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

DAMAGE IDENTIFICATION ON STRINGERS BY MODAL ANALYSIS

Marton M.*, Sokol M.**

Abstract: *The paper is dedicated to damage identification on stringers of a steel truss bridge. Different damage types on the railway bridge, like cracks, rust, permanent deformation and so more are well known but rarely identified. One of the most common type of the damage is loss of material in stringer flanges caused by rust. In practice different methods for damage identification can be used. This paper focuses on higher mode shape and eigenfrequencies of stringer web vibration, which are more sensitive to damage locations. Parametric study has been performed where the effects of different damage locations along the stringer has been investigated. Later, changes in local eigenfrequencies and modal shapes of the stringer web have been analysed with respect to different location of damage. In global analysis identifying of corresponding higher frequencies is very difficult, because the values of the eigen modes are quite close to each other. Therefore, an original subroutine has been prepared that helps to find the corresponding modal shapes of the substructure used for damage identification. Using this method it is possible to identify a location of the damage by comparing changes in eigen modes.*

Keywords: Damage identification, Stringer, Modal shape, Eigenfrequencies.

1. Introduction

Currently, there are many old railway bridges in Slovakia and Czech Republic, which are at the end of their lifespan. Therefore, many researchers are doing diagnostics to determine their condition. It is possible to identify different types of damage and failures that affect the response of the structure. According to Vičan (2016), the most common damage is rusting of some parts of stringer, loosening of fasteners or permanent deformation. The damage (rust on wall-flange connection) has been assumed because it is one of the most common damage on this type steel bridges (see Fig. 1).

Fig. 1: The most common type of damage on steel bridges. (Rust on wall).

There are several methods for detection of structural health according to Farrar (2006) or Sokol (2015) and others. Some of them are based on detecting of stresses or eigenfrequencies which are sensitive to change in stiffness. This article describes a method for detection of changing in stiffness of flange and web stringer connection using higher eigenfrequencies and mode shapes.

For purpose of this analysis, railroad bridge over the river Váh near Strečno has been investigated. The bridge consists of a truss arch bridge with a span of 57.4 m see Fig. 2. The length of stringers is 4.9 m and its height is 0.6 m.

* Ing. Martin Marton: Department of Structural Mechanics, Slovak University of Technology, Faculty of Civil Engineering, Radlinského 11; 810 05, Bratislava; SK, martin.marton@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

doi: 10.21495/5896-3-346

Fig. 2: Arch bridge over river Váh near Strečno.

2. FEM Model

A detailed numerical model of the bridge was using FEM software (ANSYS) see Fig. 3a. To study the parametric damage, it was necessary to create the most accurate model of the bridge deck, especially stringers Fig. 3b. Parametric study of damaged stringer, in the second field of the bridge, has been carried out.

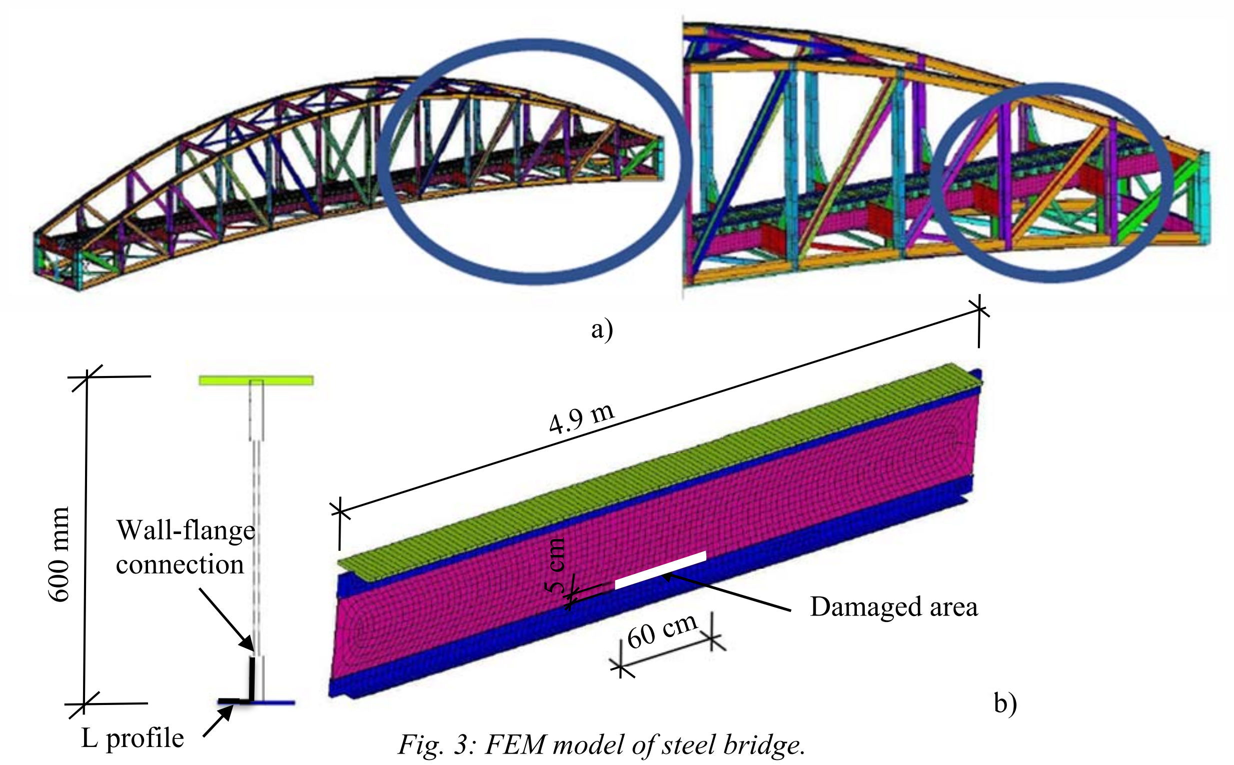


Fig. 3: FEM model of steel bridge.

2.1. Damage

It was assumed that the damage is located on the wall-flange connection above the L profile see Fig. 3b. Damage has been simulated by change the material properties – Young modulus. The modulus of elasticity was gradually reduced up to 10 %. Damage has been modelled as 60 cm long and 5 cm width damaged area with reduced material properties. The location of his damage was gradually shifted along the x-axis by 30 cm overlap of previous position. Everything has been done in cycle automatically. This cycle resulted in nine position of damage. Each of these positions affected the local eigenfrequencies and modal shapes of the stinger.

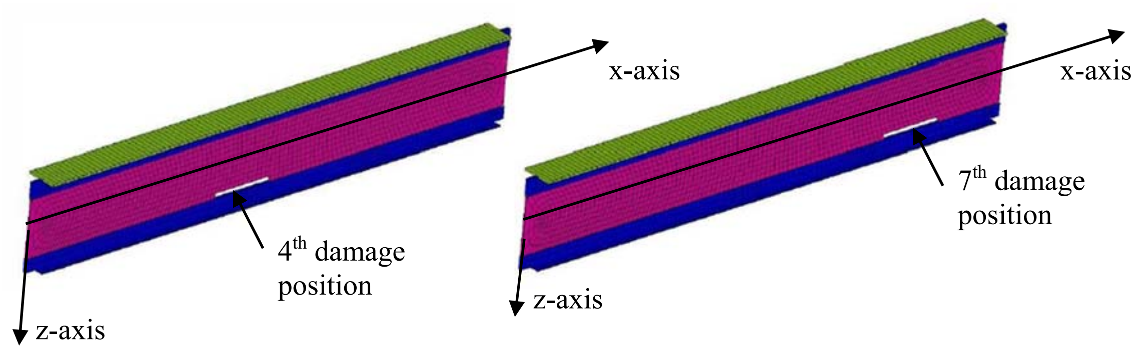


Fig. 4: Assumed damage of stringers.

2.2. Analysis of frequency and modal shapes

Big changes of eigenfrequencies were revealed at higher modes with frequencies around 160 Hz – 190 Hz see Tab. 1. The magnitudes of eigenfrequency changes are presented. The biggest change has been found in the 10th mode shape at the 5th position of the damage. The undamaged stringer has a 10th frequency 193 Hz (Fig. 5b). Assuming the damage on the 5th damage position, the frequency decreased by 14 % to the value 166 Hz. The number of eigen mode was sometimes different from the original one so the difficulty was to find corresponding ones. The corresponding modes have been identified by comparing the numbers of changes in sign of curvature measured along the web of stringer (see chapter 3.).

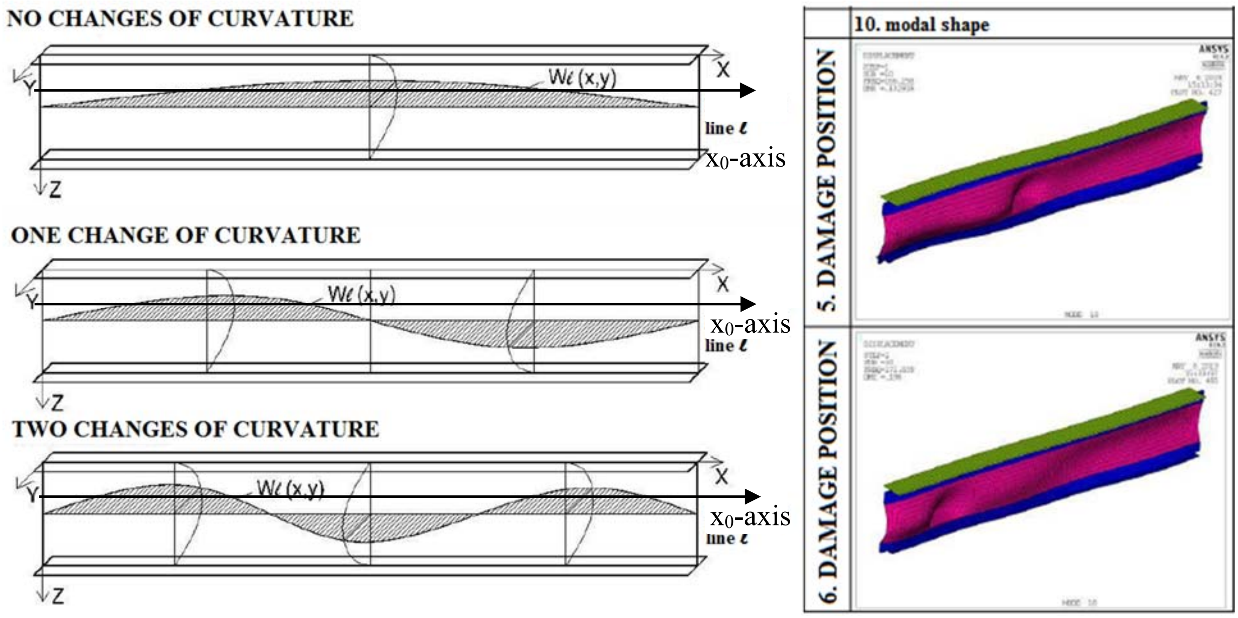
Tab. 1: Ratio of corresponding eigen frequencies (damaged/undamaged).

mode shape	1st damage position	2nd damage position	3rd damage position	4th damage position	5th damage position	6th damage position	7th damage position	8th damage position	eigenfrequency without damage
1st	1.000	0.998	0.997	0.999	1.000	0.997	0.997	1.000	41.26 Hz
2nd	1.000	0.998	0.999	0.999	0.998	0.998	0.998	0.999	53.80 Hz
3rd	0.999	0.992	0.992	0.998	0.999	0.992	0.991	0.998	69.65 Hz
4th	0.998	0.995	0.995	0.992	0.988	0.992	0.995	0.997	84.18 Hz
5th	0.958	0.976	0.991	0.998	1.001	1.000	0.994	0.987	108.68 Hz
6th	0.999	0.996	0.996	0.989	0.980	0.994	0.996	0.998	110.98 Hz
7th	0.975	0.977	0.996	0.994	0.994	0.985	0.986	0.971	128.60 Hz
8th	0.931	0.945	0.972	0.994	0.991	0.950	0.950	0.933	151.74 Hz
9th	0.976	0.953	0.960	0.970	0.940	0.957	0.938	0.979	164.05 Hz
10th	0.917	0.902	0.917	0.887	0.858	0.922	0.887	0.942	193.68 Hz
11th	0.974	0.967	0.972	0.969	0.968	0.963	0.967	0.973	198.50 Hz
12th	0.995	0.989	0.988	0.990	0.990	0.986	0.992	0.993	200.51 Hz
13th	0.989	0.976	0.994	0.970	0.975	0.974	0.977	0.994	207.76 Hz
14th	0.972	0.973	0.989	0.996	0.991	0.976	0.976	0.977	215.82 Hz
15th	0.977	0.956	0.916	0.957	0.952	0.922	0.970	0.987	235.24 Hz
16th	0.991	0.995	0.996	0.986	0.983	0.993	0.996	0.989	236.25 Hz
17th	0.983	0.996	0.998	0.999	0.995	0.992	0.988	0.969	247.99 Hz
18th	0.981	0.984	0.986	0.987	0.987	0.988	0.988	0.988	251.48 Hz
19th	0.975	0.991	0.994	0.991	0.984	0.985	0.989	0.978	256.10 Hz
20th	0.962	0.955	0.961	0.961	0.959	0.956	0.960	0.952	266.52 Hz

Results in Tab. 1. represent the changes of local mode shapes and eigenfrequencies of the stringer. These eigenvalues and mode shapes were at the beginning acquired assuming of rigid supports at connections between stringers and cross beams. However, this model doesn't consider the interaction of the stringer with the rest of the structure. For this reason the global bridge analysis was necessary, whereas in local conditions it is rather simple to reach higher frequencies, yet in case of the whole bridge it is necessary to evaluate the great number of the modes in order to find ones with frequency around 190 Hz. So the special routine has been prepared.

3. Finding modal shapes by subroutine

As mentioned above, searching for higher mode shapes in the global analysis of the whole bridge is time-consuming and difficult (because of changes the numbers of the modes), therefore a subroutine was prepared for searching the corresponding shapes. This program can find changes in the curvature of the function W_ℓ (x, y). The function W_ℓ (x, y) represents the horizontal displacement of a certain line see Fig. 5 on the left. The height of this line can be set as needed. The number of changes in curvature determines the mode shape. Based on the mode shape, the relevant eigenfrequency can be determined after damaging of the stringer.



a) b)

Fig. 5: Subroutine for finding modal shape.

4. Conclusions

This paper is focused, on the damage identification on the steel bridge structure by modal analysis. This method is applicable for higher eigenfrequency. In this case the frequencies and around 190 Hz have been evaluated. In global analysis, it is hard to identify these results. Higher modes can be affected by many factors. Due to this observation, it is not enough to compare only eigenfrequencies, but it is also necessary to follow the corresponding modal shapes. Original routine for identifying of local mode shapes based on changes in curvature has been developed. When searching for a change in the curvature of a mode section, the problem may occur when the height of the analysed axis x_0 is assumed too close to the bottom flange where a damage is located. This can lead to inaccurate results. Although the findings of the analysis were interesting there is a space for improvement of this method. But the first result seems to be promising.

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

Vičan, J. et al. (2016) Technical and economic study to improve the diagnosis of bridge structures with a direct link to transient parameters and railway safety. State Fund for Transport Infrastructure. pp. 98, (in Czech).

Farrar, R. Ch., Worden, K. (2006) An introduction to structural health monitoring. Phil. Trans. R. Soc A (2007) 365, 303-315. Los Alamos National Laboratory.

Sokol, M., Venglár, M., Ároch, R., Fábry, M. (2015) Damage Detection of a Bridge. In M2D2015. Porto: FEUP-INEGI, pp. 247-254. ISBN 978-989-98832-3-9.