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Autor: König, Gert / Giegerich, Gerald
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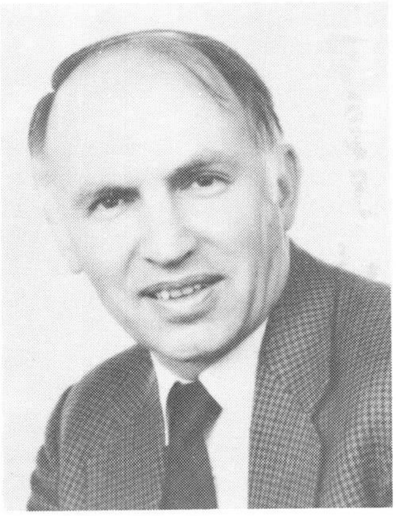
Identification of Structural Properties Using Dynamic Tests

Surveillance des structures à l'aide d'essais dynamiques

Bestimmung der Struktureigenschaften mit dynamischen Tests

Gert KÖNIG
Prof. Dr. -Ing.
Technische Hochschule
Darmstadt, FR Germany



Gerald GIEGERICH
Dipl. -Ing.
Technische Hochschule
Darmstadt, FR Germany

SUMMARY

Since the dynamic properties of structures are very susceptible even to small changes of local stiffness and mass, dynamic testing promises to be a suitable tool for the integrity monitoring of building structures. For this purpose a procedure was developed, a suitable test equipment was built and tested. Tests have been performed on a test beam as well as several times on a bridge as part of a complete inspection program.

RÉSUMÉ

Comme les caractéristiques dynamiques des structures sont très sensibles même aux petits changements de la rigidité locales et de la masse, l'application des essais dynamiques semble être un moyen approprié à la surveillance des structures. Un procédé a été développé, un équipement réalisé et testé. Des tests ont été faits avec une poutre ainsi que sur un pont dans le cadre d'un programme d'inspection.

ZUSAMMENFASSUNG

Da die dynamischen Strukturparameter sehr empfindlich auch gegenüber kleinen Änderungen der lokalen Steifigkeit und Masse sind, verspricht die Anwendung dynamischer Tests ein geeignetes Hilfsmittel für die Überwachung von Bauwerken zu sein. Zu diesem Zweck wurde ein Verfahren entwickelt, eine passende Versuchseinrichtung zusammengestellt und getestet. Versuche wurden sowohl an einem Testbalken als auch an einem Brückenbauwerk im Rahmen eines Inspektionsprogrammes durchgeführt.

1. INTRODUCTION

In the FRG the major part of bridges has been constructed in the sixties and seventies of this century. In the last years damages on many bridges became obvious and reached such an extent, that they had to be repaired. Therefore the costs for rehabilitation of bridges increased to a value of about 500 millions DM per year. In the same time the density of traffic grew up, so that bridge structures are subjected to higher stresses. Additionally the restrictions of traffic caused by repair of bridges have to be minimized.

It is obvious, that the repair of a damage in a stage just occured will be less consumable in time and money. But therefore it is necessary to have techniques available, which enable an early detection and localization of damages and their sources. Several methods actually are under development for this purpose. Because of their different physical basis they can handle different problems of damage detection. So a bundle of procedures has to be defined, which may be used in the particular steps of investigation.

The main objective of the integrity monitoring of concrete structures is to identify and to quantify changes in the load carrying capability. Since cracks may significantly impact the stiffness as well as the durability of a structure the attention is primarily directed towards monitoring of cracks and detection of their sources. In the past this was mainly performed by visual inspection. But this method may fail, when the cracked area is not accessible. For example, cracks may remain undetected, if they are in top of the sections on supports in multi-span bridge systems.

In this paper a method shall be presented, which provides the examination of bridges with dynamic tests and the detection and rough localization of damages.

2. THE DYNAMIC TEST METHOD

Systematic vibration monitoring aiming at the identification of dynamic parameters such as natural frequency, damping and mode shapes offers substantial means to quantify the stiffness changes and to localize their sources. If events like overloading, restraint or loss of prestressing result in cracks or high stress concentrations, stiffness and damping properties of the vibrating system change. With increasing damage the natural frequencies decrease whereas the damping values generally increase. Furthermore, modes which have large relative rotations in damaged zones, especially the higher modes, exhibit a higher relative change in their eigenfrequencies and thus give indications on potential damage zones. Since many mode shapes can be excited and checked with regard to their properties, for the detection of damages dynamic monitoring provides a much larger data basis than static displacement measurements.

Vibrations can be induced either by ambient vibrations or by artificial excitation (impulse, eccentric mass exciter or hydraulic actuator, Fig. 1). In any case system identification tests are conducted at very low-level excitations since testing may not cause any damage to the structure or activate other sources of non-linear behaviour. Hence, sensitive transducers are needed to capture the dynamic response of the structure.

Fig.1 Hydraulic actuator and transducers on Bridge Ulenbergstrasse

Having identified the dynamic properties of a bridge shortly after construction, a representative mathematical model can be developed by fitting parameters to those gained from the experimental data. Evaluating the data from periodically performed measurements the eigenfrequencies, damping values and mode shapes can be determined and compared with the reference values of the first measurement.

If changes are identified within the further measurements, adequate methods must be used to fit the mathematical model to the new data. This step is necessary to determine the change of structural properties such as stiffness, mass and stresses which are essential to draw conclusions concerning the state of the structure. For the interpretation a profound knowledge on nonlinear force-deflection characteristics of R/C bridges with emphasis on cracking and its effects on stiffness and damping properties must be available.

Considering the appreciable size of a bridge structure, the diversity and inhomogenity of the materials and the various environmental effects such as traffic flow, temperature, humidity, etc., it can be easily recognized that monitoring of a concrete structure is associated with serious limitations and uncertainties. In addition special phenomena like the interaction of the superstructure with nonstructural and substructural elements may pose further serious questions regarding the interpretation of the measured data.

3. LABORATORY TEST

In order to check the method on a structure with well known properties and boundary conditions a prestressed concrete beam with a span of 20 m was tested in the laboratory. This test enabled the comparison of the results with data gained from the measurement of deflections, concrete strains and steel stresses.

The beam was tested dynamically in the uncracked stage and then statically loaded until cracks appeared. After applying an alternating loading with about 28000 cycles as a simulation of the influence of traffic the beam was tested again without any load. In Fig. 2 transfer functions of the uncracked and cracked beam are plotted.

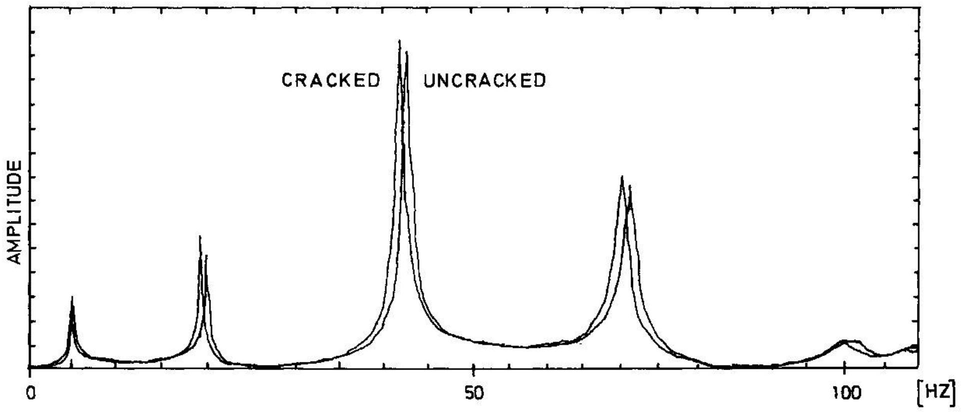


Fig. 2 Transfer functions of the test beam

The results clearly show, that the decrease of stiffness due to cracking can be recognized by dynamic testing.

4. INTEGRITY MONITORING OF BRIDGE ULENBERGSTRASSE

4.1 Structural system and test equipment

Bridge Ulenbergstrasse is a two-span roadbridge in Duesseldorf designed for the load class 60/30 (tons) according to DIN 1072 (Fig. 3). In the longitudinal direction the bridge is prestressed with 59 glassfibre tendons providing a tensile working force capacity of 600 kN per unit.

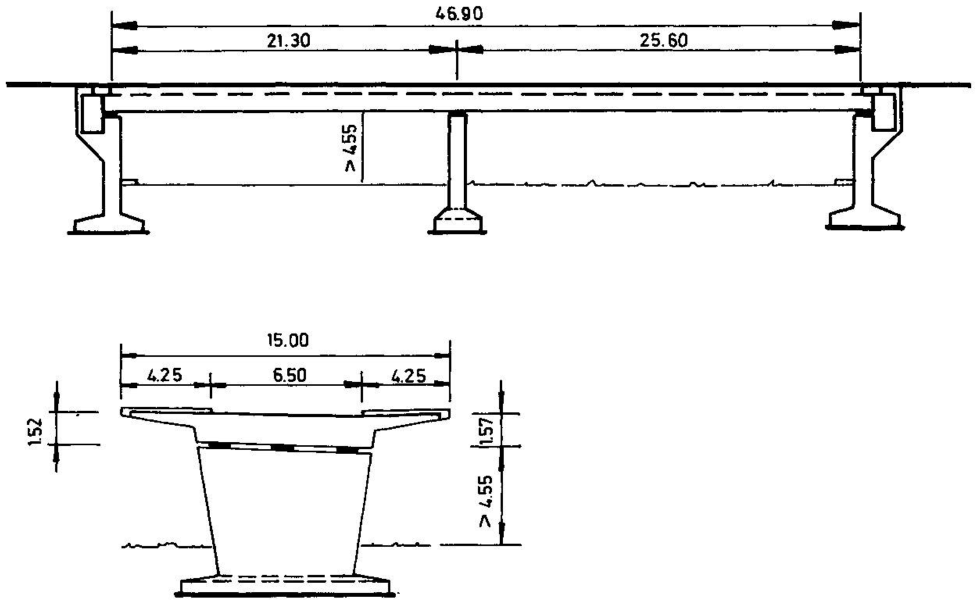


Fig. 3 Longitudinal section and cross section of Bridge Ulenbergstrasse

Prior to the application of the first dynamic test various analytical models for the bridge superstructure have been studied with regard to natural frequencies and mode shapes. A simple beam model has been quite sufficient to reflect the bending modes but because of the high width/span ratio of the superstructure it has been necessary to develop a 3D-model which captures the geometry entirely.

Based on these analytical estimates the optimal locations for artificial excitation as well as measurement points have been established. The bridge has been excited dynamically using a hydraulic actuator mounted on a concrete block and placed on the superstructure (Fig. 2). Accelerating the mass (460 kg) on the jack with a random noise in the range of 0 - 64 Hz, vertical forces have been applied to the structure. In order to avoid any damage to the structure the force level has been limited to 15 kN.

Some of the basic criteria which led to this type of excitation are:

- This excitation technique is capable to excite a wide range of frequencies at the same time and can reliably be reproduced multiple times.
- The applied force can be kept almost constant over the entire frequency range and be controlled easily.

The dynamic response of the bridge has been recorded using sensitive seismometers whereby in each configuration three measuring points and one reference point (top of exciting mass) have been recorded. The signals have been amplified and transferred to a 4-channel FFT analysator. Autospectra and transfer functions have been calculated and stored. Using a modal analysis software package the modal values of the structure have been obtained.

4.2 Results

On this bridge 4 tests have been performed in steps of 3 months, 6 months and twice one year. The first 6 natural frequencies of the first three measurements are listed in Tab. 1. Test 4 isn't still evaluated completely. The comparison of the results clearly shows a nearly equal increase of the natural frequencies, which is caused by the hardening of the concrete.

MODE	1ST TEST	2ND TEST	3RD TEST
1	4.97	5.13	5.14
2	7.14	7.37	7.47
3	9.87	10.1	10.2
4	11.9	12.2	12.1
5	16.6	17.8	17.5
6	21.7	22.4	22.3

Tab. 1 Natural frequencies of Bridge Ulenbergstrasse [Hz]

Comparing the results derived from the measurements and those obtained by analytical model discrepancies could be observed. Therefore the model was improved capturing the bearing characteristics. Studying the interaction between the main bridge structure and the sidewalk plates lower and upper limits of interaction could be defined. The comparison with the test results shows, that these lie between these limits. Nevertheless, it has to be noticed, that not all influences on the dynamic properties could be well identified in the analytical model.

5. ACKNOWLEDGEMENT

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