Elasto-Viscoplastic Modeling of Rail Ballast and Subgrade

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Settlement of Rail Ballast, Subballast is a major issue in the rail industry. Differential settlement can lead to decreased ride quality, increased wear, and, if left unchecked, derailment. Bridge approaches and other areas of non-uniform settlement are of particular interest. Most simplified models of this rail substructure do not account for permanent deformation. In this research, we develop a three-invariant soil model capable of simulating the settlement of soil under repeated loads. This model can be incorporated into finite element analysis of soils under the dynamic motions of trains.

Introduction

Under dynamic train loadings, ballast and sub-grade layers accumulate both recoverable and unrecoverable deformation vertically. The increase of unrecoverable deformation would impose considerable settlement and probably consequent stability problems for railroad track structure. The Finite Element Method (FEM) is a reliable technique for analysis and performance of the track substructure.

In order to more accurately simulate the mechanical behavior of soil layers that interact with rails, three-invariant elasto-viscoplasticity cap model is adopted. This model is based on the concepts of combined isotropic-kinematic hardening and non-associated plastic flow rule of earthen materials.

Viscoplastic modeling is critical to capture the potential settlement of the material over time, as well as the damping properties of the track substructure.

Soil Model

Soils typically yield in shear under friction, though at high mean stresses compactive failure related to pore collapse and grain crushing may occur.

A three-invariant, rate-dependent, non-associative cap plasticity model is developed to simulate the substructure materials. The model is a modified version of the Sandia GeoModel and comprises a nonlinear shear limit-state surface as well as elliptical compression and tension caps [1-3]. The viscoplasticity is taken into account using the type of overstress model originally proposed by Duvaut and Lions [4].

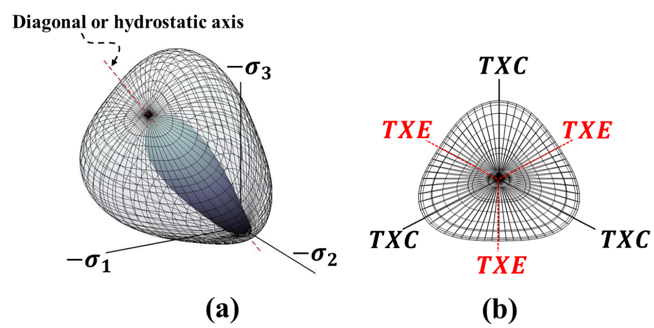

Figure 1. Yield surface of the model in principal stress space, showing difference in triaxial extension and compression strength.

A modified tension cap is also added for cohesive subgrade soils, i.e. clayey soils. An efficient numerical implementation has been created to reduce simulation times and improve robustness.

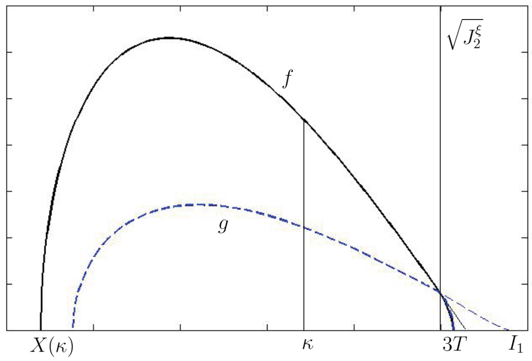

Figure 2. Yield surface and plastic potential in meridional stress space, showing tension cap (bold curve at right).

Numerical Examples

Several examples are run to test the properties of the model. Increasing the viscosity creates larger stresses under loading:

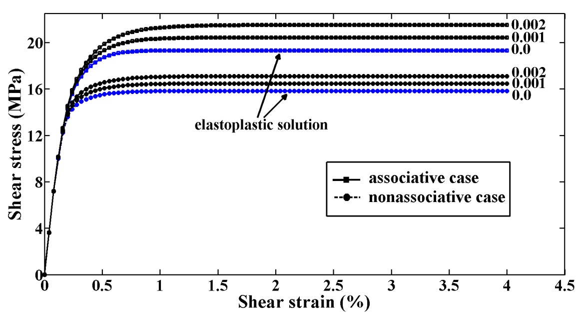

Figure 3. Effect of viscosity parameter on stress-strain response.

A combined compression/shear example tests the algorithm robustness and performance.

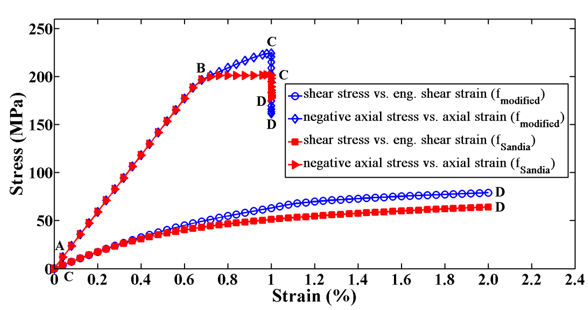

Figure 4. Stress strain plot of modified model under combined compression and shear.

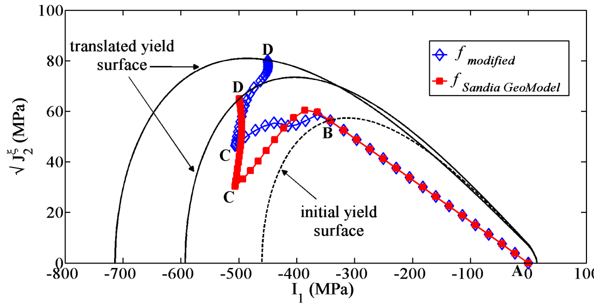

Figure 5. Combined compression/shear example in meridional stress space.

Summary and Conclusions

In summary, an advanced material model has been created to measure the transient and permanent deformation of soil under dynamic loading. This model can be implemented in finite element software for measuring settlement of the rail substructure under repeated loading.

References

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[3] Fossum A.F., R.M. Brannon, (2004), The Sandia Geomodel: Theory and User's Guide. *SAND2004-3226*, Sandia National Laboratories.

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