

Investigation of the effect of aggregate shape and surface roughness on the slake durability index using the fractal dimension approach

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Received 19 September 2005; received in revised form 25 May 2006; accepted 29 May 2006

Available online 12 July 2006

Abstract

Argillaceous rocks cover about one thirds of the earth's surface. The major engineering problems encountered with weak- to medium-strength argillaceous rocks could be slaking, erosion, slope stability, settlement, and reduction in strength. One of the key properties for classifying and determining the behavior of such rocks is the slake durability. The concept of slake durability index (SDI) has been the subject of numerous researches in which a number of factors affecting the numerical value of SDI were investigated. In this regard, this paper approaches the matter by evaluating the effects of overall shape and surface roughness of the testing material on the outcome of slake durability indices.

For the purpose, different types of rocks (marl, clayey limestone, tuff, sandstone, weathered granite) were broken into chunks and were intentionally shaped as angular, subangular, and rounded and tested for slake durability. Before testing the aggregate pieces of each rock type, their surface roughness was determined by using the fractal dimension. Despite the variation of final values of SDI test results (values of I_d), the rounded aggregate groups plot relatively in a narrow range, but a greater scatter was obtained for the angular and subangular aggregate groups. The best results can be obtained when using the well rounded samples having the lowest fractal values. An attempt was made to analytically link the surface roughness with the I_d parameter and an empirical relationship was proposed. A chart for various fractal values of surface roughness to use as a guide for slake durability tests is also proposed. The method proposed herein becomes efficient when well rounded aggregates are not available. In such condition, the approximate fractal value for the surface roughness profile of the testing aggregates could be obtained from the proposed chart and be plugged into the empirical relation to obtain the corrected I_d value. The results presented herein represent the particular rock types used in this study and care should be taken when applying these methods to different type of rocks.

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Keywords: Argillaceous rock; Fractal dimension; Slake durability; Surface roughness

1. Introduction

Argillaceous rocks are found at and near the surface of the earth owing to the geological processes such as

deposition and weathering and cover about one thirds of the earth's surface. It was reported that rocks containing large ratios of clay content (e.g., claystone, shale, marl, siltstone) covers a significant portion of the stratigraphic column (e.g., Franklin and Chandra, 1972; Blatt, 1982; Dick et al., 1994). Thus, it is often inevitable to work with the clayey rocks during geotechnical activities.

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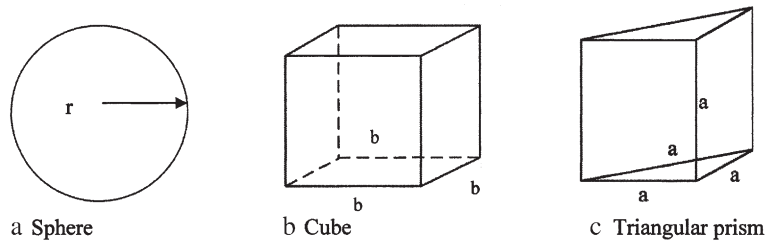


Fig. 1. Geometrical shapes used for surface area calculation.

The rocks containing high-plasticity clays may swell, shrink, and slake. The outcome of such effects could lead to the rapid weathering of exposed rocks which causes slope stability problems, failure of earthfills as well as reduction strength with rocks exposed to air in underground openings (Gokceoglu et al., 2000).

The slake durability is an important property for rock materials and rock masses (Franklin and Chandra, 1972; Rodrigues, 1991; Dick and Shakoor, 1995; Gokceoglu et al., 2000; Dhakal et al., 2002; Dhakal et al., 2004; Yilmaz and Karacan, 2005; Singh et al., 2005). One of the major problems arising during construction of engineering structures in clayey rocks results from rapid weathering. The susceptibility of such rocks to weathering and the degree of weathering could be determined using some slake durability parameters such as the slake durability index. This is an important engineering property for rocks such as mudstone, marl, ignimbrite, weakly cemented conglomerate and siltstone (Gokceoglu et al., 2000). The concept of slake durability has also been used to study the weathering processes of granitic rocks (Lee and Freitas, 1988; Zhao et al., 1994). Slake durability index (I_{d2}) was also included in the modified rock mass rating (M-RMR) and became an efficient tool for design practices on rock masses (Unal, 1996). Some researchers (e.g., Koncagül and Santi, 1998; Gokceoglu et al., 2000) used the slake durability index to establish a relationship with the uniaxial compressive strength.

Introduced by Chandra (1970) and later improved by Franklin and Chandra (1972), the slake durability test was proposed as a standard test for rocks by ISRM (1981) and also became an ASTM standard in 1990.

It was reported that the results of slake durability test are susceptible to the porosity and permeability of the rocks tested, nature of the testing fluid, resistance of rocks against swelling and disintegration, the shape of sample pieces placed in the testing drum, properties of testing equipment, conditions of sample storing, and the number of wetting–drying cycles (Franklin and Chandra, 1972). Tests omitting any of the factors listed above would lead to erroneous results.

One of the basic requirements of the slake durability test (ISRM, 1981; ASTM, 1990) is nearly spherical chunks with truncated corners, each having a mass between 40 to 60 g. Nevertheless, preparation of nearly spherical samples could be time consuming or sometimes be very difficult. Slake durability depends on many factors such as rock type, degree of weathering, grain size, mineralogical composition, and structural/textural properties. For this reason, during preparation of aggregates satisfying the standards of the test, such requirements usually are not given sufficient care. Thus, the results are thought to overestimate the value of true slake durability index which may readily cause the change of the slaking class of a rock from one to another.

There are two reasons for the severe influence of aggregate shape and surface roughness on the slake durability index. One is, depending on the degree of surface roughness, the attrition among sample pieces as well as with the inner surface of the drum increases the abrasive stresses which results into more disintegration of sample pieces. The other is, rough surface of aggregate creates more surface area. As the aggregates lose sphericity and gain higher amplitudes of asperities, the surface area exposed to testing fluid increases resulting more interaction with the fluid. In order to demonstrate this effect, the objects of the same volume but different geometrical shapes can be compared as illustrated in Fig. 1. For this, the volumes are equalled at the first step:

$$V_{\text{sphere}} = V_{\text{cube}} = V_{\text{tri.prism}} \Rightarrow 4.19r^3 = b^3 = 0.43a^3 \quad (1)$$

Because the areas are quadratic expressions, it would be convenient to raise each term to the power 2/3 such that:

$$2.6r^2 = b^2 = 0.57a^2 \quad (2)$$

Rearranging in terms of b^2 would give:

$$r^2 = 0.38b^2 \text{ and } a^2 = 1.75b^2 \quad (3)$$

The surface areas of the three figures are as follows:

$$A_{\text{sphere}} = 4\pi r^2 \quad A_{\text{cube}} = 6b^2 \quad A_{\text{tri.prism}} = 3.87a^2 \quad (4)$$

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