Engineering Geology 181 (2014) 249–260

Contents lists available at ScienceDirect

Engineering Geology

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

Structural characterization of natural loess and remolded loess under triaxial tests

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ARTICLE INFO

Article history:
Received 9 December 2013
Received in revised form 16 June 2014
Accepted 28 July 2014
Available online 14 August 2014

Keywords:
Loess
Triaxial test
Microstructure analyses
Mechanical behavior

ABSTRACT

This paper characterizes the microstructural evolution of saturated natural loess from a site in Jingyang, China, during triaxial test along two stress paths. For comparison, the same soil in remolded state is also characterized. Mercury intrusion porosimetry (MIP), scanning electron microscopy (SEM) and environmental scanning electron microscopy (ESEM) were used for the microstructure investigation. Results show that the microstructure of natural loess is similar to that of remolded loess before the consolidated undrained (CU) triaxial tests including conventional triaxial compression (CTC) test and reduced triaxial compression (RTC) test. On the contrary, their microstructures are different after the tests. Deeper examination shows that loading led to a significant change of inter-aggregate pores, without modifying the intra-aggregate pores. In addition, the volume of inter-aggregate pores after the RTC test is greater than that after the CTC test under the same consolidation stress. The microstructure features of natural and remolded loess after the tests are further used to analyze the macro-mechanical behavior for better understanding the relationship between them. The results show that it is the cementation bonds, of which breakage is influenced by stress path and confining pressure, that play important roles in the strength and deformation behavior.

1. Introduction

During the past several decades, hundreds of ground fissures appeared in the Shaanxi province in Northern China, where loess is widely distributed (Lee et al., 1996; Li et al., 2000; Zhao et al., 2009). Many researchers (Peng et al., 2006, 2013; Fan et al., 2008; Huang et al., 2009; Sun et al., 2009; Sun, 2010; Li et al., 2011; Zhao, 2011) reported that ground fissures are one of the particular urban geological hazards and have a serious threat on the future infrastructure construction when loess may undergo various stress paths (Wang et al., 2012). Therefore, the mechanical behavior of loess under different loading conditions represents a crucial issue for the development in this region of China.

The mechanical behavior of soils is often controlled by their microstructures (Osipov, 1985; Terzaghi and Peck, 1996). Previous experimental results show that the microstructure of a soil can provide important information on the shear strength, compressibility, sensitivity, hydraulic conductivity, and soil–water retention properties (Lei, 1985; Lapierre et al., 1990; Gao, 1996; Delage et al., 2006; Romero and Simms, 2008; Delage, 2010; MuÑoz-castelblanco et al., 2012). The microstructures of clayey materials under different loading conditions have been widely investigated, such as in direct shear tests (Morgenstern and Tchalenko, 1967), one-dimensional compression tests (Pusch, 1970; Martin and Ladd, 1975; Delage and Lefebvre, 1984; Guillot et al., 2001; Li and Zhang, 2009; Koliji and Laloui, 2010; Monroy et al., 2010) and triaxial compression tests (Hicher et al., 2000; Hattab and Fleureau, 2010, 2011; Hattab et al., 2013). Results show that the microstructure and its evolution upon loading differ for soil to soil. For loess, there have been some studies on the microstructure using different methods. For example, Smalley and Cabrera (1970), Cegla et al. (1971), Grabowska-olszewska (1975), Zhang et al. (2013) and Wang et al. (2014a) conducted scanning electron microscopy (SEM) studies on the microstructure of some loess deposits. Lei (1985) studied the pore size distribution characteristics of the loess in North Shan-xi, China, using mercury intrusion porosimetry (MIP) tests, and showed the significant influence of pore texture on the hydraulic conductivity. Gao (1996) showed that the particular geotechnical properties of loess soils along the Yellow River in Northern China are mainly governed by their texture and microstructure features. Assallay et al. (1997) used simple Monte Carlo methods to study metastable particle packings and open structures in loess deposits. Hu et al. (2001) carried out dynamic compaction tests, triaxial tests and quantitative micro-fabric analysis to study the evolution of the microstructure

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http://dx.doi.org/10.1016/j.enggeo.2014.07.021
0013-7952/

Table 1
Physical property indices of natural loess.

Property	Value
Moisture content at test (%)	16.9
Natural density (g/cm^3)	1.52
Specific gravity	2.71
Void ratio	1.08
Grain size distribution	
Sand >0.05 mm (%)	12.1
Silt 0.05–0.005 mm (%)	83.1
Clay <0.005 mm (%)	4.8
Atterberg limits	
w_l (%)	33
w_p (%)	18.9
I_p	14.1

of loess and the effect of microstructure on the shear strength. Delage et al. (2005) examined the collapse susceptibility of loess in Northern France in the light of microstructure observation. Pu (2000), Lei and Tang (2004) and Chen et al. (2009) performed computed tomography (CT) scanning to characterize the microstructure evolution of loess upon loading, soaking and wetting/drying, and observed that the macro-behavior of sample is closely related with its microstructure change and fracture first appears where the structure strength is weak with low density. MuÑoz-castelblanco et al. (2012) performed SEM and MIP tests to link the water retention properties to microstructure features of an unsaturated natural loess from Northern France. Wen and Yan (2014) investigated the influence of structure on shear characteristics of the unsaturated loess in Lanzhou, China by using combined methods of suction measurement and direct shear test.

Natural loess has been revealed to possess a metastable structure featured by open fabric and inter-particle bonding. Because of the existence of microstructure, natural loess behaves differently from its remolded counterpart. It is true that remolded soil has always been the subject under investigation in the critic soil mechanics. In this case, the mechanical behavior of remolded soil has been identified and thus many constitutive models have been proposed. The study on natural soil shows that the mechanical behavior of natural soil will eventually tend to approach that of remolded soil when the microstructure gradually degrades. Moreover, by incorporating the effect of microstructure, constitutive modeling of natural soil can be well developed based on the existing constitutive models for remolded soil, as originally proposed by Gens and Nova (1993). Therefore, as a first step towards the constitutive modeling of natural loess, the micro-mechanism behind the effect of microstructure on the macroscopic mechanical responses of loess needs to be investigated. This constitutes another motivation for this study.

From the above description, it is noted that very few researchers have studied the evolution of the microstructure of natural loess along different paths under triaxial test and the influence of microstructure on its shear strength and volume change. This work aims at studying the microstructure evolution of natural loess and remolded loess along different stress paths, in order to evidence the effects of microstructural characteristics especially the cementation bonds, and stress paths on the mechanical behavior. For this aim, SEM (or environmental scanning electron microscopy (ESEM)) and MIP tests were conducted for the microstructure investigation. The results obtained were further analyzed to explain the macro-mechanical behavior such as volume change behavior, characteristic of shear strength after the consolidated undrained (CU) triaxial tests. Two mechanical loading paths, i.e., conventional triaxial compression (CTC) test and reduced triaxial compression (RTC) test, were employed.

2. Loess properties

The loess samples studied shown in Table 1 were taken from the ground fissures in Jingyang, south Loess Plateau of China (Figure 1). Block samples were collected by the cutting method after the stepped exploratory trenches had been excavated. Fig. 2 presents the cross section of geology, the distribution of fissures and the sampling location. Q_4 and Q_3 represent Holocene and Late Pleistocene with three superscripts, *dl*, *pl*, and *el* denoting diluvial soil, alluvial soil, residual soil, respectively. The big dark region at the left bottom is a big crack filling,

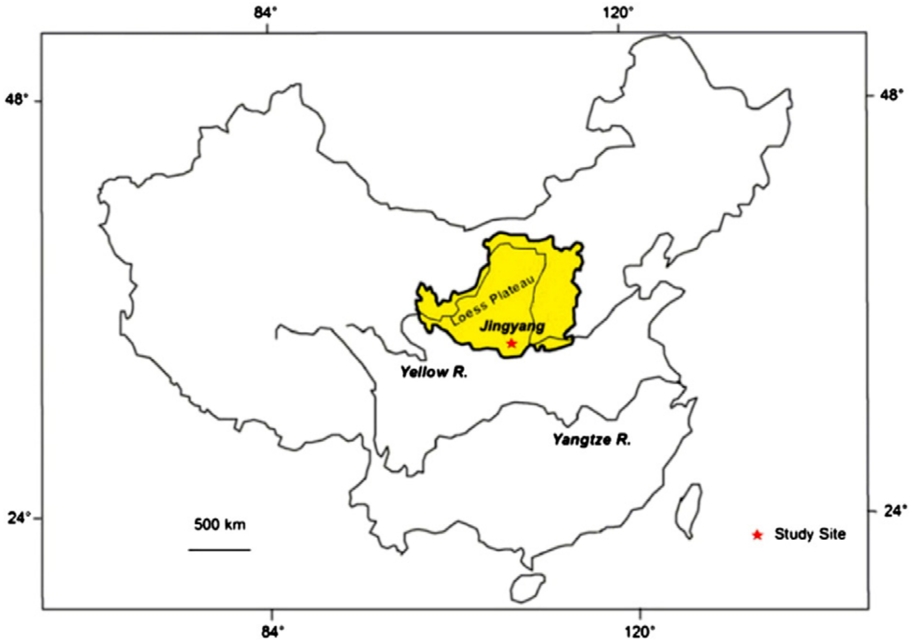

Fig. 1. Location of the study site.
Modified from Wang et al. (2014b).