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Field Measurements of a 1210 m Span Suspension Bridge during Erection

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Summary

The dynamic behaviour of a 1210 m span suspension bridge was monitored on site from the start of the erection of the main span in April 1997 to the bridge opening in December 1997 in Sweden. Measurements of accelerations, wind speed and direction were recorded continuously. This paper presents the main findings of the first 18 days of the field measurement campaign corresponding to the period of lifting and hinging of all deck segments of the main span. Variations of natural frequencies and structural damping as a function of completion of the main span are given and compared to finite element calculations. Correlation between wind speed, accelerations and aerodynamic damping are also given and compared to analytical and experimental predictions based on a section model study and an aeroelastic model study of the bridge during erection.

1. Introduction

Suspension bridges are at their most vulnerable stage with regards to dynamic wind action during the early phases of erection. The unique opportunity to study this aspect through field measurements arose in the spring of 1997 in Sweden with the construction of the Höga Kusten Bridge. A measurement campaign was initiated by the Danish Maritime Institute (DMI) in collaboration with the Department of Structural Engineering of the Royal Institute of Technology (KTH), Stockholm, and the Scandinavian Bridge Joint Venture (SBJV), the superstructure contractors for the project. This campaign was the final stage of a thorough aerodynamic investigation at DMI of this remarkable structure.

The purpose of the field measurements was to validate predictions of the dynamic behaviour of the bridge based respectively on finite-element analyses and model scale experiments in wind tunnels. At first, the field data aimed at providing estimates of natural frequencies and structural damping as a function of percentage of completion of the bridge deck. Also the campaign aimed at providing a precious evaluation of the dynamics on an asymmetric erection configuration envisaged by SBJV [1]. The wind-tunnel tests on a 12 m long aeroelastic model pointed out that the aerodynamic stability of the bridge could be enhanced if an asymmetric construction scheme, i.e. to erect more deck segments on one side of the mid-span than the other, was adopted [2].

The Höga Kusten Bridge, 500 km north of Stockholm on the east coast of Sweden, has a 1210 m main span flanked with end spans of 310 m and 280 m. The suspension cables are supported by two 180 m high concrete pylons, leading to a 40 m navigation clearance. The steel closed-box girder of the main span is 22 m wide by 4 m deep and is built in segments of 40 m weighing approximately 280 tons each. The bridge has the longest span of the regions of the world where the ground is snow-covered more than five months a year. The high exposure to strong winds and the possibility of important snow accumulation that could change the aerodynamics of the deck cross-section were taken into account in the design of the superstructure.

This paper presents the main findings of the first 18 days of the campaign corresponding to the erection of the main span [3]. Additional measurements were carried out to evaluate the changes in frequency and structural damping as the welding of the girder progressed, during the deck surfacing and after the removal of the catwalk. These observations are not reported here.

2. Monitoring procedures and instrumentation

The instrumentation was composed of five servo-accelerometers (Schævitz A225-001), one cup-anemometer and one wind-direction sensor. The wind measurement sensors were mounted on a mast fixed to a cross-bridge between the main cables 120 m from mid-span and 20 m above the deck. Wind data collected from a 10 m mast on the South end span was also made available by SBJV during the campaign. Three accelerometers were mounted at mid-span to depict lateral, vertical and torsional vibrations of the deck and were kept stationary while a set of two accelerometers were moved gradually toward one of the pylons as the erection progressed. These two accelerometers were set up to measure vertical and torsional oscillations of the deck and were moved until they reached the ¼ point, 305 m from mid-span.

Data acquisition was performed with a PC placed inside the stiffening girder at mid-span. Continuous and simultaneous recording of the signals from the sensors was made at a sampling frequency of 10 Hz after low pass filtering at 2 Hz. The time histories were all stored in files of 10 minutes on the PC hard disk. Daily visits to the site were made to ensure that all the equipment was functioning, to back-up the data and to take note of the bridge configuration.

3. Bridge configuration

The main span contains 31 girder segments, numbered 10 to 40 by SBJV. Each segment was lifted from a barge with a floating crane, attached to the hangers and simply hinged to the previous segment. The 31 segments were hinged before welding started. To avoid man made vibrations, the data analysis focused on the off-work hours, defining 12 erection stages (see Fig. 1). For the first seven stages, only stage 5 had a symmetric configuration. Stage 3, 5-7 and 12 corresponded well to the configurations studied on an aeroelastic model at DMI.

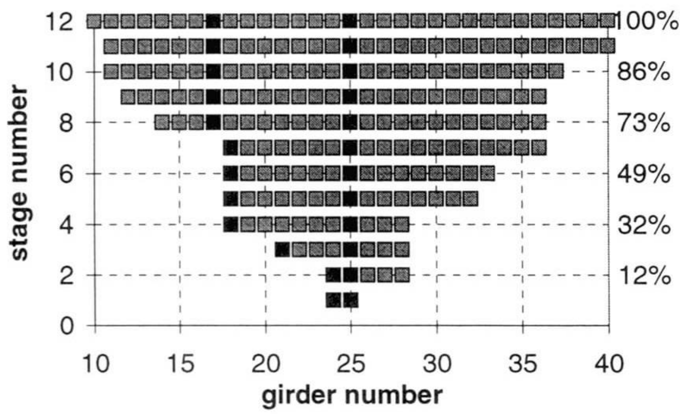

Figure 1 Deck configurations studied. Light grey: hinged segments; dark grey: accelerometers location. The percentage of completion is indicated on the right ordinate.

4. Main findings and discussions

The measurement period was characterised by winds from the WNW-NNW quadrant, more or less perpendicular to the bridge axis. The 10-minute mean wind speed at deck height was typically in the 6 to 14 m/s range with the exception of two occasions where the passage of a depression brought stronger winds from NW, in the 14-16 m/s range during stage 4 and in the 18-22 m/s range during stage 9. The construction was stopped for a full day during the latter wind storm. Fig. 2 shows time histories of the deck accelerations at mid-span recorded during that storm. The bridge response was dominated by random buffeting induced by the turbulent wind. No organised motion associated with vortex-shedding excitation or the like were observed. Also shown in Fig. 3 are the corresponding spectra of the response. In general, the wind excited mainly the lowest natural modes of each degrees of freedom, facilitating the evaluation of the bridge dynamic characteristics.

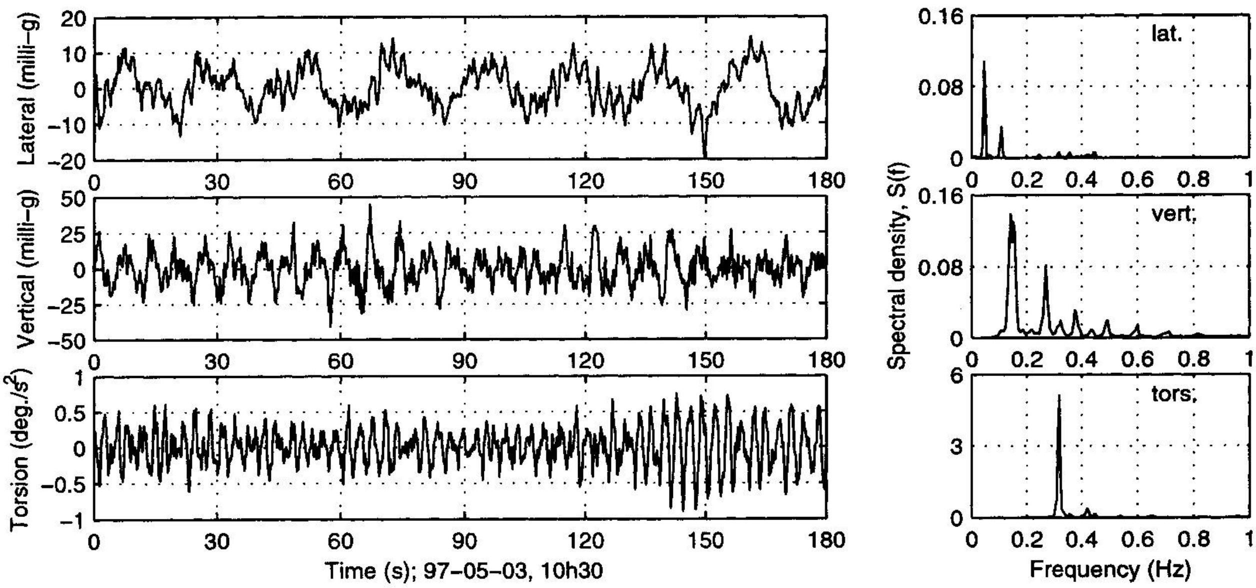

Figure 2 Typical time histories and spectral density of the bridge response at mid-span.

4.1 Natural frequencies and total damping

The data analysis was performed on groups of 3 consecutive 10-min. files selected for stationary conditions (constant wind speed and direction), good root-mean-square (rms) response and off working hours. Two techniques were used for the estimation of frequency and damping from short ambient vibration records, namely the maximum likelihood technique (MLT) and the random decrement technique (RDT). The MLT is a frequency domain approach where the spectra peaks are fitted with a single degree-of-freedom mechanical admittance function assuming a probability distribution for the spectral estimates. The frequency and damping parameters are varied until the joint probability distribution between each point and the curve fitted reaches a maximum. The spectral analysis was performed with 8192-point fast-Fourier transform. Four vertical modes and the lowest symmetric lateral and torsional modes were identified and analysed.

The RDT is based in the time domain and simply consists of removing the wind excitation from the measured response to be left uniquely with the properties of the mechanical system. Sections of the response that satisfy a certain threshold are averaged and the auto-correlation function of a given mode is built. Both methods give consistent results. Figs. 3 and 4 present respectively the estimates of frequencies and damping as a function of the bridge completion. Fig. 3 also presents the frequencies predicted from finite-element calculations using a commercial finite-element programme. The agreement is very good.

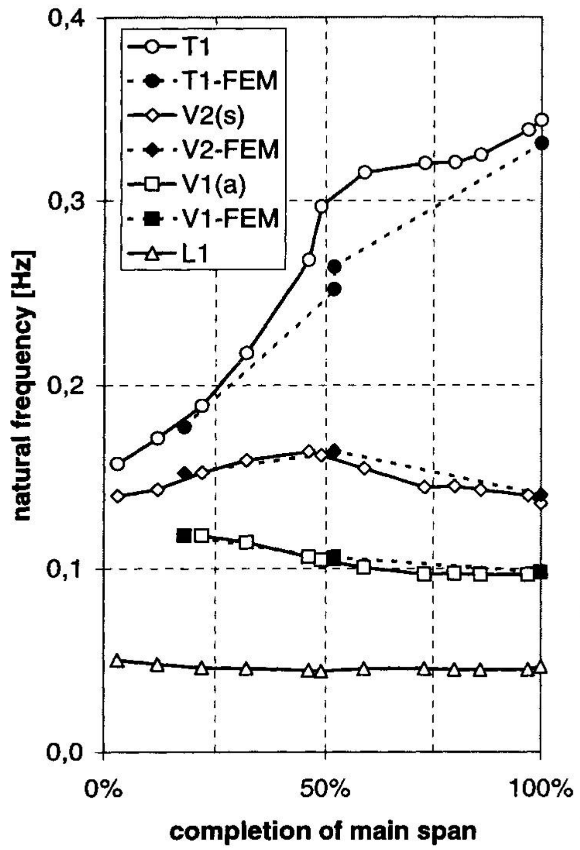

Figure 3 Variations of natural frequency as a function of bridge completion

The wind speed corresponding to the damping estimates are also given in Fig. 4 in the boxes near the data points. By inspection of Fig. 4 it is not possible to conclude if there was a systematic increase or reduction of damping as the erection of the main span progressed. However, it can be observed that the damping in torsion was in most cases 0.5 to 1% of critical which is considered to be low. For the vertical modes, the damping might have slightly increased as the bridge was built and was in most cases between 1% and 2% of critical. It was also observed that generally the damping increased with the amplitude of vibrations. For example, an increase of 15% in amplitude translated to a 20% increased in total damping for the lowest lateral mode for a constant windspeed.

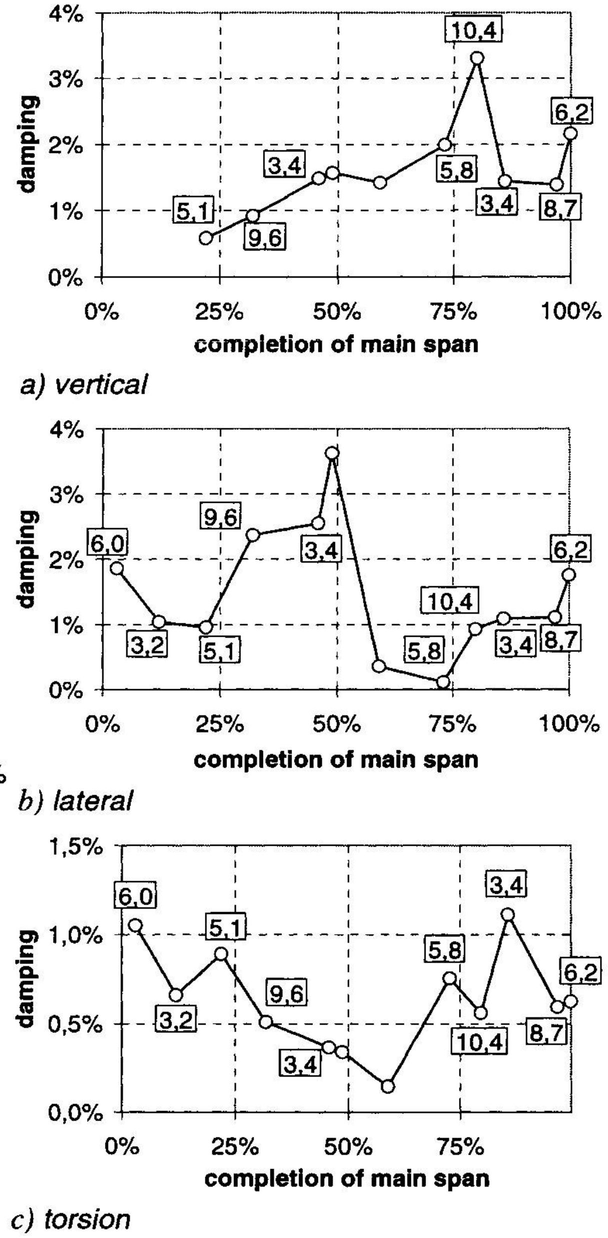

Figure 4 Variations of total damping (ratio of critical) as a function of bridge completion

4.3 Correlation wind speed and dyanmic response

Fig. 5 presents the rms acceleration at mid-span as a function of the erection period. With the exception of a number of very narrow peaks, probably caused by impacts of the lifting crane, the period of the largest rms response and therefore also the most severe wind load occurred between May 2nd, 3rd and 4th, that is, erection stage 9 during which the 10-min averaged wind speed reached above 20 m/s.

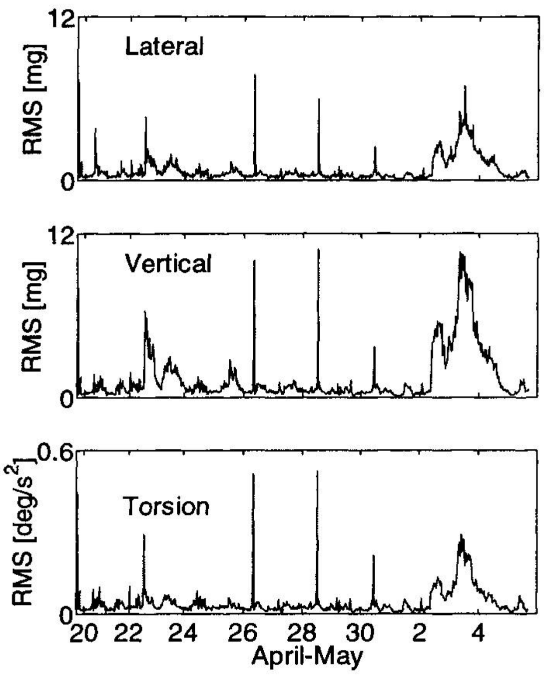

Figure 5 Variations of rms response as a function of date of erection.

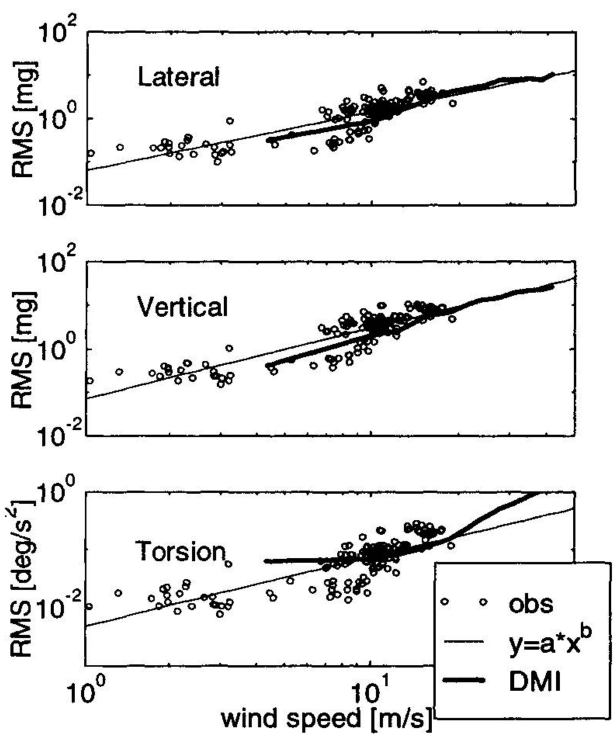

Figure 6 Variations of rms acceleration as a function of windspeed for stage 9.

The correlation between wind speed and magnitude of accelerations is clear. In Fig. 6 the rms response are plotted versus windspeed. Also plotted is a 2nd order least square fit of the observed data. Also shown in Fig. 6 are the results of the wind tunnel tests on a 1:150 scale aeroelastic model (solid line on the graphs) of the bridge for a configuration corresponding to stage 12, i.e. all deck segments are hinged but not linked to the end span. The agreement between model scale and full scale observations is excellent for the vertical and lateral degrees of freedom, the response showing similar magnitude and variation with windspeed.

4.4 Aerodynamic damping

Through analysis of the bridge response during the May 3rd wind storm it was possible to estimate the variations of total damping as a function of wind speed at deck level for winds perpendicular to the bridge axis. The results are shown on Fig. 7 for the fundamental modes of vibrations of the deck for stage 9 (main span 80% completed). It is clear that the total damping increased with windspeed. This increase is attributed to a combination of aerodynamic damping and an increase of structural damping with the amplitude of vibration. To evaluate the importance of the aerodynamic damping, curves showing predictions based on quasi-steady and unsteady aerodynamics are shown in Fig.7.

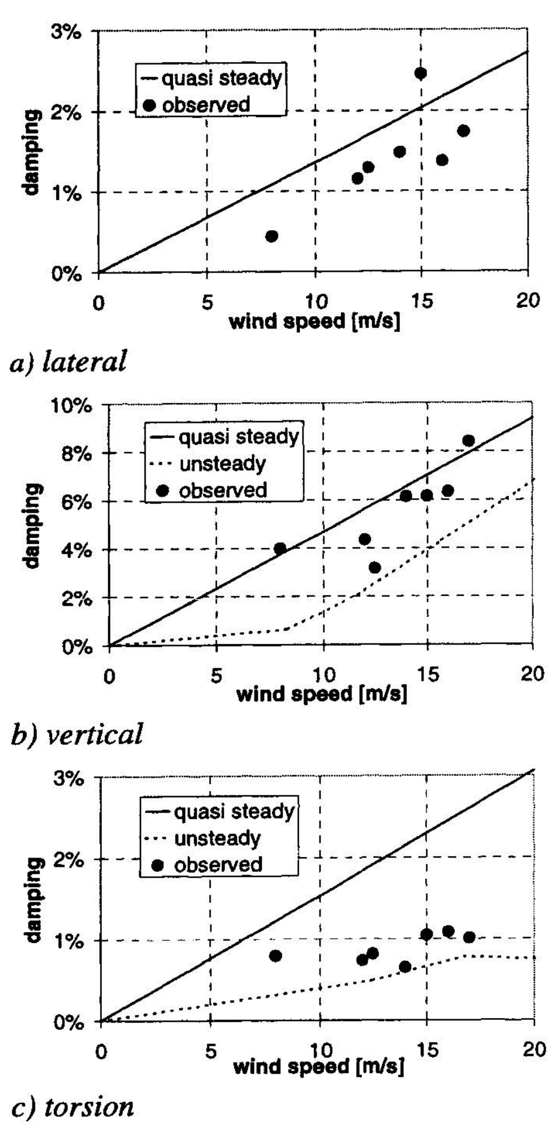

Figure 7 Variations of total damping as a function of windspeed for stage 9.

The quasi-steady aerodynamic damping predictions are based only on the static coefficients of the deck cross-section measured in turbulent flow, while the unsteady predictions are based on the measured aerodynamic derivatives through dynamic section model tests as reported in [4]. For the range of wind speeds of interest, the quasi-steady predictions overestimated the damping excepted for the lateral mode, while the unsteady predictions appeared to follow well the trend observed in full-scale .

5. Conclusions

The field measurements of the dynamic behaviour of a suspension bridge during construction have indicated that the structural damping for small amplitudes of motion can be relatively low, especially for the torsional degree of freedom of the deck. It also indicated that finite-element calculations can provide satisfactory predictions of the dynamic characteristics of the structure as it is being built. Results of wind tunnel tests on a 1:150 scale aeroelastic model compared very well with field observations. The aerodynamic damping estimated from the aerodynamic derivatives of the deck cross-section through section model tests proved to be reliable, while the predictions based on quasi-steady aerodynamics overestimated the aerodynamic damping for the range of windspeed experienced during the field measurements.

References

[1] Madsen, B.S., Höga Kusten Bridge, Sweden, construction of the bridge girder, in *Proc. of New Technologies in Structural Engineering,* LNEC. Lisbon, July 1997, pp. 821-826.

[2] Tanaka H. et al., Aerodynamic stability of a suspension bridge with partially constructed bridge deck, in *Proc. of 15th IABSE Congress,* Copenhagen, June 1996, pp. 113-118.

[3] Johnson R. and Larose G.L., *Field measurements of the dynamic response of the Höga Kusten Bridge during construction,* DMI-KTH Joint Venture Research Report, 03/1998.

[4] Larose G.L. and Livesey F. M., Performance of streamlined bridge decks in relation to the aerodynamics of a flat plate, *J. Wind Eng. & Ind. Aerodyn.,* **69-71** (1997), 851-860.