International Journal of Rock Mechanics & Mining Sciences 67 (2014) 136–144

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Dilatancy factor constrained from the experimental data for rocks and rock-type material

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ARTICLE INFO

Article history:
Received 19 September 2011
Received in revised form
22 April 2013
Accepted 28 December 2013
Available online 26 February 2014

Keywords:
Granular material
Rock testing
Dilatancy
Constitutive laws
Deformation localization

ABSTRACT

The dilatancy is as important property of rock-type (granular, frictional, cohesive, and dilatant) materials as the internal friction, but it is generally ill-constrained and is rarely taken into account in applications, being set to zero. Theoretical analysis shows that the dilatancy factor β strongly affects the onset of the deformation instability (localization). Numerical models confirm this but also reveal that evolution of this instability, resulting in the deformation localization bands and fractures observed in the experiments, is defined by the evolution of the constitutive parameters and notably of β with inelastic strain $\overline{\gamma}^p$ and mean stress σ. Therefore for the modelling of instability and rupture of rock-like materials, the knowledge (at least to a first approximation) of function $\beta(\overline{\gamma}^p, \sigma)$ and of how it can vary from one material to another is necessary. We constrain these functions from a large original experimental data set obtained for Granular Rock Analogue Material (GRAM1) as well as for hard rocks, Tavel and Solnhofen limestones, from the published data. All data are from axisymmetric compression tests conducted under different confining pressures. The data processing has shown that in spite of very different (orders of magnitude) values of elastic modulii and strengths, the aspect of the $\beta(\overline{\gamma}^p, \sigma)$ functions for all the three materials is similar: For all the materials β reduces with σ and increases with $\overline{\gamma}^p$ until certain $\overline{\gamma}^p$ value after which it reduces approaching zero. At intermediate σ values, β changes a sign from negative to positive with $\overline{\gamma}^p$. A relatively simple analytical expression of $\beta(\overline{\gamma}^p, \sigma)$ grasping this behaviour is proposed.

1. Introduction

Because of the absence of complete physics-based theory of inelastic deformation of geomaterials, different phenomenological theories relied on the available experimental data have been developed. The inherent problem of the phenomenological approach is that the available data were never sufficient to thoroughly/adequately describe the behaviour of such complex materials as rocks, or more generally, granular, frictional, dilatant, and cohesive materials. The inelastic properties of geomaterials are not only stress- and strain-, but also loading path-dependent. In the elastic–plastic constitutive formulations, this dependence is reflected in a complex evolution with equivalent inelastic shear strain $\overline{\gamma}^p$ of both yield and plastic potential functions in the stress space. To take into account this complexity, numerous constitutive models have been proposed (e.g., [1–6]). They are generally rather complicated and may include many parameters whose physical sense is not always clear. This is one of the reasons why the most used are the old and the simplest models such as that of Mohr–Coulomb. In spite of the obvious limitations of this model (e.g., independence on the intermediate stress) (e.g., [7,8]) it contains physically "transparent" parameters, the cohesion, the internal friction coefficient (or friction angle), and the dilatancy factor β (or dilatancy angle). Among these the last parameter is the least intuitive, the most poorly constrained, and probably for these reasons is practically not used in the applications, while in reality it is as important as the internal friction coefficient. This latter conclusion follows from the experimental studies [9–15], theoretical stability analysis [16–18] and numerical models (e.g., [19,20]) showing a strong impact of β on the formation of different types of deformation localization bands that are the precursors of the material fracture. The models in Fig. 1 provide an example of the impact of β on the gravitational destablization of a slope (landsliding initiation).

The dilatancy factor β is defined as a rate of change of inelastic volumetric strain ε^p with $\overline{\gamma}^p$ along a loading path corresponding to a constant mean stress σ:

$$\beta = \left(\frac{\partial \varepsilon^p}{\partial \gamma^p}\right)_\sigma \tag{1}$$

This factor is known to be dependent both on σ and $\overline{\gamma}^p$ [9,22], which results from the fact that ε^p depends on these parameters.

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http://dx.doi.org/10.1016/j.ijrmms.2013.12.014
1365-1609

Function $\varepsilon^p(\sigma, \overline{\gamma}^p)$ can be obtained only by processing a sufficiently large, good quality experimental data set from the experimental tests conducted at different confining pressures P_c. Usually, β is calculated for a loading path corresponding to P_c=const. and only at the onset of the deformation localization (i.e., only for a single $\overline{\gamma}^p$ value for a given P_c) [9,10,12,13].

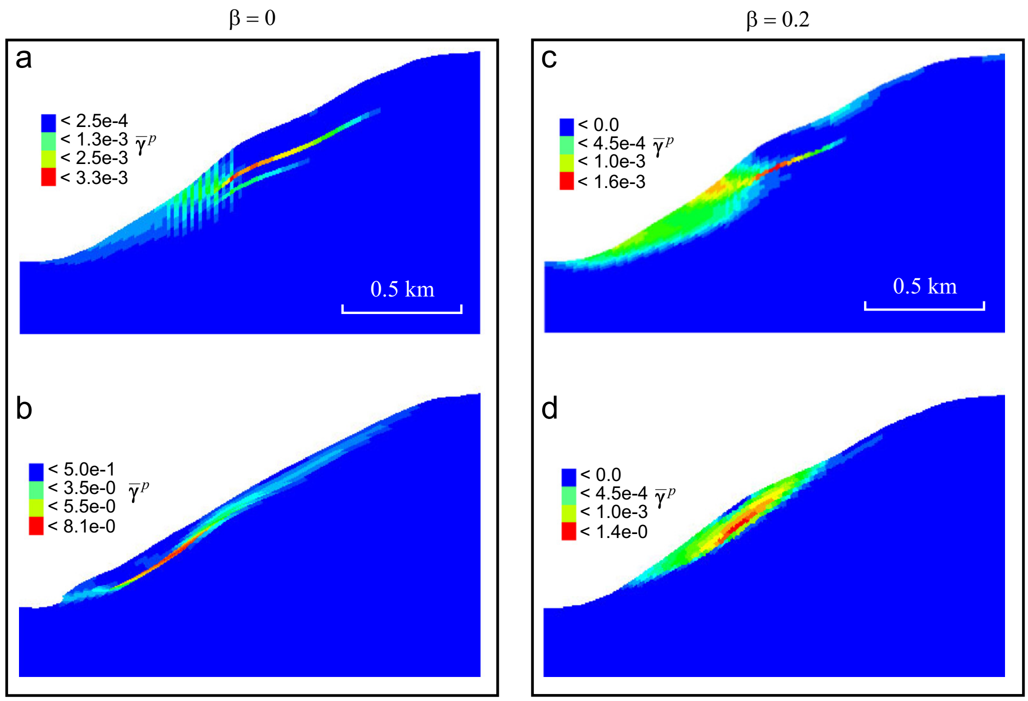

Fig. 1. Numerical models of gravitational destablization of a slope caused by a progressive reduction of the material strength due to the alteration. The models differ only by the β value: (a and b), β=0 (from [21] where the modelling details are given); (c and d), β=0.2.

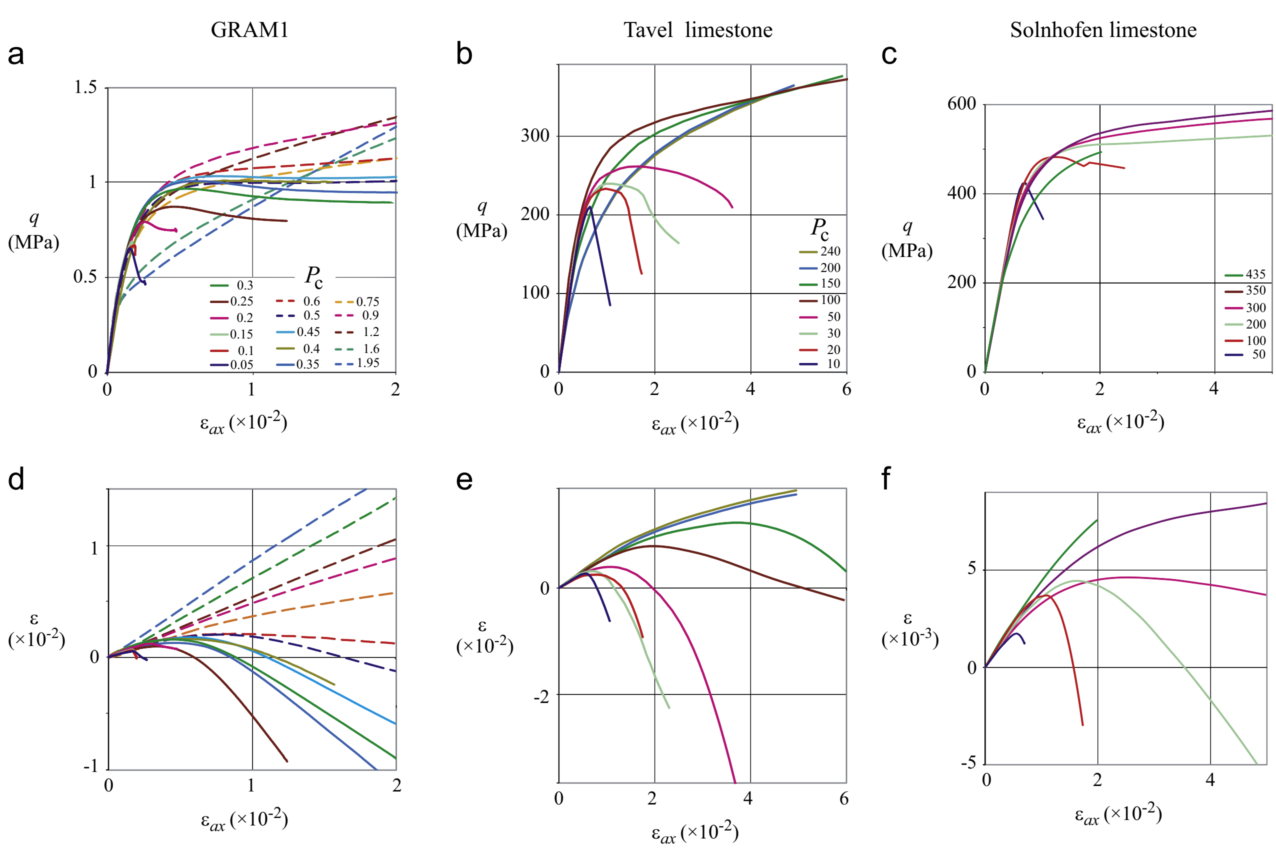

Fig. 2. Mechanical data from conventional compression tests for the three materials. q is the differential stress; ε_{ax} is the axial strain, and ε is the volume strain. The confining pressure for different curves (tests) is in MPa. (For GRAM1 only one curve for a given P_c is shown, while more curves were used in the data processing). The data for GRAM1 are from [14] and this paper; for TL, from [23], and for SL, from [11].