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Reduced order modelling of elastomeric vibration isolators in dynamic substructuring

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ABSTRACT

Dynamic substructuring is often employed to reduce the size of numerical models for structural dynamic analysis. In this paper, we discuss how elastomeric vibration isolators can be modelled within the framework of dynamic substructuring in order to obtain accurate and efficient reduced order models. For several reasons, it is beneficial to divide a structure containing elastomeric isolators into substructures at the interfaces between elastomers and surrounding parts of the structure. Therefore, we consider the elastomeric isolators as reduced coupling elements in the connections of substructure models. The coupling elements are established by reducing the number of degrees of freedom of 3D finite element models of elastomers. The main purpose of the studies presented in the paper is to evaluate the performance of different reduction method when applied to elastomer models. In addition, the effects of modelling features such as rotational coupling and frequency-dependent material properties of elastomeric isolators are investigated. A model of a wooden building structure with elastomeric isolators is used as an example case, considering steady-state dynamic analysis in the low-frequency range. The results and discussions presented in the paper provide guidance for reduced order modelling of elastomeric isolators in dynamic substructuring.

1. Introduction

Elastomers are used for vibration isolation between structures because of their low stiffness and high strain capacity. The low stiffness is beneficial for reducing the transmission of high-frequency vibrations from a source to surrounding structures. The size of the elastomers is often small compared to the structural components between which they are placed, as illustrated in Fig. 1. Examples of such structures are machines that are placed on elastomer foundations and multi-storey buildings with elastomers between storeys. In this paper, we focus on structures where the elastomeric isolators are small compared to the structure itself.

To design structures having adequate performance in terms of vibrations and structure-borne sound, it is desirable to have tools that predict the effects of structural modifications prior to construction. The finite element (FE) method is used to create prediction models in many engineering disciplines as it allows for detailed analyses of complex problems. To accurately assess the dynamic behaviour of structures, FE models that represent the geometry in considerable detail are required. However, the models are often too large for simulations to be performed within a reasonable time, implying the need for model order reduction. A methodology that is frequently used to reduce the size of the FE models is dynamic substructuring [1], which is based on a division of structures into substructures that are reduced in size and assembled to form reduced global models. The system matrices of reduced models are in general densely populated, especially if there is a large number of interface degrees of freedom (DOFs). Consequently, more than a few thousand DOFs per substructure can make analyses unfeasible.

The structure shown in Fig. 1 is preferably partitioned into substructures by making divisions at the elastomer interfaces. The resulting substructures have interface surfaces that are small relative to the complete geometry. This is an advantage when striving for a small number of interface DOFs. Furthermore, such a division into substructures allows for the elastomers to be modelled using frequency-dependent material properties as they are excluded from the substructures; conventional methods for model order reduction do not allow for frequency-dependent system matrices. Another advantage is that experimental structures often can be divided in the same manner. Each substructure can then be analysed both numerically and experimentally, enabling model correlation to be performed at the substructure level.

Elastomeric vibration isolators are often modelled using systems of linear springs and dashpots (see, for example, [2–5]). Such systems are

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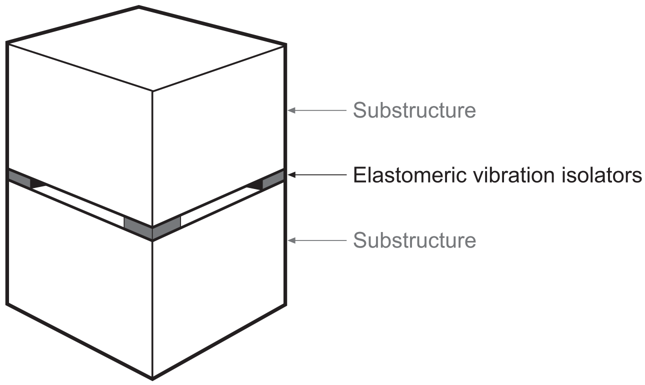

Fig. 1. Illustration of a structure involving elastomeric vibration isolators that are small compared to the structure itself.

suitable for the coupling of substructure models as they result in small numbers of interface DOFs. However, it is difficult to determine appropriate spring and dashpot coefficients since these depend on the material properties, geometries and boundary conditions of the elastomeric isolators. Manufacturers of elastomers often provide material data in terms of test results that are obtained for specific geometries and boundary conditions. Such data cannot be used to directly determine spring and dashpot coefficients for elastomeric isolators with arbitrary geometries and boundary conditions. However, the material data can be used to determine viscoelastic material properties of the elastomers by employing a procedure such as the one presented in [6]. The material properties can then be used in 3D FE models of elastomeric isolators with arbitrary shape. Such FE models account for features such as rotational coupling, frequency-dependent material properties and mass of elastomers in the coupling of substructure models. However, the use 3D FE models results in a large number of DOFs for the elastomers and a large number of interface DOFs for the substructures. Consequently, there is a need to perform interface reduction and model order reduction of FE models of elastomers in dynamic substructuring.

In this paper, we discuss different methods for reducing FE models of elastomeric vibration isolators. The methods are investigated by comparing their effects on the accuracy and computational efficiency of dynamic substructure analyses. We consider the elastomers as reduced coupling elements that are used to connect substructure models to each other, as illustrated in Fig. 2. The coupling elements are established by performing interface reduction and model order reduction for 3D FE models of elastomeric isolators. A coupling element replaces an FE model with a set of condensation nodes (one node for each interface surface) and a reduced description of its internal structure. The condensation nodes have both translational and rotational DOFs, thus containing six DOFs per node, and they represent the motion of their respective interface surface. Condensation nodes are introduced both at the elastomers interfaces and at the interfaces of the substructure models. Two substructure models are then connected by tying their condensation nodes to those of the intermediate coupling element, either by direct assembling or by using Lagrange multipliers [7].

We investigate the use of reduced coupling elements for an example case of a wooden building structure containing elastomeric vibration isolators. The purpose is to evaluate the accuracy and computational efficiency of different reduction methods when applied to FE models of elastomers. Furthermore, the effects of including different modelling features in the coupling elements, such as rotational coupling and frequency-dependent material properties, are investigated. The analyses were performed in the frequency domain to better account for the frequency-dependent properties of the elastomers. The example case is investigated in the low-frequency range, where the modal density is low and it is relevant to use deterministic methods such as the FE method.

1.1. Outline of paper

In Section 2, we discuss the dynamic properties of elastomers and how these are accounted for in the studies presented in the paper. In Section 3, we provide a brief introduction to dynamic substructuring and present the theoretical background to the reduction methods used in the paper. In Section 4, we explain the procedure employed to create reduced coupling elements representing elastomeric vibration isolators in dynamic substructuring. In Section 5, we present the studies of the example. Finally, a general discussion of the accuracy and computational efficiency of different reduction methods is presented in Section 6.

2. Dynamic properties of elastomers

Elastomers are a class of polymers that have high strain capacity. The long and tangled molecular chains of elastomers can stretch and align with the direction of straining, resulting in yield strains of up to several hundred percent. Examples of other characteristic properties are high vibration damping due to energy loss from hysteresis and low stiffness compared to common construction materials such as steel, concrete and wood. Therefore, elastomers are suitable for vibration isolation. The low stiffness implies a large difference in the impedance at the interfaces to surrounding structures, thus increasing the amount of reflected vibration energy. Furthermore, the damping properties result in energy dissipation in the elastomeric vibration isolators. The dynamic properties of elastomers depend on various parameters such as temperature, frequency and the strain level. This complicates analyses where large variations of those conditions occur. For further information about the dynamic properties of elastomers, see for example [8,9].

In the studies presented in the paper, the elastomer properties are assumed to be frequency-dependent, but independent of strain level and temperature. In other words, it is assumed that variations in strain level and temperature during steady-state dynamics have no significant effect on the response. For the example case studied in the paper, which is a wooden building structure representing part of a residential building, such assumptions do not imply any significant limitations;

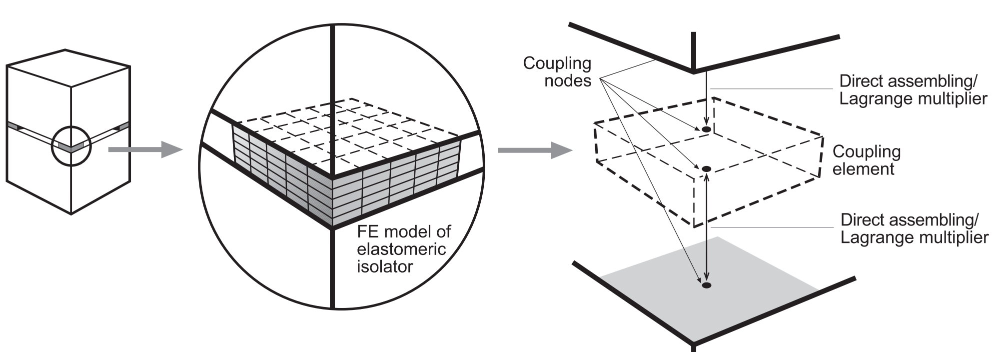

Fig. 2. Illustration of coupling elements representing elastomeric vibration isolators in dynamic substructuring.