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An Impulse Based Substructuring method for coupling impulse response functions and finite element models

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Abstract

In the field of Dynamic Substructuring (DS), large and complex structures are divided into several smaller and simpler components. The linear substructures are subsequently described in their dominant dynamics and reassembled, allowing one to compute the coupled dynamic behavior. DS methods are often classified into two distinct families, the Frequency Based Substructuring (FBS) methods and Component Mode Synthesis (CMS) techniques. In the former substructures are assembled whose dynamics are described in terms of frequency response functions (FRFs) and the latter are used to reduce and assemble the substructure finite element (FE) models. Lately a new substructuring method has been proposed, one that does not fit the framework of the FBS and CMS methods. The method, named Impulse Based Substructuring (IBS), was first used to obtain the coupled response of a system by assembling its component impulse response functions (IRFs). In this paper the IBS method is extended, thereby allowing one to determine the coupled behavior of structures that are composed of both substructure FE models and substructure IRFs. The method can be regarded as an extension to the normal time integration methods used for obtaining the time responses of FE models. As the linear substructures (described in their IRFs) are fully condensed on the interface of the FE model, one can significantly reduce the computational cost required for time integrating otherwise large FE models. However, as the linear (IRF) domains are exactly accounted for, the IBS method can be seen as a dynamic condensation on the interface, but not as a reduction method in the classical sense. Nonetheless, one can regard IRFs as a sort of "superelements in time" and the IBS method can therefore serve as an attractive alternative to CMS methods in case these are not available in the applied FE modeling programs, or if a high spectral bandwidth of the substructure is required. The method proposed in this work is based on the generalized-α time integration scheme and it is analytically proven that it can be applied in such a way that the simulation results are identical to the responses obtained from a monolithic integration of the full system, thereby guaranteeing its stability and

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accuracy. The method is demonstrated using a numerical test case, where a wind turbine FE model is coupled with a the IRFs of a marine foundation.

Keywords: Dynamic Substructuring; Impulse response functions; Time integration; Impulse Based Substructuring; Finite elements

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Nomenclature

$\mathbf{B}$	compatibility matrix (signed Boolean)
$\mathbf{C}$	damping matrix
$\mathbf{f}$	array of external forces
$\mathbf{g}$	array of connection forces
h	time step size
$\mathbf{K}$	stiffness matrix
$\mathbf{M}$	mass matrix
$\mathbf{P}$	orthogonal projector
$\mathbf{p}$	array of internal (nonlinear) elastic and damping forces
$\mathbf{R}$	set of rigid body modes
$\mathbf{S}$	Jacobian (iteration) matrix
$\mathbf{u}$	array of degrees of freedom
$\mathbf{Y}$	matrix of impulse response functions
$\boldsymbol{\alpha}$	amplitudes of the rigid body modes
$\alpha_f,\ \alpha_m$	parameters of the generalized-α time-integration scheme
$\beta,\ \gamma$	parameters of the Newmark time-integration scheme
$\boldsymbol{\lambda}$	array of Lagrange multipliers
CMS	Component Mode Synthesis
CB	Craig–Bampton
DoF	Degree of Freedom
FE	finite element
FBS	Frequency Based Substructuring
IRF	impulse response function
IBS	Impulse Based Substructuring
$\star_{[b]}$	associated to the interface DoF
$\star_n$	pertaining to time step n
$\star^{(s)}$	pertaining to substructure s
$\hat{\star}$	denoting a variable in the frequency domain

1. Introduction

Dynamic Substructuring is a family of methods based on the ancient idea of “divide and conquer”; by dividing a large and complex system into smaller and simpler subsystems, one is able to compute the dynamic behavior, which might otherwise not be possible, or greatly improve the efficiency of doing so. The first successful implementation of this idea in mathematics was published by Schwarz in 1890 [1], but the idea of substructuring did not find its way to mechanics for another 70 years. In 1960 Hurty [2] was the first to propose the so called Component Mode Synthesis technique, which triggered an entire new field and was soon followed by the methods from Hurty [3], Gladwell [4], Guyan [5], Craig [6], MacNeal [7] and Rubin [8] in the 60s and 70s.