Damage Detection for Aging Railway Bridges: A Monitoring and Machine Learning Approach

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This study introduces a real-time damage detection approach for bridges showing signs of damage or exceeding their expected service life. The method integrates monitoring and machine learning to build a data-driven approach for decision-making and damage identification. This involves monitoring critical components using strain gauges, accelerometers, and temperature sensors. Data collected at high frequencies is separated based on loading events, followed by feature extraction and real-time anomaly detection and classification using machine learning algorithms. The study uses a full-scale post-damage case-study of a steel-bascule-railway bridge, in service since 1916, with corrosion and fatigue signs. Results demonstrate the ability to capture a brittle cracking event in real-time, and classify different anomalies encountered during the monitoring campaign. The findings have significant implications for bridge owners, enabling real-time damage identification and prompt interventions.

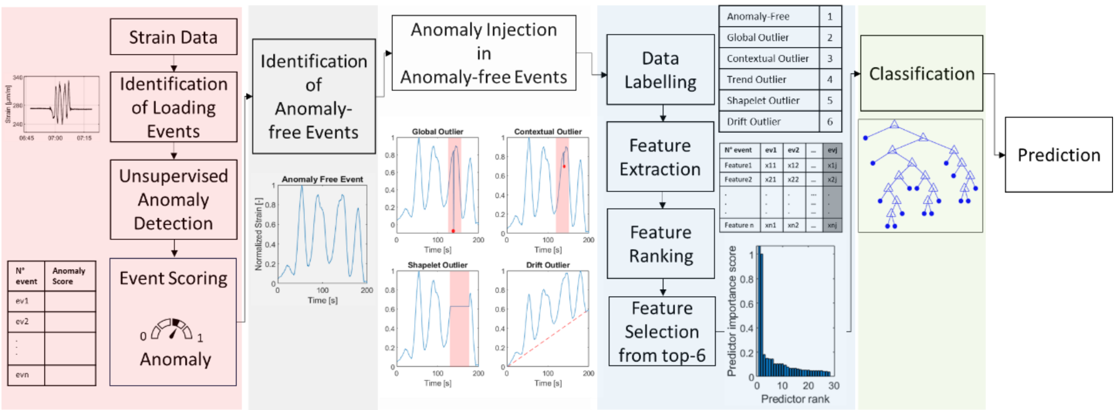

Figure 1. Methodology for supervised anomaly detection and classification in strain monitoring data for damage detection.

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Development of a measuring method for determining the displacement and load distribution behaviour of expansion joints on bridges

Rail expansion joints are deliberate separations in the track. Their purpose is to reduce the additional stresses on the rail resulting from the interaction between the bridges and the superstructure. However, the separation of the originally continuous welded rail means high dynamic forces and therefore high wear. According to Freystein (2012), other reasons for not using rail expansion joints are the high investment and maintenance costs and the negative impact on passenger comfort.

Rail expansion joints are affected by a number of different stresses, including traffic loads, weather influences and design-related constraining forces. The measurement principles used to determine the need for expansion joints are based on many assumptions that are no longer valid today. Field measurements and the development of specific measurement methods are essential to establish a systematic and clear correlation between the action and reaction of a rail expansion joint.

As part of the innovation alliance between DB InfraGo AG and the Institute for Transportation Infrastructure Engineering at the Technical University of Darmstadt, research has been carried out to update the design basis for calculating rail stresses in the superstructure of bridges. The aim of the current research is to develop suitable measuring methods for field measurements. In addition to conventional sensors such as inductive displacement transducers and strain gauges, optical sensors were also used. The measurements were verified by laboratory calibrations.

Figure 1. Field measurement directly on a rail expansion joint during a train crossing.

References

Freystein, H, “Untersuchungen zu den zulässigen zusätzlichen Schienenspannungen aus Interaktion Gleis/Brücke”, TU Berlin, Aachen, 2012

Investigating railway bridge dynamic factors through measurements

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Introduction

The quality of railway tracks deteriorates over time leading to an increase in load effects on railway bridges. While bridge design takes these into account in the form of a factor called ϕ'', current bridge design practices are based on simplified and conservative assumptions. This study aims to investigate the actual effects on a selected railway bridge which is considered to have potentially large dynamic effects due to a large irregularity of the track close to the bridge.

Analysis

Using a comprehensive measurement system equipped with various sensors, train passages of different types of trains were recorded over a defined period of time for thorough analysis. The collected data is used to calibrate and verify a 3D model of the bridge using the ABAQUS software allowing the effects of track irregularities to be isolated with simulations. Although the track irregularities themselves are not explicitly modelled, their influence is accounted for by adjusting the wheel-rail force depending on the track irregularities at the bridge’s location.

Conclusions

The results from the model and measurements indicate a dynamic load factor that is much lower than that prescribed by prevailing design standards. This work highlights the potential to refine current design methodologies and offers ways to improve the efficiency and sustainability of railway networks.

Figure 1. Train passing over instrumented bridge.

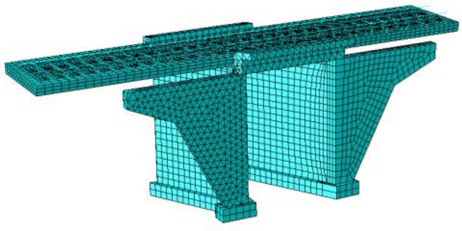

Figure 2. 3D model of studied bridge

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Quantifying error in finite-element models of Lundamo railway bridge

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The Norwegian railway network consists of a large number of bridges that have reached or exceeded their design service life. This includes the majority of the 900 steel railway bridges in the country. The initial design of these bridges did not account for modern axle loads and train speeds, nor fatigue limit states. Replacing every bridge that has exceeded its design service life would not be feasible due to immense construction cost, train service disruption, and environmental impact from replacing those bridges that are still safe. In order to assess the condition and remaining service life of bridges, finite-element models have been established using historical and future loads.

This project examines bridge damage due to fatigue – repeated loading and unloading that leads to the fracture of bridge components, and eventually their failure. Frøseth (2019) examined historical traffic conditions at bridges throughout the Norwegian railway network and identified fatigue as the primary cause of damage. Because of the difficulty of determining the precise load conditions at specific bridges, a conservative load model was developed using the train load that would cause the most structural degradation.

The accuracy of a remaining service life calculation is dependent on the accuracy of the relevant numerical model. In this project, field measurements from train passages over Lundamo bridge were collected using strain gauges affixed to each bridge component, and the results were compared to the values predicted by the model. Lundamo bridge, shown in Figure 1, is a steel bridge composed of three identical 20-meter spans. It crosses the Sokna river 38 track kilometers south of Trondheim.

Figure 1. Lundamo railway bridge.

This project quantifies the error in finite-element models in order to determine the accuracy of such models in predicting the remaining service life of bridges. In doing so, this research helps to improve the precision with which the effects of fatigue loading on remaining service life can be predicted.

References

Frøseth, G.T. (2019) "Load model of historic traffic for fatigue life estimation of Norwegian railway bridges", PhD Thesis, Norwegian University of Science and Technology.

Simplified dynamic soil-structure interaction of a three-span and a single-span high-speed railway bridge with integrated retaining walls

The increased velocity range of high-speed trains results in a broader excitation frequency. Consequently, the excitation frequency of the passing train may align with the natural frequencies of the railway bridge or their subharmonics. This alignment can induce excessive vibration levels in the structure due to resonance, potentially resulting in structural failure, passenger discomfort, and instability of the ballast system. The resonance response and vibration amplitude of the railway bridge are primarily controlled by its modal properties, which are significantly affected by the characteristics of the surrounding soils. Therefore, it is crucial to develop a simplified yet precise method to model the dynamic Soil-Structure Interaction of a railway bridge. This study analyzes a three-span and a single-span concrete slab railway bridge with integrated retaining walls. The surrounding soil components consist of the embankment soil located on the sides of the bridge, commonly referred to as the backfill soil, and the underpinning soil positioned beneath the shallow foundations of the columns and the end supports. The backfill soil is in direct contact with the bridge deck through the integrated structure. The studied bridges are equipped with multiple accelerometers and subjected to experimental testing using a hydraulic actuator, conducting linear frequency sweeps with different load amplitudes. In this study, full 3D models of each bridge-soil system are created using solid elements in Abaqus and calibrated to the experimental data using Frequency Response Functions obtained at each sensor location. Furthermore, simplified 2D models of each bridge-soil system are developed using beam elements in Abaqus, with the influence of surrounding soils modeled using concentrated springs and dashpots at the location of each soil component. The properties of these springs and dashpots are obtained from the impedance functions of the backfill soil and the underpinning soil for each degree of freedom. The resulting 2D beam models show good agreement with the 3D models regarding the modal properties of the first bending mode, which is the governing mode during high-speed train passage. Lastly, a comparison is conducted between the calibrated 3D models and the simplified 2D beam models regarding the maximum acceleration response of the bridge due to high-speed train passages.