Course offered for the PhD Program in
Structural Engineering, Geotechnics and Seismic Risk

1. Title

CONSTITUTIVE AND NUMERICAL MODELING OF GEOMATERIALS

2. Description

Soils and rocks are complex materials playing a crucial role in the design and assessment of geoengineering structures. Among the many features characterizing this class of materials, it is worth mentioning their ability to contract and dilate, the highly non-linear behavior even at very small strain, the strong pressure-dependent characteristics of their mechanical strength. To predict the salient features of geomaterials behavior, elastoplastic models have been formulated to characterize their mechanical response and capture the stress-stress behavior at different conditions.

This course is aimed to present the main hypotheses of the elastoplastic theory with focus to some constitutive approaches used to describe the behavior of soils and rocks. At the beginning of the course, the concept of Representative Elemetary Volume (REV) will be recalled along with an initial one-dimensional formulation of the theory which will be later generalized within a six-dimensional framework. Once the fundamentals equations of plasticity will be described, a set of constitutive models will be discussed starting from the most common frictional models used in engineering applications to more complex approaches characterized by more elaborated strength criteria and hardening rules. The course will continue by detailing the numerical methods used to integrate the constitutive equations. In particular, integration techniques based on explicit and implicit algorithms will be presented. The goal of this part of the course is to provide to the students the main computational tools to integrate an elasto-plastic model. For this purpose, the last part will be dedicated to show possible implementations within a Matlab/Octave platform which will be used to integrate some models as a practical exercises and validate the implementation through the integration of different stress paths.

3. Preliminary course organization

Frontal lessons (FL) and practical exercise (PE)

SYLLABUS	Lecturer	N° hours (#)	Week
Introduction to the elasto-plastic theory	Ferdinando Marinelli	6 FL	1st
Elasto-plastic approaches for geomaterials	Ferdinando Marinelli	6 FL	2nd
Numerical methods to integrate constitutive models	Ferdinando Marinelli	6 FL	3rd
Algorithms implementation	Ferdinando Marinelli	6 PE/FL	4th

4. Teachers

-Dr. Ferdinando Marinelli - Research Fellow in Geotechnical Engineering, University of Naples Federico II.

5. Duration and Credits

24 hours (2 CFU)

6. Activation mode and teaching period

The course will be held in one month, six hours per week. Tentative period: May 2022.

7. Final exam

Discussion on the practical exercise proposed during the course and some questions related to the topic presented during the course.

8. Brief CV of Ferdinando Marinelli

Marinelli Ferdinando did his PhD at University of Grenoble with the supervision of prof. René Chambon and prof. Yannick Sieffert. They investigated different constitutive approaches to describe the coupled behaviour of geomaterials. Specifically, two approaches have been explored, the former one based on the elasto-plastic theory with which an hydromechanic IBVP has been solved, while the latter based on computational homogenization approach validated through a comparison with the consolidation theory of Biot.

During his research activities, particular focus has been dedicated to the numerical modeling of localized and diffuse failure processes in high-porosity geomaterials. This topic has been investigated during a post-doctoral position in Northwestern University (United States) where emphasis has been given to the phenomenon of shear/compaction localization in high-porosity rocks, as well as to the onset of flow failure in quasi-saturated shallow sediments. To study the physics of these problems advanced models have been used based on critical state plasticity and a new constitutive framework for granular solids referred to as Breakage Mechanics. In particular, to investigate the potentialities of the critical state theory in the modeling of localization phenomena, the classical bifurcation criterion of Rice was used as a further tool to optimize and constrain a set of constitutive parameters for the proposed model. In this framework, a second gradient continuum was considered to suppress the mesh-dependency of the computed solution when strain localization develops in the simulated samples. To explain the role of time-dependency on the inception of different failure modes, a viscous version of both the critical state theory and the Breakage Mechanics was introduced in our numerical models by considering a Perzyna-like approach. In both cases, the integration of the stress at the end of a given time step is performed by means of a fully implicit algorithm (i.e. a generalized Backward Euler algorithm) which was adapted to the aforementioned rate-dependent approaches due to its properties of stability and accuracy for large time steps. By using these numerical tools, instability criteria for viscous materials were formulated to investigate delayed failures promoted by a wide range loading paths. In particular, a set of concepts already used in the past only for monophasic materials, has been extended to the more general case of multiphase materials characterized by varying degrees of saturation. In this manner, different scenarios can be explored to evaluate the likelihood of unstable phenomena, giving particular emphasis to mechanisms of failure relevant for life-threatening natural hazards, such as liquefaction events and undrained creep instabilities.

Thanks to his extended experience in computational mechanics he gained a position within a world wide recognized software company (Plaxis bv) developing an advanced Finite Element Method to simulate complex geotechnical problems. During these years a model to simulate brittle failure in rocks based on the Hoek & Brown criteria has been implemented within the PLAXIS framework. This work was presented in the 53rd symposium organized by American Rock Mechanics Association in 2019 in New York (United States). A further implementation to enrich the set of constitutive models in PLAXIS was addressed to an advanced approached aimed to deal liquefaction instability in loose deposit. The model, known in literature as NorSand, has been validated at the material point level through the integration of multiple stress paths and used to simulate the failure of a tailing dam occurred in Tar Island (Canada) in 1974.

Results from his research have produced 14 articles in peer-reviewed international journals, 10 proceedings at international conferences on geotecnics and rock mechanics. He is currently Assistant Professor in Geotechnics at the University of Napoli Federico II and he is teaching Soil Mechanics to undergraduated students. He gained the national scientific qualification for Associate Professor in 2021.