
INVESTIGATION OF AMBIENT NOISE SEISMOLOGICAL METHODS ON A BRIDGE MODEL

vEGU21 session SM3.1

Ambient seismic noise seismology: Topics, targets, tools & techniques

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Introduction:

This research is part of the GIOTTO project, in which we focus on the real time monitoring of building structures and aim to improve the damage detection methods in civil engineering.



The seismological noise-based monitoring is considered in civil engineering (Bernauer et al., 2021).



We investigated ambient noise seismological methods on a prestressed bridge model and presented the successful field application of coda wave interferometry in the low frequency range.

Main core of this research:

We monitored a pre-damaged concrete bridge model under different prestressed condition.

We applied the seismic interferometry method to reconstruct the virtual wavefield in the structure, and investigated the waveform by comparing it in different prestressed states. Coda wave interferometry was used to study the effect of the prestressing force change on the wave propagation velocity.

Test Structure - BLEIB Bridge

- 2-span concrete beam model
- with build-in unbonded post-tensioning system
- at BAM test site 50 km south of Berlin.
- has been damaged due to previous tests (Unger et. al., 2017; Wang et al., 2018)



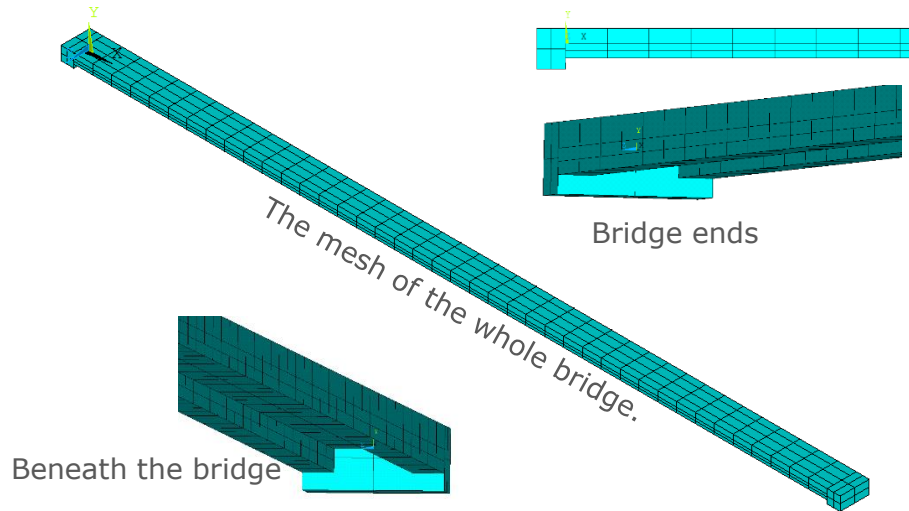
Length: 24 m, 2 spans (12m,12m), Width: 0.9 m

Simulation of BLEIB Bridge

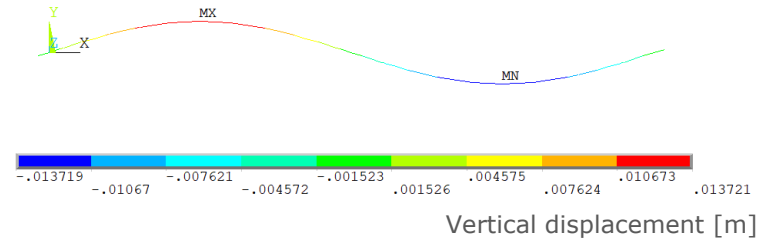
Using numerical models, we can obtain the modal frequencies of the bridge in its **intact state**.

On the left shows the finite element model of the bridge simulated by ANSYS software.

On the right is the numerical modal analysis result. Only the first mode shape is shown, which reveals the wavelength corresponding to the **natural frequency 3.9Hz**.



The deformation of the first mode.
The modal frequency is 3.9 Hz.

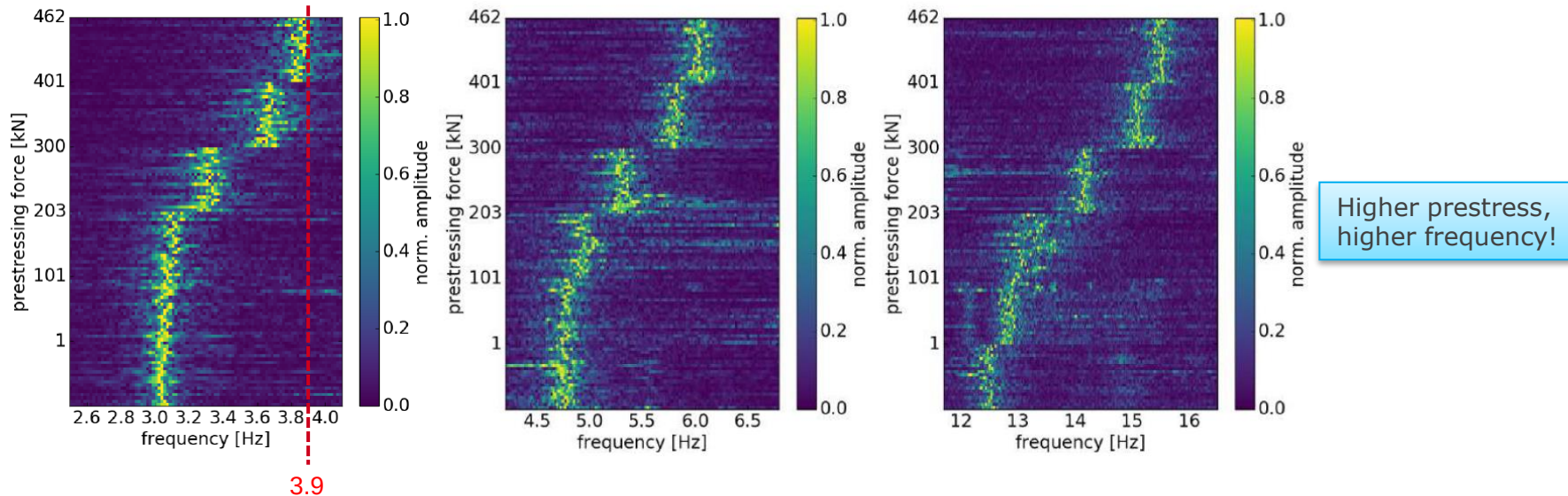


Experimental natural frequencies

The experimental natural frequencies of the bridge have been extracted from the vibration measurement data (Franziska Mehrkens, 2020).

The first 3 modal frequencies are revealed in the vicinity 3 Hz, 5 Hz and 15 Hz.

We show the 3 natural frequency trends following the prestressing force decrease (462 kN to 0 kN).

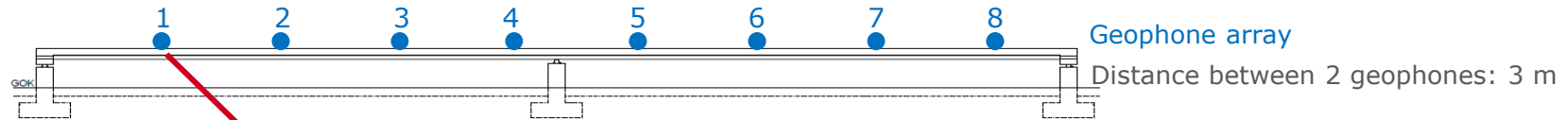


The initial natural frequency (under the very high prestress condition) approximates 3.9 Hz. It is the same as the numerical result of the intact bridge.

Ambient seismic noise measurements

In our research, coda wave interferometry is used to evaluate the passive source recordings. Our goal is to improve local damage detection, which cannot be fulfilled by monitoring the global dynamic properties (i.e. modal frequencies).

Different prestress levels are considered to generate various damaged condition.



Prestressing force

Level 1: 550 kN

Level 2: 450 kN

Level 3: 400 kN

Level 4: 350 kN

Level 5: 300 kN

Level 6: 250 kN

Level 7: 200 kN

Level 8: 350 kN

Level 9: 450 kN

decrease

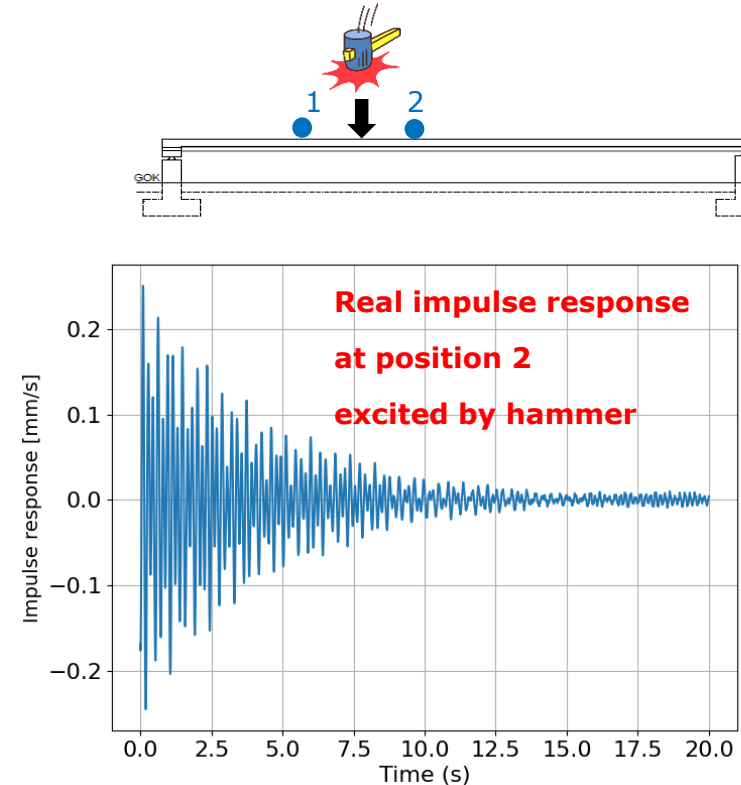
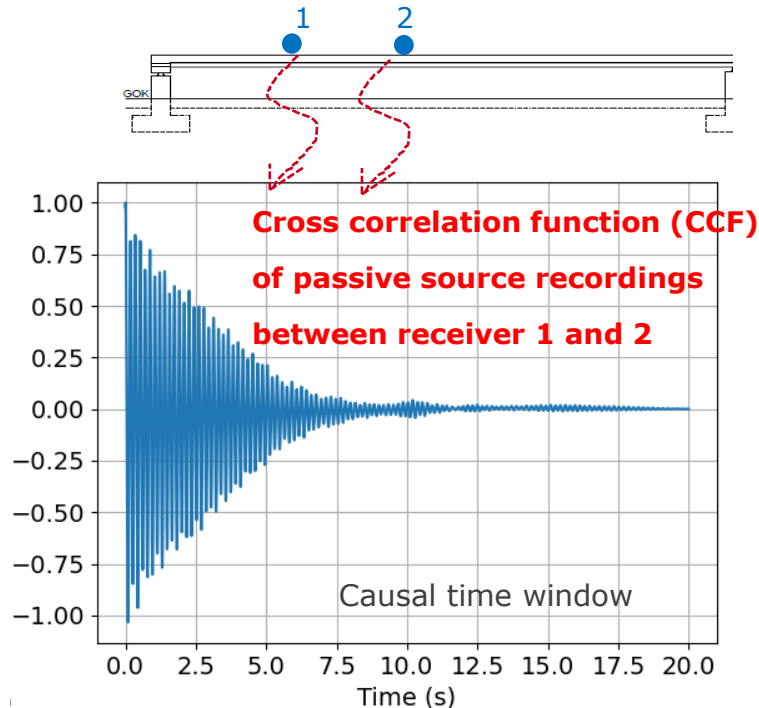
increase

Natural damage has developed due to prestress loss and weakening stiffness caused by opening or event extension of cracks.

Strength has been recovered by rising prestress and closed cracks.

Methods for wave velocity analysis

- **Seismic interferometry method** (Hadziioannou et al., 2015).



Methods for wave velocity analysis

- CCFs are investigated by coda wave interferometry.
- Relative seismic velocity changes can be identified by using the stretching method.

The stretching method:

The prestress has a homogeneous effect on the wave propagation velocity, which has the linear relation to relative time lag:

$$\frac{\delta v}{v} = -\frac{\delta t}{t}.$$

Define the stretch factor:

$$\alpha = \frac{\delta v}{v},$$

the stretched waveform is presented

$$u_s = u_o(t(1 + \alpha)),$$

the cross-correlation coefficients of the waveform in two states:

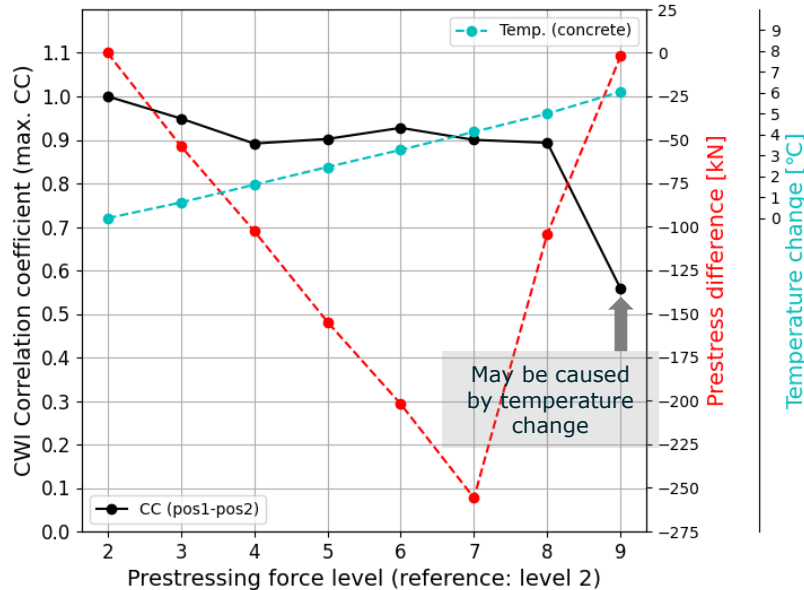
$$CC(\alpha) = \frac{\int_{t-T}^{t+T} u_o(t')u_s(t')dt'}{\sqrt{\int_{t-T}^{t+T} u_o^2(t')dt' \int_{t-T}^{t+T} u_s^2(t')dt'}}$$

- Relative seismic velocity change is determined by the max. correlation coefficient.

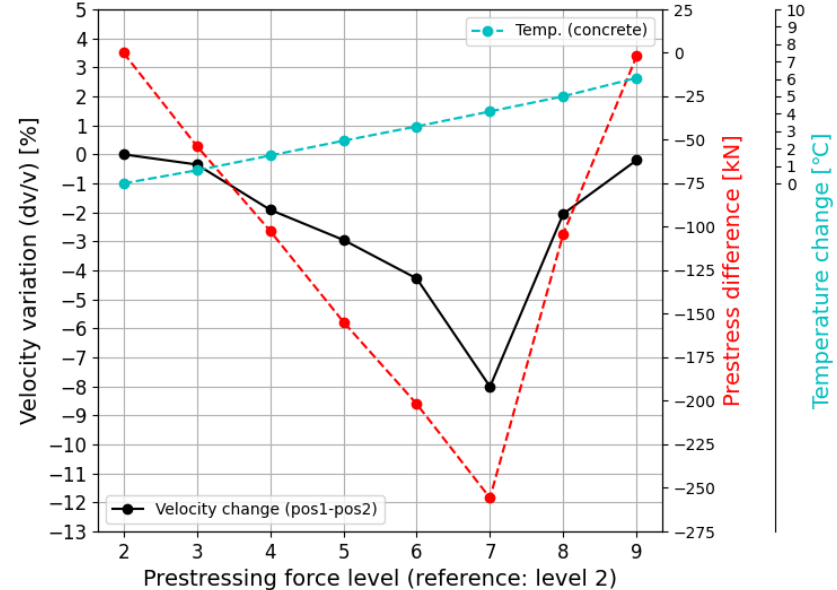
Application of CWI to CCF

The CCF at level 2 was considered as the reference comparing with the other CCFs at the other prestress levels. Any relative seismic velocity changes are identified by determining the max. correlation coefficients and reveal the influence of the prestressing force.

Max. cross-correlation coefficients of the waveform in two states

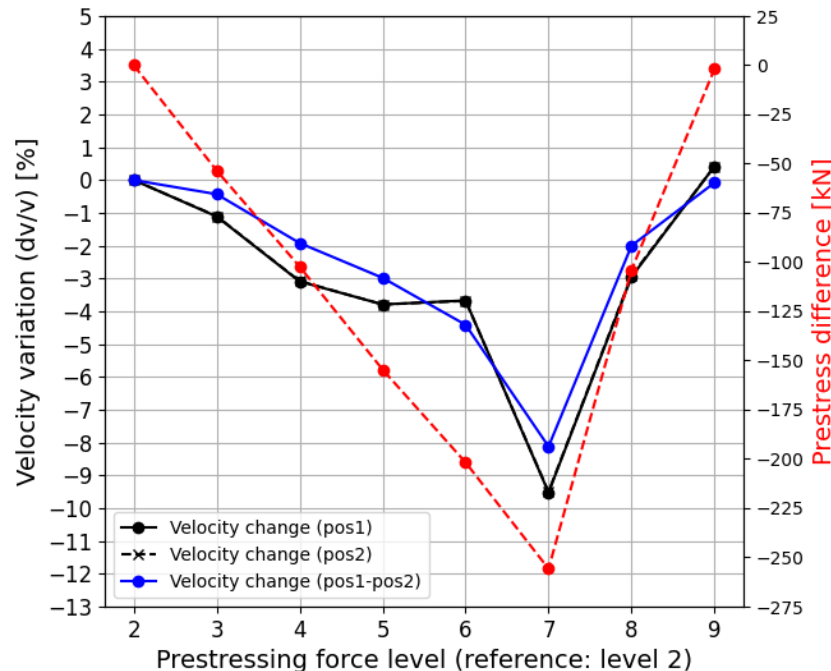


Wave velocity change in the area between receiver 1 and 2



Relative seismic velocity changes

The wave velocity variations in the passive source recordings and in the real impulse response excited by hammer impact are presented in the following figure indicated by the blue line and the black lines, respectively.



- Relative seismic velocity changes reveal the influence of the prestressing force.
- A large drop of wave velocity between level 6 and 7 reveals the effect of prestress loss – cracks opening.
- The wave velocity change in the real impulse response received at pos 1 has no difference from that at pos 2.
- Applying CWI to the passive source recordings is better than to the real impulse response (due to unknown reason causing the sudden rise at level 6).

- Temperature change can also influence the max. correlation coefficient of two CCFs. However, our study reveals that the wave velocity change in the low-frequency recordings is influenced only by the prestress loss and weakening stiffness due to opening or event extension of cracks.
 - The CCF of passive source recordings is comparable to the impulse response excited by hammer impact. Therefore, an active source will not be needed for practical implementation in civil engineering – a significant cost benefit.
 - This field application of the ambient noise seismological methods shows potential of wave velocity analysis for local damage detection.
 - In our experiment, the strength of the bridge was successfully recovered by gaining the prestressing force. It evidences that the bridge model is an idea structure for further tests to develop the local damage indicator for bridges.
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- We tend to explore the CWI method in different scales. Ultrasonic coda has also been recorded and investigated in Liao et. al., 2021. The further study about the sensitivity of CWI in different scales will be our next step.
- The experiment result approves the viewpoint of determine the damage level based on the wave velocity change. The further study will focus on the other factors that have effect on the wave velocity variation.
- Due to the measurement convenience we will apply the same technique to monitor the other types of structures. A reliable damage indicator for large-scale structures should be thereby determined.

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