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Field observations of the performance of Stockbridge dampers in suppressing severe hanger vibrations at the Hålogaland Bridge

Ole Øiseth [1], Giacomo Bacci [2], Øyvind Wiig Petersen [3]

[1]NTNU Trondheim, Norway, ole.oiseth@ntnu.no
[2] NTNU Trondheim, Norway, giacomo.bacci@ntnu.no
[3] NTNU Trondheim, Norway, Trondheim, Norway, oyvind.w.petersen@ntnu.no

SUMMARY:
The Hålogaland Bridge is a suspension bridge located in Narvik in northern Norway. Severe hanger vibrations were very often observed during the construction of the bridge. Stockbridge dampers were designed and installed to suppress the vibrations, and the dampers worked very well until many of them were damaged less than one year after the installation. It was decided to install accelerometers to study the hanger vibrations with and without Stockbridge dampers to get new insights into the long-term performance of the dampers. The monitoring data show that the hanger vibrations are severe in the absence of dampers and occur for all wind velocities. The Stockbridge dampers effectively reduce the vibrations, but there are still some vibrations that might result in fatigue damage in the dampers.

Keywords: suspension bridge hangers, vortex-induced vibrations, Stockbridge damper

1. INTRODUCTION

It is well-known that severe vibrations can occur in the cable stays of cable-supported bridges, and this is always taken into consideration during the design process. However, from problems observed worldwide, it seems less well-known that severe vibrations can also occur in the hangers of suspension bridges. Experience shows that as the diameter of hangers increase and the connection between the main cable and the bridge girder is improved (less friction), hanger vibrations become more relevant. This is because the increased diameter of the hanger decreases the frequency of the vortex-shedding-induced wind load, which means that higher modes with less damping can be excited by low wind speeds.

There are many suspension bridges in Norway. The Hardanger Bridge has the longest span of 1310 meters, and the Hålogaland Bridge is the second longest at 1145 meters. Most suspension bridges have some hanger vibrations, but since the vibration amplitudes are small, this has not been considered a problem. The vibrations of the hangers of the Hardanger Bridge was carefully studied by a team of researcher from NTNU in 2017 (Cantero et al., 2018). It was concluded that the structural damping is lower than the design recommendations in Eurocode and that the damping is lower for higher modes than the lower modes. It was also concluded that some severe but rare vibration events occur. For the Hålogaland Bridge, which opened in 2018, severe hanger vibrations were observed already during the construction phase. The vibrations were much larger and more frequent than ever experienced in Norwegian bridges, and it was decided to install Stockbridge dampers to suppress them (Larsen et al. 2022). The Stockbridge dampers reduced the vibrations significantly, and the problem was considered solved until severe damage and failure of many of the Stockbridge dampers occurred less than a year after the installation. The exact reason for the unexpected failures was not clear. It was therefore decided to monitor the hanger vibrations with and without Stockbridge dampers to get insight into possible reasons for the failure of the dampers. Some of these measurements are processed and discussed in this paper.

3. POSSIBLE REASONS FOR THE SEVERE HANGER VIBRATIONS

Line-like structures can be set in vortex-induced vibrations (VIV) if they are lightly damped and have a low mass. The Scruton number can express the sensitivity to vortex shedding:

$$Sc = \frac{2\delta_s m_e}{\rho D^2} \tag{1}$$

Here, Sc is the Scruton number, δ_s is the structural damping expressed by the logarithmic decrement, m_e is the distributed modal mass per unit length, ρ is the air density, and D is the diameter of the hanger. It is clear that reducing the mass or the damping ratio, or increasing the diameter of the hanger D reduces the Scrotun number and thus makes the hanger more susceptible to VIV. The Hardanger Bridge and the Hålogaland Bridge both have the same hanger dimension, consisting of a locked coil cable with a diameter of 68 mm. However, a polyurethane plastic pipe with a wall thickness of 7 mm is used to protect the hangers at the Hålogaland Bridge. If we assume that the mass of the plastic pipe is negligible compared to the locked coil cable, the addition of the plastic layer leads to a reduction in Scruton number of about 40%. It is also worth mentioning that the surface of the plastic pipe is very smooth compared to the painted locked coil cable at the Hardanger Bridge. These are the two main differences between the hangers at the two suspension bridges and are, in our opinion, the principal explanations for the more severe vibrations at the Hålogaland Bridge. The hangers of the Hålogaland bridge have a diameter D=86 mm, which implies that a wind velocity interval of 0-30 m/s corresponds to a vortex shedding frequencies in the interval 0-65 Hz for cross-wind excitation while the vortex-shedding loads in the direction of the flow occur in the interval 0-170 Hz.

3. FIELD MEASUREMENTS

Three of the longest hangers of the Hålogaland bridge have been instrumented with Dytran 3063B tri-axial accelerometers to study the long-term performance of the Stockbridge dampers (Petersen et al. 2021). All hangers initially had two dampers installed in orthogonal directions. One damper was intended to suppress vibrations along the bridge span, while the other was designed to suppress vibrations across the bridge span, as displayed in the left picture in Figure 1. In this work, data from two periods of the measurement campaign will be considered. In the first period, many dampers were missing due to their previous mechanical failure. The first hanger had no dampers; both had broken and been removed. The second hanger only had one damper acting in the across-span direction; the damper acting in the spanwise direction had also failed. The third hanger had two operational dampers; none of them had failed. In the second period considered, a re-installation and upgrade of dampers had taken place. Three dampers were installed in both hanger one and hanger two to further suppress vibrations, as shown in the right picture in Figure 1. All the Stockbridge dampers are placed 3 meters from the bottom end of the hangers.

Figure 1: The left picture shows a hanger with two Stockbridge dampers, while the right image shows a hanger with three Stockbridge dampers

4. ASSESSMENT OF THE PERFORMANCE OF THE STOCKBRIDGE DAMPERS

We start by considering the first period, in which many dampers were missing, leading to severe vibrations. Figure 4 shows a spectrogram of the accelerations in hanger 1 (with no dampers). The measured wind gusts vary between about 5 and 35 m/s for 8 hours. The spectrogram confirms that many modes can be excited by VIV.

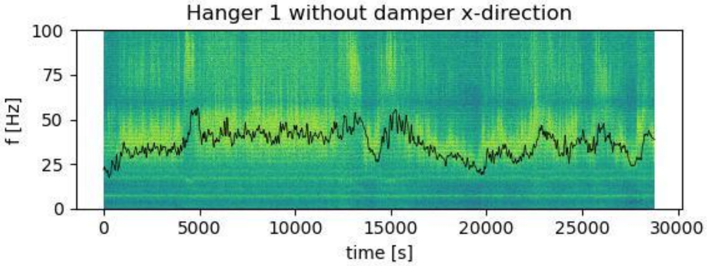

Figure 2: Spectrogram of the hanger vibration of hanger one without any dampers. The black line illustrates the vortex-shedding frequencies obtained from the wind measurements

Figure 2 shows a moving standard deviation of the hanger displacements in the along-span direction to assess the long-term performance of the Stockbridge dampers. The accelerations were numerically integrated two times and low-pass filtered to get the displacements. The figure shows, as expected that the most severe vibrations occur in hanger one since it had no dampers during this period. The vibrations in hanger 2 are significantly smaller, even though only one damper is remaining. It is also interesting to notice that the single remaining damper, which is intended to suppress cross-span vibrations, also works very well for in-span vibrations. The vibrations in hanger 3 are less than the two others since both dampers work. We next consider the second period, in which hangers 1 and 2 both had been equipped with three dampers. The measurements are processed with the same procedure as discussed above, and the across-span vibrations are presented in Figure 3. It is seen that significant vibrations still occur after three dampers are installed.

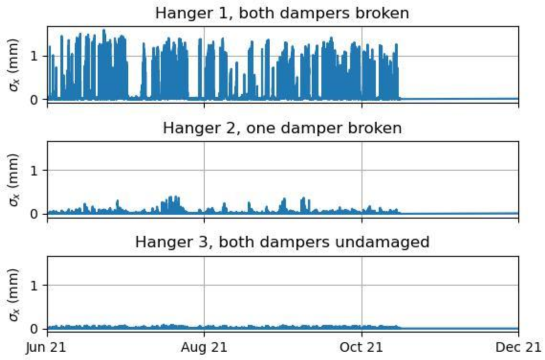

Figure 3: Moving standard deviation of the integrated accelerations for the first period, when many dampers were missing.

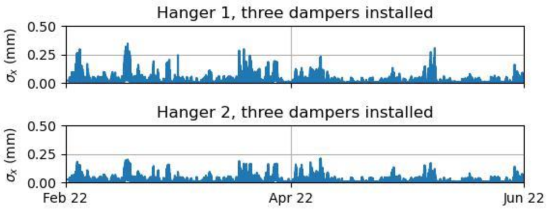

Figure 4: Moving standard deviation from the period where three dampers are installed in hangers 1 and 2

4. CONCLUDING REMARKS

Field observations of vortex-induced vibration of three of the longest hangers of the Hålogaland Bridge have been presented and discussed in this paper. The dataset contains long-term measurements of a hanger without dampers, one hanger with one damper and one hanger with two dampers. Furthermore, the dataset also includes measurements from a long-term period after the Stockbridge dampers are replaced. It is observed that continuous and severe vibrations occur very often for the hanger without any damper. The measurements show that a single damper is very efficient in suppressing the vibrations and that the Stockbridge damper works well in both directions. Installing a second and, to some extent, a third damper suppresses the vibrations even more. The dataset also shows that there are no special events with much more severe vibrations than others. This implies that it is most likely that the Stockbridge dampers were destroyed by high cycle fatigue and not by a rare and severe storm event. It is noted that the Stockbridge damper's vibrations are significant and that the high-frequency vibrations may cause critical fatigue damage in a short time.

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