DETERMINATION OF DYNAMIC PROPERTIES OF NON-LINEAR STRUCTURES USING THE PULL-RELEASE TEST

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INTRODUCTION

For the determination of the dynamic properties - natural frequencies, mode shapes and damping - of an existing structure, a number of experimental methods are available. Among the most common ones are: the shake table test for small and medium size structures; excitation by a shaker mounted on the structure and locating the resonances by sweeping across a frequency band either slowly or in discrete steps; monitoring the ambient vibrations and determining the properties by signal analysis; and pulling (or pushing) the structure and suddenly releasing it and measuring the resulting decaying vibrations. This pull-release test is one of the simplest dynamic methods for determining a complete set of dynamic properties. While it is usually employed at low amplitudes of vibration, the method can also be employed at large amplitudes and consequently to obtain amplitude-dependent dynamic properties for structures with non-linear deformation and damping properties.

This presentation focuses on the theoretical and analytical issues that have to be considered in planning such a test and interpreting the results. The practical aspects in carrying out the pull-release test and instrumentation considerations are not addressed here.

THEORETICAL CONSIDERATIONS

While the pull-release method is simple to perform, certain limitations and requirements need to be observed in order to obtain reliable results. These requirements flow from the physical characteristics of the test method. A simple SDF system will be considered first.

As the name of the test implies, the structure is pulled (or in some cases pushed) a certain distance and then suddenly released. This gives rise to the time history of vibration decay for displacement. Differentiation gives the velocity and a further differentiation the acceleration. See Fig. 1. These three interrelated time histories contain all the information necessary to characterize the dynamic properties of the structure:

i. damping can be calculated from the amplitude variation as a function of time

ii. natural frequency, is given by the zero crossings of the decay curve

iii. for non-linear systems, variations of damping or natural frequency as a function of amplitude can be determined

iv. and for a multi-degree of freedom (MDF) system, the mode shapes can be obtained from the responses at various locations on the structure.

CALCULATION OF DAMPING AND NATURAL FREQUENCY

Damping. For a viscously damped system, damping is given as a fraction of critical , or in % thereof, by the following relationships: From the logarithmic decrement

$$\delta = \ln\left(A_m / A_{m+n}\right)$$

$$n = \frac{1}{2}, 1, 1\frac{1}{2}, 2 \ldots\ldots.$$

$$\beta = \delta\sqrt{4\pi^2 n^2 + \delta^2{}_n}$$

For small δ this simplifies to:

$$\beta = \frac{1}{2\pi n} \ln \frac{A_m}{A_{m+n}}$$

where A denotes the peak amplitude in a decay curve, ***n*** the nth peak in the decay curve, and ***m*** is the number of cycles after ***n***. ***m*** can be any positive integer including zero or any integer plus 1/2.

Natural Frequency. The natural frequency can be determined at any stage of the decay curve by measuring the time T between zero crossings for one cycle, or T/2 at 1/2 cycle, and then taking the inverse (Fig. 1a). This is feasible along the entire decay curve.

This measurement of zero crossings yields the damped natural frequency T, which then can be corrected to yield the undamped natural frequency $T_o = T / \sqrt{1-\beta^2}$.

MEASUREMENT IMPLICATIONS

The properties of the decay curve described above lead to important consequences for the measurement of the relevant qualities.

The initial acceleration upon release of the structure has an infinitely steep rise time. This can only be achieved with an accelerometer of infinite frequency response and with zero time delay in release mechanisms, neither of which is achievable in practice. Consequently, the first acceleration peak will always be distorted and will not provide a reliable initial amplitude. It follows then if that initial amplitude and its rate of decay characteristic is important, the direct displacement measurement is the only one that will yield the desired information. In that case, an independent reference frame is needed to serve as a mounting platform for the displacement transducer. If on the other hand, the first amplitude peak is not of interest, then accelerometers mounted on the structure can give very satisfactory acceleration vibration decay curves.

AMPLITUDE DEPENDENT DAMPING AND FREQUENCY

The damping ratios and natural frequencies for a structure can be computed over a number of cycles, thereby averaging out small computational or experimental variances. If, however, the structure's dynamic properties are amplitude dependent, these properties have to be computed over each cycle or even half cycles. The results then represent an average value over that cycle, or half cycle, and can be plotted as damping versus mean displacement. A mean displacement can be defined as being the average of two adjacent peak amplitudes.

MULTIMODE RESPONSE

When the structure exhibits more than one mode, ie. the structure is an MDF system, the time decay record will include the combined response of a number of modes. In order to extract the desired properties of damping, frequency and modal amplitudes for any particular mode, the pure signal for that mode alone needs to be extracted. This can be done by filtering, where, the following needs to be observed. For the acceleration record, the filter cannot deal with a sudden jump at the beginning of the signal shown in Fig. 1c but will result in distortions in the peaks near the beginning of the decay curve. This can be circumvented by filtering the signal in the reverse order, in which case the "ringing" occurs before the acceleration jump, which is of no interest in the investigation. The first peak also needs to be ignored in any case since its amplitude is not realistic right from the start of the measurement phase, as was explained before.

The displacement record, Fig. 1a, experiences problems with filtering because the mean of the record is not zero and this causes a distortion of the base line. Again, a reversing of the signal permits the production of reliable filtered results right up to the time of the pull release. Thereafter (or in the original signal before the release) severe distortions will occur but these can again be ignored.

USE OF TEST DATA IN SEISMIC QUALIFICATION

One important application for the data obtained from a pull-release test is the seismic qualification of equipment for seismic response. This can relate to facilities such as boilers or heat exchangers in nuclear power plants, or free-standing structures such as high voltage power switches or line-conditioning platforms for power lines. Seismic qualification can be carried out according to the standards CAN3-N289.4-86 (CSA 1986) or IEEE Std. 344-1987 (IEEE 1987). Both standards recognize the pull-release method as one component of a combined testing and analysis approach. They view it as a low-amplitude method and caution about amplitude dependent results. With the above techniques, however, amplitude dependent result can be fully accounted for and treated in a consistent manner.

REFERENCES

CSA 1986. *Testing Procedures for Seismic Qualification of CANDU Nuclear Power Plants,* CAN3-N289.4-86. Canadian Standards Association, Rexdale, Ontario, 30 p.

IEEE 1987. *IEEE Recommended Practice for Seismic Qualifications of Class IE Equipment for Nuclear Power Generating Stations,* IEEE Std. 344-1987, Institute of Electrical and Electronics Engineers, New York, N.Y., 42 p.

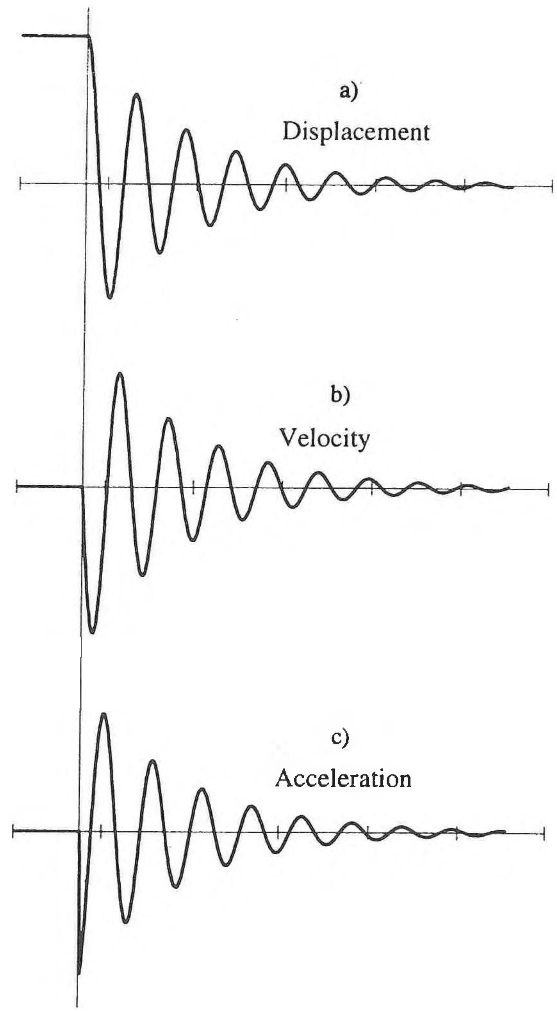

Fig. 1: Theoretical Vibration Decay Records for Pull-Release Test