Investigation of the dynamic behaviour of civil engineering structures – new developments

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The history of experimentally investigating the vibrations of civil engineering structures like bridges and buildings began more than 100 years ago with the development of mechanical devices acquiring dynamic signals and recording them on paper strips. Analytical treatment of complex structural dynamics problems has been possible for some 30 years now, since computers and finite element (FE) software packages became available. Today, electronics governs experimental signal acquisition and processing completely, and the computers have become very powerful. Hence research is now directed towards combining the two methods, which means that a preliminary FE model of a structure is updated using the information gathered from field tests. The result of the procedure is an FE model of the structure which is as close to reality as possible and which then can be used (a) to determine the system response to any static or dynamic load, (b) to determine the consequences of structural changes like strengthening, cracking, etc., and (c) to determine eventual structural changes that may have occurred in the time between two measurements.

EMPA being an institute dealing predominantly with experiments, the first step was gaining experience applying the Experimental Modal Analysis (EMA) procedure to civil engineering structures. Unlike tests where merely the structural response is measured without knowing the exciting force or even the source of excitation, EMA consists of controlled excitation of the structure in one point and measuring of the structural response in a large number of points on the structure. Calculating the frequency response functions from every response spectrum and the input force spectrum yields the information necessary to build up the experimental structural model.

The crucial practical problem to be solved here is to find a vibration generator which introduces enough energy into the structure to excite vibrations which can be measured reliably. Since 1984, EMPA has experimented with almost everything between a hammer with a 6 kg mass and rocket engines producing forces of 60 kN, as well as structures between a 6 m long reinforced concrete beam, a 250 m long bridge and a mid-sized gravity dam. For bridges with a length of up to 100 m, a servohydraulic vibration generator has proved to be the most suitable means of excitation. It consists of a 10 kN cylinder with a 500 kg mass fixed to the piston rod tip and produces a vertical dynamic load of ± 5 kN maximum amplitude (Fig. 1). In all cases, the structural response was measured using Brüel & Kjaer 8306

Fig. 1 The servohydraulic vibration generator (EMPA Photo 77'216/2).

Fig. 2 The bridge on the river Aare as of today (EMPA Photo 98'525/1).

accelerometers. The experimental dynamic model is built up using an EMA software package. FE techniques have been introduced at EMPA in 1991 and the 'Link' procedure, which updates the FE model based on the EMA results, was installed in 1992.

As a practical example, the 1992 investigation of the bridge across the river Aare at Aarburg can be mentioned. This 72 m span arch bridge was built in 1911 by Robert Maillart and renovated in 1968 (Fig. 2). It suffers from significant cracking and traffic induced vibrations. The problem here was to achieve a reliable structural model to be able to then study the effects of possible strengthening and the possibility of shifting the 3 Hz natural fundamental frequency out of the critical range of dynamic traffic actions, e.g., to 4 Hz. A band limited random force signal was used to excite the bridge and the response was measured at 142 points in three directions each. With the 8-channel EMA system, the signals of two measurement points plus the force signal

were acquired at a time. Subsequently, the accelerometers were moved to the next set of points. With 10 to 15 minutes needed for every measurement cycle, testing was completed in two nights. As an example, Fig. 3 gives bridge modes 1, 2 and 3 as achieved from EMA versus those obtained from the updated MSC/NASTRAN-FE model. The first seven modes with natural frequencies 3.03–8.07 Hz were evaluated, but a decision on the necessary structural modifications has not yet been taken. It became clear, however, that shifting the fundamental frequency a significant amount would be possible by locking one of the bridge deck abutment bearings in the longitudinal direction.

Fig. 3 Comparison of some mode shapes and frequencies as determined experimentally and as calculated with the updated FE model.