ce/papers Proceedings in civil engineering

eurosteel CRACOW 2026

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Temporary monitoring system on the pedestrian cable bridge in Sátoraljaújhely, Hungary – a case study

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Abstract

This report summarises the results of a temporary monitoring system installed on a 700 m span pedestrian cable bridge in Hungary. Measurements were carried out from March to September 2024 following a static load test and continued through the commissioning and operational phases. The monitoring system included GPS-based geodetic measurements, wind speed and direction sensors, structural temperature sensors and accelerometers, providing comprehensive insight into the bridge's structural behaviour. The measurements show that the bridge geometry is predominantly influenced by daily and seasonal temperature variations. Wind-induced effects were also observed, including vertical and torsional vibration components. Measurement results were compared to numerical model results developed during the design phase of the structure. The derived natural frequencies matched numerical predictions well, the temperature movements were correlating nicely, too. GPS-based and accelerometer-based vibration analysis matched acceptably, considering the possibilities of applied sensors. All these confirm that the structure performs in accordance with design expectations.

Keywords

monitoring system, cable bridge, pedestrian bridge, measurements, model validation, large span, case study

1 Introduction

SHM systems on bridges are increasingly important nowadays, especially for structures with special importance, behaviour or scale [1, 2, 3, 4]. The subject of the paper is the presentation and evaluation of the results of a temporary monitoring system installed on the pedestrian suspension bridge located between Szárhegy (north) and Várhegy (south) in Sátoraljaújhely, Hungary [5].

The bridge is a pedestrian cable bridge with an extremely large span of 700 m, stiffened by a wind cable system and additional tie-down cables. The bridge consists of two load bearing cable planes: the upper cable plane contains two main load-bearing cables, while the lower cable plane contains four. The vertical distance between the upper and lower cable planes is 1.29 m. The sag of the bridge at mid-span is 27 m. The span of the main wind cables is 525.4 m, and they are connected to the bridge at every crossbeam in 20 m intervals. On both sides, outside the main wind cables, there are three additional tie-down cables. The spacing of the crossbeams is 2 m, and a safety net is tensioned between the crossbeam frames. The bridge is shown in Figure 1.

The measurements presented in this report started on 27 March 2024, and data are available until 16 September 2024. During the initial phase of the measurement period, installation works were carried out on the bridge. The structure was officially commissioned on 4 June, after which the measurements continued under operational conditions.

Figure 1 View of the bridge

https://doi.org/10.1002/cepa.70404

In Chapter 2 we introduce the measurement system. Chapter 3 presents the evaluation of meteorological measurements. Chapter 4 contains the assessment of the structural response.

2 Measurement system

The conducted measurements can be classified into four groups: (i) geodetic measurements (using GPS) to investigate the bridge geometry; (ii) wind speed and wind direction measurements; (iii) structural temperature measurements; and (iv) vertical acceleration measurements (Figure 2).

Using these instruments, detailed data on the structural behaviour of the bridge were obtained during the period of 2024 spring and summer.

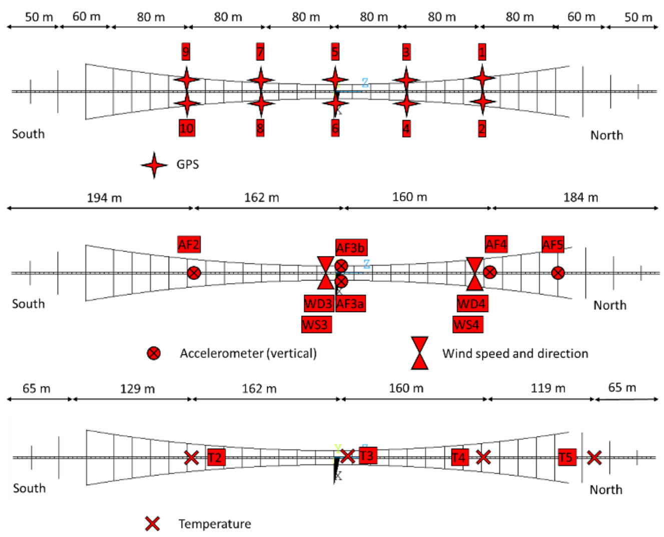

Figure 2 Sensor positions

3 Meteorological measurements

3.1 Temperature data

Based on the data, it can be stated that the daily temperature variation ranges between 15 and 25 °C, which corresponds to expectations (Figure 3). The measured maximum structural temperature exceeded 40 °C, while during the initial measurement period the minimum value was around 0 °C.

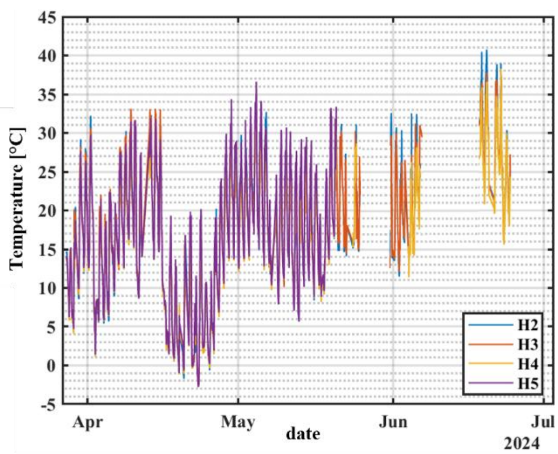

Figure 3 Temperature measurements during the observations

3.2 Wind data

The measurements were carried out with a sampling frequency of 5 Hz; however, 10-minute mean wind values were used for the evaluation. The maximum 10-minute mean wind speed during the measurement period was 15 m/s (during the night of 10 April), which corresponds to Beaufort scale 7, i.e. near gale. At the same time, the actual maximum wind gust reached an intensity of 18.7 m/s (Figure 4).

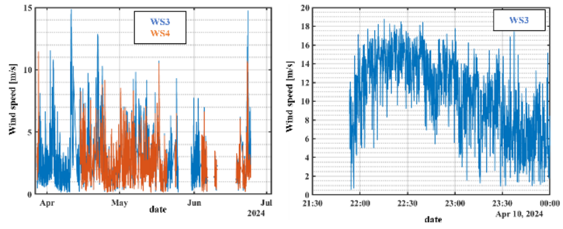

Figure 4 Wind speed measurements and peak

The intensity distribution of the mean wind speed was illustrated using a histogram, while the prevailing wind direction and wind speed were shown using a wind rose diagram (Figure 5). It can be observed that the most frequent wind speed is around 2 m/s, corresponding to light breeze. The distribution of wind speed is asymmetric, as expected. Wind direction data were significantly influenced by orographic factors, as the valley where the bridge is located runs in the east-west direction. WD3 sensor is even more affected, as this sensor is placed nearer to the side, thus nearer to the terrain.

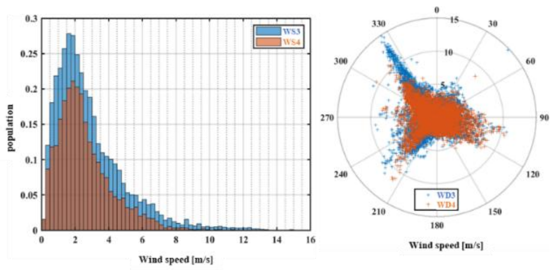

Figure 5 Distribution of wind speed and direction

4 Structural responses

4.1 Deflection measurements

The GPS receivers operated with a sampling frequency of 1 Hz. The data are available as absolute elevations above sea level; however, from a structural point of view, the change in bridge geometry is of greater importance. For this purpose, a reference time was selected (27 March 2024, 19:10:01), and all data are presented relative to this reference. At that time, the structural temperature of the bridge was approximately 13.5 °C, close to the neutral temperature, and thus close to the designated neutral bridge geometry. It should be noted, however, that due to the nature of the evaluation, the reference time does not play a significant role, as the analysis focuses on changes in geometry rather than the absolute geometry itself.

Based on the measurement results, it can be observed that the bridge geometry is primarily influenced by daily and seasonal temperature variations (Figure 6): with increasing temperature, the sag of the bridge increases. During the investigation period, the maximum vertical displacement measured at the centre of the bridge was 1067 mm (GPS6).

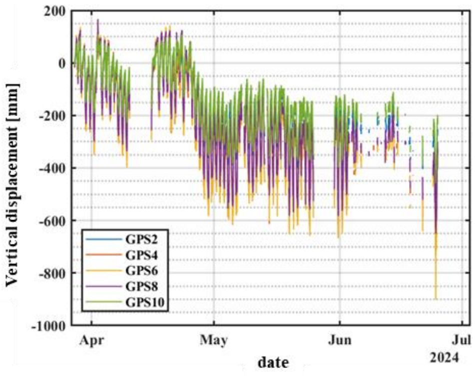

Figure 6 Vertical displacement measurements

The measurement system was capable of detecting the symmetry of deflection and possible torsion of the bridge; however, neither phenomenon occurred. Horizontal displacements were also examined, and it was determined that the bridge moves predominantly in the vertical direction, while horizontal displacements are an order of magnitude smaller than the vertical ones.

4.2 Temperature-dependent displacements

Temperature has a fundamental influence on the shape of the bridge. In order to gain deeper insight into the structural behaviour, the temperature-induced movement of the bridge was examined based on the available long-term data series. For this purpose, the daily maximum vertical displacement was plotted as a function of the daily maximum temperature change (Figure 7). Separate diagrams were prepared to illustrate the displacements at midspan (GPS5–6) and at the quarter points (GPS1–2). The measurement data clearly reveal a trend whereby increasing temperature variation leads to increasing displacements. The linearity of the relationship is evident; in the case of zero temperature change, the trend line (with the exception of GPS6) intersects the vertical axis at a maximum of 6 mm.

Using the numerical model developed during the design of the bridge, the relationship between bridge geometry and temperature was determined. According to this model, a temperature decrement of 10 °C results in a 180 mm upward movement of the bridge centre. The values obtained from the finite element model are also plotted in the diagrams (markers with black background). Based on the results, it can be concluded that the calculated values fit well within the measured data, indicating that the model reproduces the temperature-induced movements with adequate accuracy.

An interesting detail is highlighted in Figure 8. Around midday on 4 April the temperature dropped relatively rapidly by approximately 5 °C by some unknown meteorological effect (temporary increase of cloud cover or arrival of a cold wind gust). This temperature decrease is also reflected in the bridge geometry: within a short period, the bridge rose by more than 100 mm, after which it returned to the general daily movement trend. This shows how quick the body temperature of steel material can change, as it has low specific heat capacity and good heat radiation properties.

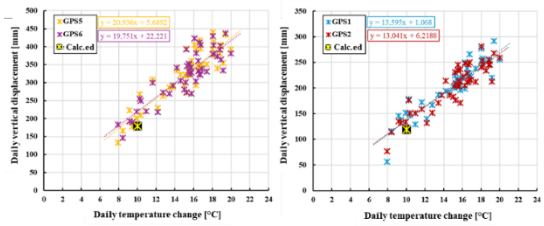

Figure 7 Correlation of daily temperature change and vertical displacement

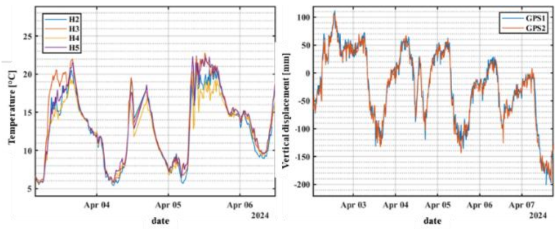

Figure 8 Close correlation between temperature and bridge geometry

4.3 Wind-dependent movements

Due to the sampling frequency of the GPS measurement data, it is limited how the vibration state of the bridge structure can be investigated. However, the 3-second measurement range of the GPS data can serve as an indicator of vibration behaviour.

The night of 21 April (21:00–22:30) was selected for evaluating the wind induced vibrations. During this period, the maximum 10-minute mean wind speed was 12.86 m/s, while the minimum was 10.54 m/s. In the vertical direction and in the horizontal direction perpendicular to the bridge axis, the measurement range was nearly identical, suggesting that the bridge experienced both vertical and torsional motion. Under calm conditions, the range is 10–20 mm, while under windy conditions it increases to 40–140 mm; the additional component can be attributed to wind-induced vibrations (Figure 9). When short-term movements are filtered out and a 60-second moving average is applied, the horizontal displacements of the bridge show a clear correlation with the 10-minute mean wind speed (Figure 10).

Figure 11 shows the measured acceleration values during the examined period. By numerically integrating the time series, an estimate of the corresponding displacements can be obtained. Since the applied sampling frequency of 50 Hz is relatively low compared to the vibration frequencies of the structure, the acceleration data were corrected by considering deviations from a moving average corresponding to a selected period during numerical integration. A similar approach was applied when deriving displacements by repeated integration of velocity data. This procedure behaves as a simple high-pass filter: frequencies equal to or higher than the selected period appear in the result, while lower frequencies do not. For the results shown in Figure 11b, a period of 4 s (0.25 Hz) was applied. The maximum amplitude is around 80 mm, which is in approximate agreement with the evaluation of the GPS data. Based on the data, it can be concluded that both torsional and bending vibration components were present.

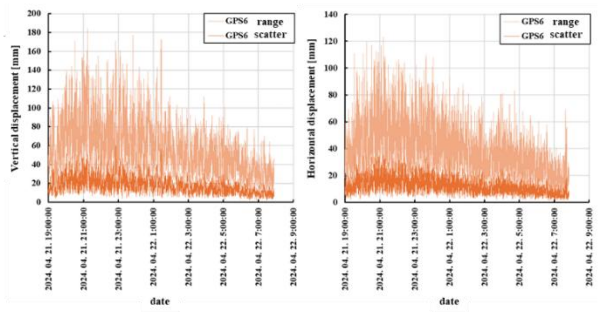

Figure 9 GPS data during windy conditions – GPS6

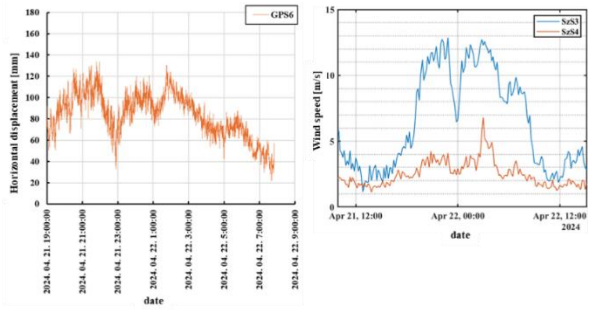

Figure 10 60-s moving average of transverse displacements and wind speed

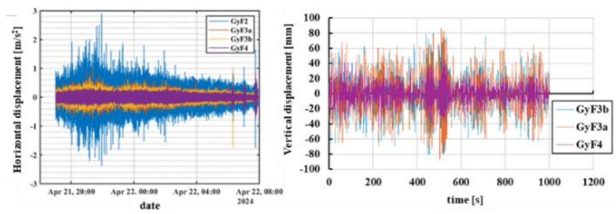

Figure 11 Accelerations during windy conditions and displacements derived from measurement results

Using the data from the GPS receivers and accelerometers, the natural frequencies of the structure were determined and are summarized in Table 1. The natural frequencies predicted by previous finite element analyses are also presented. The agreement is very good for the first modes, and the correspondence between measured and calculated values remains exceptionally good even at higher frequencies, confirming that the bridge behaves in accordance with the design assumptions.

Table 1 Measured and calculated eigenfrequencies

#	eigenfrequencies	
	calculated	measured
1	0,13	0,14
2	0,246	
3	0,256	0,246
4	0,258	
5	0,38	0,339
6	0,387	
7	0,395	0,41
8	0,435	
9	0,513	0,514
10	0,514	

5 Summary

This paper presented the results of a temporary structural monitoring system applied to a 700 m span pedestrian cable bridge in Sátoraljaújhely, Hungary. The monitoring campaign covered both the commissioning phase and the early operational period, enabling detailed observation of the bridge's response under real environmental loading. The applied measurement system provided a comprehensive overview of the bridge behaviour.

The evaluation demonstrated that the global geometry of the bridge is dominated by temperature effects, with daily and seasonal variations governing vertical displacements. A strong linear correlation was identified between temperature change and deflection, and the measured behaviour showed very good agreement with the finite element model developed during design. Wind-induced responses were also successfully identified, including vertical and torsional vibration components, with displacement amplitudes consistent across independent measurement methods. The data provided by the monitoring system helped to identify the actual structural behaviour of this special bridge structure and enabled the numerical model applied during the design phase to be validated. On this basis, the structural response to actions occurring over the design service life can be reliably predicted, thereby supporting safe operation.

References

[1] Tadeu, A.; Romero, A.; Dias, S.; Pedro, F.; Brett, M.; Serra, M.; Galvín, P.; Bandeira, F. (2022) *Vibration serviceability assessment of the world's longest suspended footbridge in 2020*. Struct. 44, pp. 457-475.

[2] Tadeu, A.; Marques da Silva, F.; Ramezani, B.; Romero, A.; Škerget, L.; Bandeira, F. (2022) *Experimental and numerical evaluation of the wind load on the 516 Arouca pedestrian suspension bridge.* J. Wind Eng. Ind. Aerodyn. 220, p.104837

[3] Bergenudd, J.; Battini, J-M.; Crocetti, R.; Pacoste, C. (2023) *Dynamic testing and numerical modelling of a pedestrian timber bridge at different construction stages*. Eng. Struct. 279, p.115429

[4] Miskiewicz, M.; Sobczyk, B.; Makowska-Jarosik, K.; Tysiac, P.; Meronk, B.; Kaluza, J. (2025) *Analysis and load testing of a 452.9 m long footbridge over the Vistula.* In Zingoni, A [Ed] *Engineering Materials, Structures, Systems and Methods for a More Sustainable Future.* 1st ed. London: CRC Press, pp. 6

[5] Dunai, L.; Kövesdi, B. (2024) *Evaluation of the results of the temporary monitoring system installed on the pedestrian cable bridge between Szárhegy and Várhegy in Sátoraljaújhely*. Experts report (in Hungarian)