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High-accuracy analytical function for NDE simulation of FEM
有限要素法を用いた超音波探傷シミュレーションの高精度解析手法

Miki Nagano†, Yoshiyasu Hirose, and Yasushi Ikegami (ITOCHU Techno-Solutions Corporation)
永野 美貴†，広瀬 意育，池上 泰史 (伊藤忠テクノソリューションズ株式会社)

1. Introduction

FEM is being adopted in an ultrasonic (US) simulator, ComWAVE program package to perform time domain three-dimensional simulations for US propagation. This software has been developing at ITOCHU Techno-solutions Corporation. The code is designed to run effectively in parallel under message passing interface (MPI), and it has been demonstrated very good scaling to calculate up to several billion elements[1].

Nowadays, large-scale US simulations are more important because most users want to inspect more complex and large-scale structures which are needed to analyse long distance wave propagation and relatively higher frequency regions. Users who work on larger and more complex systems need to introduce high- performance computers. ComWAVE implements voxel elements to reduce computational time and required memory, but huge number of elements is indispensable for larger system; 8GB memory is required for 100 million elements, and 800GB is for 10 billion, respectively. Computational time per a time step also increases in proportional to the number of elements. In addition, we shuold notice the numerical dispersion causes less accuracy outcomes in large-scale models. This is because larger models require larger number of time steps and the numerical error is accumulated as time steps become larger.

In this paper, we introduce a new method to overcome above problems with large-scale models and show the effectiveness of it.

2. Theory

Large part of simulation models concerned with US propagation is composed of plural materials whose sound speed is quite different, e.g., steel and water. Because the time step width (dt) is in inverse proportional relation to the maximum sound speed Vmax. Therefore, dt becomes shorter and the number of time steps is to larger as Vmax becomes larger.

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comwave@ctc-g.co.jp

To avoid this problem, we divide a model into plural regions which are contained the same sound speed as much as possible. This enables us to adopt larger dt in the each regions than full region analysis and to reduce total time steps. The US propagation wave can be taken over from one region to next region through a tab for sticking as shown in next section. Moreover, we can adopt a larger element size in the region with larger sound speed because the appropriate element size is in proportional relation to sound speed. Using this function, we can run equivalently larger models with smaller number of elements to keep accuracy.

3. Application

Our test model applying the method is shown in left-hand of **Figure1**. This is a US testing for a defect of dissimilar material joints. This model is composed of water and steels. The shear sound speed of steels are about two times faster than the one of water. We divide this model into 5 regions as shown in right-hand of Figure1. The region 1 and 5 are composed of only water and region 3 is only steels in which it adopt twice element size than other regions. Region 2 and 4 are tab for sticking.

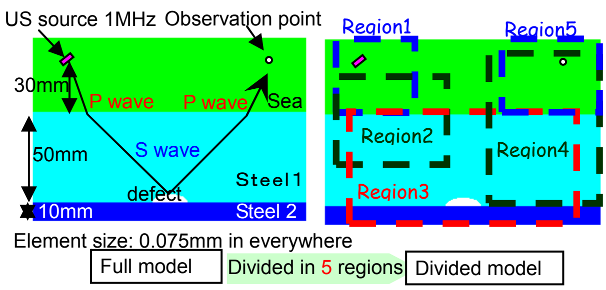


Fig1. Condition of test model

Figure2 shows the snapshots of the wave propagation process in the model. The right column is the result of divided model and the left one is the full modeling for comparison. The wave displayed with red color is longitudinal wave and blue one is share wave. Notice that only the main lobe in which we are interested is taken over in the divided model.

Figure3 shows the waveforms received at observation point which come from the defect on steel 1 surface. In reality, the observed wave should be superposition of waves which have different origins in the full model. To obtain the echo from only the defect, we ran two types of models with defect and without defect, and subtracted the latter waveform from the former one to remove the extra components. We treated the divided model same as full model for comparison although this has much smaller extra components from the beginning. Comparing these two waveforms, we can see that the divided model keeps accuracy and the influence of numerical dispersion is sufficiently small whereas the waveform in the full model is distorted.

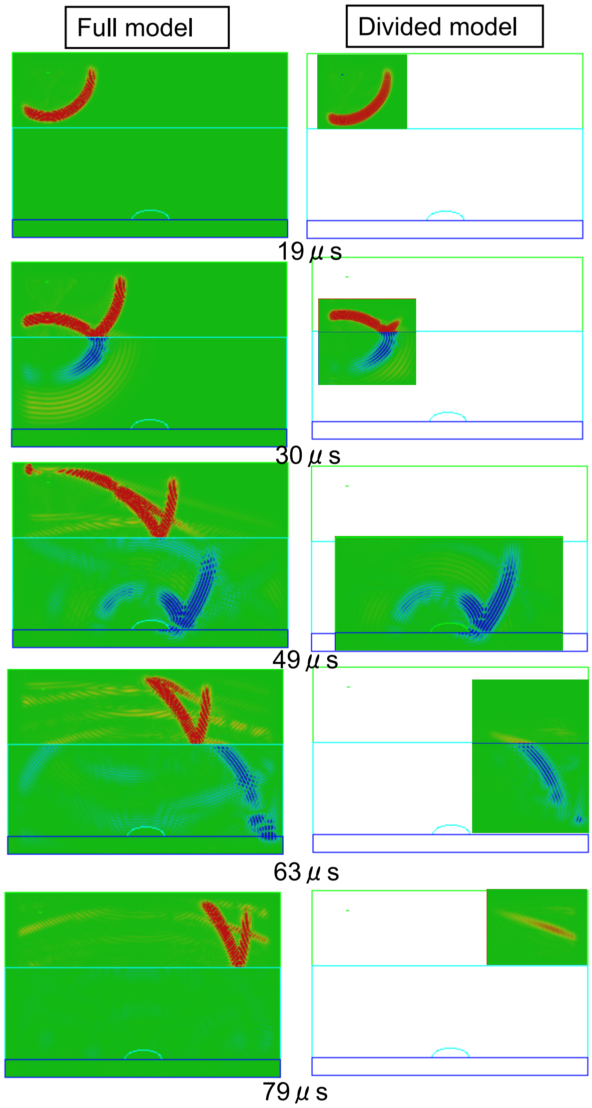
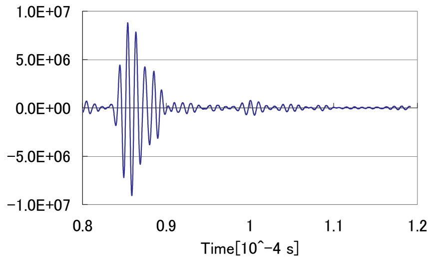
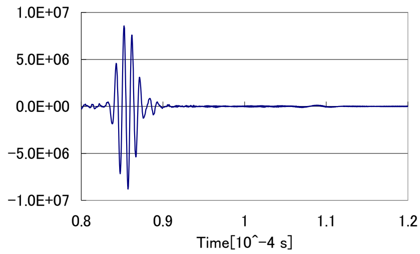


Fig2. Snapshots of wave propagation process

The main results are summarized in **Table1**. All calculations are done with 1CPU. The number of total steps in the divided model are about half. This enables us to do the analysis with keeping accuracy. Not only reducing the steps but the maximum number of elements is about one-third in the divided model. This means we can deal with equivalently larger model with smaller memory using this method. Moreover, the total calculation time of divided model is quite smaller than the one of full model. So, this method also contributes to the speedy analysis.



a) Full model



b) Divided model

Fig3. Waveform received at observation point

Table1. Comparison of Performance

	element size [μm]	num. of elements	steps	calc. time [sec]
Full model	75	2,692,000	13,901	6.960
Region1	75	363,636	487	68
Region2	75	554,400	1,092	152
Region3	150	346,400	1,508	135
Region4	75	981,178	1,729	350
Region5	75	449,329	1,056	170
Sum			5,872	875

4. Summary

In this paper, we introduce a new method to deal with equivalently larger model with keeping excellent accuracy and apply it to practical model. We showed this method also contributes to high speed computing. The method is expected to be a powerful tool for larger models.

References

1. Ikegami Y, Sakai Y, and Nakamura H, “A Highly Accurate Ultrasonic Simulator Capable of Over One Billion Elements for Non-Destructive Evaluations”, *7th Int Conf on NDE in Relation on Structural Integrity for Nuclear and Pressurized Components.2010.*