Appendix to report:

SBJ-33-C5-OON-22-RE-019

DESIGN OF STAYCABLE BRIDGE

Appendix title:

APPENDIX A TECHNICAL NOTE - BALLASTING

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Prepared by:	Henrik Skyvulstad
Controlled by:	Knut Anders Lia
Approved by:	Kolbjørn Høyland

CONCEPT DEVELOPMENT FLOATING BRIDGE E39 BJØRNAFJORDEN

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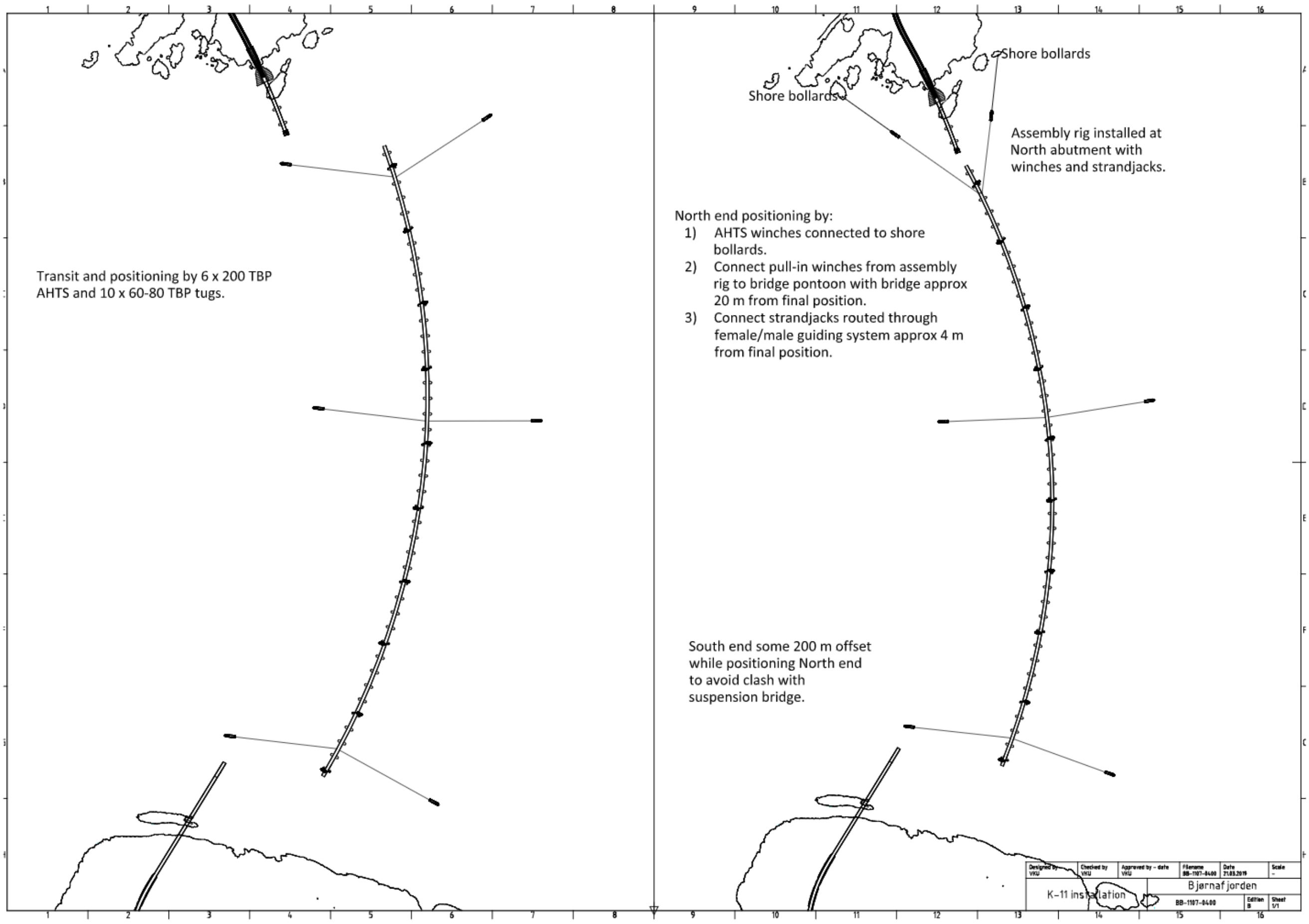
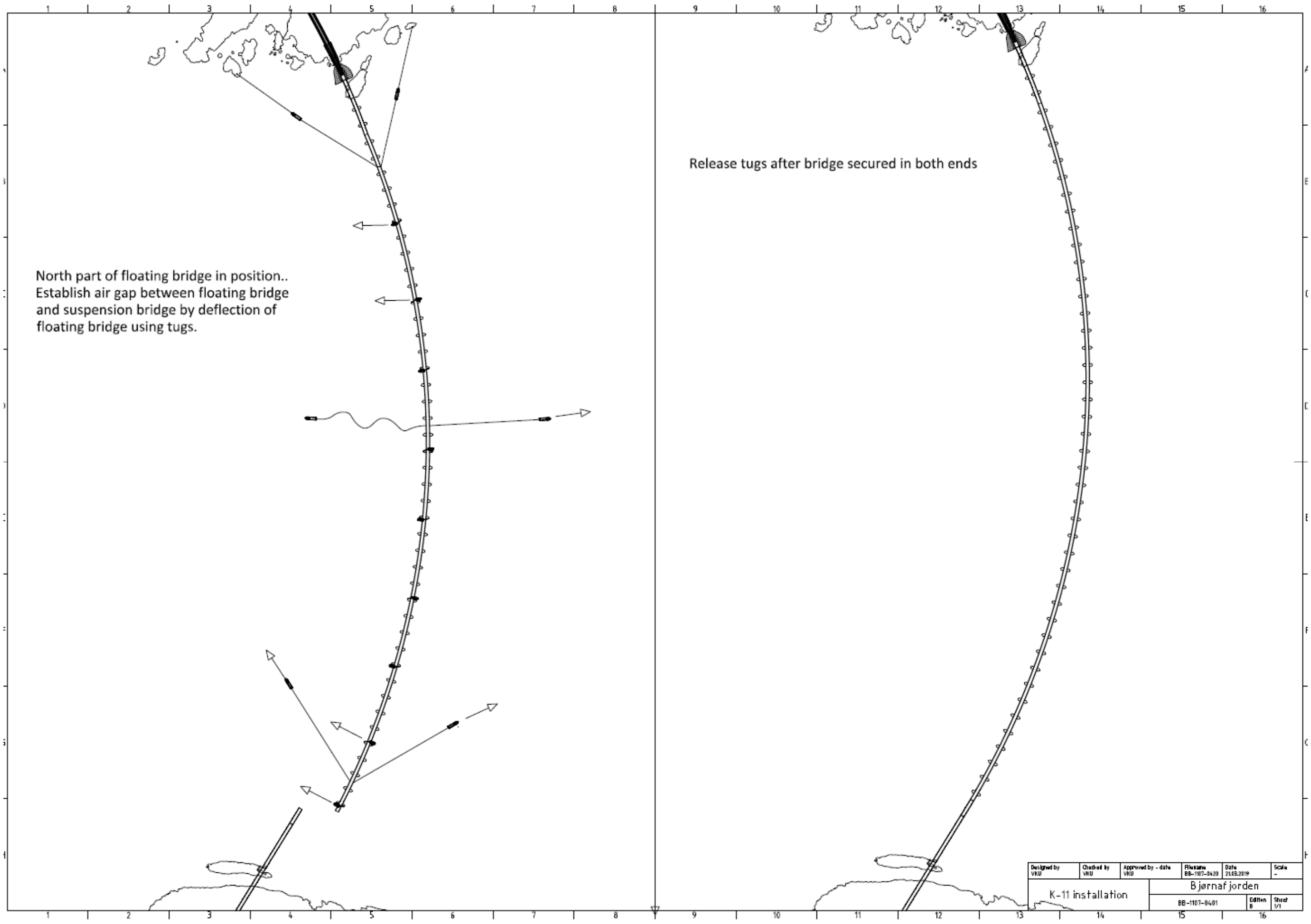
1 INTRODUCTION

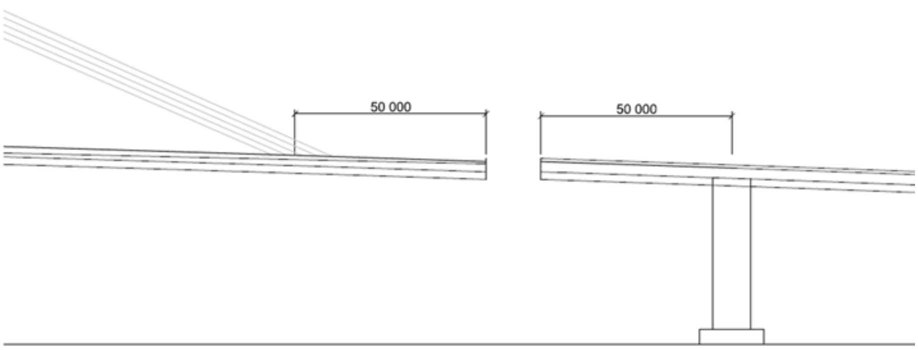
In this technical note a description of the operations during the final assembly of the floating bridge at Bjørnafjorden is addressed. This note handles the vertical-plane adjustments of the floating and cable-stayed bridge.



> *Figure 1 Installation phase 1 and 2. Transit and positioning of north end of the bridge.*



> *Figure 2 Installation phase 3 and 4. Fixing of north end to the abutment and fixing of south end to the cable-stayed bridge.*



> *Figure 3 connection cable stay and floating bridge cantilevers*

To be able to connect the floating and cable-stayed bridge correctly and weld the bridge girder according to “Technical note – welded connection of bridge girder”, adjustments of the free cantilevers needs to take place. Both vertical height and curvature in the beam-length vertical plane needs to be adjusted.

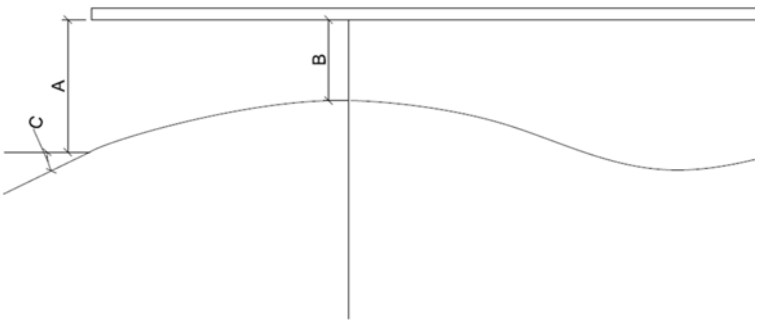
The general goal of the coarse adjustments:

- Rotation of the free cantilevers should match; it is chosen to use 0-degree of rotation of the sections
- Vertical adjustments so the free ends have the same height
- Variable height adjustment to counter tidal change

2 FLOATING BRIDGE ADJUSTMENTS

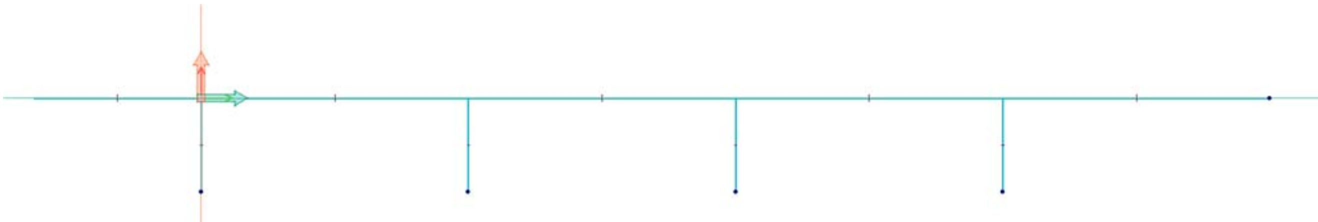
The adjustments on the floating bridge is divided into the following parts:

- Displacement of the floating bridge due to dead-weight of the bridge
- Displacement of the floating bridge due to dead weight from machinery for connection of the parts
- Ballast with main goal for adjusting rotation
- Ballast with main goal for adjusting for tide



> *Figure 4 height measures on floating bridge*

To be able to assess the displacement of the free end of the floating bridge a simplified FEM-design model has been made.



> *Figure 5 FEM-model of floating bridge*

The bridge has been modeled with a 50m long cantilever, 120m center distance between pontoon, and 42m bridge columns. For simplicity variable column height has not been considered. The pontoons have a vertical stiffness of 9300KN/m. The girder is constraint horizontally at the right end. The stiffness of the girder and column is the same as for the real bridge.

The following load has been applied on the system:

I. 50kN/m upward self-weight to check the effect of added asphalt
II. 500kN point load at the end of the cantilever from machinery
III. 127kN/m from self-weight of the girder
IV. 4200kN distributed load in center first span to serve as rotational ballast. Se figure 12 region A.
V. 9120KN on the first and second pontoon to work as vertical ballast.

The displacement and rotations are measured in 3 points, A, B and C, see figure 4.

> *Table 1*

Rotational ballast	A[mm]	B[mm]	C[deg]
I	-652	-596	-0.09
II	134	42	0.11742
III	1658	1516	0.2286
IV	-106	202	-0.355608
Sum, without III	**1034**	**1164**	**-0.009588**
Dedicated for vertical ballast			
V	1000	1000	0

2.1 Ballast types

2.1.1 Rotational ballast

Two suggestion of rotational ballast:

- 13 pieces of 20ft iso water tanks weighing 4 tons empty and 25 tons full. One tank has the measure of 6x2.5x2.5m.
- 80m of 80mm asphalt. With center ballast in center span.

A combination is also possible. Some adjustments are often needed so some tanks are mandatory.

2.1.2 Vertical ballast

The actual tidal height that needs to be compensated for is discussible. But if we mount 38 20ft iso water tanks on the first and second pontoon, this could adjust vertical height up to 1,0m. Meaning that we could handle adjustment of the tide of ±0,5m. The tanks needs to be half full if we want to have maximum displacement possibility, half full tanks are 38*160kN=6080.

This will in turn reduce the height of the pontoon with 624mm. And final height is now: 1650 – 1034 – 842mm = -200mm. This lowering of the floating bridge compared with permanent position needs to be compensated in the stay-cable part.

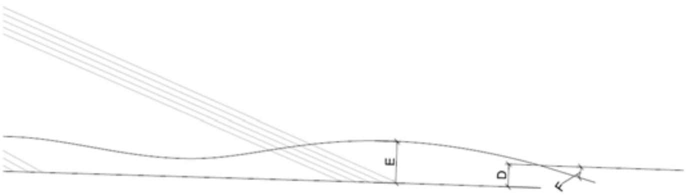
3 STAY CABLE BRIDGE ADJUSTMENTS

The adjustments of the stay cable have the goal of making the rotation of the end of the cantilever around 0 degree. The bridge has some additional height due to lack of asphalt.

The construction has these phases:

i. Permanent iterated geometry with free end of stay-cable bridge
ii. Permanent geometry without asphalt, 50kN/m vertical load
iii. Point load on the end of the bridge from machines, 500kN
iv. Height adjustments of second longest cable package. 0.35m longer cables
v. Ballast in region B (figure 11) around second longest cable package, 80kN/m inside area

The bridge height is measured at point D, E and F. Se figure 6.



> *Figure 6 Height measures on stay-cable bridge*

Displacement is calculated with the Abaqus-model of the stay cable bridge. Se report of stay-cable for more information.

> *Table 2*

Stay-cable bridge	D[mm]	E[mm]	F[rad]
i	-1197	-460	0.01672
ii	1085	1367	0.00694
iii	-393	-201	0.00439
SUM, all permanent	692	1166	0.01133

> *Table 3*

Stay-cable bridge	D[mm]	E[mm]	F[rad]
Sum, all permanent	692	1166	0.01133
iv	53.55	128.45	-0.00371
SUM, with longer cables	745.55	1294.45	0.00762
v	-944.0995733	-1316.970128	-0.00762
SUM, all measures	-198.5495733	-22.52012802	0

With this set up, the height and rotation match on both cantilevers.

3.1 Ballast types

It is recommended to ballast with 80cm asphalt + 10 iso tanks in region B (figure 11).

4 PLACEMENT OF BALLAST TANKS

Local placement of the ballast tanks is not fully handled in this phase, and there is a lot of possibilities.

4.1 On pontoons

On the pontons, there are room for about 40 tanks without stacking the tanks. Tanks can also be standing on top of the girder without any eccentricity from the column.

4.2 On the girder

It is recommended that the tanks are placed in 2 lines eccentric around the centerline of the girder to be able to control some unexpected torsional rotation. There are plenty of room on the girder.

5 DESIGN LOAD OF THE BRIDGES

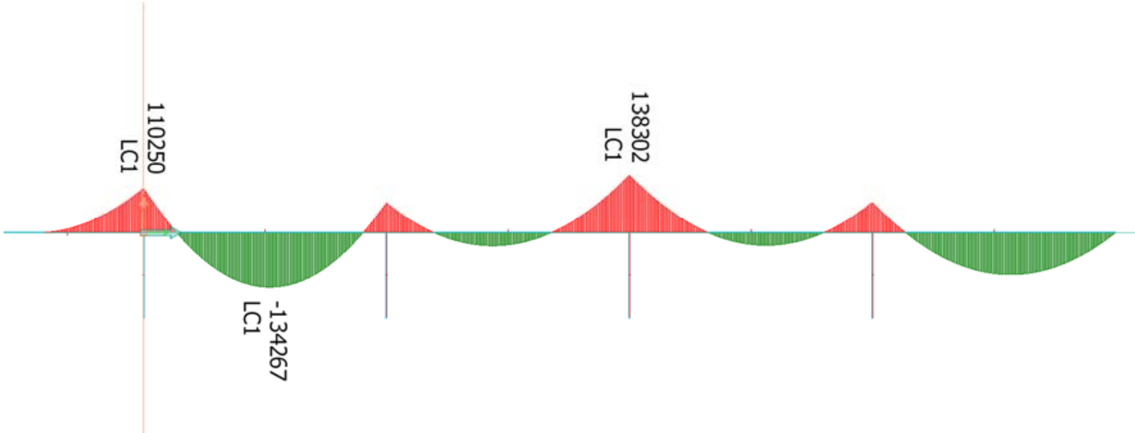
5.1 Stay cable design

The impact on the ballasting on the stay-cables are part of the stay-cable design in construction phases. This can be found in [1].

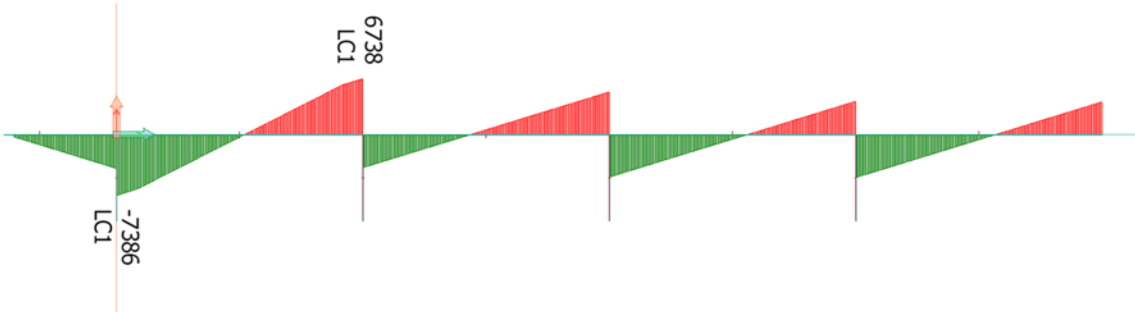
5.2 Floating bridge

The floating bridge moment and shear forces are rather limited. The ballast directly on the pontoons go straight down into buoyancy and gives minimal with forces locally.

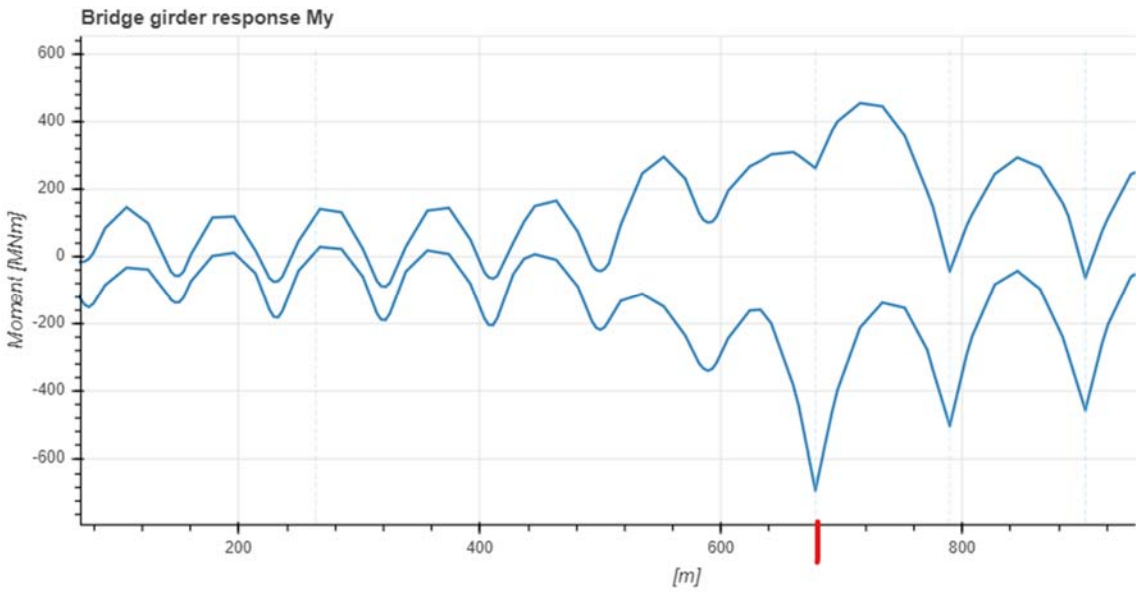
For the floating bridge, the maximum force including maximum ballasting for tidal forces is:



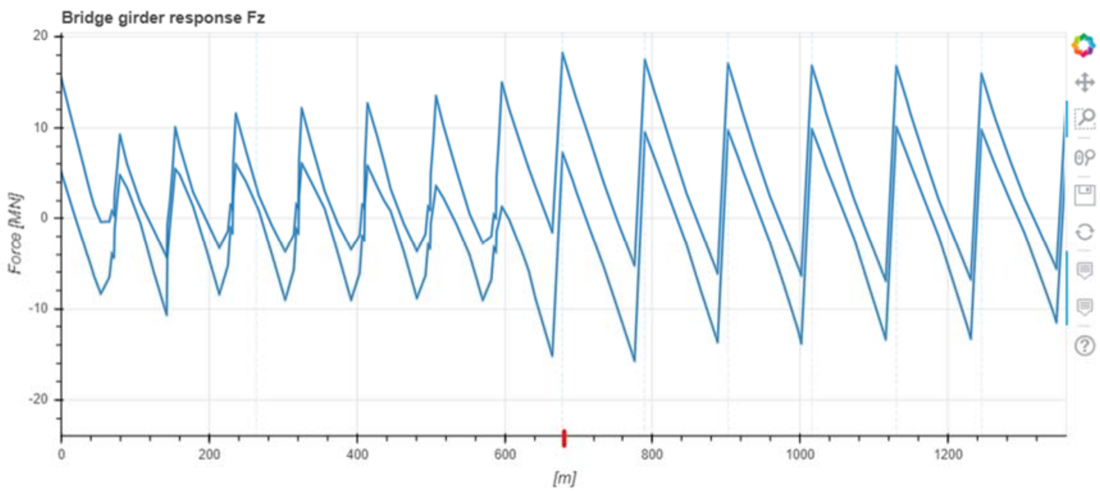
> *Figure 7 Weak axis bending moment[kNm] along bridge girder, ULS*



> *Figure 8 Weak axis shear force[kN] along floating bridge, ULS*



> *Figure 9 Weak axis ULS moments, forces in girder from Greenbox (interactive), Red line is placement of joint between floating and stay cable bridge*



> *Figure 10 Weak axis Shear force ULS, from Greenbox (interactive). Red line is placement of joint between floating and stay cable bridge*

Forces in installation phase is considerably less than forces in ULS. No further investigation is deemed necessary.

6 DESCRIPTION OF RECOMANDED PROCEDURE

Floating bridge:

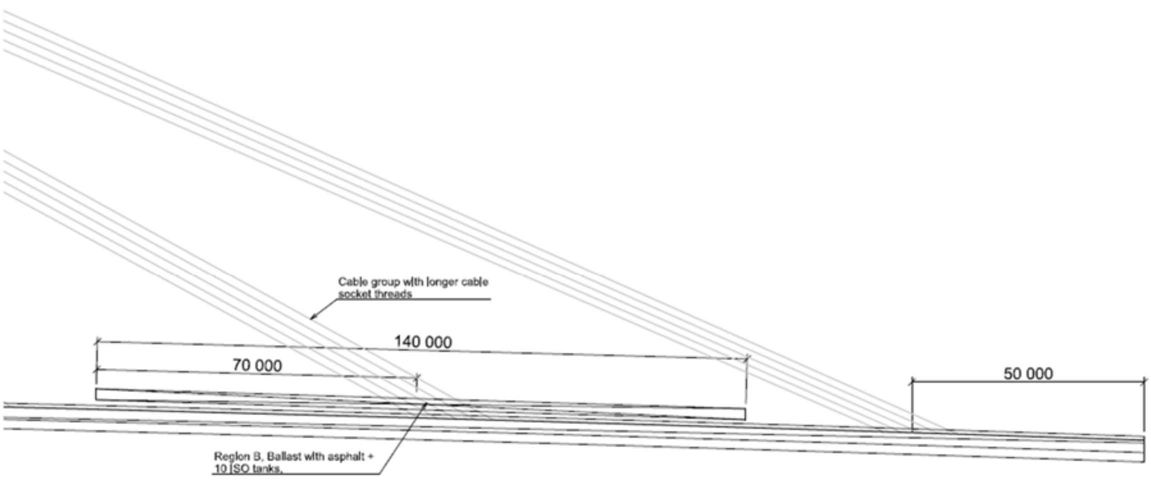
1. Install 38 ballast tanks (type 20ft ISO 24000liter) on both first and second pontoon. Install pumps for filling and removing of water. Fill these tanks halfway for mean sea level height. Filling amount of water equals 4560kN. Control the water level to adjust for change of tides. Maximum adjustment is ±0,5m.
2. Install 14 full iso tanks or 80m of asphalt centered on the girder between first and second pontoon (region A figure 11). Total ballast weight is 4000kN.

Cable-stayed bridge

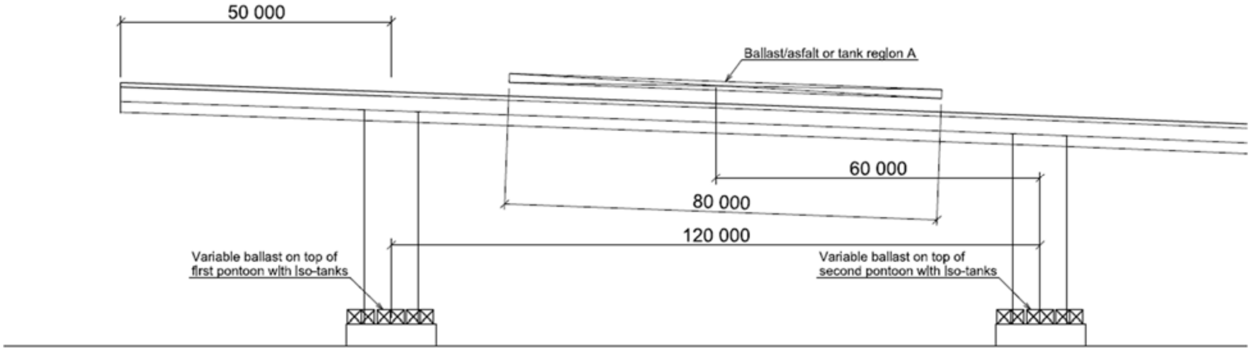
1. Install the second longest cable group 35cm longer than in permanent phase. This is done though extra threaded area on the cable sockets.
2. In region B (figure 12) lay the permanent asphalt or install 24 iso tanks. In addition, install 10 iso tanks symmetric in the same region. Total ballast weight is 10 000kN.

With this procedure the rotation of the cantilevers and the height of the cantilevers match. The tidal change of water height is adjusted with the tanks on the pontoons. Rotation of the cantilevers is 0-degrees and height above permanent position for mean water level is -200mm.

For adjustability, it is recommended to increase the number of tanks in region A and B (figure 11 and 12) with 30% filling and compensating by filling the rest of the tanks less. Tanks on the girder can be placed in pairs with symmetric cross-length eccentricity for adjustment of torsional rotation.



> *Figure 11 Detailed stay cable adjustments*



> *Figure 12 Detailed floating bridge adjustment*

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