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Evaluation of Parallel Version of Nonlinear FEM Solver FINAS*

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FINAS* is an in-house nonlinear FEM solver, which has been developed as a core solver of multi-physics analysis systems in ITOCHU techno-solutions corporation. In this paper, speed and accuracy of the parallel version of FINAS* are evaluated.
Key Words*: Parallel computing, nonlinear FEM*

1. INTRODUCTION

FINAS* is a core solver of multi-physics systems, which has been developed in ITOCHU techno-solutions corporation, consisting of linear and nonlinear FEM components of structural analysis, heat transfer analysis, electromagnetic field analysis, civil analysis and seismic analysis. FINAS* is parallelized based on MPI with several parallel algorithms of linear equation solver implemented.

The objective of this paper is to evaluate speed and accuracy of the parallel version of FINAS*. An elasto-plastic problem with large deformation is calculated and comparison is performed among different parallel algorithms and a direct solver.

2. PARALLEL ALGORITHMS IN FINAS*

The following parallel algorithms of linear equation solver are implemented in FINAS*.

・Conjugate gradient method with Jacobi preconditioning, conveniently called as PCG in this paper.

・Domain decomposition method with diagonal scaling preconditioning (DDM).

・Balancing domain decomposition method (BDD) [1].

・Balancing domain decomposition method with diagonal scaling (BDD_DIAG) [2].

・Modified balancing decomposition method (MBDD).

In all these methods, the analysis domain is divided into some subdomains calculated on different CPUs in parallel. PCG solves the linear system of all the free degrees of freedom, while DDM and BDD solve only that on the boundary of subdomains and involve calculating the Schur complement of each subdomain. For that reason, the computing cost of DDM or BDD in each iteration step is more than that of PCG, whereas the number of iteration steps can be much less.

BDD improves the convergence by coupling local problems on subdomains with a coarse problem which propagates the error globally, but needs to solve the local problems on all subdomains in every iteration step that is typically singular. In order to avoid the singularity and reducing the computing cost, BDD_DIAG simplified the local problem into a diagonal matrix.

MBDD, a modified version of BDD, will be presented in other paper by the authors.

3. CONVERGENCE OF BDD

As known, the convergence rate of PCG and DDM is dependent on the matrix property, fast for well conditioned models such as blocky structures but slow for ill conditioned ones for example thin-walled structures. BDD is proposed to improve the matrix condition by the balancing Neumann-Neumann preconditioning and reduce the dependency on the matrix property [1].

In order to verify the BDD's convergence, three models are calculated. One is a cube, a most typical blocky structure, as shown in Figure 1. The second is a pipe, a thin-walled structure, as shown in Figure 2. Another is a wheel, a usual FEM model in practice, as shown in Figure 3.

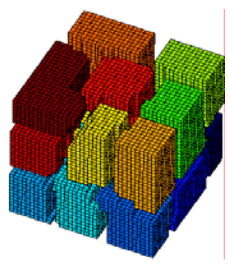

Figure 1 A cube model of 24,000 DOFs

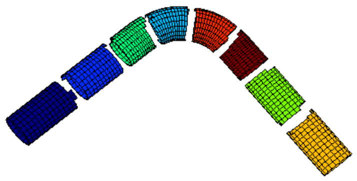

Figure 2 A pipe model of 101,520 DOFs

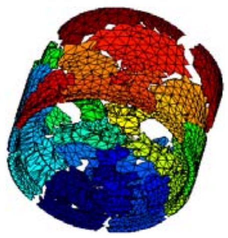

Figure 3 A wheel model of 76,371 DOFs

It can be found from Figure 4-6 that the BDD's convergence is much faster than that of DMM for all three models.

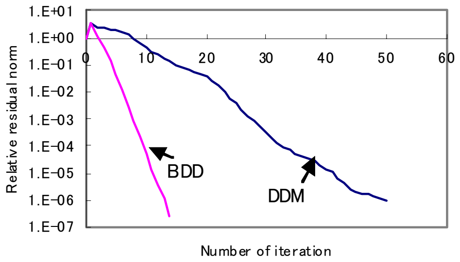

Figure 4 BDD's Convergence of the cube model

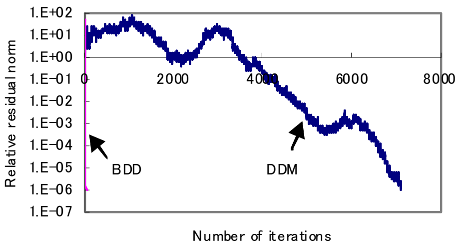

Figure 5 BDD's Convergence of the pipe model

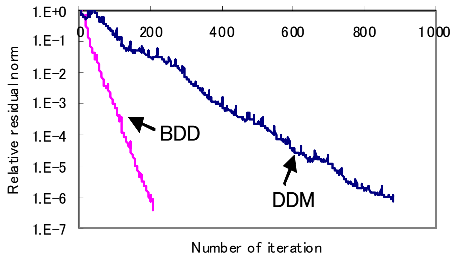

Figure 6 BDD's Convergence of the wheel model

4. EVALUATION REULTS

A rotation bending problem of a wheel is calculated as an elasto-plastic analysis considering the effect of large deformation. The elasto-plastic model is given as a J_2 model with isotropic hardening. The logarithmic strain and the updated Lagrange algorithm are adopted for large deformation analysis.

The FEM mesh consists of 299,569 nodes and 1,572,842 elements. Five parallel algorithms described in Section 2 are applied decomposing the whole analysis elements into 4096 subdomains as shown in Figure 7 and parallelizing as 4 processes. The results of vonMises stress and displacement are compared to that of a direct solver for all these algorithms, and that the differences are in the range of error tolerances is confirmed. The quadratic convergence of the Newton-Raphson iteration is achieved by all these parallel algorithms as same as that by the direct solver.

The specification of the computer used for this evaluation is as following:

・OS: SUSE linux enterprise server 9
・CPU: Opteron 8468(2.0GHz)×4
・Memory: 16GB.

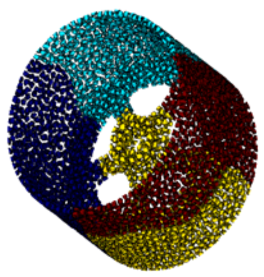

Figure 7 4096 decomposed subdomains of the wheel model

The ratios of the elapsed time of the above algorithms to that of PCG are listed in Table 1. In this analysis, MBDD is the fastest.

Table 1 Ratios of elapsed time to that of PCG

PCG	1
DDM	2.73
BDD	0.77
BDD_DIAG	0.87
MBDD	0.53

5. CONCLUSIONS

The convergence of BDD implemented in FINAS* is verified by three typical models. The calculation accuracy of the parallel version of FINAS* is confirmed by comparing to a direct solver. The speed of five parallel algorithms is tested and MBDD is the most effective for the wheel model of 1.5M elements of elasto-plastic analysis with large deformation.

REFFERENCES

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