6. Plasticity of Geological Materials

In this chapter we describe some of the most common plasticity material models used to represent the behavior of geomaterials and present computational procedures for stress integration of these models. The computational algorithms represent an application of the governing parameter method of Section 4.2.

In Section 6.1 we first define some fundamental notions of soil mechanics and present a general view of soil behavior under loading. Then we give a short historical review of soil plasticity. In Sections 6.2, 6.3 and 6.4 we consider the cap model, the Cam-clay model, and a general soil plasticity model, respectively. For these models we develop the computational procedures for implicit stress integration and derive expressions for the consistent tangent elastic-plastic matrices. With suitably solved examples we illustrate the characteristics of the material models and of the computational algorithms.

As it is usual in geomechanics, we use the *compressive stresses and strains as positive.* Hence, *the normal stresses and strains that in the other chapters are positive, are all negative in this chapter, and vice versa.*

6.1 Introduction to the Mechanical Response of Geomaterials

The mechanical response of geological materials is complex due to the heterogeneous material structure, and due to variation of both the mechanical properties of these materials and the physical conditions in the real in situ environment. The complexity of a geological material response is particularly pronounced when the material undergoes permanent (large) deformations. The formulation of material models and their applications require laboratory investigations and in situ measurements.

One of the basic characteristics of the material behavior considered in the previous chapters was the isochoric character of the inelastic strains. Only in the case of the Gurson model (Example 4.5.11) did we have volumetric plastic strain develop during plastic flow. In the cases of isochoric inelastic deformations considered the mean stress does not affect the inelastic deformations. This characteristic pertains mainly to metals. On the other hand, the

elastic-plastic models for geological materials, such as soils, rocks and concrete, are more complex, with yield criteria dependent on the mean stress, and with a permanent (plastic) volumetric strain. Many yield criteria have been proposed for geological materials and we will present some of them in the subsequent sections.

In order to describe the main mechanical characteristics of geological materials we first introduce some basic notions generally used in geomechanics.

6.1.1 Basic Notions in Geomechanics

We begin with the fact that geological materials are porous, composed of *solid material* and *pores*. Pores can be filled with a gas (or a mixture of gases) and/or a liquid (or a mixture of liquids). If the whole pore volume is filled by a liquid, the state is called *saturated*. The geological materials are *inhomogeneous* in nature, as schematically shown in Fig. 6.1.1. However, in large scale considerations, common in engineering practice (and assumed here), the geological materials are represented as *continuous media*.

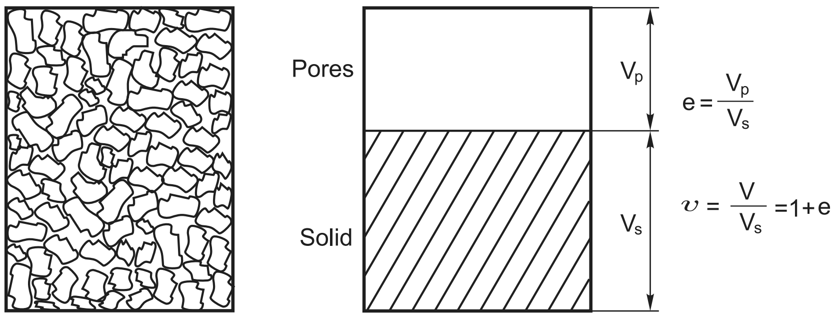

Fig. 6.1.1. Volume element V of a geological material

One of the main characteristics, relevant for the material response under a mechanical action, is the *void ratio* e, defined as

$$\boxed{e = \frac{V_p}{V_s}} \tag{6.1.1}$$

where, as shown in Fig. 6.1.1, V_p and V_s are, respectively, the volumes occupied by pores and the solid material within a volume V. Another quantity of the same character, used as an inherent property of the material, is the *specific volume* v,