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Review

Model reduction methods for viscoelastic sandwich structures in frequency and time domains

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ABSTRACT

This paper deals with modeling and model reduction methods intended to sandwich structures with viscoelastic materials. The modeling step is carried out by combining the First order shear deformation theory (FSDT) with the Golla–Hughes–Mc Tavish (GHM) model. The GHM model introduces auxiliary coordinates to take into account the frequency dependence of viscoelastic materials which, combined with the finite element method (FEM), leads to large order models. This paper focuses on the use of model reduction methods. The reduced models compared to the full model are illustrated by three numerical examples in order to outline the performance, the practical interest of these methods and their validity domains.

Contents

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1. Introduction

The use of viscoelastic [1,2] sandwich structures [3] has been regarded as a convenient strategy for many industries such as aeronautics, marines and automotives. In fact, these structures present a high way of vibration control in terms of lightweight and high specific stiffness, especially when they incorporated viscoelastic materials.

Several theories [4–7] were developed in order to approximate the displacement and the mechanical deformation of such structures. One of the well-known and useful theories is the classical theory of plates (CPT), which assume that a plane section initially normal to the midsurface before deformation remains plane and normal to that surface after deformation. Hence, this theory neglects the effect of shear deformations and leads to inaccurate results for laminated plates. So, it is obvious that transverse shear deformations have to be taken into account in the analysis. Thus, the first order shear deformation theory (FSDT) introduced by Reissner and Mindlin [4,7] takes into account this effect and assumes a linear variation of the midplane displacements through the thickness of the structure. This method has a significant advantage due to its simple implementation and low computational cost. Another laminated theory based on Reddy's refined [8] high order shear deformations theory (HSDT) which includes both bending and shear effects was carried out by Ferreira et al. [9], and by Chugal and Shimpi [10]. Unfortunately, this method requires a prohibitive computational time which is undesirable for such applications. Some other researchers [11,12] have used the layerwise theory for modeling the sandwich structures. Indeed, this theory assumes a displacement field in the form of zigzag along the thickness of the structure, allowing a kinematic description of each layer as a piecewise linear function. In addition, this theory is applicable to both thin and thick structures. Nevertheless, when the study is intended for thin structures, the first order shear deformation theory (FSDT) presents a suitable choice for the modeling of sandwich structures favored by its simple implementation in most finite element codes.

However, these structures exhibit viscoelastic damping, which combines viscous and elastic character. Hence, this dual character leads to a complicated behavior which requires a correct modeling approach. More recently, Golla, Hughes and Mc Tavish [13,14] have proposed the so-called GHM model. This model provides an effective method which includes viscoelastic damping through the addition of auxiliary coordinates called dissipation coordinates as a sum of elementary mini-oscillators.

Furthermore, the GHM model, combined with the finite element method (FEM) [15], allows the introduction of viscoelastic material properties through element mass, stiffness, and damping matrices. The addition of internal mini-oscillators for each viscoelastic finite element allows a general description of frequency-dependent viscoelastic materials properties behavior. The main advantage of this method consists in its efficient modeling of viscoelastic material behavior; but its major drawback is the largely finite element dimension system which requires a prohibitive computing time. Consequently, a model reduction should be applied to the augmented GHM model.

The present paper proposes an alternative of model reduction such as dynamic [16,17], Guyan [18,19], modal and modal in physical space (SEREP) [20–23] reduction methods for this problem. The first one is based on the elimination of unwanted variables; it partitions the full degree-of-freedom (dofs) into master and slave dofs and uses the modal properties of the slave part of the structure when the master dofs are grounded. Hence, the derived slave modes are operated to enrich the dynamic basis leading to a drastic reduction method. The simplest yet very useful model reduction method is the well-known Guyan reduction method. It is a particular case of dynamic reduction method according to which the inertia associated with the slave coordinates is neglected; only master dofs are retained. Thereby, the unwanted variables are removed, leading to a reduced model which is a subset of the original system in a restricted range of frequency. However this method is limited by its validity domain [24,25]. Another reduction method is the frequently used modal reduction method according to which the derived modes associated with the undamped structure are incorporated in the GHM damped model, yielding an exact transformation basis. This basis restitutes correctly the undamped modes of the original system leading to a drastic reduction. The modal reduction method can expand the projection from generalized coordinates system to the physical coordinates system, leading to another strategy of reduction called modal reduction in physical space method. This method restitutes also the first modes of the undamped structure and partitions the modal basis into master and slave dofs. This leads to several cases which will be tested examining both the number of retained modes and the number of master dofs.

On the other hand, the modeling of viscoelastic sandwich structures has attracted many researchers, but only a few papers have dealt with the GHM model [26,27]. However, these papers remain limited mostly to frequency domain analysis with major uses of the space state modal reduction method for model reduction. In fact, Trindade et al. [28] and De Lima and Rade [29] used the modal reduction in their studies frequently. It consists in transforming the second-order equation of motion into an equivalent first-order form (space-state model). Unfortunately, this method leads generally to a space state model of dimension at least the double of the total dimension of the GHM model (2 N) and the quadruple dimension of the structural dofs which requires a prohibitive time of calculations.

Therefore, the application of the proposed reduction methods, which are often used with the undamped structures, combined with the GHM model allows one to add the effects of viscoelastic components to the sandwich structures without increasing the order of the finite element models. Furthermore, these reduction methods can be applied to sandwich structures described kinematically by the other mentioned theories.

In this paper, both the theory related to the implementation of the FSDT theory combined with the GHM method and the theory related to its reduction methods are presented. Numerical simulations applied to beam, plate and non-linear assembled beams in both frequency and time domains are also illustrated. These examples will highlight the performance of reduction methods and its practical interest in the dynamic analysis of viscoelastically damped sandwich structures.

2. Three-layer viscoelastic finite element model

Multilayer structures are typically used for its light-weight, high specific stiffness and strength values in many engineering