Development of the Next-generation Computational Solid Mechanics Simulator for a Virtual Demonstration Test

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We have been developing an advanced general-purpose computational mechanics system, named ADVENTURE, which is designed to be able to analyze a three-dimensional (3D) finite element model of arbitrary shape with a 10–100 million degrees of freedom (DOF) mesh. Module-based architecture of the system with standardized I/O format and libraries are developed and employed to attain flexibility, portability, extensibility and maintainability of the whole system. Domain-decomposition-based parallel algorithms are also implemented in pre-processes (domain decomposition), main processes (system matrix assembling and solutions) and post-processes (visualization), respectively. The hierarchical domain decomposition method (HDDM) with a preconditioned iterative solver is adopted in the main processes as one of the major solution techniques. The one of main processes module for solid analysis has been implemented on the Earth Simulator consisting of 128 nodes, i.e. 1,024 processing elements (PEs), and applied for an elastostatic analysis of a precise nuclear vessel model of 35 million DOF mesh with 1.9 TFLOPS, which is 23.75% of the peak performance. In this report, the solid analysis module is successfully applied for an implicit dynamic elastic analysis such as seismic response of a nuclear vessel model and implemented on the 256 nodes, i.e. 2,048 PEs. It succeeds in solving an elastostatic problem of a nuclear pressure vessel model of 100 million DOF mesh with 5.08 TFLOPS, which is 31.75% of the peak performance.

Keywords: CAE System, Parallel Finite Element Analysis, Hierarchical Domain Decomposition Method, Balancing Domain Decomposition

1. ADVENTURE system

The ADVENTURE system [1] has employed a hierarchical domain decomposition based massively parallel algorithm as one of the major solution algorithms in order to efficiently handle a huge-scale finite element model with 10–100 million DOF. We have been developing several kinds of main processes for implicit elastic-plastic analysis, rigid-plastic analysis, impact-contact analysis, thermal conductive analysis, thermal-fluid analysis and electromagnetic analysis. Especially, the implicit elastic-plastic analysis module, named ADVENTURE_Solid, is improved to apply to massively parallel processors (MPP) with over 1,000 PEs and successfully to analyze a simplified pressure vessel model with 100 million DOF mesh [2]. The parallel architecture of the ADVENTURE_Solid is based on a hierarchical domain decomposition method (HDDM) [3], and employed a preconditioner, named balancing domain decomposition (BDD) [4, 5].

2. Seismic response analysis of the ABWR model with 35 million DOF mesh

This system is applied for a seismic response analysis of the advanced boiling water reactor (ABWR) model with 35 million DOF mesh on the 1,024 PEs. As boundary conditions, a bottom plane of its skirt portion is fixed. As a seismic load, the acceleration history of 1,940 Elcentro earthquake ground motion (Fig. 3) is taken, whose data is provided by the Building Center of Japan [6]. Fig. 3 shows the stress distribution and the deformed configuration in 40 and 80 time steps.

Fig. 4 shows the histories of residual norm, solved with a diagonal-scaling preconditioner, denote as DDM, and with the BDD preconditioner, respectively. The BDD succeeded in calculation time about 6 times speed-up compared with DDM. Table 1 shows the calculation performances. Consequently, the present system is successfully to analyze a seismic response analysis of a precise and whole structure model of 200 time steps in about 7 hours.

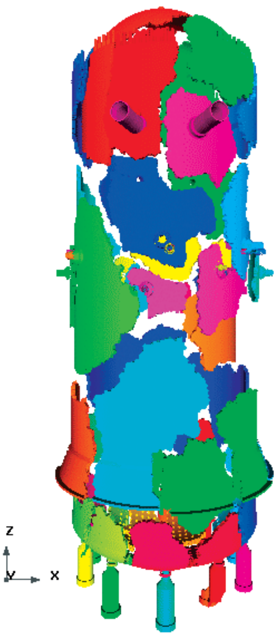


Fig. 1 Part decomposition of ABWR model.

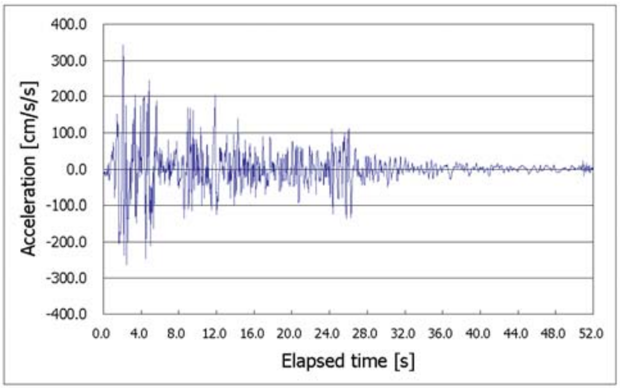
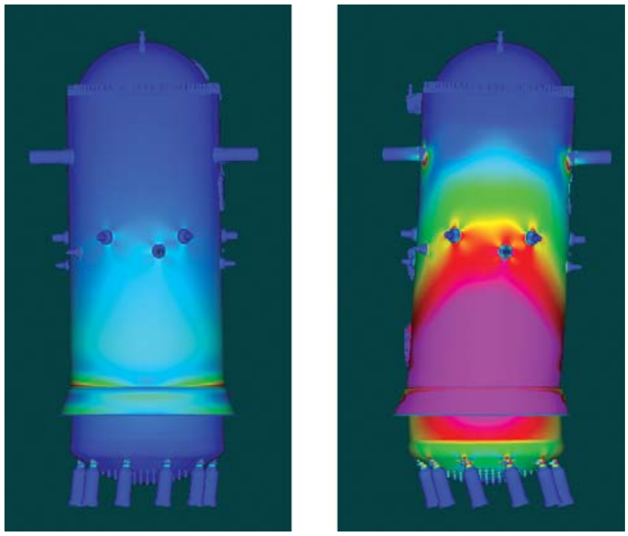


Fig. 2 ElCentro earthquake ground motion 1940, NS direction, provided by the Building Center of Japan.



Elapsed 0.8 seconds
(40 time steps)

Elapsed 1.6 seconds
(80 time steps)

Fig. 3 Stress distribution and deformed configuration of the ABWR model.

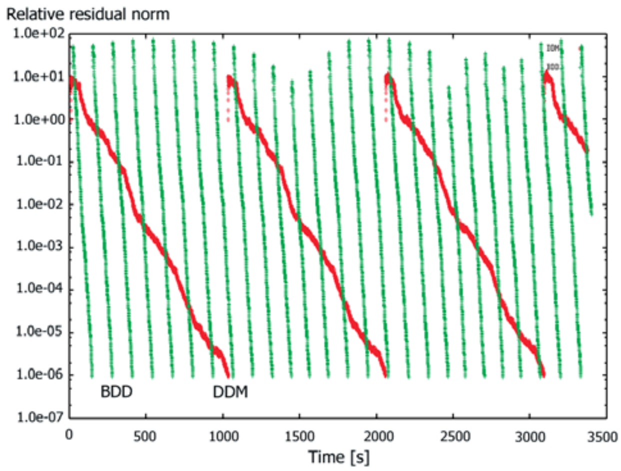


Fig. 4 Comparison with DDM and BDD of history of residual norm.

Table 1 Calculation performances of dynamic elastic analysis of the ABWR model.

Time steps (elapsed time)	Time	FLOPS	(to peak)	V.OP. RATIO
100 (2.0sec)	3.51 hr	987 G	(12.0 %)	96.9 %
200 (4.0sec)	7.08 hr	982 G	(12.0 %)	96.9 %

3. Elastostatic analysis of pressure vessel model with 100 million DOF mesh

This system is applied to a simplified nuclear pressure vessel model with 100 million DOF mesh on the 1,024 and 2,048 PEs. As boundary conditions, a bottom plane is fixed and body force by the gravity is taken. Table 2 shows the performances with 1,024 and 2,048 PEs. The present system with the BDD preconditioner is successfully to analyze with good performances in FLOPS and vectorization. By considering those results, with the analysis model that is divided into 34,816 subdomains, the present system successfully achieved 1.97 TFLOPS, which is 24.6 % of peak performance, on the 1,024 PEs. However, it archived 2.88 TFLOPS, which is 18% of peak performance, on the 2,048 PEs. In the DDM algorithm, the number of subdomains affects performance of the calculation. Even in the same model, the optimized number of subdomains depends on the computer environments, i.e., number of processors or amount of memory. In this case, the optimized number of subdomains is about 35,000 on the 1,024 and on the other hand, it is about 6,000 on the 2,048 PEs. With such optimized number of subdomains, shown in Table 2, the present system performed better vectorization, and then successfully archived 5.08 TFLOPS, which is 31.75 % of peak performance.

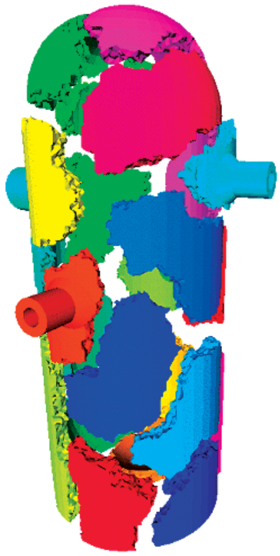


Fig. 5 Part decomposition of a PV model with 100 million dofs.

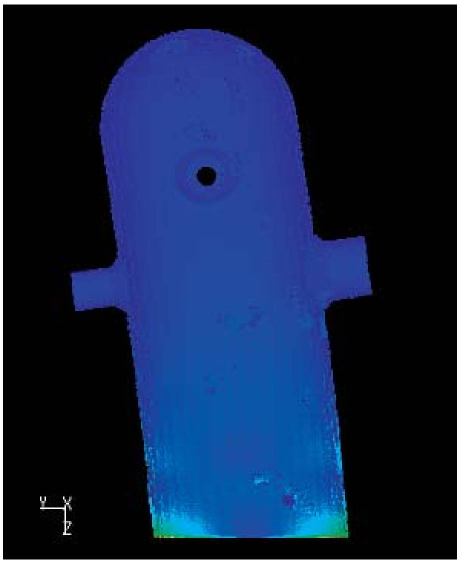


Fig. 6 Stress distribution and deformed shape of PV model.

Table 2 Calculation performances of 100 million model.

# PEs	Subdomains	Time	Iterations	FLOPS	(to peak)	V.OP RATIO
1,024	34,816	960 sec	1,038	**1.97 T**	**(24.6%)**	**98.0 %**
2,048	34,816	835 sec	1,330	**2.88 T**	**(18%)**	**97.9 %**
2,048	6,144	514 sec	496	**5.08 T**	**(31.75%)**	**98.8 %**

References

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