Fatigue of Threaded Rods in Cable Anchorages due to Vortex Shedding

Bert SNIJDER
Professor, Eindhoven
University of Technology
Eindhoven, The Netherlands
h.h.snijder@tue.nl

Bert Snijder, born 1959, received his civil engineering degree from Delft University of Technology. He is a professor of structural engineering and has worked on numerous structural projects.

Johan MALJAARS
Senior Researcher
TNO, Delft,
The Netherlands
johan.maljaars@tno.nl

Johan Maljaars, born 1976, received his civil engineering degree and PhD from Delft and Eindhoven University of Technology respectively. He is a researcher on metal structures.

Summary

The 'Hovenring' is a bicycle roundabout flyover built as a signature bridge with a central steel pylon carrying a circular bridge deck suspended through stay-cables. Shortly after installation of the bridge, the stay-cables turned out to vibrate in the wind due to vortex shedding. These vibrations have possibly caused fatigue damage in the threaded rods of the cable anchorages. Therefore, fatigue assessments were made using both traditional S-N-curves (Wöhler curves) in combination with the Palmgren-Miner damage accumulation rule as well as fracture mechanics analyses using crack growth data. The design fatigue life of the threaded rods appeared to be extremely short and therefore it was decided to replace them. This paper shows that it is a dangerous design procedure to deliberately not consider vortex shedding and possible fatigue damage in the design stage and to take measures against vortex shedding only after completion of a bridge structure.

Keywords: fatigue; stay-cables; threaded rod; cable anchorage; vortex shedding; fracture mechanics; bridge; flyover.

1. Introduction

Based on an example of a real structure, it is shown that vortex shedding of stay cables can result in an extremely short design fatigue life. The 'Hovenring', built in the years 2011-2012 in Eindhoven, The Netherlands, is a suspended cable-stayed bicycle roundabout flyover (Fig. 1) with a central 70 meter high steel pylon carrying a 72 meter diameter circular bridge deck through 24 stay-cables. The bridge deck is virtually floating over a motorway junction. It separates bicycles from cars, thus offering a safe passage to cyclists. It is a landmark structure and a signature bridge especially developed for this location.

End of the year 2011, shortly after installation of the bridge, it turned out that the stay-cables vibrated in the wind at moderate wind speeds. After about 23 days it was decided to stabilize the stay-cables by adding temporary cords between them. This introduced enough damping to prevent the stay-cables from vibrating in the wind. Then investigations started to determine the exact cause of the vibrations aiming at a final solution to prevent them. It turned out that vortex shedding was the cause of the vibrations and finally Salvi dampers were attached to the stay-cables.

Fig. 1: Cable-stayed bicycle roundabout flyover 'Hovenring' (photo courtesy of Municipality of Eindhoven)

The stay-cables are of the locked

https://doi.org/10.2749/222137813808627488

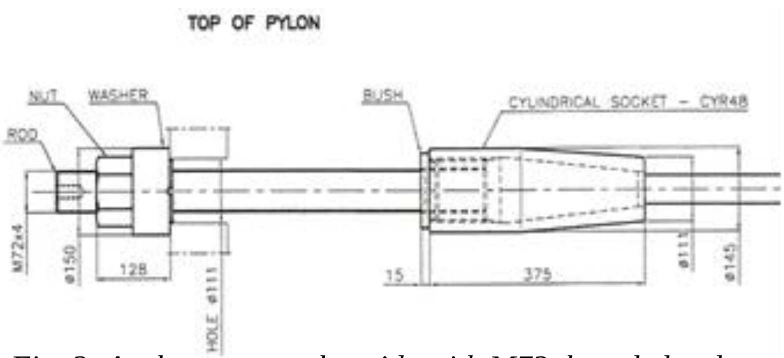

Fig. 2: Anchorage at pylon side with M72 threaded rod

coil type with a diameter of 50 mm and they have an adjustable anchorage. The cable strands are anchored in a socket which is connected to a threaded rod. The threaded rods – M72x4 at the pylon side and M100x6 at the bridge deck side – contain a nut that carry on bearing plates. The most critical part, being the threaded rod in the cable anchorages at the pylon side (Fig. 2), was assessed on susceptibility to fatigue damage.

Due to vortex shedding the threaded rods are unintentionally loaded in bending in combination with their axial loading. The bending stresses and the bending stress histograms for the 23 day period of vortex shedding of the stay-cables were determined. These were used as input for the fatigue assessment using traditional S-N-curves (Wöhler curves) in combination with the Palmgren-Miner damage accumulation rule. In addition, fatigue was assessed through fracture mechanics analyses using crack growth data. These assessment methods are extensively discussed in the full paper.

2. Results and discussion

An overview of the design fatigue lives as calculated is shown in Table 1.

Table 1: Overview of design fatigue lives (in hours) determined with discussed assessment methods

Fatigue assessment method	Preliminary fatigue assessment Single stress range based	Accurate fatigue assessment Stress range histogram based
S-N-curves based – Eurocode category	0,9	0,7
– Test based category	2,9	2,4
Fracture mechanics based	5,6	4,7

The stress range based preliminary fatigue assessments yield short fatigue design lives. The longest design fatigue live is obtained using fracture mechanics because 1) the more favourable effect of bending stress can be taken into account in the fracture mechanics based fatigue assessment and 2) the size effect in the S-N-curves based code is more severe than calculated with fracture mechanics. Similar observations can be made for the stress range histogram based accurate fatigue assessment methods. All fatigue assessment methods result in far too short design fatigue lives.

3. Conclusions

On the basis of S-N-curves and fracture mechanics based fatigue assessments of the threaded rods in the stay-cable anchorages of the bicycle roundabout flyover ‘Hovenring’ - resulting in very short design fatigue lives - it was decided to replace the threaded rods after Salvi dampers were installed to prevent further vortex shedding of the stay-cables. The short design fatigue lives indicate that vortex shedding should be explicitly considered in the design stage. It can be a dangerous design approach to take measures against vortex shedding only after a structure is built, because severe fatigue damage may already have taken place before dampers or other devices are installed. In vortex sensitive structures, this phenomenon should be explicitly considered in the design stage.

4. Acknowledgement

The authors wish to thank the Municipality of Eindhoven (Gemeente Eindhoven), The Netherlands, for their permission to publish this paper and prof. ir. A.C.W.M. Vrouwenvelder (TNO, TU-Delft) for his advice throughout the project.