An Inverse Approach for the Determination of Viscous Damping Model of Fibre Reinforced Plastic Beams using Finite Element Model Updating

Subhajit Mondal and Sushanta Chakraborty
Department of Civil Engineering, Indian Institute of Technology Kharagpur, Kharagpur- 721 302, India

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Investigations have been carried out both numerically and experimentally to settle with a practically feasible set of proportional viscous damping parameters for the accurate prediction of responses of fibre reinforced plastic beams over a chosen frequency range of interest. The methodology needs accurate experimental modal testing, an adequately converged finite element model, a rational basis for correct correlations between these two models, and finally, updating of the finite element model by estimating a pair of global viscous damping coefficients using a gradient-based inverse sensitivity algorithm. The present approach emphasises that the successful estimate of the damping matrix is related to a-priori estimation of material properties, as well. The responses are somewhat accurately predicted using these updated damping parameters over a large frequency range. In the case of plates, determination of in-plane stiffness parameters becomes easier, whereas for beam specimens, transverse material properties play a comparatively greater role and need to be determined. Moreover, for damping matrix parameter estimation, frequency response functions need to be used instead of frequencies and mode shapes. The proposed method of damping matrix identification is able to reproduce frequency response functions accurately even outside the frequency ranges used for identification.

1. INTRODUCTION

The accurate determination of dynamical responses is very important from the viewpoint of safety, serviceability, and operation of any structure. The geometrical complexities, material property distributions, existing boundary conditions, and applied loading are the key factors that influence the dynamic responses. The elastic and inertial properties are somewhat correctly represented through finite element modelling with suitable simplifying assumptions, whereas uncertainties in response prediction still remain due to imperfect boundary conditions and the presence of damping, which are difficult to deal with. No generally acceptable modelling techniques for damping have been proposed in previous research that can be confidently used for complicated structures. The damping mechanism may comprise three effects — material damping resulting from micro-structural behaviour, friction damping resulting from looseness at boundaries, and environmental damping effects, such as interaction with the surrounding fluid. Depending on the practical situation, one or more component may be less significant than the others, making the modelling effort easier for the particular structure under consideration.

Although the phenomenon of damping is mostly nonlinear, the assumption of small damping makes many equivalent linear models practically acceptable. For example, Dowell and Schwartz[1] presented a methodology for accounting for dry friction damping arising from axial sliding of surfaces inside supports, and concluded from studies on plates and beams that an equivalent linear viscous damping ratio can be agreed upon, even if nonlinear Coulomb law for the friction and geometric nonlinearity of beams are present. Tang and Dowell[2] further investigated experimentally to verify the theory presented in the previous paper. It was concluded that the methodology works well in lower mode ranges, especially with the fundamental mode. Sometimes, it will be possible to accept on practical terms the linear damping models for much more complicated environmental effects, such as interaction of a beam with the surrounding air, etc. Filipiak, et al.[3] presented such an approach to determine the effects of air damping on small beams housing miniature sensors. How far such efforts are applicable to realistic full scale structures remain an open question.

If linear damping is agreed upon with small damping assumptions, it can be modelled as a multiplier of conveniently chosen state variables with constant coefficients. The success of such a model can be judged by its ability to replicate the actual observable responses over a frequency range of interests. Then, the entire domain of linear modal testing can be employed and a damping matrix can finally be put forward in the model to be treated in a fashion similar to the stiffness and mass matrices. Mostly, instantaneous velocity is chosen as the state variable, and the damping can be stated to be viscous.[4]

Fibre Reinforced Plastics (FRP) have long been used in weight-sensitive aerospace, naval, automotive, and high performance sports applications. However, it took some time for the engineering community to appreciate the other positive aspects of FRPs, such as durability, fatigue, and corrosion resistance to pave the way for its infrastructural applications. Recently, many standard structural forms such as various beam sections, plates, and shells have been routinely manufactured and employed for structural applications. Pultruded sections in regular forms such as rectangular, angle, 'T', etc., are likely to replace most of the current infrastructures made of conventional material such as steel. Condition assessment and health monitoring of such huge infrastructures made of FRPs will be a challenge in the future, especially if they degrade over long periods of time, but still remain serviceable. The exist-