Journal of Rock Mechanics and Geotechnical Engineering 8 (2016) 277–293

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Review

Disturbed state concept as unified constitutive modeling approach

Chandrakant S. Desai*

Department of Civil Engineering and Engineering Mechanics, University of Arizona, Tucson, AZ 85721, USA

ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form
29 January 2016
Accepted 30 January 2016
Available online 1 April 2016

Keywords:
Disturbed state concept (DSC)
Constitutive model
Parameters
Soils
Interfaces
Validations

ABSTRACT

A unified constitutive modeling approach is highly desirable to characterize a wide range of engineering materials subjected simultaneously to the effect of a number of factors such as elastic, plastic and creep deformations, stress path, volume change, microcracking leading to fracture, failure and softening, stiffening, and mechanical and environmental forces. There are hardly available such unified models. The disturbed state concept (DSC) is considered to be a unified approach and is able to provide material characterization for almost all of the above factors. This paper presents a description of the DSC, and statements for determination of parameters based on triaxial, multiaxial and interface tests. Statements of DSC and validation at the specimen level and at the boundary value problem levels are also presented. An extensive list of publications by the author and others is provided at the end. The DSC is considered to be a unique and versatile procedure for modeling behaviors of engineering materials and interfaces.

1. Introduction

Accurate solutions to engineering problems using conventional or advanced methods are dependent significantly on the responses of materials that compose the engineering systems. Hence constitutive modeling of materials such as soils, rocks, concrete, interfaces between structures and soils, and joints in rocks, plays a vital role in reliable solutions to geomechanical problems. A number of constitutive models, from simple to the advanced, have been proposed and available. Most of them account for specific characteristics of the material behavior. However, as stated before, a deforming material may experience simultaneously many characteristics such as elastic, plastic and creep strains, loading (stress) paths, volume change, microcracking leading to failure, strain softening or degradation, liquefaction and healing or strengthening.

Hence, there is a need for unified models that account for such characteristics simultaneously. This review paper presents a unique approach called the disturbed state concept (DSC) that includes a number of available constitutive models for solids and interfaces as special cases, and provides a unified model that allows the above factors simultaneously. The DSC includes models for the behavior of the continuum part of material for which the hierarchical single surface (HISS) plasticity model can be often used for the continuum; hence, the model covered here is called DSC/HISS. Descriptions of various constitutive models and the DSC/HISS are presented in various publications, e.g. Desai (2001).

Computer methods (e.g. Desai and Abel, 1972; Desai, 1979; Desai and Zaman, 2014) with appropriate constitutive models for behavior of geologic materials and interfaces have opened a new era for accurate and economic analysis and design for problems in geomechanics and geotechnical engineering. Such procedures account for many significant factors such as initial or in situ stress or strain; elastic, irreversible (plastic) and creep deformations; volume change under shear and its initiation during loading; isotropic and anisotropic hardening; stress (load) path dependence; inherent and induced discontinuities; microstructural modifications leading to fracture and instabilities like failure and liquefaction; degradation or softening; static, repetitive and cyclic (dynamic) loading; forces like loads, temperature, moisture (fluid) and chemical effects; anisotropy, nonhomogeneities, and strengthening or healing.

The reviews of available models based on elasticity, plasticity, elastoviscoplasticity, damage, fracture, and micromechanics are presented in Desai (2001, 2015a,b); they present details of DSC/HISS for a number of disciplines in engineering. A brief description of the DSC model and applications is given below together with relevant publications.

2. The disturbed state concept (DSC)

The DSC is a general and simple approach that can accommodate most of the forgoing factors including discontinuities that influence the material behavior, and provide a hierarchical

* Tel.: +1 520 577 9642.
E-mail address: csdesai@email.arizona.edu.
Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2016.01.003

framework that can include many of the available models as special cases. One of the attributes of the DSC is that its mathematical framework for solids can be specialized for interfaces and joints, thereby providing consistency in using the same model for both solids and interfaces (Desai, 2001).

In the DSC, a deforming material element is considered to be composed of two or more components. Usually, for a dry solid, two components are assumed, i.e. a continuum part called the relative intact (RI) which is defined by using a theory from continuum mechanics, and the disturbed part, called the fully adjusted (FA), which is defined based on the approximation of the ultimate asymptotic response of the material (Fig. 1).

The origin of the DSC constitutive modeling can be traced to the papers by Desai (1974, 1976) on the subject of behavior of overconsolidated soils and free surface flow in porous materials, respectively. The DSC is based on rather a simple idea that the behavior of a deforming material can be expressed in terms of the behaviors of its components. Thus, the behavior of a dry material can be defined in terms of the continuum (called relative intact – RI, i) and microstructurally organized, e.g. micro cracked part which approaches, in the limit, to the fully adjusted (FA, c) state; the latter can be essentially considered as collection of particles in failure. The behavior of the FA part is unattainable (or unmanifested) in practice because it cannot be measured; therefore, a state, somewhere near the residual or ultimate, can be chosen as approximate FA state (Fig. 1). The space between the RI and FA denoted by (i) and (c), respectively, can be called the domain of deformation, whose observed or average behavior (can be called manifested) occurs between the RI and FA states (Figs. 1 and 2). The deviation of the observed state from the RI (or FA) states is called *disturbance*, and is denoted by D. It represents the difference between the RI and observed behavior or difference between the observed and FA behavior, which can be considered as a parameter.

The observed material behavior is defined in terms of the behavior of RI (continuum) and that of the fully adjusted parts. The disturbance, D, acts as the coupling mechanism. The DSC thus provides for the coupling between two parts of the material behavior, rather than on the behavior of particle(s) at the micro level. Thus, the emphasis is on the modeling of the *collective behavior of interacting mechanism in clusters of* RI and FA states, rather than on the particle level processes, thereby yielding a *holistic* model. These comments are similar to those in the self-organized criticality concept (Bak and Tang, 1989), which is used to simulate catastrophic events such as avalanches and earthquakes. In this context, the DSC assumes that as the loading (deformation) progresses, the material in the continuum state

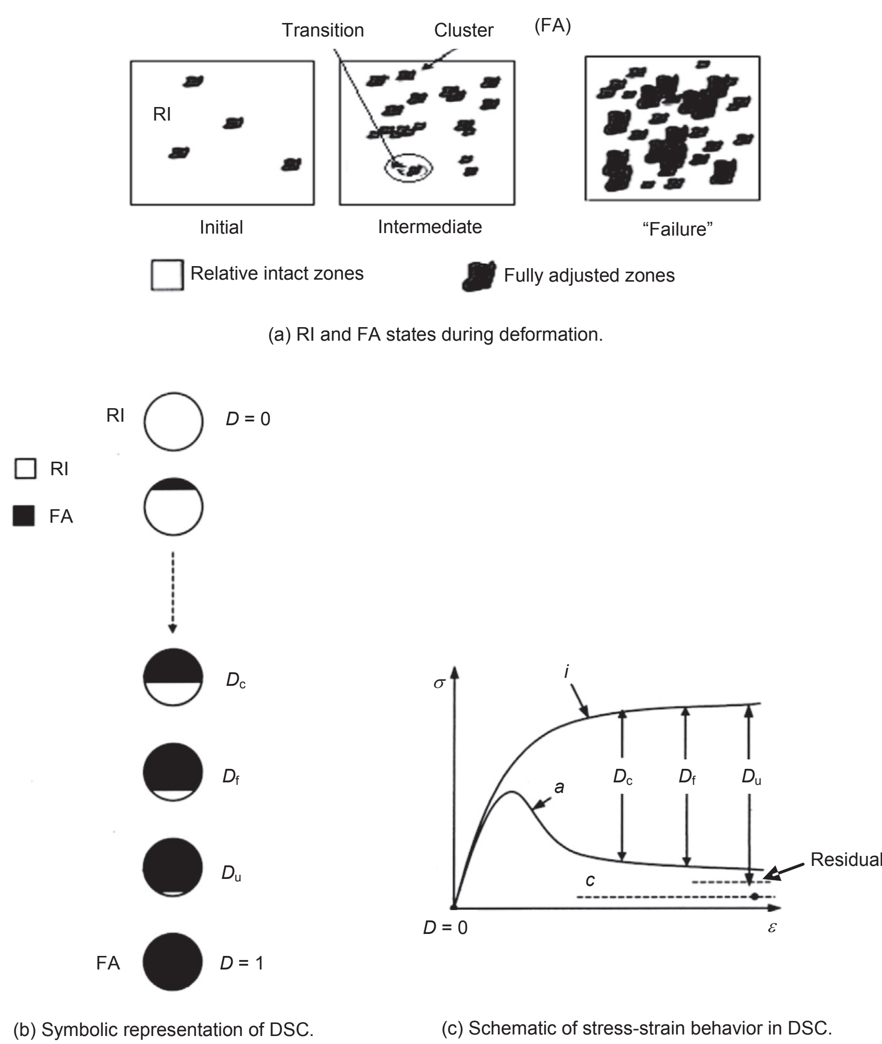

Fig. 1. Schematics of DSC. D_c, D_f and D_u denote initiation of fracture, failure and ultimate disturbance, respectively.