STRUCTURAL HEALTH MONITORING OF A RAILWAY TRUSS BRIDGE USING LOW- AND HIGH-FREQUENCY METHODS

PRZEMYSŁAW KOŁAKOWSKI[1,2], JACEK SZELĄŻEK[1],
KRZYSZTOF SEKUŁA[1,2], ANDRZEJ ŚWIERCZ[1,2]
[1]*Institute of Fundamental Technological Research, Polish Academy of Sciences, Pawińskiego 5B, 02-106 Warsaw, Poland, e-mails: pkolak@ippt.gov.pl, jszela@ippt.gov.pl, ksekula@ippt.gov.pl, aswiercz@ippt.gov.pl, web: http://www.ippt.gov.pl*
[2]*Adaptonica sp. z o.o., R&D company, Szpitalna 32, 05-092 Łomianki, Poland, web: http://www.adaptronica.pl*

Abstract

The paper presents results of in-situ investigation of a railway truss bridge in the context of SHM. Three experimental methods are examined. Dynamic responses of the bridge recorded by strain gauges are confronted with alternative ways of acquisition using piezoelectric sensors and ultrasonic probeheads. Numerical model corresponds to experimental data.

1. Introduction

A railway bridge has been the object of investigation since mid 2007 as a response to increasing interest in SHM by Polish Railways. The final objective of the investigation is to design, test and implement an SHM system dedicated to railway infrastructure.

The patent-pending monitoring system [1] consists of two integrated parts. The first part is responsible for weighing of trains in motion, which aims at dynamic load identification. The second part is the actual SHM system applied to the railway truss bridge. The source of excitation for the bridge are passing trains only, which can be regarded as ambient excitation in terms of type. However the integrated system includes the weighing of trains in motion, which will determine the character of excitation unlike in operational modal analysis. There are many aspects of the whole system to be examined and tested e.g. measurement methods, design of customized hardware, development of monitoring software. Some of them have already been reported [2] - [3].

This paper is concentrated on measurement methods applied to monitor the structural health of the selected railway truss bridge. Dynamic strain is the measured physical quantity. Three methods of strain-in-time acquisition taking advantage of dynamic excitation of the bridge by passing trains are tested and compared. Low-frequency direct registration of strains with piezoelectric patch sensors and standard strain gauges is confronted with a high-frequency method using the time of flight difference for elastic waves between two closely-mounted ultrasonic probeheads. The paper will present experimental results obtained with the three methods and also show the conformity of the corresponding numerical model of the bridge to these results.

2. General view of the monitoring system

The investigated object is a typical railway truss bridge spanning a channel in Nieporet near Warsaw. There are several hundreds of similar bridges of various spans all over Poland. The bridge, shown in Fig. 1, is made of steel and has a span of 40 m and height of 8 m. The rail traffic on the bridge is rather low. Like many other bridges it is just visually inspected once in a few years, which is the basis of maintenance decisions.

Fig. 1 Investigated railway truss bridge in Nieporet

The patent-pending monitoring system [1] consists of two integrated parts as depicted in Fig. 2. The first part is responsible for weighing of trains in motion, which aims at dynamic load identification. The second part is the actual SHM system applied to the railway truss bridge pictured in Fig. 1.

The weigh in motion (WIM) part of the system provides a load input for modelling of bridge responses. The idea is somewhat similar to the ambient excitation in the sense of using an existing source to make the structure respond, but is different in the sense of quantifying the input force. The WIM part is supposed to weigh the passing trains at their actual velocities. It should be mounted in the vicinity of a monitored bridge e.g. 50 m away. This part may also exist on its own to provide information about rail traffic.

The bridge monitoring part assumes a calibrated numerical model regularly supplied with measurement data sent remotely via the Global System for Mobile (GSM) communications. The data include both the load information from the WIM part and the bridge responses to passing trains (see Fig. 2). By determination of deviations in the measured bridge responses, exceeding a pre-defined threshold value, the damage detection stage is satisfactorily completed. The more advanced stage of damage identification employs a VDM-based numerical analysis [4], which points out defective elements of the monitored truss structure and quantifies the intensity of damage in such elements. With a record of archived results e.g. 3 year regular monitoring, the structural degradation rate and remaining lifetime may be assessed.

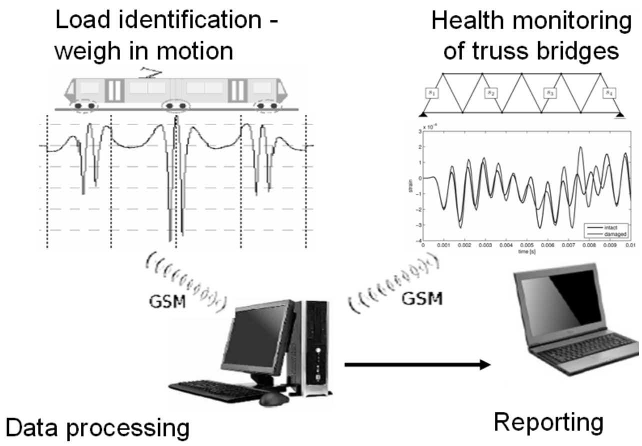

Fig. 2 The integrated monitoring system for railway truss bridges: left – weigh in motion part, right – structural health monitoring part

3. Vibration-based measurements

In Fig. 3 the location of all sensors mounted on the bridge for SHM is shown. In location 2, three concurrent measurements were carried out – ultrasonic, piezoelectric and strain gauge sensors. This location has been chosen for comparison of responses in section 6.

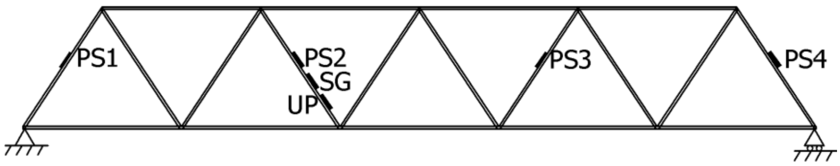

Fig. 3 Layout of sensors mounted the on bridge for SHM purposes: PS – piezosensor, SG – strain gauge, UP – ultrasonic probe

Vibration responses of the bridge due to passing trains were collected by two types of sensors. Standard strain gauges were used to obtain reference responses. Additionally, piezoelectric sensors were glued to the bridge elements as an alternative. There were two types of piezoelectric sensors used – PFC (piezo fibre composite) and PZT (piezoceramic material) – producing very similar results. All the mentioned types of sensors applied to collect vibration responses of the bridge are pictured in Fig. 4.

The strain gauge was operating in the half bridge configuration. Piezoelectric sensors were connected to charge amplifiers in order to provide proper processing of the very low frequency content (below 1 Hz) in the acquired signal.

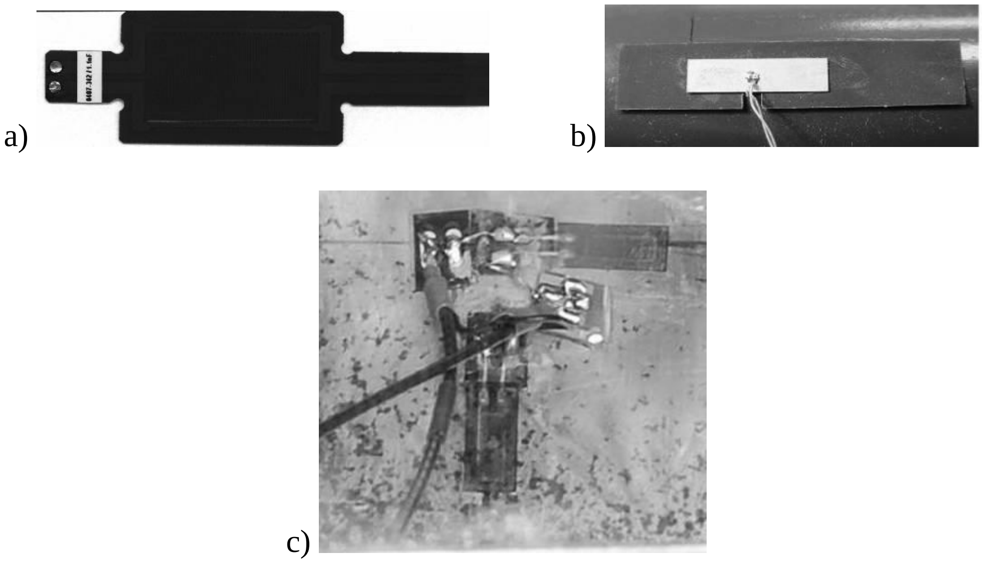

Fig. 4 Types of sensors used: a) PFC, b) PZT, c) strain gauge

4. Ultrasonic measurements

In the ultrasonic IMPUL system, pulses of longitudinal waves are used to determine stress changes. A scheme of measurements is presented in Figure 5. Two ultrasonic probeheads, equipped with piezoelectric transducers, plastic wedges and strong, permanent magnets are acoustically coupled to the surface of the element under investigation. Machine oil is used as a couplant. One probehead transmits ultrasonic pulses, the other one – receives. The angle of plastic wedges is equal to the first critical angle allowing for generation of longitudinal waves propagating close to the surface (subsurface waves). Such waves can be detected by the receiving probehead situated on the same surface. Due to ultrasonic beam divergence, it propagates also oblique to the surface, reaches the opposite surface of the investigated element and after reflection is received by the receiving probehead. The distance between probeheads, depending on the element thickness, is between 200-300 mm. During the measurements presented in section 6, this distance was 300 mm. Probeheads are connected to an ultrasonic device generating and receiving ultrasonic pulses. This device measures the time of flight (TOF) with nanosecond accuracy.

In stress free state the distance between probes is *L*. TOF for subsurface wave depends on the velocity of longitudinal wave, distance between probeheads, material grade and material and probeheads temperature. For the reflected wave TOF depends additionally on specimen thickness.

In a stressed state the distance between probeheads, fixed to the sample surface, changes due to material deformation. Also, due to the elasto-acoustic effect, the velocity of longitudinal wave changes. The TOF of the reflected wave will also change due to the specimen thickness changes (Poisson effect).

The velocity of subsurface longitudinal wave is in practice not influenced by the condition of the element surface. This advantage allows to use this type of wave on elements covered with paint or debris. To perform the measurement it is necessary to remove the paint only in places under the probehead faces. In the measurements presented in section 6, the longitudinal wave frequency was 2 MHz. For this frequency, longitudinal wave can be effectively generated and detected with the 0.5 mm paint layer.

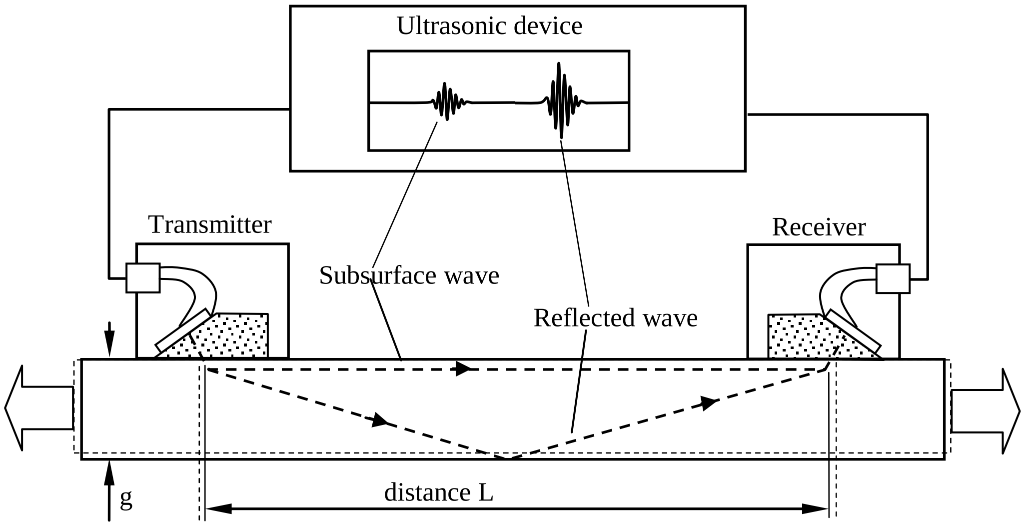

Fig 5. Scheme of the TOF measurement with longitudinal subsurface and back reflected waves (IMPUL system)

5. Numerical model

The WIM part of the system provides input for the SHM part. Knowing the dynamic load exerted on rails by a passing train, one can perform time-domain VDM-based dynamic analysis as explained in [4]. With a numerical model of the bridge, schematically depicted in Fig. 6 we can determine responses of the bridge excited by a passing train using the Newmark method of integration of equations of motion.

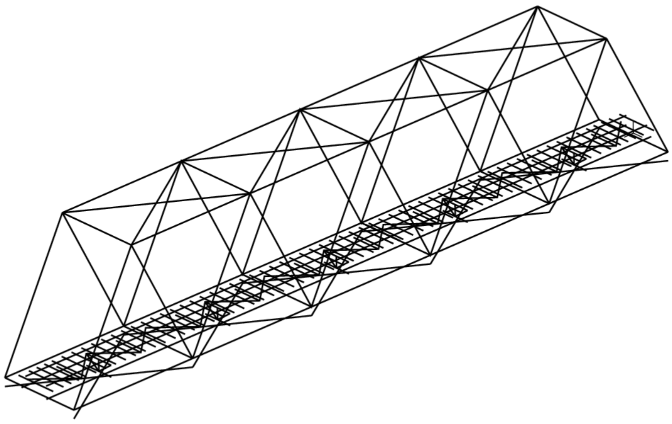

Fig. 6 3D model of the bridge built in ADINA

The model has been built using technical documentation made available by Polish Railways. The stage of calibration of the model to experimental responses is still a challenging task to be accomplished. Once this has been done, the identification procedure described in [4] can be run.

In fact, the justification of building the model in a commercial FE program ADINA is a user-friendly way of visualizing it. Our in-house code lacks a professional post-processor. The mechanical characteristics of the bridge will be contained in the influence matrices, which are series of responses due to local perturbations calculated with the ADINA model. If the matrices are extracted from the commercial program, our in-house software will be used solely for identification purposes.

6. Confrontation of results

Figures 7-9 depict a comparison of experimental responses collected with all types of sensors and confronts them with the described numerical model. Generally, good conformity can be observed.

7. Conclusions

In this paper three alternative methods of collecting dynamic responses of a bridge subjected to the passing train load have been presented. Measurements by standard strain gauges were compared with alternative ways using piezoelectric patch sensors and ultrasonic probeheads. The obtained conformity of the experimental results is satisfactory. The good matching observed between the ultrasonic and non-ultrasonic methods validates all measurements. The ideal numerical model discards some nuances which are present in in-situ collected signals.

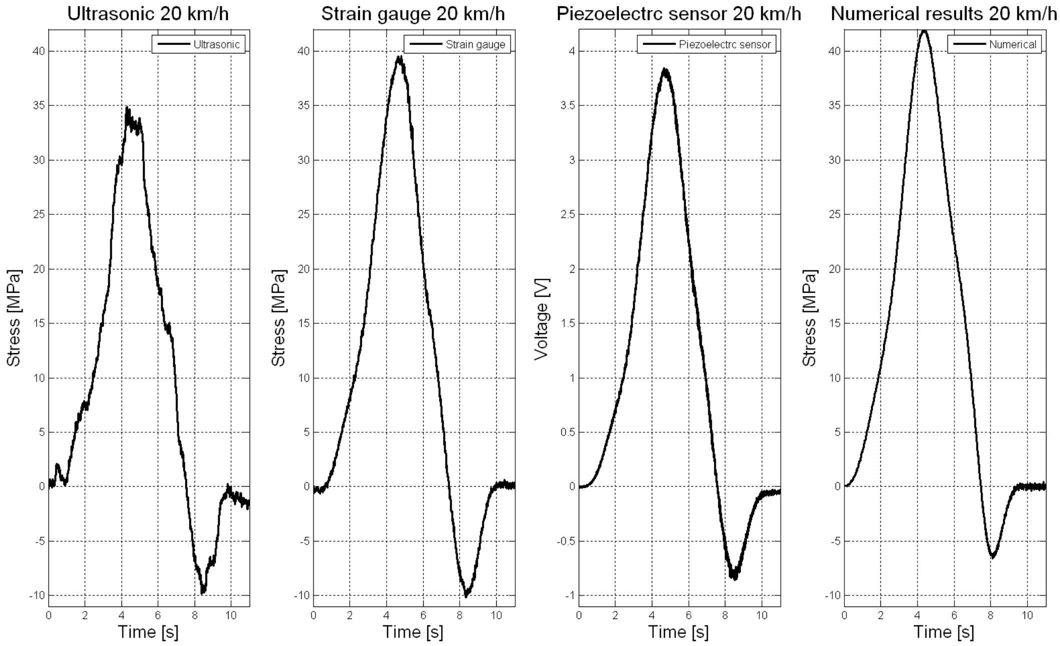

Fig. 7 Response of diagonal truss member due to passage of the ET-22 locomotive at 20 km/h a) ultrasonic probeheads, b) strain gauge, c) piezoelectric sensor, d) numerical model

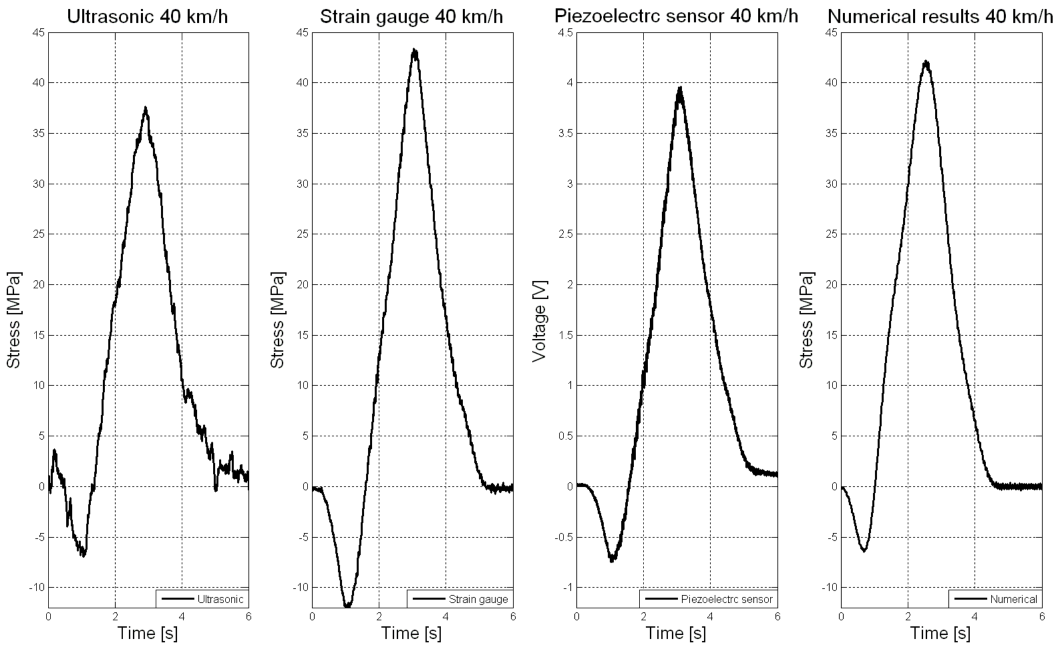

Fig. 8 Response of diagonal truss member due to passage of the ET-22 locomotive at 40 km/h a) ultrasonic probeheads, b) strain gauge, c) piezoelectric sensor, d) numerical model

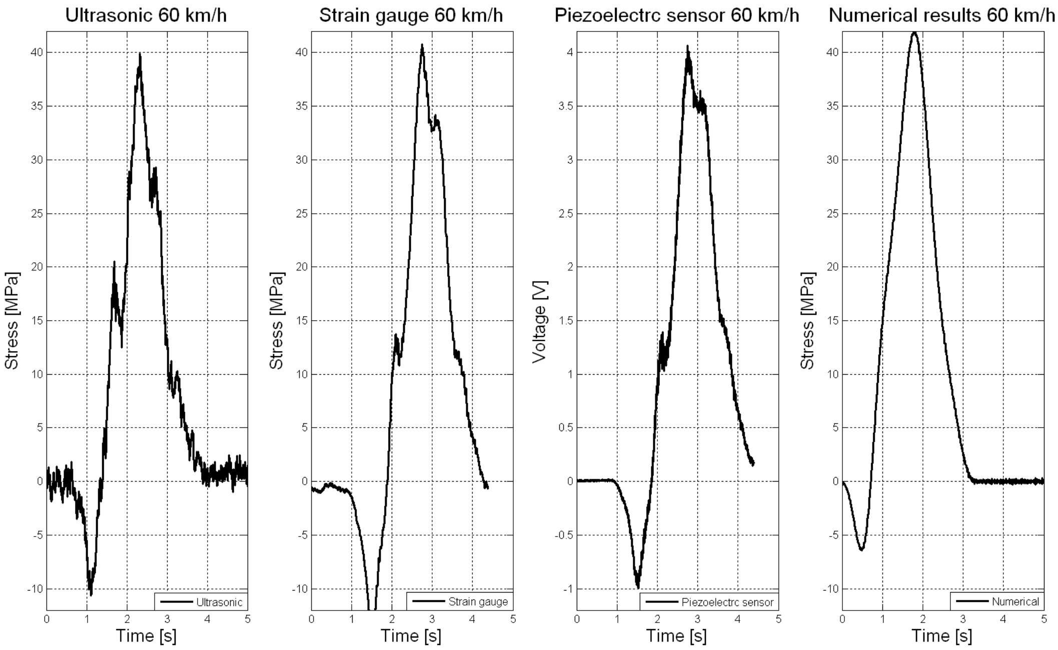

Fig. 9 Response of diagonal truss member due to passage of the ET-22 locomotive at 60 km/h a) ultrasonic probeheads, b) strain gauge, c) piezoelectric sensor, d) numerical model

Acknowledgements

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