# Structural analysis and modelling of a reinforced concrete bridge based on full scale data

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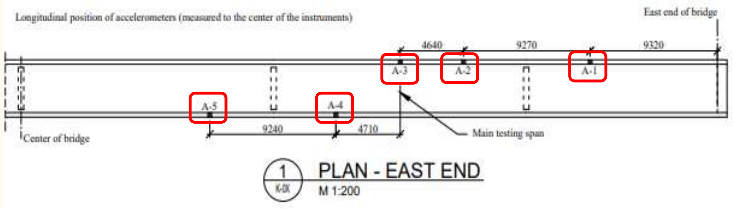
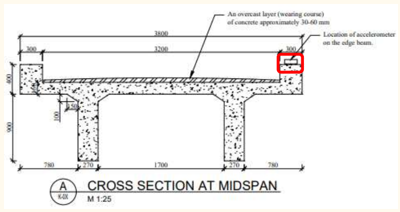
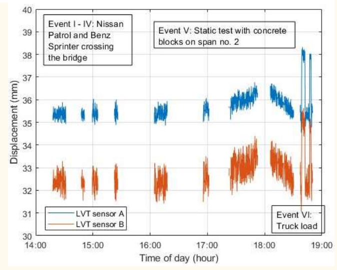
Rannsóknasjóður Vegagerðarinnar

## Introduction

- The focus of this study was the old bridge over Steinavötn, a single lane, 102m long, reinforced-concrete beam bridge built in 1964.
- The purpose of the project was to study the structural characteristics and dynamic behaviour of the bridge.
- Finite element-based modelling of the bridge structure and operational modal analysis of ambient acceleration data recorded on the bridge, comprise the core of this study.
- The objective is to improve the understanding of the bridge properties to be able to better simulate the behaviour of concrete bridges and provide reliable estimates of response to various loading processes.

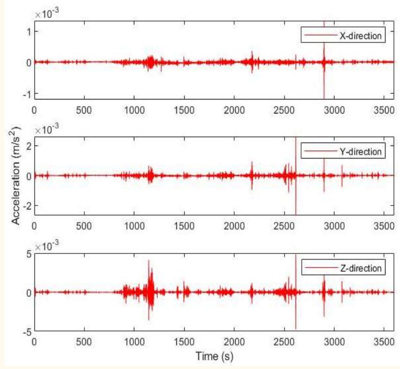


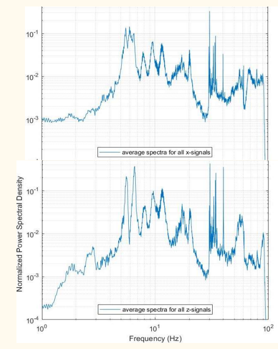




## Measurements – July 2019

- Five 3-axial accelerometers were installed on the side beams of the bridge deck.
- They were systematically distributed around the center of 2nd span from east, which was the main testing span.
- Two LVDT sensors were installed underneath the deck girder at the center of the 2nd span from east, to measure the displacement of the span during static tests.
- The loading consisted of various vehicles driving onto and off the bridge and concrete blocks that were placed at the middle of the testing span.
- The acceleration was measured continuously for 6 hr from 13 to 19 at 200 Hz on all 15 channels.
- To get an idea of the frequency content of the recorded accelerations, power spectral density plots were made for each time series.
- Clear frequency peaks are particularly visible in the vertical signal, where 5 relevant modes can be identified (5.6 Hz, 6.6 Hz, 8.0 Hz, 9.6 Hz and 11.4 Hz).



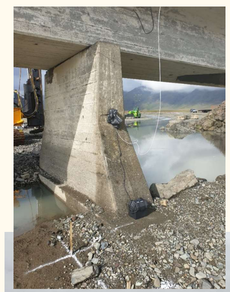

*Time series example from accelerometer #3 in July 2019, showing spiky ambient excitation due to some undefined action on the bridge.*

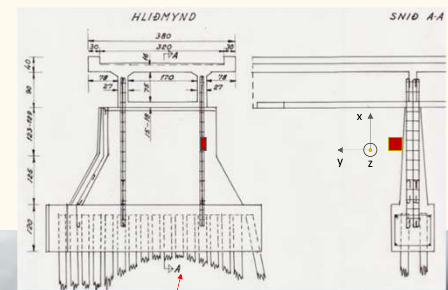


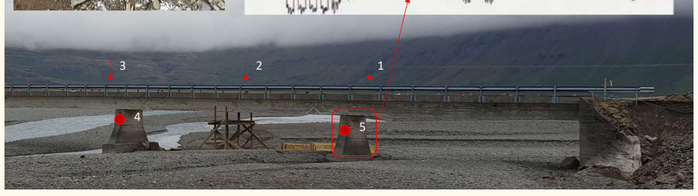

*July - PSD plots, normalized with respect to the variance, showing the average for all recorded signals for each direction, as a function of frequency (in a log-log scale).*

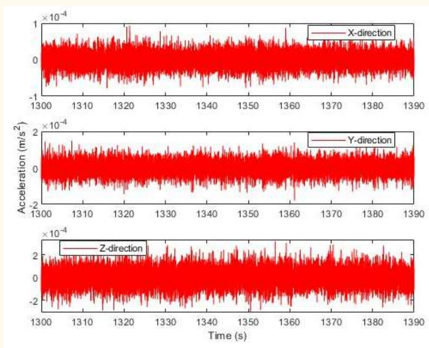
## Measurements – August 2019

- In August, five accelerometers were installed, three of them were installed on either side of the the 2nd span from east, using the same deck locations as in July, but two of them were now placed on the pillars adjacent to the 2nd span.
- The idea was to record both the motion transferred into the deck via the pillars and the response motion of the deck. As the objective was to identify the deck response from the pile driving excitation right next to the bridge.
- Acceleration was measured continuously on all 15 channels for a period of about 24 hours, providing nighttime ambient excitation and daytime excitation from the pile driving operation.
- Additionally, a seismometer was placed on the sand to record the ambient vibrations in the sand overnight. Those measurement helped to estimate the frequency response of the sand, which could be used to estimate the thickness of the sandy gravel layer around the bridge.

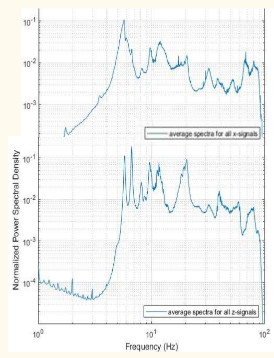






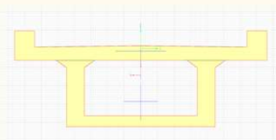

*Time series recorded during the night in August 2019, showing a 90 sec segment of very stable low amplitude ambient noise.*

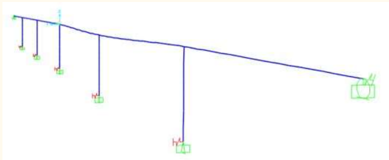


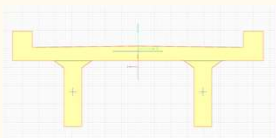

*August - PSD plots, normalized with respect to the variance, showing the average for all recorded signals for each direction, as a function of frequency.*

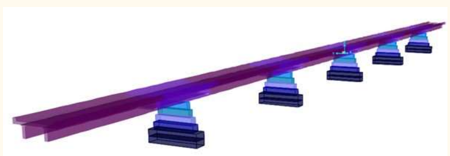
## FEM – Beam elements

- The bridge has a closed box section around the pillars, and an open double T-section in between.
- The deck cross sections were modelled in the section designer in SAP2000 to evalute the relevant geometric properties
- The pillars supporting the deck were modelled as five blocks, varying in size, one on top of the other, approximating the true dimension.
- The average length of each deck element is about 67 cm, giving a total of 193 beam elements and 1125 DOF.
- The displacement and rotations of the pillar were fixed at the boundary, except the rotation about an axis perpendicular to the deck.
- Displacements at the ends were restricted and longitudinal spring stiffness was introduced at the end supports to allow longitudinal movement that fitted the frequency of the first mode.



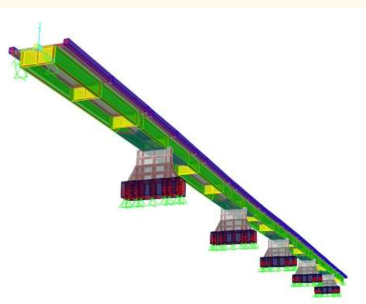


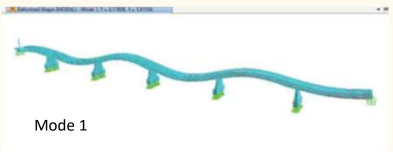


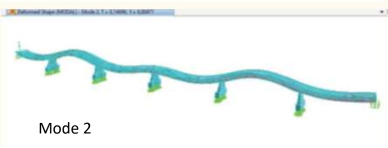


## FEM – Shell elements

- The Shell model shown, consists of 4280 shell elements and has 27678 DOF.
- After a convergence study, it was decided to use a mesh size of 50 cm, to insure a good flexibility and reliable estimation of natural frequencies.
- Essentially the same BC'c were used for the shell model as the Beam model, although the Shell model required higher axial stiffness at the end supports.
- The shell element model provides a true three-dimensional geometric view of the modes of vibration for the bridge, allowing a more realistic view of any torsional effects than the beam model is capable of.

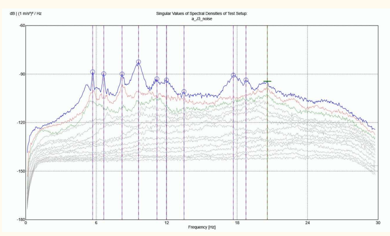


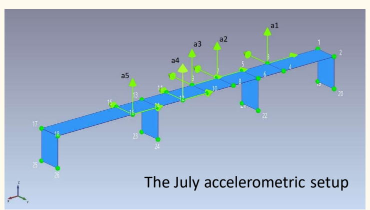


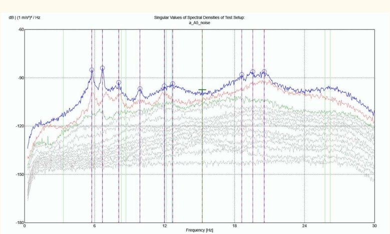



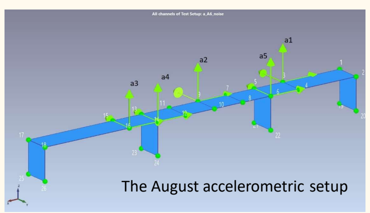

## Operational Modal Analysis (OMA)

- Three data sets of ambient excitation were selected for analysis:
  - 30 min segement from July
  - 10 min segment from August
  - 1 hour segment from August
- The tools used:
  - A FDD Matlab toolbox from Rune Brincker at DTU &
  - ARTeMiS – Frequency Domain Decomopsiton (FDD) & Enhanced FDD (EFFD)
- The ARTeMIS approach:
  - Geometry driven, requires a simple model of the structure, measurement channels are tied to geometrical nodes for animation of modes.
  - Based on peak picking modes from a plot of singular value decomposition of the spectral densities of spectral response.
  - The EFDD method gives both frequency and damping of the picked mode.
  - Variability in the identification, depends on the characteristics of the data and the peak picking choices made by the user.
- The FDD matlab toolbox is gives the possibility to validate further the natural frequencies and damping ratios of selected modes.
  - Based on defined modal frequencies and bandwith of spectral peaks.








## Conclusions

- OMA gives reliable results for the first 4 modes
- The higher modes (above ~12 Hz) are difficult to identify from the ambient data, additional sensors might have improved the accuracy of the analysis.
- The critical damping ratio varies between 1% to 1,5% for the first 5 modes.
- Differences are observed between the ambient data sets in July and August, this is likely related to:
  - Time of day of measurement (night vs. day)
  - Different water level in the river and the sand
- Beam and Shell element models give a good fit to the OMA results for the first 4 modes
  - Vertical modes are controlled by rotation of the deck at the pillars and vertical displacements of the deck
  - Mode 1 is influenced by a longitudinal motion
  - Different behaviour is observed between the models for the higher modes, demonstrating the influence of a true 3D modelling with shell elements.
- The static loads applied on the bridge span were all minimal compared to the capacity of the bridge. The maximum displacement measured was ~2.5mm when a 16-tonne truck stopped at the center of the span measured.

Table 5.1: Comparison of modes of vibration identified by OMA and FEA.

| Finite Element Analysis | | | | ARTeMIS OMA | | MATLAB OMA | |
|---|---|---|---|---|---|---|---|
| Mode no. | | BEAM | SHELL | FDD & EFFD | | FDD/ITD | |
| Beam | Shell | f (Hz) | f (Hz) | f (Hz) | ζ (%) | f (Hz) | ζ (%) |
| 1 | 1 | 5.72 | 5.62 | 5.73 | 0.94 | 5.68 | 1.40 |
| 2 | 2 | 6.91 | 6.80 | 6.67 | 1.09 | 6.68 | 0.90 |
| 3 | 3 | 7.96 | 7.97 | 8.13 | 0.82 | 8.07 | 1.46 |
| 4 | 4 | 9.50 | 9.59 | 9.73 | 1.29 | 9.74 | 1.37 |
| - | 5 | - | 10.06 | 10.12 | 0.34 | - | - |
| 5 | - | 11.27 | - | 11.16 | 1.54 | 11.09 | 1.27 |
| - | - | - | - | 11.96 | 1.57 | 12.17 | 1.27 |
| 6 | 6 | 12.39 | 12.43 | 12.42 | 1.17 | 12.26 | 2.69 |
| 7 | - | 13.08 | - | - | - | | |
| 8 | 7 | 13.29 | 13.44 | 13.41 | 0.46 | | |
| 9 | - | 13.66 | - | - | - | | |

Vegagerðin

29. október 2021

**20. Rannsóknaráðstefna Vegagerðarinnar**