

Investigation of the Mechanism of Fault Formation Using Bifurcation Analysis

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ABSTRACT

We investigate a mechanism of fault formation by detecting the surface instability of ground using bifurcation analysis based on finite deformation theory. The bifurcation analysis is carried out in the case of a simple boundary value problem – the plane strain compression test of half-space made of incompressible isotropic and anisotropic hypo-elastic materials. Closed form solutions of bifurcation stress are obtained for many diffuse deformation modes defined by the number of the half wavelength of sine wave. The bifurcation stress of any diffuse deformation mode decreases with decreasing Young's modulus of horizontal direction compared to that of the vertical direction. In several diffuse modes, ground movement and the contour of maximum shear strain are examined to predict where fault formation occurs. The ground movements obtained by the bifurcation analysis show the surface instability of ground as sine waves, the amplitude of which decays rapidly with depth. In many cases, maximum shear strain is strongly localized beneath areas of ground sinking, due to bifurcation phenomenon. Moreover, comparatively large maximum shear strains appear in the deep parts of heaving grounds. The mechanism of fault formation can be explained using the distributions of localized maximum shear strains.

KEY WORDS: anisotropy, bifurcation analysis, plane strain, shear band, strain localization

INTRODUCTION

In general, deformation of geomaterials is uniform in the early stage of loading. However, deformation changes from uniform deformation to non-uniform deformation near maximum load, and strain localization occurs as a result. This strain localization then leads to failure of specimens through formation of shear bands. This mechanism accords with the mechanism of fault formation. Using bifurcation analysis, stress states at which deformation changes from uniform deformation to non-uniform deformation can be investigated.

A standard bifurcation problem is formulated for a rectangular block which is constrained to plane deformations and is subjected to tension in one direction (e.g. Biot, 1965; Hill and Hutchinson, 1975). In case of the fault formation in ground, bifurcation problem is applied to a half-

space which is constrained to plane deformations and is subjected to compression in one direction.

The surface instability of the half-space was first analyzed by Biot (1965) for the case of incompressible hypo-elastic materials. Biot (1965) showed that the half-space lost rigidity of some value of compressive stress, and that this loss of rigidity corresponded to the phenomenon of surface buckling. Bardet (1990) carried out investigation of surface instability using the finite element method and analyzed the performance of this method by comparing numerical and analytical results. In these previous study, however, strain localizations which are related to fault formation were not examined. The contour of maximum shear strain has been investigated using velocity field based on bifurcation analytical results (e.g. Yatomi and Shibi, 1997; Shibi and Kamei, 2006).

The objective of this investigation is to propose a mechanism of fault formation from the viewpoint of bifurcation analysis based on finite deformation theory. The bifurcation analysis was carried out in the case of a simple boundary value problem – the plane strain compression test of half-space made of incompressible isotropic and anisotropic hypo-elastic materials. Closed form solutions of bifurcation stress are obtained, and ground movement and the contour of maximum shear strain are examined in diffuse modes to predict where fault formation occurs.

CONSTITUTIVE RELATION

Since the present analysis is focused on the surface instability of grounds and mechanism of fault formation, two particular types of hypo-elastic model were used for the constitutive relation of granite.

It is well known that the constitutive relations for saturated rocks should be based on the effective (Cauchy) stress tensor T'_{ij} , which is defined by

$$T'_{ij} = T_{ij} + u\delta_{ij}. \quad (1)$$

Here, T_{ij} is the total Cauchy stress tensor, u is the pore water pressure, and δ_{ij} is Kronecker's delta.

Here and in what follows we regard tension and extension positive and compression and contraction negative, except u , and stress σ , exchange of the sign in rock mechanics needs a special care and makes