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Modal damping identification of suspension bridge hanger under different damper configurations

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SUMMARY:
To support improved vortex-induced vibration mitigation strategies for suspension-bridge hangers, a full-scale experimental campaign was conducted on the first hanger of the Hålogaland Bridge, Narvik, Norway. The objective was to quantify modal damping and evaluate its variation under different Stockbridge damper configurations. Impact hammer testing was performed at three excitation heights, with responses measured at three locations along the cable. The identification process was challenged by the presence of closely spaced modes, and very low intrinsic structural damping. In addition, several estimation approaches showed a strong sensitivity to the observation window length, leading to biased damping estimates for the lowest modes. By adopting complementary identification methods, consistent damping values were obtained. The influence of the dampers is clearly observable: damping increases significantly within the frequency range where the devices are dynamically active, while remaining largely unaffected outside this band. The data provide full-scale evidence to support damper placement optimisation for vortex-induced vibration control.

Keywords: Impact hammer, Hanger vibration, Stockbridge, Modal damping, Vortex-induced vibration

1. INTRODUCTION

Reliable estimates of modal damping in bridge hangers are essential for predicting and mitigating vortex-induced vibrations (VIV). However, full-scale damping data for suspension-bridge hangers remain scarce, and available estimates often rely on simplified analytical assumptions. Larsen et al., 2022 approximated the damping of the hangers of the Hålogaland Bridge using the semi-empirical Rawlings model originally developed for overhead power lines (Rawlins, 1983). Earlier, Main, J. and Jones, N., 2001 predicted the modal damping of stay cables by solving a complex eigenvalue problem for a taut string formulation. More recently, Cantero et al., 2018 conducted impact hammer tests on the hangers of the Hardanger Bridge and reported that modal damping ratios increase with decreasing modal frequency. Two major challenges consistently emerge in such investigations. First, suspension-bridge hangers exhibit very closely spaced modes, often with fundamental frequencies below 1 Hz, complicating modal separation and damping identification. Second, aerodynamic damping can contaminate structural damping estimates, making the realisation of long observation windows, required for low-frequency estimations, complicated. In the present study, a full-scale hammer-testing campaign was conducted on a hanger of the Hålogaland Bridge during a day characterised by negligible wind, thereby minimising aerodynamic contributions and enabling a clearer assessment of intrinsic structural damping of the hanger and comparison of the effectiveness of different dampers' condifurations.

2. IMPACT TESTING AND DAMPING IDENTIFICATION

The first hanger of the Hålogaland Bridge was instrumented with three uniaxial accelerometers distributed along its length. The structural properties of the hanger are summarised in

Table 1. Impulse excitation was applied using a 5.5 kg ICP impact hammer at three distinct heights. This configuration provided nine input–output combinations, allowing construction of a 3×3 frequency response function matrix. For each excitation–response pair, the frequency response function was estimated in the frequency domain using the H1 estimator. Modal parameters were subsequently identified using two complementary approaches: the Circle Fit (CF) method and a data-driven stochastic subspace identification (SSI-data) method implemented in the `strid` package. The CF method relies on the near-circular locus traced by a single-degree-of-freedom response in the complex plane around resonance. Under the assumption of local modal dominance, a limited frequency band around each peak is considered. The natural frequency is identified from the location of maximum curvature of the Nyquist arc, while damping is obtained from the angular separation of symmetric points around resonance. In parallel, SSI-data was applied directly to the measured output time histories. The method constructs block Hankel matrices of the response signals and extracts system matrices through singular value decomposition, yielding poles of a state-space model from which natural frequencies and damping ratios are computed. This approach provides a global identification framework and allows cross-validation of the frequency-domain estimates, particularly for closely spaced and low-frequency modes. Since damping is regarded as a structural property, modal estimates obtained from different input–output combinations were combined through a weighted average, yielding a single natural frequency and damping ratio for each mode.

Table 1. Hanger properties.

	L [m]	m [kg/m]	f_0 [Hz]
Hålogaland, hanger 1 (Bacci et al., 2024)	122	30	0.776
Hålogaland, hanger 55 (Larsen et al., 2022)	122	30	0.732
Hardanger, hanger 2 (Cantero et al., 2018)	119	-	-

3. RESULTS AND DISCUSSION

3.1. Modal damping of the bare hanger

Fig. 1 compares the identified modal damping ratios of the bare hanger with values reported in the literature. The properties of the cables analysed in the literature are reported in Table 1. The experimentally estimated damping is generally very low and exhibits a slowly increasing trend with increasing mode number. This behaviour is consistent with the semi-empirical estimates reported by Larsen et al., 2022 for another hanger of this same bridge. The identification of the lowest modes, characterised by very small damping ratios and closely spaced frequencies, proved particularly sensitive to the adopted estimation method. In particular, approaches based on local least-squares fitting of transfer-function peaks showed a tendency to produce damping estimates proportional to $1/(T_m f_i)$, where T_m is the length of the observation window and f_i the modal frequency. This leads to an apparent increase in damping as frequency decreases, which is an artefact of the finite record length rather than a physical property of the structure. When plotted against $1/f_i$, such estimates align along a linear trend, revealing their dependency on the measurement window. As frequency increases or damping becomes larger, this bias is progressively attenuated and the different identification methods tend to converge. This effect may partially explain some decreasing or anomalous damping trends reported in the literature for similar structures (e.g. Cantero et al., 2018), which might therefore not fully reflect the intrinsic structural damping behaviour.

3.2. Effect of damper configuration

Fig. 2 presents the modal damping ratios obtained under different Stockbridge damper configurations. For this comparison, the Circle Fit method provided a clearer and more consistent

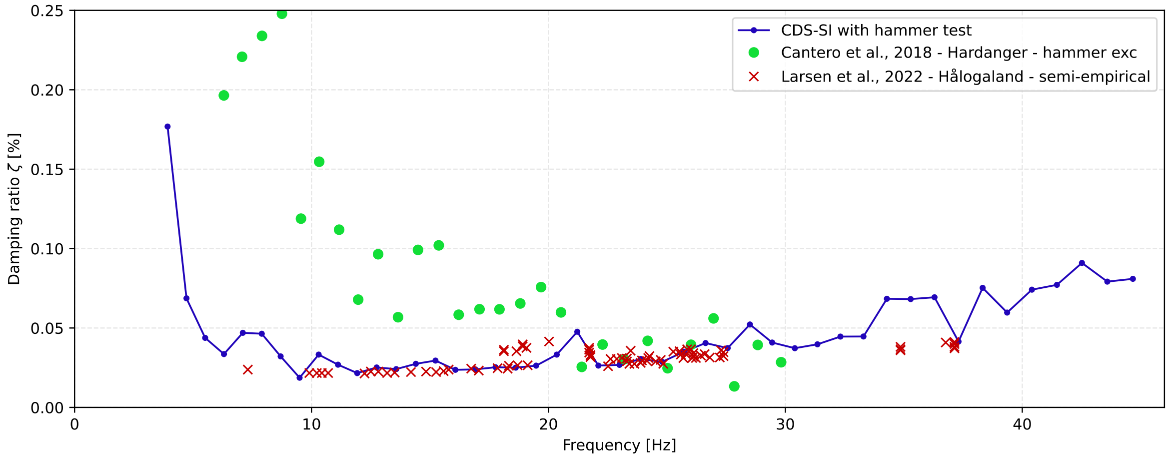

Figure 1. Comparison between the experimentally identified modal damping in the present work and values reported in the literature. The relevant cable properties are provided in Table 1.

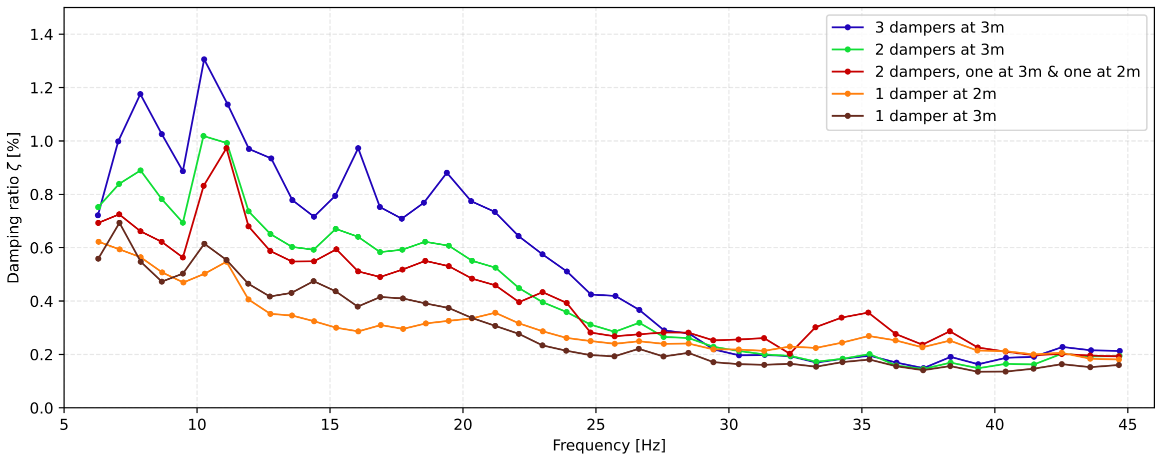

Figure 2. Comparison of modal damping ratios of Hanger 1 of the Hålogaland Bridge for different Stockbridge damper arrangements.

representation of the differences between configurations. The influence of the devices is clearly frequency-dependent. The real part of the impedance function of the Stockbridge damper is dynamically active primarily between approximately 3 and 30 Hz (Bacci et al., 2026). Since the average power dissipated by the device is proportional to the real part of its mechanical impedance, the frequency range where the real component of the impedance is significant directly corresponds to the range where modal damping is expected to increase. This is directly reflected in the measured damping: relative to the bare configuration, a marked increase is observed predominantly within this frequency range, while higher modes remain largely unaffected. The configuration with three dampers provides the highest overall damping increase. A progressive reduction in damping increase is observed as the number of dampers decreases from three to two and one. For the configurations with two and one dampers, the positioning of the device plays a non-negligible role. When one damper is relocated to a lower position along the hanger, damping slightly decreases in the 5–15 Hz range but increases in the 20–40 Hz range. This behaviour is consistent with the spatial dependence of modal curvature: relocating the damper modifies its modal participation, enhancing effectiveness for higher modes while reducing it for lower ones. Overall, the results provide clear full-scale evidence that both the number and spatial arrangement of Stockbridge dampers govern the modal damping distribution along the frequency spectrum, with direct implications for VIV mitigation strategies.

4. CONCLUSIONS

A full-scale experimental campaign was conducted to estimate the modal damping of the first hanger of the Hålogaland Bridge in Narvik, Norway, through impact hammer testing. The primary objective was to provide reliable field data to support improved vortex-induced vibration mitigation strategies and damper placement optimisation for suspension-bridge hangers. Modal identification was performed for multiple Stockbridge damper configurationsusing complementary frequency-domain and stochastic subspace methods, enabling a direct comparison of damping ratios under different arrangements. Particular attention was given to the sensitivity of low-frequency modes to the observation window length, as some estimation approaches were shown to introduce a bias proportional to $1/(T_m f_i)$. By adopting identification procedures less affected by this artefact, consistent damping estimates were obtained. The results confirm that the intrinsic structural damping of the bare hanger is very low and exhibits a slowly increasing trend with frequency, in agreement with trends reported in the literature for similar cable-supported structures. The influence of the dampers is clearly demonstrated by a significant increase in modal damping within the frequency range where the devices are dynamically active. Moreover, the comparison between configurations highlights that both the number and spatial placement of dampers affect the distribution of modal damping across the frequency spectrum. Overall, the study provides full-scale experimental evidence to inform the design and optimisation of vortex-induced vibration control strategies for suspension-bridge hangers.

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