A New Cost Efficient Measurement System for Bridges

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Summary

The test and maintenance of existing bridges require a large part of the available resources. In order to analyse the bridges faster and economically the Institute for Structural Engineering at University of the German Armed Forces in Munich is developing a system, which enables the user to estimate the bending stiffness of a bridge without any documents of the structure. Therefore a shaker system will be developed, which will be installed temporally on the bridge. It will vibrate the bridge with selective frequencies. The response of the bridge will be measured and recorded at the same time. In the second step a procedure will be developed to obtain the bending stiffness of the bridges by means of the calculated modal parameters such as natural frequencies.

Keywords: Vibration measurement, bending stiffness, modal analysis, inertial exciter, natural frequencies, magnification factor, existing bridge

1. Introduction

Over the last 60 years the Infrastructure especially in Germany grew up rapidly. The expansion of roads and railways in the recent years, especially in Germany, is the result of the growing together with European countries. In Germany there are currently about 120,000 bridge structures with the total value of approx. € 80 billion. The test and maintenance of these aging bridges require more and more the available recourses. Bridge monitoring is regulated by DIN 1076 (10/99). Every three years a visual inspection is carried out. The assessment of the bridge relies on the knowledge of the bridge inspector. It is desirable to provide an objective procedure to determine the condition of the bridge. One of the most important questions is to carry out the load capacity of the bridge. This report describes the development of an equation to estimate the bending stiffness of a bridge with modal-analysis.

2. Identification of the Bending Stiffness with Modal Analysis

There are different approaches to determine the bending stiffness of constructions. The stiffness can be determined by static or dynamic methods. The static system based on deformation and inclination measurements. For the dynamic determination the vibration-based measurement are used. A summary and evaluation of different methods for direct determination of the global stiffness is finding in the literature for example in [1]. In this report 3 methods are described to determine the bending stiffness by modal parameters: Direct stiffness Calculation, Modal Bending Lines and Modal Force Residual Method.

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Previous procedures determine the bending stiffness of the beam at the point of resonance. In the following section a method is shown that calculate the bending stiffness not directly in the resonance point but at the boundary area. For a single-degree of freedom system the equation of motion can be determined by the homogeneous differential equation taking the steady-state vibration into account [2]. For the excitation of the single-degree of freedom system an unbalance exciter is used. The centripetal force F depends on the unbalance mass m_0, the radius r and the excitation frequency Ω. The acceleration sensors are often used to measure the vibration of the structures or component due to the high sensitivity of the sensors. Therefore the equation of motion x will be transformed into the equation of acceleration x''. Furthermore the bending stiffness of a single-span girder can be described as a function of a single load and deflection. All these equation can be combined into the following term (1).

$$EI = \frac{l^3}{48} \cdot \frac{m_0 \cdot r \cdot \Omega^4}{\hat{\ddot{x}} \cdot \sqrt{\left(1 - \frac{\Omega^2}{\omega_1^2}\right)^2 + \left(2\zeta \frac{\Omega^2}{\omega_1^2}\right)^2}} \tag{1}$$

For the calculation of the stiffness the first eigenfrequency ω_1 must be found in the first measurement. At the second one, the acceleration must be measured at the exciter frequency of $\Omega = 0.7\omega_1$. In this case the damping factor contains $\zeta = 0.05$.

3. Experiments with Inertial Exciter

In general the natural excitation is used for the vibration measurement. In this case, the excitation of the bridge is due to wind, small excavation, transports as well as acoustic sources. For the above-described identification method, the different frequencies of the bridge must be activated by an exciter system. At the test bridge of the University of the German Armed Forces (fig. 2) the inertial exciter (fig. 1) was tested. The goal of this test was to determine the natural frequencies and the mode shapes with a high quality. Also the magnification factor should be determined, since it is a part of the estimation of the stiffness as well. The result of the experiments showed that the fine modal parameters can be obtained through this system. The magnification factor was found only in the higher frequency range with a good accuracy.

Fig 1: Test Bridge

Fig 2: Inertial Exciter

4. Conclusion

This report has presented the development of an equation, which can estimate the bending stiffness of a single-span bridge only with the results of a vibration measurement. Therefore the bridge has to be oscillated by the use of the unbalance exciter or inertial exciter. The tests on the sample bridge have shown the excitation in the lower frequency range is still quite low. In the next step of this research project a specific exciter should be built with a greater mass and a greater length of stroke. Furthermore the estimation of the bending stiffness should be calculated by multiple natural frequencies.

5. References

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