Improved tools for structural monitoring – new test techniques with reaction mass exciter VICTORIA and a software for sensitivity studies

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1. New test techniques

Arsenal research has a long history of carrying out insitu tests of civil structures (dams, bridges, etc) and of fitting FE models to the test results. More than 20 years ago the first eccentric mass exciter was designed and built by arsenal. Since 1985 the first reaction mass exciter of arsenal was in use. A flat bed trailer was adopted in order to transport the reaction mass exciter. The trailer is equiped with a lifting jack mounted on a frame. The exciter can be lifted from the trailer and lowered to the object through a hole in the bottom plate.

In recent years the exciter was deployed also on a variety of railway projects where vibration transfer was measured. Since April 2001 the entire device was reengineered in respect of experiences made with the first reaction mass exciter.

Recently there where three projects, where it was not possible to place the exciter directly on the structure. Hence the exciter could not be used in the „classical" way and another technique of excitation had to be developed. These projects were:

- a railway bridge in use (elaboration of global vibrational behaviour)
- two masonry buildings in Vienna, where reconstruction was planned and a new earthquake analysis was requested by the authorities. As it is quite difficult to model this type of structure quite realistic, insitu testing was chosen in order to elaborete modal frequencies and modeshapes. A FE Model was fitted to the test results.

In all three cases a rod – chain was put between the structure and the reaction mass. In the case of the railway bridge the exciter was placed under the bridge, which was excited in vertical direction. In the case of the masonry buildings the rod chain was placed under 45°, giving a horizontal as well as a vertical force component. The horizontal excitation gave the frequencies and mode shapes in horizontal direction, while the vertical component made it possible to measure „local" vertical eigenfrequencies of several floors.

The force of excitation was 20 kN, the force transducer is integrated into the chain. The sinusoidal excitation force was swept in the range 0 – 10 Hz. In the case of the masonry buildings the response was measured at each storey level in several points by velocity transducers (Hottinger SMU 30A). In order to measure in all points, the frequency sweep had to be repeated several times. For each measurement point a transfer function is obtained, which is the optimum basis for an experimental modal analysis. In the case of the first masonry building (Kölblgasse, U – shaped building) 5 horizontal eigenfrequencies, modeshapes and damping ratios were identified within the range 0 – 10 Hz. The fundamental frequency is 3,11 Hz. In addition, the eigenfrequencies of several floors were identified. The equipment and the first and the fourth modeshape are given in Figure 1 and 3.

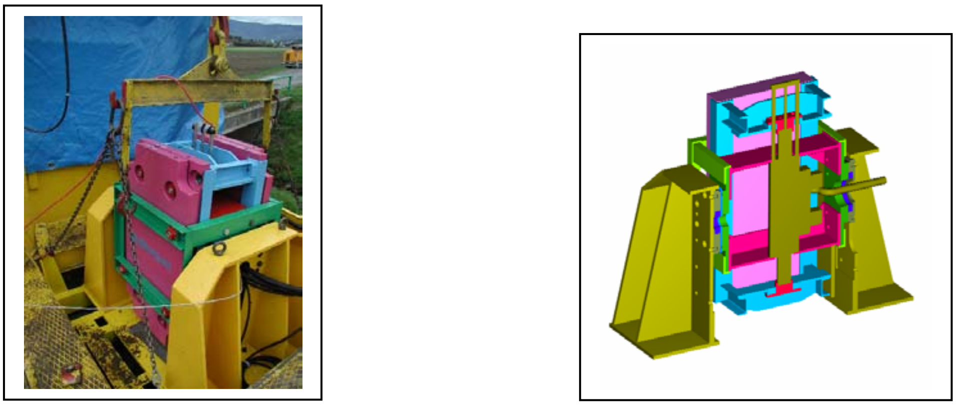

Fig. 1: Details of reaction mass exciter VICTORIA

Fig. 2: Insitu test of masonry building Kölblgasse/ Vienna

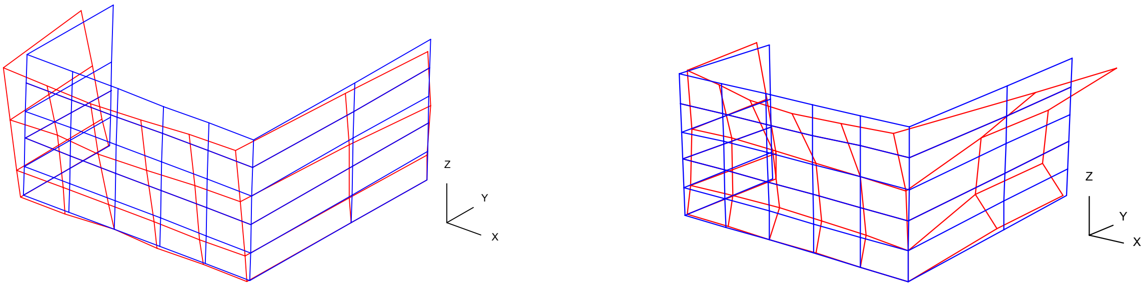

Fig. 3: First modeshape at 3,11 Hz und fourth modeshape at 7,33 Hz

2. Software for sensitivity studies

If monitoring techniques should be used for safety inspection or even for the assessment of the status of a structure, a FE Model has to be fitted to the test results (measured eigenfrequencies and modeshapes). Updating is still an open field. Some progress was obtained during the SIMCES project (*System Identification to Monitor Civil Engineering Structures*, BRPR-CT96-0277, DG 12 - RSMT), but the possibilities do not cover all civil engineering needs. The reason for all the problems is, that the number of available frequency - differences is less than the number of updating parameters, which results in rectangular matrices and the problems with the pseudo inverse. New optimisation procedures are necessary which look for the minimum of the difference between measured and calculated results and do not use the derivates from sensitivity matrices.

For „sensitivity based“ updating probably only semi- automatic „engineering-knowledge based“ procedures are possible. To have a complete sensitivity matrix is certainly a good thing. A step-wise updating, e.g. to start with the boundary conditions could be a possible strategy. But especially soil springs can create sometime big problems (e.g. change of modal sequence). The automatic check of modeshapes and also the use of measured modeshapes should be included into future updating procedures.

Hence, sensitivity studies are an important tool for structural monitoring. These studies are necessary for a „realistic updating“ of the mathematical model and also to elaborate warning- and alarm levels, if changes of modal parameters should be used for quantification and localisation of structural damage. In order to get a better understanding of the effects of a local damage on modal frequencies and modeshapes, arsenal research started the development of a special software, which visualizes these changes. The software is based on excel sheets and macros. First, FE calculations must be carried out, where a stiffness change is applied element by element. The above software reads the output text files (eigenfrequencies and modeshapes) for every calculated variant. In principle it can be adapted for any FE program, in our case we use the SOFISTIK software. The development is still in process. Two examples of simple structures are shown in what follows. The first example is a beam with 36 m length and 48 elements (hollow girder cross section). The bending stiffness of every element was reduced to 20% of the „undamaged“ value one after the other.

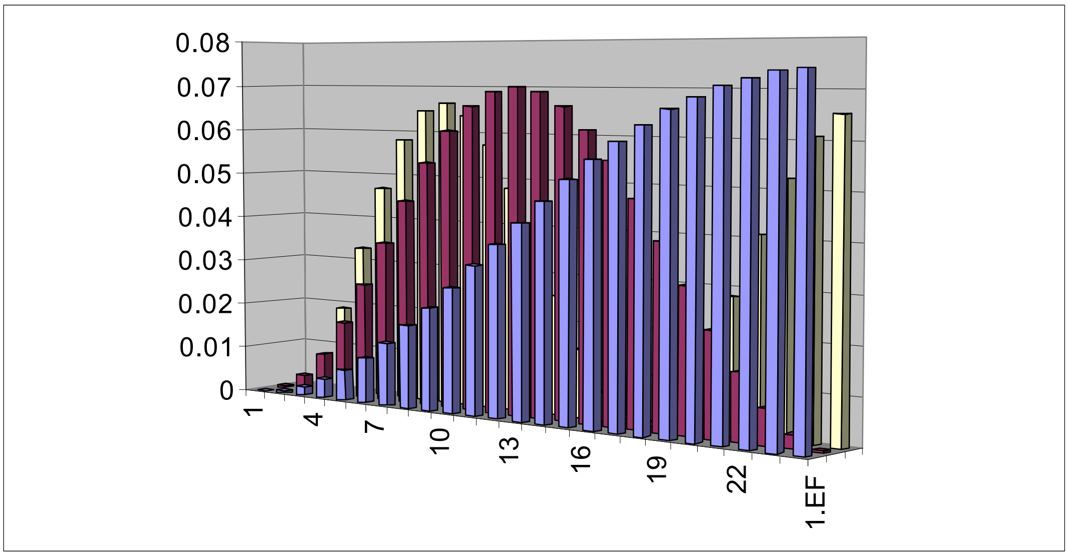

Fig. 4: Decrease of 1st ,2nd and 3rd modal frequency in [Hz] as a function of stiffness decrease in a single element (no. 1 – 24)

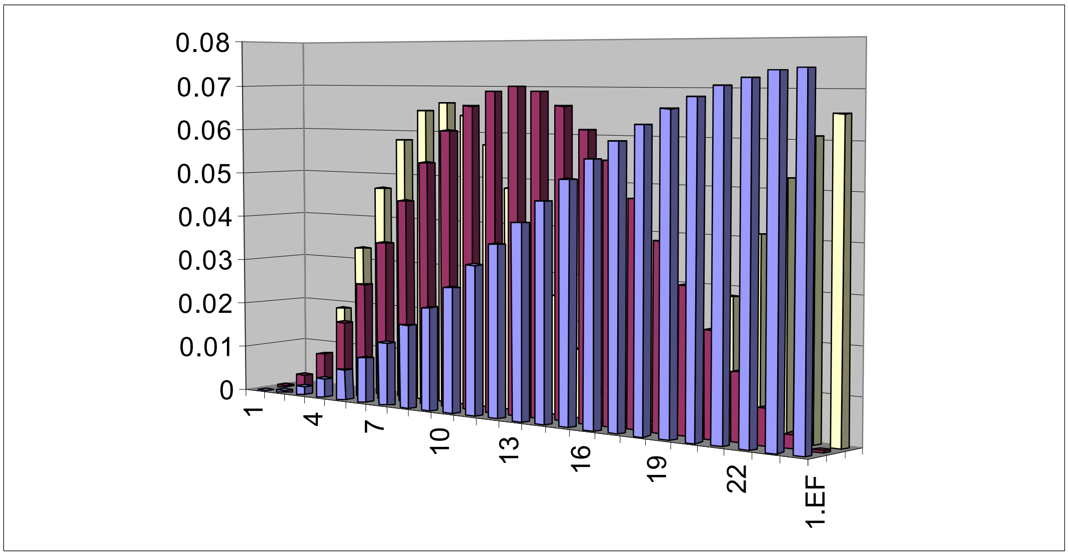

Fig. 5: Decrease of 4th ,5th and 6th modal frequency in [Hz] as a function of stiffness decrease in a single element (no. 1 – 24)

Besides the changes of the modal frequencies also the changes of modeshapes were investigated. The different shapes can be viewed for every variant. Further, parameters were investigated, which are a measure for the „overal“ change of the shape. The graphs of these parameters look very similar to the graphs of the frequency changes, which is plausible. Every local stiffness decrease will produce a certain pattern of frequency changes, which should be helpful for damage location. Eg., for the stiffness decrease of element 8 the following pattern would result:

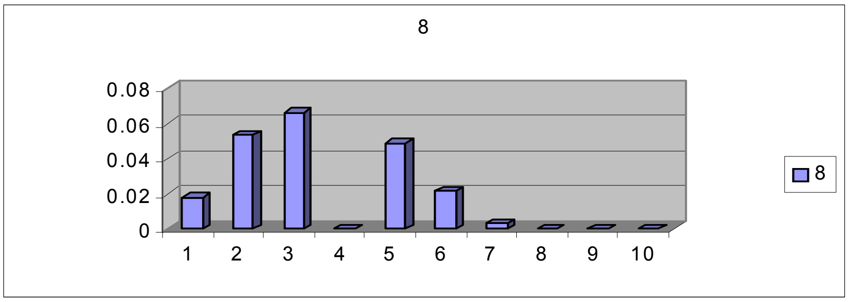

Fig. 6: Decrease of the modal frequencies 1 – 10 due to the stiffness reduction in element 8 to 20% of the original stiffness.

The second example is a slab with the dimensions 12 x 6 m. It consists of 16 x 16 elements. In this case, the elastic modulus was decreased to 40% of the original value element by element. In this 2D case it is much more complicated to find a good visualisation of the effects of a local stiffness decrease on the modal frequencies and modeshapes. The development is still ongoing. Some examples of the changes of the modeshapes due to the stiffness decrease in element 24 (row 2, 8th element) are shown in what follows.

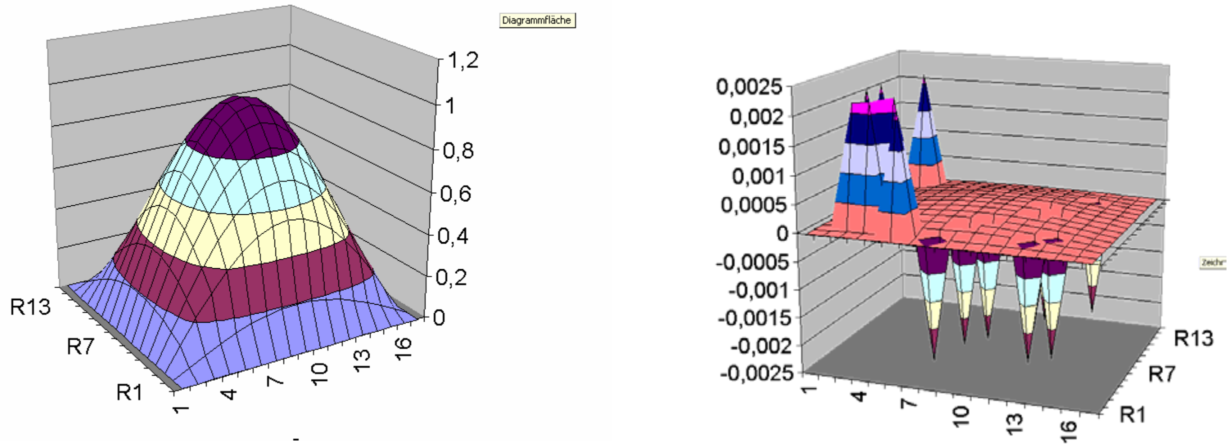

Fig. 7: a) First modeshape at 5,526 Hz (original) **b)** local change of modal amplitudes due to stiffness decrease to 40% of original value in element 24. Decrease of frequ. to 5,525 Hz.

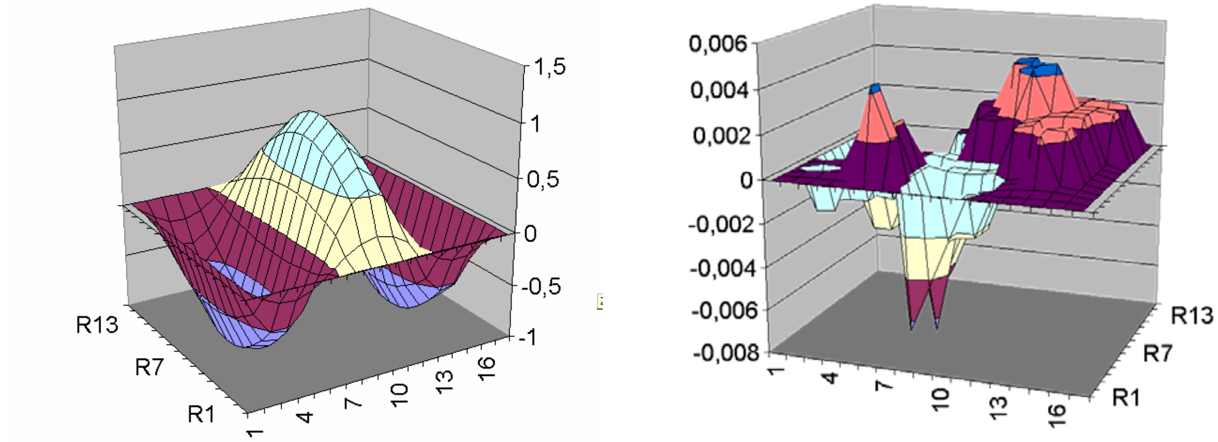

Fig. 8: a) Third modeshape at 14,305 Hz (original) **b)** local change of modal amplitudes due to stiffness decrease to 40% of original value in element 24. Decrease of frequ. to 14,291 Hz.

Figures 6 and 7 are very promising. The highest gradiant of the changes of modal amplitudes is found to be close to the location of the stiffness change. We are very optimistic, that this software can be developed towards a powerful tool for monitoring and assessment.