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Fracture and Size Effects in Weakly Cemented Sand

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Brittleness characterizes the mechanical behavior of stiff soils, such as overconsolidated clays and cemented sands. Although there is no single reason for this behavior, many researchers have called attention to the fact that the presence of flaws—i.e. fissures, cracks, joints—has a great effect on the strength and overall stress-strain behavior of such materials. These defects result in stress concentrations that lead to local failure and reduction in the overall strength of the material as the failure propagates through the intact region. This phenomenon shows that the failure mechanisms of earth structures, such as slopes in cemented sand, are different from traditional shear failure. In other words, conventional analysis techniques based on classical strength criteria might not be adequate. To represent failure phenomena, fracture mechanics can appropriately be adopted as a tool for analysis of these materials. However, the use of fracture mechanics concepts, especially for cemented sands, is faced with difficulties in obtaining relevant parameters, because fracture parameters and predictions are highly dependent on the material constituents and specimen size as well as particle size. Four-point beam bending tests were conducted involving specimens of 3 different sizes and 3 different grain sizes. Through these techniques, we found that the fracture behavior of cemented sands is greatly dependent on both the grain size of the constituent material and the size of the specimens.

INTRODUCTION

When engineers encounter design and analysis challenges involving natural and man-made slopes, shallow and deep foundations, and deep excavations in stiff or brittle soils, they often observe that the shear stresses at failure are much smaller than the shear strength obtained from traditional laboratory experiments and basic limit equilibrium analysis (Lo, 1972). Plus, the failure mechanism is often very different from the classical limit plasticity, characteristics and limit equilibrium mechanisms with which geotechnical engineers are familiar.

In the past, the cause of the reduction of overall strength and the path to a different failure mode were often unclear. However, it is generally known that cracks, fissures and joints have a significant effect on the strength and overall stiffness behavior of solids, and especially of brittle materials. That is, any flaws such as cracks, fissures and joints induce or cause stress concentrations, so that local failure may occur and finally lead to a reduction in the overall strength of the earth structure systems.

In manufactured engineering materials, it has been observed that the presence of any type of flaw can affect the strength of materials, such as brittle metal alloys. Numerous studies, which have contributed to the development of fracture mechanics, have been carried out experimentally as well as theoretically ever since Griffith first formulated the energy balance theorem of fracture mechanics in 1921. In the past couple of decades, many investigators in other engineering fields, when evaluating the behavior of rocks and cementitious materials such as concrete, have applied fracture mechanics concepts, which consider the stress concentration at the tip of the crack. Very recently, LEFM (Linear Elastic Fracture Mechanics) has been applied to geotechnical engineering problems (Saada et al., 1985; Cai et al., 1990; Sture et al., 1999).

Nevertheless, in most cases the soil has been treated as a continuous and homogeneous material, and failure criteria have been widely used, ranging from traditional strength-of-materials approaches, such as the Mohr-Coulomb criterion, to more complex constitutive formulations. However, these strength criteria may not be applicable to all kinds of soils. For all cohesionless granular and normally consolidated soils, classical strength criteria are quite satisfactory, but they seem not to be applicable to brittle and cohesive materials, especially for fissured and stiff overconsolidated clays and cemented sands, which are characterized by a nominal peak shear strength followed by strain-softening and a residual shear strength level (Rizkallah, 1977). It might be, according to Weibull's theory, because these soils have flaws with variably changing strengths, and the strength of fissured stiff soils often decreases with a specimen's increasing size. That is, the larger the size of the specimens, the higher the probability of encountering the largest defect in the material, and the greater the potential of early and progressive failure. However, strength-based failure criteria cannot generally explain size effect related to strength, since this would be in contrast to classical continuum principles based on local stress and strain concepts without any characteristic length scale. For these reasons, and because of the natural variations found in soils, there is a strong motivation for adopting fracture mechanics concepts to predict the performance of geotechnical systems, especially when including cemented brittle soils.

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