# Wind and wind gust effect on narrow composite arch bridges

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## Summary

The effect of cyclic wind loading during short periods on narrow composite bridges is being discussed, through the case of a bridge to be built in Norway. In the past, high-frequency measurements of instantaneous wind speed enabled to derive a reliable time distribution of wind load for the Northsea coast. Data for short period average wind speed have been adapted to comply with Norwegian conditions. Both the Eurocode 1-4 procedure and the cyclic loading have been applied to the narrow network arch being considered. The transient response of the bridge seems not to be in phase with cyclic loading, since the fundamental mode shape consists of a general twisting movement about a vertical axis, due to insufficient lateral stiffness of the arch springs. Additional stiffening of the spring areas results in milder resonance, corresponding to a fraction of the natural frequency. The quasi-static calculation process still detects high stress conditions, although these may be qualified as satisfactory. This implies that the Eurocode recommendation may provide safe solutions and allows detecting critical situations effectively.

Keywords: short period cyclic wind, transient response of steel bridge, network arch

## Abstract

Due to their rather small lateral stiffness, narrow slender bridges, in particular steel arches, are sensitive to wind load. Obviously, bracing is effective to connect parallel arches and increase lateral resistance. Unfortunately the bracing cannot continue to the arch springs and lateral clamping of the latter becomes indispensable. Even abundant bracing cannot compensate insufficient clamping of the arch springs. During design, the case of wind load is generally treated by applying factors to static wind pressure.

The effect of cyclic wind loading with short periods has been assessed previously for several bridges in Belgium. Presently, the effects on a narrow slender composite arch bridge, to be built in Norway are taken as an example to discuss the adopted process. This bridge will be built across the Brandagersund, to the North of Bergen.

Network arches are reputed to possess extreme slenderness and lightness. This type of bridge was first proposed by P. Tveit and behaves differently from other tied arch bridges. The arch and lower chord are connected by hangers, each one arranged in inclined position. A particular characteristic is that each hanger must intersect at least twice with other hangers, thus introducing a complex behaviour. Compared to classical tied arches with vertical hangers, bending moments, both in arches and in the lower chord are substantially lower. Obviously, this multiple connection guarantees large in-plane stability of the compressed arches and allows using a posttensioned concrete lower chord and light standard steel profiles for the arches. This implies that network arches are essentially composite bridges. Due to the lightness of the arches heavy upper bracings are required. The bracing system is of similar complexity as the hanger system, although it is essentially a truss.

The first vibration mode of the bridge being discussed corresponds to a frequency of 0.1673 $s^{-1}$ and

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is obviously related to distortion of the edge portal frame of the wind bracing. Two half-waves are generated, the maximum amplitude of the horizontal displacements being located at the horizontal end truss of the bracing. Stiffening of the H-profile of the arch by additional plates may improve the situation by increasing the natural frequency. If 2 lateral plates of 25 mm thickness are added in the lower parts of the arch to the H-profile, the frequency is increased to 0.3433 $s^{-1}$ and the mode shape corresponds to a single half lateral wave of horizontal displacements. Clamping of the arch springs appears to be sufficiently improved, although the end portal frame of the wind bracing still disturbs a fluent line of the horizontal mode.

The behaviour of the structure due to cyclic wind loading has been determined by modal analysis and transient response. Calculations require at least 80 modes and the time step does not exceed 0.5% of the wind gust period. The numerical simulation results in time histories of accelerations and displacements as well as normal forces and bending moments. Referring to the mode shapes, the section where the end bracing truss is connected to the arches, might be more relevant than the arch top. Most of the calculated quantities are completely in phase with the variation of the characteristics of the arch top. In addition, the top sections of both parallel arches are completely moving simultaneously.

The period of cyclic wind loading is rather uncertain, due to lack of a sufficient number of high-frequency measurements of the instantaneous wind speed. Consequently, various periods have been considered. Clearly, a period between 4 and 5 s or 0.20 to 0.25 $s^{-1}$ corresponds to rather heavy resonance, in particular at the intersection with the bracing end truss. Hence, resonance actually is determined by the twisting fundamental mode shape. This is also true for the second peak in the frequencies of 8 s or 0.125 $s^{-1}$. The values of the critical frequencies demonstrate that the response of the bridge is not entirely matching the cyclic wind loading.

The effect of additional stiffening has been considered. It has been noticed that the curves for the arch top and for the end truss section are completely similar, since the asymmetric mode shape no longer exists and vibrations of both sections are in phase. In addition, the largest amplitude is found at the arch top and not at the truss section, the ratio of both maxima now reaching 1.36. In the case of the unstiffened alternative, this ratio equals 2.02. As resonance corresponds to a fraction of the fundamental frequency, the vibration energy in this condition is lower comparing to the former case and the peak in the resonance versus period graph is flatter. However, the evolution with the period of accelerations shows, apart from a similar to the displacements, a peak for T = 10s and also a less important maximum for T = 6s.

## Conclusions

In a general manner, clamping of arch springs and lateral stiffness of narrow high bridges is indispensable in those areas where upper bracing is ineffective, mainly near both ends of the bridge. Should this not be the case, as in the initial design of the Brandagersund bridge, the fundamental mode shape does not correspond to a general lateral sway of both parallel arches, but it reaches a maximum value at the end trusses where the bracing is stopped. This type of fundamental mode introduces a twisting vibration of both arches about a vertical axis, with maximum amplitude near the end trusses. Resonance seems not to be in phase with the period of cyclic wind loading, its frequency being shifted to a lower value. However, the problem is being detected by the quasi-static calculation process as recommended by Eurocode 1-4.

If a more satisfactory solution is adopted, providing higher lateral stiffness near the arch springs, up till the area where the wind bracing is effective, milder resonance still can occur for wind periods corresponding to a fraction of the natural frequency. The quasi-static calculation process still detects high stress conditions, although these may be qualified as satisfactory. Additional damping devices may thus become indispensable. This implies that the Eurocode recommendation may provide safe solutions and allows detecting critical situations effectively.