A Déli összekötő vasúti Duna hídon működő monitoring rendszer mérési eredményeinek értékelése

Evaluation of Structural Health Monitoring Measurements of Southern Danube Railway Bridge

***MANSI Ali** [1,2*], **DUNAI László** [1]*

1 Department of Structural Engineering, Faculty of Civil Engineering, Budapest University of Technology and Economics, Műegyetem rkp. 3, H-1111, Hungary
2 Department of Civil Engineering, Faculty of Engineering, University of Anbar, Ramadi 31001, Iraq
*Corresponding author, e-mail: aliismael.mansi@edu.bme.hu

Abstract

This study evaluates strain measurements recorded on the Southern Danube Railway Bridge (SDRB) by Structural Health Monitoring (SHM) techniques. A denoising process enhanced signal clarity while preserving key strain features. The analysis indicated correlations between strain signals and train characteristics such as axle load and configuration. Symmetric strain gauge data confirmed the reliability and consistency of measurements. Periodic monitoring highlighted the effects of environmental factors and ensured ongoing structural integrity.

Keywords: railway bridge, structural health monitoring, signal denoising, strain measurements evaluation.

Kivonat

A cikk a Déli összekötő vasúti Duna hídon rögzített feszültségmérések értékelését mutatja be szerkezeti monitoring technikák alkalmazásával. A mérési zajokat tartalmazó adatokat egy zajszűrési eljárással javítottuk, úgy, hogy a feszültségek szerkezeti viselkedés szempontjából fontos jellemzőit megőriztük. Az elemzésekkel meghatároztuk a feszültségek és a vonatok jellemzői – pl. tengelyterhelés és konfiguráció – közötti összefüggéseket. A szimmetrikusan elhelyezett szenzorok eredményei igazolták a mérések megbízhatóságát és konzisztenciáját. A mért feszültségekkel szemléltetjük a környezeti tényezők hatásait is.

Kulcsszavak: szerkezeti egészségmonitorozás, jelzajszűrés, feszültségmérések értékelése

1. INTRODUCTION

The increasing traffic volumes led to the rapid development and construction of road and railway infrastructures. Many steel bridges are still in service, reaching their design life [1]. Regarding steel railway bridges, a survey by the European Project on Sustainable Bridges found that most railway bridges are between 50 and 100 years old, 75% of steel railway bridges are over 50 years old, and nearly 35% are over 100 years old [2]. Research conducted by the American Society of Civil Engineers (ASCE) reveals that 80–90% of failures in steel structures are attributed to fatigue and fracture [3]. Moreover, due to numerous bridge collapses worldwide, it became evident that relying solely on visual inspections might be insufficient for accurately assessing bridge conditions [4]. Structural Health Monitoring (SHM) is essential for evaluating steel bridges, given the critical importance of their safety and integrity [5]. Fatigue is a crucial phenomenon; a recent research report revealed that 38% of metallic bridges fail because of fatigue [6]. Moreover, assessing the fatigue life of structural components in metallic bridges is a significant challenge for bridge engineers to ensure proper maintenance and management of these structures [7]. SHM measurements must be checked regularly for inquiries about the condition of structures, enhancing the maintenance process and avoiding risks of catastrophic failures.

The subject of the current study is the SHM system, installed on the new Southern Danube Railway bridge (SDRB). It is a symmetric through-truss structure that works in conjunction with the orthotropic deck system. It consists of three identical separated superstructures. The bridge carries Hungary's heaviest domestic and international railway traffic, so any interruption leads to critical economic and social consequences. Figure 1(a) shows the bridge built with six spans adapted to the existing substructures, measuring 49.26 + 4 × 98.52 + 49.26 meters; the structure's total length is 492.6 meters. The trusses consist of upper chords manufactured as hat sections with constant geometry along the entire bridge and welded I-sections for the truss members. The welded orthotropic deck system comprises I-section longitudinal girders, deck plates, and longitudinal stiffeners. The cross girders are arranged at a spacing of 8.21 m to match the lower joints of truss members. The cross-section of the orthotropic deck system is shown in Fig. 1(b). The truss is designed with an upper wind bracing system. The orthotropic deck includes a continuously supported, elastically fastened railway track system. A cantilevered inspection walkway is constructed on one side of the cross-section [8].

The research aims to evaluate the strain gauge measurements recorded by the SHM system. It has a focus on analysing signal characteristics, applying denoising techniques to improve data quality, and assessing the consistency and reliability of the measurements over time for accurate monitoring of the bridge's structural condition. This paper outlines the current stage of the research.

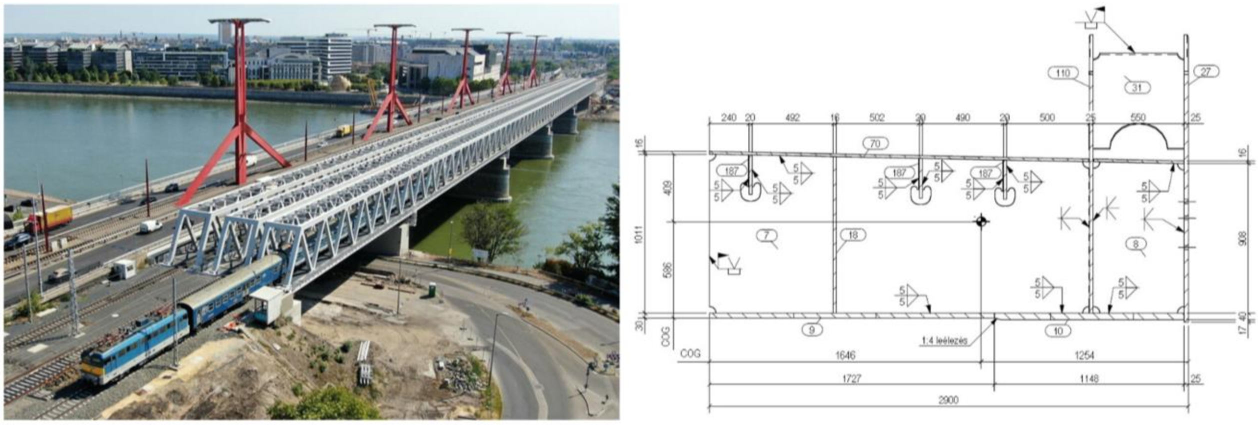

Figure 1: *(a) Southern Danube Railway.* *(b) Cross-section of the orthotropic deck Bridge.*

2. STRUCTURAL HEALTH MONITORING SYSTEM OF SDRB

Structural health monitoring systems significantly ensure structural safety, reliability, and longevity. The sensors embedded in or attached to structures continuously collect and analyse data; SHM systems can detect early signs of structural damage and deterioration. This enhances the timely maintenance, reducing the risk of catastrophic failure and minimizing repair costs. Additionally, SHM systems support efficient asset management and help optimize new structure design and lifecycle planning.

SDRB is instrumented with a long-term monitoring system consisting of various sensors such as displacement, strain gauge, thermometer, Barkhausen noise, axle load, and wheel detection sensors. To investigate the local condition of the bridge, 64 two-way strain gauges were fixed through each infrastructure at identical locations through the deck system and distributed over the cross girders. Figure 2 illustrates the typical locations of strain gauges over cross girder #72. The system uses data collectors to convert the data measured by the sensors into electrical signals and transmit it to the MÁV (Hungarian State Railways Co.) internal network. Then, the data is archived, evaluated, and stored in a database. The sensors of the monitoring system are divided into three main groups: (i) slow measurement sensors monitor the general condition of the structure at low sampling rates, (ii) fast measurement sensors detect changes caused by passing trains with high-frequency sampling, and (iii) periodic measurement sensors are conducted at designated intervals.

3. STRAIN GAUGE MEASUREMENTS

3.1. General

Strain gauges fixed to SDRB continuously monitor the structural behaviour and integrity of the bridge under train loads. These gauges are typically installed close to critical details of the structural elements where stress concentrations are expected, as shown in Fig. 2. The measured data provides valuable insights into the stress distribution, load impact, and potential fatigue over time. Continuous or periodic monitoring using strain gauges helps engineers ensure the safety and performance of the bridge, detect early signs of wear or damage, and make informed decisions about maintenance and repairs, ultimately extending the structure's lifespan.

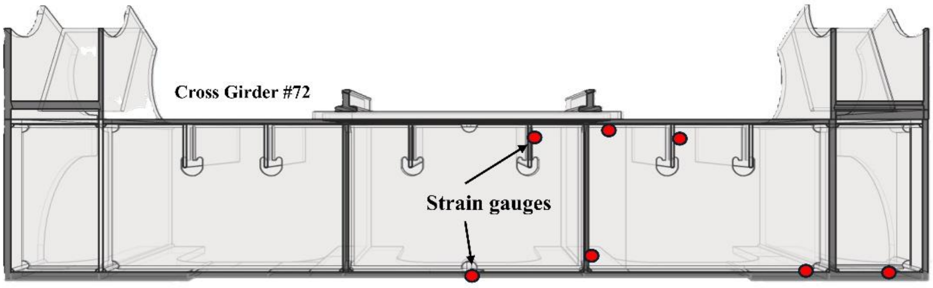

Figure 2: *Strain gauge distributions over the cross girder*

3.2. Signal denoising

The noise phenomenon is well-known for engineers working with dynamic measurements. Noise can be generated from various sources, such as sensor limitations, environmental and data transmission effects, which may corrupt the main features of signals and result in non-precise conditions. A critical issue within the SDRB strain gauge measurements is that it exhibits noisy pattern signals, which obscure significant signal details. Therefore, further evaluation cannot be achieved without overcoming the existing noise.

The current study investigated a parametric denoising process to remove the insignificant noise while preserving the critical signal details. Wavelet denoising transforms implementing five wavelet mother functions (Haar, Daubechies, Symlets, Coiflet, and Biorthogonal) conjugated by two universal (hard and soft) thresholding methods, which in turn use four threshold techniques (Sqtwolog, Rigrsure, Minimaxi, and Heursure) to eliminate the noise and preserve the critical signal details. Three evaluation metrics, signal-to-noise ratio (SNR), square root of the error (RMSE), and the correlation coefficient (CC), are used to estimate the denoising performance. Further smoothness refinement of the denoised signal is achieved by investigating two filtering techniques (lowpass and Savitzky-Golay) (this work is completed in a different paper). Figure 3 compares the filtered and raw signals recorded by a strain gauge of the cross girder.

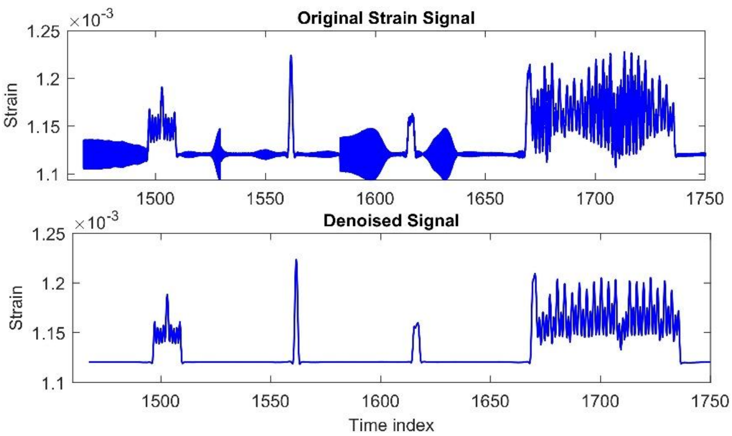

Figure 3: *Comparison of raw and denoised strains*

4. EVALUATION OF MEASURED STRAINS

4.1. Signal characteristics and interpretation

The strain gauges continuously record dynamic strain responses generated by passing trains. The characteristics of these signals are influenced by train-specific parameters such as axle load, number of axles, and train composition. Figure 4 presents stress time series recorded by the same strain gauge during the passage of different trains on separate days, each pulse represent the effect of single train. Despite being measured at different times, the signals display similar overall patterns, indicating that the trains likely share comparable configurations in terms of axle numbers and spacing. However, a noticeable difference in the baseline (i.e., the zero-load measurement) between the signals suggests the influence of environmental factors, such as temperature variations, on the strain gauge readings. This highlights the importance of accounting for thermal effects in long-term monitoring. Additionally, slight differences in the amplitude of stress peaks may point to variations in axle loads or train speeds. The consistency in signal shape and pulse spacing confirms the reliability and repeatability of the SHM system in capturing train-induced stress responses.

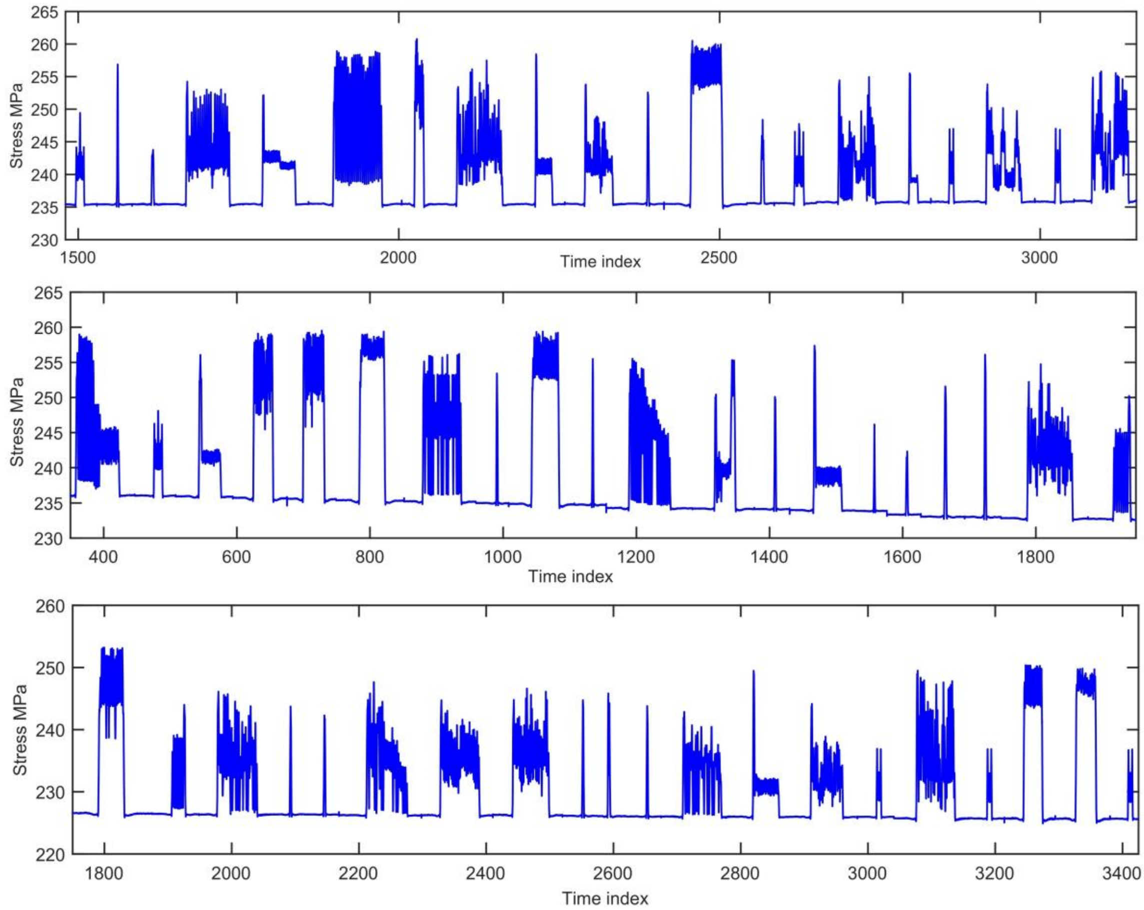

Figure 4: *Stress time series recorded by a typical strain gauge at separated days*

4.2. Consistency of strain gauges

The strain gauge measurements are evaluated by investigating the consistency of completely symmetric strain gauges. The study investigated the measured data from two strain gauges placed at symmetrical locations with identical material and geometric properties. Figure 5 demonstrates a stress time series measured by strain gauges due to the passing of two different trains; the first strain gauge, SG-1 is placed at the midpoint of cross girder #72, positioned at the centre of the bridge's third span on the Buda side. A second strain gauge, SG-2 is installed at the corresponding location at cross girder #48 on the Pest side. Although strain gauge baseline values vary, both sensors recorded identical signals with convenient stress ranges, indicating that strain gauges efficiently provide precise information.

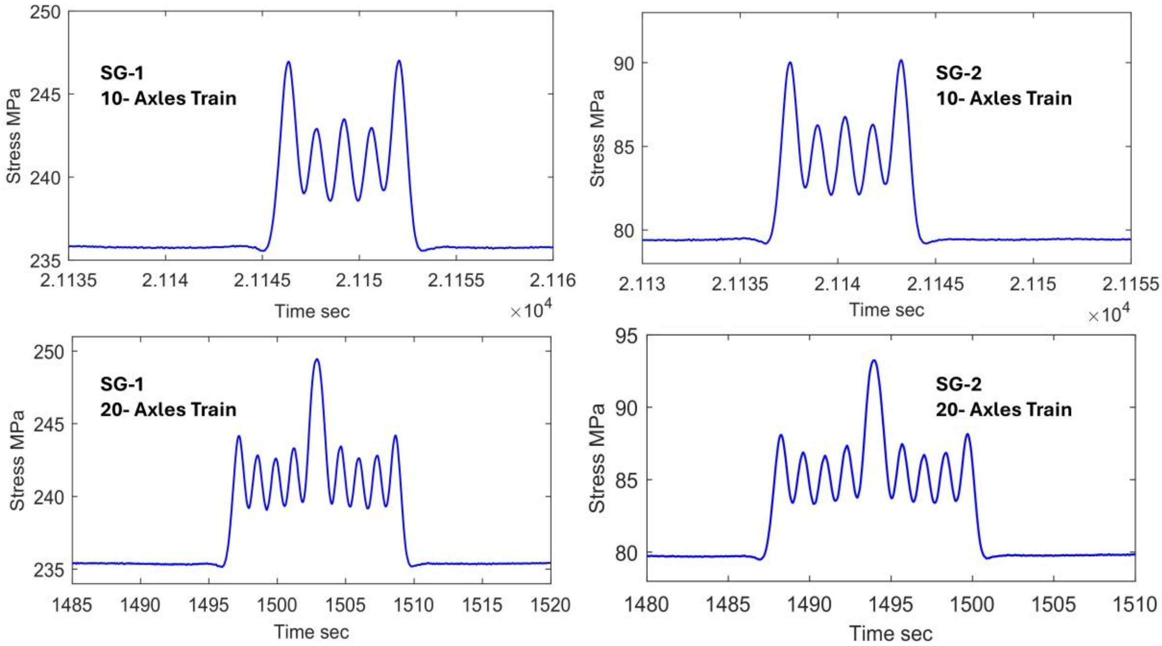

Figure 5: *Strains recorded by SG-1 and SG-2 strain gauges due to passing two trains*

4.3. Periodic evaluation of measurements

Bridge conditions may be exposed to deterioration due to loading, ageing, and weather effects, which may appear through the measurements. This study investigated the strain gauge measurements across different seasons to evaluate the effects of temperature variations and other factors on the bridge's structural behaviour. This seasonal monitoring helps to identify short-term changes due to thermal expansion or contraction.

Additionally, an annual evaluation of strain gauge measurements is conducted to detect the long-term trends or signs of structural deterioration, ensuring the ongoing safety and integrity of the bridge.

Figure 6 illustrates the stress-time series generated by the passage of an identical 10-axle train at various times throughout the year. This figure shows that the baseline value of the strain gauge (i.e., the zero-load measurement) varies over time, following the fluctuations in temperature. Additionally, the strain gauge consistently recorded similar signal patterns and stress ranges, suggesting that the bridge structure remains in good condition.

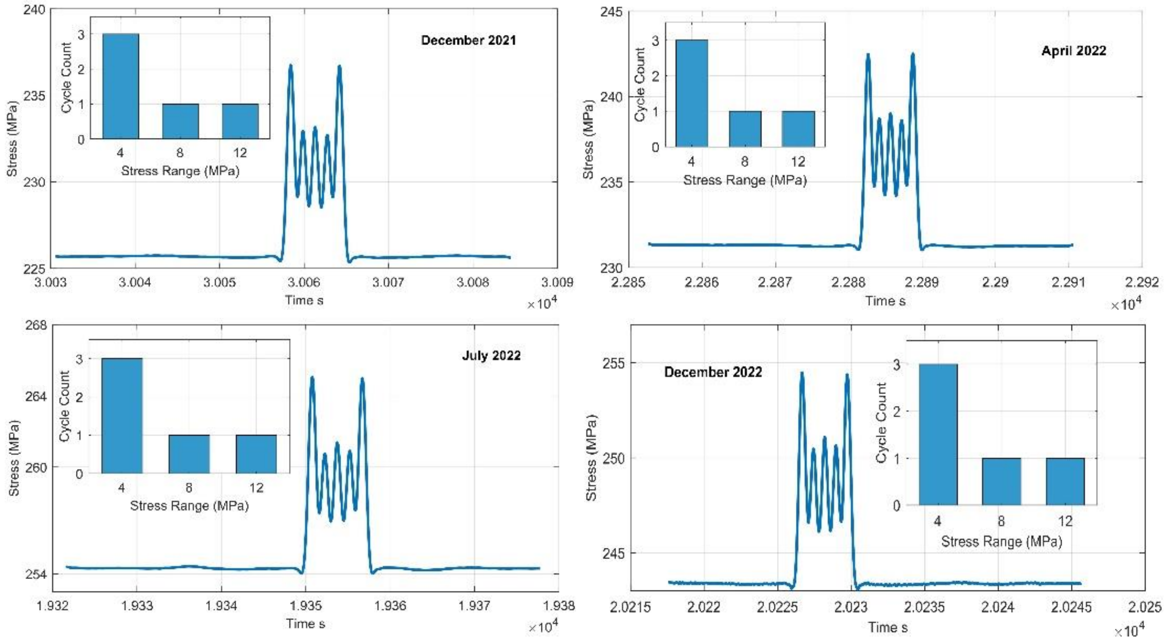

Figure 2: *Strain gauge measurements at different periods of time*

5. CONCLUSIONS

The study aimed to assess the effectiveness and reliability of strain gauge measurements as part of the SHM system installed on the new Southern Danube Railway Bridge. Based on the analysis and findings, the following key points can be highlighted:

- Strain gauge measurements effectively captured train-induced stress responses on the bridge.
- Train-specific parameters, such as axle load and configuration, significantly influenced the recorded signals.
- Wavelet-based denoising enhanced signal clarity while preserving critical structural information.
- Symmetrically placed strain gauges confirmed the reliability and consistency of the measurement system.
- Periodic evaluations showed consistent signal behaviour over time, indicating that the bridge's structural condition remains good.

The ongoing research work focuses on extending the use of strain gauge data for fatigue assessment of critical structural components on the bridge.

6. REFERENCES

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