National Conference with International Participation
ENGINEERING MECHANICS 2003
Svratka, Czech Republic, May 12 – 15, 2003

paper no.
295

RELIABILITY ASSESSMENT OF CAMOSUC METHOD

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Summary: *The endeavour to use the changes of dynamic characteristics for the determination of damage or other imperfections of structures is not new. The rudimentary application of structural evaluation and damage assessment by vibration monitoring has been practiced since ancient times.*

Experimental work in the field of modal analysis of real structures from the 70s and 80s of last century (offshore oil drilling platform (Kenley& Dodds, 1980)). Modal analysis was used also in the laboratory tests of plastics (Adams at al.,1975). Identification of damages of R.C. bridges by means of frequency spectra of response are known from the 90s (Flesh at al., 1990; Pirner, 1989).

1 Introduction

The authors of this paper present their experience amassed since the 80s of last century during experimental tests of real structures and models; they founded the attention to the *CAMOSUC* method (The ChAnge of MOde SUrface Curvature).

In the 90s the damage identification methods started to apply experimentally a comparison of forced vibration modes in the virgin and the damaged states (Pirner & Urushadze, 2001). It is the *MAC* - Modal Assurance Criterion and *COMAC* - Co-Ordinate Modal Assurance Criterion.

2 Mode surface curvature

The ChAnge of MOde SUrface Curvature (*CAMOSUC*) was applied to the identification of the imperfection of a structure and its location about 1990, as stated by the authors of the method (Pandey at al., 1991; Pandey at al., 1994; Biswas at al., 1989).

The first author of this paper used the changes of mode surface curvature in the verification of cracks in a floor structure of a department store building as early as 1986 (Pirner, 1986).

This method is based on the relation between flexural stiffness of the structure and its curvature during forced vibrations due to a near-resonance harmonic load or to a random load with subsequent modal analysis. The appropriate formula is

$$v'' = M/(EJ) \qquad (1)$$

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where the curvature of neutral axis in point i, or the curvature of the surface is determined, using the experimentally determined displacements in discrete points, by the formula

$$v_i'' \doteq (v_{i+1} - 2v_i + v_{i-1}) / h^2 \tag{2}$$

where h is the distance of the points i+1, i, i-1 in which the dynamic response is measured.

If we can express the relation (2) for the virgin state (index v) and the damaged state (index d), we can determine the difference

$$v_d'' - v_v'' \tag{3}$$

possibly the ratio

$$v_v'' / v_d'' \tag{4}$$

The numerical processing of Eq. (3) or Eq. (4) requires the normalization of measured displacements by the response in the reference point v_{ref}.

2.1 Ratio of Curvatures

Once again we assume that we know the dynamic response in two states. Under certain assumptions (the first is expressed by Eq. (6a), the other by Eq. (6b)) we can use Eq. (4). The first assumption can be applied if the structure, even if damaged by cracks, is still serviceable, the other in case of standard building materials (concrete, steel, timber; it does not apply to plastics, composite materials, etc.(Adams at al., 1975). When we express Eq. (1) for the virgin and the damaged states in point i

$$\begin{aligned} (v_{i+1} - 2v_i + v_{i-1})_v / h^2 &= M_v /(EJ_v) \\ (v_{i+1} - 2v_i + v_{i-1})_d / h^2 &= M_d /(EJ_d) \end{aligned} \tag{5}$$

and admit in further considerations that

$$M_v \approx M_d \tag{6a}$$

$$E = E_v = E_d \tag{6b}$$

we obtain

$$J_d / J_v = (v_{i+1} - 2v_i + v_{i-1})_v /(v_{i+1} - 2v_i + v_{i-1})_d \tag{7}$$

Similarly it holds e.g. for a rectangular slab of constant thickness.

Note :

As Eqs. (5, 6, 7) use displacements v in the grid the elements of which usually exceed the thickness t, the ratios J_d / J_v do not express a local change, but a change corresponding with the area determined by the dimension $2h$.

3 Example of identification

In (Pandey at al., 1991), we can find the absolute differences between the natural mode curvatures of the virgin state and the damaged state of a simply supported beam and a cantilever beam processed numerically; the solution is simple, because all quantities required are in a single plane. The solution of three-dimensional structures is more difficult because the cracks influencing the curvature change are manifested, if they are in a plane perpendicular to the plane in which we monitor the curvatures; the cracks in the plane parallel to the plane of monitoring do not manifest their influence and the influence of those in the plane at an angle to the monitoring place is limited.

3.1 Square slab model

To verify the reliability of application of the *CAMOSUC* the autors used a 1000 x 1000 mm plexiglass slab 10 mm thick. The response was measured by means of 5 accelerometers, normalized by a reference accelerometer. The slab was vibrated either by a B&K hammer or by a RFT-Dresden vibration exciter. Both excitations differed, particularly by excitation amplitude.

Fig.1: Slab with accerometers and exciter.

The slab was excited in the virgin state: f = 23.2 Hz. Subsequently it was damaged by a cut 3 mm wide and 1.5 mm deep kerf across its whole width parallely with the line connecting both suspension points (in the Y axis direction). Subsequently the depth of the cut was increased to 2.5 mm and then to 5 mm, while its width was preserved. The numerical processing of Eq. (4) used the first excited natural mode because it corresponded with the requirement of orthogonality of the kerf and the plane of its curvature.

Major damage can be identified very well; the curvature ratios ascertained in 81 points was proved damage in 60 cases, i.e. 74%. Minor damage was proved in 54% of the total number of points. The smallest damage was proved in 40% of the total number of points.

The Fig. 3 below shows the results. The values $v_v''/v_d < 1$ are in the points, where the curvature of damaged structure is greater than in the virgin state; in these points are cracks in cross beams.

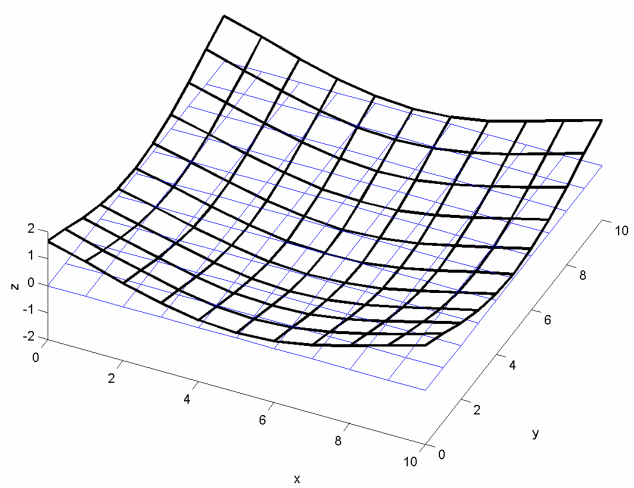


Fig. 2: First natural mode.

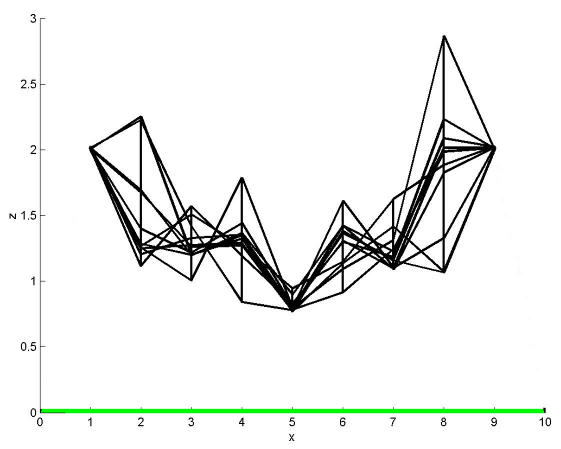


Fig.3a: Ratio of curvatures v_v'' / v_d'' (damage 5 mm). View in the Y axis direction.

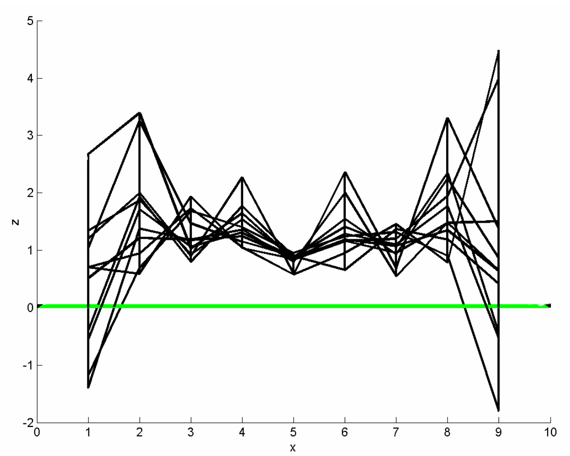


Fig.3b: Ratio of curvatures v_v'' / v_d'' (damage 2.5mm). View in the Y axis direction.

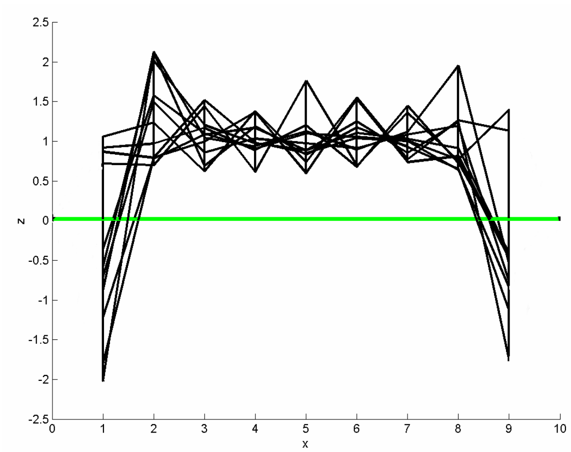


Fig.3c: Ratio of curvatures v_v'' / v_d'' (damage 1.5mm). View in the Y axis direction.

In all cases the damage location was proved explicitely in the kerf, i.e. on the vertical of Point 5 of axis X.

3.2 The determination of $J_{d\,\mathrm{real}}$

We determine the ratio $(J_d / J_v)_{\mathrm{real}}$ from the ratio $(J_d / J_v)_{\exp}$ given by experiments after eq. (7) for given slab thickness and for difference *h* after formula

$$\left(\frac{J_d}{J_v}\right)_{\mathrm{real}} \approx 1 - \sqrt[2,9]{\frac{1-\left(\frac{J_d}{J_v}\right)_{\exp}}{0.357}} \tag{8}$$

The Fig. 4 shows the ratio $(J_d / J_v)_{\exp}$ and $(J_d / J_v)_{\mathrm{real}}$ after experiments; from this ratios was determined the formula (8).

The Fig. 5 shows the summary of experiments with slab.

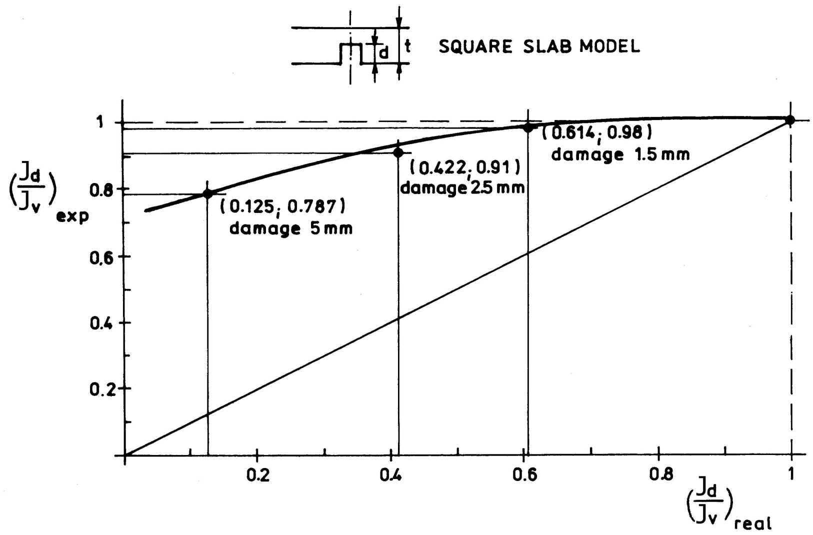
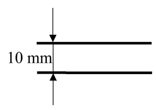
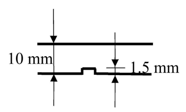


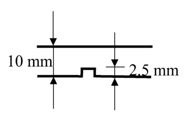
Fig. 4: Ratio $\left(\frac{J_d}{J_v}\right)_{\exp}$ on $\left(\frac{J_d}{J_v}\right)_{\mathrm{real}}$



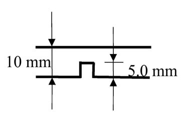
Virgin state; $f_{(1)v}$=23.20 Hz



$\left(\frac{J_d}{J_v}\right)_{\exp} = 0.98$; $\left(\frac{J_d}{J_v}\right)_{\mathrm{real}} = 0.614$; **$f_{(1)d}$=23.09 Hz**



$\left(\frac{J_d}{J_v}\right)_{\exp} = 0.91$; $\left(\frac{J_d}{J_v}\right)_{\mathrm{real}} = 0.422$; **$f_{(1)d}$=23.00 Hz**



$\left(\frac{J_d}{J_v}\right)_{\exp} = 0.787$; $\left(\frac{J_d}{J_v}\right)_{\mathrm{real}} = 0.125$; **$f_{(1)d}$=22.40 Hz**

Fig. 5: Results from experiments with slab model.

The relation (4) in the direction of axis Y (the direction of damaged cross girders) was given by dynamic response measurements in 35 point on the model surface; the electrodynamic exciter was soft connected with model on its lower surface.

4 Conclusion

Laboratory experiments on models and on actual structures have confirmed that the vibration-based inspection methodology for global structures health monitoring of structures is a promising technique enhanced by decreasing cost, good reliability and high sensitivity of modern transducers and computer technology (Frýba at al., 2001). This claim must be further proved by its application to complex three- dimentional structures and their models.

5 Acknowledgement

The support of the Grant Agency of the Czech Republic under Grant No 103/1/0243, GA AS CR A2071103 and EC grant No. ICA1-CT-2000-70013 (5^{th} FP) ARCCHIP is gratefully acknowledged. The authors are indebted to Mr. O. Vála for the reliable performance of experiments.

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