Initial Design and Study of the *X-Bridge*

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Problem Introduction

One of the main challenges with the project *Ferry-free coastal route E39* is the high costs tied to the wide and deep fjord crossings along the western coast of Norway. The estimated cost for the entire project increased from 150 to 340 billion NOK in just three years [1].

Rune Risnes in Risnes Innovation AS has come up with a new bridge design utilizing proven technology in combination with avoiding large cost drivers as subsea operations, heavy lifting operations and bridge towers in order to reduce the cost. The concept has been given the name *X-Bridge* due to its shape.

Objectives

- Come up with main dimensions for bridge girders, towers and pontoon sizes
- Hydrodynamic analysis of pontoons
- Establish a coupled SIMO/RIFLEX model using SIMA
- Investigate static and dynamic response

Main Dimensions

Main Dimensions Bridge	[m]
Crossing Distance	4000
Radius	6000
Navigation channel height	40
Navigation channel width	400
Segement length	183.9
Free clearance low bridge	10

Pontoon		Large	Medium	Small
L	[m]	68.00	60.82	48.08
B	[m]	28.00	25.04	19.80
R	[m]	14.00	12.52	9.90
H	[m]	14.50	13.12	12.85
D	[m]	9.78	9.10	8.84
A_{WP}	[m^2]	1735.75	1388.60	867.88
∇	[m^3]	16967.63	12641.50	7669.11
M	[kg]	1.14×10^7	9.19×10^6	5.77×10^6

References

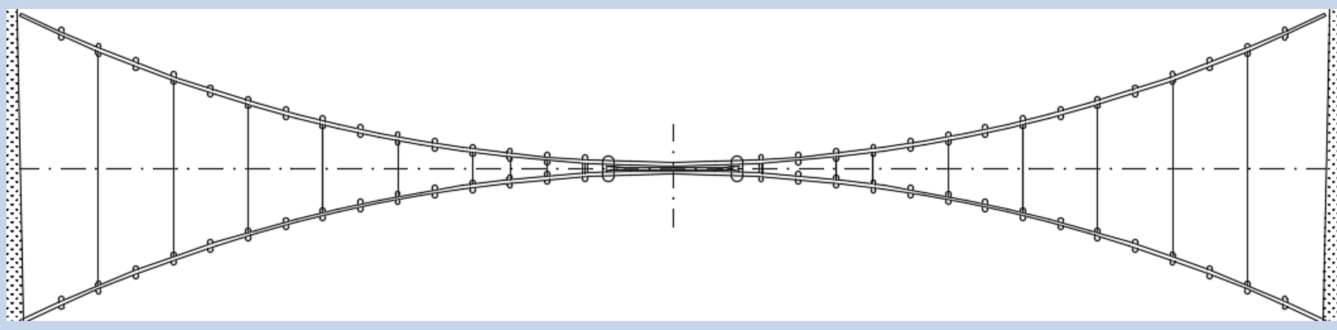
[1] Sølve Rydland, Fayruz Sado: - *Budget deficit on roads are a big democratic issue*, NRK (2016)

[2] Eiichi Watanabe and Tomoaki Utsunomiya: *Analysis and design of floating bridges*, Progress in Structural Engineering and Materials, (2003)

[3] Ivar Langen and Ragnar Sigbjørnsson: *Dynamic analysis of structures*, (1979)

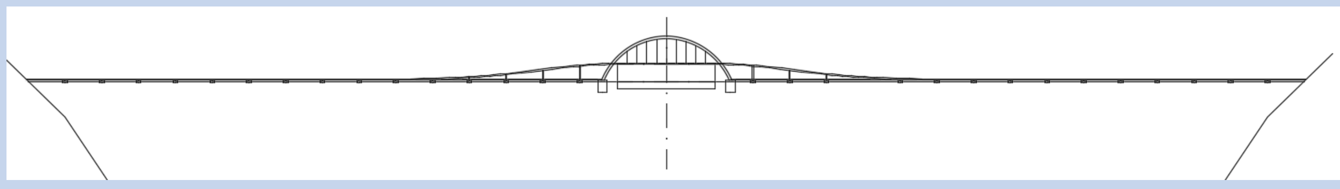
Concept Idea and Layout

The *X-bridge* concept consists of two bridge girders in an X-shape. A curved bridge will carry lateral loads as tension or compression depending on the direction of load. This eliminate the need for lateral support by mooring lines and is advantageous at crossings where the seabed is either deep, soft or a combination of both as this makes anchoring complicated. The principle is explained by [2]: *when the current is coming from the convex side, the bridge shape acts as an arch rib giving a much higher stiffness in the horizontal plane compared to a straight beam. In the other case, the bridge acts as a catenary cable.*



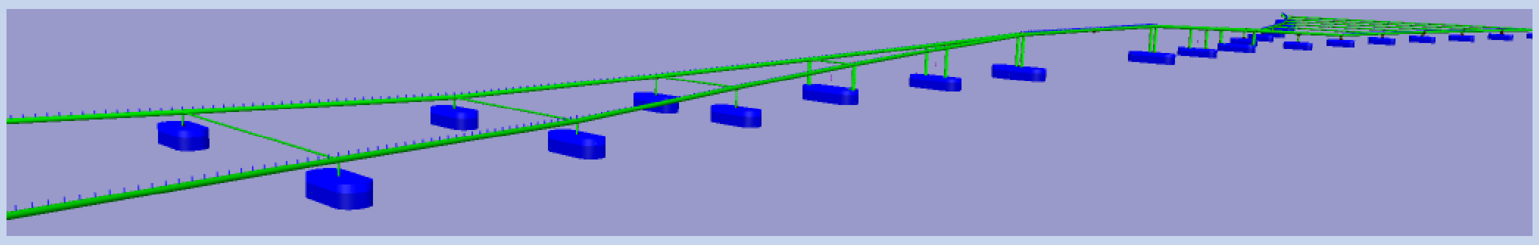
A problem with the arch design is that when the loading comes from the convex side, it creates compression forces in the arch. With high loads this could lead to buckling of the arch. Other concepts have solved this problem by adding mooring lines on the convex side. Instead of arch compression, forces will be transferred as tension to the mooring lines. But, the X-bridge concepts is avoiding mooring lines to reduce costs.

In order to reduce the compressive forces in the arch experiencing loading from its convex side, the idea is to transfer these forces to the other arch which will carry these as tension forces. To achieve this, the arches are connected along the whole span with cables.



Model

The bridge is modelled as a coupled SIMO/RIFLEX model in SIMA. The superstructure consists of slender RIFLEX elements and the pontoons are modelled as SIMO bodies. Hydrodynamic properties for the pontoons are obtained using Wadam in HydroD. The results from Wadam includes *First order Wave Force Transfer Function*, *Linear Damping* and *Radiation Data* as added mass and retardation functions.



Results

The first mode shape of the bridge structure is shown on the figure on the right. It shows that the first mode shape is in the horizontal plane and consists of three half waves. The first 8 modes are dominated by horizontal motions. These modes have eigenperiods ranging from 77.52 s to 13.64 s. The first mode shape dominated by vertical motion is mode 9 with an eigenperiod of 11.89 s. Solving the eigenvalue problem does not give any information about the magnitude of the vibrations. It only gives information about the shape of the vibrations [3].

The next figure shows the static bending moment of the bridge girder. As it shows, the bending moment is extremely large for the long span over the navigation channel.

The last figure shows the dynamic bending moment for two of the bridge girders at the low bridge. It shows that the static bending moment about the horizontal axis is dominant. Calculations also shows that the system has a linear response, meaning that increasing the wave height by a factor, the response will increase with the same factor.