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Experimental study on fracture toughness and tensile strength of a clay

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Abstract

Fracture toughness K_{IC} is an important mechanical parameter of a material to indicate its ability to resist fracture failure under mode I load conditions in fracture mechanics. The method to determine K_{IC} of geomaterials and the relationship between K_{IC} and other mechanical parameters such as tensile strength σ_t were paid close attention by many studies. In this study, the K_{IC} of a clay, which is the core material of a high earth-rock fill dam in Western China, was determined by an improved 3-point bending beam loading assembly on single edge cracked soil beams. The testing results indicated that linear elastic fracture mechanics is suitable for investigating the fracture behavior of the clay. The values of the K_{IC} of the clay vary from 7.10 to 31.43 kPam$^{0.5}$ with changing water contents or dry densities of the soil beams. The σ_t of the clay was investigated by a uniaxial tension loading assembly on cylindrical compacted specimens. The testing results indicated that the tensile failure of the soil columns is brittle, and the strain before failure can be neglected. The values of the σ_t of the clay vary from 19.00 to 90.00 kPa with changing water contents or dry densities of the soil columns. Based on testing data, an empirical linear relationship between the K_{IC} and the σ_t of the tested clay, which is $K_{IC}=0.3546\,\sigma_t$, was suggested. By analyzing other studies, it was found that the fracture toughness and tensile strength of many geomaterials such as cohesive soil, frozen soil, soft rock and hard rock are also linearly correlated. But the proportionality coefficients are different for different soils or rocks and testing methods.

Keywords: Failures; Geotechnical engineering; Models (physical); Strength and testing of materials

1. Introduction

In the past three decades, linear elastic fracture mechanics (LEFM) has established its proper position in geotechnical engineering (Sture et al., 1999). The successful engineering examples of using LEFM can be collected in many published literatures in geotechnical engineering. This is because failure criteria such as Tresca, Mises or Coulomb based on yield dominant

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Nomenclature

a	Depth of crack
A	Cross-sectional area of specimen
B	Thickness of specimen
F_{max}	Maximum tensile force
G	Total weight of loading pole, upper grip and upper part of the specimen from fault face
G_S	Specific gravity
I_P	Plasticity index
K_I	Stress intensity factor
K_{IC}	Fracture toughness
P	Load applied on the specimen
p_a	Atmospheric pressure
r	Coefficient of determination
S	Effective length of specimen
W	Width of specimen
W_L	Liquid limit
W_P	Plastic limit
α	A proportion coefficient
γ_w	Unit weight of water
σ_t	Tensile strength
σ_{ys}	Yield stress of material

failure of material may be adapted to investigate the failure of materials induced by yield, but cannot be proved to be adapted to investigate the fracture dominant failure of brittle materials (Chudnovsky et al., 1988). LEFM was proved by Morris et al. (1992) and Krishnan et al. (1998) as a powerful tool for investigating the fracture dominant failure or rupture of many geomaterials such as stiff and over-consolidated soils, especially those with cracks.

Fracture toughness K_{IC} is an important mechanical parameter of material in LEFM, which reflects the ability of the material to resist fracture failure under mode I load conditions. Many testing methods have been proposed to measure the parameter K_{IC} of geomaterials such as soils (Lee et al., 1988; Chang et al., 2002). Single edge cracked beam (SECB) was used to determine the parameter K_{IC} of soils in some studies such as Nichols and Grismer (1997) and Hallett and Newson (2001). In testing of soils, it is a very difficult problem to remove or minimize the influence of specimen's self-weight on the testing results. Some studies suggested improvements on the assembly of 3-point bending fracture tests for SECB, such as Chandler (1984), Hallett and Newson (2001), and Nichols and Grismer (1997).

As a material mechanical parameter, the fracture toughness K_{IC} should be correlated with other material mechanical parameters such as tensile strength σ_t. Gunsallus and Kulhawy (1984) and Bhagat (1985) found that the fracture toughness K_{IC} is proportional to the tensile strength σ_t of many rocks. The linear correlations for rocks were published by Haberfield and Johnston (1989) and Zhang (2002). The two parameters of compacted cohesive soil were also proved to be linearly correlated by Harison et al. (1994).

Investigating the inducement and propagation of the cracks in soil core of earth-rock fill dam is a very important and difficult problem in dam engineering. In order to solve the problem, LEFM should be used as a tool (Wang and Zhu, 2007), and the fracture toughness K_{IC} of the core material should be firstly determined. In this study, the fracture toughness K_{IC} of a clay, from the vertical clay core of *Nuozhadu* earth-rock fill dam in Western China, was determined by an improved 3-point bending beam loading assembly, and its tensile strength σ_t was determined by a uniaxial tension loading assembly. The earth-rock fill dam has a vertical clay core with 261.5 m in height, 10.0 m and 111.8 m in top and bottom thicknesses, respectively. Based on testing data and some analyses, the relationship between the parameters K_{IC} and σ_t of the clay was investigated.

2. Tested soil

A clay containing a small amount of gravels was used in the study. The basic physical properties of the soil are