Engineering Geology 152 (2013) 155–161

Contents lists available at SciVerse ScienceDirect

Engineering Geology

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

Role of expansive soil and topography on slope failure and its countermeasures, Yun County, China

Hongtao Jiang [a,*], Baojun Wang [b], Hilary I. Inyang [c], Jin Liu [b,d], Kai Gu [b], Bin Shi [b]

[a] School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing, 210093, China
[b] School of Earth Sciences and Engineering, Nanjing University, Nanjing, 210093, China
[c] University of North Carolina at Charlotte, NC 28223, USA
[d] School of Earth Sciences and Engineering, Hohai University, Nanjing, 210098, China

ARTICLE INFO

Article history:
Received 5 April 2011
Received in revised form 26 October 2012
Accepted 29 October 2012
Available online 13 November 2012

Keywords:
Expansive soil
Topography
Slope failure
Countermeasure
Yun County

ABSTRACT

High content of expansive clay minerals coupled with exposure to moisture content fluctuations, is known to cause alternate swelling and shrinkage of soils. Typically, this phenomenon causes deformation and failure of structures that are constructed on such soils. The design and implementation of countermeasures against slope failures and associated failures of structural foundations in field scenarios in which expansive soils are exposed require an integrated analysis of the soil mineralogical structural characteristics and stratification, site topography and the orientation of structures relative to the unstable soil beds. In this combined field and laboratory study, it has been found that mantling of ridge tops by expansive clay soils in Yun County, China, makes buildings sited therein, more susceptible to settlement and structural damage than on the slopes and valley floor where sandstone and gravelly rock pose limited volume change risks. This investigation shows that topography of the ridge-and-gully and engineering properties of expansive soils are two significant determinants of the severity of slope failure, and the engineering measures taken in the past 25 years have been validated to be cost-effective for controlling slope failures in Yun County, China.

1. Introduction

Soils that contain high quantities of expandable clays such as montmorillonite and illite, are usually highly dispersive and plastic. They exhibit volume changes in cyclical dry and wet environments (Li et al., 1992; Nelson and Miller, 1992; Yilmaz, 2008). Research on expansive soil has a long history (Cooke, 1984; Vuichard, 1986; Chen, 1988; Kenny, 1990; Butler, 1994; Ohmori and Shimazu, 1994; Gill, 1996; Fiebiger, 1997; Lang et al., 1999; Schick et al., 1999; Devabhaktuni, 2002; Miao et al., 2002; Wilkerson and Schmid, 2003; Kariuki and Meer, 2004; Glade, 2005; Chinn, 2006; Bollschweiler and Stoffel, 2007; Fall and Sarr, 2007; Ene and Okagbue, 2009; Yitagesu et al., 2009; Dorn, 2010; Kurtulus et al., 2010). Expansive soils are found in more than 40 countries and regions in the world (Ramana, 1993). China is one of the countries with extensive presence of expansive soils. In China, they are found in more than 20 provinces and regions. Alternate swelling and shrinkage of an expansive soil can cause non-uniform settlement of structures, cracking of walls and pavements and disruption of surface drainage patterns. Consequently, many investigations and mitigation measures have been developed to control soil expansivity in regions where it is common (Alcantara-Ayala, 2002; Xu et al., 2009).

The volume change magnitude of expansive soils depends on the mineralogy and amount of clay present in the soil. Soils that contain expansive clays have high swelling–shrinkage potential because their molecular structures can provide large specific surface for water adsorption (Vaught et al., 2006; Zemenu et al., 2009). Changes in field moisture conditions that can result from natural phenomena and/or human activities, may lead to swelling or shrinkage of these soils (Tang et al., 2009). At the regional scale, the hydrological changes that accompany climate change and manifest as droughts and floods, have also produced structural changes in expansive soils (UFC, 2004). Essentially, soil composition and hydrological environment are the two key factors that control the severity of swelling–shrinkage of expansive soils.

In some cases, expansive soils with relatively high swelling–shrinkage potential have not produced serious structural damages. On the contrary, some expansive soils with relatively low swelling–shrinkage potential have caused extensive structural damage. Analysts often ignore the role of topography as a significant determinant of the severity of such structure damages in the field. Topography plays a significant role into the extent of access of moisture to the expansive soils. This is the case in Yun County, China.

Yun County is located in the northern side of the middle reaches of the Han River, which exists in the northwestern part of Hubei Province, China. About 3.5 km^2 of this county is urbanized. Land development has expanded to the second terrace of the Han River since 1958, when the river was dammed to create the Danjiangkou reservoir. As of 1973,

* Corresponding author.
E-mail address: jianghongtao@nju.edu.cn (H. Jiang).

0013-7952/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.enggeo.2012.10.020

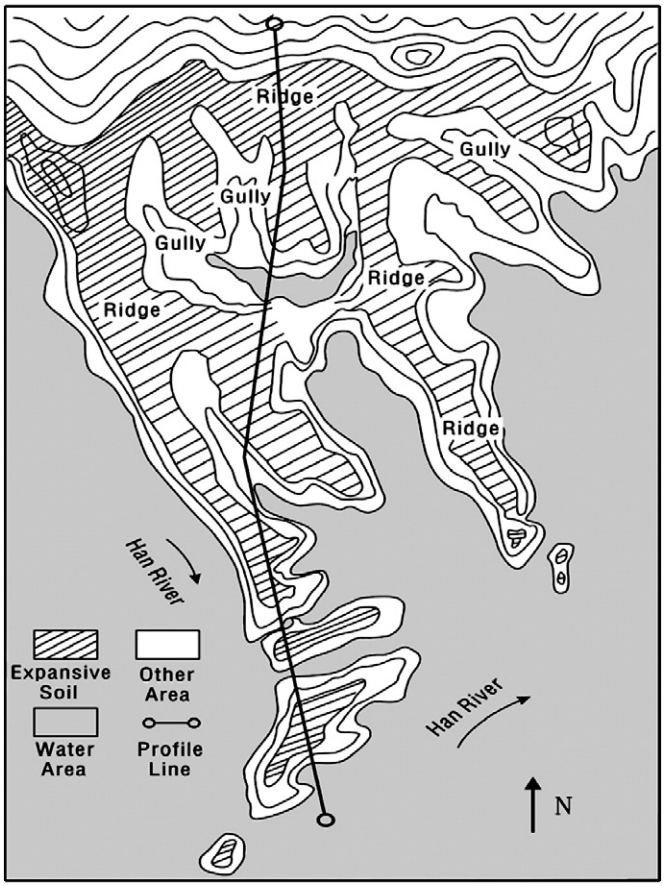

Fig. 1. Geomorphology and distribution of expansive soils in Yun County, China.

more than 70% of buildings in the county were either deformed or cracked as a result of expansion of the foundation soil. This produced significant economic and property losses. The focus of this paper is on the courts of two field surveys that were performed in September, 1985 and March, 2010, along with the laboratory based characteristics of the expansive foundation soil, to analyze the significance of the local soil stratigraphy on the recorded slope failures. The twenty five years between the two soil surveys provided a detailed time interval for manifestation of the effects of volume change on structures at the site. Herein, the role of expansive soil properties at the foundation and topography on slope failure is analyzed. The effectiveness of the countermeasures taken in the past 25 years in Yun County, China to mitigate this problem is also evaluated.

2. Geological and topographic characteristics of the study area

The study area in Yun County is located in the second terrace between Blackrock Mountain and the Han River. This Quaternary soil cover has a base that comprises red sand and gravelly rock of the Tertiary period. The first and second terraces have elevations of 130–150 m and 170–200 m, respectively. Numerous gullies have developed in the second terrace because of erosion by surface water. Most of the gullies are aligned predominantly in a north–south trend. However, some secondary gullies that exhibit an east–west trend have also developed in the area. These gullies are distributed on the terrace in an alternating ridge–gully pattern. Most of the ridges have gradients in the range of 15°–30°, with some exceeding 30°. Fig. 1 shows the distribution of expansive soils and their associated geomorphological characteristics in Yun County. As observed, there is a strong correlation between the spatial distribution of expansive soil and the study area's topography. Expansive soil is found as mantles, mostly on ridges, while sandstone and gravelly rock of the mid-Pleistocene-series are found on the toe of gullies. Fig. 2 shows the typical relationship between geology and topography in the urban area of Yun County. As shown, the expansive soil is located in the second terrace as an outcrop on the ground surface.

3. Expansive soils and their engineering properties

3.1. Expansive soils

A typical soil profile in a slope of the North-Gate is presented in Fig. 3, and its columnar section is presented in Fig. 4. The red sandstone and gravelly rock of the second terrace are covered with some layers of Pleistocene soil. From bottom to top of the terrace the soils exist as consecutive layers of low plastic clay (gravel–silt, CL), medium plastic clay (CM) and high plastic clay (expansive soil, CH). Soil particles are coarse in the bottom layer but fine in the upper layers, forming a binary structure that is typical of river terraces in the region. The combined thickness of both the low plastic clay (CL) and medium plastic clay (CM) is 6–7 m. Strata (CH) that attain about 6.0 m in thickness are found in the top layer. The upper layer is brownish clay (ES-2) with some streaks of gray clay, and contains some cracks; the middle layer is cracked gray clay (ES-1), and the bottom one is lightly cracked

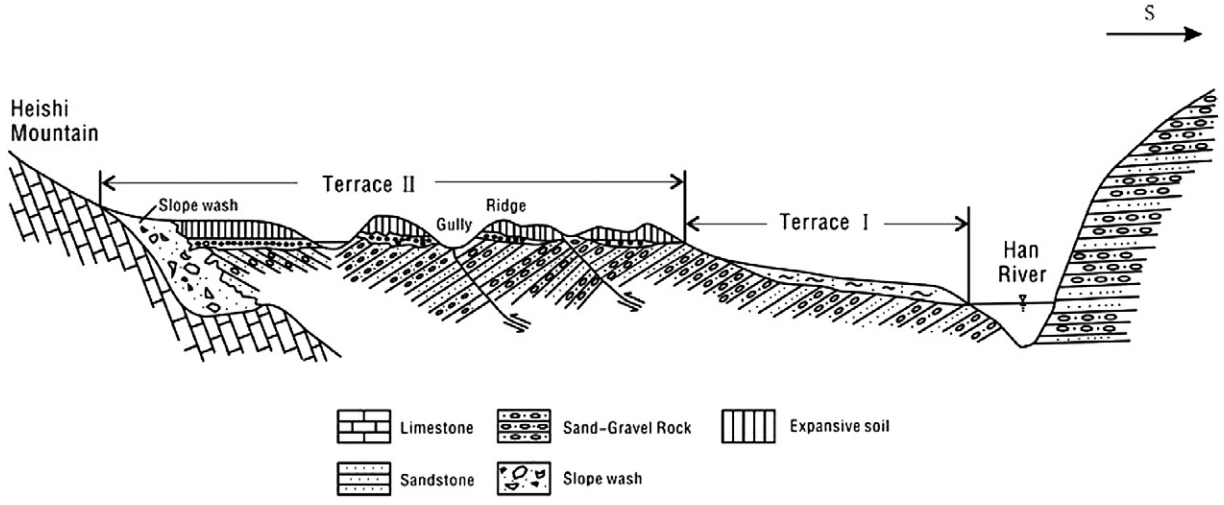

Fig. 2. Geological and geomorphological stratigraphies of the urban area of Yun County, China.