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Original Research Article

STRUCTURAL HEALTH MONITORING FOR DĘBICA RAILWAY STEEL ARCH BRIDGE IN POLAND

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Abstract

The study presents the vibration-based SHM system for the Dębica railway bridge located in Poland. The railway bridge owner was concerned about the excessive and self-excited vibrations of the hangers, the vibration measurement of 8 hangers per span in a total of two spans being monitored. The dynamic responses in both the transverse and longitudinal directions for each hanger under different load events over a nine-month period were recorded and introduced in this paper. The tension force and stress on each hanger are estimated through the natural frequency of the experimental vibration analysis. The proposed approaches could be used to develop a smart alarm system integrated into a vibration-based data-driven SHM system for heavy railway bridges.

Keywords: railway health monitoring, railway arch bridge, natural frequency, vibration analysis

1. INTRODUCTION

The transport infrastructure system is the lifeblood of every country. The construction, maintenance and management of transport networks are beneficial for economic, social, political and military purposes. Sustainable transportation improves connectivity between local regions, transport modes, and countries. It can be seen that well-managed transportation facilitates various activities. On the other hand, when the transportation is not well developed, everything is delayed. Infrastructure asset operators, managers and owners have been seeking the cost-effective, real-time reliable and onsite safe solutions for intelligent civil infrastructure data processing and management to enhance smarter decision-making information [1].

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Structural Health Monitoring (SHM) embedded advanced signal processing algorithms is one of the comprehensive and systematic ways in tracking the health condition of different civil structures including: aerospace, offshore oil platforms, docks, rotating machinery, wind turbines, tunnels, bridges, buildings, railways, hydroelectric dams, pavements, deep foundations, geotechnical construction, etc. There are many research challenges and potential applications of SHM technologies for the civil sectors, specifically complex and heavy bridges during traffic loading events, environmental conditions, flood hazards, earthquakes, etc.

Diagnostic bridge testing is used to understand the distribution of the load throughout the structure, while long-term health monitoring is used to track changes over time in potential structural problems. For testing bridge structure, in which static, quasi-static and live loads can be applied to collect historical structural responses in the field used for load ratings and predicting load limits and overload via the finite element (FE) model calibration [2]. The FE model updating can be a powerful tool for determining the load-carrying capacity of existing bridges, used for the SHM system. Some bridges in Poland were tested under static and dynamic loads, as shown in Figure 1.

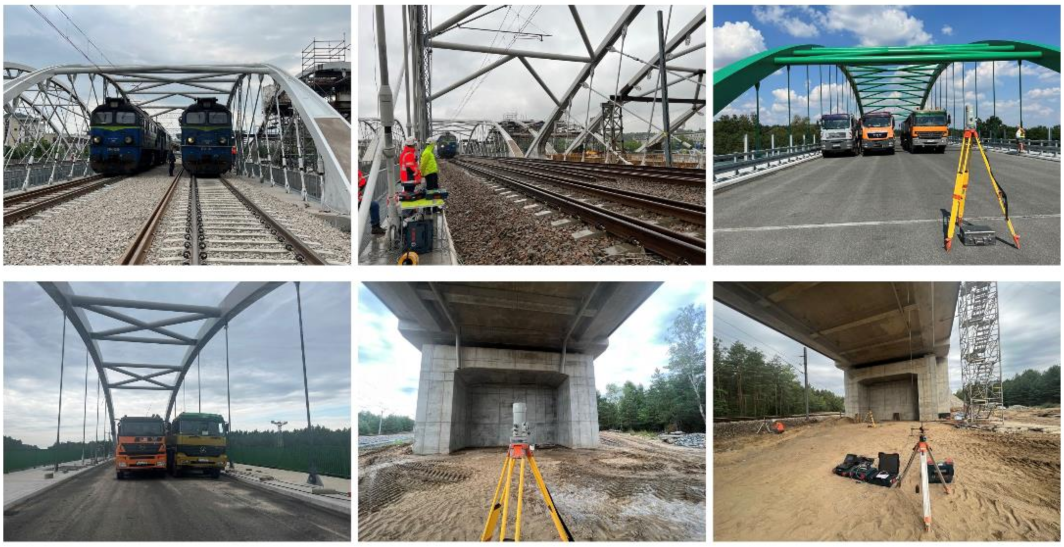

Fig. 1. Steel arch bridge load testing in Poland

2. SHM USED FOR DĘBICA RAILWAY STEEL ARCH BRIDGE

The Dębica railway bridge (Poland), consisting of two single-track railway arch bridge structures (72.8m in length each span) and a prestressed concrete span (17m). The structural members (or steel components) of the bridge are made of the steel grade S355J2+N (18G2A), while the material property of the concrete deck is C40/50(B50). The structural health monitoring system using vibration sensors was installed on bridge spans 1 and 2 to monitor hanger dynamic behavior during nine months (December 2019 - September 2020) [1], as shown in Figure 2. The hangers include the following W4NT1, W5NT1, W6NT1, W7NT1, W4ST1, W5ST1, W6ST1, W7ST1 for span 1; W4NT2, W5NT2, W6NT2, W7NT2, W4ST1, W5ST2, W6ST2, W7ST2 for span 2, in which each hanger was equipped with a bidirectional vibration sensor. For each span, the bridge deck was instrumented with an IEPE (Integrated Electronics Piezo-Electric), consisting of AT1 and AT2 sensors. The weather station was placed at the top of the arch to monitor weather events.

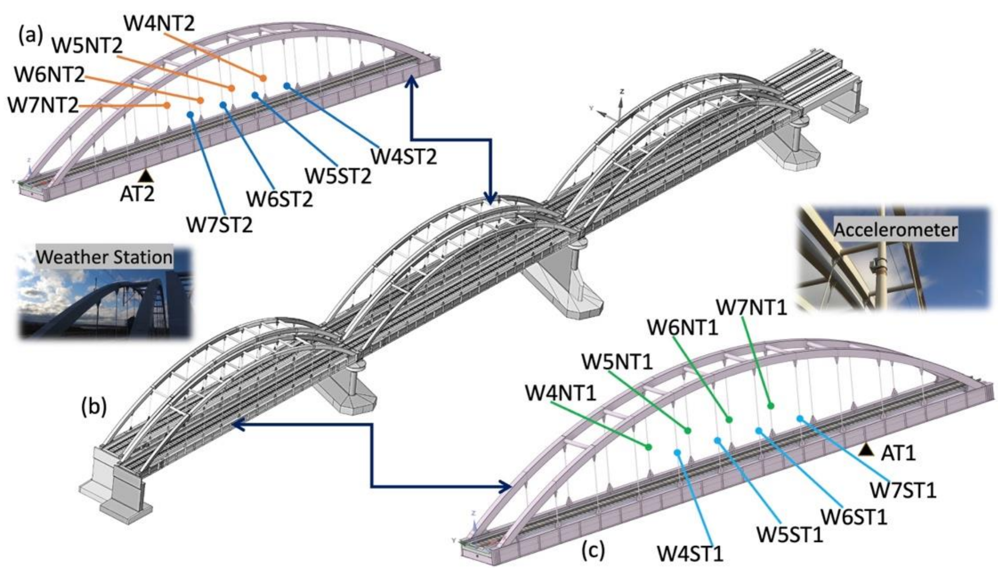

Fig. 2. Structural health system for the Dębica railway bridge in Poland: a) SHM used for span 2; b) railway bridge information; c) SHM used for span 1

3. DATA PROCESSING FOR SHM SYSTEM

The purpose of this section is to present an innovative solution to estimate both the tension force and the stress on each hanger. The tension force can be calculated using the natural frequencies of dynamic behavior of hanger monitoring collected from the SHM system, is described by the following equation, see equation 1 [3], [4], [5]. The stress of each hanger under train load events and wind excitation can be determined from the tension force, is defined in the equation 3.2.

$$F = \rho\, A \left(\frac{2\, L\, f_n}{n}\right)^2 \tag{3.1}$$

$$\sigma = \frac{F}{A} \tag{3.2}$$

where F is the tension force of hanger (N or Tons); ρ is the density of steel (kg/m^3); A is the section area (m^2); L is the effective length of hanger (m); f_n is the n^{th} natural frequency (Hz); σ is the stress (MPa).

4. RESULTS ACHIEVED AND DISCUSSION

In the following section, the estimated stresses of the hangers (W7S, W6S, W5S, W4S, W7N, W6N, W5N, W4N) on the bridge span 1 during nine months were analyzed and presented. Hanger health monitoring has been conducted under train load events and wind excitation to record vibration signals from each hanger (total of 8 hangers on each span) in the transverse (y-axis) and longitudinal (x-axis) directions. The measured natural frequencies of the hangers were estimated from the vibration analysis of the dynamic behavior of hangers using the FFT algorithm. The hanger vibration signals are analysed using "**pwelch**" function in the MALTAB software. The tension force and stress values of each hanger were determined from the acquired experimental natural frequencies using the above equations. From Figure 3 to Figure10 show the stress values of the hangers consisting of W4NT1, W4ST1, W5NT1, W5ST1, W6NT1, W6ST1, W7NT1, and W7ST1, respectively. The maximum, minimum, and average values of the hanger stresses for each month were illustrated in these graphs.

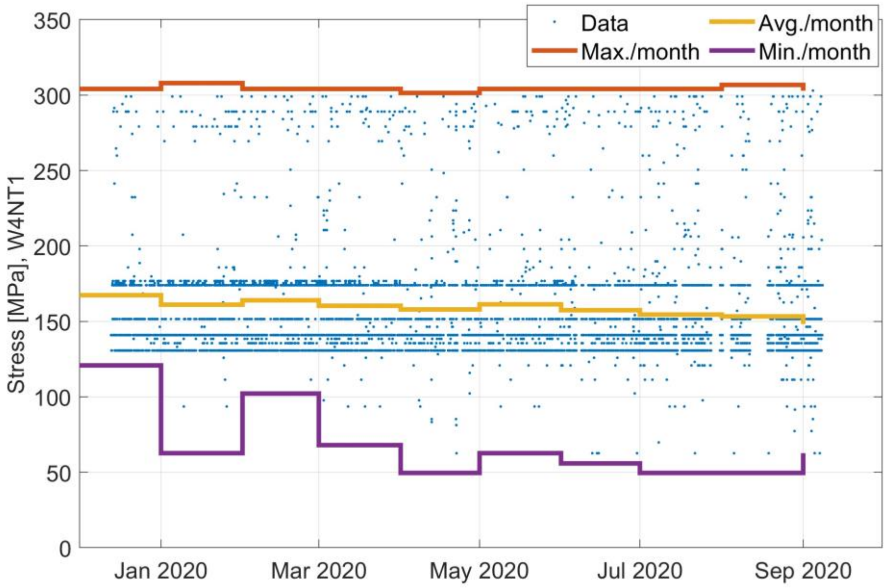

Fig. 3. The stress values for the hanger W4NT1

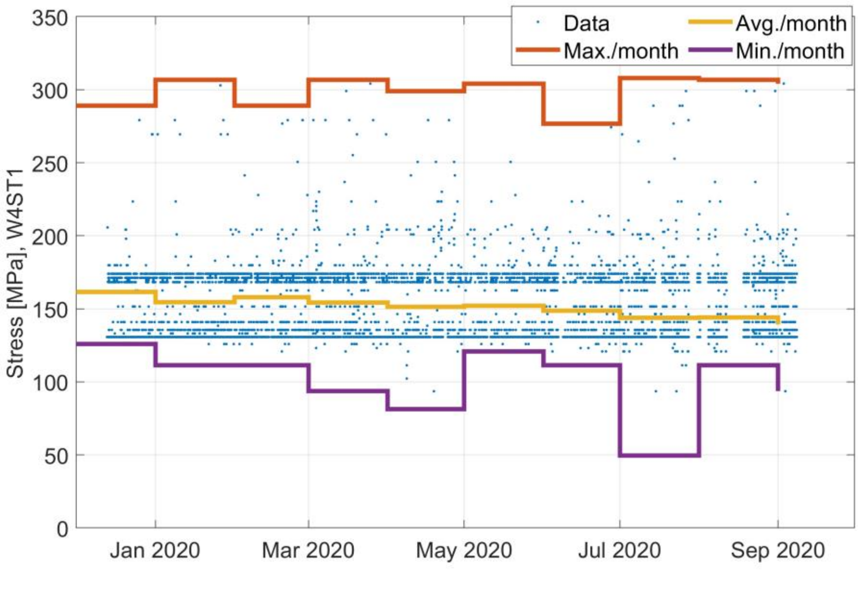

Fig. 4. The stress values for the hanger W4ST1

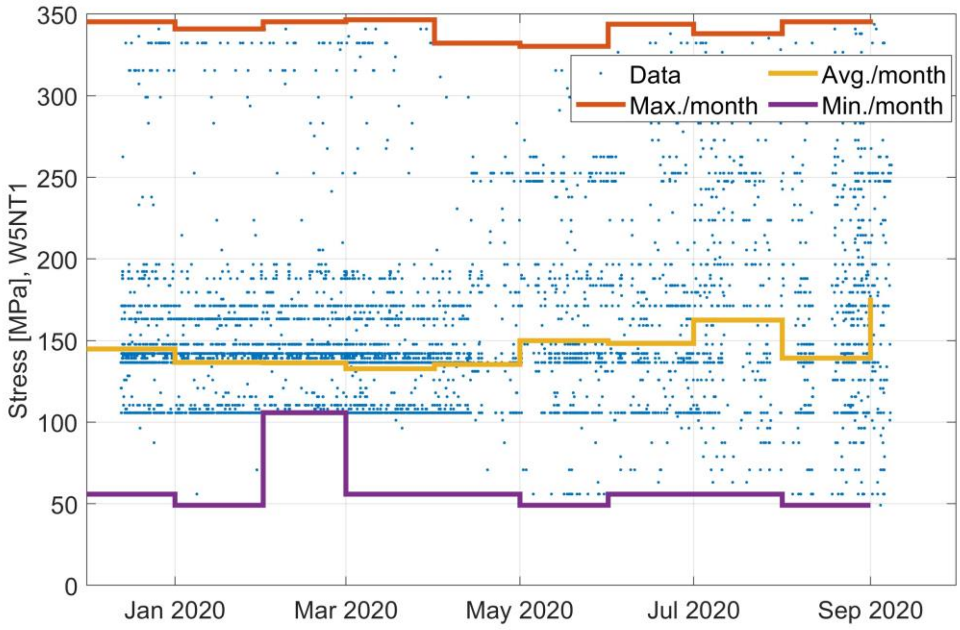

Fig. 5. The stress values for the hanger W5NT1

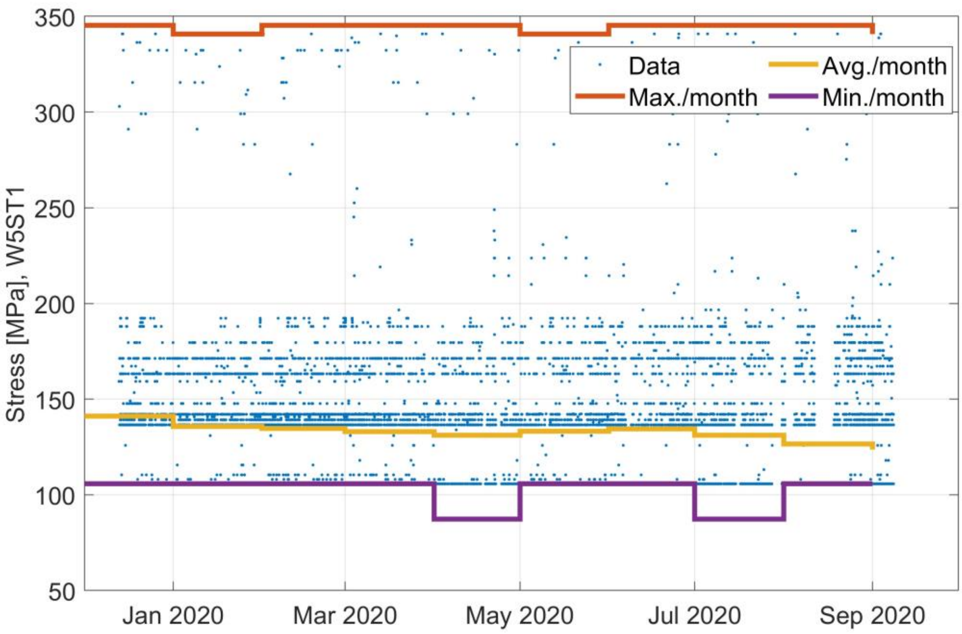

Fig. 6. The stress values for the hanger W5ST1

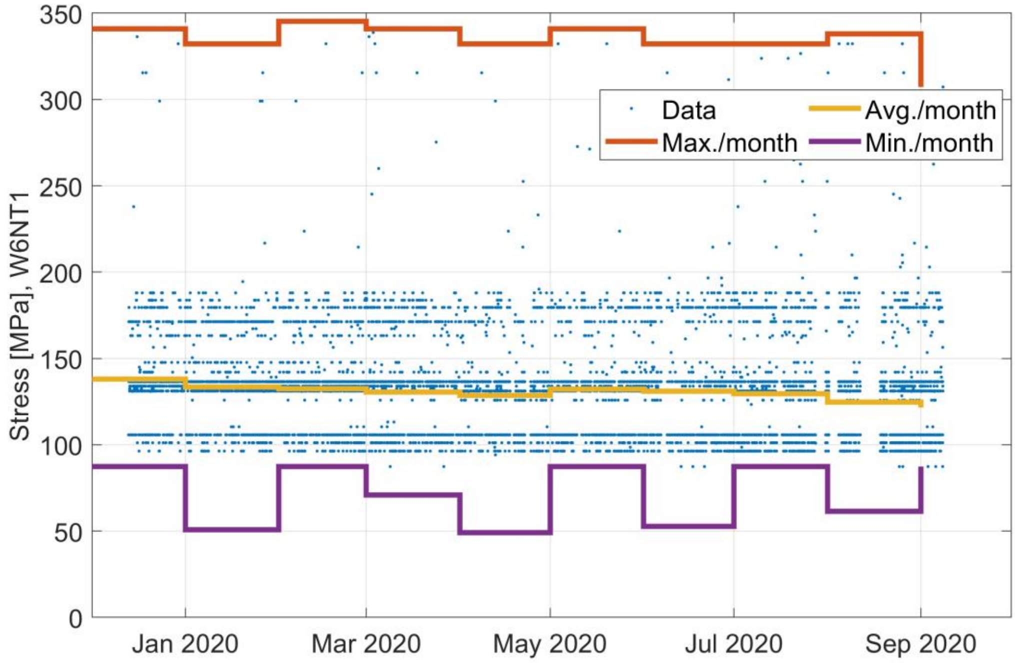

Fig. 7. The stress values for the hanger W6NT1

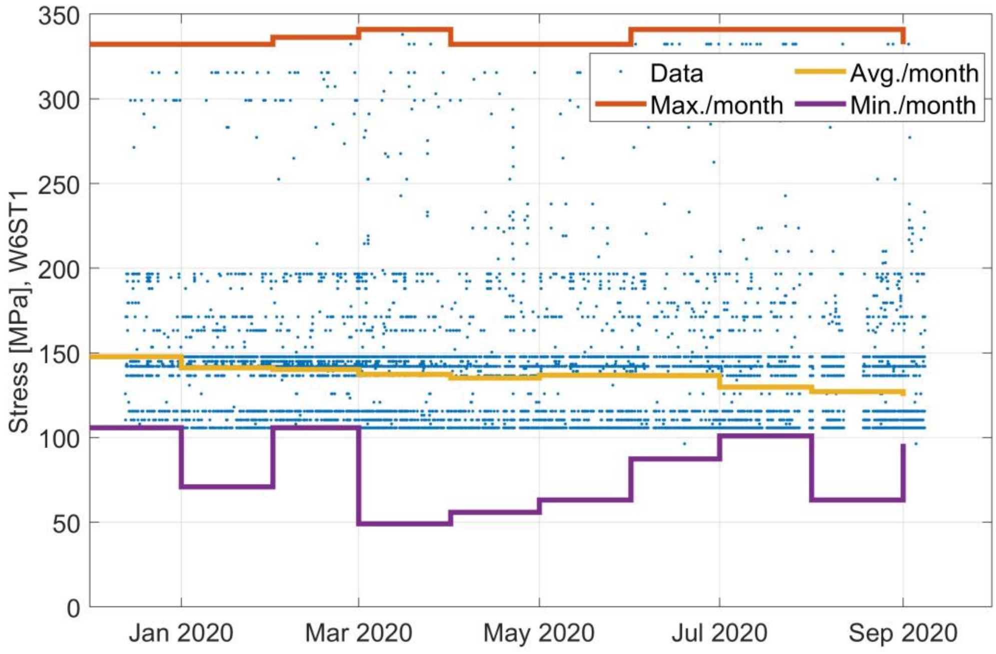

Fig. 8. The stress values for the hanger W6ST1

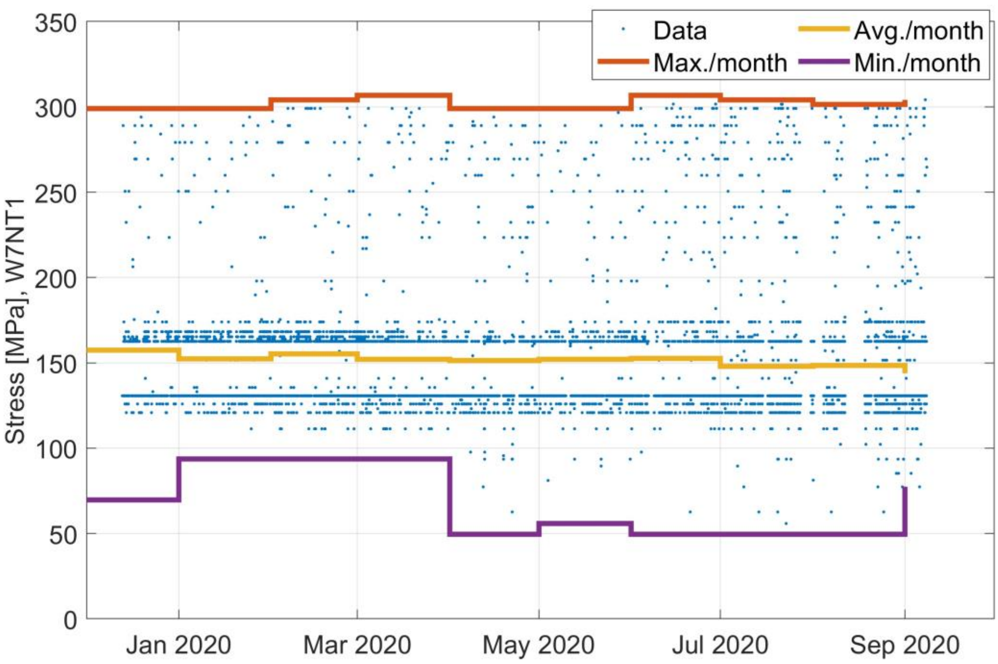

Fig. 9. The stress values for the hanger W7NT1

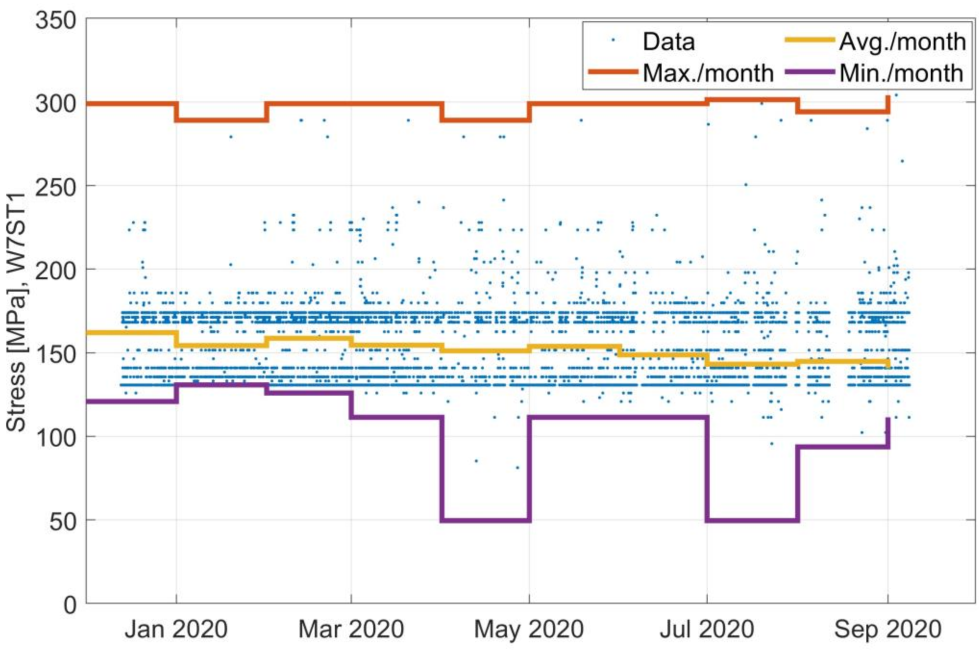

Fig. 10. The stress values for the hanger W7ST1

5. CONCLUSIONS

In this paper, the hanger health monitoring approach for the railway steel arch bridge based on vibration measurement was presented. Estimating the tension force and stress on each hanger was proposed to investigate hanger health conditions through a data-driven SHM system in the field. Based on the vibration measurement of the hangers, the natural frequencies of each hanger could be determined using the FFT algorithm. Hanger health states could be predicted via the tension force and stress values computed from the first, second or third natural frequencies on each hanger. The FE model can be considered to validate the load capacity of the hangers based on the measured tension force values in the field.

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