26th International Conference
ENGINEERING MECHANICS 2020
Brno, Czech Republic, November 24 – 25, 2020

RADAR INTERFEROMETRY TESTS OF THE BRIDGE RESPONSE DURING FULL TRAFFIC

Lamperová K.*, Sokol M.**

Abstract: *This paper is devoted to measuring and evaluating displacements of the Prístavný most in Bratislava, Slovakia. It is a combined four-span highway and railway bridge with a length of 460.8 m. It is important to have knowledge of the functioning of the observed structure. Without a thorough and detailed numerical analysis, it is very difficult to correctly evaluate all measured data. Without detailed calibrated numerical models, in some cases it would not be possible to verify response of the structures. By comparing the numerical calculations and the measured data, we have the possibility to detect some structural defects that may not be visible. At the same time, we were be able to verify the impact of some non-structural elements of the structure on its behavior.*

Keywords: Structural health monitoring, Radar interferometry, Numerical model.

1. Introduction

Structural health monitoring (SHM) of bridges is a very important topic worldwide. The reason is the increasing age of bridge structures and insufficient maintenance. In addition to conventional structural response measurement methods, many research teams will choose for less widespread displacement measurements using interferometric radar (Sokol, 2019; Talich, 2019; Pieraccini, 2019; Raventós, 2017; Gocal, 2013). Radar interferometry is a technology for measuring distances and displacements of multiple points simultaneously using interferometric radar. Radar measurements are particularly suitable for measuring displacements of structures with restricted access or in situations where very rapid remote monitoring of the structure is required. The radar transmits microwave frequencies in very short pulses, and distances are determined based on the time difference between the transmitted and received (reflected) signals (IDS, 2010; Gentile, 2010). Depending on the intensity of the reflected signal, a measurement accuracy of 0.1 mm can easily be achieved (IDS, 2010). The use of this technology is therefore very suitable for measuring the response of a structure without traffic restrictions on the bridge. During measurement, traffic situation must be thoroughly recorded with a video camera to enable later verification of the correct functioning of the structure by numerical simulations. Traffic restrictions are very expensive. It is therefore an affordable monitoring without interrupting the traffic.

This paper is devoted to measuring and evaluating displacements of the Prístavný most in Bratislava, Slovakia. It is a combined motorway-railway bridge with a length of 460.8 m, which consists of four spans. The main structure has two floors. There is a railway line in the lower part of the bridge and a highway in the upper part. In the lower part there are footbridges for pedestrians and cyclists on both sides of the bridge.

2. Numerical model of the bridge

When monitoring the condition of bridge structures, it is very important to know the functioning of the observed structure. Experience has shown that without a thorough and detailed numerical analysis, it is very difficult to evaluate correctly all measured data. Without calibrated numerical models, in some cases it would not be possible to verify the proper functioning of the structures. By comparing the numerical

* Ing. Katarína Lamperová: Department of Structural Mechanics, Slovak University of Technology, Faculty of Civil Engineering, Radlinského 11; 810 05, Bratislava; SK, katarina.lamperova@stuba.sk

** Prof. Ing. Milan Sokol, PhD.: Department of Structural Mechanics, Slovak University of Technology, Faculty of Civil Engineering, Radlinského 11; 810 05, Bratislava; SK, milan.sokol@stuba.sk

calculations and the measured data, it is the possible to detect some structural failures that may not be visible. At the same time, we can verify the influence of some non-structural elements on its behavior.

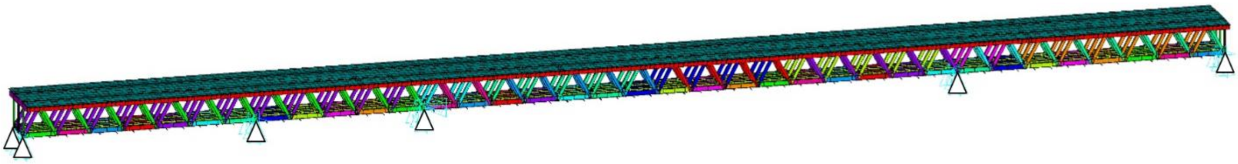


Fig. 1: Numerical model of the bridge.

A detailed FEM model has been created (Fig. 1). The model was calibrated and verified to provide a good match of stresses, displacements, eigenfrequencies and eigenmodes compared to experimental measurements.

3. Measuring using the interferometric radar

Interferometric radar IBIS-S was used to measure the displacements of this structure. The measurement was carried out without traffic restrictions on the bridge. Traffic was recorded with the video camera during the measurement. Using these records, it was possible to realize numerical simulations, when the real traffic load was applied to the numerical model (Fig. 3). These calculated displacements were compared with the measured data. The difference between the test and numerical data was significant (up to 25 % - Tab. 1). It was necessary to find out the reason for the difference between the data. The question was whether it is a result of measurement error or change in the functioning of the structure. Regarding the accuracy of the measurements, we focused on the structure, namely the condition of bearings connecting the upper concrete deck to the steel structure (Fig. 2).

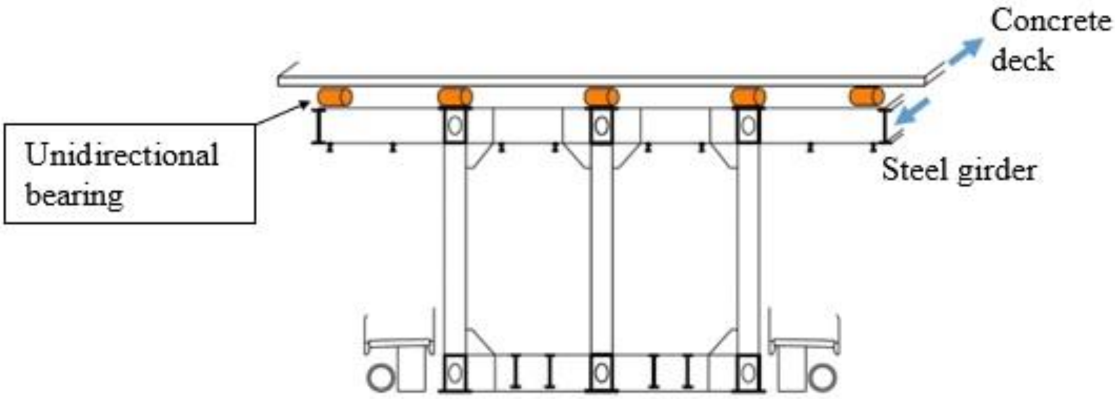


Fig. 2: Friction forces in bearings.

Since we do not know the condition of the bearings connecting the steel structure to the concrete deck, several alternatives had to be investigated numerically. The first alternative was that the bearings function perfectly, and therefore we consider the friction coefficient in the bearing with value 0.00. Another alternative was when we considered the opposite state and the friction in the bearing was 0.95 – 1.00. The last alternative was such a situation that the friction coefficient in the bearing was assumed with a value only 0.10.

Fig. 3 shows a comparison of the displacement record of the measured point Bin63 (black line) and the calculated displacement values with different friction in the bearings (friction 0.00 - red dotted line, friction 0.10 - green dashed line, 0.95 – 1.00 - solid orange line). Figure also contains a picture of the selected traffic situation at time t = 96 s, when the displacement of the Bin63 point was maximal. A more significant displacement between 90 s and 100 s causes the passage of a personal train (situation A) in direction form Bratislava, Ružinov. At the same time, there are several trucks on the bridge in the direction from Bratislava, Petržalka.

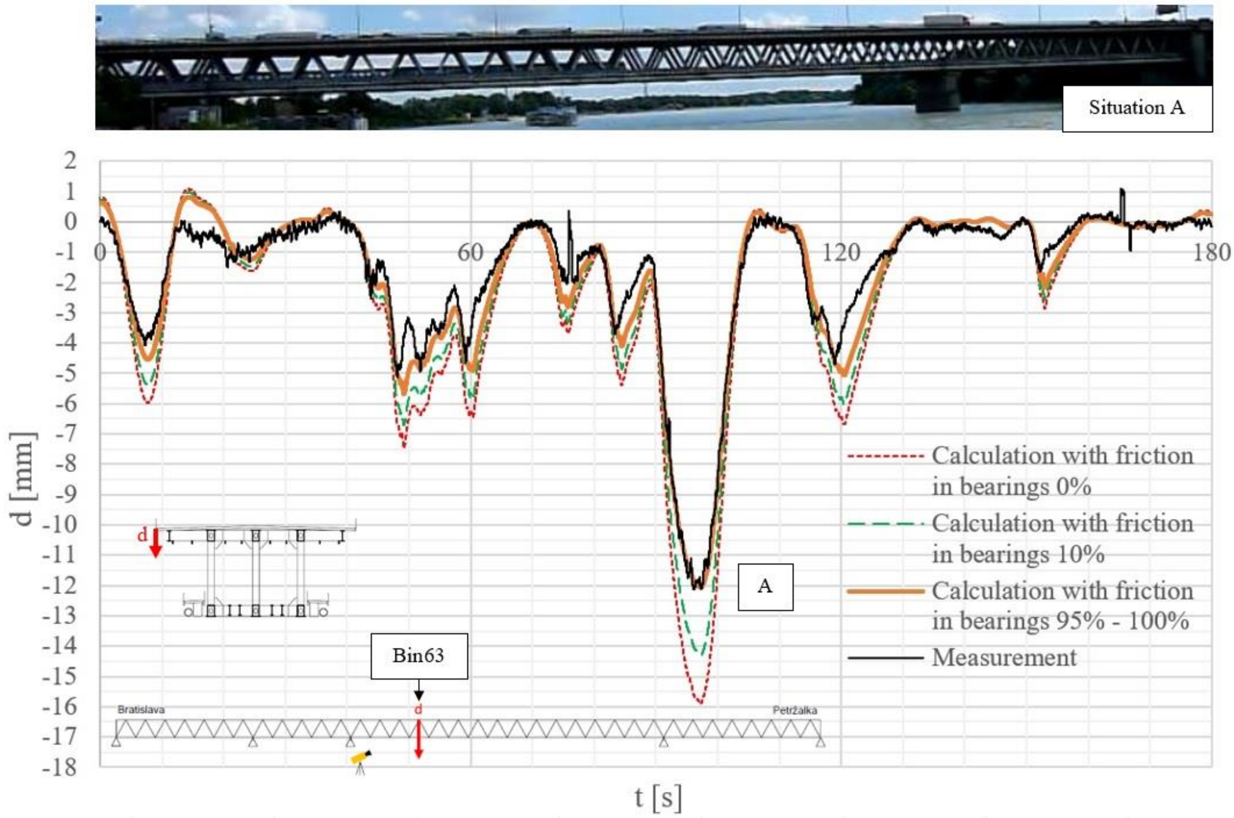


Fig. 3: Comparison of measured and calculated displacements.

The maximum displacement of the measured point Bin63 in situation A d_{test} was 11.9 mm. Numerically determined values of displacements d_{num} of this point are shown in Tab. 1. The performance indicator (PI_d) according to equation (1) is defined to compare numerical results with test data. This indicator shows how the result of the numerical model corresponds to those from the test data.

$$PI_d = \frac{d_{num}}{d_{test}} \tag{1}$$

Tab. 1: Comparison of measured and calculated displacements.

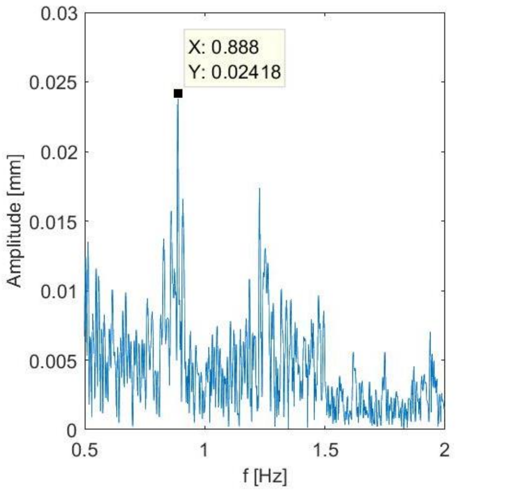
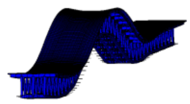
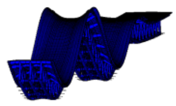
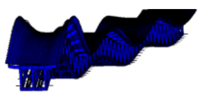
Friction coefficient	d_{num} **[mm]**	PI_d **[-]**
0.00	15.9	0.75
0.10	14.3	0.83
0.95 – 1.00	12.1	0.98

The calculated values of displacements considering friction coefficient around 0.95 are in a good agreement with the measured quantities. According to the results summarized in Tab. 1, it is obvious that the friction in the bearings influences the results considerably. On average the friction coefficient reaches the value of about 0.95, otherwise differences between the test and numerical results are approximately 25 %.

4. Comparison of eigen frequencies

In addition to measured displacements, the first few vertical frequencies have been acquired. The change in the results due to different friction has been proved. In Tab. 2 can be seen a comparison of the first three eigenmodes in the vertical direction. Obviously, the calculated eigenfrequencies of the structure with friction coefficient in bearing about 0.95 are in a good agreement with the measured values. Amplitude spectrum from radar is in Tab. 2 (last column), where first frequency 0.89 Hz is well identified. The other two modes and frequencies have been acquired using accelerometers located in vertical direction along the main span.

Tab. 2: Comparison of eigenmodes and eigenfrequencies.

<table>
<tr><th colspan="2" rowspan="3">Eigenmode
(vertical direction)</th><th colspan="3">Eigen frequency [Hz]</th><th>Amplitude spectrum of displacements from the test data</th></tr>
<tr><th rowspan="2">Test</th><th colspan="2">Calculated</th><td rowspan="5">
</td></tr>
<tr><th>friction 0.00</th><th>friction 0.95</th></tr>
<tr><td>1</td><td></td><td>0.89</td><td>0.79</td><td>0.89</td></tr>
<tr><td>2</td><td></td><td>1.96</td><td>1.80</td><td>1.95</td></tr>
<tr><td>3</td><td></td><td>2.31</td><td>2.13</td><td>2.23</td></tr>
</table>

5. Conclusions

Using two independent measurements (using accelerometers and interferometric radar) and comparing them with a calibrated numerical model, we can assume that the bearings between the concrete deck and the steel cross members are for some reason non-sliding or only partially sliding. These bearings should be sliding in the longitudinal direction. This may be due to corrosion, pollution, poor maintenance, etc. Obviously, additional effects (stresses in the longitudinal direction) caused by the interaction of both parts are transmitted to the deck. Only after considering such a model did the size of the measured displacements approach the calculated ones, and the eigenfrequency of the vertical oscillation was equal to that obtained by the operational modal analysis. This allows us to state that the measurements are correct, and the numerical model is well verified and calibrated.

Acknowledgement

This paper has been supported by the grant No. 1/0749/19 provided by VEGA Agency of Ministry of Education, Science, Research and Sport of the Slovak Republic.

References

Gentile, C. (2010) Application of radar technology to deflection measurement and dynamic testing of bridges – Chapter 8, in: Radar Technology, Rijeka, pp. 141-162.

Gocal, J. et al. (2013) Determination of displacements and vibrations of engineering structures using ground-based radar interferometry, Wydawnictwa AGH, Krakow (Poland).

Ingegneria Dei Sistemi (IDS) S.p.A. (2010) IBIS-S Controller Software ver. 02.02.000 – User Manual. IDS, Pisa (Italy).

Pieraccini, M. et al. (2019) Experimental dynamic impact factor assessment of railway bridges through a radar interferometer. Remote sensing, 11, 19.

Raventós, J. et al. (2017) The use of InSAR technology to monitor ground and structural displacement, in: INGEO 2017 Proceedings of the 7th International Conference on Engineering Surveying, Lisabon, pp. 303-310.

Sokol, M. and Lamperová K. (2019) Dynamic response of bridges tested by radar interferometry, in: New Trends in Dynamics of Structures: conference proceedings. 37th International Conference on Vibroengineering, JVE International, Bratislava, pp. 138-143.

Talich M. (2019) The effect of temperature changes on vertical deflections of metal rail bridge constructions determined by the ground-based radar interferometry method, in: World Multidisciplinary Earth Sciences Symposium, Prague.