Journal of Sound and Vibration (1997) **203**(4), 728–729

A CRITIQUE OF LOCATION CRITERIA IN MODAL METHODS FOR STRUCTURAL DAMAGE IDENTIFICATION

J. Brandon

School of Engineering, University of Wales, Cardiff, PO Box 917, *Cardiff CF*2 1*XH*, *Wales*

(*Received* 14 *October* 1996, *and in final form* 20 *November* 1996)

The topic of *structural damage identification* is—for good reasons—of topical concern in structural dynamics. Indeed the theme of the 1997 International Modal Analysis Conference (IMAC) is *structural damage assessment*. The majority of research studies attribute the basic ideas to Cawley and Adams [1].

The mathematical rationale for modal methods for damage detection can be recognized directly from the Rayleigh quotient $\omega = \boldsymbol{\phi}^t\mathbf{K}\boldsymbol{\phi}/\boldsymbol{\phi}^t\mathbf{M}\boldsymbol{\phi}$. The most common assumption in damage identification is that there is a local degradation in stiffness but no variation in mass. Thus, when utilizing the Rayleigh quotient, the natural frequencies may—in general—be expected to decrease progressively as the structure degrades. When used uncritically this assumption can give rise to absurd results. For example, Williams and Salawu [2] reported a testing programme of a concrete bridge where natural frequencies decreased after repairs. A tentative explanation offered was the possibility that the moisture content of the concrete—and hence its mass—had varied during the course of the test. The dates of testing (autumn/fall—before repair, and spring—after repair) tend to support this conjecture.

The common feature of the overwhelming majority of modal methods known to the author is that the location and severity of damage is identifiable by quantifying changes in frequency and mode shape. The purpose of the current note is to question the whole rationale for this approach.

Aficionados of the Sherlock Holmes stories will know the story of *Silver Blaze*. Holmes recognized that the reason that a guard dog did not bark in the night was because it recognized the criminal and therefore felt no need to raise the alarm:

"*Is there any other incident to which you would wish to draw my attention?*"
"*To the curious incident of the dog in the night-time.*"
"*The dog did nothing in the night-time.*"
"*That was the curious incident*", *remarked Sherlock Holmes*. [3]

The lesson for the current note is that there is just as much information—if not more—in those *modes which do not change in frequency or mode shape* during structural degradation. Although this *was* remarked by Adams *et al*. [4], in a publication which pre-dates their most often cited paper [1], the knowledge has rarely been noted or, presumably, exploited subsequently.

To explain this apparently perverse viewpoint, it is remarked that, for structural damage to have no effect on the frequency or mode shape, the structural degradation must take place at a node of the mode. If it is known that structural degradation has taken place, and that several modes are unaffected by damage, then the damage must be located in a position which is nodal for each of these modes. Thus the position of the damage can be inferred.

Once remarked, it is reasonable to enquire whether this knowledge is anything other than an interesting curiosity. Where the behaviour of the structure is predominantly linear,

0022–460X/97/240728 + 02 $25.00/0/sv960883

this is probably so. When the response is non-linear, however, the amplitude of excitation in the modal test is an important factor for consideration. Unlike those modes which are changed by the damage, the modes which are nodal at the damage are likely to be less affected by amplitude non-linearities.

ACKNOWLEDGMENT

It would appear that Sherlock Holmes should be required reading for all structural dynamicists! The referee reminds me that Holmes used the tap test nearly one hundred years ago:

"... *I could think of nothing save that he was running a tunnel to some other building*. ... *I surprised you by beating upon the pavement with my stick*. *I was ascertaining whether the cellar stretched out in front or behind*. *It was not in front*."

REFERENCES

1. P. Cawley and R. D. Adams 1979 *Journal of Strain Analysis* **14**, 49–57. The location of defects from measurements of natural frequencies.
2. C. Williams and O. S. Salawu 1994 in B. I. G. Barr *et al*. (editors), *Bridge Assessment*, *Management and Design*, Elsevier, 67–72. Concepts of condition assessment of bridges using vibration testing and analysis.
3. A. Conan Doyle "Silver Blaze" in *Sherlock Holmes*: *The Complete Illustrated Short Stories*. Chancellor Press, 1985, 250.
4. R. D. Adams, P. Cawley, C. J. Pye and B. J. Stone 1978 *Journal of Mechanical Engineering Science* **20**, 93–100. A vibration technique for non-destructively assessing the integrity of structures.
5. A. Conan Doyle "The red-headed league" in *Sherlock Holmes*: *The Complete Illustrated Short Stories*. Chancellor Press, 1985, 48.