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SMS – A High Performance Eigenvalue Solver

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INTRODUCTION

Eigenvalue analysis of structural models is a common analysis task. Often the lowest natural frequencies are directly related to some performance index of the structure. In addition, eigenvalue information is used to create a modal reduction of the structural model to reduce the cost of frequency response and/or transient dynamic analysis. Therefore, an improvement in the performance of the eigensolution process will have a direct effect on many analysis tasks. Vanderplaats Research & Development (VR&D) introduces a new eigenvalue solver implementation that dramatically reduces both the CPU and elapsed times for all ranges of problem sizes compared to the current state-of-the-art Lanczos algorithm. This new solver, named SMS, will be available in the upcoming GENESIS Structural Analysis and Optimization Software Version 7.0 release, as well as in a new stand-alone product, Vrand/SMS.

THE SMS ALGORITHM

The SMS algorithm is an extension of the Craig-Bampton method for coupling substructures[1]. The Craig-Bampton method extends static-condensation based substructuring to dynamic analysis by partially accounting for the inertial loading of the substructures by way of a set of basis vectors based on the substructure "component" or "fixed-interface" modes. This technique has been widely used to manually reduce large eigenvalue problems to more manageable sizes.

Bennighof and Kaplan[2] presented the idea of automating the Craig-Bampton method by applying it to automatically generated substructures, as part of a technique for solving the frequency response problem. This innovation opened to door to applying Craig-Bampton style reductions to arbitrary sparse matrices.

SMS is an implementation of an algorithm that applies the Craig-Bampton method to each stage of processing in a sparse matrix reduction. Because the method is based on creating approximate reduced models, it provides approximate eigenvalues and eigenvectors. The implementation is designed such that calculated natural frequencies at the upper end of the desired frequency range have less than about 0.3% error. Calculated natural frequencies at the lower end of the spectrum typically have less than 0.001% error.

The use of approximate results should not be troublesome to analysts who understand that numerical analysis of structures is always involves approximation. It is expected that lower modes are sufficiently accurate for use in design and optimization, while the higher modes are sufficient for modal reductions.

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[1] Craig, R.R., and Bampton, M.C.C., "Coupling of Substructures for Dynamic Analysis", *AIAA Journal*, Vol. 6, No. 7, 1968, pp.1313-1319.

[2] Bennighof, J.K., and Kaplan, M.F., "Frequency Sweep Analysis using Multi-Level Substructuring, Global Modes and Iteration", *Proceedings of 39th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference*, Long Beach, CA, April 1998.

The SMS method is designed for natural frequency analysis, and is not suitable for buckling analysis. The method requires a reasonable upper bound on the desired natural frequency calculation range.

There are three stages to the SMS method. The first stage is the reduction phase. This phase combines a sparse factorization with many small dense eigenvalue problems. The time for this stage depends on both the problem size, as well as the number of modes in the desired frequency range. The second stage consists of solving the final reduced eigenvalue problem. The time for this stage depends solely on the number of modes in the desired frequency range. The final stage consists of the recovery of the full eigenvectors.

SMS USAGE

SMS is available in GENESIS version 7.0 as an alternative to the two existing eigensolvers, namely the Lanczos method and the subspace iteration method. The SMS method is selected by the user by using “SMS” in the method field of the EIGR entry. If the SMS method is selected, the frequency upper bound (V2) must also be specified on the EIGR entry.

SMS is also available in the new product, Vrand/SMS. Vrand/SMS is an external matrix solver designed to work with third-party finite element programs that can export stiffness and mass matrices (for example, NASTRAN). Vrand/SMS imports the matrices, solves the eigenvalue problem using the SMS method, and exports the eigenvalues and eigenvectors in a format suitable for importing back into the third-party code.

SMS EXAMPLES

To illustrate the savings possible with the SMS method, timings for three examples are presented. The three models were analyzed in GENESIS, each using both the SMS method and the Lanczos method. All models were run on an HP 785/C3600 workstation, and each method was given the same amount of memory. One of the primary advantages of the SMS method over the Lanczos method is in Input/Output. The Lanczos method requires a great deal of I/O, and this requirement increases sharply as the number of modes calculated increases. Conversely, the SMS method requires much less I/O, and this translates directly to reduced elapsed times. The following table shows the elapsed times for both methods for each example problem.

Comparison of Lanczos and SMS Eigensolver Performance

Degrees of Freedom	Number of Modes Calculated	Lanczos Elapsed Time	SMS Elapsed Time	Time Saved
473853	200	4.6 hrs	0.4 hrs	4.2 hrs
218262	1155	7.6 hrs	1.0 hrs	6.6 hrs
848517	192	10.4 hrs	1.4 hrs	9.0 hrs