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Dynamic *in Situ* Tests on a Damaged Historical Building

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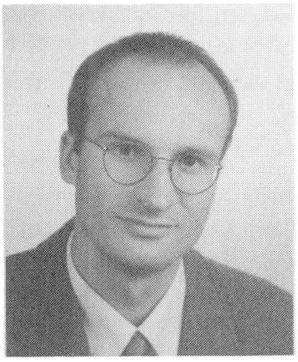

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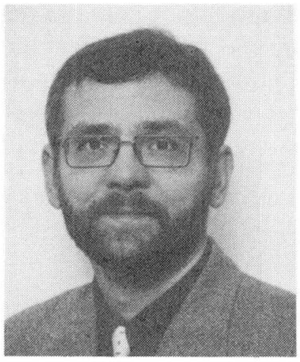

Summary

The numerical description of the structural behaviour of an existing, damaged structure is a challenging engineering task. The basis for the solution of this problem is the evaluation of the actual behaviour on site using advanced experimental and numerical techniques. In this study, the severely damaged bell tower of the church of Krölpa (Thuringia) was investigated. By utilizing an FEM-package several natural frequencies with the corresponding vibration modes, transfer functions and modal damping ratios were obtained from the measurement data. It became obvious that the dynamic behaviour of the structure depends not only on the frequency but also on the amplitude and direction of the exciting force. The presented methods appeared to be suitable tools for the identification of dynamic system properties even though difficulties in the numerical description of the nonlinear effects remained.

Keywords: structural dynamics, system identification, structural damage, experimental testing, nonlinear dynamics

1. Investigations on site

Fig. 1 : The bell tower, view from south-west

The appearance of the medieval Krölpa church tower is significantly characterized by its inclination which was caused by an uneven settlement of the ground. Today the tower is about 2.2 degrees out of the vertical and shows deep vertical cracks in the masonry of its four walls. These damages gave the reason for an investigation of the dynamic structural behaviour of the tower in its current state. It was intended to identify dynamic system properties as well as to model the structure with its specifics numerically.

The *in situ* tests were carried out in May 1997. A servo-hydraulic vibration generator was posed in the former place of the belfry in order to produce a harmonic exciting force. The frequency of the force was increased incrementally from 0.3 Hz to 9.7 Hz. The experimental programme consisted of several test series with the exciting force acting in different directions and with different amplitudes. The response of the system was registered by accelerometers which were placed in the corners of the tower in three levels.

2. Identification of system properties

From the stored time histories of the measured accelerations and the exciting force, the complex transfer functions were calculated as the ratio of the Fourier transform of the reaction and that of the excitation. Problems which are connected with the Fast Fourier Transformation algorithm were avoided by using an alternative method for the computation of the Fourier transforms.

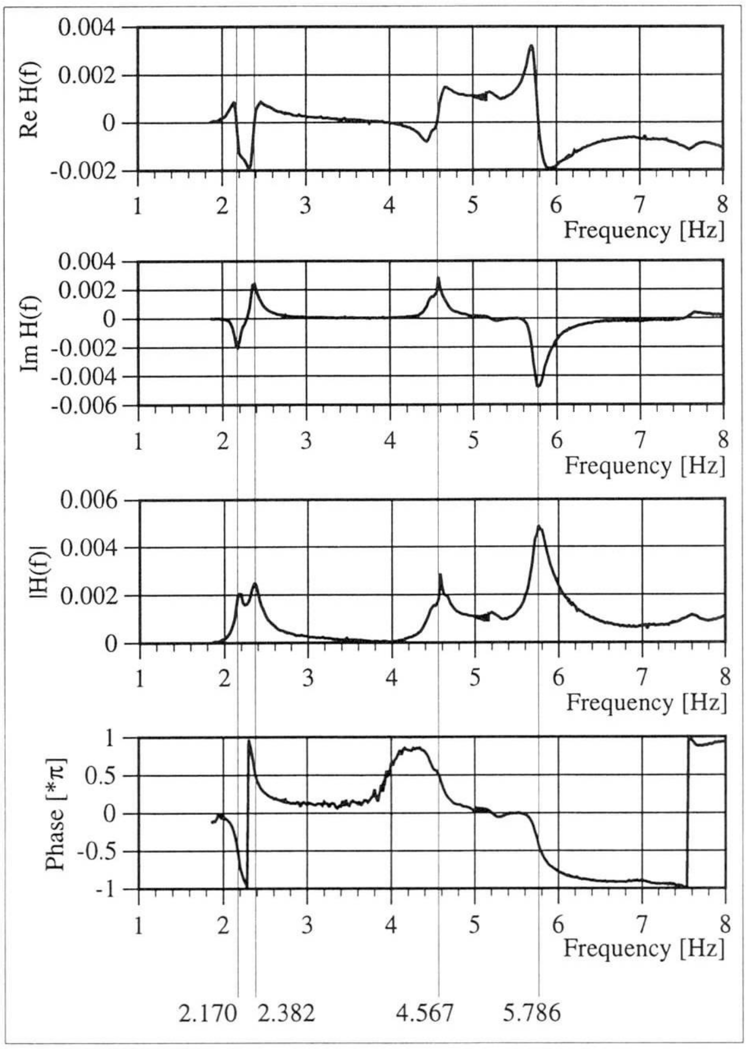

Fig. 2: Complex transfer function of acceleration obtained from the measurements (accelerometer at level B, NE-corner, N-S-direction, excitation E-W, max. F=2.0 kN)

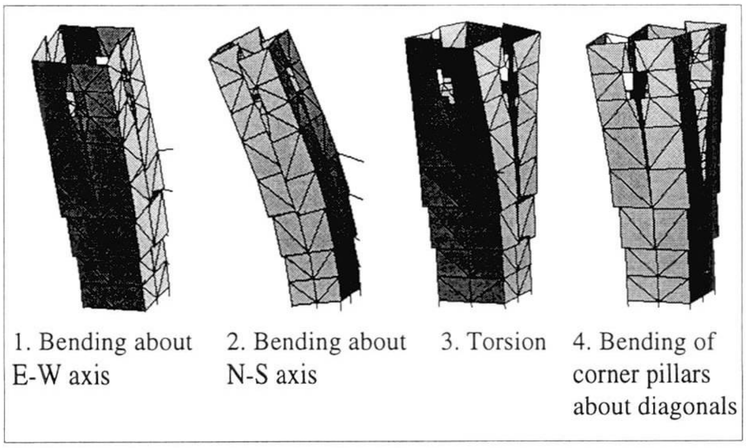

Fig. 3: First four identified mode shapes

The phase angles were directly determined from the complex transfer functions. The obtained curves allowed the identification of four resonances. Modal damping ratios for the resonance frequencies could be deduced from the phase angles at resonance.

A finite element model of the tower was created. By means of the method of dynamic condensation and the deflections obtained by integrating the accelerations twice four modes of vibration, which correspond to the resonances, were identified.

The results of the test series showed several nonlinearities in the dynamic behaviour of the bell tower. The resonance frequencies decreased with an increased amplitude of the exciting force. It could also be observed that the occurence of resonances depends on the direction of excitation.

3. Conclusion

Structural damages can lead to changes of the structural system and significantly alter the dynamic behaviour of a structure. The described techniques can be considered as a suitable method for the identification of dynamic system properties.

A number of nonlinear effects in the behaviour of the damged bell tower was observed. It can be concluded that the properties and the behaviour of the investigated structure strongly depend on the frequency, the magnitude and the direction of a load imposed on it. The numerical modelling of these phenomena remains the subject of further research.