Engineering Geology 167 (2013) 95–104

Contents lists available at ScienceDirect

Engineering Geology

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

Engineering geological characterization of clayey diatomaceous earth deposits encountered in highway projects in the Tengchong region, Yunnan, China

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ARTICLE INFO

Article history:
Received 19 March 2013
Received in revised form 11 October 2013
Accepted 14 October 2013
Available online 22 October 2013

Keywords:
Diatomaceous earth
Clay mineral
Swelling
Mechanical property
Geohazard

ABSTRACT

A type of clayey diatomaceous earth of Pliocene Mangbang Formation (N_2m) was encountered in highway projects in the Tengchong region of Yunnan Province, Southwest China. The Tengchong clayey diatomaceous earth is characterized using multiple test methods, such as granulometric analysis, chemical analysis, X-ray diffraction (XRD) and scanning electron microscopy (SEM) analysis, shrinkage and swelling tests, unconfined or uniaxial compression test, triaxial test and direct shear tests. The chemical and mineralogical compositions, physical and hydraulic properties and engineering properties of the clayey diatomaceous earth are presented in this paper. It is revealed that the Tengchong clayey diatomaceous earth is an unusual soil or rock which has characteristics of both typical diatomaceous earth and swelling clayey soil or soft clay rock. The diatoms in the earth enhance the connection between micro-structures, and improve the mechanical properties of diatomaceous earth. However, due to the existence of a significant amount of swelling clay minerals, the Tengchong clayey diatomaceous earth becomes swelling soft rock, and is prone to engineering problems or geohazards. Based on the test results, a number of issues regarding classification, discrimination and geohazard control related with the clayey diatomaceous earth are discussed to provide both some basic understanding and new insight into the characteristics of the clayey diatomaceous earth deposits.

1. Introduction

Diatomaceous earth deposits are located in marine and lacustrine deposits of Miocene and Pliocene age worldwide (Harben, 2002). Diatomaceous earth is generally characterized as a chalk-like, soft, friable, earthy, very fine-grained, siliceous sediment, usually light in color, i.e., white if pure, commonly buff to gray in situ, and rarely black (Ilia et al., 2009). It has been earlier studied in the field of engineering geological research (Iijima and Tada, 1981; Isaacs, 1982; Chaika and Dvorkin, 2000; Koizumi et al., 2009; Calvo et al., 2012), or as a material for industrial applications in filtering, bleaching, filling, electrical insulating, and building (Stoemer and Smoll, 2001; Fragoulis et al., 2005; Ilia et al., 2009; Liu and Zhao, 2009; Van Garderen et al., 2011).

The engineering and mechanical properties of diatomaceous earth have received continuous attention in the last decade. Day (1995) studied the diatomaceous fill in south California, showing its high water content and low dry density. Tateishi (1997) studied diatomaceous earth in Japan, indicating that it has not only very high water content, but also very high strength and elastic modulus. Hong et al. (2004a) investigated changes of micro-structures of diatomaceous earth in Japan under different stress levels, and proposed the relationship between the micropores in the diatomaceous earth and stress levels. The influences of diatoms on engineering properties of diatomaceous earth have been addressed in many researches, which suggested that the presence of diatoms can increase the plastic limit and the liquid limit of sediments (Tanaka and Locat, 1999; Shiwakoti et al., 2002; Palomino et al., 2011), the plasticity index, the shear strength and the internal friction angle (Shiwakoti et al., 2002), the compressibility and hydraulic conductivity (Rajasekaran, 2006), and decrease the shrinkage limit (Palomino et al., 2011). The previous researches have revealed the contributions of diatoms in improving the mechanical properties of diatomaceous earth. For example, the natural diatomaceous earth sample with diatom content of about 75% from Linqu of Shangdong Province, China, remained integrated without swelling–slaking when soaked in water (Hu and Wen, 2005). However, when the amount of clay minerals, especially the swelling clay mineral of montmorillonite, increases to a certain level, the controlling factors for the mechanical properties of diatomaceous earth may be changed. This can be evidenced by frequent occurrence of slope geohazards associated with the clayey diatomaceous earth, such as the landslides of diatomaceous earth in Shengzhou of Zhejiang Province, China (Gao et al., 2007). Thus, study of the engineering geological properties of clayey diatomaceous earth deposits, especially the influence of

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http://dx.doi.org/10.1016/j.enggeo.2013.10.009

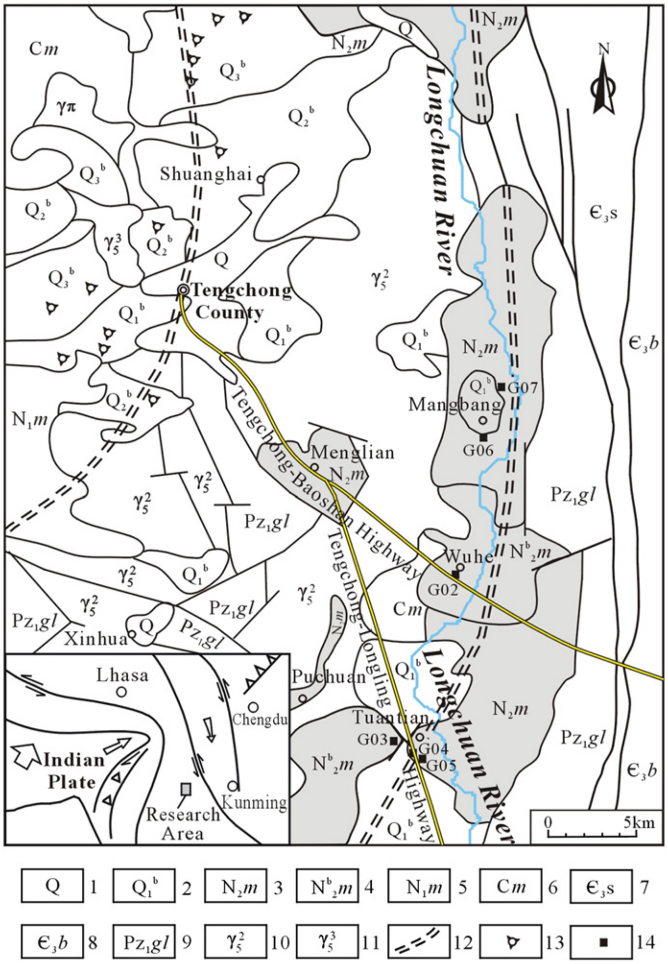

Fig. 1. Distribution of diatomaceous earth of the Pliocene Mangbang Formation in the Tengchong region 1—Quaternary sediment; 2—Quaternary volcanic rock; 3—Pliocene Mangbang Formation; 4—Volcanic rock of Mangbang Formation; 5—Miocene Nanlin Formation; 6—Carboniferous Menghong Formation; 7—Cambrian Shahechang Formation; 8—Cambrian Baoshan Formation; 9—Lower Paleozoic Gaoligongshan group; 10—Late Yanshanian granite; 11—Early Yanshanian granite; 12—Regional tectonic zone; 13—Crater; 14—Sampling spot.

swelling clay minerals, is also one of the interesting and essential subjects in the engineering geology field.

Although diatomaceous earth deposits were found in 18 provinces of China (Cui, 2008), few studies have been conducted on their engineering geological and mechanical properties. During engineering geological survey for highway projects in the Tengchong region, Yunnan Province, Southwest China, in the past two years, a type of expansive clayey diatomaceous earth of Pliocene Mangbang Formation (N_2m) was encountered (Zhang et al., 2012). Several slope failures including surface debris avalanches and landslides occurred in the highway slopes. In this paper, based on tests on typical diatomaceous earth deposits, the physical and engineering properties of the diatomaceous earth are obtained and analyzed. The associated engineering geological problems or geohazards, the control measures, as well as the classification considering the swelling property of clayey diatomaceous earth, are discussed to provide both some basic understanding and new insight into the characteristics of the diatomaceous earth deposits.

2. Geological settings

The Pliocene diatomaceous earth deposits in the Tengchong region appear in lake facies sediments of the Mangbang Formation (N_2m), especially in its third member (N_2m^3). The formation is widely distributed in basins along the Longchuan River, such as the Mangbang, Tengchong, and Lianghe basins. It is 352–630 m thick and consists of gravel-bearing granite sand, gravel, clayey diatomaceous earth, brown coal and intercalated basalt, volcanic breccia and tuff, forming several volcanic sedimentary cycles.

In the Mangbang basin, the Pliocene diatomaceous earth is mainly exposed in such locations as Qushi, Yongan, Menglian, Sanjiajie, Tuantian, Wuhe, Mangbang, and Shangyin (Fig. 1). According to Shang (2003) and Zhang et al. (2012), the distribution of diatomaceous earth was obviously controlled by two factors. One is associated with Cenozoic basalt in basins. Due to the warm climatic condition, chemical weathering of basalt provided a lot of free SiO_2 and Mg^{2+}, which was favorable for the formation of montmorillonite or illite–montmorillonite mixed layer mineral which is the main composition of Tengchong diatomaceous earth. Another is the Longchuan River fault zone (Fig. 1), which controlled the distribution of such basins as Mangbang, Tuantian, and Puchuan where diatomaceous earth was deposited.

The diatomaceous earth can coexist or be intercalated with basalt or weakly cemented clay rock or silty sandstone (Fig. 2a, b and c) or occur as a single layer (Fig. 2d and e). In some sections, its thickness is even up to 40 m. The layered diatomaceous earth is nearly horizontal or gently dipped. Along the Tengchong–Baoshan Highway and Tengchong–Longling Highway under construction, it can be seen that undisturbed diatomaceous earth is usually compact-massive and very light and has well-developed lamination. It is mainly gray white, yellowish brown, dark gray or black in color, depending on its existence environment. After being air dried, it is usually cracked with shrinking fissures and hence vulnerable to flaking (Fig. 2a, e, f and h).

3. Materials and methods

Seven bulk samples of diatomaceous earth were collected during the geological survey. Two samples were taken from a highway slope south of Wuhe Town (G02-1, G02-2), another two from a highway slope in Mannong (G05-1, G05-2), the others from a diatomaceous earth mine slope in Manpa (G04-2), a borrow pit by the highway south of Mangbang (G06), and a highway slope in Zhangjiacun (G07), respectively. Each of them was extracted from subsurface without disturbance and natural water content was maintained. The samples were fine-grained and homogenous, having three color tones: black or dark gray, gray white, and yellow or yellowish brown respectively, which can reflect the existence of micro-environment.

Tests on the chemical and mineralogical compositions, physical and hydraulic properties and engineering properties of the diatomaceous earth, including compressive strength and shear strength, were conducted. Unless specifically indicated, all the test results were obtained by a single test, and tests were carried out on bulk samples to ensure good correlation between physicochemical and index properties.

The composition and structure of minerals were determined by X-ray diffraction (XRD) and scanning electron microscopy (SEM) analyses. The clay mineral tests by XRD were carried out, using the $<2\,\mu m$ fraction, on untreated samples, glycol-saturated samples and samples heated to 550 °C, respectively. SEM was used to examine the microstructure of the biogenic silica, mostly diatom frustules, in the bulk samples.

Fig. 2. Clayey diatomaceous earth exposed along the highways in Tengchong region. a—Thick-bedded clayey diatomaceous earth with air-dried fissures by the highway south of Wuhe Town; b—Collapsed debris below the slope of thick-bedded clayey diatomaceous earth in Wuhe Town; c—Contact of diatomaceous earth with basalt on the highway slope in Mannong Village; d—Diatomaceous earth landslide of the highway slope in Mannong Village; e—Slope of thick-bedded clayey diatomaceous earth in Manpa Village; f—Collapse debris on the highway slope of clayey diatomaceous earth in Mannong Village; g—Clayey diatomaceous earth with the weathered upper part on the highway slope in Mannong Village; h—Weathered thick-bedded clayey diatomaceous earth in the highway borrow pit south of Mangbang Town.