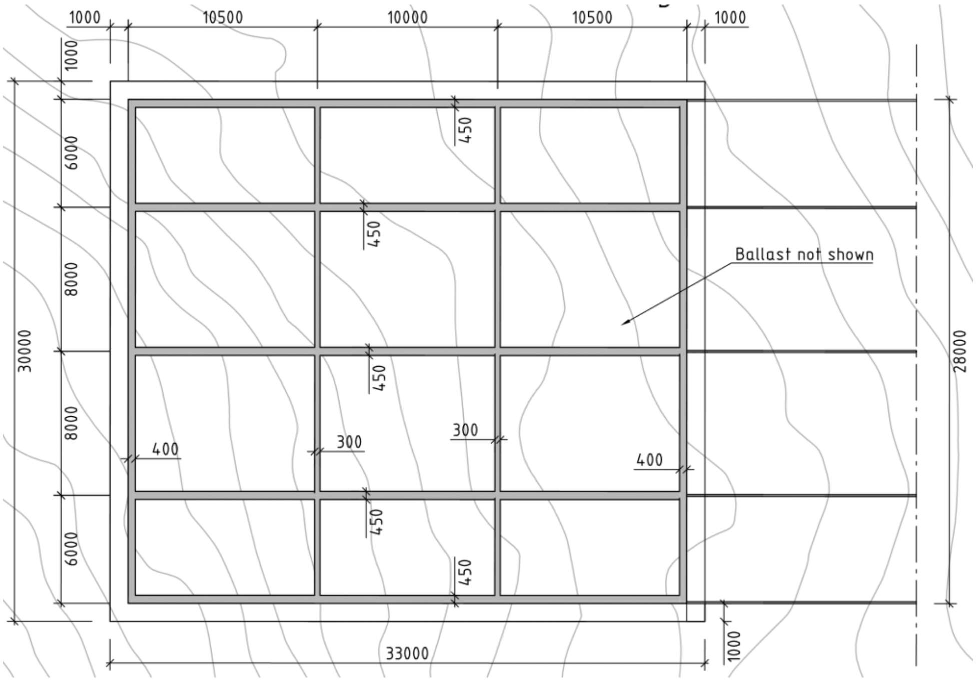


Figure 6-5: South abutment plan view

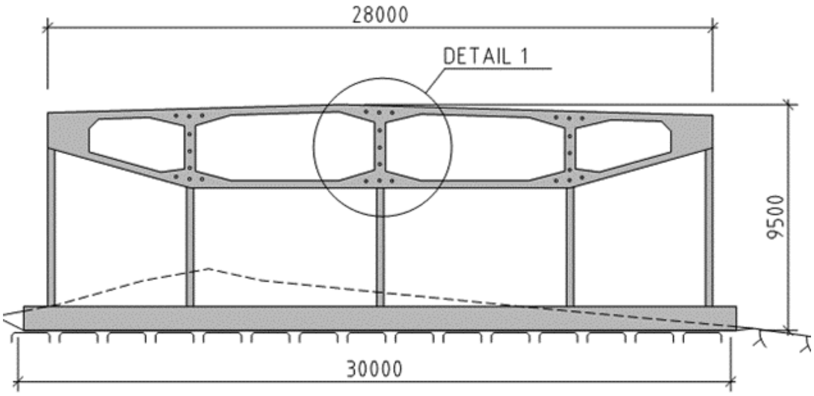


Figure 6-6: South abutment elevation view

7 Assembly of floating bridge sections

The assembly of the floating bridge sections will take place in Søreidsvika to the south east of the final location of the Bjørnafjorden bridge.

The floating bridge will be assembled at two different locations in Søreidsvika; one for the low floating bridge and one for the high floating bridge. The short north section will be assembled at the same assembly site as the low floating bridge.

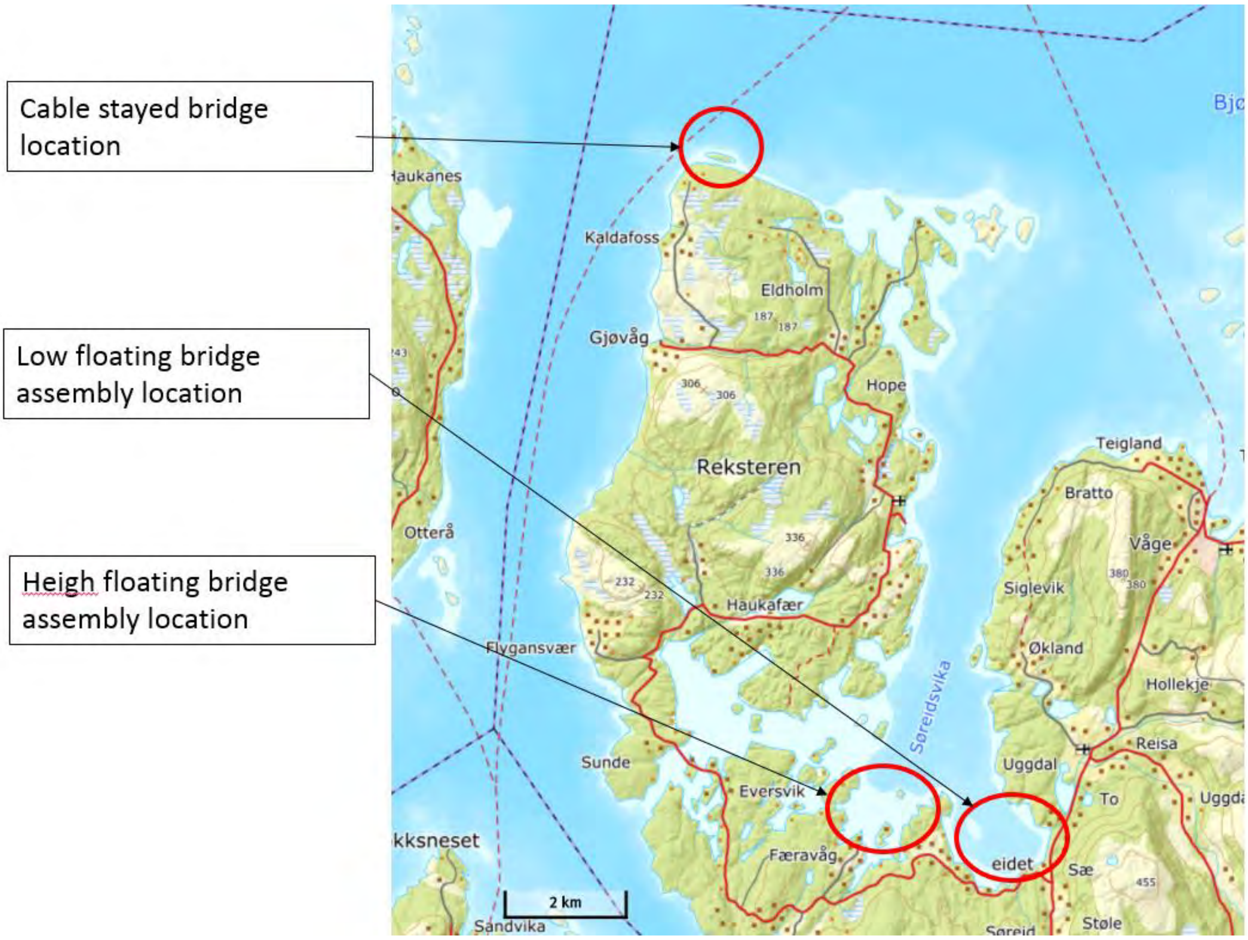


Figure 7-1: Locations for assembly of the floating bridge

7.1 Assembly site and site set-up

The bridge girder will be welded by combining 25m long bridge girder segments. Every 125m there will be a column and a pontoon. The factory is designed such that 150m of bridge girder can be assembled. Once the 150m section is finished, the bridge will be pulled further out in the assembly fjord and a new section will be constructed. For the assembly of the low floating bridge, three North Sea barges are used as a platform for welding of the bridge girder segments. The barge needs to be set up with a skidding system in order to accommodate the pay out of the bridge after the 150m section is finished. In order to be able to float in the pontoon with column, the skidding system needs to be elevated approximately 10m. The layout is shown in the figure below.

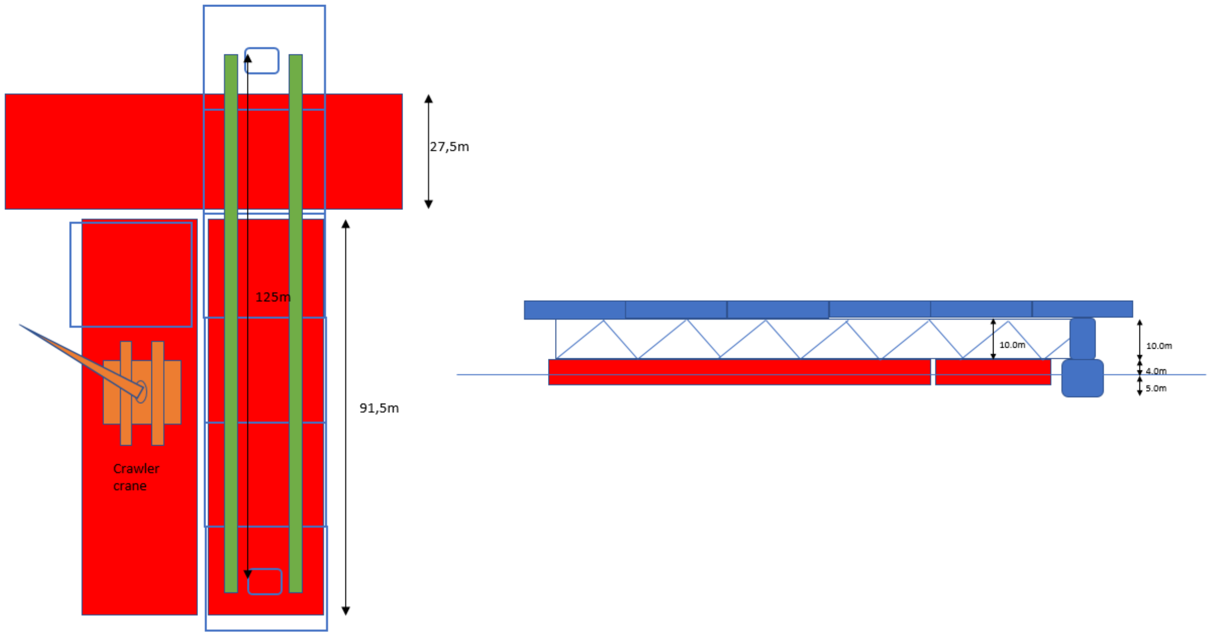


Figure 7-2: Low floating bridge assembly site set up

The 3 barges for the assembly site will be moored together as shown in the above figure. The elevated skidding system will be extended over the length of one barge and the width of one barge. The skidding system is assumed to have a cantilever outreach in order to support the bridge girder segments that will be connected to the column. The length of the skidding system needs to support 6 bridge girder segments.

The third barge will be equipped with a heavylift crawler crane for lifting the girders from a transportation barge and onto the skidding system. This barge may also be used for storing bridge girder segments and other equipment.

The barges will be moored at the south east (inner) end of Søreidsvika providing good shelter for the welding facility. An access platform from shore to the barges will be installed.

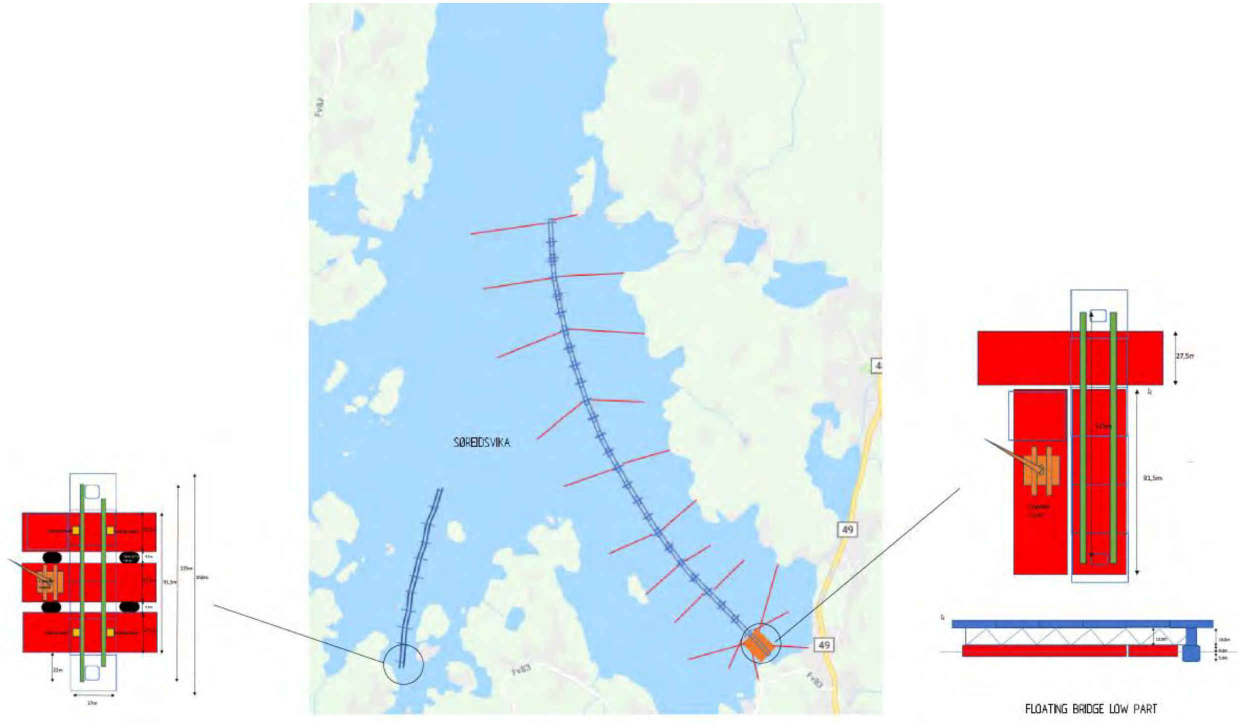


Figure 7-3: Low bridge and high bridge assembly site set up location in Søreidsvika

The set-up for the high floating bridge is similar to the one for the low floating bridge. The assembly will also take place on three North Sea barges. For the high bridge they are arranged differently, in order to increase stability. The assembly method is based on jacking towers. The barge needs to be moored a distance from shore for the pontoons to be connected at both sides of the barge. To allow for land access a spacer barge or similar may be utilised. The barges will be equipped with a grillage support system to support up to 6 bridge girder segments(150m). In addition, there will be 4 jacking towers that can jack the assembled bridge section (5 or 6 girder segments) to the defined height for installation of the columns and pontoons. The barges will also be equipped with a heavylift crawler crane to lift girder segments onto the grillage support. The grillage support beams will also need a skidding system in order to get the bridge girder segments to correct position for welding. In the figure below the high bridge assembly set up is illustrated.

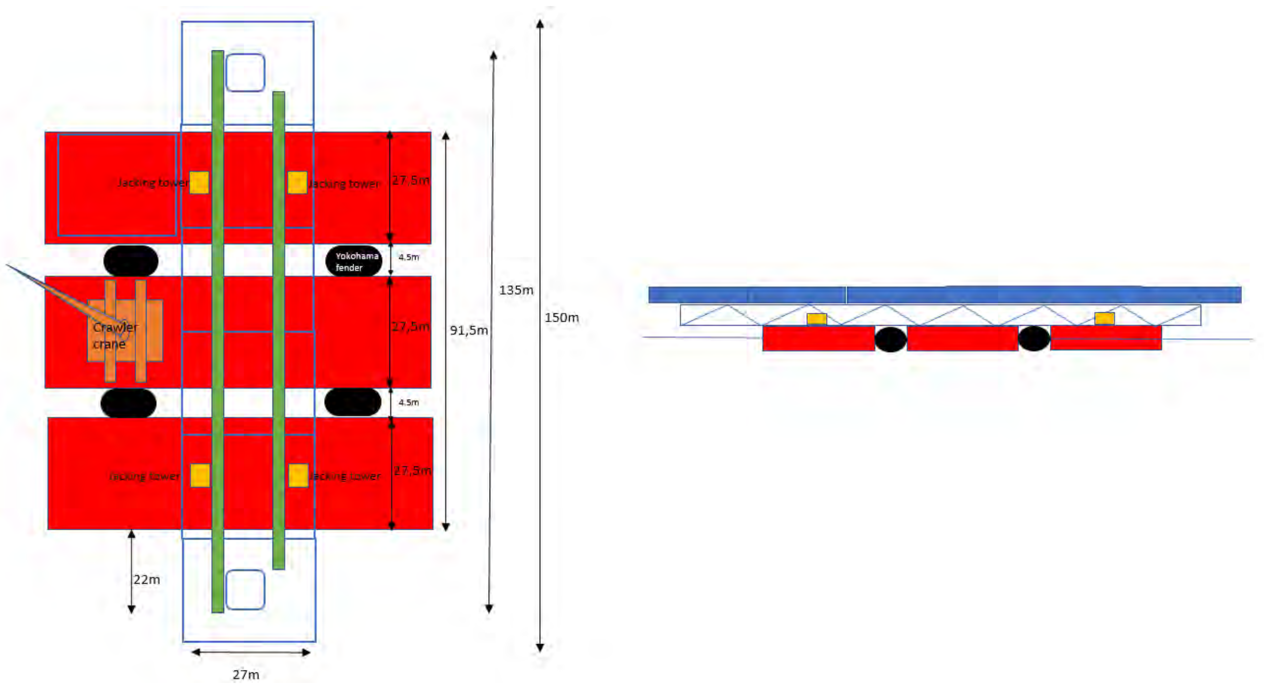


Figure 7-4: High floating bridge assembly site set up

7.2 Low floating bridge assembly method

The method for assembly of the low floating bridge is illustrated in figure below.

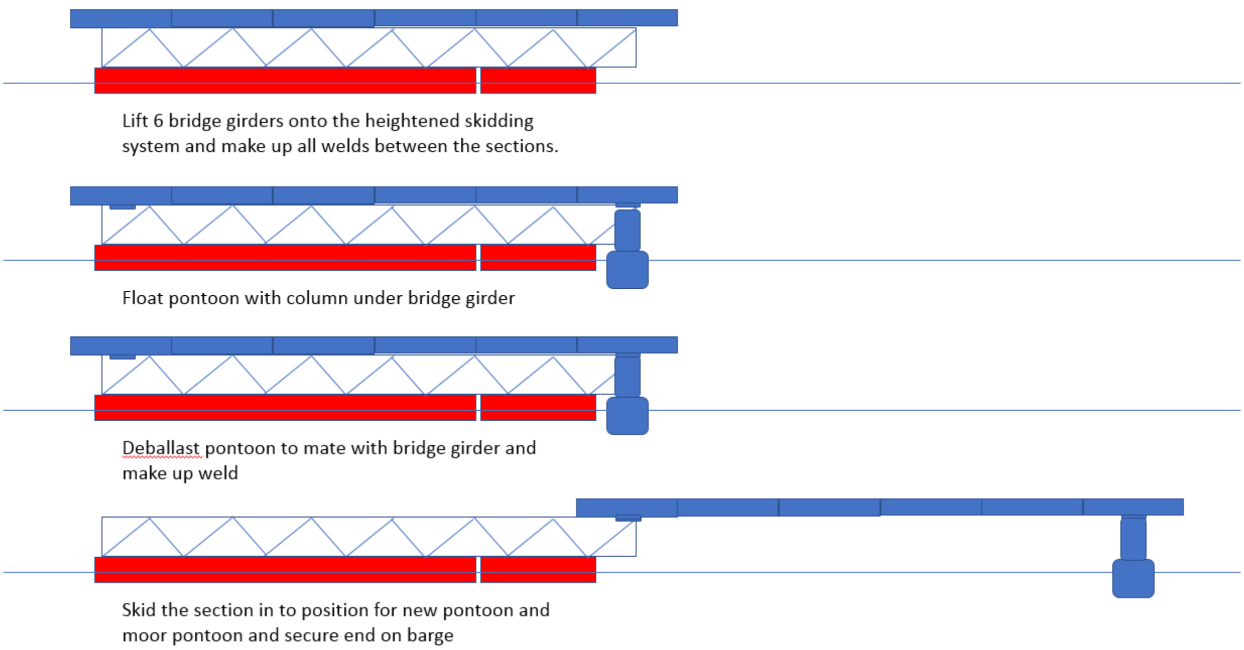


Figure 7-5: Low floating assembly sequence – 1

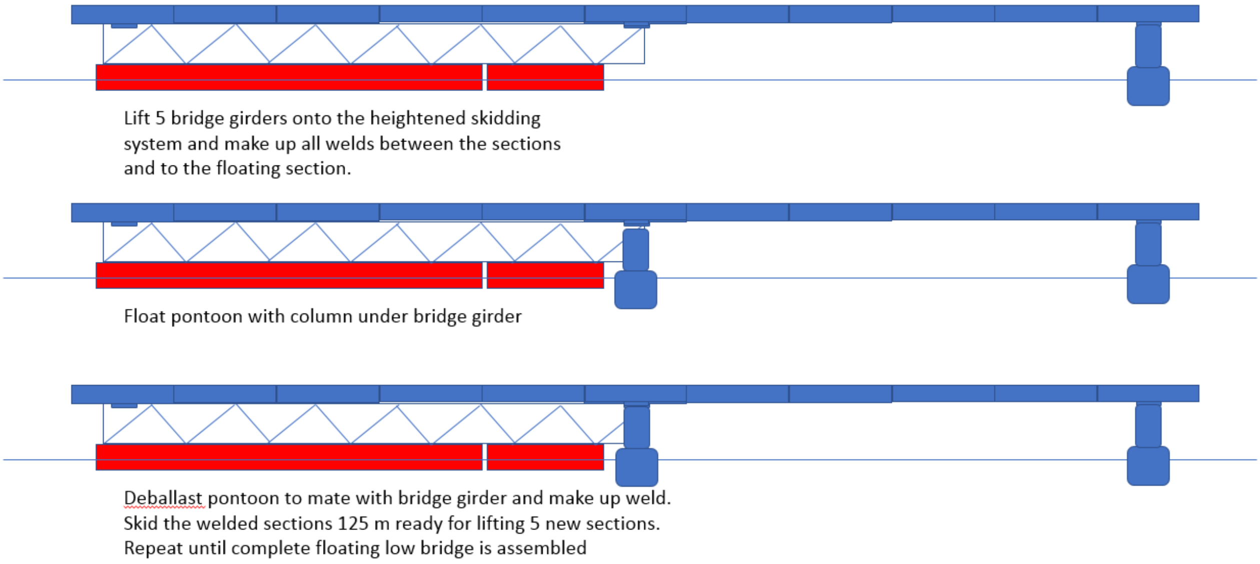


Figure 7-6: Low floating assembly sequence – 2

The process described above is repeated until all bridge girder segments and pontoons for the low bridge are assembled. The assembled bridge is secured with moorings as it is skidded out from the barge.

The bridge girder segments will be fabricated with stopper plates and locking devices. When the segments are lifted onto the skidding system the stopper plates are aligned and locking devices activated. There will typically be more locking devices between the girders on the barge and the floating section where there might be some environmental loads. The locking system will be similar to the locking system presented for the joints in Bjørnafjorden, but scaled down to suit the environmental loads. A similar system will be used in the connection between the girder and columns/pontoons.

All the bridge girder segments will have a designated position from fabrication and each connection between the segments should be pre-assembled during fabrication to verify that the connecting girders will match. All the bridge girder segments will be straight, with skew connection to achieve the curvature of the bridge.

When 5 bridge girder segments and a pontoon/column have been assembled, the assembled bridge will be skidded/pulled 125m north (out from the barges). When pulling the bridge, the moorings will need to be rearranged.

7.3 High floating bridge assembly method

The method for assembly of the high floating bridge is based on the method for the low floating bridge and on utilizing jacking towers.

Figure 7-7: Examples of jacking towers (from ALE)

Jacking tower systems from ALE has been used for this study.

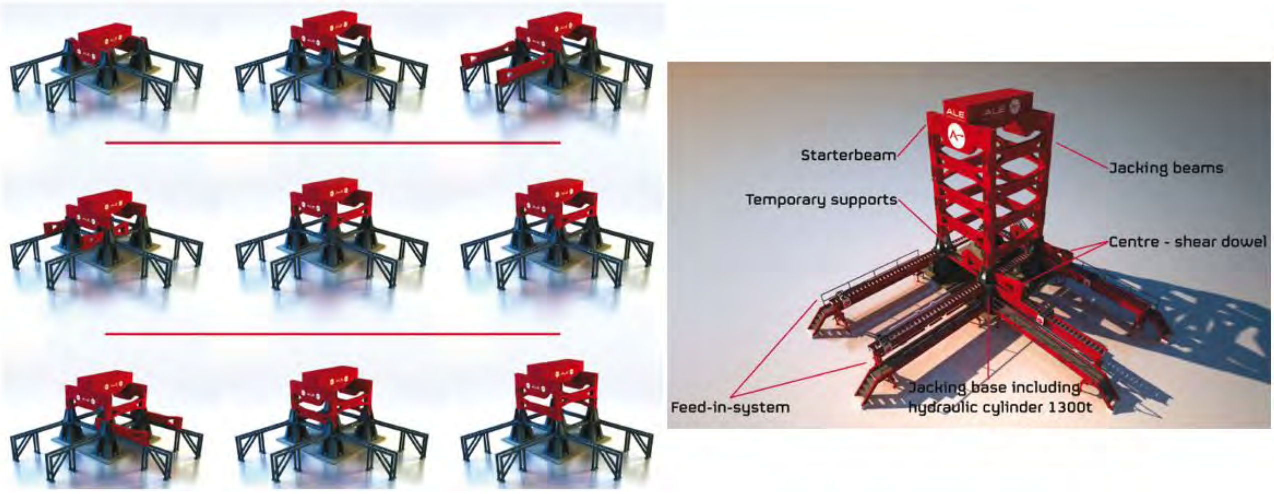


Figure 7-8: Jacking towers principle

The method for assembly of the high bridge is illustrated in figure below.

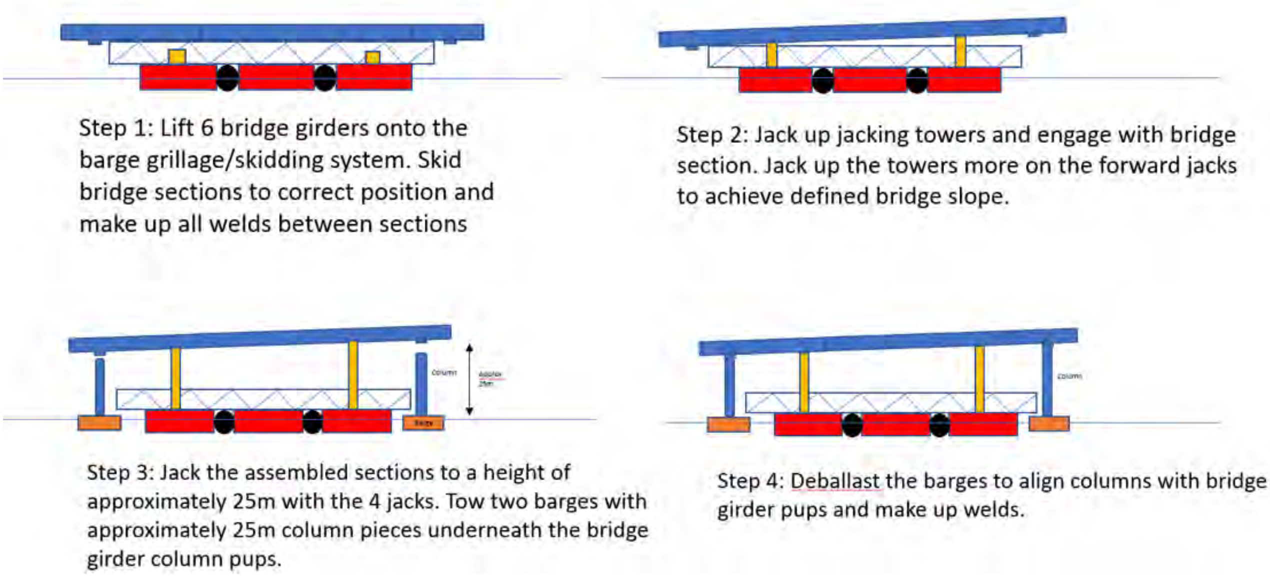


Figure 7-9: High floating assembly sequence – 1

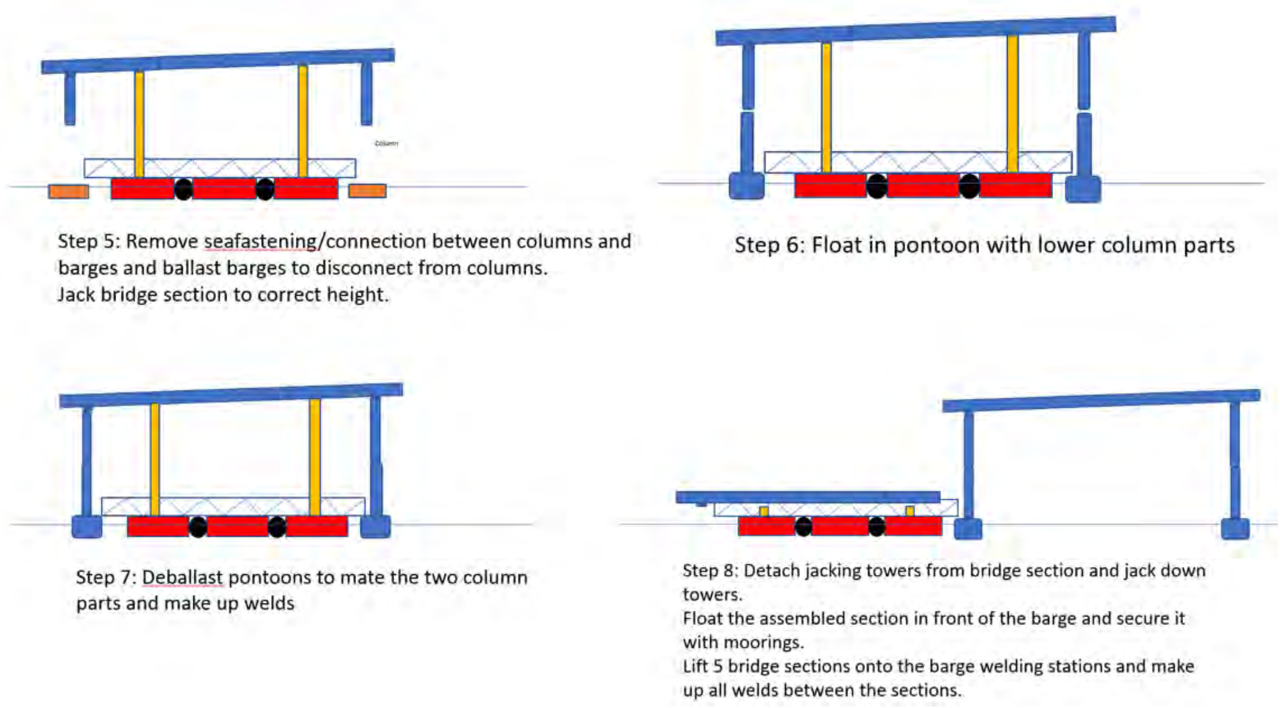


Figure 7-10: High floating assembly sequence – 2

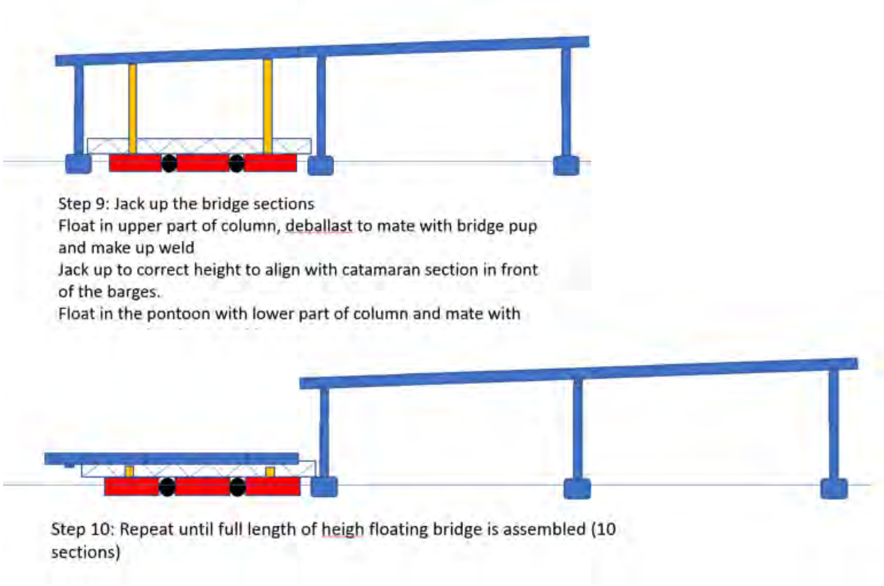


Figure 7-11: High floating assembly sequence – 3

The supplier of the jacking towers (ALE) have performed a feasibility study of this method. Their conclusion is that the working methodology is considered as viable and realistic. The feasibility study is enclosed in this report (Enclosure /2/ and /3/).

7.4 Stability of Pontoons

The single pontoon with a 30m high column has been checked for intact and damage stability against the criteria of DNV-OS-H101. The pontoon has been ballasted to a draft of approximately 4m. The pontoon with column fulfils all requirements in this condition.

7.5 Stability of Pontoons and high bridge section

The highest catamaran section (two pontoons with a 150m bridge section) has been checked for intact and damage stability against the criteria of DNV-OS-H101. The catamaran fulfils all requirements in this condition.

7.6 Connection of low floating bridge and high floating bridge

The high floating bridge and low floating bridge will be assembled in parallel in Søreidsvika. The two sections will be joined together in Søreidsvika prior to the towing operation to the destination. The mating operation of the two bridge sections will follow the same principles as the final connections in Bjørnafjorden. Reference is made to Section 10.4. The jointing operation will also be useful with regards to proving the jointing/mating methodology prior to the final installation.

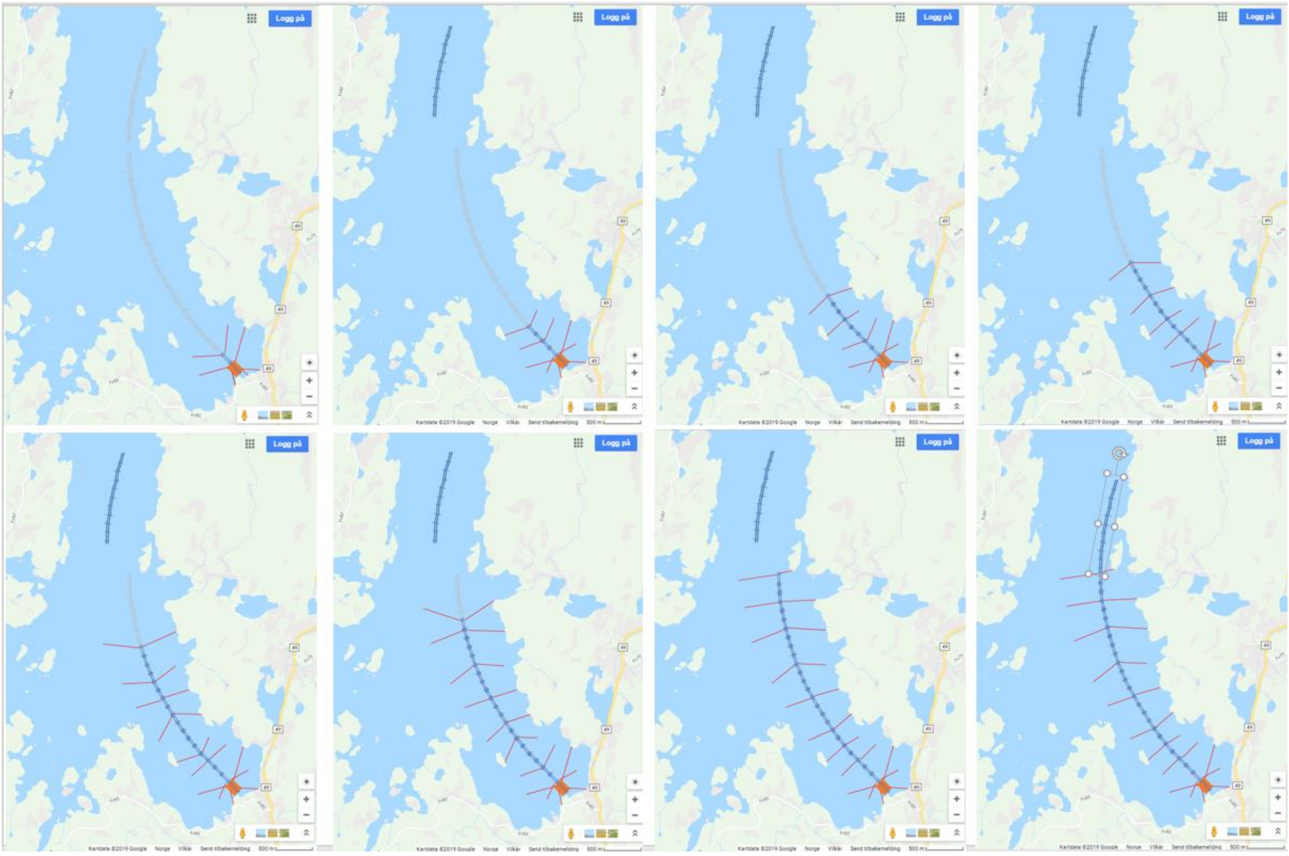


Figure 7-12: Low floating assembly and mooring process

7.7 Mooring system for assembled sections

The bridge construction will last in excess of 180 days and therefore the moorings will need to withstand 100-year wind and Hs criteria as well as 10-year current criteria.

The prevailing weather direction is along the fjord (and thus along the bridge)

Table 7.1: Metocean values for Søreidsvika to be used in moorign design

Type	Description
Wind	23m/s (50 year value)
Waves	Hs= 0.54-1.11m (depending on sector and location in fjord) Tp= 2.5-4.5 s (depending on sector and location in fjord)
Current	0.5-0.77m/s (depending on sector and location in fjord)

As the floating bridge is assembled and skidded away from the barge, the floating bridge will be moored. The moorings will be attached to anchors or onshore bollards where feasible. The mooring system will typically be arranged as shown in the figure below. Towards the fjord there will be a heavy (bottom)chain which is connected to an anchor pontoon. From the anchor pontoon to the bridge pontoon there is a wire/fibre rope. Towards the east, one will try to use as many onshore locations as possible for mooring. Here a synthetic rope (for elastic damping) will most likely be used.

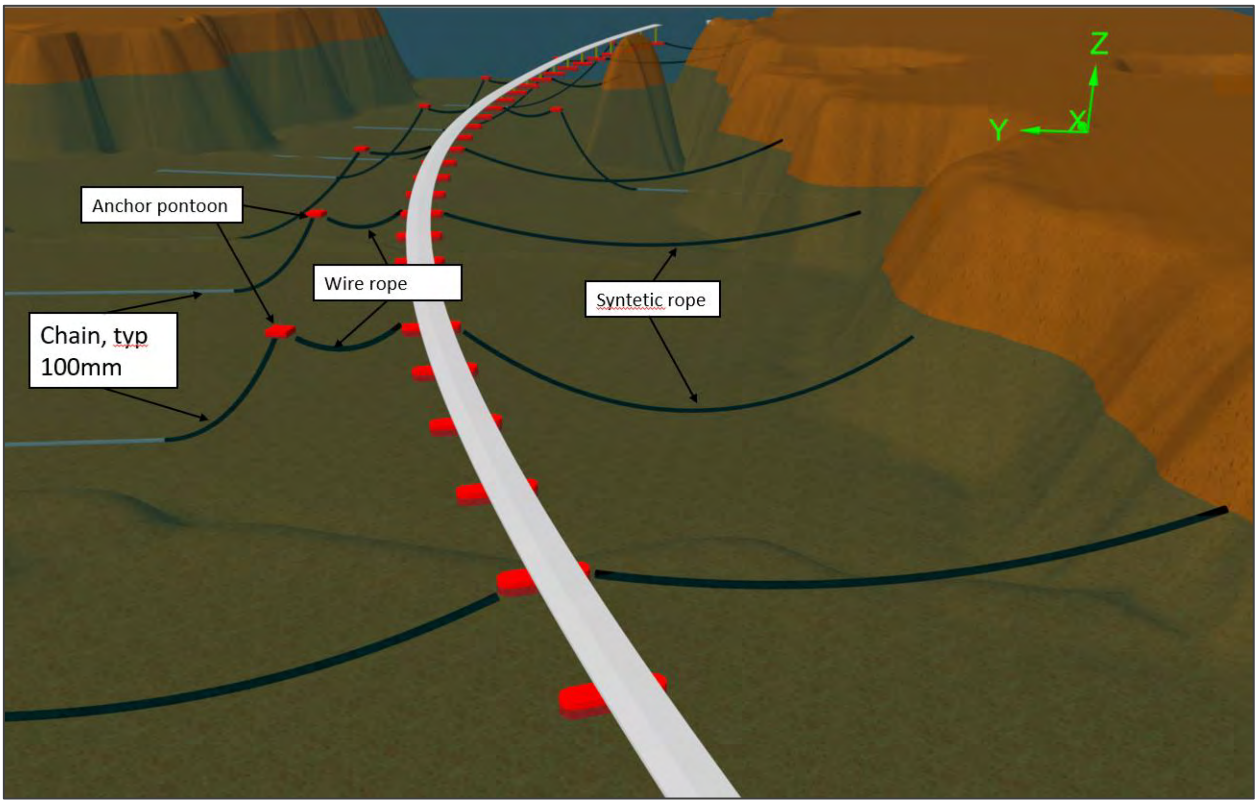


Figure 7-13: Typical moorings system layout

The figure below shows a screenshot from the preliminary Orcaflex analysis.

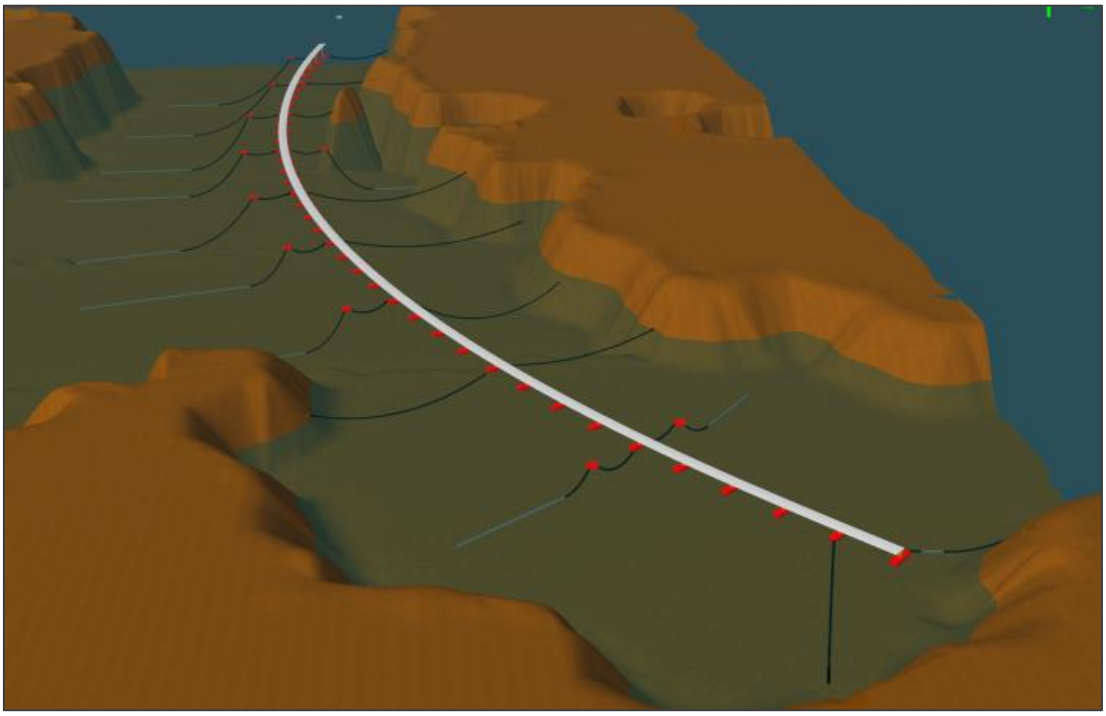


Figure 7-14: Mooring arrangement just prior to completion of bridge

The 50 year return values (100 year was not given) for wind have been assessed in order to find the following requirements for the holding capacity of the mooring system. From the most adverse direction the mooring system needs to withstand about 9000kN of force from Wind. The forces due to current are limited, upto 700kN in the longitudinal direction and 400kN in the cross direction.

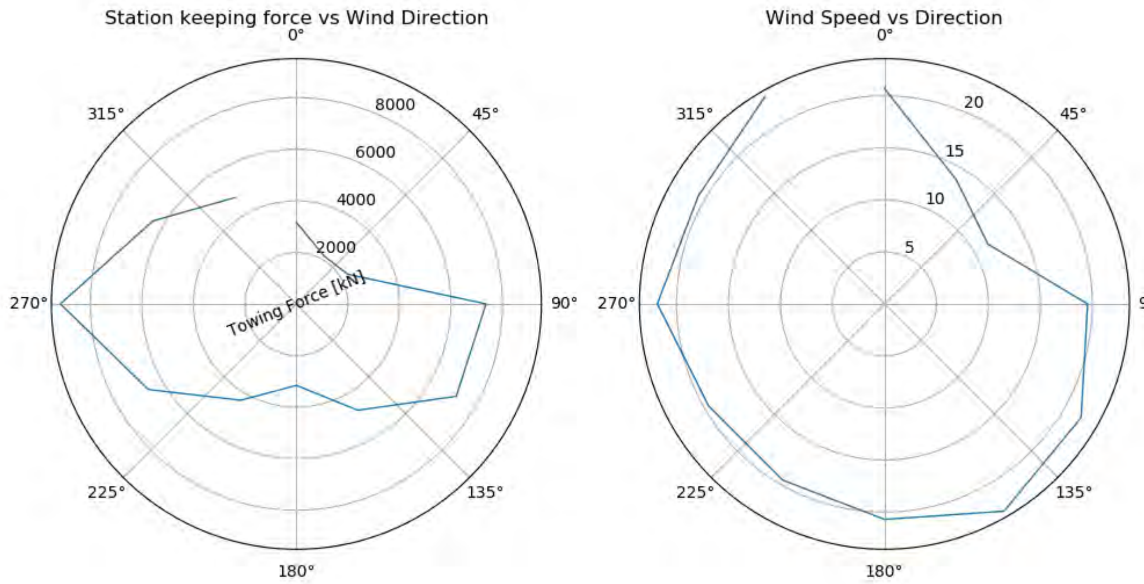


Figure 7-15: Forces acting on the bridge due to wind. (Wind from north = 0 deg)

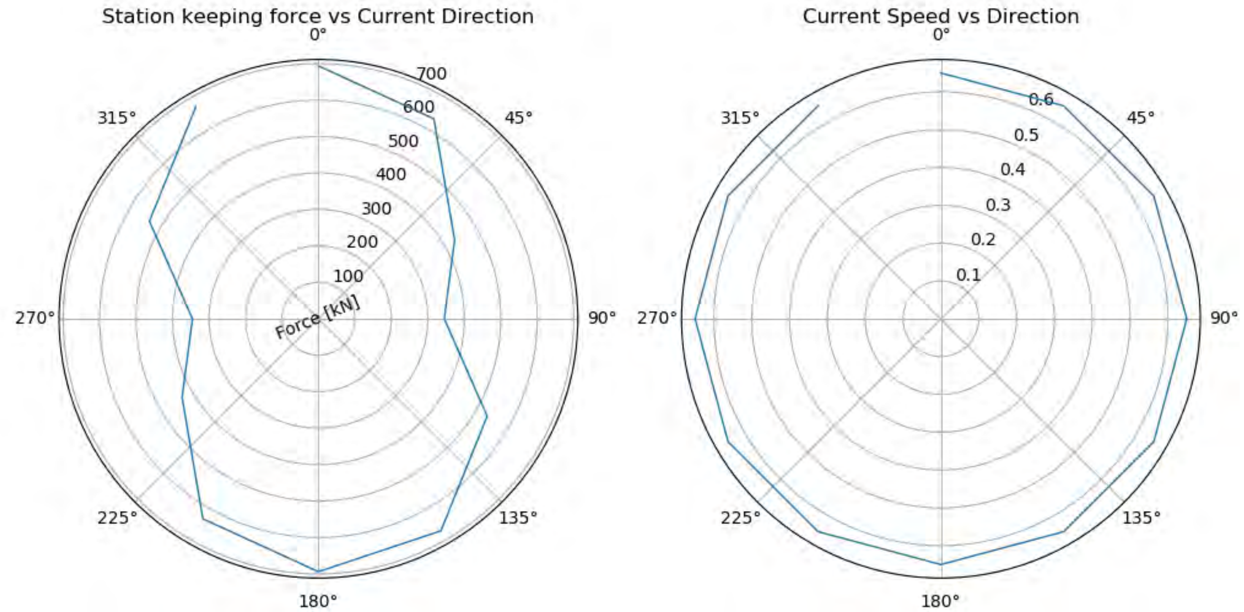


Figure 7-16: Forces acting on the bridge due to current. (Current towards north = 0 deg). Omnidirectional assumptions.

It has been assumed that there are 10 mooring pontoons (every 4th pontoon) and that the bridge can drift up to 17m sideways in extreme weather conditions.

The mooring system will be designed such that a single mooring line failure easily can be accounted for.

Chains with diameters of 100mm are utilized. Such chains can be rented given enough lead time.

Table 7.2: Mooring system dimensions

Water Depth	Layback	Chain Diameter	Horizontal pre-tension at pontoon
50	120	100mm	300kN
100	250	100mm	600kN
200	300	100mm	700kN

The length of the mooring lines will be planned such that transfer of mooring lines is easily facilitated during movement of the bridge. Winches will be placed either on the anchor pontoons or on the bridgepontoons in order to be able to adjust the pre-tension. When the bridge shall be moved the tension in the mooring lines is reduced and the bridge is advanced. The movement in the bridge will be facilitated either by a tug,land-mounted winches or the mooring system itself which will pull the bridge. The higher pre-tension in the mooring lines will be re-established once the move is complete. Some of the connections between the mooring lines and the pontoons will be shifted such that the mooring system is balanced at all times.

8 Towing of Bridge Sections

8.1 Design principles for towing operation

During the towing of bridge sections, it is paramount to have control over the towed sections at all times of the operations. The following conditions need to be fulfilled:

- Planning will be performed to minimize exposure of personnel, environment and material The towing fleet needs to have ample power to withstand local environmental conditions and fulfil rule- and regulatory requirements
- The bridge needs to be able to withstand the towing forces applied to it
- At all times there must be accurate control of the positions of the vessels comprising the towing fleet
- At all times there must be accurate control of the position and orientation of the bridge. The deformation of the bridge due to towing forces and environmental forces needs to be considered
- Contingency plans need to be established for incidents such as (but not limited to): Loss of towing vessel, adverse weather, loss of visibility, loss of positioning system, adverse deformation of the bridge
- Holding areas / Waiting on weather areas to be defined
- HAZID, HAZOP prior to installation

Simulation of the towing operation in a simulator is recommended.

8.2 Environmental conditions for towing operation

The environmental conditions applicable for investigating the towing operation can be split in two categories:

- DNVGL towing criteria
    - This is the criteria that will be considered for assessment of storm riding conditions. The following parameters have been considered:
        - Wind Speed: 20 m/s (according to DNVGL rules for towing)
        - Current: 1 m/s (according to metocean data)
        - Towing Speed: 0.5 m/s (according to DNVGL rules for towing)
        - Waves: none
- Operational criteria
    - This is the criteria that will apply to the required weather window to commence the operation. This criterion is not detailed at this stage, but will be significantly lower than the DNVGL towing criteria, assumed to have a maximum wind speed limit of 10-12 m/s. Following this, the operational criteria will not be governing for dimensioning the towing spread.

8.3 Summary of towing forces for planning of operations

The floating bridge will be towed in one section (except for a small north section with two pontoons).

To assess the total forces applicable for determining the towing fleet size, an estimation of the total forces on the bridge based on the DNVGL towing criteria is determined. Figure 8-1 shows the forces for different environmental headings based on the bridge model, where 0 degrees indicate towing along the longitudinal axis. A maximum force of almost 13500 kN is observed.

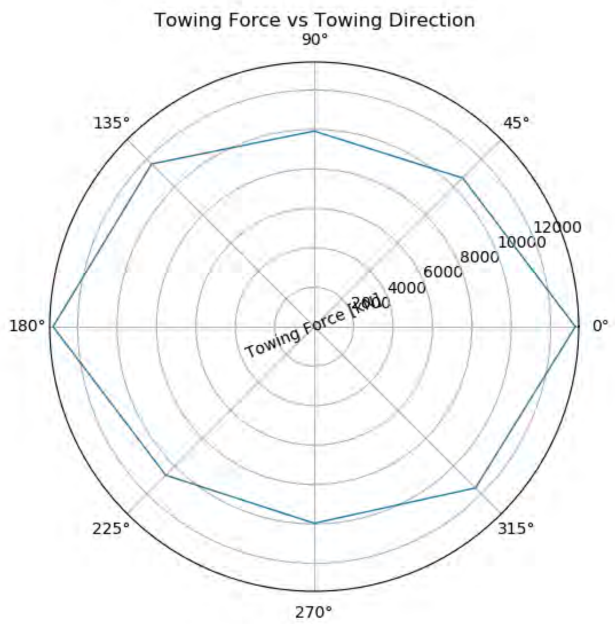


Figure 8-1 Towing forces rose plot

Further, an assessment of the required number of towing vessels is included, based on the following considerations:

- Weather veining is included for by assuming the vessel is aligned with the longitudinal axis towards the weather. In this situation, it is possible to utilize vessels connected on both sides of the bridge. It is further assumed that each tug on average can provide pull at 45 degrees relative to the weather.
- An average bollard pull of 200 tonnes is considered for each vessel, with an efficiency factor of 0.8.
- In total each vessel is on average capable of providing 113 tonnes force towards the weather.
- It is considered that an even number of towing vessels is applied to achieve a symmetric setup.
- It has been confirmed that run off of one of the 200tBP tugs will not lead to compromise of the structural integrity of the bridge (see previous versions of the report)

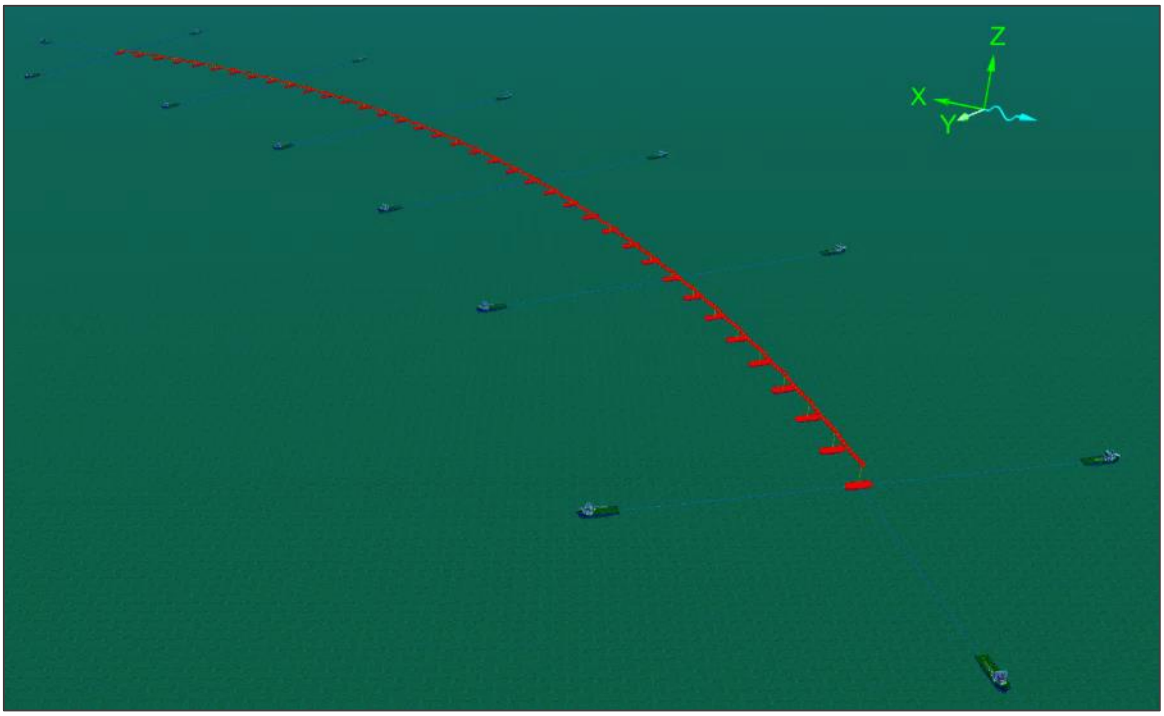


Figure 8-2 Towing configuration – Entire

8.4 Towing Considerations

A total of 12 tugs will be required based on the DNVGL towing criteria for towing the entire bridge. However, depending on the final operational criteria for the towing operation, several tugs that participate in the tow, will likely be passive in periods.

The towing operation can be split in 2 sub-operations, where the first is towing from Søreidsvika to safe condition in Bjørnafjorden, and the second is towing from the safe condition to the installation location.

The towing distance from Søreidsvika to safe condition in Bjørnafjorden is approximately 13 km. A total operation period of 36 hours is assumed for this sub-operation:

- Final connection of towing vessels and disconnection of temporary mooring – 24 hours
- Towing out Søreidsvika in narrow waters, 8 km at 0.5 knots – 9 hours
- Final tow to safe condition area, 5 km at 1 knot – 3 hours

The towing distance from the safe condition are to the installation is approximately 6.4 km. Assuming a towing speed of 1 knot yields a towing duration of 4 hours.

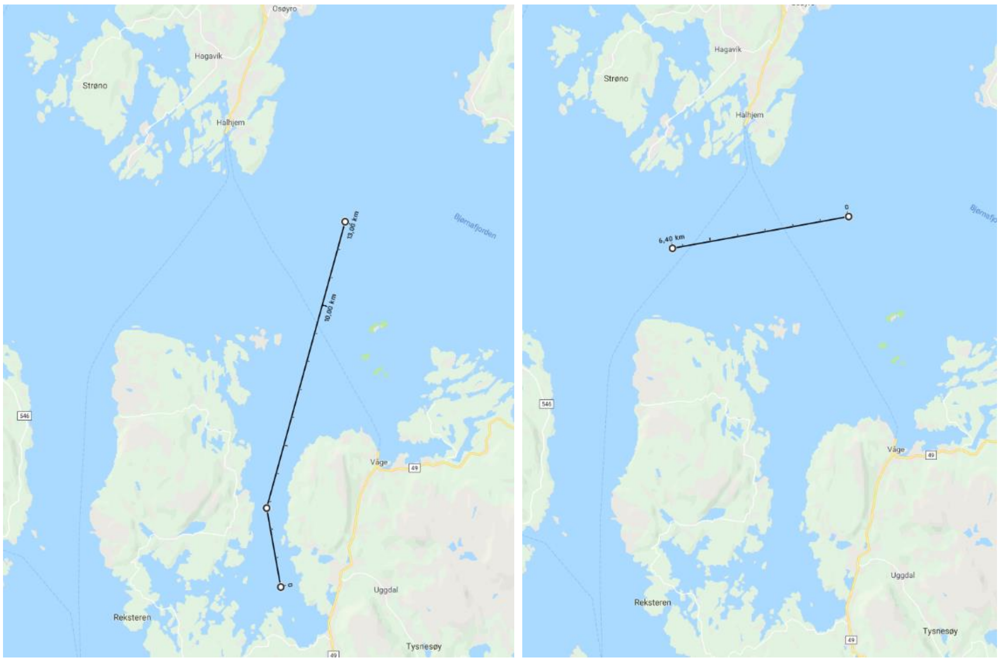


Figure 8-3 Towing from Søreidsvika to safe conditions (left), towing from safe condition to installation location (right)

Further illustration of the towing operation is given below with Orcaflex screenshots showing a timeline of the towing from the fabrication site in Søreidsvika to the final installation location, based on the K12 bridge model.

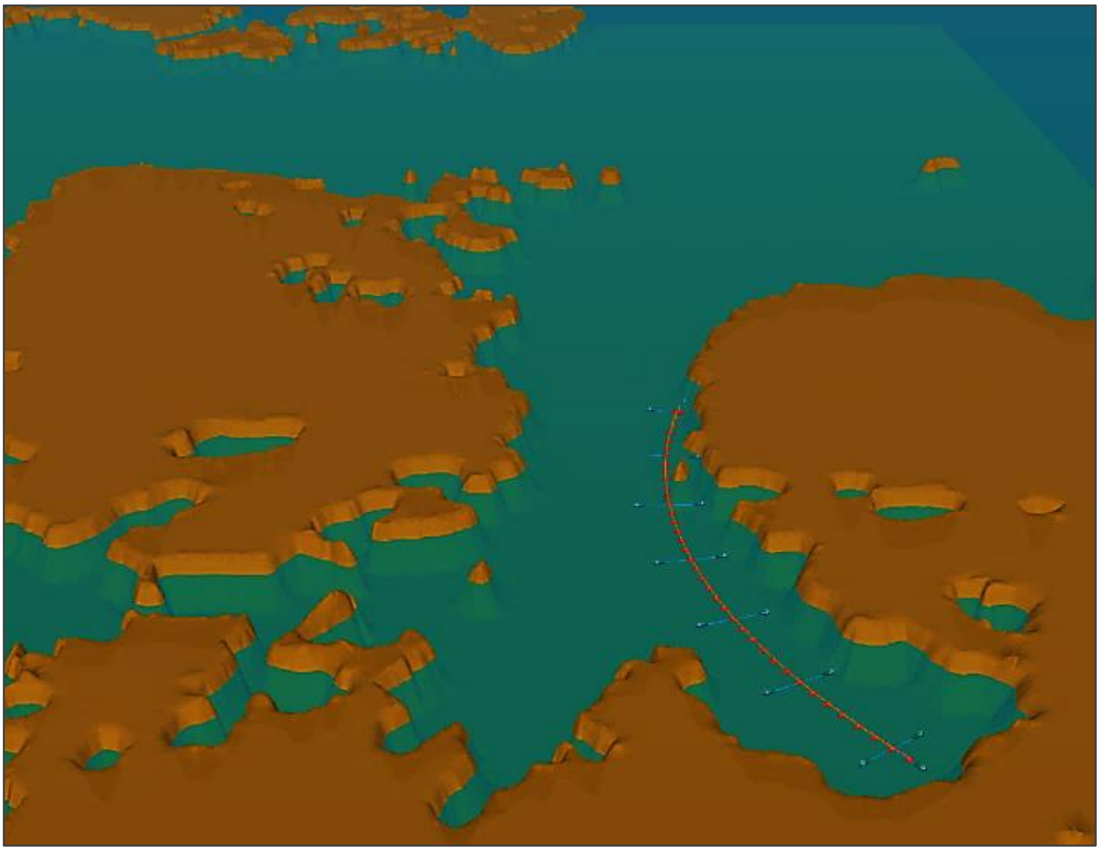


Figure 8-4 Let go of moorings and connect towing fleet

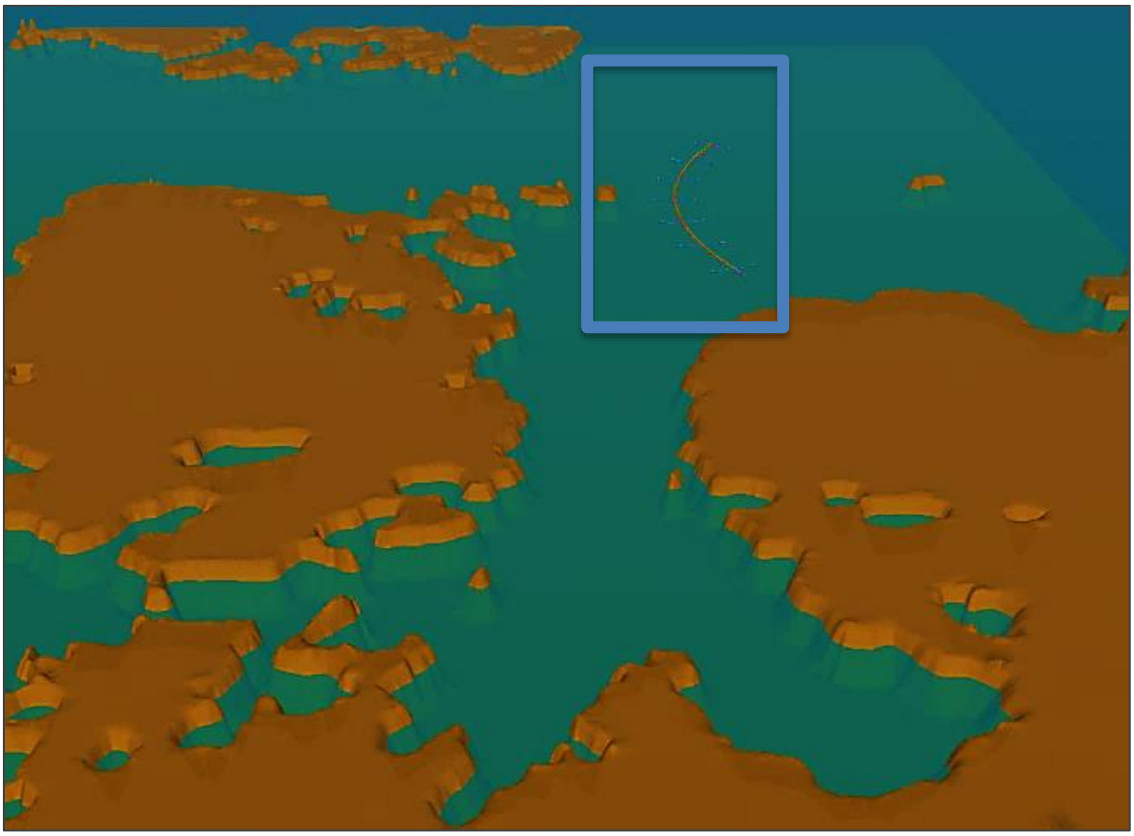


Figure 8-5 Move towards Bjørnafjorden

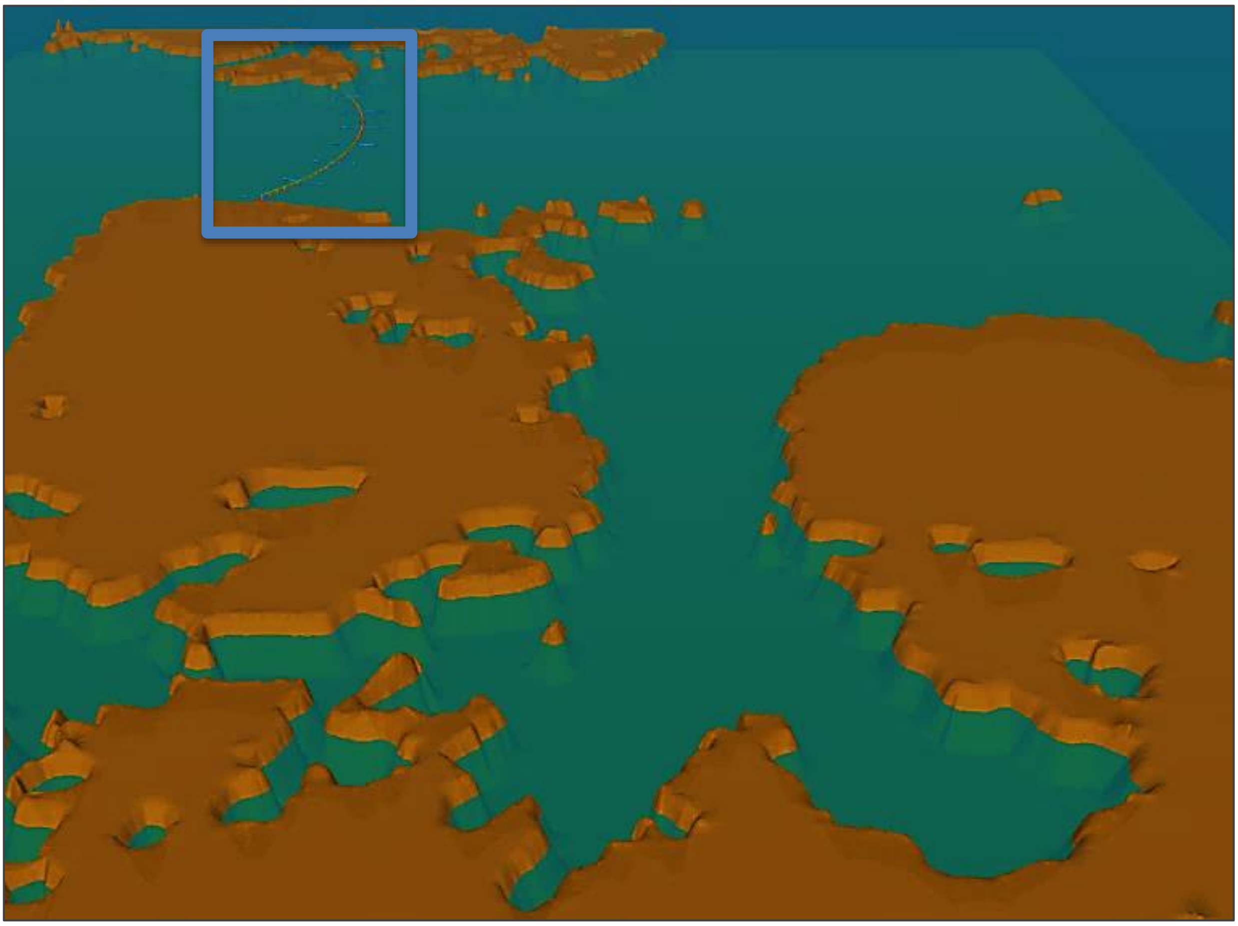


Figure 8-6 Perform final installation and positioning

8.5 Tow/Tug Management system

The towage will be managed with a Tug management system. The system will be based on a standard system for towing of rigid structures (vessels,platforms) but will be adjusted such that it will also incorporate the deformation monitoring of the bridge. A secondary tow management system will also need to be included.

DNVGL Rules will be adhered to:

*"**Navigational equipment***
4.5.2.1 The navigation of the towed object shall be monitored by means of two independent systems.
4.5.2.2 The secondary system should be separate from the primary system, both in principle and location.
4.5.2.3 At critical phases of the towage such as when departing from a mooring location, towing in narrow waters and arrival, both systems should be used as a cross-reference to each other.
4.5.2.4 For towing in narrow channels and for accurate positioning, the compatibility of the navigation equipment on board the survey ship and lead tug should be verified by tests carried out prior to commencement of the tow."

One of the tug management systems which can be used is the iNav system by iSurvey, which is outlined in the Enclosure.

9 Mooring system

9.1 Mooring system description

The bridge has 12 mooring lines. Each mooring line consists of a top chain, a wire segment, a bottom chain and an anchor. Mooring line layout is illustrated in Figure 9-1.

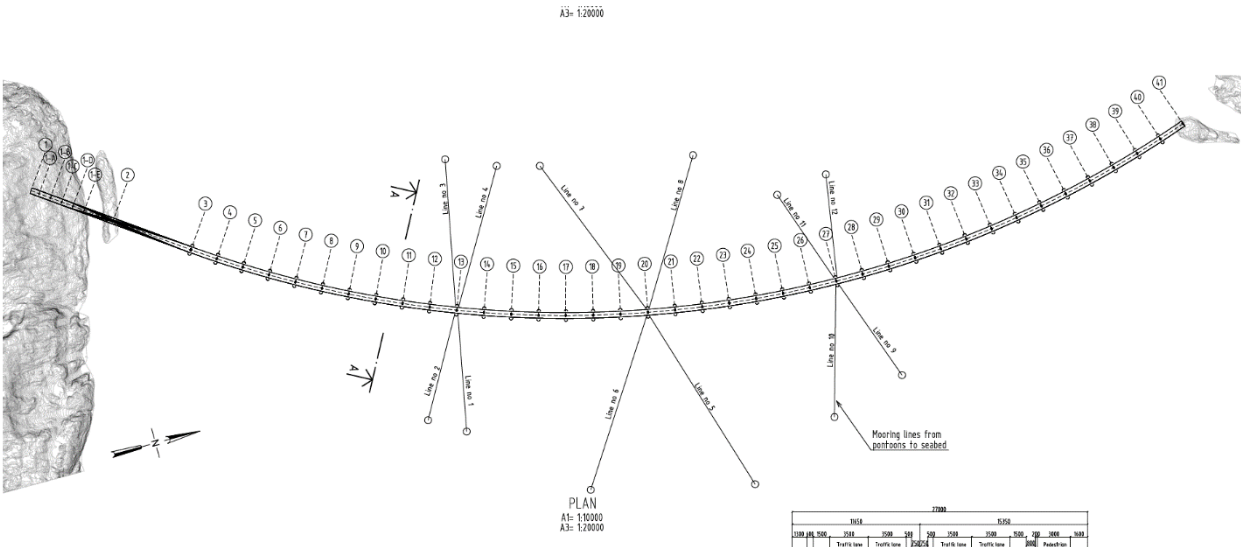


Figure 9-1 Principle mooring line arrangement

The mooring line properties and line segmentation are detailed in Table 9.1.

Table 9.1 Mooring Line Segment properties

Line segment	Segment type	Diameter
Top chain	Studless chain, R4	147 mm
Wire	Spiral strand wire – SPR2Plus	124 mm + 11 mm coating, OD 146 mm
Bottom chain	Studless chain, R4	147 mm

All anchors are cylindrical suction anchors and the main dimensions are given in the table below.

Table 9.2 Anchor system summary

Anchor	Diameter (m)	Depth (m)	Dry weight (t)
1	6	18	144
2	6	18	144
3	6	18	144
4	6	15	126
5	6	15	126
6	6	15	126
7	6	15	126
8	6	18	144
9	8	14	169
10	6	10	97
11	6	15	126
12	8	14	169

9.2 Installation principles

It is assumed that a mobilisation base close to the bridge location may be used for installation of the anchors and mooring lines, e.g. Eldøyane at Stord.

The anchors are proposed installed without the mooring line attached about one year before the bridge installation to ensure settling of the seabed before the anchors are loaded.

The mooring lines are installed in a separate installation campaign planned such that all mooring lines are installed in due time before assembly of the floating bridge at bridge location starts. The mooring lines will be wet-stored on the sea floor.

From a wet storage point of view there are certain challenges with regards to unexploded ordnances and bathymetry.

9.3 Installation of anchors

9.3.1 Installation requirements

The installation vessel needs to be able to lift the anchors with sufficient lifting height and clearance as indicated below.

Table 9.3: Anchor lifting characteristics

Anchor no	Anchor	Comment
Max weight	169 t	
Lifting Height	30 m	Height of anchor + 2xDiameter
Lifting radius	12 m	Radius of anchor + assumed crane pedestal radius of 2m + 5 meter clearance to vessel side

Installation tolerances for suction anchors are given in:

- Position (tolerances radius)=±5m
- Orientation (heading)= 0-5degrees
- Verticality = ±5degress (only relevant for suction/pile anchors)

The tolerances above are considered for planning of all anchor installations.

9.3.2 Installation vessel

Currently the maximum weight of the anchors is about 170t at a lifting height of about 30m. Whereas the majority of lifts will be in the 100-150t range.

There are a large number of offshore construction vessels available with 250-400t cranes, which would be able to perform these lifts. The newest generation of offshore vessel has cranes with up to 600t capacity, such as the Edda Freya shown below.

Suction anchor installations of this kind are typically performed in sea states of up to 3m Hs offshore.

Figure 9-2: Edda Freya with 600t crane (©DeepOcean)

9.3.3 Transportation of anchors

The suction anchors may be transported on the deck of a construction vessel

An example of a deck layout based on two installation trips is also shown below for a typical North-Sea construction vessel is shown below. For vessels with 400t cranes or higher capacity it will be possible to optimize the deck layout to accommodate all anchors in one trip. A typical lifting curve of a 400t crane is also shown. It shows that the smallest anchors may be lifted at a radius of up to 36m and the largest anchors may be lifted at a radius of approx. 26m.

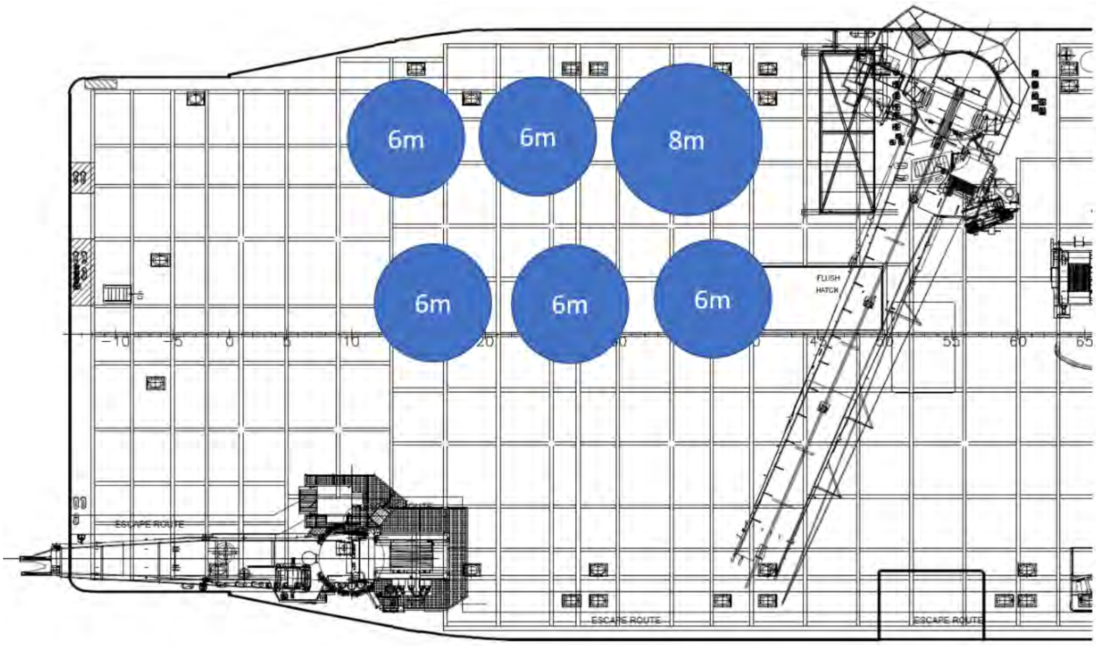


Figure 9-3: Deck Layout of typical installation vessel

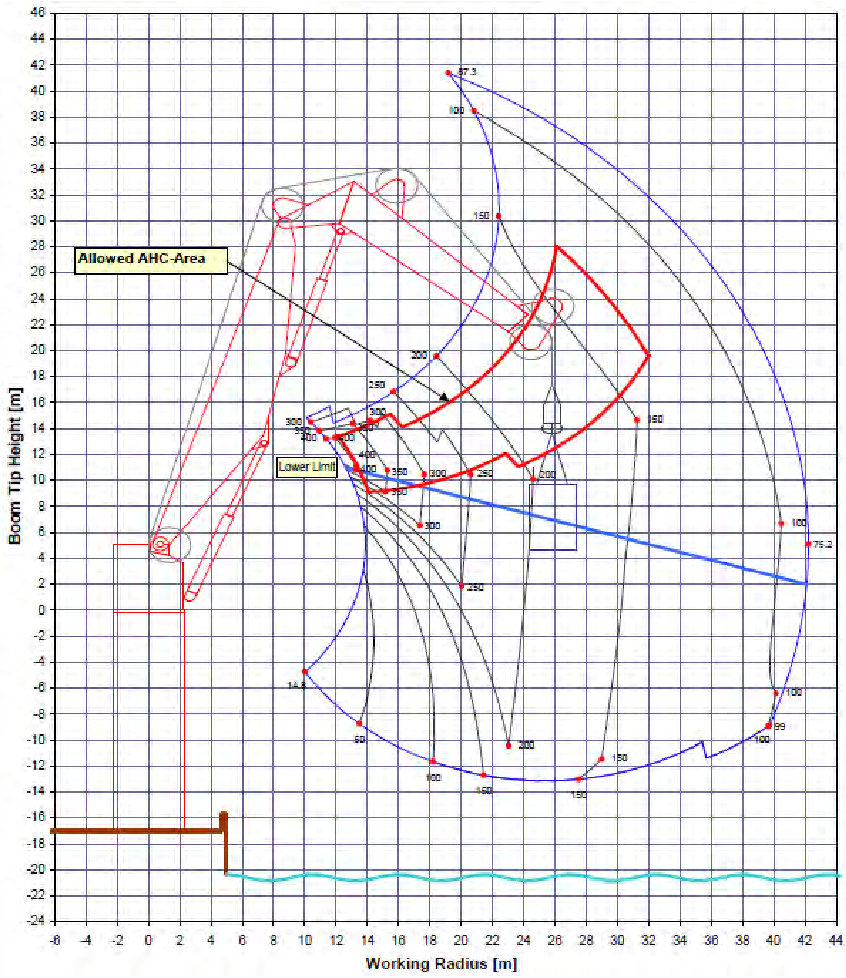


Figure 9-4: Crane chart of typical 400T crane

9.3.4 Installation of anchors

The installation is performed as follows:

- Connect crane hook to anchor lifting arrangement
- Cut anchor sea fastening
- Overboard anchor and submerge
- Install instrumentation module on anchor (positioning beacon) using ROV
- Descend anchor until about 20m above sea bed
- Position anchor by moving vessel, observation by ROV
- Lower anchor to touch down
- Verify/adjust anchor position
- Set down/penetrate anchor
- Dock ROV with suction skid on anchor suction flange
- Installation of anchor further down to sea bed by applying suction
- Remove ROV and suction skid
- Install hatch on anchor suction flange

- Disconnect crane hook from anchor lifting arrangement using ROV
- Retrieve instrumentation module on anchor using ROV

It is expected that installation of one suction anchor 12-18 hours.

Figure 9-5 Overboarding of suction anchor from BOA DeepC (250T crane). 152mm mooring chain running across deck. Wire-segments stored on reel drive system. (© Stefan Schlömilch)

9.4 Pre- Installation of mooring lines and wet-storage

9.4.1 General

The mooring lines are pre-installed in a separate installation campaign such that all mooring lines are installed in due time before assembly of the floating bridge at bridge location starts.

After connection of mooring line to the anchor, the upper end of the mooring line is wet stored (as outlined in this report)

9.4.2 Installation vessel

For pre-installation of mooring lines, it is proposed to use a 200t BP DP Anchor handling vessel equipped with two off WROV systems. An example vessel is shown in Figure 9-6.

The vessel should have sufficient deck capacity and chain lockers to transport at least 6 complete mooring lines. The vessels should be prepared for wire handling operations with reel drive and wire grippers.

Figure 9-6 Example installation vessel Maersk Leader with two off temporary WROV systems

Figure 9-7 Installation of wire grippers on wire. Used for deployment during Skarv Mooring installation (© Stefan Schlömilch)

9.4.3 Subsea mooring connection

There are several off the shelf subsea mooring connectors available on the market. It is proposed to use H-shackles with ROV-kit, as the H-shackle is believed to have superior properties for 100 year operational design life (fatigue and corrosion). The mooring connector is of conventional type and if same type as connectors used to connect other segments of the mooring line (i.e. no need for qualification of subsea mooring connector), but the installation method is different, where the removable ROV-kit allows for operation of the H-shackle subsea.

The H-shackle with ROV-kit is shown in Figure 9-8.

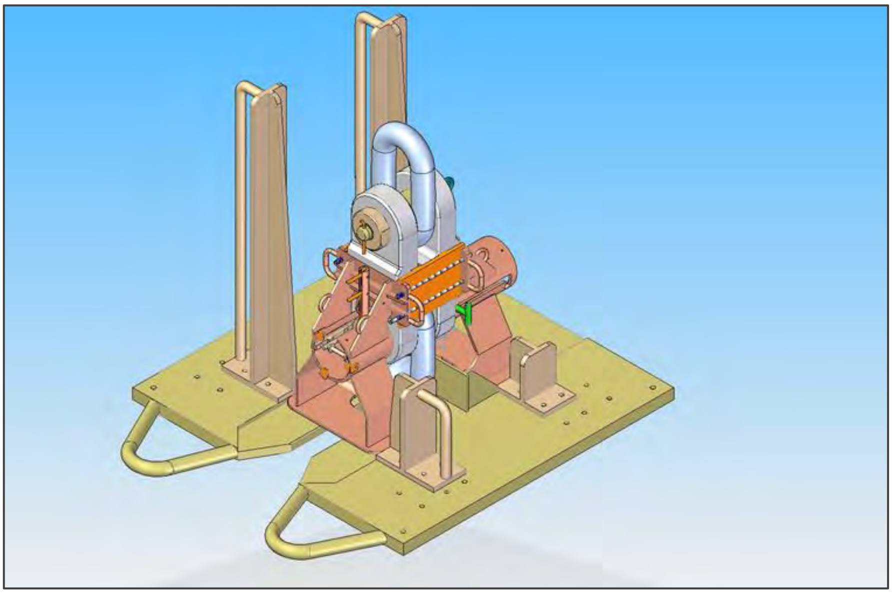


Figure 9-8 H-shackle with ROV kit during connection to chain supported on anchor hang-off table (illustration by Vicinay)

A small segment of the bottom chain is installed together with the anchor. The chain segment is hung off at the anchor hang-off table as shown in Figure 9-9.

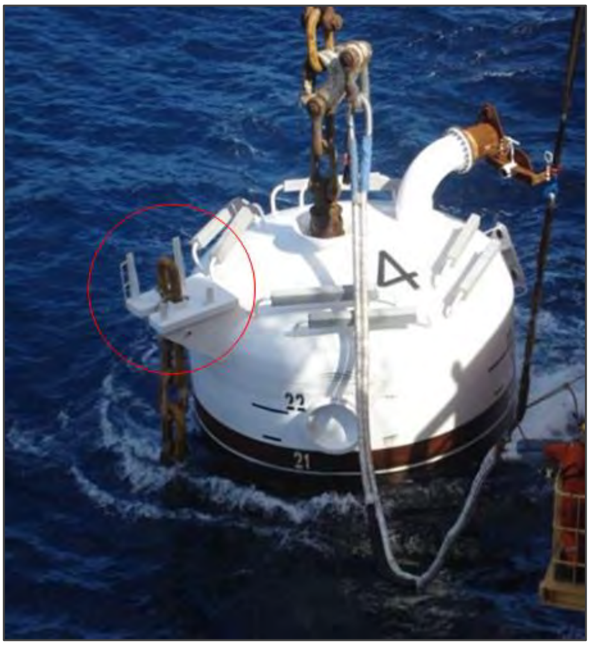


Figure 9-9 Installation of anchor with bottom chain connected at anchor hang-off table (Photo by Vicinay)

During installation of mooring line, the H-shackle with ROV kit is connected to the upper part of the bottom chain as shown in Figure 9-10.

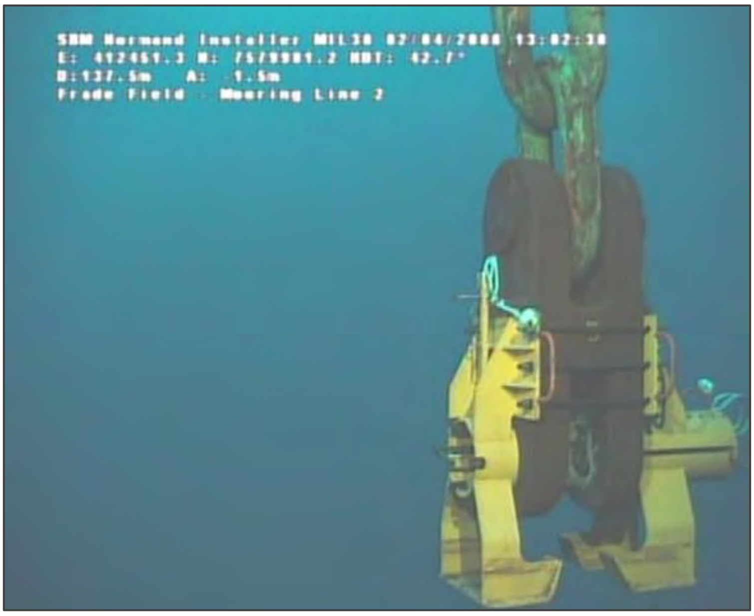


Figure 9-10 H-shackle with ROV-kit connected to bottom chain

The H-shackle with ROV-kit is landed on the chain on the anchor hang-off table and the ROV is used to insert the shackle pin through shackle body and shackle nut.

Once the connection is made, the H-shackle safety pin is installed by ROV. The H-shackle is lifted above the anchor hang-off table and pulled out the hang-off table slot. The ROV-kit is then disconnected from the H-shackle using ROV.

The installation method is used for multiple mooring installations offshore and is considered proven.

9.4.4 Installation sequence

The installation vessel should be fitted with about 800m of work chain for mooring line handling during installation of wire segments.

The installation is performed as follows:

- Connect H-shackle with ROV kit to bottom chain
- Overboard and pay out bottom chain with H-shackle
- Connect bottom chain to wire segment and work chain (work chain connected by sling)
- Pay out wire segment with wire grippers
- Connect top chain to wire segment
- Position H-shackle over anchor chain end
- Guide H-shackle over anchor chain end
- Insert H-shackle pin and secure
- Lift chain out of anchor hang-off table
- Disconnect ROV-kit

- Cut sling and retrieve work chain
- MARK the top chain link which gives the desired pre-tension based on anchor installation position and nominal bridgeposition
- Pay out top chain
- Connect temp chain to top chain
- Pay out and lay in wet storage position as described below

9.4.5 Wet Storage

The figures below show an outline of the principle proposal of a wet-storage layout of the mooring lines. Some more refinement is needed to ensure that the following conditions are met:

- No crossing lines
- Straight sections of bottom chain from the anchor
- Seabed stability of the wet stored line
- No conflicts with unexploded ordnance
- Flexibility with regards to order of connections of lines
- Possibility to retrieve lines with bridge in place

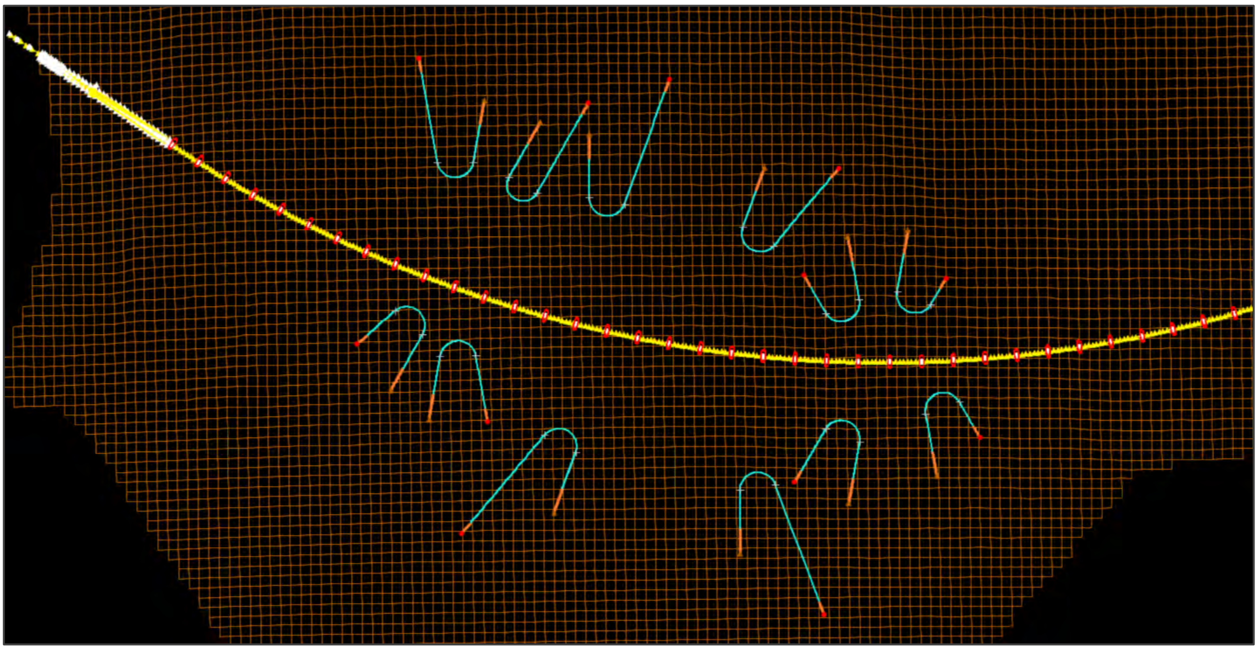


Figure 9-11: Field layout plan view

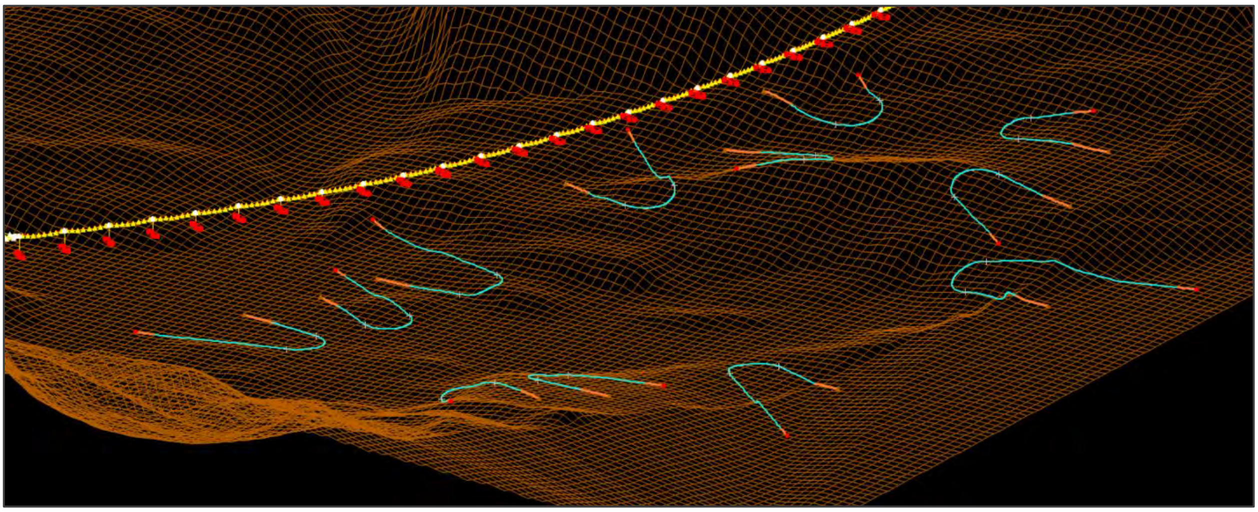


Figure 9-12: Field Layout ISO view

9.5 Hook-up and tensioning of mooring system

The middle mooring cluster will be hooked up inside the initial weather window just after the bridge has been attached with the "positioning system". One vessel will be working to connect the two mooring lines on the west side of the bridge while the other one will connect the mooring lines on the east side of the bridge. After the middle cluster has been connected, the bridge will be in a summer storm safe condition.

The hook up of the remaining clusters will continue directly after if the weather allows.

The hook-up describes the operation of transferring the mooring line from its wet-stored location to being hung off through the fairlead and chain stopper on the bridge.

Figure 9-13: Dual axis fairlead with chain stopper (©Flint-tech and MacGregor Pusnes)

9.5.1 Installation vessel

Depending on the time available and the size of the installed bridge segment one to four installation vessels can be used for hook up of mooring lines to the bridge. For hook-up of bridge sections to the mooring lines, it is proposed to use 200t BP DP Anchor handling vessels. An example vessel is shown in Figure 9-6.

The vessel must have sufficient winch capacity to tension the mooring lines to target pre-tension.

9.5.2 Transfer of mooring lines

The installation vessel picks up the mooring line from the seafloor and moves towards the pontoon

A pennant (messenger wire is pre-rigged through the chain stopper, with both ends available on pontoon as shown below.

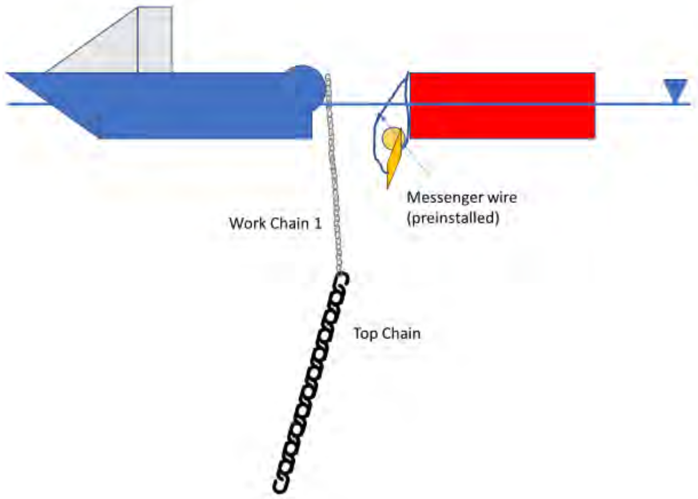


Figure 9-14: Transfer of mooring line- step 1

The messenger wire is transferred from the pontoon to the installation vessel by using either a line thrower or a small helper-boat.

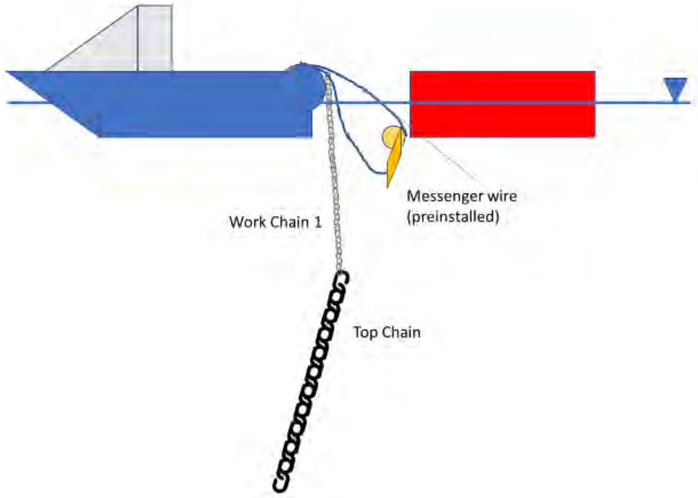


Figure 9-15: Transfer of mooring line- step 2

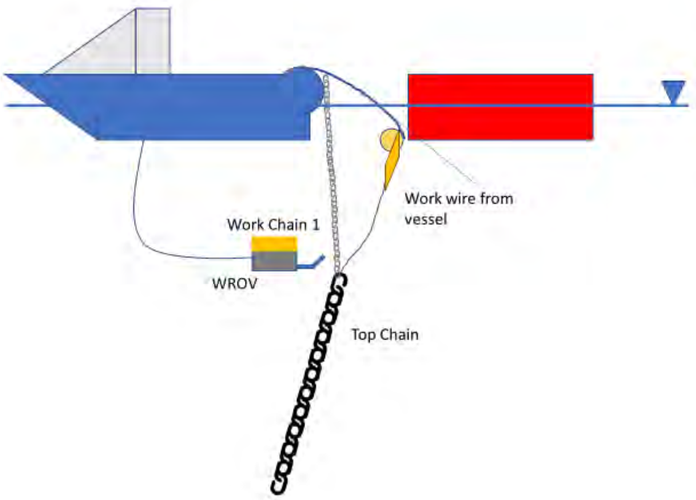


Figure 9-16: Transfer of mooring line- step 3

The work wire of the vessel is routed through the fairlead with the help of the preinstalled messenger wire. The work wire of the vessel can then be attached to the top chain.

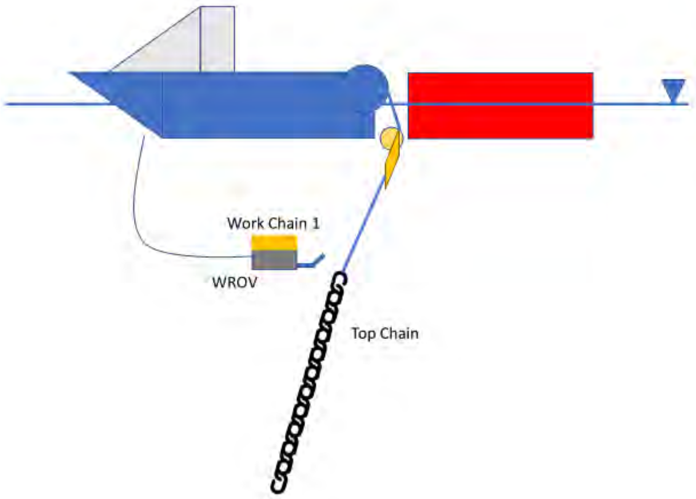


Figure 9-17: Transfer of mooring line- step 4

Tension is released from the work chain and work chain is disconnected. The work wire from the vessel will now have the full load of the mooring line. The vessel moves closer to the pontoon and starts heaving in on the work wire

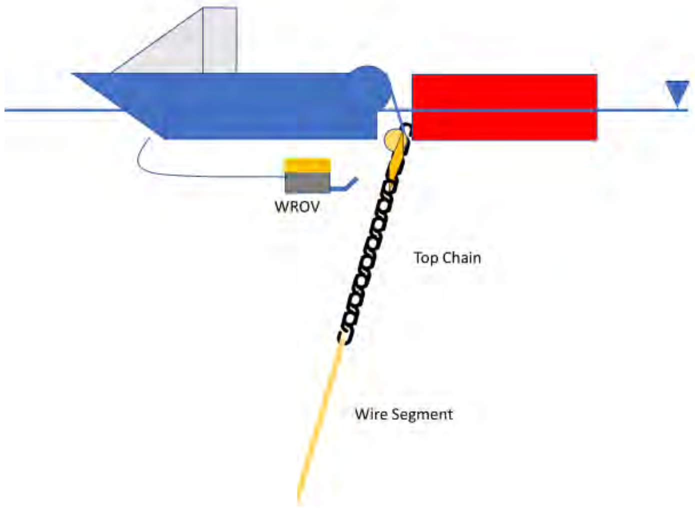


Figure 9-18: Transfer of mooring line- step 5

The work wire is pulled through the fairlead until the correct link is at the chain stopper.

9.5.3 Tensioning of mooring line

The operation should be planned such the need for high thrust operations close to the pontoons is reduced to a minimum.

The figures below show tensioning can be performed at the pontoon. The vessel is equipped with a rubber coated bumper system to avoid any damages on the pontoon in case of contact. The work chain (blue) runs over the stern-roller and dives vertically towards the fairlead. Since the work chain is vertical, the vessel will not be exposed to large horizontal forces and will not need to have high thrust on the rear propellers. The front tunnel thruster/retractable azimuth thrusters can be used for station-keeping and heading control.

Tension is applied to the work chain and the mooring line is pulled to the desired tension.

Prior to the mooring line installation, it is calculated which top chain link should be in the chain stopper in order to achieve the desired top tension. The top chain link will be color coded or otherwise marked. During the pull in operation one will use a combination of an observation ROV, a pole mounted camera and transponders to confirm that the correct link is in the chain stopper. The fairleads are also equipped with tension monitoring devices and thee read-outs can be used as backup. It should be noted that the fairlead readout is dependent on tidal and other environmental variations while the marking is not.

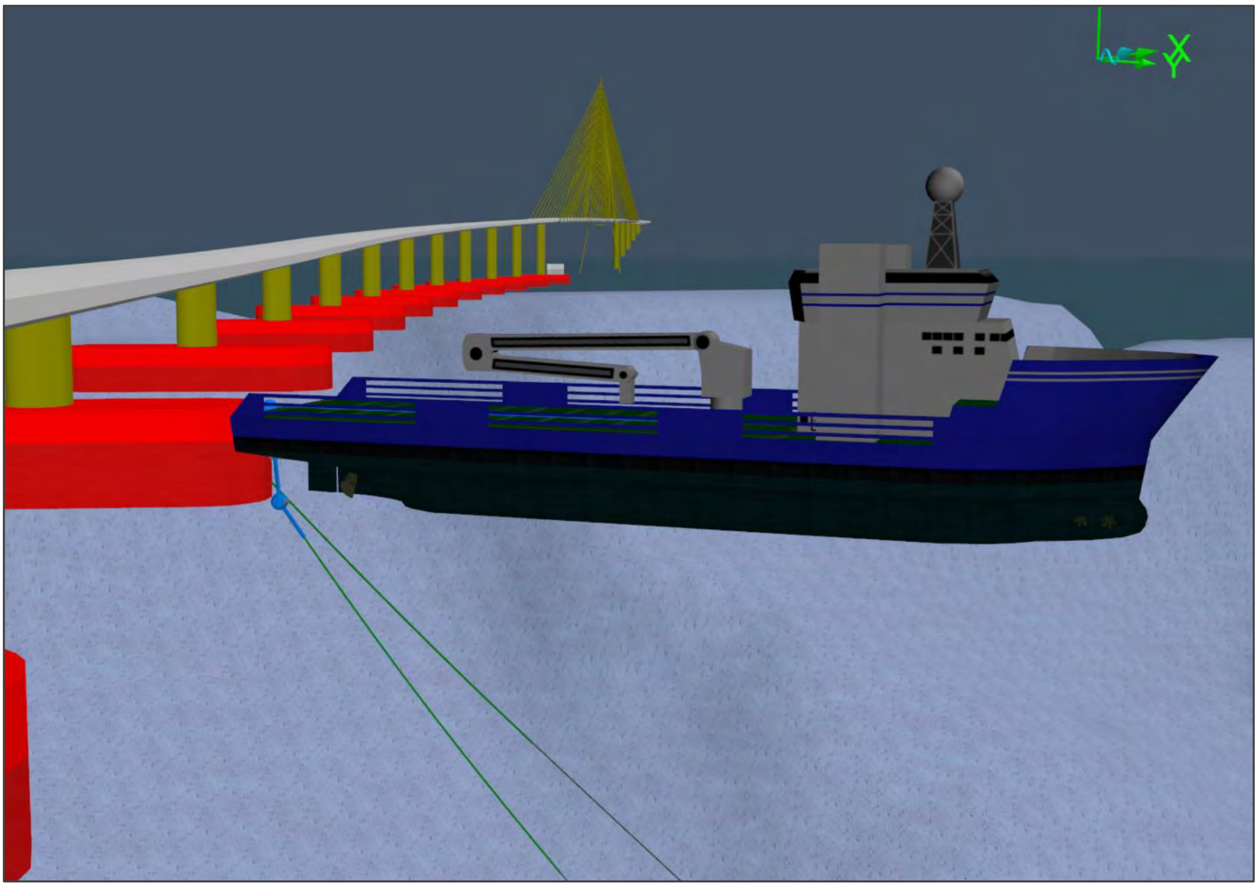


Figure 9-19: Mooring line tensioning at pontoon with bumper. Only very low thrust forces are needed in this configuration.

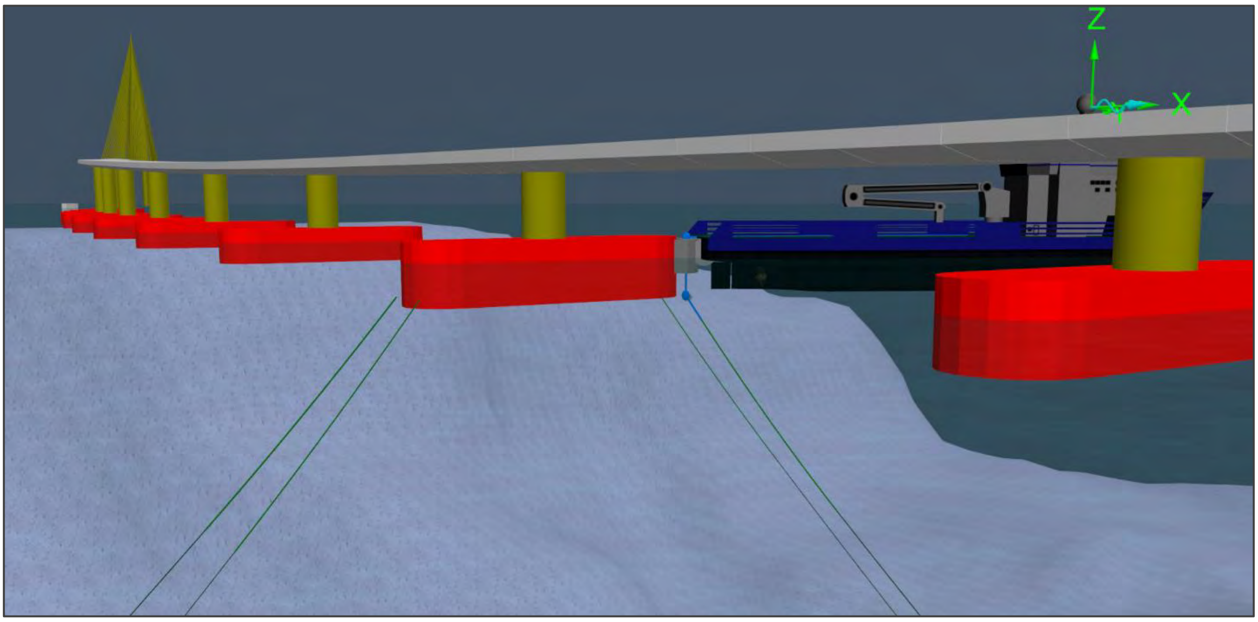


Figure 9-20: Mooring line tensioning at pontoon with bumper. Only very low thrust forces are needed in this configuration.

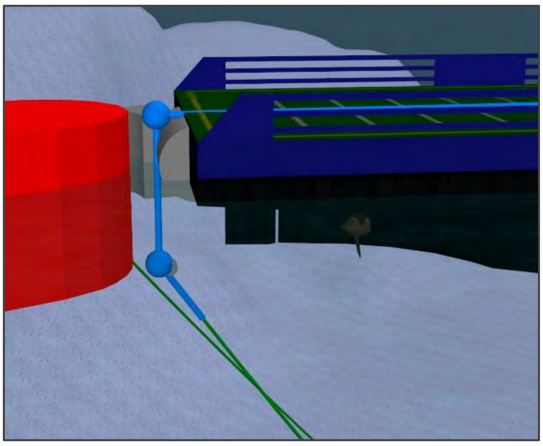


Figure 9-21: Close up

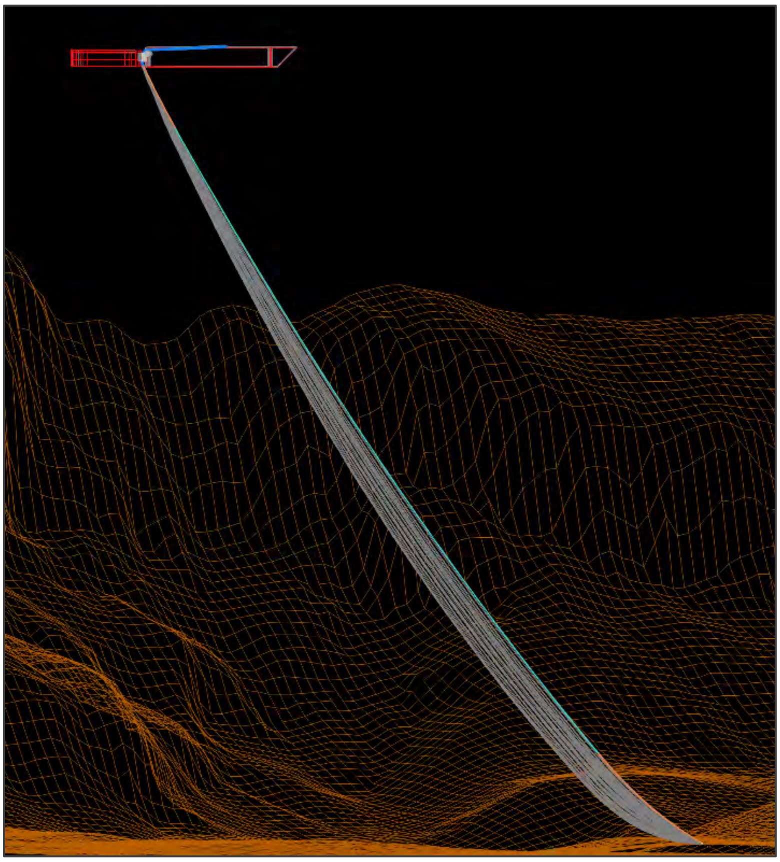


Figure 9-22: Overview/Time trace of tensioning process when tensioning at pontoon

Superfluous top chain can either be cut or hung off at the pontoon or cut.

Tensioning of two mooring lines (working on two lines in parallel) is estimated to take about 9 hours.

10 Installation of floating bridge

10.1 General

The installation of the floating bridge is based on the principle to minimize the welding in Bjørnafjorden (bridge location), which means to tow and install as large sections as feasible.

The floating bridge will be installed in two sections; one short north section to be installed towards the north abutment with transition section, and one long section to be installed between the north section and the cable stayed bridge.

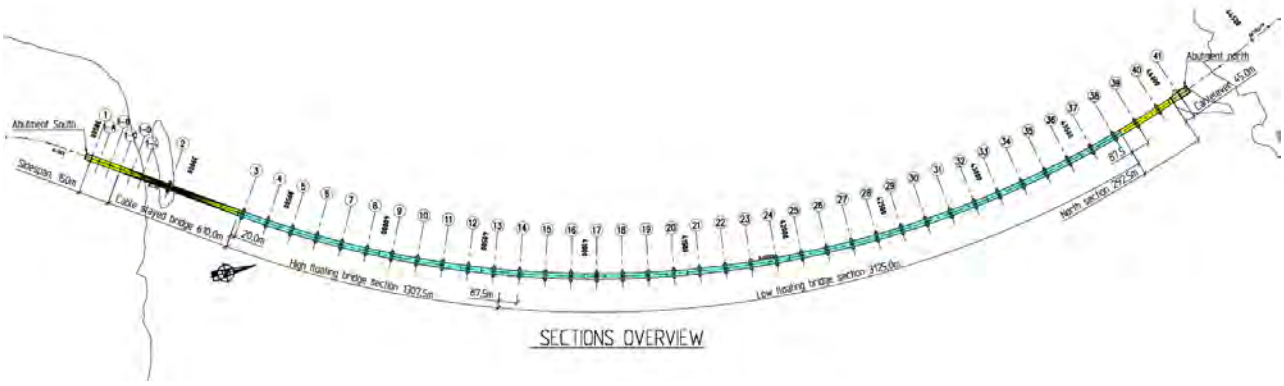


Figure 10-1: Overview of sections to be installed

Prior to the installation of the floating bridge the cable stayed bridge, the north abutment, and sections to be installed, are prepared with a guiding system, a positioning system and a locking system)

10.2 Installation of north section towards north abutment

A short section (a catamaran) is installed towards the north abutment before the large section is towed to field and installed. The section to be installed towards the north abutment will consist of two pontoons and cantilevers on both side of the pontoons that is 87.5m towards south and 80m towards north. The cantilevers will be supported by a column standing on a barge.

The north abutment will have been installed with a steel section connected to the concrete abutment (ref section 6) so that the connection between the floating part and the abutment can be made up in the same manner as the other connections.

The method for installation of the north section is shown in the figure below.

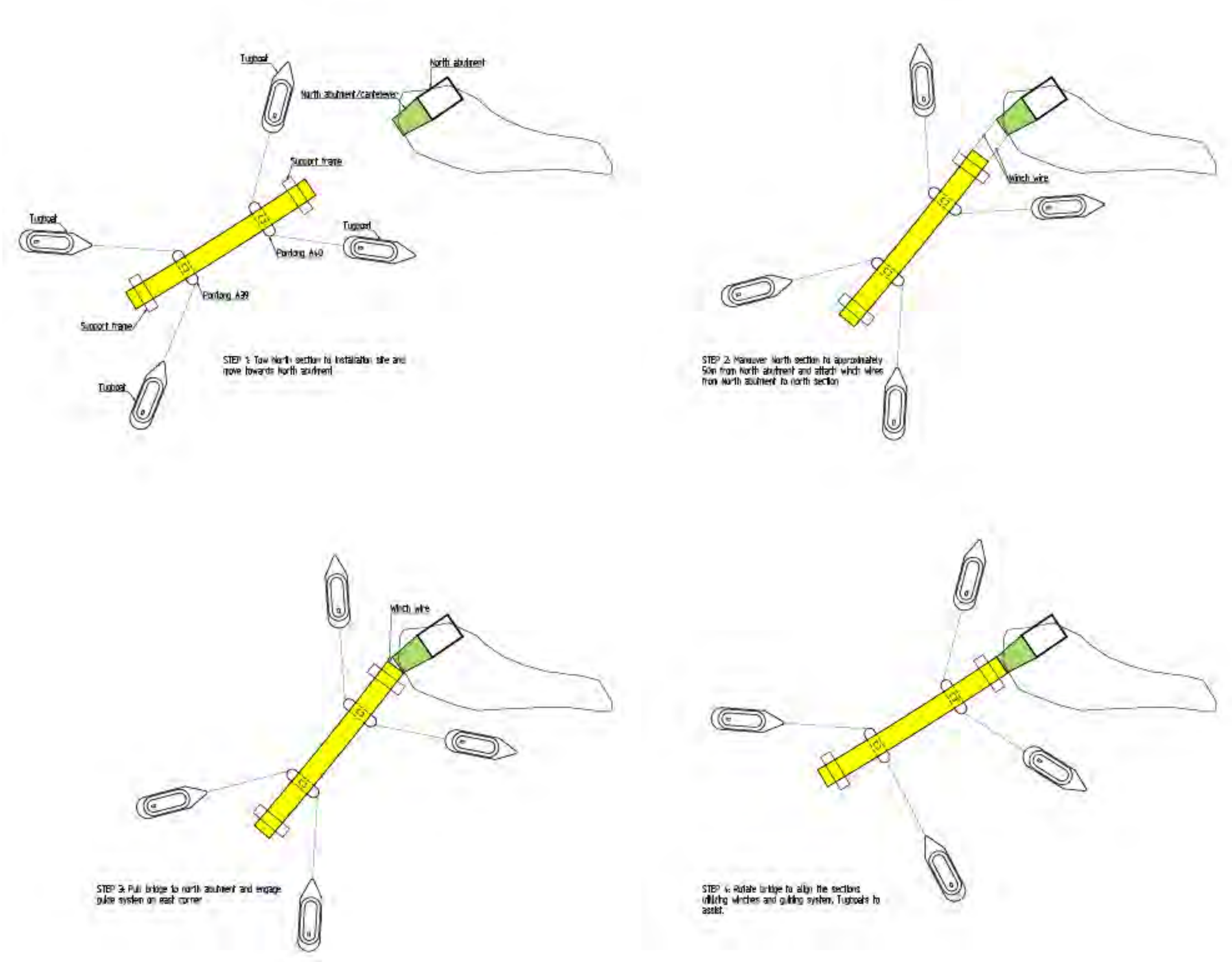


Figure 10-2: Installation of north section

The installation steps are:

Step 1: Tow north section to installation site and move towards north abutment

Step 2: Manoeuvre north section to approximately 50m from north abutment and attach winch wires from north abutment to north section

Step 3: Pull bridge to north abutment and engage guide system on east corner

Step 4: Rotate bridge to align the sections utilizing winches and guiding system. Tugboats to assist.

Step 5: Engage positioning and locking system

Step 6: Weld joint

10.3 Installation of floating bridge section

The floating bridge will be installed as one section towed to location and connected to the cable stayed bridge and the small north floating section.

The floating bridge will be assembled as one complete section with pontoons from axis 3 to axis 38 with a short cantilever extending from the two ends.

The floating bridge section will be released from its moorings and towed to the installation site in Bjørnafjorden.

When the bridge has been towed to site, an assessment of the weather forecast will be performed to ensure that the weather forecast is within the operational criteria for the estimated installation period.

The principles for the installation are shown in the figure below.

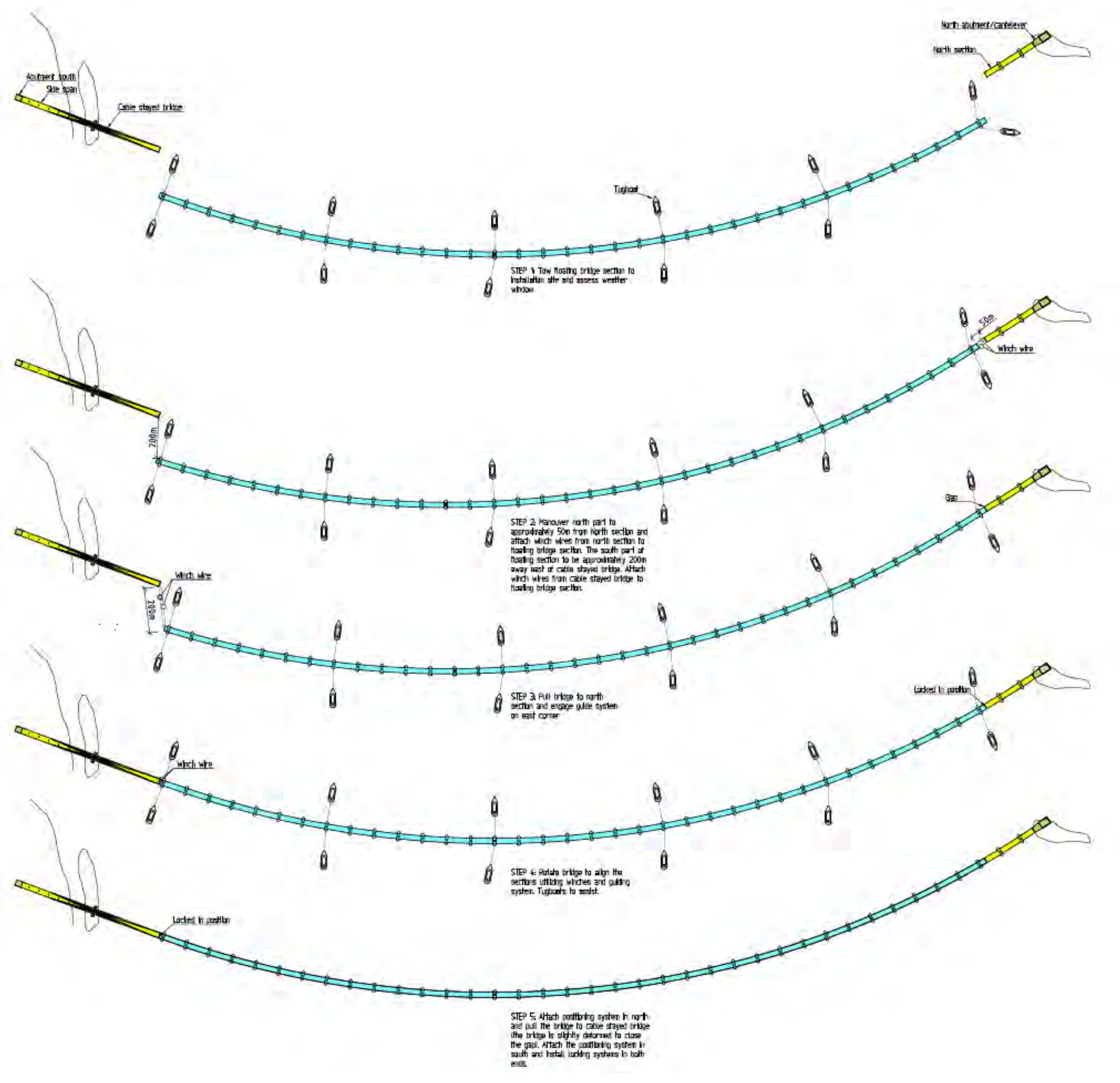


Figure 10-3: Installation of north section

The installation steps are:

Step 1: Tow floating bridge section to installation site and assess weather window

Step 2: Manoeuvre north part to approximately 50m from north section and attach winch wires from north section to floating bridge section. The south part of floating section to be approximately 200m away east of cable stayed bridge. Attach winch wires from cable stayed bridge to floating bridge section.

Step 3: Pull bridge to north section and engage guide system on east corner

Step 4: Rotate bridge to align the sections utilizing winches and guiding system. Tugboats to assist.

Step 5: Attach positioning system in north and pull the bridge to cable stayed bridge. Attach the positioning system in south and install locking systems in both ends.

4 mooring lines will be installed by two Anchor Handling Tugs (AHT) within the weather window.

The operational period for the installation of the floating bridge section from safe position to safe position have been estimated in the table below.

Table 10.1: Operational period for K12 floating bridge installation

Operational periods			
Step	**Operation**	**Planned duration**	**Contingency duration**
1	Maneuver bridge towards north end and connect to onshore bollards on North side	4	4
2	Maneuver the bridge towards north abutment to a distance of approx. 50m and connect winch wires between north section floating bridge	2	2
3	Rotate the bridge to a distance of approx. 200m between bridge end and cable stayed bridge and connect winch wires	3	3
4	Maneouver/pull with winch wires the bridge towards the northsection until contact with guideing system	3	3
5	Rotate bridge into position and engage positioning system in north end	4	4
6	Pull bridge towards cable stayed bridge and engage positioning system	4	4
7	Secure both ends with locking system to take a seasonal storm	24	24
8	Hook up of 4 mooring lines (performed parallel with securing the bridge. 8 h per line by 2 AHTs)	0	0
	TOTAL DURATION	**44**	**44**
TOTAL DURATION Including Contingency		**88**	

The operation may also be aborted up until step 6, and the floating bridge brought back to the fjord in a safe position until if the weather forecast should deteriorate.

After the middle mooring system is connected and the locking system is in place, the bridge will be in a summer storm safe condition.

The finishing steps are to install the remaining mooring lines and to perform the site welds.

10.4 Construction joints

For installation of the floating bridge, construction joints within steel deck box girder will be necessary at the site of Bjørnafjorden. Construction joints will be requested at three different locations as shown in Figure 10-4 below.

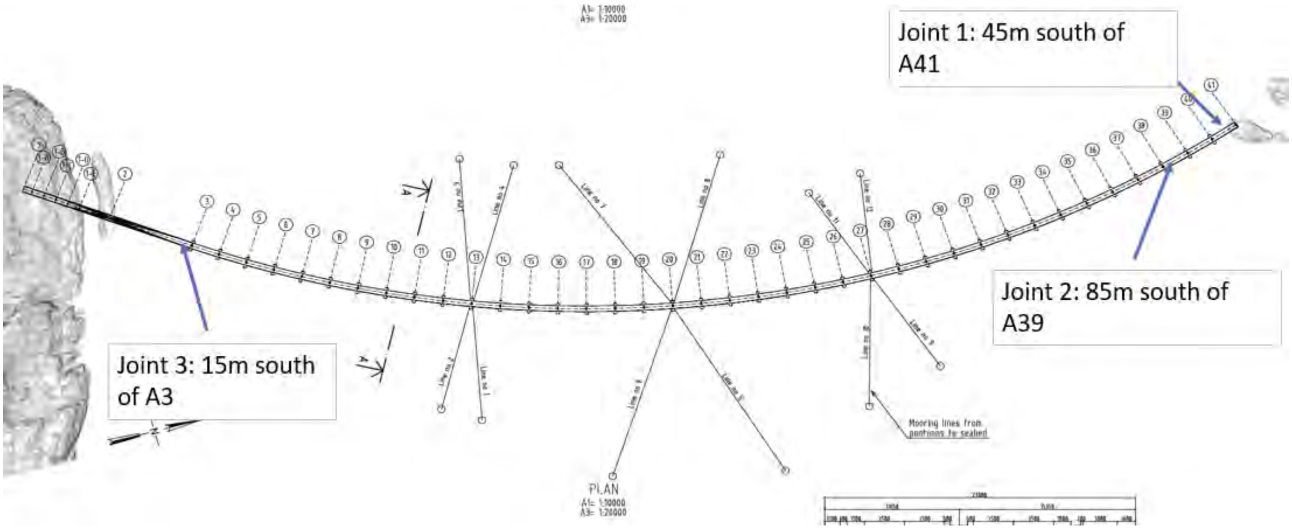


Figure 10-4 Construction joints within deck box girder - 2 at north bridge end and 1 at south bridge end towards the cable stayed bridge

For the two construction joints installed first at the north bridge end (joint 1 and 2) the bridge ends will be joined together directly, while the last installed construction joint (joint 3), at the south bridge end towards the cable stayed bridge, will be joined together using an infill piece of 0.80 m.

This section deals with a possible design concept for the construction joints proving they will be safe and able to withstand a summer storm. The concept will furthermore allow the welding work joining the two deck elements to be carried out in a safe and easy way without causing unnecessary delays for the entire floating bridge installation.

10.4.1 Three joint types

The construction joint consists of three different joint types forming the final welded joint within the deck box girder:

Guiding joint: Tool/equipment necessary for guiding the new floating bridge part to the already installed bridge within the bridge line.

Positioning joint: Tool/equipment necessary for positioning the new floating bridge part correctly towards the already installed bridge within the bridge line. By hydraulic jacks the positioning joint will be able to adjust the two bridge sections within all 3 directions and rotations. The joint will be able to withstand the environment loading within the requested weather window of 3 days within the summer period for installation until the locking joint is fully in place.

Locking joint: Tool/equipment necessary to lock and secure the new floating bridge part being erected against the environmental loading within the requested period of welding the two bridge sections together. The locking joint will be able to resist a 10 year summer storm until the permanent joint takes over the full loading.

A cross section of the construction joint can be seen in Figure 10-5. Typical, the skin plates are 12 to 16 mm thick with trough thickness of typical 6 or 8 mm. In order for the deck structure to be extra robust and able to withstand the local joint system at the construction joints it is foreseen to strengthen both the skin plates and troughs locally. The length in longitudinal direction of the local reinforcement could be a few meters each side of the joint meaning that the it will have no impact on the overall deck stiffness and quantities. It is found beneficial to have 16 mm skin plate thickness in combination with 8-10 mm trough stiffeners to be able to withstand the additional local bending moments caused by the temporary joint system. The strengthening can moreover be seen as a precaution if extra installation tolerances of the joining steel plates are requested.

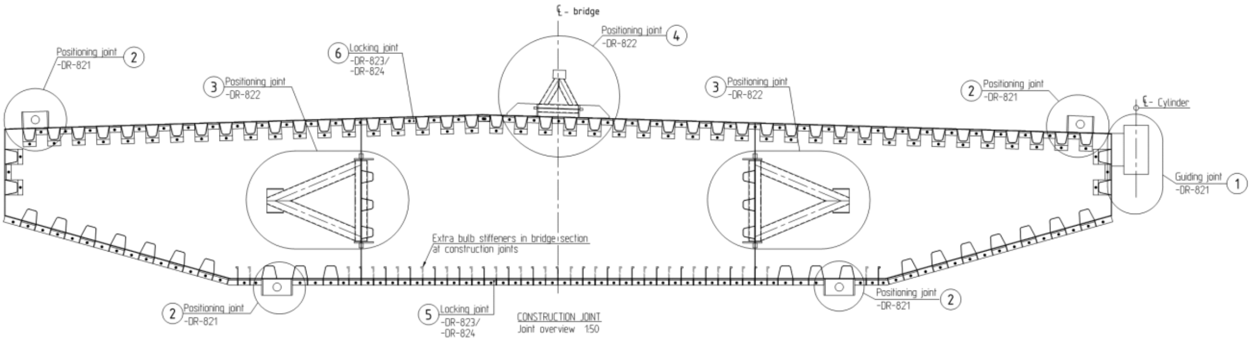


Figure 10-5 Cross section in bridge deck of floating bridge, 4.0 m deep and 27.0 m wide
Guide joint ①, positioning joint ②③④, locking joint ⑤⑥

The concept for the three joint types is developed addressing the following items:

- Easy and fast installation of all three joint types shall be possible in the given weather window
- The three joints shall be strong and able to withstand the given design loading within the weather window
- For the positioning joint, easy adjustment of the bridge joining parts shall be possible in any direction and rotation
- The three joints shall be easy to dismantle partly/fully if requested due to weather conditions
- For the locking joint, easy access for welding process shall be provided e.g. by installing stiffener arrangement on the opposite site of the welding operation
- For the locking joint, easy and fast welding shall be possible best in flat position - bridge deck plate shall then be welded from outside and the webs and bottom plates shall be welded from inside
- The locking joint shall ensure no opening of the joint in the selected design situations
- The locking joint shall ensure low strain during welding of skin plates

The layout of the three joints can be done in many ways, but one possible solution is presented here where the strengthening for the site joint is done continuous along the entire outer circumferential of the deck box. This layout ensures minimal reinforcement of the box girder itself as well as small strain variations over the joint during the welding operation.

10.4.2 Guiding joint

The guiding joint principle and how the two bridge sections are mated utilising the winches and the guide joint is shown in the figures below.

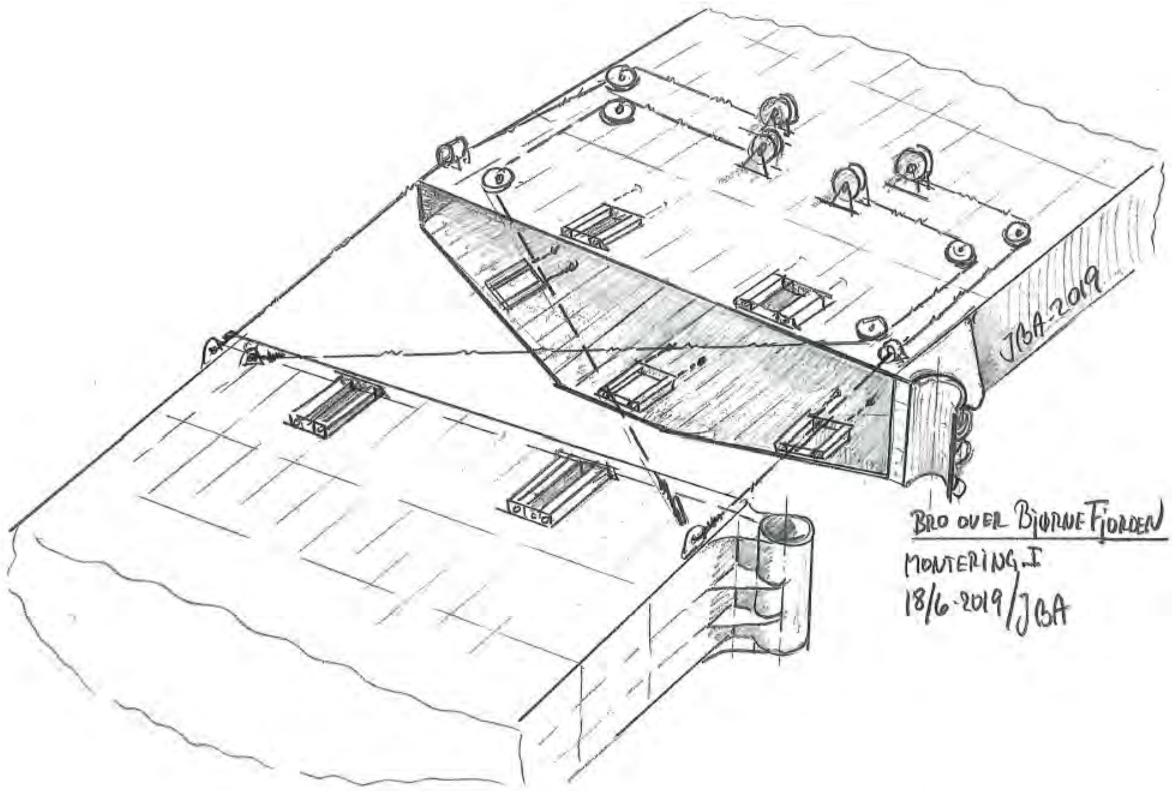


Figure 10-6 Bridge mating by guide joint - 1

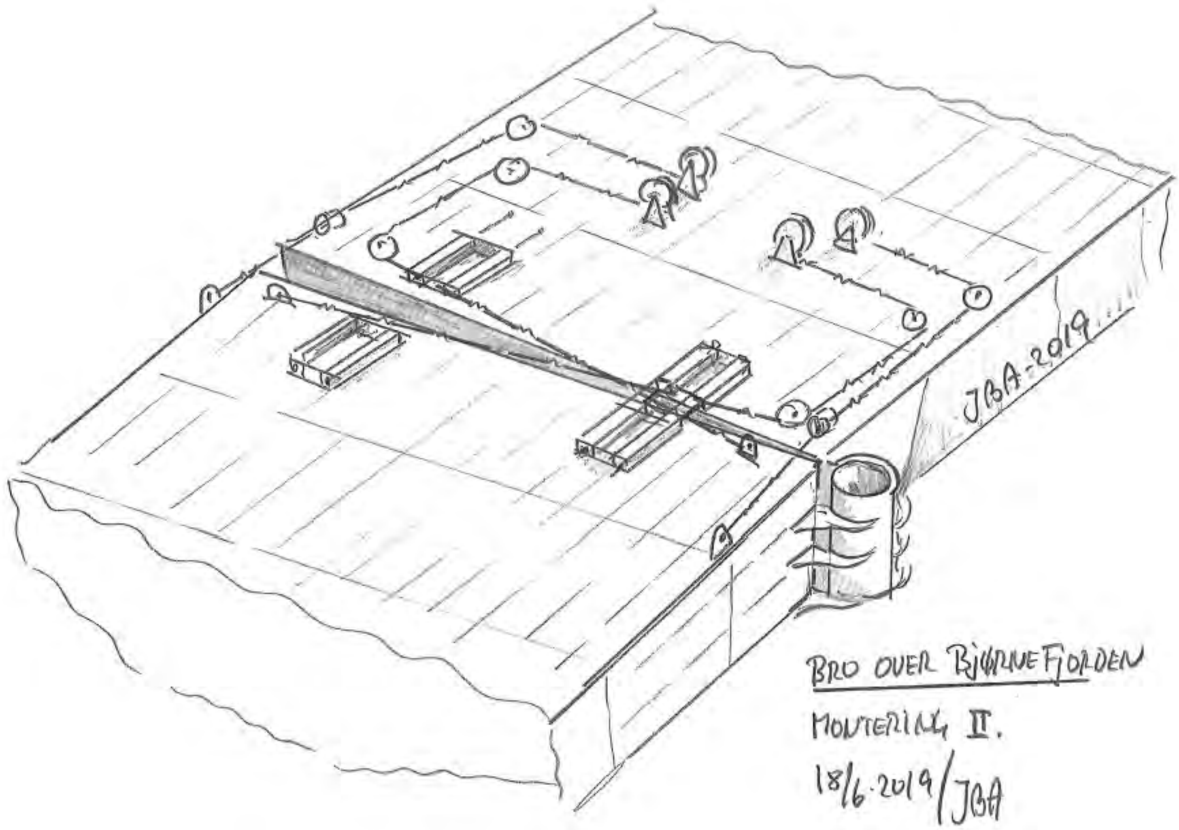


Figure 10-7 Bridge mating by guide joint - 1

The guiding joint is shown in principles in Figure 10-8 and Figure 10-9 and is utilised for guiding the new floating bridge part to the already installed bridge positioned in bridge line. The joint will be utilised for construction joint 1 & 2 at the north bridge end. The purpose is to control the guiding of the bridge end during the first part of the installation ensuring correct bridge position within ±100 mm. The guide joint consists of a tube system where one tube rotates within the other half tube and together with a fender system and winches controlling the first joining process.

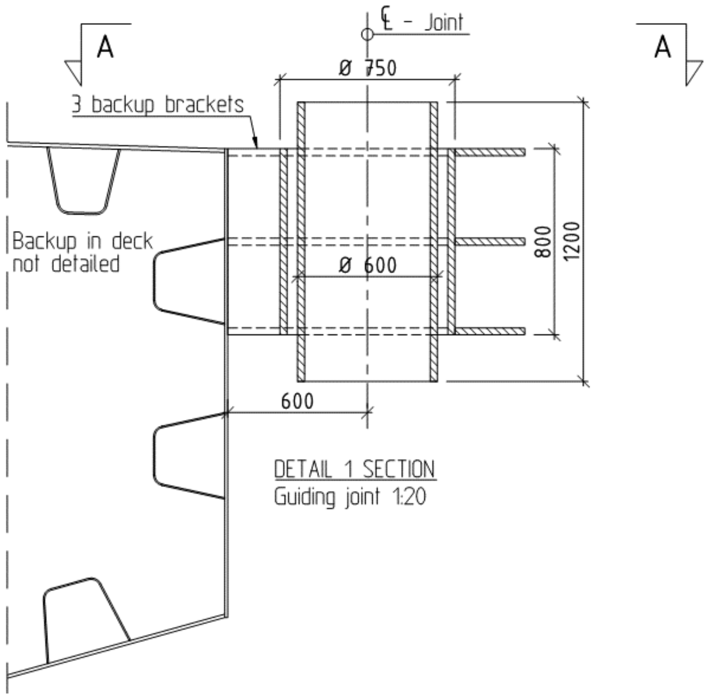


Figure 10-8 Guiding joint, section in construction joint

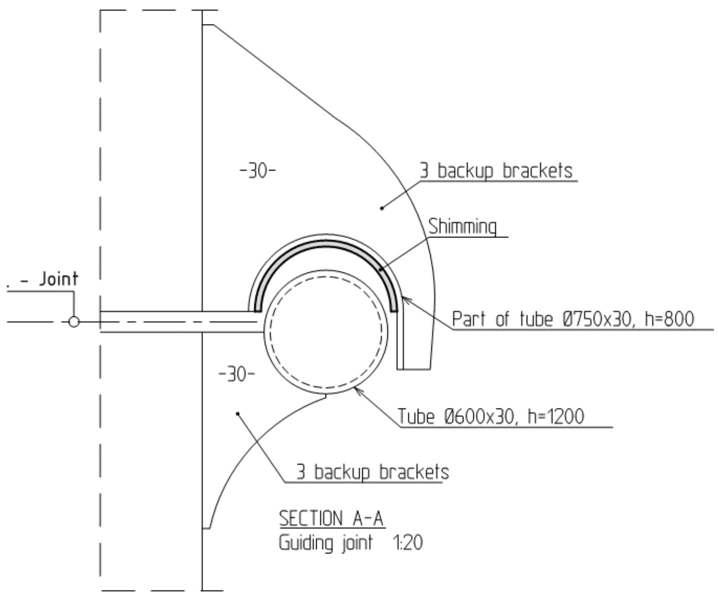


Figure 10-9 Guiding joint, plan view

10.4.3 Positioning joint

The positioning joint is shown in Figure 10-10 to Figure 10-17 and is utilised for positioning the new floating bridge part correctly towards the already installed bridge within the bridge line. By hydraulic jacks the positioning joint will be able to adjust the two bridge sections within all 3 directions and rotations. The joint will be able to withstand the environment loading within the requested weather window of 3 days in the summer period for installation until the locking joint is fully in place and takes over the loading.

The longitudinal bridge positioning and rotation round vertical and horizontal axis are controlled by the 4 jacks marked ② in Figure 10-5. The longitudinal positioning system is moreover shown in Figure 10-10 and Figure 10-11. The jacks have a safe working load (SWL) of 500 t each and can adjust within a range of ±100 mm. When the bridge parts are positioned with a range of ±100mm by the guiding joint, the joint ② is rotated into position and the jacks are activated.

The jacks will push the two bridge parts together until its final distance is reached. The adjustment is done by shimming the gap between the transverse plates within the locking joint system.

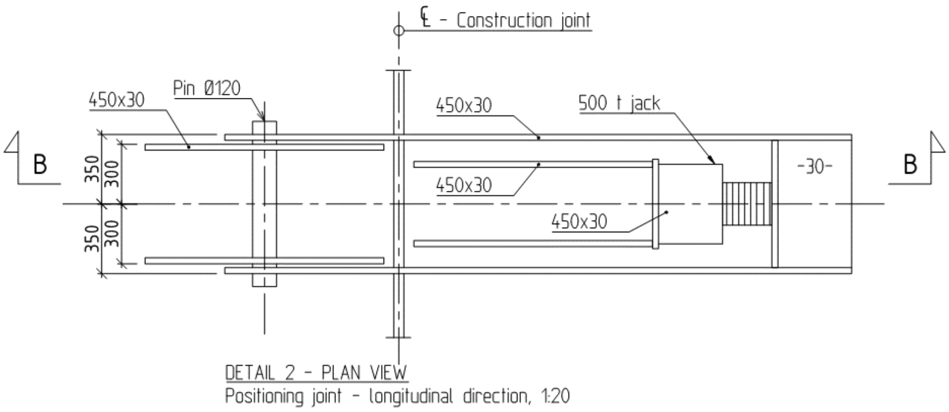


Figure 10-10 Positioning joint, longitudinal direction, plan view

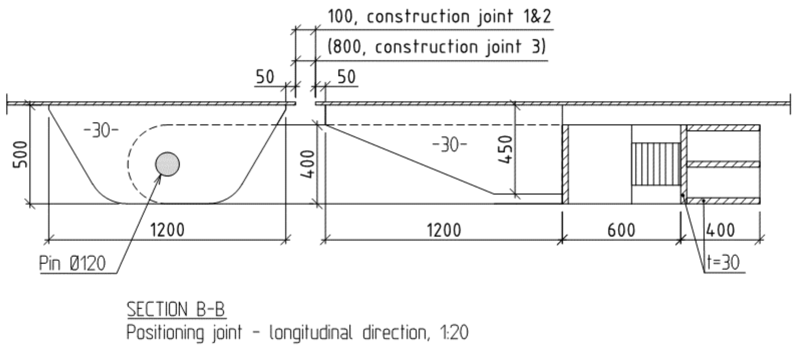


Figure 10-11 Positioning joint, longitudinal direction, section

Figure 10-12 shows a picture from the erection of the Öresund Bridge using the same positioning joint system as descried above.

Figure 10-12 Öresund bridge, jacking system for longitudinal bridge direction

The vertical bridge positioning and rotation round the bridge axis are controlled by the 2x2 jacks marked ③ in Figure 10-5. The jacking system is moreover shown in Figure 10-13 and Figure 10-14. The jacks have a safe working load (SWL) of 200 t each and can adjust within a range of ±100 mm.

When the bridge parts are positioned with a range of ±100mm by the guiding joint, the joint ③ is rotated into position and the jacks are activated.

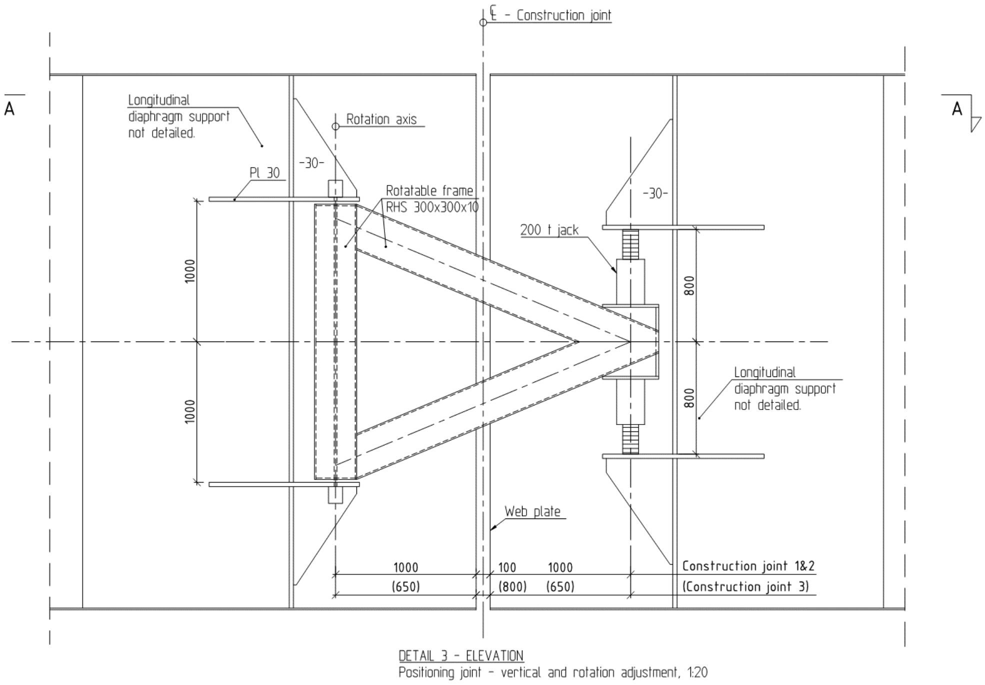


Figure 10-13 Positioning joint, vertical direction, elevation

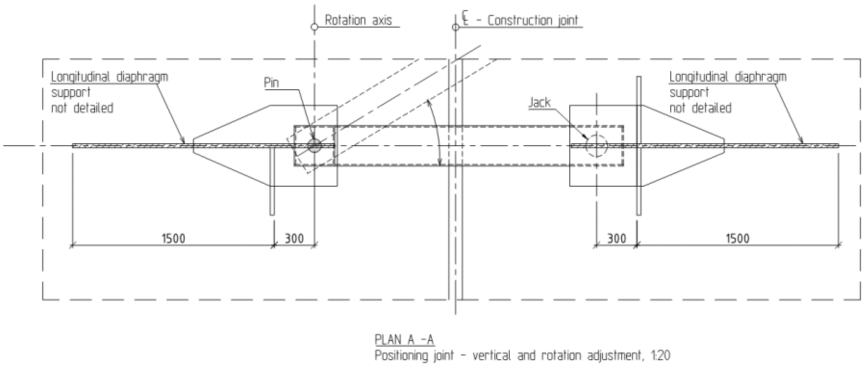


Figure 10-14 Positioning joint, vertical direction, plan view

Figure 10-15 shows a picture from the erection of the Pont de Normandie using the same positioning joint system as descried above. From the picture can furthermore be seen the installation of an infill piece, which will also be done here for the construction joint 3 positioned at the south bridge end.

Figure 10-15 Pont de Normandie, jacking arrangement for vertical bridge positioning

The transverse bridge positioning is controlled by the 1x2 jacks marked ④ in Figure 10-5. The jacking system is moreover show in Figure 10-16 and Figure 10-17. The jacks have a safe working load (SWL) of 100 t each and can adjust within a range of ±100 mm.

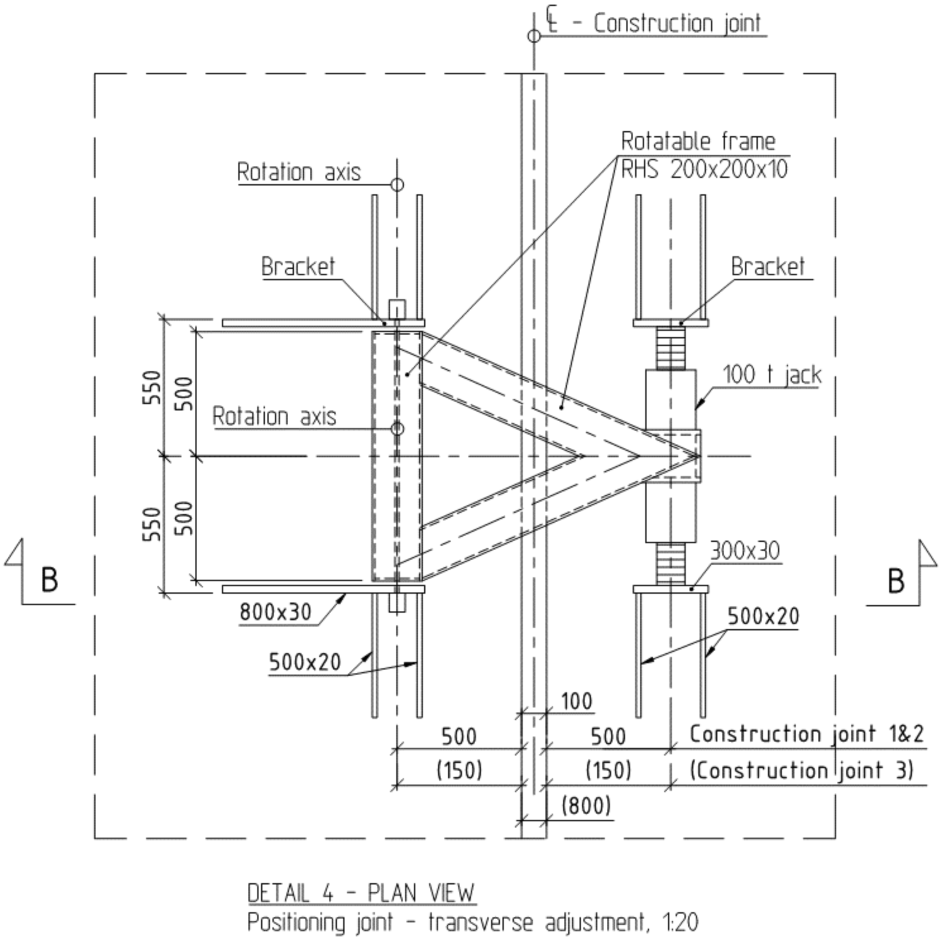


Figure 10-16 Positioning joint, transverse direction, plan view

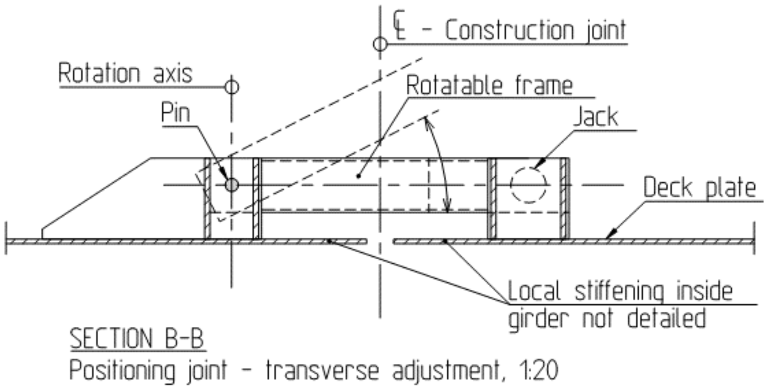


Figure 10-17 Positioning joint, transverse direction, side view

When the bridge parts are positioned with a range of ±100mm by the guiding joint, the joint ④ is rotated into position and the jacks are activated.

10.4.4 Locking joint at construction joint 1 & 2

The locking joint for construction joint 1 & 2 at the north bridge end is shown in Figure 10-18 to Figure 10-23. The locking joint for construction joint 1 & 2 is without any infill piece and is utilised to lock and secure the new floating bridge part against environmental loading from a 10 year summer storm. The locking joint will furthermore ensure minimal and acceptable strain variations over the construction joint during the welding operation. The detailed FE-analyses and belonging verification of the strain variation during the welding process are not part of this document and dealt with elsewhere.

The locking joint is prefabricated in the fabrication yard and trail assembled before brought to the bridge line. Within the bridge line, the anchor rods shall be installed together with the shimming and finally pretension of the rods. The locking system will be installed, tensioned and activated within the 3 days erection period and takes over the full loading from the positioning system. The locking joint will be able to resist a 10 year summer storm until the permanent joint is finalised and takes over the full loading.

The locking joint system utilised for the web and bottom plates is marked ⑤ in Figure 10-5 and is shown in more details in Figure 10-18 to Figure 10-20.

It can be seen that the locking joint arrangement is positioned at the outside of the skin plates making the welding process possible from inside of the box using ceramic backing. Hereby an easy and fast welding process becomes possible with plan welding position without obstructions from the locking system.

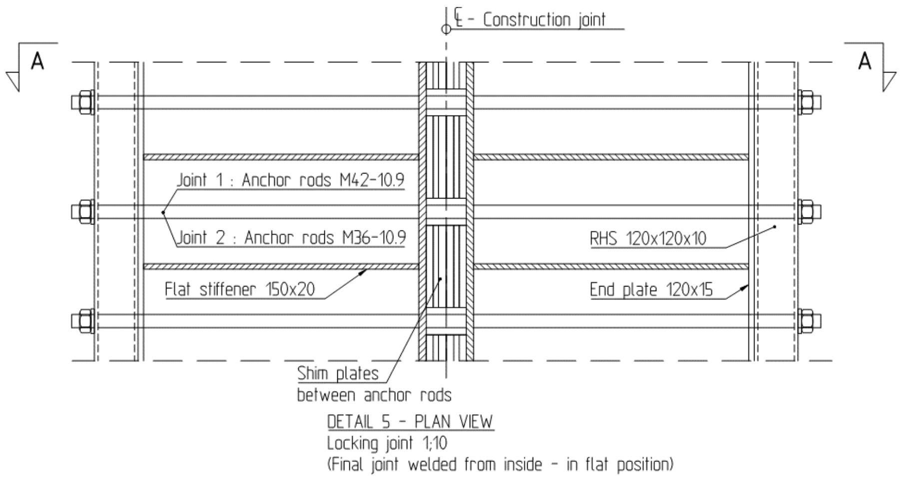


Figure 10-18 Locking joint for web- and bottom plates, construction joint 1 & 2, plan view

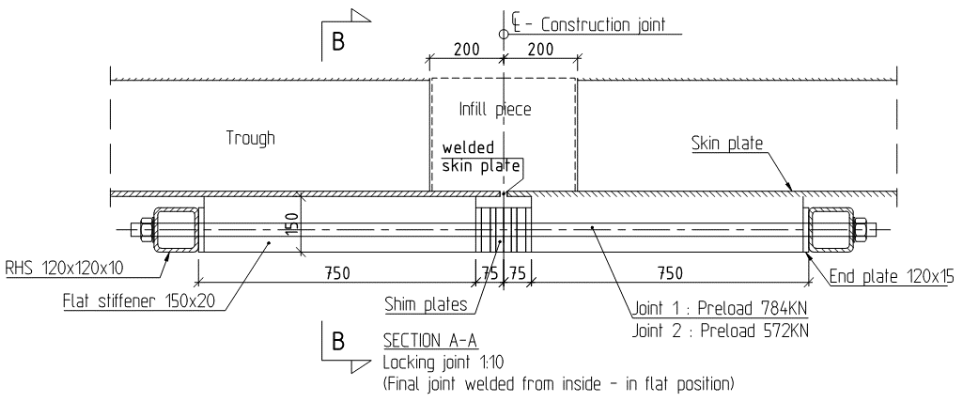


Figure 10-19 Locking joint for web- and bottom plates, construction joint 1 & 2, longitudinal section

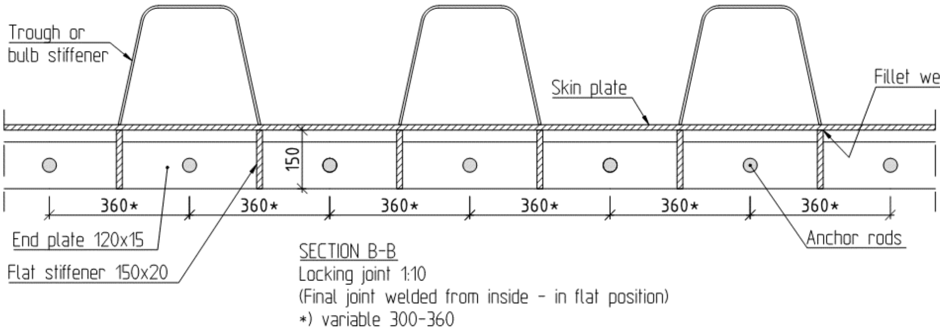


Figure 10-20 Locking joint for web- and bottom plates, construction joint 1 & 2, transverse section

The locking joint system for the deck plate is marked ⑥ in Figure 10-5 and is shown in more details in Figure 10-21 to Figure 10-23.

It can be seen that the locking joint arrangement now is positioned at the inside of the deck plate making the welding process possible from outside of the box using ceramic backing. Hereby an easy and fast welding process becomes possible with plan welding position without obstructions from the locking system.

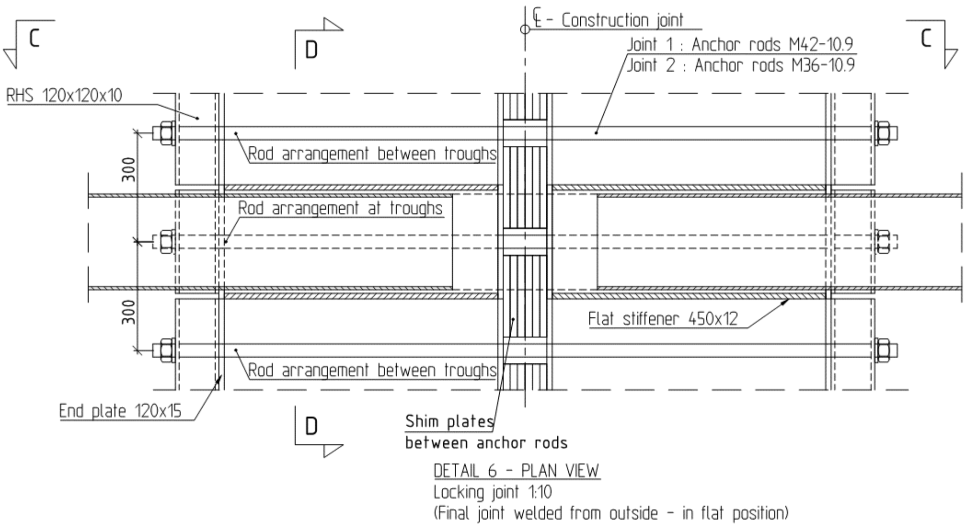


Figure 10-21 Locking joint for deck plate, construction joint 1 & 2, plan view

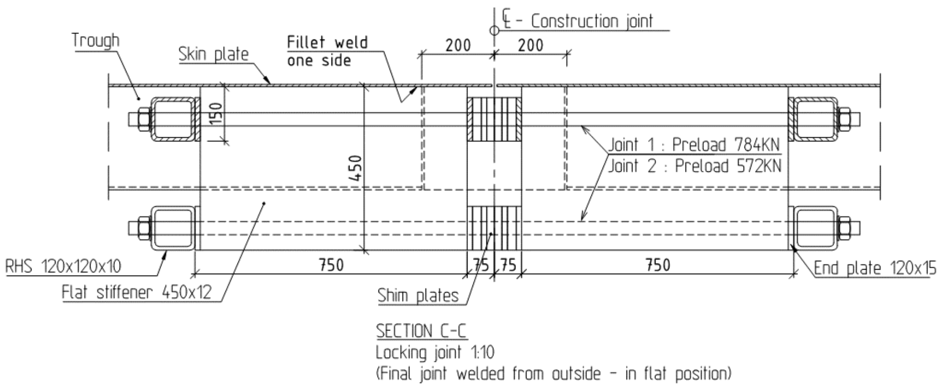


Figure 10-22 Locking joint for deck plate, construction joint 1 & 2, longitudinal section

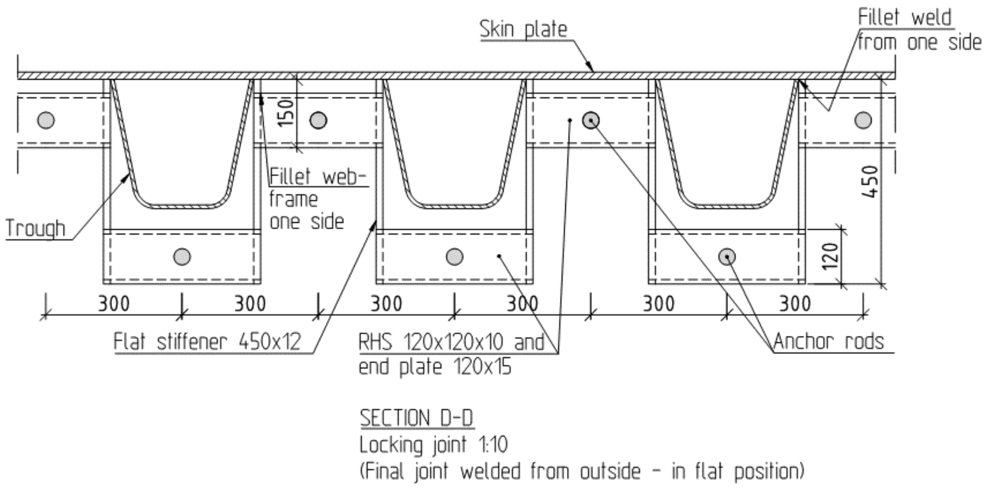


Figure 10-23 Locking joint for deck plate, construction joint 1 & 2, transverse section

10.4.5 Locking joint at construction joint 3

The locking joint for construction joint 3 is shown in Figure 10-24 to Figure 10-27 and is utilised to lock and secure the new floating bridge part against environmental loading from a 10 year summer storm.

The locking joint for construction joint 3 is special as includes and infill piece of 800 mm length. The locking joint utilised to lock and secure the new floating bridge part against environmental loading from a 10 year summer storm. The locking joint will furthermore ensure minimal and acceptable strain variations over the construction joint during the welding operation. The detailed FE-analyses and belonging verification of the strain variation during the welding process are not part of this document and dealt with elsewhere.

The locking system will be installed, tensioned and activated within the 1 day erection period and takes over the full loading from the positioning system. The locking joint will be able to resist a 10 year summer storm until the permanent joint is finalised and takes over the full loading.

The locking joint system utilised for the webs and bottom flanges is marked ⑤ in Figure 10-5 and is shown in more details in Figure 10-24 and Figure 10-25.

As for construction joint 1 & 2, the locking arrangement is positioned at the outside of the skin plates making the welding process possible from inside of the box using ceramic backing. Figure 10-24 shows the joint with an 800 mm gap while Figure 10-25 shows the same joint now with infill skin plates and stiffeners welded in. The remaining part of the joint now becomes similar to the same locking joint utilised for construction joint 1 & 2.

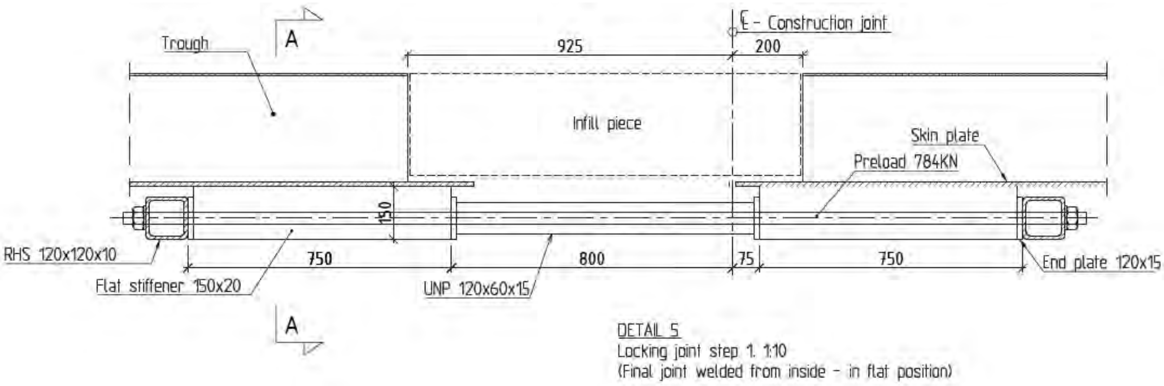


Figure 10-24 Locking joint for web- and bottom plates, construction joint 3 inclusive 800mm infill piece, longitudinal section

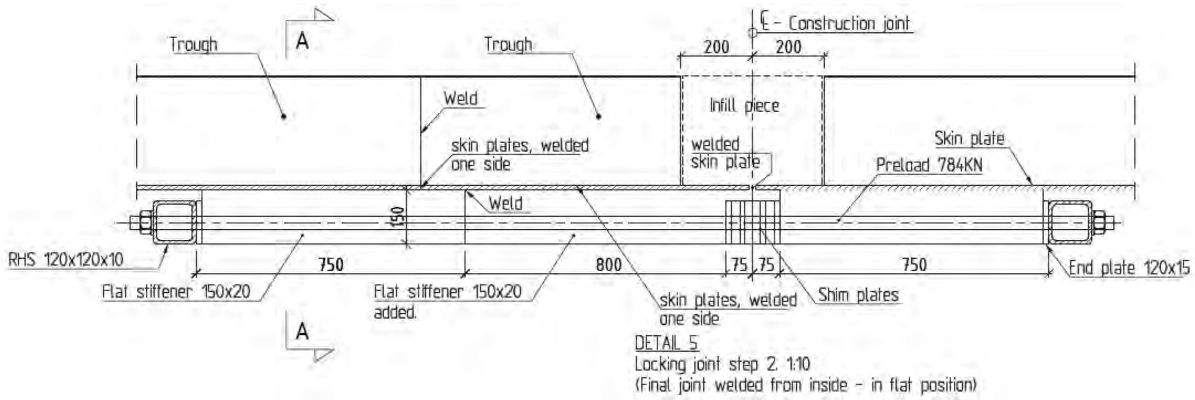


Figure 10-25 Locking joint for web- and bottom plates, construction joint 3 inclusive 800mm infill piece, longitudinal section Infill skin and stiffener plates now welded into position

The locking joint system utilised for the deck plate is marked ⑥ in Figure 10-5 and is shown in more details in Figure 10-26 and Figure 10-27.

As for construction joint 1 & 2, the locking arrangement is positioned at the inside of the skin plates making the welding process possible from outside of the box using ceramic backing.

Figure 10-26 shows the joint with an 800 mm gap while Figure 10-27 shows the same joint now with infill skin plates and stiffeners welded in. The remaining part of the joint now becomes similar to the same locking joint utilised for construction joint 1 & 2.

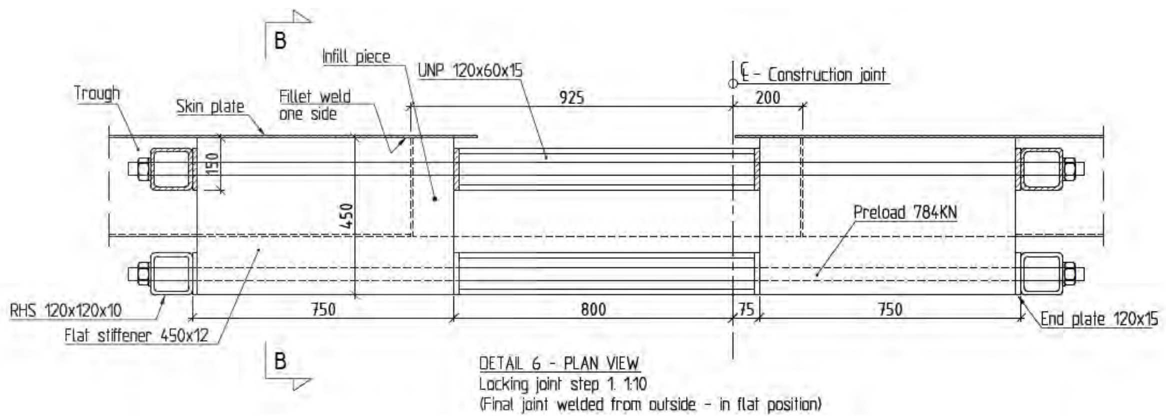


Figure 10-26 Locking joint for deck plate, construction joint 3 inclusive 800mm infill piece, longitudinal section

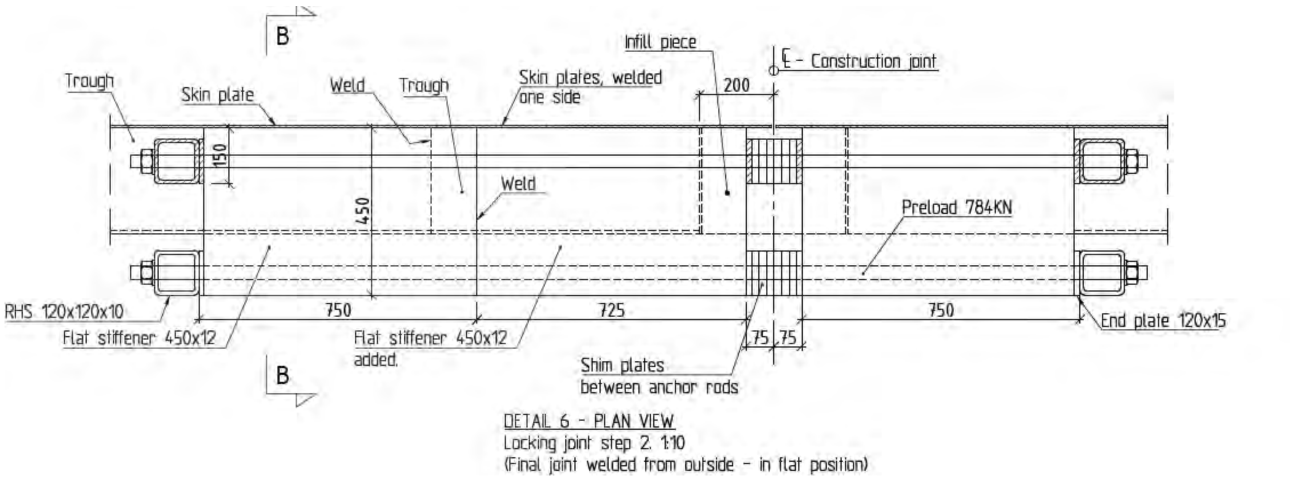


Figure 10-27 Locking joint for deck plate, construction joint 3 inclusive 800mm infill piece, longitudinal section Infill skin and stiffener plates now welded into position

10.5 Dimensioning environmental conditions

In order to generate dimensioning loads for the various joints and systems a large number of parameter variations and screenings have been run. After an iterative process the following assumptions are made:

Table 10.2 Analysis run for the forces during mating

System	Weather limitations	Comments
Guiding system	Max design Hs=0.5m with associated Tp No swell Wind=8m/s	While the guiding system is engaged, the towing vessels will still be connected, greatly reducing the horizontal dynamics of the bridge. The guiding system will not exert any moments on the bridge.
Positioning system	Max design Hs=0.5m with associated Tp No swell Wind=8m/s	While the positioning system is engaged, the towing vessels will still be connected, greatly reducing the horizontal dynamics of the bridge. **The design Hs of 0.5m will yield an operational Hs of 0.3m due to alpha factor considerations***
Locking system unrestricted	Windwaves: Hs=1m; Tp=4.3s from 300 degrees Swell: Hs=0.16m; Tp=20 s from 300 degrees Wind=23m/s	The locking system is conservatively designed to withstand forces without moorings. Environmental conditions correspond to 1 year seasonal return values for wind waves and swell and 10 year seasonal return value for wind.
Locking system during welding	Max design Hs=0.5m with associated Tp No swell Wind=8m/s	Welding will commence after moorings are installed. **The design Hs of 0.5m will yield an operational Hs of 0.45m due to alpha factor considerations****

*All marine operations need to adhere to DNVGL alpha factor considerations as discussed in section 3.2.1. The alpha factor quantifies the uncertainty in the weather forecast at the start of an operation and the planned duration of the operation. The design wave height needs to be multiplied with the alpha factor in order to achieve the “allowable operational Hs”. For the installation phase of the bridge the alpha factor is found to be 0.61 according to DNV rules. This means that the weather window needs to show a lower Hs than 0.5*0.61=0.3m in order to commence the installation operation.

**Following the same argumentation as the footnote above. The alpha factor during welding takes into account the shorter timeframe of the *initial* welding operation. In this case the alpha factor is 0.9 and thus the allowable operational Hs for the welding operation is 0.9*0.5=0.45m.

10.5.1 Dimensioning of positioning system and locking system during welding.

The positioning system should be able to withstand a design weather condition of 0.5m Hs and 8m/s wind, both coming from the most onerous direction. The locking system should be able to withstand the same forces during welding while also keeping welding strains to a minimum. Full dynamic analysis have been performed and the following results have been found.

Note that the values below are only the variation in the moments. The static contribution from self-weight is not included. The forces do not include load factors. It is assumed that some ballasting operations on the pontoons will be performed during the operational phases, such that the contribution of tidal difference is close to negligible.

Table 10.3 Analysis results for 0.5m Hs and 8m/s wind conditions

	Joint 1	**Joint 2**	**Joint 3**
	Location 45 m south of A41	**:ation 85m south of A**	**Location 15m south of A3**
	Full dynamic	**Full dynamic**	**Full dynamic**
Weak Axis Moment variation [MNm]	**15**	**10**	**14**
Strong Axis Moment variation[MNm]	**30**	**35**	**20**

10.5.2 Dimensioning of locking system (Storm condition)

The following values need to be adhered to in the design of the locking system for a survival condition.

The static contribution from self-weight is not included. The forces do not include load factors.

Table 10.4 Analysis results for dimensioning of locking system (storm conditions)

	Only A38-A41 included								
	Joint 1			**Joint 2**			**Joint 3**		
	Location 45 m south of A41			**Location 85m south of A39**			**Location 15m south of A3**		
	Full dynamic analysis (Wind, Swell and waves)	Static loads from tidal difference	Static loads from current	**Full dynamic analysis (Wind, Swell and waves)**	Static loads from tidal difference	Static loads from current	**Full dynamic analysis (Wind, Swell and waves)**	Static loads from tidal difference	Static loads from current
Dynamic variation of Weak Axis Moment [MNm]	**50**	110 MN pr meter tidal difference	0	**30**	5	0	**55**	40	1
Dynamic Strong Axis Moment [MNm]	**300**	0	30	**250**	0	20	**220**	0	18

10.5.3 Locking system during welding

The same forces as 10.5.1 can be used for dimensioning

10.6 Construction joint verification

In this section a design verification will be carried out for the two joint types "positioning joint" and "locking joint".

10.6.1 Positioning joint

Forces are taken from Table 10.3:

Construction joint 1 at north bridge end: M_{strong} = ±30 MNm, M_{weak} = ±15 MNm (SLS)

Construction joint 2 at south bridge end: M_{strong} = ±35 MNm, M_{weak} = ±10 MNm (SLS)

Construction joint 3 at south bridge end: M_{strong} = ±20 MNm, M_{weak} = ±14 MNm (SLS)

The positioning joint will be designed for the above load situations as the operation can be aborted if the H_s becomes higher than 0.3 m. Conservatively, instead a load factor of y_d = 1.6 can be multiplied on the above characteristics loads and then the positioning joint can be designed for the ULS situation as well.

Here it will be verified that the positioning joint is able to withstand the ULS load situations. The correlation between the two moments is conservatively set to 1.0, meaning that max M_{strong} will be combined with max M_{weak}.

The ULS load situation becomes:

Construction joint 1 north bridge end: M_{strong} = ±48 MNm, M_{weak} = ±24 MNm (ULS)

Construction joint 2 north bridge end: M_{strong} = ±56 MNm, M_{weak} = ±16 MNm (ULS)

Construction joint 2, 3 at south bridge end: M_{strong} = ±32 MNm, M_{weak} = ±22 MNm (ULS)

The vertical lever arm for M_{weak} is approximately 3.8 m and the transverse lever arm for M_{strong} is set to 16.0 m.

Maximum (ULS) loading of one positioning joint becomes:

Construction joint 1: (48/16.0 + 24/3.8)*0.5 MN = 1.50 + 3.17 MN = 4.7 MN, (2.9 MN SLS)

Construction joint 2: (56/16.0 + 16/3.8)*0.5 MN = 1.75 + 2.11 MN = 3.9 MN, (2.5 MN SLS)

Construction joint 3: (32/16.0 + 22/3.8)*0.5 MN = 1.00 + 2.89 MN = 3.9 MN, (2.5 MN SLS)

The selected jacks of 500 t SWL is seen to have double capacity when compared to SLS.

Tension element 400x30, pin Ø120: σ_N = 4.7e6/((400-120)*30)*0.5 MPa = 280 MPa, ok S355

Bending of bracket: σ_M = 4.7e6*300/(1/6*1200^2*30)*0.5 MPa = 98 MPa, τ = 4.7e6/(1200*30)*0.5 = 65 MPa, σ_{mises} = 150 MPa, ok S355

Ø120 pin: τ = 4.7e6/(120^2*PI/4)*0.5 MPa = 208 MPa, σ_{mises} = 360 MPa, room for bending also, steel quality to be selected later

From above is concluded that the positioning joint has sufficient capacity.

10.6.2 Locking joint (Survival mode)

Forces are taken from Table 10.4

For construction joint 1 the static load from tidal difference cannot be fully accounted for by the present joint. It is considered to extend the bridge length further out from the North abutment to reach a more acceptable design bending moment round weak axis. At present 20 MNm has been selected for the tidal difference, combined with maximum moment envelopes round both weak and strong axis.

At present the following values have been selected for design verification of the locking joints

Construction joint 1 north bridge end: M_{strong} = ±(300+30) MNm, M_{weak} = ±(50+20) MNm (SLS)

Construction joint 2 at south bridge end: M_{strong} = ±(250+20) MNm, M_{weak} = ±(30+5) MNm (SLS)

Construction joint 3 at south bridge end: M_{strong} = ±(220+18) MNm, M_{weak} = ±(55+40) MNm (SLS)

The ULS load situation becomes ULS = 1.6*SLS:

Construction joint 1 north bridge end: M_{strong} = ±528 MNm, M_{weak} = ±112 MNm (ULS)

Construction joint 2 at north bridge end: M_{strong} = ±432 MNm, M_{weak} = ±56 MNm (ULS)

Construction joint 3 at south bridge end: M_{strong} = ±381 MNm, M_{weak} = ±152 MNm (ULS)

Anchor rods

The locking joint will be designed for the above SLS load situation and verified that no separation will occur in the preloaded bolt connection. The correlation between the two moments is conservatively set to 1.0, meaning that max M_{strong} will be combined with max M_{weak}.

The locking joint will be designed for the above ULS load situation and again the correlation between the two moments is conservatively set to 1.0, meaning that max M_{strong} will be combined with max M_{weak}.

The SLS and ULS design verification will be done using a simplified box girder of rectangular shape with dimensions width*height of 26.5 m*3.8 m. Along the 2*26.5m = 53 m long deck, bottom and web plates 170 nos 10.9 anchor rods are positioned. For bending moment round strong axis, a plastic moment of resistance will be utilised.

M42 10.9 anchor rods:

Preload force F_p = 0.7*1000*1120 N = 784 kN

Design preload $F_{p,Cd}$ = F_p/1.1 = 713 kN, load per m - 170*0.713/(2*26.5) MN/m = **2.29 MN/m (SLS)**

Tension resistance F_t = 0.9*1000*1120 N = 1008 kN

Design tension resistance $F_{t,Rd}$ = F_t/1.25 = 806 kN, load per m - 170*0.806/(2*26.5) MN/m = **2.59 MN/m (ULS)**

M36 10.9 anchor rods:

Preload force F_p = 0.7*1000*817 N = 572 kN

Design preload $F_{p,Cd}$ = F_p/1.1 = 520 kN, load per m - 170*0.520/(2*26.5) MN/m = **1.67 MN/m (SLS)**

Tension resistance F_t = 0.9*1000*817 N = 735 kN

Design tension resistance $F_{t,Rd}$ = F_t/1.25 = 588 kN, load per m - 170*0.806/(2*26.5) MN/m = **1.89 MN/m (ULS)**

Lift-off of locking joint in SLS:

Construction joint 1: 330/(2*¼*26.5^2) + 70/(3.8*26.5) = 0.94 MN/m + 0.70MN/m = 1.64 MN/m,

M42 rod $F_{p,Cd}$ per m = 2.29 MN/m > 1.64 MN/m, ok

Construction joint 2: 270/(2*¼*26.5^2) + 35/(3.8*26.5) = 0.77 MN/m + 0.35MN/m = 1.12 MN/m, M36 rod $F_{p,Cd}$ per m = 1.67 MN/m > 1.12 MN/m, ok

Construction joint 3: 238/(2*¼*26.5^2) + 95/(3.8*26.5) = 0.68 MN/m + 0.94 MN/m = 1.62 MN/m,

M42 rod $F_{p,Cd}$ per m = 2.29 MN/m > 1.62 MN/m, ok

Capacity of anchor rods

In the following ULS verification a plastic design approach is utilised for moments round strong axis which is deemed acceptable as the two maximum moments are added together.

Construction joint 1: 528/(2*¼*26.5^2) + 112/(3.8*26.5) = 1.50 MN/m + 1.11MN/m = 2.61 MN/m,

M42 rod $F_{p,Cd}$ per m = 2.59 MN/m ~ 2.61 MN/m, ok

Construction joint 2: 432/(2*¼*26.5^2) + 56/(3.8*26.5) = 1.23 MN/m + 0.56MN/m = 1.79 MN/m,

M36 rod $F_{p,Cd}$ per m = 1.89 MN/m > 1.79 MN/m, ok

Construction joint 3: 381/(2*¼*26.5^2) + 152/(3.8*26.5) = 1.09 MN/m + 1.51 MN/m = 2.59 MN/m,

M42 rod $F_{p,Cd}$ per m = 2.59 MN/m ~ 2.59 MN/m, ok

Flat stiffeners 150x20 and welds

Flat stiffener of 150x20 S420 with double sided a5 or single sided a10 fillet weld. In the design check 16 mm thick skin plate of length 300 mm is added as well for the design check.

The stiffener shall be designed taking 1 time the preloading force (0.784 MN) and furthermore transfer 1 time the max compression load within joint (0.806 MN).

σ = (0.784e6+0.806e6)/(150*20+16*300) = 204 MPa < 400 MPa

Shear transfer to skin plate 0.806e6/(750*10) = 107 MPa < 242 MPa

Skin plate and trough - 16mm skin plate and 10 mm trough

The effective section properties for 16 mm skin plate with 10 mm trough can be found below in below Table 10-5.

Max tension/compression force (2 rods per trough section):

F = 2*806 kN

Effective area taken from Table 10-5 A_{eff} = 1.75e4 mm^2

σ_N = 2*806e3/1.75e4 = 92 MPa

Max local bending moment transferring the force from rods to centre of gravity for the trough section.

For stiffener arrangement placed outside F = 2*806 kN, lever arm rod/skin plate = 75 mm, lever arm trough section/skin plate (y_{0eff} in Table 10-5) = 80 mm

Smallest effective section modulus $W_{bottom,eff}$ = 1.09e6 mm^3

σ_M = 2*806e3*(75+80)/1.09e6 = 229 MPa

σ_{total} = 92 + 229 MPa = 321 MPa < 420 MPa

For stiffener arrangement placed inside F = 2*806 kN, lever arm rod/skin plate = 250 mm, lever arm trough section/skin plate (y_{0eff} in Table 10-5) = 80 mm

Smallest effective section modulus $W_{bottom,eff}$ = 1.09e6 mm^3

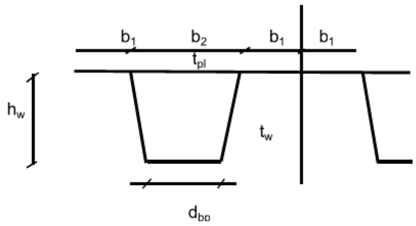
σ_M = 2*806e3*(250-80)/1.09e6 = 208 MPa

σ_{total} = 92 + 251 MPa = 343 MPa < 420 MPa

Based on the above calculations the local strength of the locking joint is hereby verified.

Date of preparation:
Initials:

Buckling of plates and panels (EN 1993-1-1:2005 / EN 1993-1-5:2006)



Steel grade	1: Table 3.1		s420
γ_{M1}	3), 1: 6.1	[-]	1.10

	Reference	Unit	
Plate			
b_1		[mm]	150
b_2		[mm]	300
t_{pl}		[mm]	16
Ψ_{pl}	5: Table 4.1	[-]	1
$K_{\sigma,pl}$	5: Table 4.1	[-]	4
f_y	1: Table 3.1	[MPa]	420
f_{yd}	1: (6.48)	[MPa]	382
ε	5: (4.3)	[-]	0.748
λ_1	1: (6.51)	[-]	68.555
$\lambda_{p,b1}$	5: (4.3)	[-]	0.441
$\lambda_{p,b2}$	5: (4.3)	[-]	0.441
ρ_{b1}	5: (4.2)	[-]	1.00
ρ_{b2}	5: (4.2)	[-]	1.00
$b_{1,eff}$		[mm]	150
$b_{2,eff}$		[mm]	300
Stiffener webs			
h_w		[mm]	300
t_w		[mm]	10
Ψ_w	5: Table 4.1	[-]	1
K_w	5: Table 4.1	[-]	4
f_y	1: Table 3.1	[MPa]	420
f_{yd}	1: (6.48)	[MPa]	382
ε	5: (4.3)	[-]	0.748
λ_1	1: (6.51)	[-]	68.555
$h_{st.incl}$		[mm]	304
λ_{pw}	5: (4.3)	[-]	0.716
ρ_w	5: (4.2)	[-]	0.97
$h_{w.incl,eff}$		[mm]	147
$t_{w.\ equiv.}$		[mm]	10.14
$h_{w,eff\ equiv.}$		[mm]	145
Stiffener bottom plate			
d_{bp}		[mm]	200
t_{bp}		[mm]	10
Ψ_{bp}	5: Table 4.1	[-]	1
K_{bp}	5: Table 4.1	[-]	4
$\lambda_{p,bp}$	5: (4.3)	[-]	0.471
ρ_{bp}	5: (4.2)	[-]	1.00
$d_{bp,eff}$		[mm]	200

	Reference	Unit	
Panel			
L_{cr}		[mm]	4000
α	1: Table 6.1	[-]	0.34
f_y		[MPa]	382
Gross section			
A		[m²]	1.77E-02
S		[m³]	1.44E-03
y_o		[m]	0.081
I_x		[m⁴]	3.63E-04
I		[m⁴]	2.47E-04
W_{top}		[m³]	2.54E-03
W_{bottom}		[m³]	1.10E-03
Effective section			
A_{eff}		[m²]	1.75E-02
S_{eff}		[m³]	1.41E-03
$y_{o,eff}$		[m]	0.080
$I_{x,eff}$		[m⁴]	3.59E-04
I_{eff}		[m⁴]	2.46E-04
$W_{top,eff}$		[m³]	2.55E-03
$W_{bottom,eff}$		[m³]	1.09E-03
Buckling			
λ		[m⁴]	33.86
λ –		[-]	0.491
ϕ		[-]	0.670
χ		[-]	0.888
$\chi \times A_{eff}/A$		[-]	**0.878**
Critical stresses			
σ_{cr} plate		**[MPa]**	**382**
σ_{cr} stiffener		**[MPa]**	**369**
σ_{cr} panel		**[MPa]**	**335**

Axial resistance

$N_{b,Rd}$		[MN]	5.93

Table 10-5 Section properties for trough section with 16 skin plate and 10 mm trough

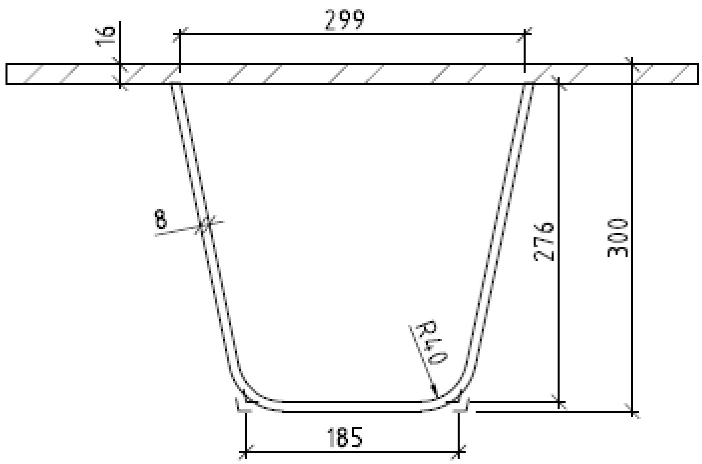


Figure 10-28 Deck and trough configuration used in

10.6.3 Locking joint FE analysis (Strains during welding)

The locking joint shall ensure that the strains in the weld between the skin plates during welding is kept at a minimum for dynamic loading. The purpose is to prevent cracks in the weld which can reduce fatigue life. A local FEM has been created and run with a weak axis bending moment (14MNm) corresponding to a wind sea with Hs 0.5 m.

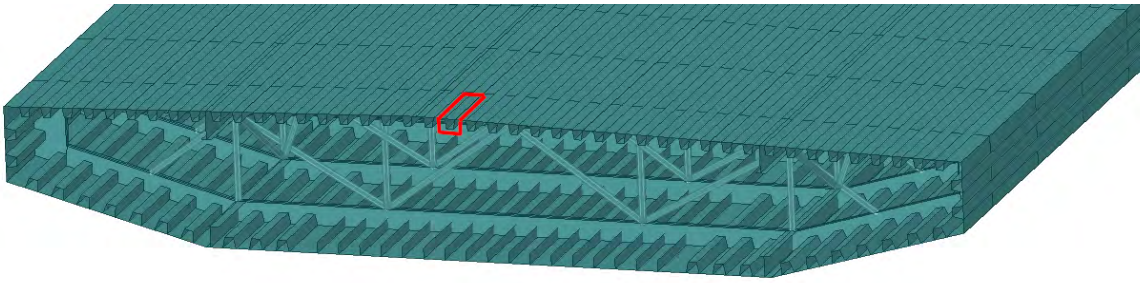


Figure 10-29 Part selected for local model

The modelled part is representative for the bottom plate, as the top plate will have the locking joint on the inside of the girder. The principle however will be the same.

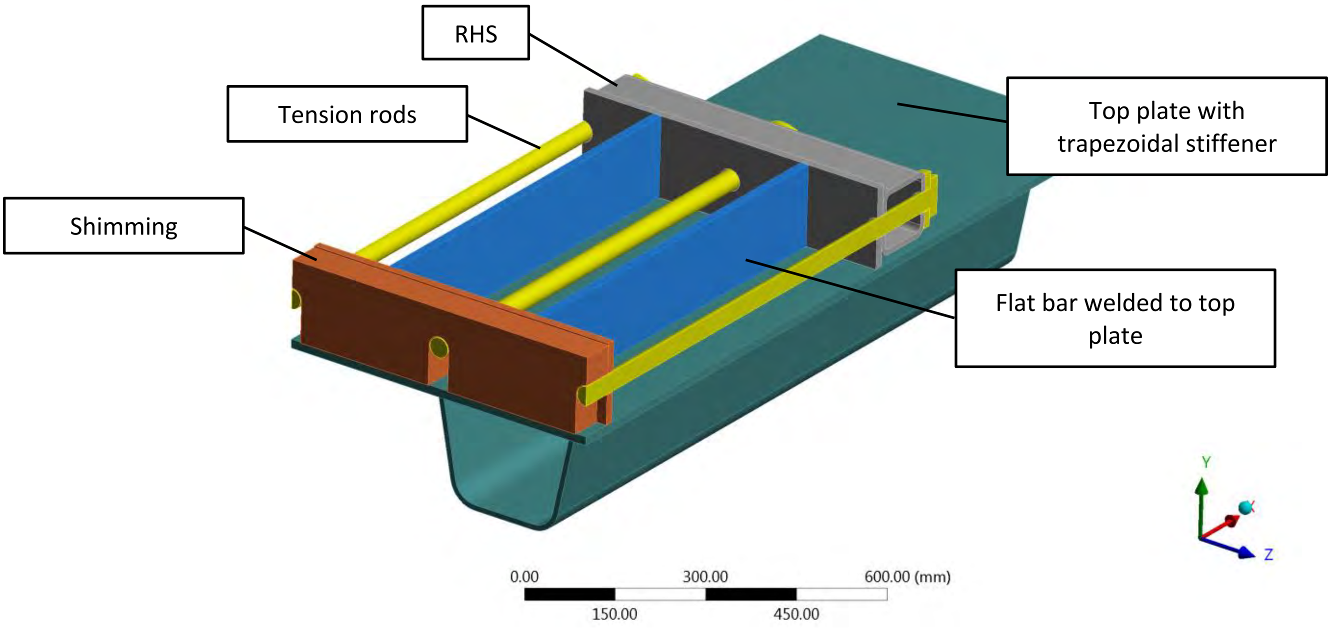


Figure 10-30 Local model, ISO view

Flat bars are welded to the plate of the bridge girder. Rods are tensioned pressing the flat bars against shimming plates, effectively restraining the skin plate ends of the two girders at a predefined distance prior to welding. The gap prior to welding is set to 5 mm at bottom.

Results from the FEM show that the stress and strains in the weld are acceptable throughout the assembly from the first bead is welded to the weld is finished. Detailed results can be found in Enclosure /1/.

The locking joint is a flexible solution and can be optimized so that the weld stress and strain is kept at an acceptable level if the relevant environmental loading in a detailed phase change.

11 Schedule and Basis for cost

The overall schedule for the construction of the Bjørnafjorden bridge is presented in the figure below.

Name	Current start	Current finish
⊟ **Schedule - Marine Operasjoner**	**03.01.2022**	**30.04.2027**
Preparatory works	03.01.2022	30.06.2022
Cabel stayed bridge - Abutment and Side spans	01.07.2022	22.12.2023
Cabel stayed bridge - Tower	01.07.2022	22.12.2023
Cabel stayed bridge - Fabrication of girders	01.08.2022	31.07.2024
Cabel stayed bridge - Assembly of girders	02.01.2024	30.06.2025
Fabrication of girders, floating bridge	01.03.2023	29.08.2025
Fabrication of columns and pontoons, floating bridge	02.01.2023	29.11.2024
Assembly of low floating bridge	01.02.2024	30.04.2026
Assembly of high floating bridge	02.09.2024	31.10.2025
Mooring system - Fabrication and Installation	01.03.2024	30.09.2025
North Abutment	01.09.2022	30.08.2023
Concrete section in North	01.10.2024	30.05.2025
Final construction of road in North	02.06.2025	28.11.2025
Tow and hook up of bridge in Bjørnafjorden	04.05.2026	30.06.2026
Features, paving and testing	01.07.2026	30.04.2027

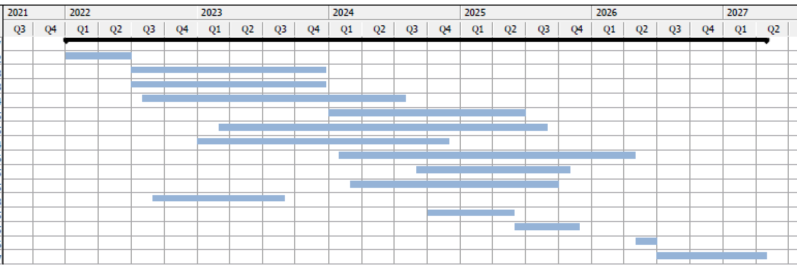


Figure 11-1: Schedule for the Bjørnafjorden bridge construction

In this section the basis for the cost of the assembly and installation of the floating bridge is presented. The basis presented does not include the following:

- Fabrication and transport of the bridge girder segments to west coast of Norway
- Fabrication and transport of the pontoons and columns to west coast of Norway
- Construction of the cable stayed bridge
- Construction of the north abutment

11.1 Logistics base and transport of elements to assembly site

A logistics base will be set up in order to receive bridge girder segments and and pontoons / columns from the various fabrication sites. The assembly site in Søreidsvika is not set up for the receipt, storage and handling of the large quantity of girders and pontoons. The logistics base will require

- A quay side (where the transportation vessels and barges can moor for offloading and onloading of bridge girder segments),
- Land for storage of girder segments,
- A heavy lift crawler crane (for lifting of girders at various locations on the site)
- A multiwheel trailer
- Location for mooring of the pontoons.

As basis for this study, Stord Base has been used.

The figure below shows the duration of usage of the logistics base. This is linked to the duration of the floating bridge assembly

⊟ **Logistics of Bridge girders and pontoons / columns**	**01.01.24 00:00**	**12.05.26 00:00**	**862 d**
Preparation for receipt of bridge girders	01.01.24 00:00	15.01.24 00:00	14 d
Receipt of 1st load of bridge girders	15.01.24 00:00	04.02.24 00:00	20 d
Storage, handling, receipt and load out of bridge elements	04.02.24 00:00	28.04.26 00:00	814 d
Demobilise Logistics base	28.04.26 00:00	12.05.26 00:00	14 d

Figure 11-2: Low floating bridge assembly plan

The cost for rental of two North sea barges is also included in the transport of the bridge girder segments from the logistics base to the assembly site in Søreidsvika.

For the transport of girders and pontoons to the assembly site a tug (120Te -180Te BP) is also accounted for.

11.2 Low floating bridge assembly

The basis for the cost for the assembly of the low floating bridge is based on equipment and personnel for a given duration. A high level plan for the low floating bridge has been developed and is presented in the figure below.

Assembly low of floating bridge (including North section)	**01.02.24 00:00**	**05.05.26 00:00**	**824 d**
Set up of Sausage factory	**01.02.24 00:00**	**13.03.24 00:00**	**41 d**
Construction preparations on land for logistics to sausage factory	01.02.24 00:00	02.02.24 00:00	1 d
Tow of barges to assembly site (3 barges)	02.02.24 00:00	09.02.24 00:00	7 d
Mooring of barges at site	09.02.24 00:00	12.02.24 00:00	3 d
Ramp to barge and building of heightened skidding system	12.02.24 00:00	13.03.24 00:00	30 d
Mobilisation of heavy lift crawler crane and other required equipment	13.02.24 00:00	19.02.24 00:00	6 d
Lift and weld sections between axis 14 - 15	**13.03.24 00:00**	**18.04.24 00:00**	**36 d**
Lift 5 section onto barge and align ready for welding	13.03.24 00:00	18.03.24 00:00	5 d
Weld box girder to each other (4 welds times 5 days per weld)	15.03.24 00:00	04.04.24 00:00	20 d
Skid 2 sections (sausage factory) and float in pontoon with column	04.04.24 00:00	05.04.24 00:00	1 d
Weld column to box girder	05.04.24 00:00	07.04.24 00:00	2 d
Lift 2 section onto barge and align ready for welding	07.04.24 00:00	08.04.24 00:00	1 d
Weld box girder to each other (2 welds times 5 days per weld)	08.04.24 00:00	18.04.24 00:00	10 d
Skid 125m section (move sausage factory with mooring and moor bridge)	09.04.24 00:00	11.04.24 00:00	2 d
Lift and weld sections between axis 15 - 16	**11.04.24 00:00**	**12.05.24 00:00**	**31 d**
Lift and weld sections between axis 17 - 18	**12.05.24 00:00**	**12.06.24 00:00**	**31 d**
Lift and weld sections between axis 18 - 19	**12.06.24 00:00**	**13.07.24 00:00**	**31 d**
Lift and weld sections between axis 19 - 20	**13.07.24 00:00**	**13.08.24 00:00**	**31 d**
Lift and weld sections between axis 20 - 21	**13.08.24 00:00**	**13.09.24 00:00**	**31 d**
Lift and weld sections between axis 21 - 22	**13.09.24 00:00**	**14.10.24 00:00**	**31 d**
Lift and weld sections between axis 22 - 23	**14.10.24 00:00**	**14.11.24 00:00**	**31 d**
Lift and weld sections between axis 23 - 24	**14.11.24 00:00**	**15.12.24 00:00**	**31 d**
Lift and weld sections between axis 24 - 25	**15.12.24 00:00**	**15.01.25 00:00**	**31 d**
Lift and weld sections between axis 25 - 26	**15.01.25 00:00**	**15.02.25 00:00**	**31 d**
Lift and weld sections between axis 26 - 27	**15.02.25 00:00**	**18.03.25 00:00**	**31 d**
Lift and weld sections between axis 27 - 28	**18.03.25 00:00**	**18.04.25 00:00**	**31 d**
Lift and weld sections between axis 28 - 29	**18.04.25 00:00**	**19.05.25 00:00**	**31 d**
Lift and weld sections between axis 29 - 30	**19.05.25 00:00**	**19.06.25 00:00**	**31 d**
Lift and weld sections between axis 30 - 31	**19.06.25 00:00**	**20.07.25 00:00**	**31 d**
Lift and weld sections between axis 31 - 32	**20.07.25 00:00**	**20.08.25 00:00**	**31 d**
Lift and weld sections between axis 32 - 33	**20.08.25 00:00**	**20.09.25 00:00**	**31 d**
Lift and weld sections between axis 33 - 34	**20.09.25 00:00**	**21.10.25 00:00**	**31 d**
Lift and weld sections between axis 34 - 35	**21.10.25 00:00**	**21.11.25 00:00**	**31 d**
Lift and weld sections between axis 35 - 36	**21.11.25 00:00**	**22.12.25 00:00**	**31 d**
Lift and weld sections between axis 36 - 37	**22.12.25 00:00**	**22.01.26 00:00**	**31 d**
Lift and weld sections between axis 37 - 38	**22.01.26 00:00**	**22.02.26 00:00**	**31 d**
Lift and weld sections between axis 38 - 39	**22.02.26 00:00**	**25.03.26 00:00**	**31 d**
Lift and weld sections between axis 39 - 40	**25.03.26 00:00**	**29.04.26 00:00**	**35 d**
Mate and weld high floating bridge to low floating bridge	**29.04.26 00:00**	**05.05.26 00:00**	**6 d**

Figure 11-3: Low floating bridge assembly plan

The cost is based on a short period for setting up the site (sausage factory) and a long period for when the sections are assembled. It is assumed that barracks are set up close to the site for accommodation of the personnel working. It is assumed that personnel are working 14 days shifts working 7 days a week. All barges, tugs, cranes, winches, generator sets, etc are assumed rented on a day rate basis. 900 hours effective welding time is assumed for each bridge girder joint. 15 welders are used. In addition to welders several support functions are required (NDT, quality, foremen, riggers, scaffolders, etc), giving a personnel count of 40.

The short north section is included in the assembly of the low floating bridge and will be fabricated as a separate part.

In the table below the basis for the cost items are presented.

Table 11.1 Equipment and personnel required for low bridge assembly

Process	Item	Quantity	Days	Note
Set up of sausage factory	Bygge forberedelser på land for logistikk av pølse fabrikk	1		Lump sum
	Utleie av land for fabrikk beliggenhet	1	824	Day rate
	Mobilisering av Last flåter	3		Day rate
	Barge outfitting (grillage, skidding beams, scaffolding, work platforms, etc)	1		17MNOK in previous phase (based on 200T steel x
	Tugs for tow of barges (100Te BP)	1	30	Day rate
	Mob of crawler crane	1		Lump sum
Fabrication of floating bridge activeties	North Sea Cargo Barge (sausage factory)	3	824	Day rate
	Crawler crane	1	824	Day rate
	100Te mobilkran m/fører	1	824	Day rate (for miscelleneous lifts)
	Mooring winches on barges	8	824	Day rate
	Harbor tug for mooring operations	1	824	Day rate
	Forklift	2	824	Day rate
	Catering and accomodation	40	824	Day rate for number of personnel
	Welders	15	824	Day rate
	NDT	3	824	Day rate
	Quality	2	824	Day rate
	Foremen, engineers	5	824	Day rate
	Support functions (fire watch, riggers etc)	15	824	Day rate
	Travel costs	2197		Lump sum based on 14 days rotation for the personnel
	Gen sets for power generations	4	824	Day rate
	Welding equipment	1	824	Day rate
	Welding consumables	1	824	Day rate
	Ballast pumps	3	824	Day rate
	Scaffolding and tents	1	824	Day rate
	Temporary steel for bumper guides (main bridge)	2		Lump sum (including labour)
	Temporary small North section (main bridge)	2		Lump sum (including labour)
	Structure for support of cantilever	2		Lump sum (including labour)
	Barge rental for support of cantilever	3	100	Day rate (average no. of days)
	Tugs for moving bridge (assume average 4 tugs for each move)	12	28	Day rate. Assume 3 days for each movement
Mooring systen	Mooring lines system to shore	7		Lump sum
	Mooring lines to seabed	11		Day rate
	Anchors rental with chain and pontoon bracket	11	824	Day rate
	Mooring winches	9	824	Day rate

11.3 High floating bridge assembly

The basis for the cost for the assembly of the high floating bridge is like the one for the low floating bridge. Similar equipment and personnel are required. Additionally, jacking towers and personnel to operate these are required.

Since fewer connections are required the timeline for the assembly is shorter. A schedule for the high bridge assembly is shown in the figure below.

⊟ Assembly of High floating bridge	**01.12.24 00:00**	**11.02.26 00:00**	**437 d**
⊟ Set up of Sausage factory for high bridge	**01.12.24 00:00**	**11.01.25 00:00**	**41 d**
Construction preparations on land for logistics to sausage factory	01.12.24 00:00	02.12.24 00:00	1 d
Tow of barges to assembly site (2 North sea barges and 2 small barges))	02.12.24 00:00	09.12.24 00:00	7 d
Mooring of barges at site	09.12.24 00:00	12.12.24 00:00	3 d
Ramp to barge and building of heightened skidding system	12.12.24 00:00	11.01.25 00:00	30 d
Mobilise and set up jacking system	13.12.24 00:00	21.12.24 00:00	8 d
Mobilisation of heavy lift crawler crane and other required equipment	13.12.24 00:00	19.12.24 00:00	6 d
⊟ Lift and weld sections between axis 03 - 04	**12.12.24 00:00**	**27.01.25 00:00**	**46 d**
Lift 6 section onto barge and align ready for welding	12.12.24 00:00	17.12.24 00:00	5 d
Weld box girder to each other (5 welds times 5 days per weld)	17.12.24 00:00	11.01.25 00:00	25 d
Jack up bridge and float 1st column part in	11.01.25 00:00	12.01.25 00:00	1 d
Weld columns to box girder	12.01.25 00:00	16.01.25 00:00	4 d
Jack up bridge and float 2nd column part in	16.01.25 00:00	17.01.25 00:00	1 d
Weld columns to box girder	17.01.25 00:00	21.01.25 00:00	4 d
Jack up bridge to final position and float pontoons in	21.01.25 00:00	22.01.25 00:00	1 d
Weld columns to box girder	22.01.25 00:00	26.01.25 00:00	4 d
Move high bridge catamaran section away from barge and moor ready for connection to next section	26.01.25 00:00	27.01.25 00:00	1 d
⊞ Lift and weld sections between axis 04 - 05	**27.01.25 00:00**	**09.03.25 00:00**	**41 d**
⊞ Lift and weld sections between axis 05 - 06	**09.03.25 00:00**	**19.04.25 00:00**	**41 d**
⊞ Lift and weld sections between axis 06 - 07	**19.04.25 00:00**	**27.05.25 00:00**	**38 d**
⊞ Lift and weld sections between axis 07 - 08	**27.05.25 00:00**	**04.07.25 00:00**	**38 d**
⊞ Lift and weld sections between axis 08 - 09	**04.07.25 00:00**	**11.08.25 00:00**	**38 d**
⊞ Lift and weld sections between axis 09 - 10	**11.08.25 00:00**	**18.09.25 00:00**	**38 d**
⊞ Lift and weld sections between axis 10 - 11	**18.09.25 00:00**	**26.10.25 00:00**	**38 d**
⊞ Lift and weld sections between axis 11 - 12	**26.10.25 00:00**	**03.12.25 00:00**	**38 d**
⊞ Lift and weld sections between axis 12 - 13	**03.12.25 00:00**	**07.01.26 00:00**	**35 d**
⊞ Lift and weld sections between axis 13 - 14	**07.01.26 00:00**	**11.02.26 00:00**	**35 d**

Figure 11-4: High floating bridge assembly plan

Table 11.2 Equipment and personnel required for high bridge assembly

Process	Item	Quantity	Days	Note
Set up of high bridge factory	Construction preparations on land for logistics to sausage factory	1		Lump sum
	Rental of land for factory location	1	437	Day rate
	Mobilisation of cargo barges	3		Lump sum
	Barge outfitting (grillage, skidding beams, scaffolding, work platforms, etc)	1		Lump sum
	Tugs for tow of barges (100Te BP)	1	20	Day rate
	Mob of crawler crane	1		Lump sum
Fabrication of floating bridge activeties	North Sea Cargo Barge (sausage factory)	3	437	Day rate
	Crawler crane	1	437	Day rate
	100Te mobilkran m/fører	1	437	Day rate
	Mooring winches on barges	8	437	Day rate
	Harbor tug for mooring operations	1	437	Day rate
	Forklift	2	437	Day rate
	Catering and accomodation	40	437	Day rate
	Welders	15	437	Day rate
	NDT	3	437	Day rate
	Quality	2	437	Day rate
	Foremen, engineers	5	437	Day rate
	Support functions (fire watch, riggers etc)	15	437	Day rate
	Travel costs	1165		Day rate
	Gen sets for power generations	3	437	Day rate
	Welding equipment	1	437	Day rate
	Welding consumables	1	437	Day rate
	Ballast pumps	2	437	Day rate
	Jacking system	1	437	Day rate
	Scaffolding and tents	1	437	Day rate
	Temporary steel for bumper guides	2		Lump sum
	moving bridge (assume average 2 tugs for each mo	6	9	Day rate
Mooring systen	Mooring lines system to shore	5		Lump sum
	Mooring lines	7		Lump sum
	Anchors rental with chain and pontoon bracket	12	437	Day rate
Connection to low bridge	Connection to low bridge	1		Lump sum

11.4 Anchor Installation

The 12 suction anchors are to be installed a year prior to the installation of the floating bridge for settlement of the anchors. It is assumed that the installation vessel needs two trips for the anchor installations. The cost basis is presented in the table below. Temporary equipment consists of lift rigging, seafastening and suction kit.

Table 11.3 Vessels, equipment and storage for anchor installation

	Days / Qty	
Mob/de-mob of Installation Vessel (IV)	5	days
Outfitting with ROV systems	2	days
Installation suction anchors	12	days
Demob ROV systems	2	days
Temporary equipment	12	qty
Site rental for Anchor storage	1	qty

11.5 Mooring lines wet-storage

The mooring lines will also be installed and wet stored one year prior to the installation of the bridge. The cost basis is presented in the table below

Table 11.4 Vessels, equipment and storage for anchor installation

	Days / Qty	
Mob/de-mob of IV	3	days
Install reel drive	2	days
Outfitting IV with ROV system	1,5	days
Wet storage of 12 lines	19	days
De-mob ROVs	2	days
Temporary equipment per line	12	qty
ROV-kit for H-shackle	12	qty
Rental of Reel drive	1	qty
Rental of work chain	1	qty
Mob base rental	1	qty

11.6 Mooring lines hook-up and tensioning

The mooring lines hook-up will be performed just after the bridge has been towed to site and connected. To be able to hook up 4 moorings within the bridge installation window, 2 anchor handling tugs (AHT) will be used. The AHTs will be equipped with two WROVs.

Table 11.5 Vessels, equipment and storage for anchor installation

	Days / Qty	
Mob/de-mob of AHTs (2off)	6	days
Vessel prep for ROV	3	days
AHT hook-up of12 lines	13	days
De-mob of AHT including transit	3	days
Work chain and temporary equipment	1	qty

11.7 North Section Installation

4 towing vessels are used for the tow of the north section to the bridge site. The cost is based on 3 days for the vessels, one day for disconnection from mooring system and towing to bridge site, and two days for installation. Waiting on weather is not considered.

Table 11.6 Cost basis for the north Section installation

	Days	Number
Mobilisation of 120 - 180 Te towing vessels	2	4
Disconnect, tow and connect bridge, 100Te vessels	3	4
DeMobilisation of 100 Te towing vessels	1	4
Towing brackets on pontoons		4
Ballast pumps	5	2
Winches for pull-in (approx 30Te)	5	2
Barge for support of cantilever	120	2

11.8 Floating bridge Installation

12 towing vessels are used (average 200Te BP) for the tow of the floating bridge section to the bridge site. The cost is based on 6 days for the vessels, two days for disconnection from mooring system and 1 day for the towing to bridge site, and three days for the installation.

Table 11.7 Cost basis for the floating bridge installation

	Days	Number
Mobilisation of 200 Te towing vessels	2	12
Disconnect, tow and connect bridge, 200Te vessels	6	12
Demobilisation of 200 Te towing vessels	1	12
Towing brackets on pontoons		12
Gen sets	5	2
Ballast pumps	5	4
Winches for pull-in (approx 30Te)	5	8

11.9 Final connections of bridge at Bjørnafjorden

For welding of the final connections in Bjørnafjorden the following personnel and equipment is assumed for 20 days. The temporary steel for the guiding, positioning and locking joints have been included for in the floating bridge assembly.

Table 11.8 Equipment and personnel for final connections

	Days	Qty
Welding equipment	20	LS
Welding consumables	20	LS
Welders	20	15
NDT, quality, foremen etc,	20	10
Support function	20	10
Gen sets	20	2

12 References

/1/ SBJ-32-C4-SVV-90-BA-001 Rev 0 Design Basis Bjørnafjorden floating bridges

/2/ SBJ-32-C4-SVV-01-BA-001 Rev 1 Design Basis MetOcean

/3/ SBJ-32-C4-SVV-26-BA-001 Rev 3 Design Basis Mooring and Anchor

/4/ SBJ-31-C3-MUL-24-RE-100 Bjørnafjorden, straight floating bridge phase 3 - Construction and marine operations (Base Case) (by Multiconsult)

/5/ SBJ-30-C3-NOR-90-RE-108 K7 Bjørnafjorden End-anchored floating bridge - Appendix H – Construction and installation (by Norconsult)

/6/ eRoom correspondence 304624-1-A-0051

13 Enclosures

/1/ 10205546-13-NOT-185 Finite element analysis of locking joint, rev. 0

/2/ CAL-AB016101-001 Feasibility Study for Jacking of Bridge Sections, ALE, rev. A

/3/ DRW-AB016101-001 Jacking of bridge sections (2 sheets)