学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

A three-dimensional constitutive model for rocks based on a variable elastic modulus
(可変型弾性係数に基づいた岩石の三次元構成モデル)

No constitutive equations can fully represent true triaxial stress–strain curves considering the effects of intermediate principal stress, and a realistic curvilinear stress-strain relationship is needed for precise analyses of rock structures. Therefore, this study aims to propose a three-dimensional (3D) constitutive model with fewer parameters, realistic stress-strain curves, and convex failure envelopes.

Our research group previously proposed a simple two-dimensional (2D) constitutive model for rocks to simulate not only the axial stress–axial strain relationship but also the axial stress–lateral strain relationship, with few complicated equations. The simple 2D model is better than the variable-compliance-type model because it can simulate the axial stress-lateral strain relationship. The simple 2D model is also simpler than the conventional elasto-plastic model. However, the predicted failure envelope was linear, and the effect of intermediate principal stress was not considered.

Therefore, the simple 2D model was modified to have a convex failure criterion. A stress-dependent elastic modulus was introduced based on increased secant Poisson's ratio with confining pressure under triaxial compression. The effects of the parameters on the failure envelope were observed, and a procedure to approximate the stress–strain curves and failure envelopes was proposed. This model approximated the stress–strain curves and failure envelopes for real rocks much better than conventional 2D models with fewer equations and parameters.

The 2D model was applied to a pressurized thick-walled cylinder under the plane strain condition. The stress distribution of the thick-walled cylinder calculated by the model is similar to those of Bray's analytical elasto-plastic solution, but the shapes around the plastic zone are different. The shape from Bray's solution appears somewhat angular, while this from the simple 2D model is more rounded, reflecting the difference in the stress–strain relationship. The inward displacement by the simple 2D model rapidly increases near the inner wall. This rapid increase may represent the dilatancy of rock failure better than Bray's solution, which is based on the rupture plane slip in the plastic zone.

Then, the simple 2D constitutive model was extended to a simple 3D model. The stress–strain curves under triaxial compression for rock are approximated well first, and then the true triaxial behavior was predicted. Intermediate principal stain exhibited extensile behavior for low to moderate intermediate

principal stress. However, it showed contraction for high intermediate principal stress. True triaxial stress–strain curves for real rocks under specific values of intermediate principal stress and minimum principal stress were well approximated by the 3D model with only four parameters. However, the predicted peak stress–intermediate principal stress relationship was linear.

Finally, the 3D model was developed by introducing the stress-dependent elastic modulus. A procedure was proposed to approximate the failure envelopes and stress–strain curves. The peak stress–intermediate principal stress relationship for true triaxial compression first increased and then decreased with intermediate principal stress as actual rocks. The constitutive equations can also simulate biaxial compression and axial extension behaviors with the same parameters. True triaxial stress–strain curves and failure envelopes for real rocks were simulated reasonably. Using the modified 3D model to represent nonlinear stress–strain relationships well is better while following the true triaxial failure envelope. A method to represent axial unloading behavior was also proposed.

This modified 3D model is the only one that can fairly represent the true triaxial nonlinear stress–strain curves and convex failure envelopes. Combining it with a 3D finite element method could improve the design of rock structures.