Analysis and Design Bjørnafjorden Floating Cable-Stayed Bridge subjected to Large Ship Collisions and Extreme Environmental Loads

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Introduction

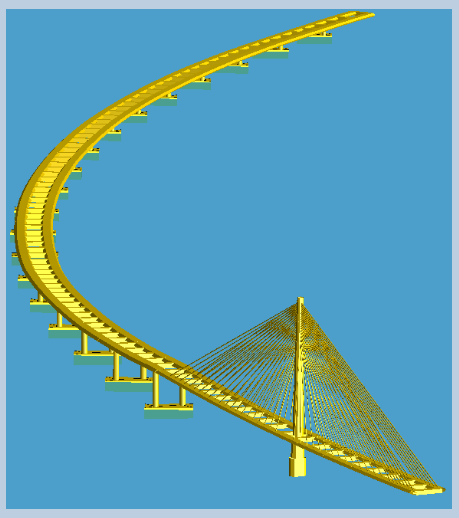
As a part of the National Transport Plan, the Norwegian Public Road Administration (NPRA) have ambitions of a continuous coastal highway between Kristiansand and Trondheim within 20 years [1]. This goal includes building fixed links to cross many of the fjords along the coast. Due to the large width and depth of these crossings, conventional bridge designs are not adequate and thus new concepts are needed. Bridges at these locations may also be exposed to harsher environment as well as possible large ship impacts, putting strict requirements to the design.

Objective

The objective is to analysis the global behaviour of one of the proposed bridge designs for the Bjørnafjorden crossing, when exposed to wind and wave loads, in addition to large ship impacts. A global bridge model received from Postdoc Yanyan Sha is used for the analysis.

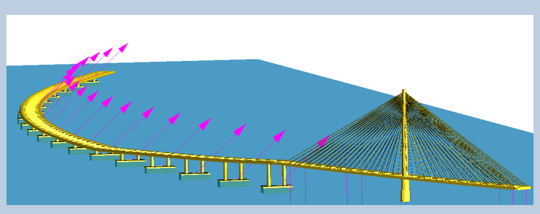
Bridge design

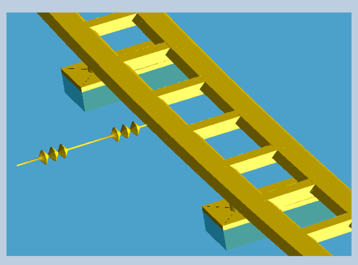
The design consists of a curved bridge girder with a total length of nearly 5 kilometers. This curved shape enables transverse loading to be taken as membrane action in the bridge girder, which consists of two parallel box girder supported by a floating and cable stayed section. The design is illustrated in the figure below.



Method of analysis

Linear and slowly-varying wave loads are established using first and second order transfer functions of the pontoons respectively. These are applied to the global bridge model as time varying loads, illustrated by the arrows in the leftmost figure below. 90 one-hour simulations are used to calculate the characteristic response for the worst wave condition, using the contour method. The effect of wind is studied in separate analysis including wind and waves, and compared against pure wave response.





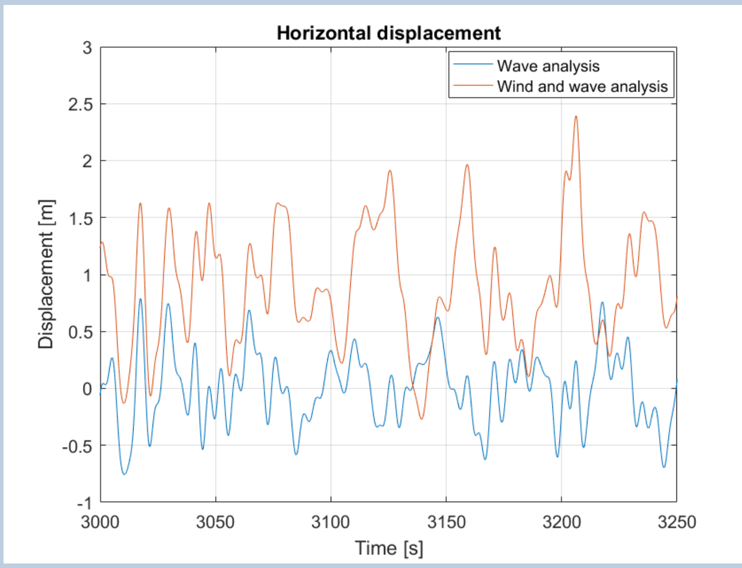
Ship impacts have been simulated by use of a spring element with assigned vessel strength properties illustrated in the rightmost figure above. The bridge behaviour have been examined for different collision locations and speed.

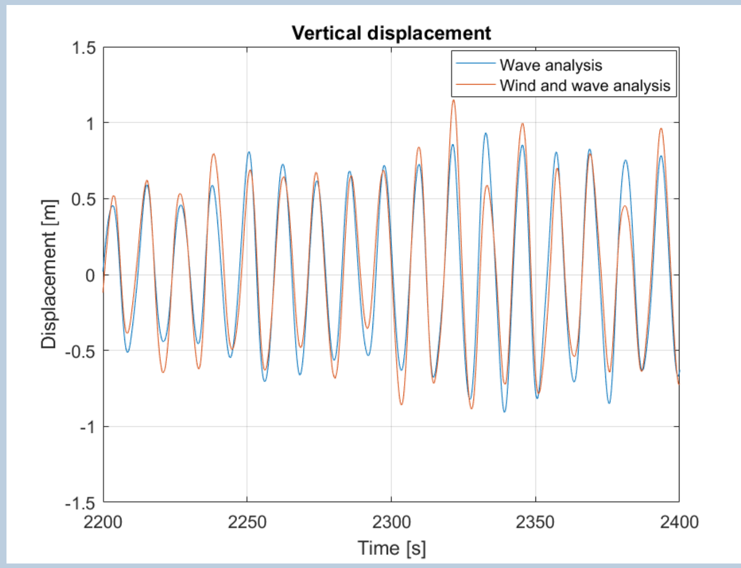
Results, Environmental loads

Waves with a heading of 45°relative to the pontoons have been used to establish the characteristic wave response. These loads induce large moments at the intersection between the bridge girder and columns, where the columns connects the pontoons to the bridge girder. The largest characteristic values of these moments is presented below, which alone gives stresses of 454.61 [MPa] and 621 [MPa] for the bridge girder and column, respectively. As the design resistance is 400 [MPa] the characteristic values implies a too low capacity against bending moment at both locations.

	Maximum value **Minimum value**	**Unit**
Weak axis moment, bridge girder	1656.11 -1594.59	[MNm]
Bending moment, column	1683.97 -1583.55	[MNm]

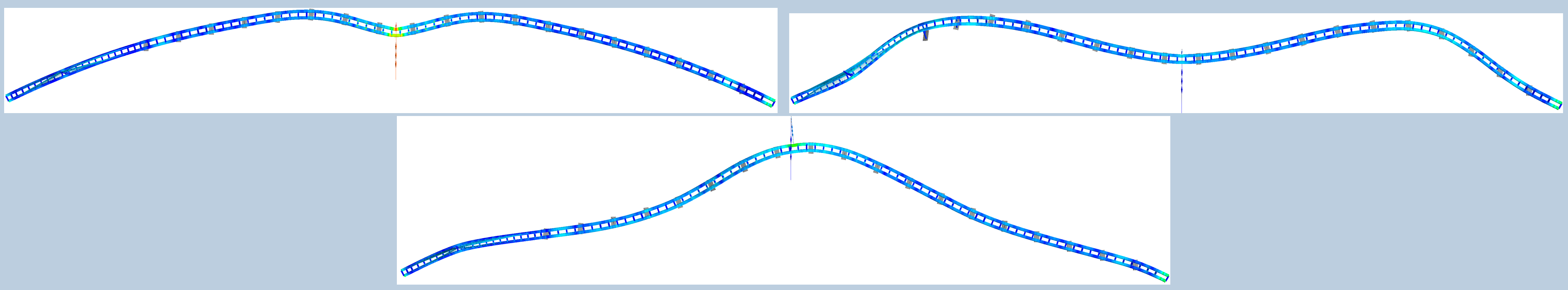
The relative importance of wind and waves have been studied assuming both having the same direction. This showed that the vertical motions are predominated by waves, while wind gives a large contribution to the horizontal motions transverse to the bridge girder. These findings are illustrated in the figures below, where the transverse bridge girder displacement is presented to the left and vertical motion to the right. Both are measured at the middle of the bridge. The differences in motion is also reflected in the induced bridge girder loads, where wind mainly gives contribution to bending in the horizontal plane.





Results, ship impact

Figures below illustrates the global transverse motions of the bridge girder for the first 32 seconds after ship impact at the middle of the bridge. The bridge is viewed from above and the upper leftmost, upper rightmost and lower middle figures are 3.33, 10.17 and 31.99 seconds after the initial contact, respectively. The initial impact takes 4.28 seconds and during this stage collision load is supported locally which turns into global oscillations as times evolves. The first shock wave reaches the tower and rightmost support after 10 and 11 seconds. At 32 seconds the bridge has pushed away the ship and starts the free oscillations.



The effect of using different ship impact speed is illustrated in the table below for transverse displacement and acceleration at the middle of the bridge. Initial energy of 1500 [MJ], 1000 [MJ] and 300 [MJ] corresponds to speeds of 9.28, 7.58 and 4.15 [m/s], respectively.

	1500 [MJ]	**1000 [MJ]**	**300 [MJ]**	**Unit**
Horizontal displacement	10.56	8.52	4.54	[m]
Horizontal acceleration	2.79	1.90	1.01	[m/s^2]

Conclusion

Based on the results the bridge needs to be strengthened against bending moments induced by wave loads. It is also seen that wind loads gives more transverse displacement than induced bridge girder loads, compared with waves. With respect to collision; the bridge appears to have large capacity for bridge girder impact at the middle part. Further conclusions will be made the next two weeks.

References

[1] Statens vegvesen (2016): *The E39 Coastal Highway Route*