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New approach of fracture treatment in finite element based soil engineering modeling

New numerical scheme in fracture treatment,
Finite element computations, Soil engineering modelling

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1. INTRODUCTION

Fracture treatment in most of the soil engineering problems is a complex process in a space and time. Naturally fracture process is a discontinuous in nature which demands the set of discontinuous functions to describe the mathematics and physics of the phenomena pertinent to the fracture. In view of this inherent difficulty, we seek the simple and reliable scheme in finite element computations which permits to use the transition discontinuous function during the evolution of fracture; which not only describes the traction free boundaries within the fracture but also reliably explain the progressive nature of fracture. This simple scheme is expected to simulate most of the soil engineering problems, such as slope instability, soil-bioengineering, soil erosion, tunnel engineering etc. It can efficiently be modeled geotechnical centrifuge in slope instability modeling. More over it can effectively be addressed soil variability and elasto-plastic behavior of soil.

2. PROBLEM FORMULATION

Governing equation

The common finite element platform uses sophisticated constitutive relationship:

$$\left(\overline{C}_{ijkl} u_{kl}(X,t)\right)_{,j} + f_i(X,t) = \overline{\rho}\ddot{u}_i(X,t) - in - \Omega$$
$$u_i(X,t) = \hat{u}_i(X,t) - on - \partial\Omega(t)$$
$$\sigma_{ij}(X,t) n_j(X,t) = \hat{t}_i(X,t) - on - \partial\Omega(t)$$

In the above set of equations, $\overline{C}_{ijkl} = \sum_m W_m (C_{ijkl})_n$ represents the elasticity tensor for linearly elastic isotropic material, and $\overline{\rho} = \sum_i W_i \rho_i$, mass density of the material, where W_s denotes the weight function of soil, and ρ_s is for density of soils. $\sigma_{ij} = C_{ijkl}\varepsilon_{kl}$ (Generalized Hook's Law), and $\varepsilon_{ij} = 0.5(u_{i,j} + u_{j,i})$ (For infinitesimal deformation), where n_j represents the unit normal in the direction of j.

Fracture Treatment

Fracture is considered to be evolved along the element edge. As the precise physical formalism is not known for the fracture phenomena, consideration of the fracture process is somehow empirical. Nature of the fracture evolution is determined by the edge (surface) stress $(\sigma_{ij})_{edge(surface)}$ and nodal stresses $(\sigma_{ij})_{node}$ of the corresponding edge (surface) simultaneously. Any of the existing fracture criteria can be applied with equal ease. Continuous displacement functions are used until the occurrence of fracture. After the fracture, fractured edge (surface) is changed into the traction free or specified traction boundaries, thus introducing the elegant way of consideration of discontinuous displacement functions. There are three possible ways of fractures depending on the location of failed node. When the failed node lies on the boundary, crack will be initiated at the boundary node and will propagate to the inner intact node. In this process a new node and a new edge will be generated as shown in Fig.1. Another possible way of fracture will be when the failure node lies in the domain of the continuum. In this case separation of only one edge is incompatible; hence, crack will be initiated from an edge which exceeds the yield criteria starting from a node of higher stress and accompanied with a next edge with highest stress among the remaining edges meeting at the failed node. Thus in this case one new node and two new edges are generated. When the failed node lies near the boundary, then all the conditions will be similar with the case when the failed node lies in the domain, except that the boundary node will also get failed. Therefore there will be generation of two failed edges and two failed nodes as shown in same Fig.1.

3. SOIL ENGINEERING MODELLING

Soil-bioengineering

New numerical scheme in finite element method is used to simulate both the progressive nature of failure and interaction of the soil-root matrix continuum (discussion based on Griffiths, 1999 and Li, 2007). Computations suggest that within the effective RAR range, stability factor increases initially and tends to saturate to a constant factor as shown in Fig. 2. Hence, the simulation based on the more reliable understanding of the various effects of vegetation on soil slope stability, and the efficient numerical procedure for the progressive fracture phenomenon can give the reliable result for the soil-bioengineering slopes thus enabling the more accurate way for hazard preparedness.

Simulation of natural slopes

A new numerical scheme in Nonlinear Finite Element Method (FEM) along with Mesh Free Method (MFM) and suitable convergence criteria (Yagawa and Furukawa, 2000) is used to simulate the natural slopes as shown in Fig. 3. Computations shows that water profile, surcharge effect, soil profiles and vegetation all have significant role on stability factor of natural slopes. Hence, the simulation based on the more reliable understanding of the various parameters affecting the natural slopes can give the reliable results thus enabling the more accurate way for landslide hazard preparedness practice and also helps to design the structurally safe and economic slopes as well.

Tunneling

This common platform in FEM can effectively be applied in tunnel engineering especially for stress computation (Fig. 4) and support system analysis. The study of characteristic curves of support conditions of different tunnel sections under different stressed condition and material composition helps to identify the appropriate and effective support system for particular section of tunnel under study.

Soil erosion

Does landslide cause soil erosion (Erosion due to landslides or slope failure)? Does soil erosion cause landslide or slope instability (Landslides or slope failure due to soil erosion)? How to estimate erosion depth, and quantity of eroded material? These are the few basic questions on which this finite element analysis is performed. This further discusses theoretically the implications of soil erosion in slope instability phenomena (as discussed by Morgan, 1996). A typical result of soil erosion modeling is shown in Fig. 5.

Soil liquefaction

Finite element analysis is a powerful tool to solve the boundary value problems; it cannot simulate the liquefaction phenomena reliably, because the liquefaction phenomenon is associated with discrete nature. Hence, new numerical modeling technique is necessary for the simulation of liquefaction behavior of soil. A typical FEM model of soil liquefaction is shown in Fig. 6.

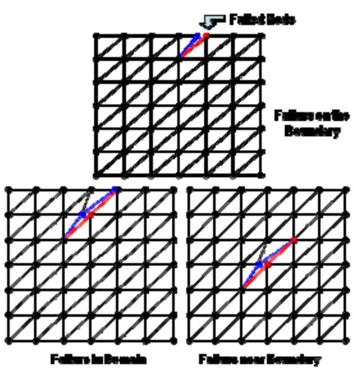

Fig. 1 Possible ways of fracture treatment.

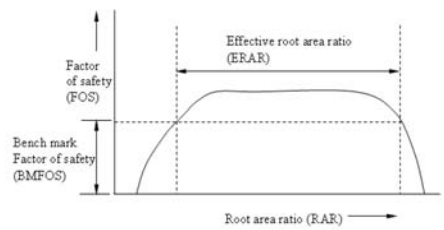

Fig. 2 Soil-bioengineering slopes.

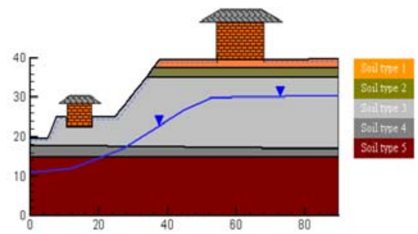

Fig. 3 Simulation of natural slope.

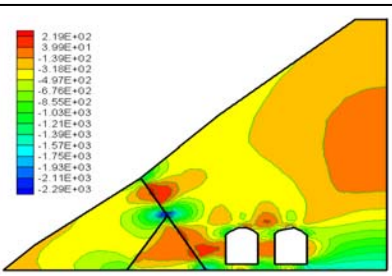

Fig. 4 Tunnel stress (σ_{11}).

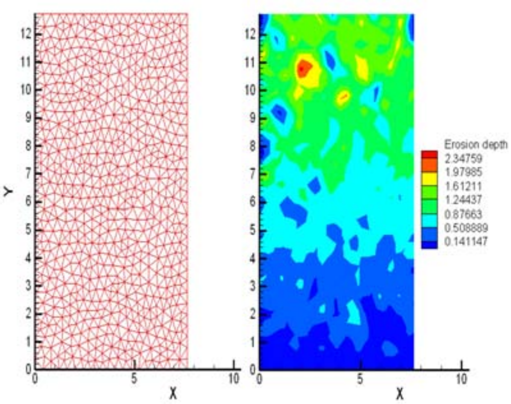

Fig. 5 Soil erosion estimation.

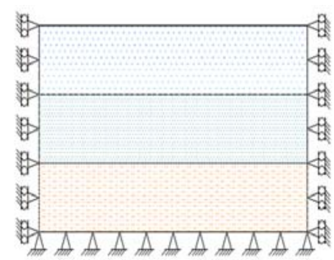

Fig. 6 Soil liquefaction model in FEM platform.

4. CONCLUDING REMARKS

This paper presents the simplified numerical procedure of soil engineering problems such as slope instability, tunnel support system, erosion etc in common FEM platform incorporating new scheme in fracture treatment. This simple scheme is expected to simulate large number of soil engineering problems, both deterministically and probabilistically (as discussed by Cho, 2007) and aimed to handle wide range of material model and domain size.

5. REFERENCES

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