Analysis of crustal deformation due to slip across faults using finite element method

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In Advance Soft Cooperation a computer program, named FrontSTR/GEOS, has been developed for the calculation of deformation due to fault slips and magma migration using finite element method. This program utilizes for the finite element calculation the program Front/STR that was obtained in the MEXT project "The Research and Development of Innovative Simulation Software" and contains some additional parts that have been developed by us to represent the effects of fault displacements and magma migration. In the finite element calculation displacements at nodal points are usually calculated in an iterative CG method. The program can be executed with a personal computer or a large computer allowing parallel computing.

The mesh for the finite element calculation is generated automatically in the following two steps by the program "meshgen" that has been developed by us. Namely, the region in question is first divided by hexahedron elements to make the whole mesh and then faults are put into the whole mesh. These two steps are independent so that we do not have to remember the whole mesh when we define faults.

The whole mesh consists of one or several blocks. Each block is divided by hexahedron elements whose sizes are constant or change at a constant rate with the location of the element. The surface topography can be taken into account by adjusting the thicknesses of the top elements. The effects of artificial boundaries placed on the sides and floor of the region can be made sufficiently small by introducing infinite elements along the boundaries. Elastic constants of each element can be set consistently with a three-dimensional distribution of seismic velocities.

The fault surfaces are defined by assemblies of triangles or quadrangles. The fault slip is specified at each vertex of the triangles or quadrangles and interpolated into their interiors. There may be more than one faults in the region but they cannot be intersected one another. Furthermore, each fault must stay within one of the blocks.

The elements through which one of the faults passes are further divided by the fault plane into some elements that have additional nodal points on the fault plane. Each of these new nodal points have double displacement values whose difference represents the slip or opening of the fault. In the finite element calculation the double displacement values are calculated with other displacements in the MPC method so as to meet both elastic equilibrium condition and prescribed constraints put on the double displacements.

The basis of our computer program is the calculation of elastic deformation due to prescribed displacement difference across the fault. The relaxation of viscoelastic deformation is traced with time based on the nature that the viscoelastic effect can be represented as an additional external force in the calculation of elastic deformation. The effect of gravity is taken into account in this calculation of relaxation. Some stress conditions on fault planes can be treated by adjusting suitably the constraints on the double displacements.

The program is applied to the deformation due to the fault slip during the great earthquake east off the northern district of Japan, March 11, 2011. The influence of fault geometry and slip distribution on crustal deformation is examined for this event. Relaxation of deformation after the event is evaluated under a suitable assumption of viscosity distribution. The merit in representing fault slip by double displacements is also demonstrated using this event.

Keywords: finite element method, fault slip, the great earthquake east off the northern district of Japan

