Modeling and Analysis of Floating Bridge Concepts Exposed to Environmental Loads and Ship Impact

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I. Introduction

The need for increasing quality of infrastructure in Norway meets challenges when developing solutions to cross the wide and deep fjords along the Norwegian coastline. The Norwegian Public Road Administration (NPRA) is behind an ongoing project, "The Ferry Free Coastal Highway E39" where by replace eight ferry crossings with floating bridges and submerged tunnels, todays travel time between Kristiansand and Trondheim will be reduced by 50 percent. The project has faced major economic and technological challenges related to the solutions when advanced offshore technology and existing bridge solutions has been combined to establish solutions that satisfy the design criteria. This has lead to an increase in product cost from 150 to 340 billion NOK. The future project progress will be dependent on economic limitations and development of future solutions.

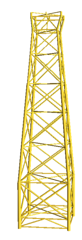
II. Thesis Description

This Thesis carries out a concept study of a floating bridge concept for crossing the Norwegian Halsafjord. The Thesis is carried out for the NPRA with the long term goal of reduced response at lower costs than presented for the Ferry Free Coastal Highway E39 up until today. The planned distance reaches 2.1 km from Halsneset to Urdneset. Inspiration is taken from the proposed curved bridge for crossing the 4 km long Bjørnafjord. Two concepts are compared, where the curved bridge girder is supported by offshore jackets, cable stay bridges and floating pontoons combined as follows:

Concept 1: Curved bridge supported by one steel jacket placed 400 m from the east abudment at 139 m water depth, the span given additional support from cable stays. The remaining bridge girder is supported by 10 floating pontoons.

Concept 2: Curved bridge supported by two steel jackets, each placed 400 m from the east and west abudment. The bridge girder between the jackets is supported by six floating pontoons.

The concepts are modeled in the finite element software ANSYS Mechanical APDL 18.2. Prop- erties of the jacket are obtained from analysis using the USFOS software and implemented in the ANSYS model. Response for both concepts during environmental loading conditions including wind, current and tidal variation is measured in a static analysis. Eigenvalues are extracted and coincidence with relevant wave periods in the area are checket. A regular wave analysis is performed on the floating bridge supported by two jackets for charachteristic waves in the relevant area. A ship collision scenario is modeled in USFOS to measure the jackets response when exposed a collision of 209 MJ.



III. Analysis Approach

ANSYS Mechanical APDL: The analysis is approached by establishing necessary parameters, elements, materials, constant sets and cross sections in the preprocessor. The geometric modeling is based on a bottom-up approach, where lines are established between keypoints, areas between lines etc. The geometric segments are assigned their belonging properties, depending on element type. The girder is divided into floating and strengthened sections as shown in the figure below. When properties and geometry is established, the meshing may be performed such that the model is divided into a finite number of elements. In closing, relevant boundary conditions restraining nodes and external forces are applied.

USFOS: An USFOS model of the Kvitebjørn jacket is provided. The model is modified to fit length requirements regarding water depth and stripped for mass elements representing drilling equipment. USFOS is further used to obtain structural parameters such as effective mass contribution and the horisontal stiffness contribution that was modeled in ANSYS. The ship collision scenario is modeled using USFOS. The static impact is considered with a constant velocity. This analysis method gives a result without using significant computational time. All dynamic effects are however disregarded. In the dynamic analysis, the mass is given an initial velocity and force/deformation curves are applied.

Static and Regular Wave Analysis: Static response is measured for the following seven load cases: Self weight, traffic load, Wind (1 year return), wind and current (1 year return), Wind and current (100 year return), high tide and low tide.The response from the static ANSYS analysis is measured in terms of global displacement, rotations, bending moments and Von Mises stress. For the regular wave analysis, accelerations are also measured. The regular waves applied to the model are of combitations of Hs and Tp in the figure below.

	Direction	Parameter	1 year	100 year	10 000 year
Locally Wind Generated Sea	270	Hs [s]	1.2	1.8	2.1
Locally Wind Generated Sea	270	Tp [s]	≤ 5	≤ 6	≤ 7
Locally Wind Generated Sea	225/315	Hs [s]	0.8	1.2	1.4
Locally Wind Generated Sea	225/315	Tp [s]	≤ 5	≤ 6	≤ 7
Locally Wind Generated Sea	0/180	Hs [s]	0.4	0.6	0.7
Locally Wind Generated Sea	0/180	Tp [s]	≤ 5	≤ 6	≤ 7
Swell	250-290	Hs [s]	0.3	0.45	0.53
Swell	250-290	Tp [s]	6-18	6-18	6-18

The model shall aim for satisfying the response parameters in the figure below (excluding ship collision response)

Motion	Load	Criterion
Vertical Deflection Due to Traffic	0.7xTraffic	1 [m]
Rotation about bridge axis (Roll) due to traffic loads	0.7xTraffic	1 [deg]
Rotation about bridge axis (Roll) due to environmental loads	1 year storm	1.5 [deg]
Vertical Acceleration	1 year storm	0.5 [m/s^2]
Horizontal Acceleration	1 year storm	0.5 [m/s^2]

Modal Analysis: The modal analysis will indicate which wave frequencies that possibly could coincide with the natural modes of the system, causing resonance. No external loads are applied. In the modal analysis, the 30 first eigenfrequencies are extracted to examine possible coincidence with wave periods.

Ship Collision: A static and dynamic ship collision scenario is modeled in USFOS to measure the jackets response when exposed a collision of 209 MJ.

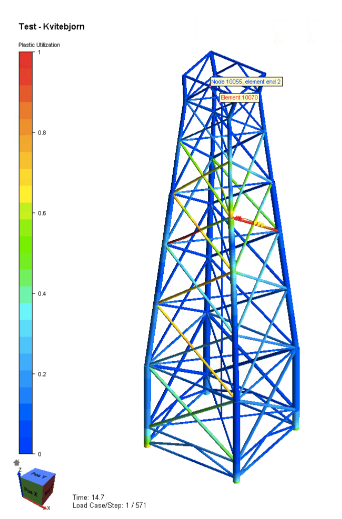
IV. Results and Discussion

Response from the static analysis satisfies response criteria except during tidal change. The results from the tidal change load cases need attention. The exceeding of the criteria will require that the modeling approach is changed and redesign of the bridge. E.g, the pontoon and column supporting the inclined section should be remodeled such that this span section is prevented from such large displacements. However, it is preferable that during rise and decrease of mean sea level the bridge should partially follow the water level such that the ends are relieving the large moments that are absorbed if the bridge restraints this motion.

The swell generated waves with 1, 100 and 10 000 year return period bound of the highest period, and overlap mode 3-6 for both concepts. This indicates change of resonance. Mode 7-9 should be evaluated as vertical mode shapes are in this range. For swell generated waves, the lower mode shapes are outside the wave period range which gives lower change of resonance. For the locally wind generated sea with return period of 1 and 100 years, independent of direction, eigenperiod 7-30 coincides and there is change for resonance. For locally wind generated sea with return period of 10 000 years, mode 6-30 coincides. The most critical sea state is the locally wind generated sea with direction 270 deg with its significant wave height of 2.1 metres and peak period of 7 seconds or less.

All located maximum accelerations are within the criteria, which is as expected due to the low wave height on the forces acting on the bridge. The larges accelerations occur in the vertical direction for wave period 7.

For the ship collision analysis, jacket response in terms of displacement is governed by transverse displacement (in the x-direction) when struck by the vessel. Diagonal members are exposed to large compressive forces that causes buckling as can be seen in the figure below. Examining the plastic utilization of the jacket throughout the analysis it is seen that the plastic utilization reaches 1 for the three diagonal members pointed out with arrows in figure **??**. These are the members connected to, and adjacent of the struck node point. The structure suffers critical damage.



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