Virtual Demonstration Tests using the Next-generation Computational Solid Mechanics Simulator

Project Representative
Ryuji Shioya Faculty of Engineering, Toyo University

Authors
Ryuji Shioya Faculty of Engineering, Toyo University
Masao Ogino Faculty of Engineering, Kyusyu University
Hiroshi Kawai Faculty of Engineering, University of Tokyo

We have been developing a next-generation computational solid mechanics simulation system based on the ADVENTURE, which is designed to be able to analyze a three dimensional Finite Element (FE) model over hundreds of millions of Degrees Of Freedom (DOFs), to achieve the implementation of a virtual demonstration test on the Earth Simulator (ES). Main FE analysis process of the system, ADVENTURE_Solid based on the hierarchical domain decomposition method and an IBDD-DIAG method, was ported to the vector-parallel supercomputer. For a post process of a huge scale analysis, we have developed a parallel off-line visualization system, which is able to implement on PC clusters and the ES. Moreover, to utilize our system on parallel computers via computer networks, we developed an integrated user support system, which is implemented on Windows PC and has a function of an agent-technology. As an implementation of a virtual demonstration test using our system, a Boiling Water Reactor (BWR) pressure vessel of a nuclear power plant, whose model is provided in cooperation with industries, has been analyzed. Furthermore, a Carbon Fiber Reinforced Plastics (CFRP) composite tank model, which is for the purpose of high-pressure hydrogen storage, has been analyzed. In this report, we present an outline of our integrated user support system based on computer networks, and show computational performances of a seismic response analysis of the BWR model and a 3-D elastoplastic analysis of the CFRP tank model.

Keywords: Network-based CAE system, CFRP hydrogen tanks, BWR pressure vessels, balancing domain decomposition, virtual demonstration test

1. Introduction

The ADVENTURE system [1] is an advanced general purpose computational mechanics system, and designed to be able to analyze a three dimensional Finite Element (FE) model of arbitrary shape over hundreds of millions of Degrees Of Freedom (DOFs) 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. One of main process modules for solid analysis, named ADVENTURE_Solid based on the hierarchical domain decomposition parallel algorithm, employs an IBDD-DIAG method as a solution technique for linear equations.

In our project, the ADVENTURE system has been ported to the Earth Simulator (ES). Especially, ADVENTURE_Solid is vectorized well, and then it shows good performances of vectorization and parallelization [2]. Using our system, as an example to realize the virtual demonstration test, a Boiling Water Reactor (BWR) pressure vessel model consisting of many local features, whose DOFs amount to 204 million, is performed. The BWR pressure vessel model is analyzed for an earthquake-proof design. Besides, a Carbon Fiber Reinforced Plastics (CFRP) composite tank for the purpose of the high-pressure hydrogen gas storage is also performed. The CFRP tank model is analyzed to improve a pressure-resistance design. For the post process of such huge scale 3-D (three dimensional) structural analyses, we hacve developed a parallel off-line visualization system, which is a pure software-based polygon renderer to implement on the computational server. Furthermore, for the utilization of our system as the Computer Aided Engineering (CAE), we have developed an integrated user support system to use the ADVENTURE system on parallel computers via computer networks.

In this report, an outline of the integrated user support system via computer networks is presented and as a realization of the virtual demonstration test, a seismic response analysis of the BWR model and an elastoplastic analysis of the CFRP tank model are demonstrated.

2. Development of an integrated user support system to utilize the ADVENTURE via computer networks

CAE systems are widely used in the fields of engineering. In order to shrink the development period and improve the design precision, such systems are regarded as infrastructural tools for the present industries. However, complexity and difficulty of the system installation procedures and user operations of parallel computers have also become a heavy burden on CAE users. It is essential to develop a user interface which helps CAE users to perform a large scale analysis much easier. To solve these issues, we provide an integrated CAE system for Windows OS, named ADVENTURE_on_Windows (AdvOnWin). AdvOnWin does not require the installation of any ADVENTURE modules and has user support functions, called "Agent technology", which helps users and tells them what they should do next. In here, AdvOnWin can perform on a single processor only. Therefore, to utilize our system on parallel computers such as the ES, we developed an integrated CAE system, which can use parallel computers through computer networks [3].

Figure 1 illustrates the system flow of the ADVENTURE. AdvOnWin uses the modules surrounded by thick lines, and then invokes these modules on a local PC. As the ADVENTURE employs a module-based architecture and each module is performed with other modules or individually. To analyze large scale problems, four modules of them, surface patch generation, mesh generation, domain decomposition, and solid static analysis are invoked on the server computers remotely. Figure 2 shows a work flow in this study. For a secure connection between the client and servers, the SSH protocol was employed. To establish the SSH communication, we used Java Secure Channel (JSch), which is an open source library for the SSH communication and released by JCraft [4]. Although we have also developed a web-based CAE system [5], that system doesn't show a good harmony with a supercomputers by necessity of *http or https* daemon on the server. On the other hand, the present system requires only the SSH daemon to servers to send/receive files by *scp* and throw jobs via *ssh*. Figure 3 shows a screenshot of developed system on a client PC.

As an example to test a large scale analysis using our

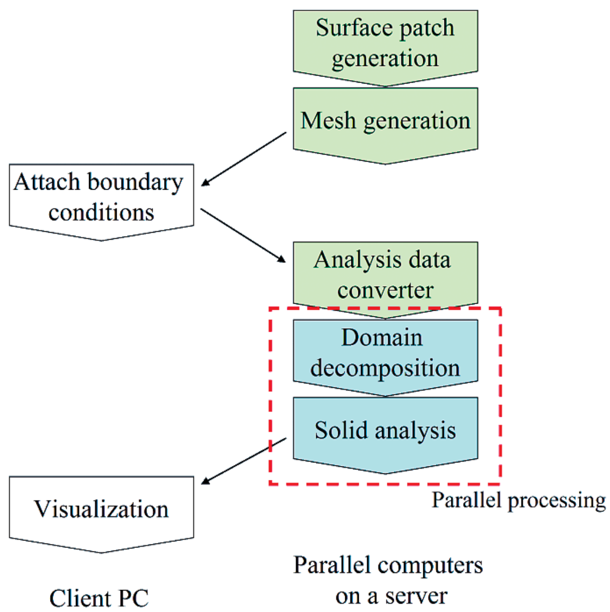

Fig. 2 Work flow of CAE processes on a client-server system. Solid arrows mean sending or receiving files.

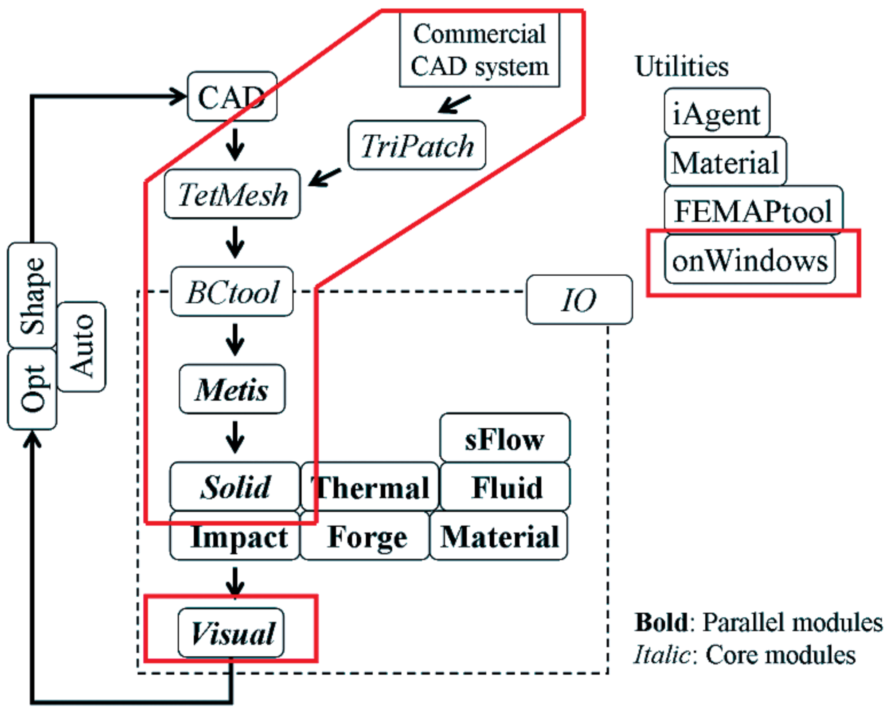

Fig. 1 System flow of ADVENTURE system with module-based architecture.

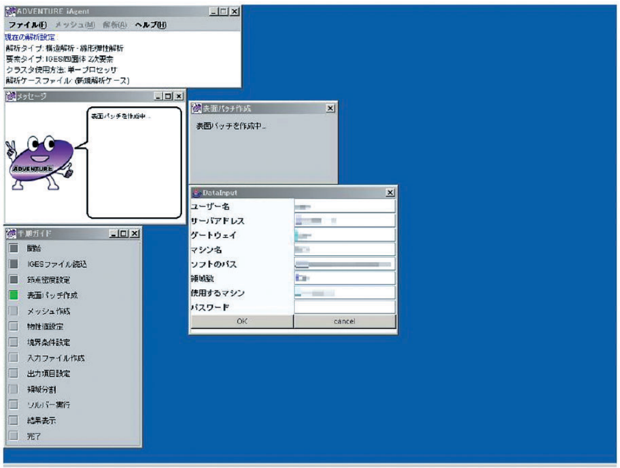

Fig. 3 A screenshot of an integrated CAE system on a client PC.

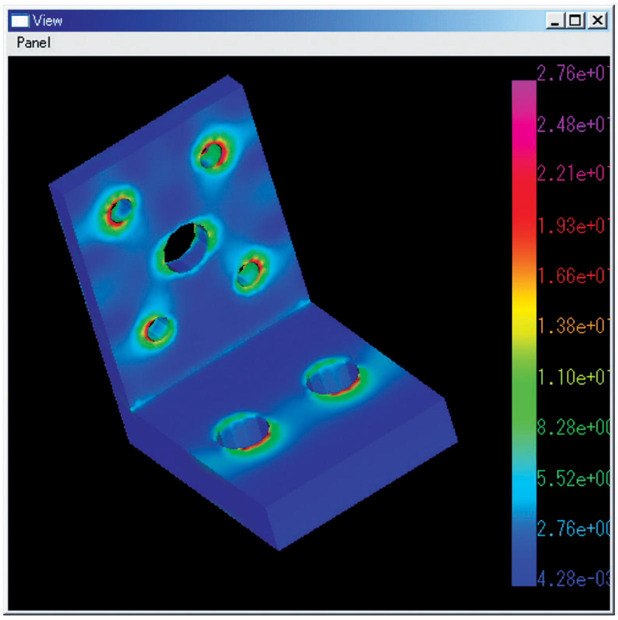

Fig. 4 Equivalent stress distribution of a test model with 4 million nodes.

client-server system, an elastostatic analysis with a 4 million nodes model is demonstrated. Table 1 shows the system configuration of a client and server computers, and Fig. 4 shows an equivalent stress distribution of a test model. Table 2 shows the computational performances of an elastostatic analysis using 16 processors of server computers. We have successfully analyzed the 4 million nodes model with parallel computers by simple operations like AdvOnWin. In Table 2, each performance includes operation time of mouse and keyboard to input analysis parameters. Moreover, attachments of boundary conditions include to select some surfaces with moving a model, and then visualization of analysis results is the time when a model is displayed. Here, when CAE processes continue on the server shown in Table 2, the file transfer between a client and servers does not required. Besides, the surface information of the model is enough to attach boundary conditions and visualize results in the structural analysis. These are advantages to treat files of large size for the large scale analysis. In the future work of this study, we have to incorporate an off-line polygon rendering system [6][7] to visualize data of the huge scale analysis.

Table 1 System configuration of a client and server computers.

	Client PC	Computational node of server
CPU	Intel Core2Duo 2.4GHz	Intel Core2Duo 2.4GHz
Memory	2GB	4GB
OS	Windows XP SP2	openSUSE Linux 10.3 x86_64

Table 2 Computational performances of an elastostatic analysis of a 4 million nodes model using 16 processors of server computers. Each performances include operation time of mouse and keyboard to input analysis parameters.

CAE process	Client/Server	CPU time [sec]
Surface patch generation from CAD data	server	120
Solid mesh generation from surface patches	server	450
Attachment of boundary conditions with GUI	client	270
Analysis data converter for AdvIO	server	90
Domain decomposition	server	100
Elastostatic analysis by FEM	server	627
Visualization with GUI	client	55
Total time		1,685

3. A Seismic response analysis of the BWR pressure vessel model

In these three years, as an example to realize a virtual demonstration test, we have analyzed a seismic response problem of the BWR pressure vessel of a nuclear power plant in cooperation with industries. The pressure vessel is precisely modeled with internal structures, and then the total DOFs of the problem amount to about 204 million. In the results at FY2007, the 1,000 time steps problem of 204 million DOFs has been performed by 25 times batch job, and then successfully analyzed in about 26 hours [8]. However, to practical use such huge scale models, the computational performance should be improved much more. Especially, the number of batch jobs should be reduced. Therefore, we have improved a convergence performance of a linear solver, which is an IBDD-DIAG method [9] in ADVENTURE_Solid. As a result, it succeeded in reducing the number of iterations nearby in half, and then the total number of batch jobs is also expected to be reduced. Moreover, the reduction of the number of batch jobs will cause much more reduction of the total computation time on the supercomputer.

4. 3-D elastoplastic analysis of a CFRP composite tank for the high-pressure hydrogen storage

In this section, as the second example of a virtual demonstration test, 3-D elastoplastic analysis of a CFRP composite tank for the purpose of high-pressure hydrogen storage is demonstrated. Figure 5 shows the external appearance of the CFRP tank model. The linear hexahedral solid element is used as the FE mesh, then the total number of DOFs is about 16 million. In our target model, the CFRP tank is composed of a metallic linear and many CFRP layers. Besides, CFRP layers are called a helical layer or a hoop layer by winding angles of the fiber. At hoop winding layers, as fibers are circumferentially wound up, it is assumed to be unidirectional laminated CFRP. On the other hand, as fibers are wound up with a lower angle at helical winding layers, it is assumed to be angle-ply laminated CFRP. For a 3-D elastoplastic analysis, CFRP is modeled as the orthotropic material in a local system, and especially CFRP at helical winding layers has averaged material properties of angle-play laminated CFRP. For the design optimization of a liner shape and a winding rule of the fibers, we will obtain effects of the autofrettage treatment and evaluate a fatigue under the cyclic loading.

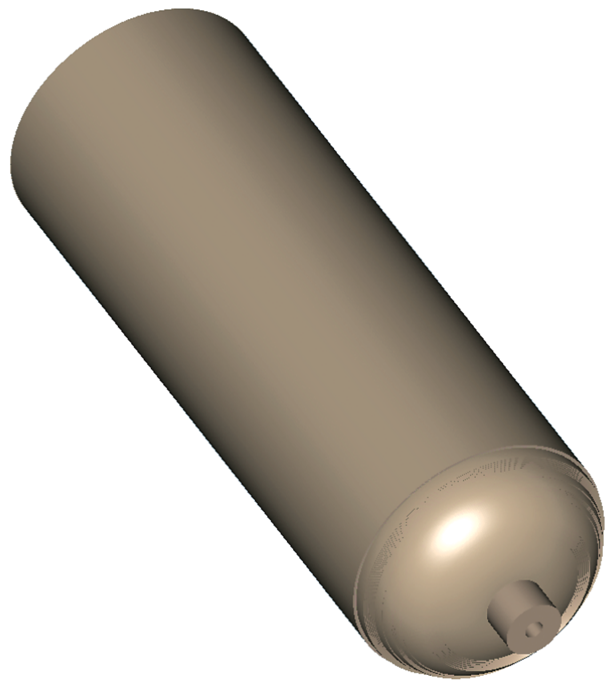

Fig. 5 A CFRP tank model for the high-pressure hydrogen storage.

5. Conclusions

To utilize our developed system on parallel computers such as the ES, an integrated user support system is developed. As the system is implemented on Windows PC and has a function of an agent-technology, users could solve a large scale problem using parallel computers easily. To realize the virtual demonstration test, a seismic response analysis of the BWR pressure vessel model and a 3-D elastoplastic analysis of the CFRP tank model are performed. By improving computational performances of a linear solver, the practicality of a huge scale analysis with our system is also improved. Moreover, as an angle-ply laminated CFRP model, we have been developing new functions of ADVENTURE to expand the application field of our study.

Acknowledgements

The authors would like to thank Tokyo Electric Power Co. and Hitachi Ltd. for providing a model data of the BWR reactor pressure vessel. This work is performed as a part of the ADVENTURE project and the authors also would like to thank all the members of the ADVENTURE project.

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次世代計算固体力学シミュレータを用いたバーチャル実証試験

プロジェクト責任者
塩谷　隆二　　東洋大学　工学部

著者
塩谷　隆二　　東洋大学　工学部
荻野　正雄　　九州大学大学院　工学研究院
河合　浩志　　東京大学大学院　工学系研究科

本プロジェクトでは、1億自由度級の大規模メッシュを用いた人工物や自然物の丸ごと詳細解析を可能とする汎用計算力学システムADVENTUREを地球シミュレータに移植し、バーチャル実証試験を実践するための次世代計算固体力学シミュレータの開発を行っている。ADVENTUREの主要並列ソルバの1つである構造解析モジュールADVENTURE_Solidでは、階層型領域分割法に基づく並列負荷分散と高速安定な線形ソルバであるIBDD-DIAG法を採用し、それらのアルゴリズムを地球シミュレータ向けに移植することで高いベクトル性能及び並列性能が得られている。また、大規模メッシュの3次元可視化を実現するために、ベクトル機向けの参照テーブルを用いた高速並列オフライン可視化技術を開発し、有限要素解析分野においても、地球シミュレータの計算ノードを用いて速やかなシミュレーション結果の検証を可能としている。本システムを用いたバーチャル実証試験として、産業界から提供を受けたBWR型原子炉圧力容器の地震応答解析を進めている。圧力容器に加えて内部構造物まで詳細にモデル化を行い、非構造メッシュを用いたモデル総自由度数は約2億となった。地球シミュレータ2,048プロセッサを用いることで、継続時間10秒間、つまり陰的動弾性解析1,000時間ステップを約26時間で実現した。

新たなバーチャル実証試験として、高圧水素ガス貯蔵タンクの耐圧性能評価を進めている。金属性の圧力容器に炭素繊維強化プラスチックが幾層にも巻き付けられたモデルに対して、繊維巻き付け角度の異なるFRP層を詳細に3次元モデル化し、モデル総自由度数は約1千6百万となった。地球シミュレータを用いて、弾塑性解析に成功した。

さらに、開発システムの利便性を高めるために、Windows上で動作し、外部ネットワークの並列計算機を利用した大規模解析を可能とする、統合ユーザ支援システムを開発した。複雑なCAE操作を補助するエージェント機能を搭載しており、Windows上におけるマウスとキーボードを用いた簡単な操作によって大規模解析を可能とした。

本報告書では、開発システムの利便性向上や応用範囲拡大を目的とした統合ユーザ支援システムの概要、2億自由度規模BWR型原子炉圧力容器モデルにおける線形ソルバの収束性改善、1千万自由度規模CFRP高圧水素タンクモデルにおける斜交積層材の考慮による結果を示す。

キーワード：Network-based CAE system, CFRP hydrogen tanks, BWR pressure vessels, balancing domain decomposition, virtual demonstration test