Development of a system for FEM-based crustal deformation analysis

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Introduction

It has recently become possible to measure volcanic crustal deformation in a mountainous area in detail with the improvement of volcano observation techniques such as SAR. With this background, it is necessary to improve crustal deformation calculation for source modeling. Effects of topography and inhomogeneous underground structures should be taken into account for crustal deformation calculation at volcanoes. We have developed a crustal deformation analysis system using a three-dimensional (3D) finite element method (FEM) which is specified to volcanoes. In this presentation, we will introduce the outline of the system for FEM-based crustal deformation analysis, and show the effects of crustal deformation calculation incorporating topography and underground structure.

Overview of analysis system

The analysis system mainly consists of three processings: element division in a calculation domain, deformation calculation by 3D-FEM, and estimate of deformation source. Linear elastic deformation based on the infinitesimal deformation theory is considered. Deformation is calculated using Advance/FrontSTR software developed by the Advance Soft Corporation. In this system, 10m-mesh-size digital elevation model released by the Geospatial Information Authority of Japan is implemented, thus users can set up any land in Japan for an analysis domain, and perform crustal deformation calculation and source modeling there. Users can set an analysis domain (latitude, longitude, and depth), the number of element divisions, and the source information by graphical user interface (GUI) operation. In addition, three types of deformation sources; rectangular crack, sphere, and spheroid, which are often used in analyzing volcanic crustal deformation, can be selected from the GUI system. The calculation results are output in a “vtk” format file, and can be displayed and operated in 3D using the visualization software ParaView.

For improving calculation speed

In this study, in order to improve the computational efficiency, which is a disadvantage of FEM, we implemented several techniques such as infinite elements and partial-fine-meshing. In FEM calculation, artificial errors are produced due to the effects of side and bottom surfaces of calculation domain because calculations are performed within a finite area. Therefore, this system implements the function of infinite elements. By setting the infinite element at the horizontal and bottom boundaries excluding the ground surface, the calculation can be performed in the same way as adding a finite element reaching infinity to the boundary of the calculation domain. Furthermore, we implemented a function that finer meshes are set in the proximity of deformation source. By these implementations, we successfully improved the calculation speed without degrading calculation accuracy while preventing an excessive increase in the number of elements.

Effects of calculation incorporating topography and underground structure

The effect of topography and underground structure was investigated through calculations at actual volcanoes. Here we assumed an inflation source within the body of Mt. Ontake volcano, and examined how the ground deformation is affected by the position of the source. As a result, we found that the deformation is strongly affected by the topography when the source is located at the shallow part. We

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demonstrated that the uplifted area turned into subsidence and the polarization of tilt turns out to be an opposite direction as the source position changes from deep part to shallow part. In addition, the effect of the underground structure was investigated at Sakurajima volcano. When we calculated the ground deformation with taking into account the underground structure obtained by seismic explorations, we revealed that the surface displacement increases by several tens of percentages in the proximity of the source, compared with the conventional method assuming a homogeneous medium.

Keywords: FEM, volcanic crustal deformation, topography, underground structure

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