Statens vegvesen

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CONCEPT DEVELOPMENT, FLOATING BRIDGE E39 BJØRNAFJORDEN

Global response from drydocking of pontoons

CLIENT

Statens vegvesen

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REPORT

PROJECT	Concept development, floating bridge E39 Bjørnafjorden	DOCUMENT CODE	SBJ-32-C5-AMC-90-RE-190
SUBJECT	Global response from drydocking of pontoons	ACCESSIBILITY	Restricted
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		RESPONSIBLE UNIT	AMC

SUMMARY

The effect of attaching a drydocking barge to a pontoon to the Bjørnafjorden bridge for maintenance operations has been assessed in this report. The barge is assumed to be rectangular with main dimensions (LxBxDxH) 70x31x16x22m and a displacement of 34700 tons. The displacement of the barge is equivalent to approx 30% of the displaced mass of the total bridge and is therefore assumed to affect the global response of the bridge considerably. The barge has been modelled in Wamit and hydrodynamic coefficients have been found, which have been used for global analysis in Orcaflex. Four representative barge locations have been assessed (A3, A13, A24 and A40).

The presence of the drydock disturbs the bridge modes and response significantly. Strong-axis response may be improved during drydocking, but weak-axis response is deteriorated. Tidal effects increase towards either end due to the increased waterplane area. The analysis reported in this document indicate that the proposed drydock method for dry access for maintenance of pontoons is a feasible option.

- Drydocking of non-moored pontoons in the low bridge was found to be acceptable without weather restrictions, even for ULS3 conditions (100-year return period).
- Drydocking of moored pontoons was found to be acceptable within the ULS2 conditions, but it is recommended to perform the operation during the summer season to limit the possibility of parametric excitation.
- Drydocking of pontoons towards the northern abutment was found to be acceptable within the ULS2 conditions (1-year return period), but with refined metocean basis for wind sea and swell waves close the northern abutment the drydocking methodology may also be acceptable for ULS3 conditions.
- Some work remains in order to verify drydocking of the pontoons in the high bridge for ULS2 and ULS3 conditions. Considering the possibility of repair of a collision-damaged pontoon with a long duration it is not recommended to rely on seasonal metocean conditions in the high bridge. Refined metocean conditions (esp. for swell) and refined simulations may reveal sufficient capacity.

A number of items for further work have been proposed, see section 6 for details.

0	20.12.2019	Final issue	Arnt Fredriksen	Per Norum Larsen	Svein Erik Jakobsen
REV.	DATE	DESCRIPTION	PREPARED BY	CHECKED BY	APPROVED BY

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Revision history

Revision	Description of changes
0	First issue

1 Introduction

The lifetime of the proposed Bjørnafjorden bridge is designed to be 100 years. During this time, regular maintenance of the bridge tower and bridge deck will be planned. In an unlikely event where the pontoon is damaged from a ship collision, a floating drydock may be used to do repairs. It might also be necessary to perform maintenance and inspection of the pontoons, above water, in the splash zone and on the sections which usually are submerged.

A simple illustration of the drydock barge is shown below.

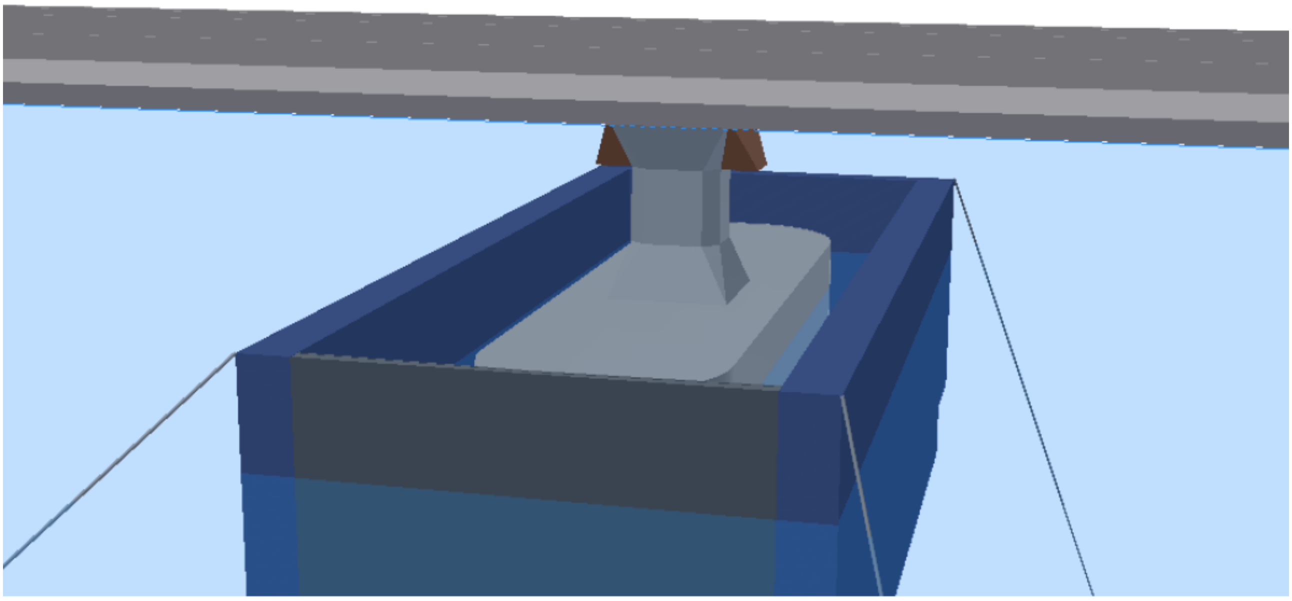


Figure 1-1: Inspection and maintenance drydock barge from [1]

This report will assess the hydrodynamic and analytical feasibility of having such a drydock barge attached to the bridge. The influence on the global behavior of the bridge will be assessed for a 100-year and a 1-year environmental condition (wind, wind-waves and swell) combined with tide, current, temperature, gravity and traffic loads to obtain ULS2 and ULS3 capacity evaluations.

The drydock barge will influence both the excitation loads acting on the bridge (from tide and waves) and the bridge response due to changed mass and eigenmodes.

Four locations are investigated; on axis A3, A13, A24 and A40 to broadly cover the possible range of bridge responses.

2 Design Basis and modelling assumptions

The following design basis and modelling assumptions are adhered to. The following information has either been taken from Norconsult's proposal from phase 3 of the project [2], Oceantech's report detailing the drydock method [1] or has been based on sound engineering judgement from lessons learned during the work on the previous project phases for the crossing. The bridge concept is described in [3].

The drydock barge shall be usable on all 38 pontoons (35 regular pontoons and 3 mooring pontoons). To limit the scope of the analysis within this report, a limited number but representative set of drydock locations have been checked. The following locations have been checked, with associated reasoning:

- A3. This is the pontoon closest to the cable stay bridge and here both the weak and strong bending moments are the largest. This is also the pontoon with the highest risk of ship collisions and thus the highest potential need for maintenance.
- A13. This pontoon is a mooring pontoon.
- A24.This pontoon is chosen as a representative regular pontoon in the lower part of the floating bridge without mooring. It is located midway between mooring pontoons A20 and A27.
- A40. This pontoon is closest to the northern abutment and here the highest loads due to tidal variations are expected. In addition, there are high weak and strong axis bending moments.

It is assumed that maintenance of a moored pontoon can be performed during a weather window that allows for release of mooring lines without the need for temporary mooring arrangements. This should be feasible for the K12_07 bridge with the possible exception of parametric resonance.

2.1 Geometry

The geometry of the drydock barge has been assumed to be a rectangular box with particulars given in Table 2-1. The geometry in this report is simplified compared to the Oceantech report, because the level of detail in the Oceantech report was insufficient to model it correctly. Sound engineering judgement has been used to approximate the distribution of structural steel and ballast water in order to assess the inertial values of the barge. The applied inertial values are given in Table 2-1.

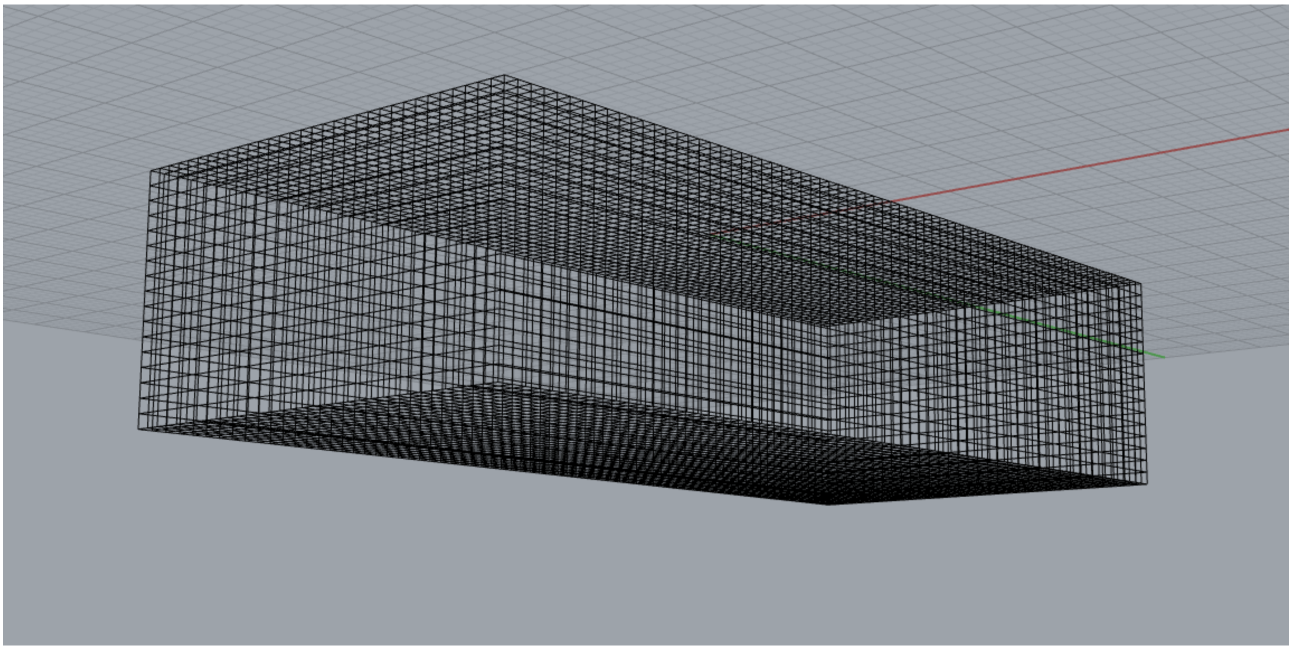


Figure 2-1: Geometric model of barge

Table 2-1: Main particulars of drydock barge

Length	70	m
Width	31	m
Draught	16	m
Height	22	m
Lightship weight	13625	ton
Ballast in operation	20094	ton
Pontoon weight	985	ton
Operational displacement	34700	ton
VCG	-10.0	m
I44	4.0E+06	ton m^2
I55	1.6E+07	ton m^2
I66	1.8E+07	ton m^2
r44	10.8	m
r55	21.2	m
r66	22.8	m

2.2 Connection between drydock and pontoon

For this report a monolithic connection between the pontoon and the drydock is assumed.

The pontoon will most likely be carried by deck timber between the drydock and the pontoon, with guides and knee plates restricting it from moving transversely and longitudinally. It is recommended to include the actual connection between the drydock and the pontoon in a more detailed study at a later stage to investigate if there will be lift-off between the barge and the pontoon.

2.3 Ballast operations and uncertainties

The bridge response will be sensitive towards the ballasting operations of both the drydock barge and the pontoon itself. The ballasting shall be performed such that the nominal vertical position of the bridge remains unchanged. The analysis should however accommodate operational uncertainties and therefore the following ballasting tolerances will be assessed as a sensitivity study:

- - 500 ton
- Perfect balance (nominal position)
- + 500 ton

A ballast inaccuracy of 500 ton will lead to about 22 cm change in draught. This is likely well within operational limitations and measurement accuracy and serves as an upper bound inaccuracy for the drydocking process. This is not expected to cause a significant change in static or dynamic bridge girder response.

2.4 Duration of maintenance operation

The duration of the maintenance operation is assumed to be short enough to allow for use of seasonal weather conditions. This is in line with the assumptions in [1], but should be investigated during a refined study.

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. For weather restricted conditions, Weather limitations are imposed during the engineering phase due to analytical or operational considerations.

Based on DNVGL-ST-N001 and the tables for LRFD return values the following weather restrictions/ Return values are proposed, see Table 2-2.

Table 2-2 Suggestion of weather restrictions with corresponding return period

Phase	Duration	Weather restrictions / Return values
Docking of drydock barge and load transfer	<3 Days	Weather restricted operation. Weather limitations to be decided at later stage
Maintenance of pontoon (short duration) *	7<Days<30	Weather unrestricted operation. Seasonal 1-year return values for waves Seasonal 10-year return values for winds
Maintenance of pontoon (long duration) *	30<Days<180	Seasonal 10-year return values for waves Seasonal 100-year return values for winds
Maintenance of pontoon (very long duration)*	180<365 Days	(Seasonal if applicable) 100-year return values for waves and winds

Undocking of drydock barge	<3 Days	Weather restricted operation. Weather limitations to be decided at later stage

*If the maintenance operation is planned such that the drydock can disconnect at any time in less than 3 days, the operator may choose to perform the docking as a weather restricted operation with a continuously updating weather window.

2.5 Analysis methodology

The main goal of the analysis is to evaluate the change of the global bridge response as a result of the changed (hydro)dynamic properties imposed by the drydock barge. Results will be assessed in the columns and in the bridge deck and compared to the unmodified bridge. Most of the analysis have been calculated by the frequency domain solver in Orcaflex and the load combinations have been performed using the factor method. In addition, a coupled time domain analysis has been performed for the case with the drydock in axis A3.

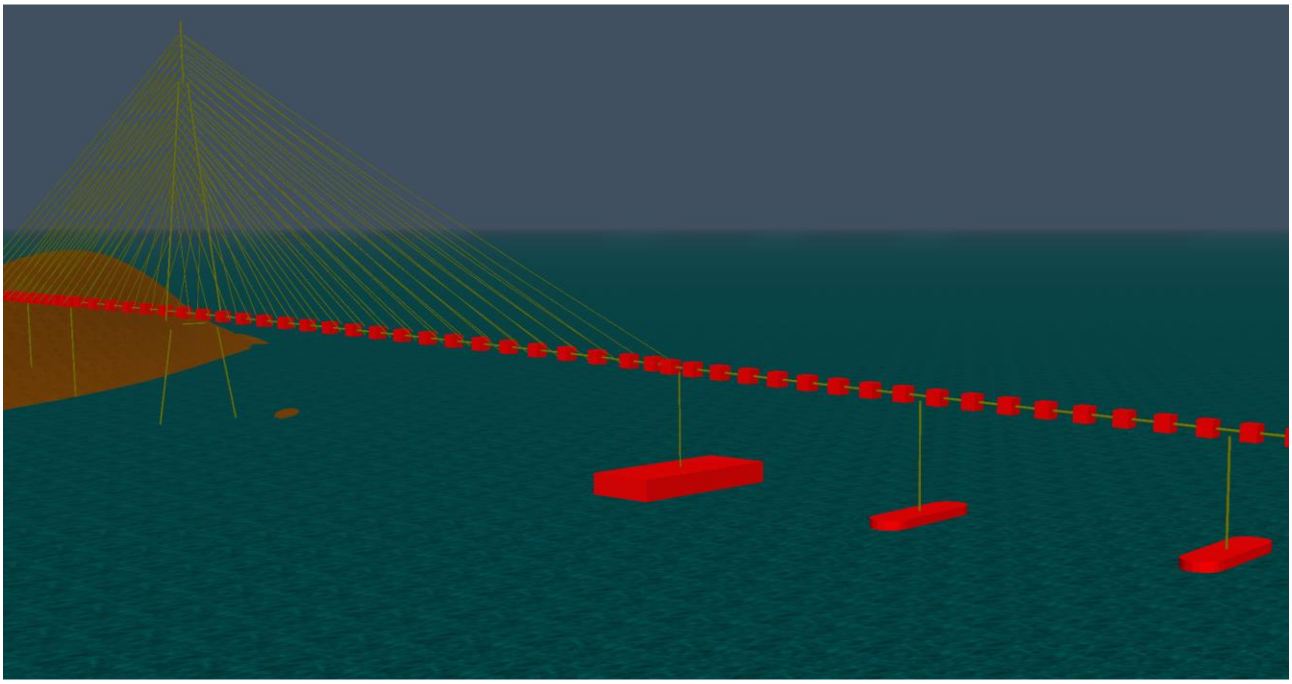


Figure 2-2: Shaded view of Orcaflex model with drydock in axis A3

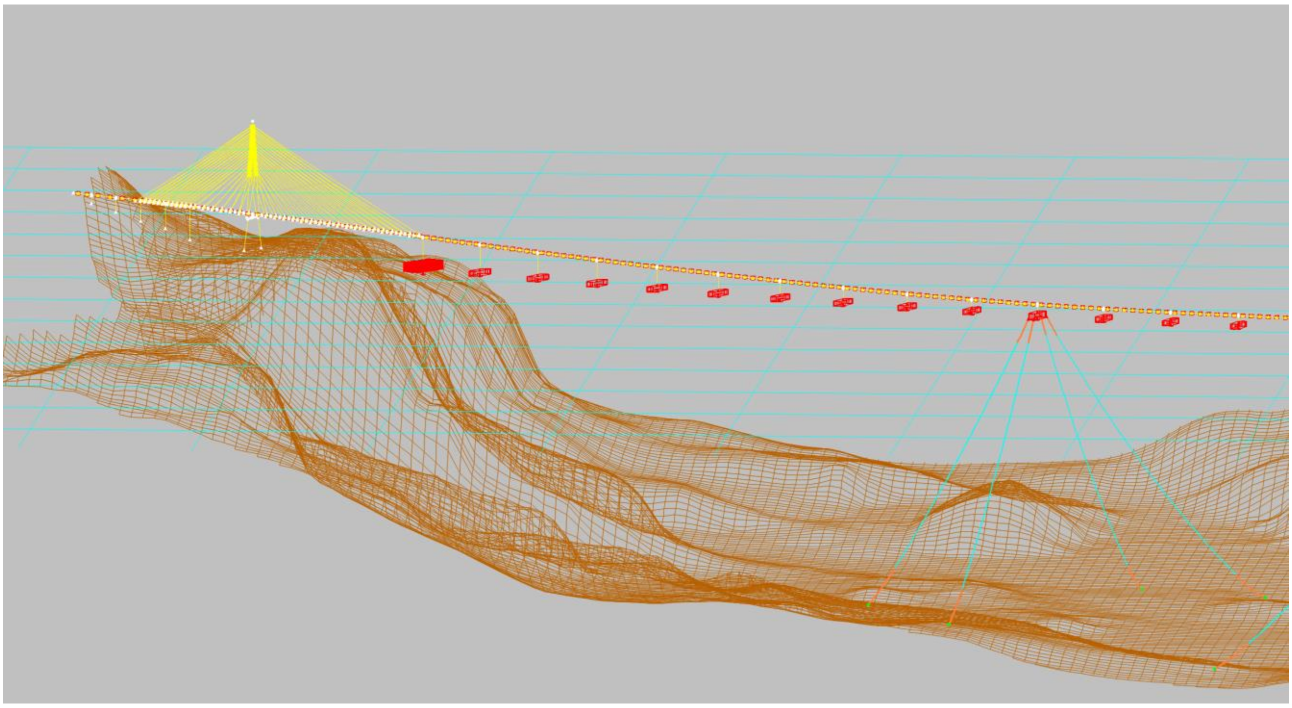


Figure 2-3: Isometric model with barge at Axis A3

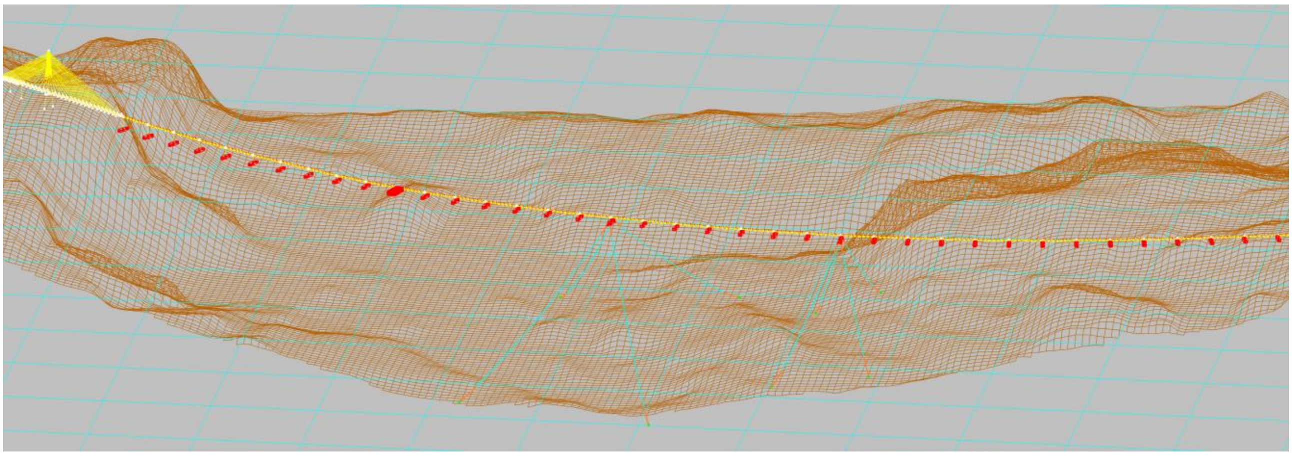


Figure 2-4: Isometric model of with barge at Axis A13

All analyses performed in this study will be based on the methodology and models developed for the global analysis of the K12_07 bridge, and the simulation setup is similar to that from phase 5 (see [4, 5]). The response analysis is performed without viscous damping effects on the pontoons, but viscous damping of the moorings is included through the analytical mooring line damping scheme defined in phase 5 (see [6]).

The effect of the drydock shall be checked for 4 different positions. For different runs the drydock will enclose the pontoons A3, A13, A24 and A40. For each of the runs the original pontoon will, in the analysis, be replaced by an updated model which includes the hydrodynamic properties of the drydock barge and the combined inertial properties of the pontoon and drydock barge.

The optimal solution from an operability standpoint would be that *any* pontoon can be maintained *anytime* for *any duration* without affecting the up-time, response and fatigue life of the bridge. If limitations need to be imposed, one needs to single out if the limitations should be imposed by pontoon type/location, season or duration. This enables the maintenance operator to optimize the plan for effective operations.

2.5.1 Hydrodynamic analysis of drydock barge

The hydrodynamic analysis has been performed in WAMIT. The main goal of the hydrodynamic analysis is to establish the hydrodynamic properties which will be used in the global Orcaflex analysis.

The barge is modelled as a rectangular box with the barge's main dimensions. It uses symmetry about 2 planes. Wave periods of 2-60 seconds have been assessed.

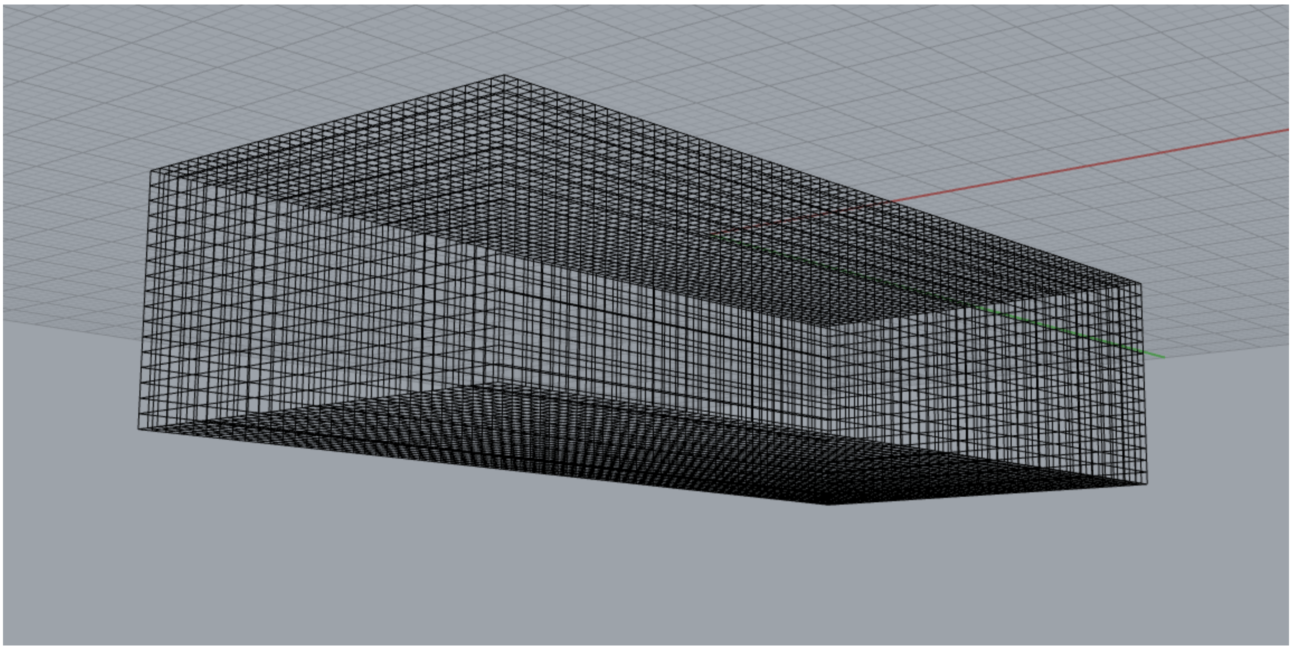


Figure 2-5: Mesh view of drydock barge

2.5.2 Loads

When assessing the behavior of the bridge, the following loading groups was used:

- Dynamic loads: (wind, wind sea, swell)
- Static loads: (self-weight, tide, current, traffic)

The following load combinations was checked:

- 100 year conditions for all non-moored pontoons (A3, A24 and A40)
- 1 year return conditions and traffic loads for pontoons (A3, A13, A24 and A40)

The results of the analysis will be used to assess and quantify the operational aspects of the maintenance operations.

Parametric excitation [7] is not evaluated herein. It is assumed that as long as the mooring lines are in place any parametric response amplitude is efficiently limited by viscous damping. The exception to this is when the moored pontoons are drydocked, for which it is assumed that the lines are simply disconnected without temporary moorings on the drydock itself or neighboring pontoons. For this condition seasonal weather may be applied to ensure proper bridge response during a short drydocking period.

3 Bridge response from waves

In the following the bridge response during drydock maintenance is compared to the response of the intact bridge.

3.1 Screening of wind waves

From previous experiences the highest response of the bridge in wind generated waves is found in the sea states with the highest wave period. The screening has therefore been performed with one combination of Hs-Tp for every 5th degree corresponding to the sea-state with the highest 1-y/100-y wave height and period.

In Figure 3-1 the results for the weak axis moment for three different cases with drydock in A3, A24 and A40 are compared with the base case (K12_07). In the upper part of the plot, the base case results are termed *BF* (blue line) and an envelope of the three drydock locations are termed *All* (orange line). The drydock has a local effect on the weak axis moment, the largest influence is when the drydock is situated in axis A40 (Figure 3-2). The screening results in Figure 3-3 show a slightly increasing strong axis moment with the drydock.

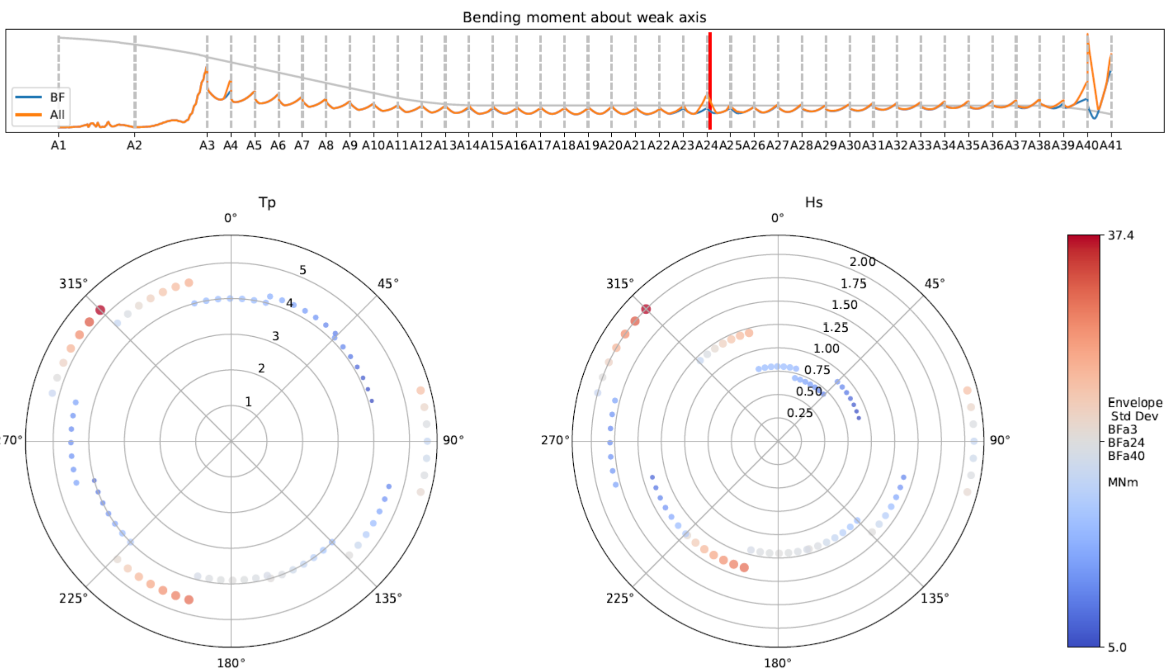


Figure 3-1 Wind wave screening 100-year results, for weak axis moment. The upper plot gives the envelope of results for base case (K12_07) in blue and envelope of screenings results for the cases with drydock in A3, A24 and A40. The rose plots illustrate the standard deviation for the different wave directions for the cross-section illustrated with the red line in the upper plot.

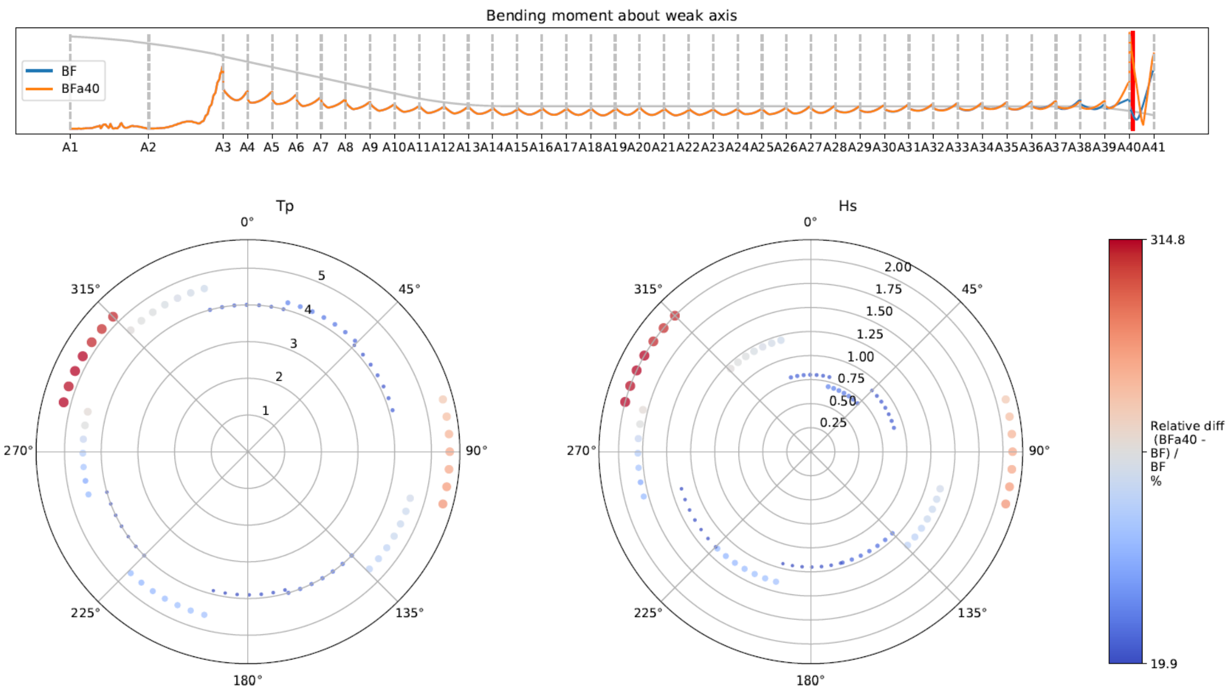


Figure 3-2 Upper plot: Envelope of the weak axis moment for the 100-year wind wave screening for the base case (K12_07) and the for the screening when the drydock is placed in axis A40. The lower rose plots give the relative difference between the screening for the weak axis moment in the bridge girder at A40.

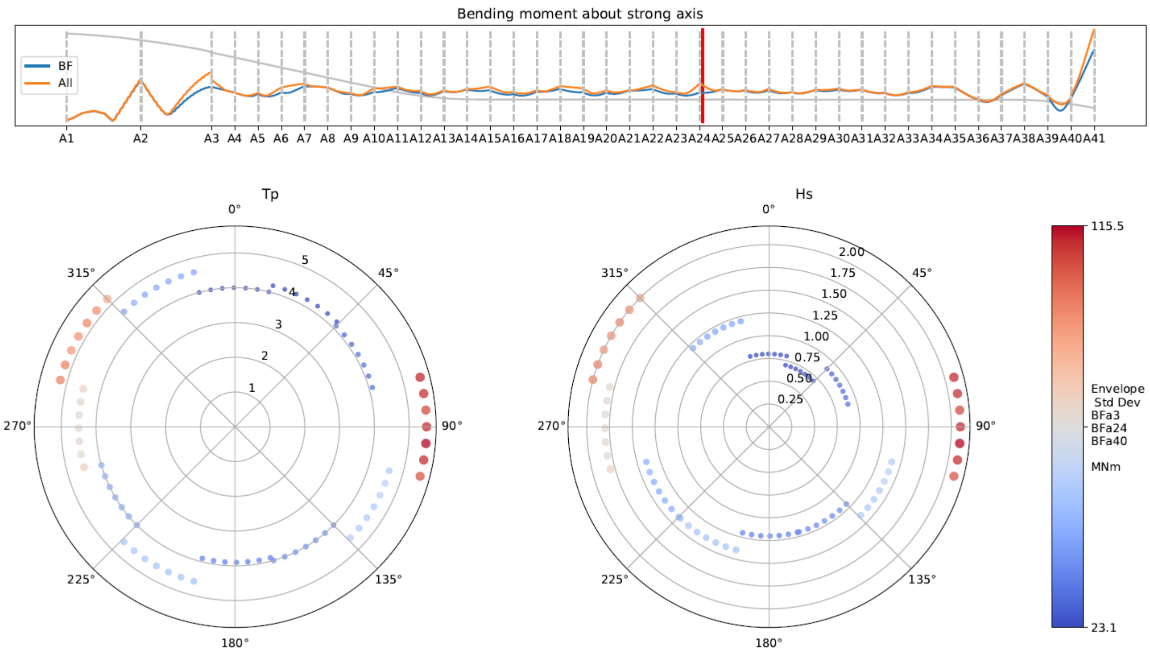


Figure 3-3 Wind wave screening 100-year results, for strong axis moment. The upper plot gives the envelope of results for base case (K12_07) in blue and envelope of screenings results for the cases with drydock in A3, A24 and A40. The rose plots illustrate the results for the different wave directions for the cross-section illustrated with the red line in the upper plot.

3.2 Screening swell wave

It has earlier been found that the dynamic behavior of the bridge system in swell sea states is sensitive with respect to the discretization of the wave spectra, wave direction and wave period. A method that has been found to be robust, is to use a dense screening matrix with regards to wave period and wave direction.

Figure 3-4 shows the comparison of the weak axis moment for screening in swell sea states. The drydock has a local effect on the weak axis moment on all three selected locations, where the drydock increases the weak axis moments for all cases. The most significant increase is seen in the high bridge where a resonance at 19.5s occurs as a result of a pendulum mode, see further discussion in section 3.4.1.

For the strong axis moment (Figure 3-5 and Figure 3-6), introducing the drydock leads to a decrease in response when it is placed in axis A3 or A24. The screening results suggests that the change in eigenmodes due to presence of the drydock is beneficial with respect to the strong axis moment.

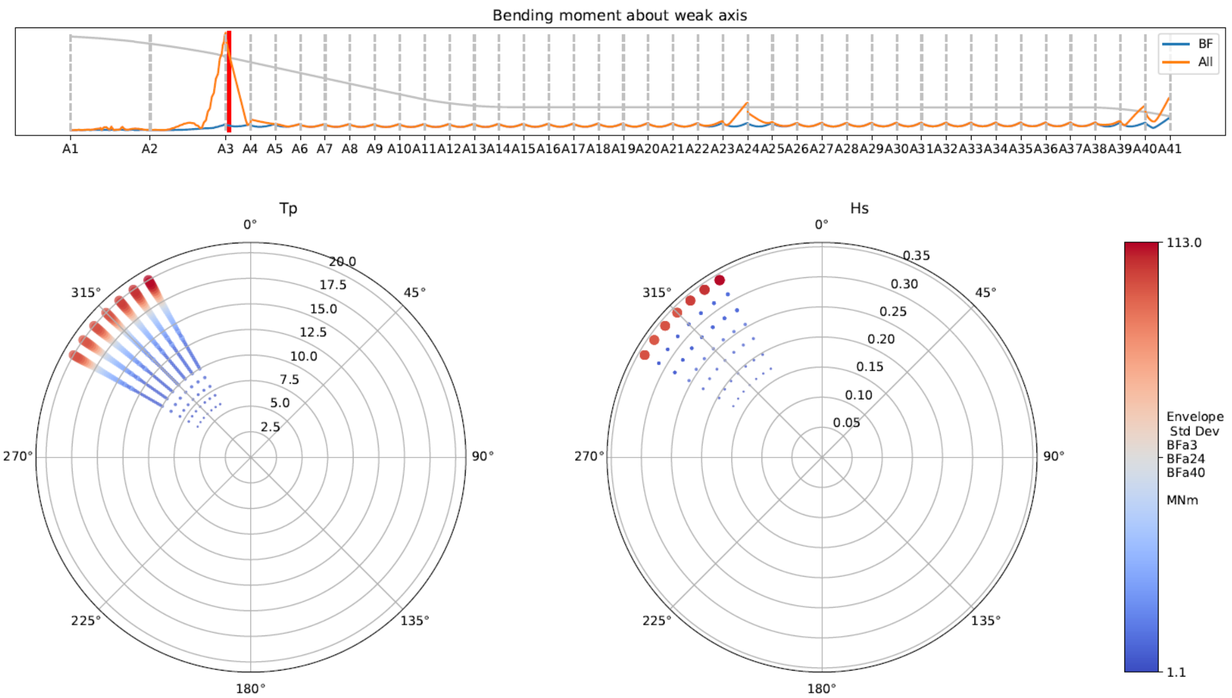


Figure 3-4 Swell wave screening 100-year results, for weak axis moment. The upper plot gives the envelope of results for base case (K12_07) in blue and envelope of screenings results for the cases with drydock in A3, A24 and A40. The rose plots illustrate the results for the different wave directions for the cross-section illustrated with the red line in the upper plot.

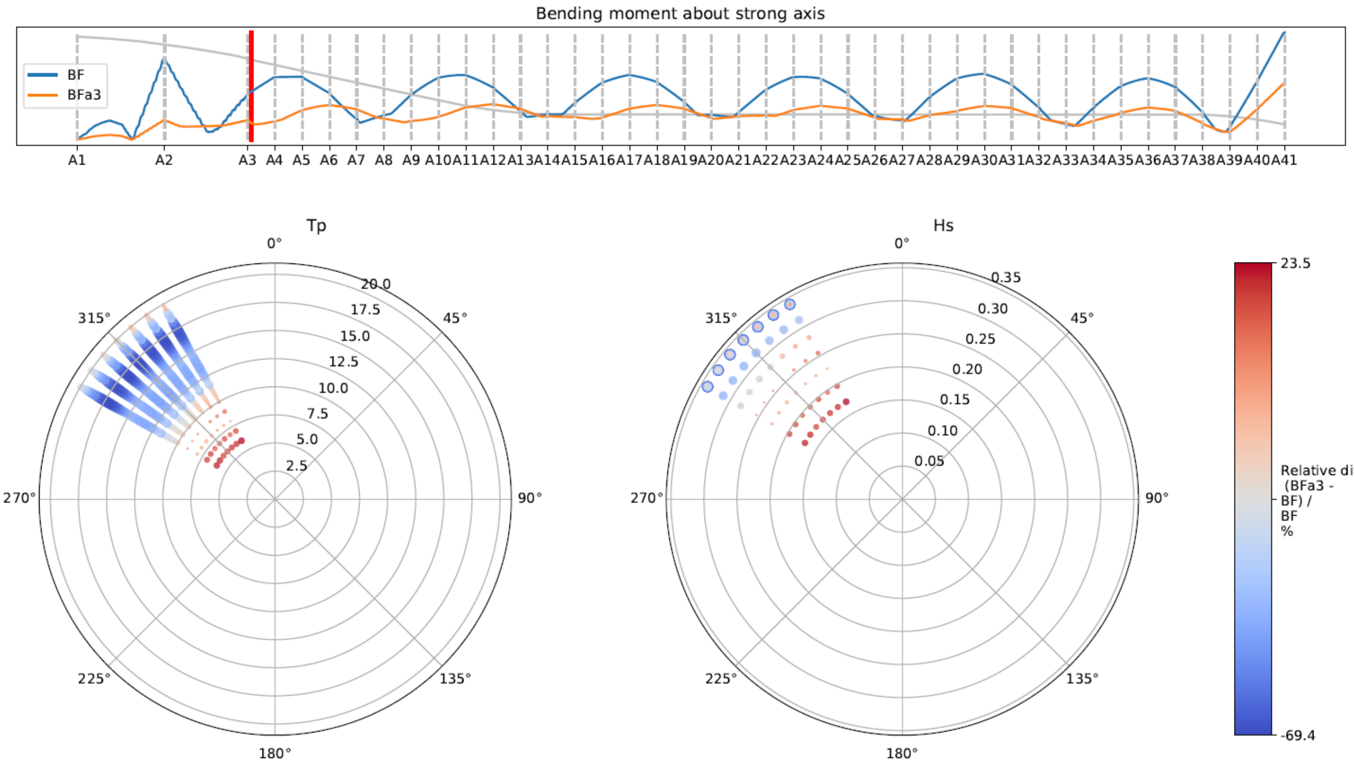


Figure 3-5 Swell wave screening 100-year results, for strong axis moment. The upper plot gives the envelope of results for base case (K12_07) in blue and envelope of screenings results for the case with drydock in A3. The rose plots illustrate the relative difference between the base case and the case with drydock in A3 for the different wave directions for the cross-section illustrated with the red line in the upper plot.

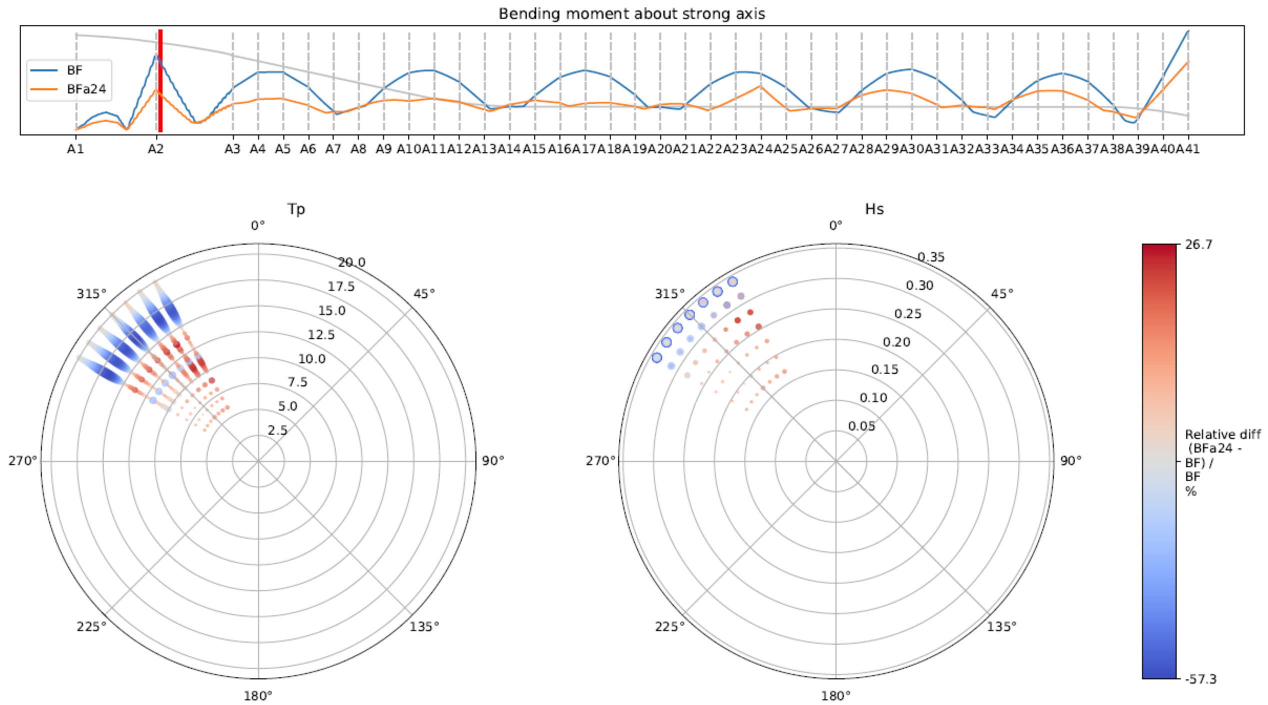


Figure 3-6 Swell wave screening 100-year results, for strong axis moment. The upper plot gives the envelope of results for base case (K12_07) in blue and envelope of screenings results for the case with drydock in A24. The rose plots illustrate the relative difference between the base case and the case with drydock in A24 for the different wave directions for the cross-section illustrated with the red line in the upper plot.

3.3 Selection of sea states from screening

From the wind wave and swell screenings some sea states are selected and chosen for load combination. This is not a trivial task, as different sea states can contribute on different parts of the bridge, different modes and different response variables. In order to assess a large number of sea states for final load combination, the selection of cases from screening has been performed iteratively until the maximum difference between max envelope results for all simulations and the max envelope of the few selected sea states are within a certain tolerance. This ratio is termed Envelope, error in the following. Figure 3-7 shows an example of the envelope over all 91 simulations are perfectly represented (0% error) by only five discrete simulations. These selected sea states are then used for load combinations for the ULS2 and ULS3 conditions.

The sea states selected from screening to be used for load combinations is given in Table 3-1 and Table 3-2.

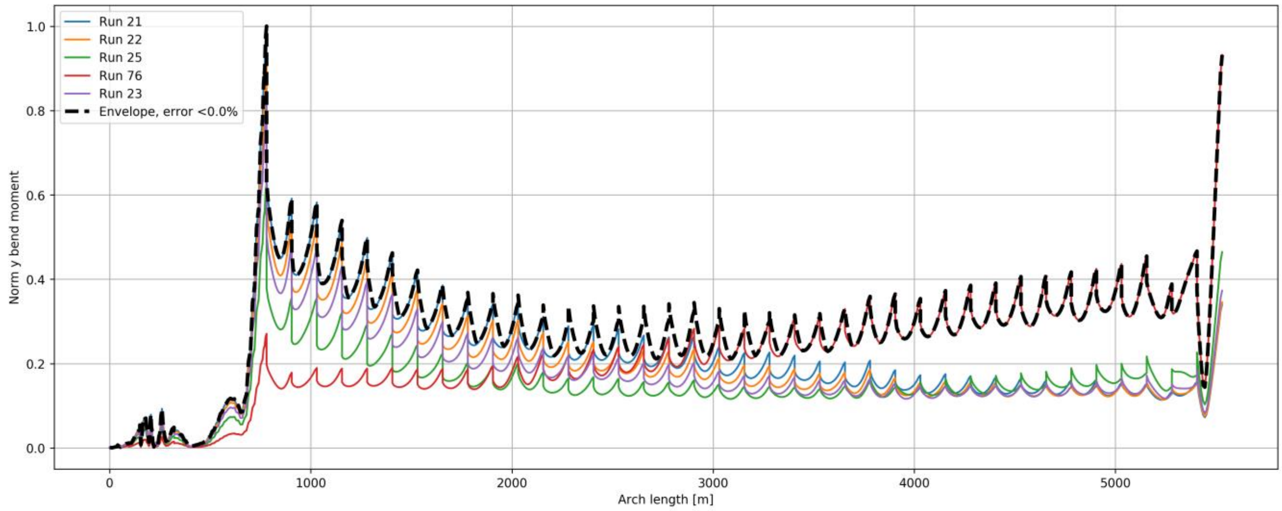


Figure 3-7 An example of the selection of sea states from screening. For wind generated waves it is typical that different sea states have maximum values on different parts of the bridge.

Table 3-1 Selected wind sea sea-states for ULS3 load combination

Sea state nr:	Hs	Tp	Dir	K12_07	A3	A24	A40
21	2.1	5.5	75	X	X	X	X
22	2.1	5.5	80	X		X	X
23	2.1	5.5	85	X		X	X
24	2.1	5.5	90				X
25	2.1	5.5	95	X	X	X	X
27	2.1	5.5	105	X		X	X
49	1.4	4.6	195	X	X		X
50	1.4	4.6	200		X		
76	2.0	5.2	315	X	X	X	X

Table 3-2 Selected swell sea sea-states for ULS3 load combination

Sea state nr:	Hs	Tp	Dir	K12_07	A3	A24	A40
12	0.34	12.0	300		X		
17	0.34	13.25	300				X
18	0.34	13.5	300	X	X		
21	0.34	14.25	300			X	
32	0.34	17.0	300	X			
33	0.34	17.25	300	X			X

39	0.34	18.25	300			X	
62	0.34	13.25	305	X			
71	0.34	15.5	305		X		
282	0.34	12.0	330	X	X	X	X
313	0.34	19.75	330		X		

3.4 Eigenmodes

The displacement of the pontoon during operation is approx. 30% of the total displacement of the bridge. Therefore, attaching the drydock to the bridge changes the dynamic properties both globally and locally of the bridge system.

3.4.1 Pendulum mode of high-bridge columns when drydocked

When drydocking axis A3, it is equivalent to placing a large mass with a long arm (the column) from the bridge girder. This introduces a pendulum mode in which this mass rotates around an axis transverse to the bridge girder, thereby giving large weak-axis moments in the bridge girder and column. This is illustrated in Figure 3-8, and the mode shape is given in Figure 3-9. This mode can be excited by swell waves without significant sheltering due to the pontoon location.

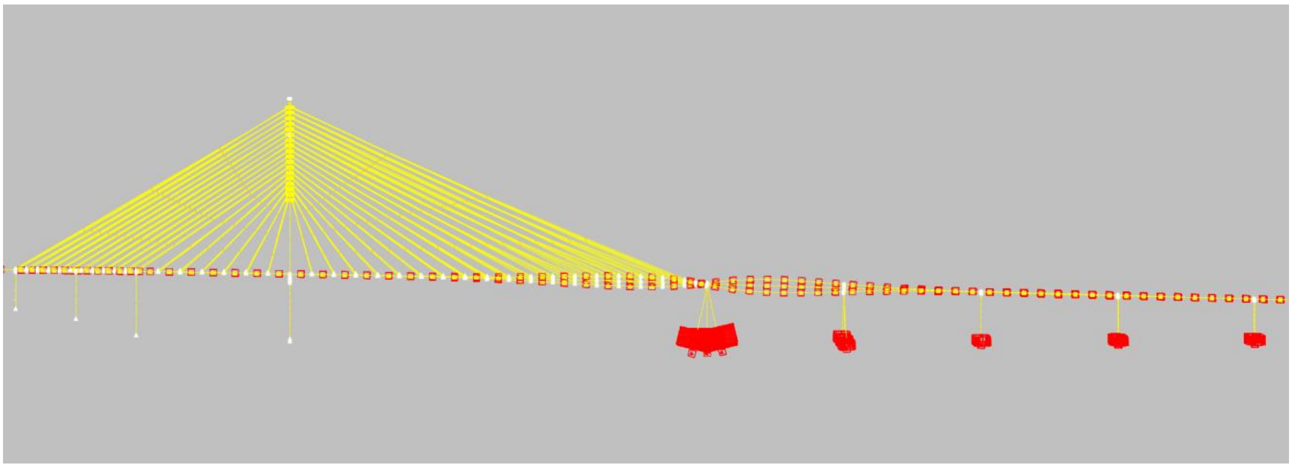


Figure 3-8: Orcaflex visualization of eigenmode with pendulum motion at axis A3 (displacement scaling used for clarity)

The work scope of this study was limited to drydocking of one high-bridge pontoon (A3). It is however of interest to evaluate the change in pendulum mode as the other pontoons in the high bridge are drydocked. Eigenmode calculations were performed to investigate this, and the results in Table 3-3 shows that the eigenmode period changes from 19.5 to 16.5 seconds depending on which pontoon that is drydocked. Hence, it is of interest to have as good data as possible on the swell behavior in this period range to understand possible weather windows for the drydocking operation (such as seasonal weather restrictions).

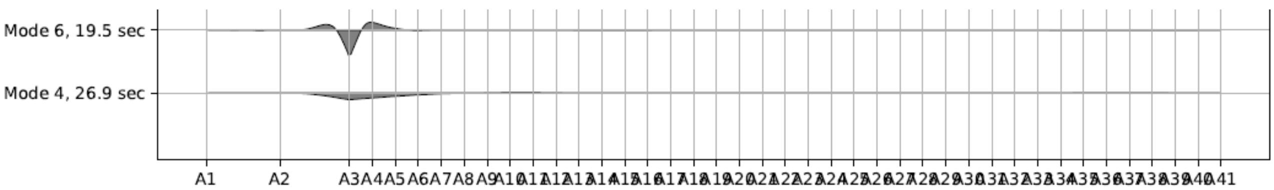


Figure 3-9 Pendulum mode (mode 6) when axis A3 is drydocked.

Table 3-3 Eigenperiod of pendulum mode during drydocking of the high-bridge pontoons

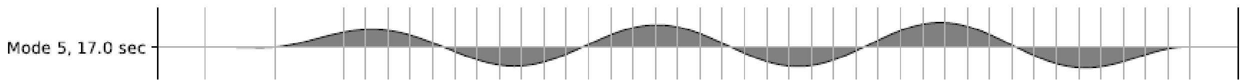
Drydock in axis	Modal period [s]
A3	19.5
A4	18.8
A5	17.6
A6	16.7
A7	16.5

3.4.2 Effect on long strong axis modes

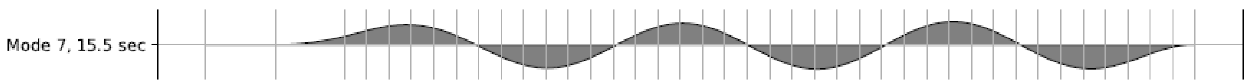
As seen in the results from the swell screenings (in section 3.2) the strong axis response is significantly different with the drydock in axis A3 and A24, compared to the base case (K12_07) and with drydock in A40. This is due to the suppression of response on the 17 seconds bending mode. From the phase 5 work this mode was seen to be sensitive, and easily excited by pure loads such as swell alone. When coupled simulations with wind sea, swell and wind were performed the response of the 17 s mode was suppressed.

When the drydock is placed in axis A3 the high mass leads to that the effective length of the mode is shortened; the resulting eigenperiod is therefore lowered from 17.0s to 15.5s. However, when the drydock is placed in axis A24 the eigenperiod is increased as a result of higher modal mass. It should be noted how the shape is changed and becomes more irregular in Figure 3-10. More studies are needed to fully conclude on this, but the irregular mode shape can be harder to excite by waves. There is therefore a potential reduction effect on the dynamic response of the bridge by having a bridge system design with irregular mode shapes.

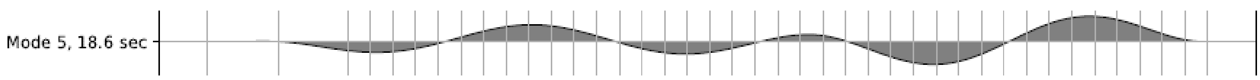
A heavy pontoon may be used as a permanent design feature to efficiently shift the bending mode. This may be beneficial if e.g. parametric excitation is of increased concern, but its dynamic effects should be thoroughly studied to ensure that there are no unwanted side effects.



a) K12_07 bridge without drydock



b) Drydock in A3



c) Drydock in A24

Figure 3-10 Change in strong-axis bending mode when drydock is placed in A3 or A24.

4 Bridge response in load combinations

Load combination results are for simplicity shown only in terms of yield utilization. Stresses are calculated based on the same principles and sectional resistances as in [5] in the cross-sectional points shown in Figure 4-1.

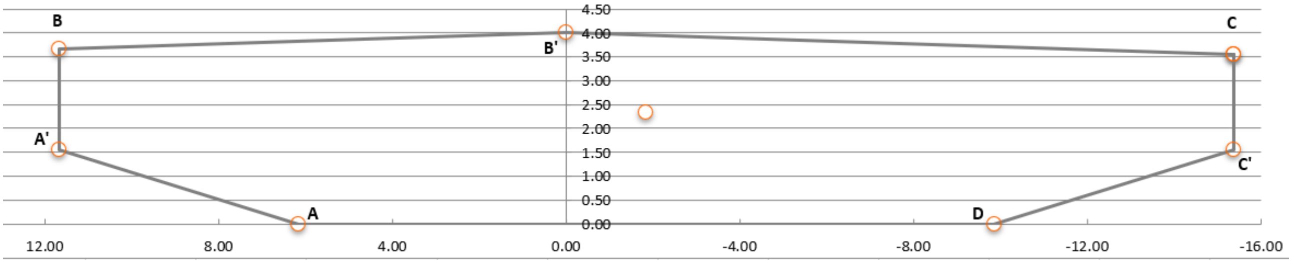


Figure 4-1 Overview of points in the cross-section used for stress evaluations

4.1 Stress calculation by the factor method

4.1.1 ULS3

The envelope of all stress points for the ULS3 conditions is given in Figure 4-2. When the drydock is in axis A3 the capacity of the bridge girder is exceeded due to the large pendulum motion in swell seas. A closer look at the different stress points in Figure 4-3 reveal that most of the cross-section of the bridge girder is exceeding the capacity. The maximum stress from the factor method is found when the weak axis is treated as dominant. A breakdown of the different force contributions when the weak axis is treated as dominant is shown in Figure 4-4. The stresses are dominated by the contribution from the weak axis bending moment in swell. The reduction of strong axis moment in swell sea states also has an impact on the resulting stresses, but not sufficient to avoid high utilization due to weak axis bending.

The capacity of the bridge girder is also exceeded when the drydock is placed in axis A40 (see Figure 4-5 and Figure 4-6). The spatial change in wave height and wave period across the fjord for swell and wind generated sea states will influence the results for the northern pontoon in axis A40, as it is expected to be somewhat sheltered. Hence, the main contribution from wind sea and swell in Figure 4-6 is expected to be overly conservative.

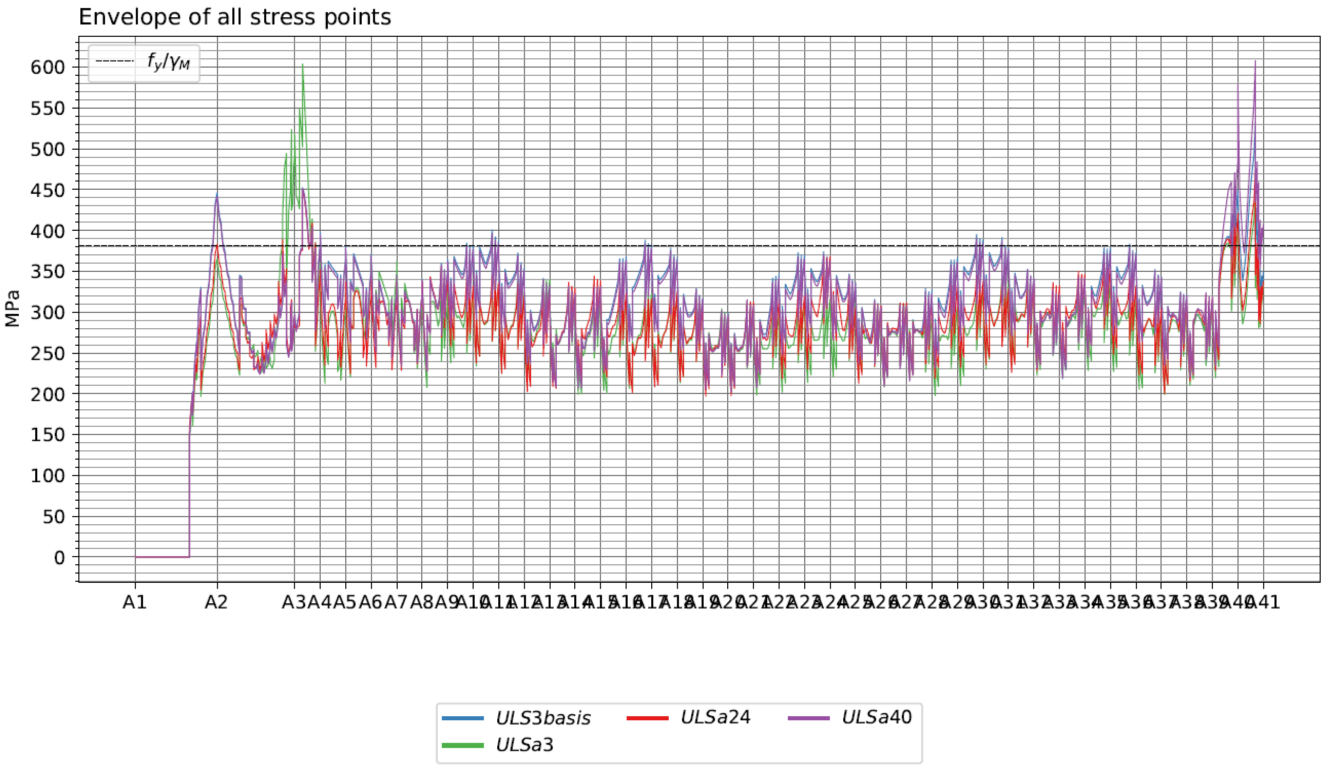


Figure 4-2 Envelope of all stress points for ULS3 load combination

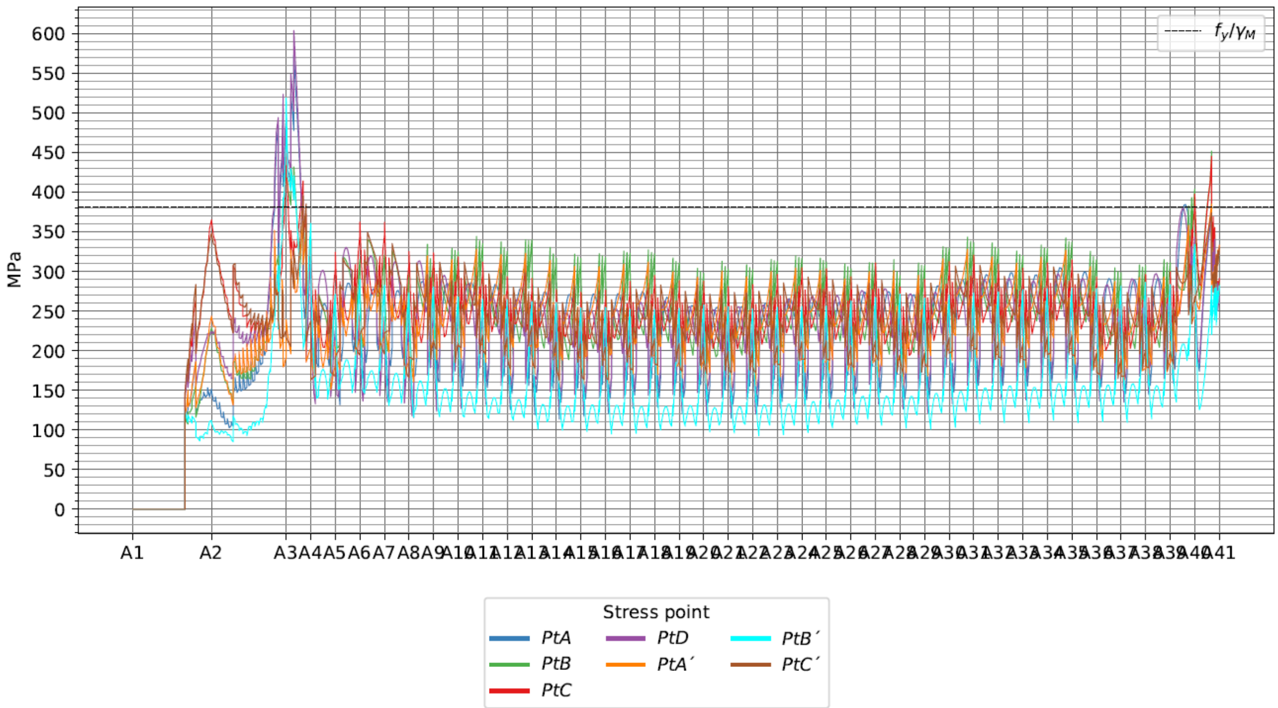


Figure 4-3 Overview of the stress distribution in the bridge girder for the case with drydock in A3

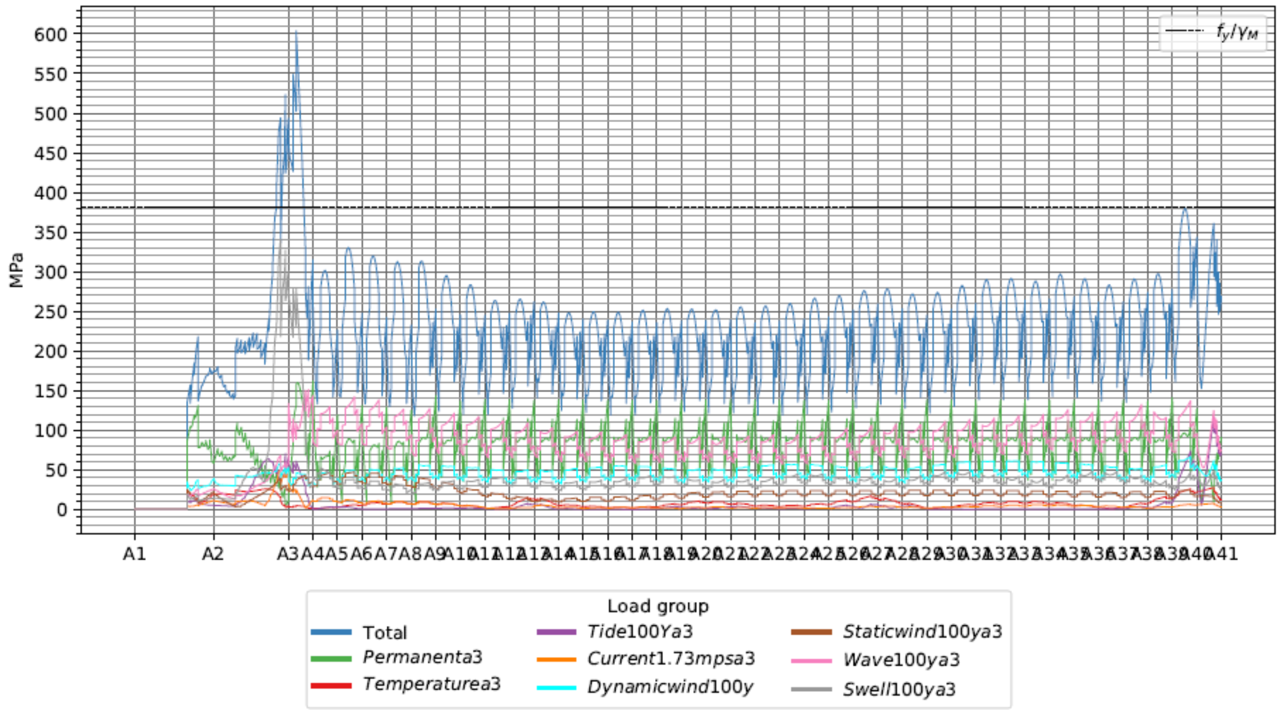


Figure 4-4 Breakdown of the different force contribution with drydock in A3 for the resulting case where the weak axis is treated as dominant

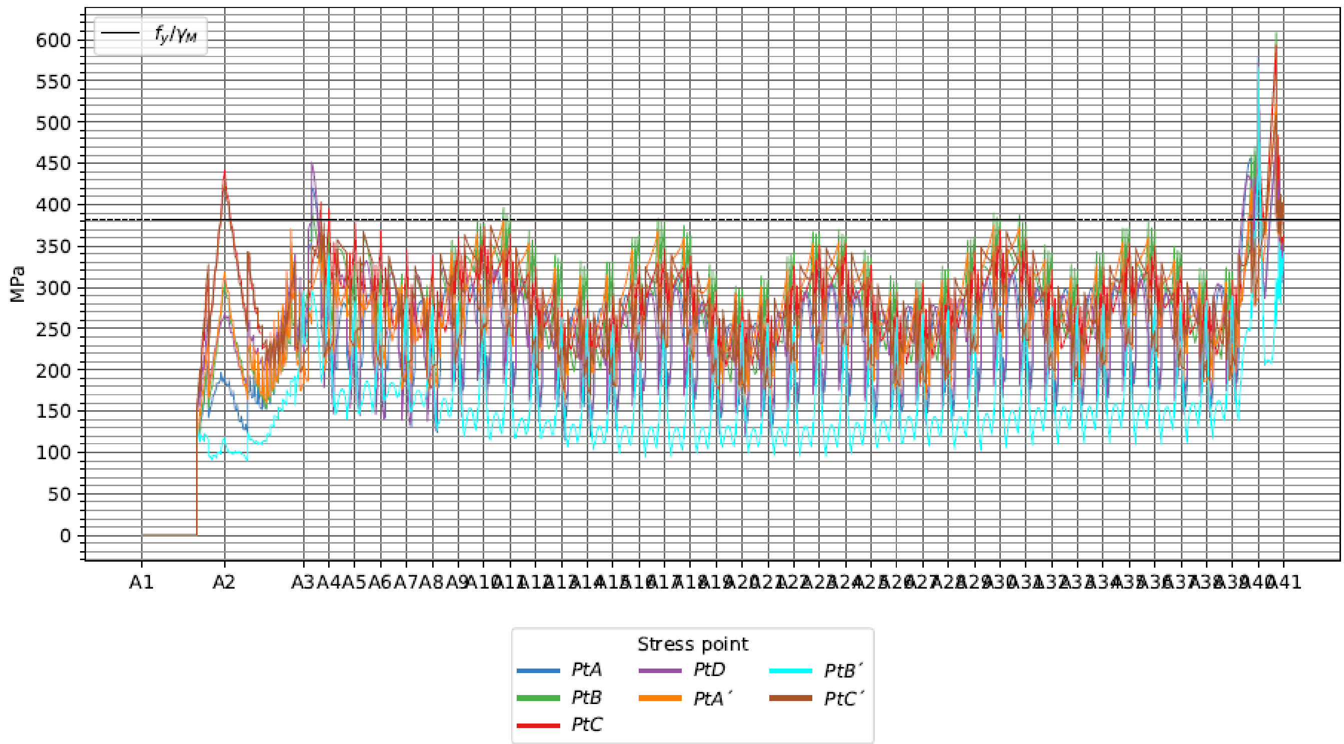


Figure 4-5 Overview of the stress distribution in the bridge girder for the case with drydock in A40

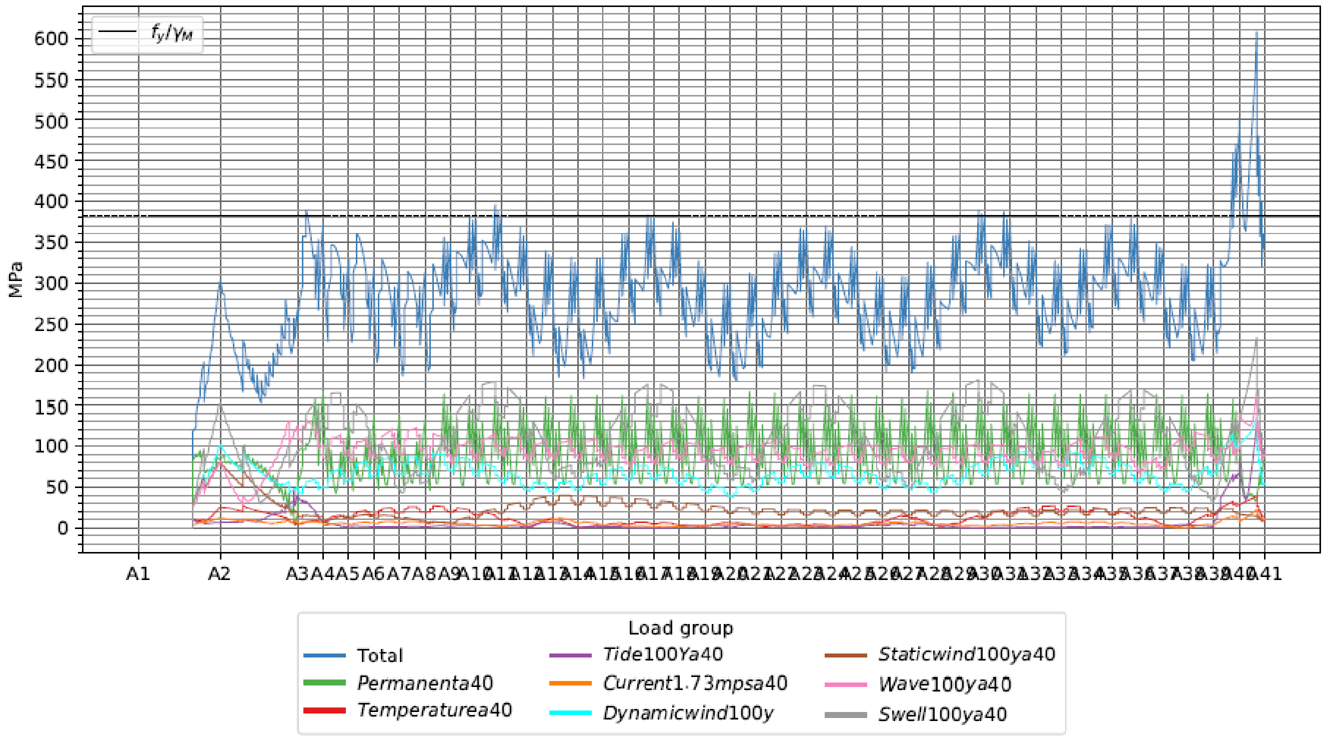


Figure 4-6 Breakdown of the different force contribution with drydock in A40 for the resulting case where the strong axis is treated as dominant

4.1.2 ULS2

The resulting ULS2 results are given in Figure 4-7. In general, the stress level is lower than for ULS3, and mostly within the acceptable limits. However, there is still an exceedance of the capacity in axis A3. An additional case compared to ULS3 is analyzed, with drydock in A13 and moorings to this axis removed.

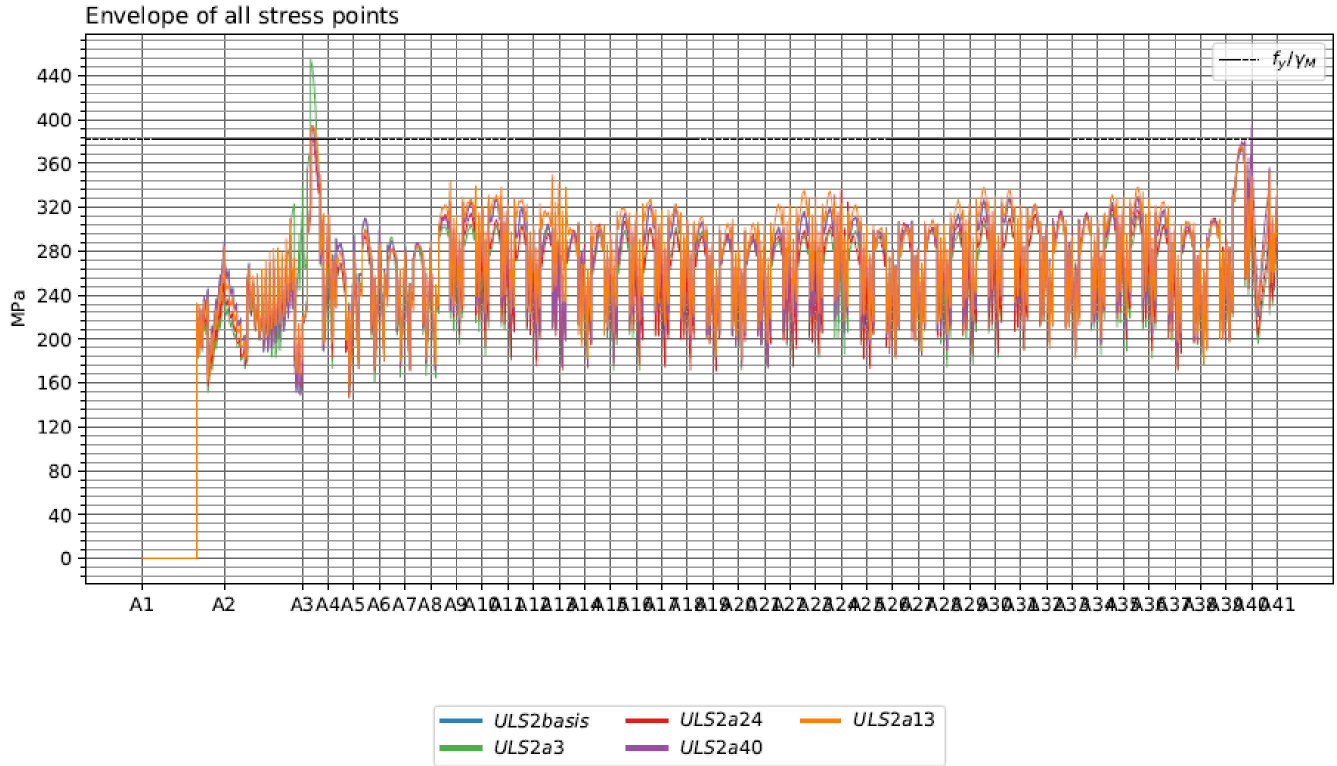


Figure 4-7 Envelope of all stress points for ULS2 load combination

4.1.3 Discussion of bridge response using the factor method

When using the factor method it was found that drydocking of pontoons in the low bridge (except towards the northern abutment) is acceptable both for ULS2 and ULS3 conditions, and can as such be performed without weather restrictions. However, due to the risk of parametric resonance it is recommended to perform drydocking of the moored pontoons during the summer season to minimize the possibility of swell conditions that may cause parametric resonance.

For the high bridge under ULS3 conditions it was predicted that the yield capacity of the bridge girder is exceeded in the high bridge due to the swell-excited pendulum mode of the drydocked pontoon and column, and that swell and wind sea gives and exceedance towards the Northern abutment. However, for ULS2 the response was found acceptable except for when drydocking the high bridge pontoons. Hence, short duration work on pontoons towards the northern abutment is acceptable within a 1-year return period environmental condition.

Stresses calculated with the factor method are known to be conservative around the high bridge and northern abutment (see Enclosures to [5] with the direct method and the factor method). Hence, an exceedance of the allowable utilization when using the factor method does not necessarily mean that there is an unacceptable response. Further investigations using more coupled environmental loading and a direct stress approach is recommended for final verification of the drydocking procedure. A preliminary study is shown in section 4.2.

4.2 Direct stress calculation

4.2.1 ULS3

In principle the load factors used in the factor method should be calibrated for every unique structure. It is therefore important to check the results by performing a direct stress calculation, based on a coupled wind-wave analysis in time domain. For the present study we have chosen a single realization for the case with drydock in axis A3. Note that a full design check requires amongst other things more realizations with different seeds of the wind and wave conditions.

The coupled wind-wave analysis is performed in time-domain including drag damping on pontoons (not the drydock), second order slow drift forces and a nonlinear structural model.

The resulting stresses are given in Figure 4-9. The environmental conditions used in the coupled analysis is 100-year wind from west and the wave conditions given in Table 4-1.

Table 4-1 Wave conditions coupled analysis

	Wind wave	Swell wave
Tp (s)	5.5	19.75
Hs (m)	2.1	0.34
Direction from north	75	330
Gamma	2	5
Spreading exponent	4	10
Number of directions	11	15

The weak axis bending moment from the coupled analysis is given in Figure 4-8. Compared to Figure 3-4 there is a significant decrease in the response, more analysis is needed to conclude if this reduction is actual and that the chosen seed is representative. If the results are representative it indicates that the pendulum mode is less excited with coupled environmental conditions and that the results from frequency domain simulations as used with the factor method are conservative.

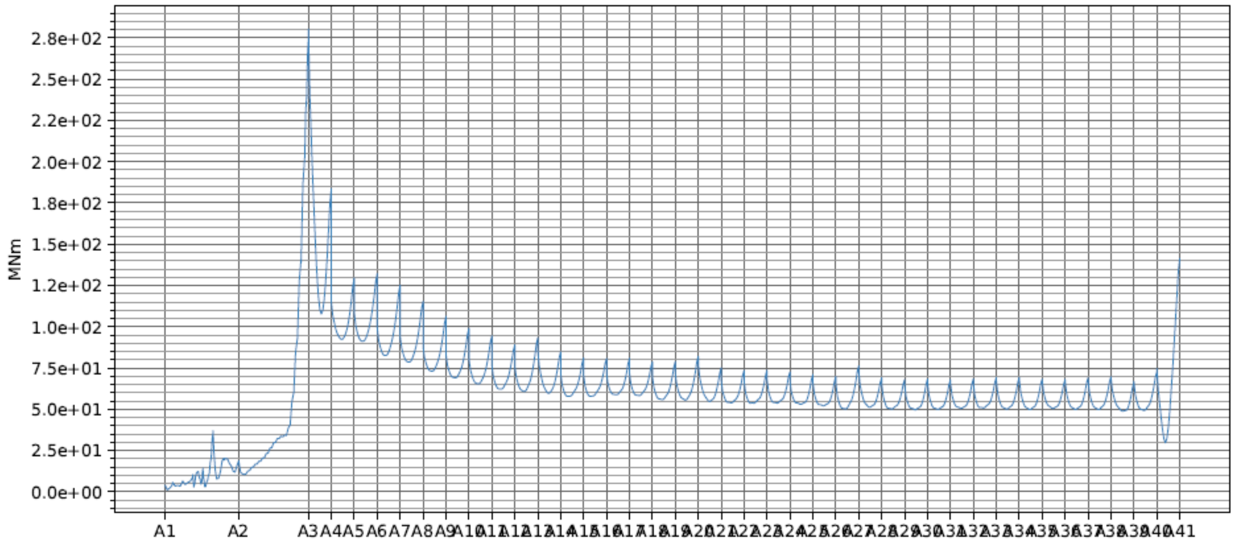


Figure 4-8 Weak axis bending moment from coupled wind-wave analysis. (expected max values).

Bridge girder

The resulting stresses in the bridge girder from the coupled wind-wave analysis is given in Figure 4-9.

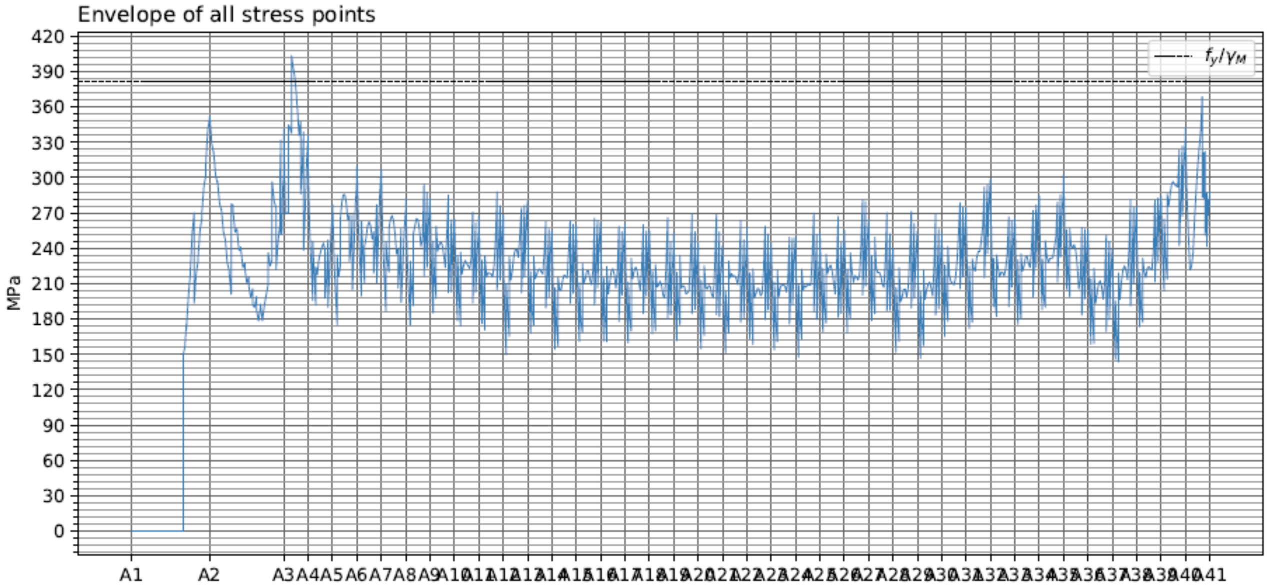


Figure 4-9 Direct stress calculation based on coupled wind-wave analysis

Columns

The minimum (Table 4-2) and maximum (Table 4-3) column forces have been extracted at the top and bottom of the column. Compared to the column response in K12_07 (see section 6.4.2 in [5]) the moment about the transverse axis (pendulum mode) increased from 524 to 910 MNm. This is probably within the column capacity as ship collisions resulted in the governing load.

A more comprehensive study should be performed to verify the column capacity using a more thorough simulation regime.

Table 4-2 Minimum column forces for drydock in axis A3, where 0.0 refers to the bottom of the column

		Min					
		N	**M longit**	**M transv**	**T**	**V longit**	**V transv**
		MN	**MNm**	**MNm**	**MNm**	**MN**	**MN**
column_3	**0.00**	-34.34	-204.87	-194.15	-761.85	-15.11	-7.04
	45.57	-29.61	-210.83	-910.32	-761.96	-14.30	-7.58
column_4	**0.00**	-44.82	-32.75	-37.37	-69.14	-7.95	-5.53
	41.85	-40.67	-231.38	-384.42	-69.14	-7.69	-6.22

Table 4-3 Maximum column forces for drydock in axis A3, where 0.0 refers to the bottom of the column

		Max					
		N	**M longit**	**M transv**	**T**	**V longit**	**V transv**
		MN	**MNm**	**MNm**	**MNm**	**MN**	**MN**
column_3	**0.00**	-7.07	326.33	158.20	770.27	16.04	5.59
	45.57	-2.27	260.29	724.71	770.36	16.22	5.11
column_4	**0.00**	-29.42	86.06	35.44	65.88	7.85	4.00
	41.85	-24.92	186.03	364.40	65.85	8.49	3.63

4.2.2 Discussion of the bridge response using the direct stress method

A preliminary study using time-domain coupled wind-wave analysis to calculate direct stresses have been performed, this study only contains one realization for one environmental condition for the case with drydock in axis A3. It is seen compared to the factor method that the stresses are reduced, mostly due to a reduction of the weak axis response due lower response of the pendulum mode at axis A3. The response still exceeds the capacity of the bridge girder, however more work and analyses are needed to investigate the difference between the preliminary direct stress calculation and the factor method.

5 Conclusion

The presence of the drydock disturbs the bridge modes and response significantly. Strong-axis response may be improved during drydocking, but weak-axis response is deteriorated. Tidal effects increase towards either end due to the increased waterplane area.

The analysis reported in this document indicates that the proposed drydock method for dry access for maintenance of pontoons is a feasible option.

- Drydocking of non-moored pontoons in the low bridge was found to be acceptable without weather restrictions, even for ULS3 conditions (100-year return period).
- Drydocking of moored pontoons was found to be acceptable within the ULS2 conditions, but it is recommended to perform the operation during the summer season to limit the possibility of parametric excitation.
- Drydocking of pontoons towards the northern abutment was found to be acceptable within the ULS2 conditions (1-year return period), but with refined metocean basis for wind sea and swell waves close the northern abutment the drydocking methodology may also be acceptable for ULS3 conditions.
- Some work remains in order to verify drydocking of the pontoons in the high bridge for ULS2 and ULS3 conditions. Considering the possibility of repair of a collision-damaged pontoon with a long duration it is not recommended to rely on seasonal metocean conditions in the high bridge.
    - Refined metocean conditions (esp. for swell) and refined simulations may reveal sufficient capacity
    - Reinforcement of the bridge girder is a possible last outcome, but it is not expected to be necessary

6 Further work

The concept of using a drydock barge for maintenance is feasible for the majority of the pontoon locations. However, for the high-bridge (A3 to A8) and A40 stresses in the bridge are exceeded with the current solution and therefor the following further work is proposed. These are categorized in the following subchapters in prioritized order.

6.1 Metocean data

The dynamic response of the bridge is sensitive to wave periods in the swell sea range. These are waves that propagate from offshore through the fjord-systems and into Bjørnafjorden. The presence of these and their expected extreme wave height has a large influence on the resulting bridge response; for the intact bridge, for parametric excitation and for drydocking conditions in the high bridge and towards the northern abutment.

At the same time the swell wave conditions are not well described in the Phase 5 metocean design basis [7]. A few points are suggested for further specification of the swell conditions:

- Shape of wave propagation in the fjord; how should the wave interaction with each individual pontoon be addressed?
- Seasonal probability of swell direction, period and wave height should be established.
- Probability of swell alone (without wind sea and wind) should be discussed

6.2 Establish return period for swell for ULS2

The bridge will be monitored and closed when gust wind is above 35.0 m/s, for Bjørnafjorden it is a coincidence that this corresponds to 1-year wind wave condition. However, the correlation to the return period of swell is not given. This affects the current definition of ULS2 and should be reevaluated.

6.3 More comprehensive response study

A more comprehensive response study with coupled environmental loading and a direct stress calculation method is recommended as an early step towards solving the challenges related to drydocking of the high bridge. Ideally this study is based on refined metocean input as discussed above.

6.4 Refinement of model and simulations

The first step of checking the global results of a fixed drydock barge have been concluded in this report. For the next phase a more detailed analysis is proposed. The following items should be checked:

- The complete load transfer operation, including assessment of first and second order motions, station-keeping, weather windows (duration and conditions)
- Solutions for withstanding vertical and horizontal interface loads between the drydock barge and the pontoon. Verify that there will be no relative motions during operation
- Accident scenarios
  - Drydock barge needs to be installed onto a damaged pontoon, which has lost its ballasting opportunities.
  - Accidental sinking of drydock barge and release.

  - Emergency disconnect between drydock barge and pontoon (without possibility to ballast pontoon)
- Based on the refined methodology and new considerations of the duration of the maintenance work a realistic time schedule should be established such that the requirements to the return period of weather conditions can be evaluated.

Preliminary proposals for the execution of the proposed analyses are outlined in the subchapter below.

6.4.1 Analysis and planning of operational phases

The complete load transfer operation should be modelled in the time domain. The following phases should be modelled in a continuous operation in Orcaflex:

1. Drydock barge modelled as vessel and situated approx. 0.5-1m below pontoon. Both bridge and drydock barge are experiencing first order motions.
2. De-ballasting of the drydock barge is simulated with realistic pump speeds.
3. Correct fendering and mating units are modelled in order to model contact and load transfer.
4. Pontoon and drydock barge remain modelled as two separate independent vessels in Orcaflex, only connected by contact elements such that horizontal and vertical forces can be assessed
5. Optimization of the ballasting procedure such that the vertical position of the bridge remains unchanged.

Durations and relative motions as well as realistic ballasting accuracies shall be investigated.

6.4.2 Damaged pontoon

If a pontoon has been exposed to a ship collision its structural integrity might be uncertain. The drydock-barge must thus have some flexibility with regards to load transfer drafts and support arrangements.

In the most extreme cases the whole pontoon might need be replaced. It should be assessed whether the maintenance drydock barge should accommodate such a scenario or if this should be planned as an unrelated event. Proposals from previous project phases indicate a load transfer between the barge and the bridge girder rather than the barge and the pontoon. This may be a reasonable option to study.

6.4.3 Sinking of barge

The interface between the drydock barge and the pontoon must be designed in such a way that severe damages to the drydock barge *will not* lead to severe damages on the bridge. In case of sinking of the drydock barge it must be able to sink without imposing large loads to the bridge. The details of the interface system must be designed in order to allow for such behavior. This system must be verified by analysis. Alternatively, the strength and behavior of the bridge must be assessed with a completely water filled drydock barge attached to it

6.5 Drydock hydrodynamic optimization

By assessing other drydock geometries the exceedance of the capacity in the bridge girder might be avoided.

- For the drydock in the high bridge it should be looked at means to avoid or reduce the motion of the pendulum mode.
    - Larger mass will increase the period
    - Optimized pontoon shape can reduce the excitation load.
    - Including viscous damping in the numerical model may improve the response
- For the drydock in axes close to the north abutment a reduction in hydrostatic stiffness will most likely be beneficial.

6.6 Design of alternative bridge with irregular eigenmodes

The presence of the drydock in the low bridge part of the bridge significantly lowered the strong axis bending moment in swell sea, due to a change in eigenperiod and change in the shape of the eigenmode. Can similar design changes result in eigenmodes with more irregular shapes that are harder to excite by waves and thus result in lower stresses.

6.7 Comments to Oceantechs report

There are some discrepancies between the assumptions made in the Oceantech report and the general work performed by AMC during the engineering phase 5. Based on this there should be a full review and alignment of Oceantechs report and the final results found in phase 5. Some of the topics which should be highlighted/reviewed are outlined below:

- Increased detail of the proposed design of the drydock barge
- Update size of drydock barge to accommodate the proposed phase 5 pontoon geometry (both for mooring and regular pontoons)
- Operations should be designed such that it is unnecessary to moor the drydock barge, even if a mooring pontoon is being maintained.
    - Assess use of barge-mounted thrusters
- It should be checked if the bridge will be in an acceptable state with only two mooring clusters attached. Weather windows and seasons can be defined if necessary
- Spreadsheet in appendix C contains errors and is not complete
- The ballasting procedure needs to be outlined in a greater detail. Various ballasting and de-ballasting orders should be checked in order to have a robust methodology.
- Complete review of vessels and workboats taking part in the operations and complete update of drawings and schematics
- Detail a system for transfer of vertical and horizontal loads, and at the same time allowing for access to all parts of the pontoon.
- Duration of the maintenance operation should be further defined

References

[1] SBJ-05-C5-OTI-32-RE-001-A. Rev. 03., “Methodology for dry access to pontoons of floating bridge Bjørnafjorden,” 19.07.2019.

[2] SBJ-30-C3-NOR-40-TN-002. Rev. 0. , “K7 Bjørnafjorden End-anchored floating bridge. Technical note: Method for major repairs of steel pontoons,” 13.06.2017.

[3] AMC, “SBJ-33-C5-AMC-90-RE-100 : Preferred solution, K12 - main report Rev. 0,” 15-08-2019.

[4] AMC, “SBJ-33-C5-AMC-90-RE-106 : Appendix F: Global Analyses - Modelling and assumptions Rev. 0,” 15-08-2019.

[5] AMC, “SBJ-33-C5-AMC-90-RE-107 : Appendix G: Global Analyses - Response Rev. 0,” 15-08-2019.

[6] 10205546-11-NOT-095 Rev 1, “Analytic mooring line damping,” 24.05.2019.

[7] SBJ-01-C4-SVV-01-BA-001 Rev. 1, “MetOcean Design Basis,” 30.11.2018.

[8] AMC, “SBJ-33-C5-AMC-90-RE-119 : Appendix S: Parametric excitation Rev. 0,” 15-08-2019.