POTENTIAL APPLICATIONS OF SBFEM ALGORITHM TO VISCOELASTIC PROBLEMS OF ROCK MECHANICS

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Due to the time-dependent constitutive relationships, complex boundary conditions, geometry etc., analytical solutions of viscoelastic problems for real engineering systems are usually limited, and it is of much interest to develop efficient numerical approaches. This project is aimed to apply advanced numerical methods to solve complex geotechnical problems such as the problem of long-term strength and stability of underground structures, tunnels and mining excavations. Such problems are no doubt of interest in recent scientific publications [1,2] and references inside. Solving such problems is especially important for geomaterials and rock masses since they are highly heterogeneous and solving viscoelastic problems for heterogeneous materials is a non-trivial task.

The Scaled Boundary Finite Element Method (SBFEM) is a semi-analytical numerical method for solving linear partial differential equations, and particularly useful in situations involving stress singularities, and unbounded domains. It combines the advantages of the finite element and boundary element methods [3].

Previously a new Temporally-Piecewise Adaptive Algorithm Scaled Boundary Finite Element Method (TPAA-SBFEM) to solve viscoelastic problems was presented in [4]. The major merits include:

(1) By virtue of an adaptive piecewise algorithm in time domain, a coupled spatial-temporal viscoelastic problem can be decoupled into a series of recursive spatial problems, which are solved by SBFEM that is semi-analytical, and advantageous in dealing with the problems involving unbounded domains and stress singularity.

(2) A temporally piecewise self-adaptive computation is realized via the change of expansion powers, and the computing accuracy controlled by the error tolerance can be achieved via the adaptive computation for different sizes of time steps.

More recently, the TPAA-MsSBFEM was developed to make it more suitable for multiscale viscoelastic analysis [5]. The basic idea of TPAA-MsSBFEM is to reduce the solution scales by recourse of a bridge between small-scale and large-scale via numerical base functions constructed by SBFEM, and the SBFEM with polygonal and quadtree elements provides the convenience to effectively deal with the heterogeneous material, conduct image-based analysis, and tackle with the stress singularity.

The proposed method can be widely used in geomechanics and rock mechanics to ensure safety and durability of underground structures and stability of rock masses. Namely, it can be used to compute viscoelastic stress-strain state of geotechnical systems. In this report, the following creep model is proposed for such calculations:

$$\varepsilon(t) = \frac{1}{C_3+1} C_1 \sigma_{eqv}{}^{C_2} t^{(C_3+1)} e^{-\frac{C_4}{T}} + C_5 \sigma_{eqv}{}^{C_6} t e^{-\frac{C_7}{T}} + \varepsilon_0,$$

This creep models allows to evaluate viscoelastic deformation of rock masses considering two creep stages, which makes long-term strength calculation possible. The time period of calculation can include from several month to decades. In addition to this in is proposed to use the complex limit state criterion to evaluate the rock mass stage at any time point [2].

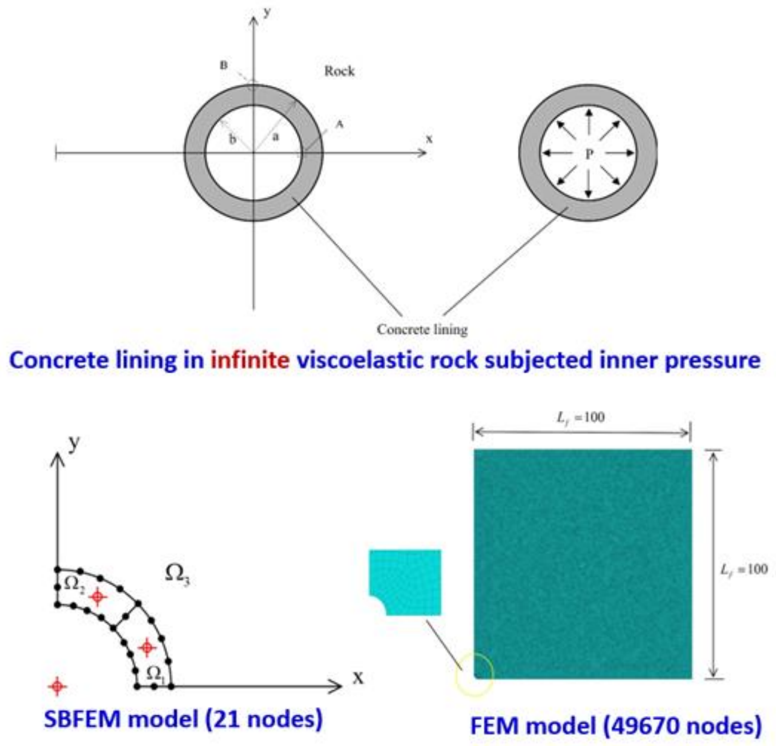

Fig. 1. Comparison of SBFEM and FEM for a single mining excavation problem

Combination of the SBFEM with the proposed model allows to solve stability and durability problems for complicated geotechnical system with high accuracy since it allows to consider the unbounded domain of the rock mass (on the opposite to classic FEM) and consider heterogeneous structure of the rock mass. For example, this method can be used to solve the durability problem of a single supported mining excavation, located in a heterogeneous rock mass as shown in Fig. 1.

References

1. H. Wagner. Deep Mining: A Rock Engineering Challenge. Rock Mechanics and Rock Engineering. Vol. 52, pp. 1417-1446, 2019.

2. Zhuravkov M.A., Lapatsin S.N., Ji S. Complex limit state criterion for rock masses. Acta Mechanica Sinica. 39(1), 722194, 2023.

3. J.P. Wolf, Ch. Song, Finite-Element Modelling of Unbounded Media, John Wiley and Sons, Chichester, 1996

4. Yiqian He, Haitian Yang. Solving viscoelastic problems by combining SBFEM and a temporally piecewise adaptive algorithm. Mechanics of Time-Dependent Materials. 21(3): 481–497, 2017

5. Xiaoteng Wang, Haitian Yang, Yiqian He. A temporally piecewise adaptive multiscale scaled boundary finite element method to solve two-dimensional heterogeneous viscoelastic problems. Engineering Analysis with Boundary Elements. 155, 738-753, 2023.