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A reduced interface component mode synthesis method using coarse meshes

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Abstract

Component mode synthesis is a technique to simplify the analysis of complicated finite element models. A structure is split into substructures from which reduced order models can be generated and subsequently assembled. A model reduction performance gain can be limited if the component interfaces contain many degrees of freedom, which is often the case for high resolution models. In this paper a substructuring framework with interface reduction is presented. The method first splits a detailed model into substructures. The substructures' fine mesh is then coarsened on the internal region, while keeping the boundary mesh intact. Thereafter a Guyan reduction is performed on each coarse mesh substructure. The Guyan computations are cheap due to the reduced size of the linear equation system necessary to solve for the coarse mesh system. After synthesis of the statically reduced systems, a reduction basis for the interface degrees of freedom is computed. Thereafter a Craig-Bampton reduction is performed on each fine mesh substructure using projections with the reduced interface degrees of freedom and fixed interface modes. The method is verified on a dense mesh plate model consisting of two substructures.

Keywords: Substructuring; component mode synthesis; interface reduction; mesh coarsening

1. Introduction

Initial ideas for the component mode synthesis (CMS) method were first published by Hurty [1,2] and Gladwell [3]. These ideas were further developed by Guyan [4], resulting in the well known Guyan method for condensing the internal degrees of freedom (DOFs) to the boundary DOFs, and later extended by Craig and Bampton [5] as a substructuring method where the internal dynamics were also accounted for by including fixed interface modes in the reduction basis. The Guyan and Craig-Bampton (CB) methods are widely used in industry and are available in most finite element (FE) software. Throughout the years there have been many variations and advances made to the previously mentioned methods. For a historical review see [6].

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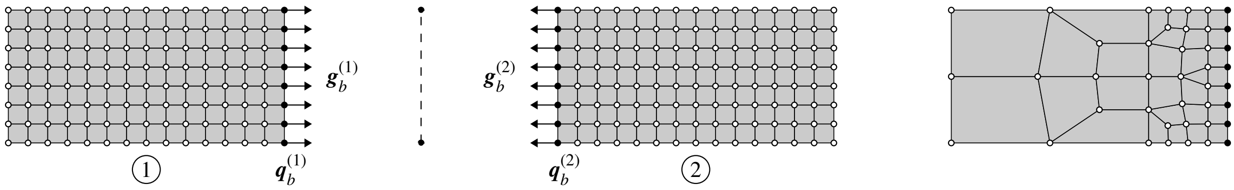

(a) (b)

Fig. 1: (a) two identical substructures to be joined, and (b) a coarsened internal mesh of one substructure. Here ∘ denote internal nodes associated with $\boldsymbol{q}_i^{(s)}$ and • denote boundary nodes associated with $\boldsymbol{q}_b^{(s)}$. The arrows ⟶ denote boundary forces $\boldsymbol{g}_b^{(s)}$ felt from neighbouring structures.

The CB reduction method relies on the formulation of a reduction basis consisting of static constraint modes and fixed interface normal modes. The static constraint modes are computed using Guyan reduction and are directly related to the number of boundary, or interface, DOFs. The numbers of fixed interface modes can be selected arbitrarily by the user to capture the dynamical range of interest. In applications where the fixed interface modes are small in comparison to the static constraint modes, or the FE model mesh is very dense with many boundary DOFs, the CB reduction efficiency decreases. Therefore, methods have been proposed to reduce the interface DOFs. The problem was first considered by Craig and Chang [7], where modal, Guyan and Ritz reduction methods were proposed. In [8] Balmès proposed a generalisation of the static constraint modes, simply denoted generalised interface DOFs. The generalised static constraint modes are defined as linear combinations of the static modes through a basis of interface deformations. The basis can be formed in various ways with the underlying assumption that it is representative of the actual displacements around the interfaces. For free and hybrid interface methods Tran [9] extended the interface reduction methods, with applications to cyclic symmetrical problems, and further extended the method for partial interface reduction [10], i.e. when some physical DOFs of the interface are kept out of reduction. In [11] Aoyama and Yagawa proposed that interface vibration modes for the CMS method be computed from local interface modes of connected substructures. Zhang, Castanier and Pierre noted in [12] that a static constraint mode is usually heavily localised to the surrounding of the associated interface DOF. Therefore, if internal DOFs experience negligible displacement, the corresponding static reduction basis elements can be set to zero, i.e. a filtering of elements less than a certain threshold was proposed. Other approaches to the interface reduction problem exist, such as the wave-based substructuring approach by Donders et al. [13]. For further methods see [6,14–16].

In this paper a simple methodology for fast interface reduction is presented. The Guyan reduction is made efficient through mesh coarsening, so that the size of the linear equation system in the Guyan reduction computations is considerably reduced. Results from an implementation of the method in MATLAB will be presented here. This paper is organized as follows. In Section 2 the theory behind the method is explained and in Section 3 the numerical results of the analysis of a plate with three holes and a high density mesh is shown. Further, in Section 4 the method is related to other interface reduction methods and in Section 5 the paper is concluded.

2. Theory

No notational differences for system matrices and vectors of the coarse and fine substructures are made here, rather it should be obvious from the context. The equations of motion (EOMs) for an undamped, linear mechanical system of some component (s) can be written as

$$\boldsymbol{M}^{(s)}\ddot{\boldsymbol{q}}^{(s)}(t) + \boldsymbol{K}^{(s)}\boldsymbol{q}^{(s)}(t) = \boldsymbol{f}^{(s)}(t) + \boldsymbol{g}^{(s)}(t) \tag{1}$$

where $\boldsymbol{M} \in \mathbb{R}^{n\times n}$ and $\boldsymbol{K} \in \mathbb{R}^{n\times n}$ represent the mass and stiffness matrices, respectively. Here $\boldsymbol{q} \in \mathbb{R}^{n\times 1}$ denote the displacement vector associated to the DOFs, $\boldsymbol{f} \in \mathbb{R}^{n\times 1}$ the external excitation force vector and $\boldsymbol{g} \in \mathbb{R}^{n\times 1}$ the interface force vector representing the counteracting forces from neighbouring structures, denoted boundary forces. The dot notation is adopted for time differentiation. Explicit time dependence (t), and substructure (s) notation is here on dropped for brevity. The derivations will be made for one substructure, but the procedure is identical for the other substructures and should be obvious from the presentation. The following treats the eigenproblem and therefore