Engineering Geology 175 (2014) 22–34

Contents lists available at ScienceDirect

Engineering Geology

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

Experimental and analytical framework for modelling soil compaction

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ARTICLE INFO

Article history:
Received 17 April 2013
Received in revised form 8 January 2014
Accepted 24 March 2014
Available online 3 April 2014

Keywords:
Compaction
Laboratory tests
Constitutive relations
Anisotropy
Partial saturation
Deformation

ABSTRACT

Compacted materials are fundamentally unsaturated soils whose behaviour can be expansive or collapsible depending upon changes in water content or stresses. Their behaviour is strongly dependent upon matric suction, water content, and stress history.

This paper presents a methodology for investigating the stress/strain, and suction/water content paths during one dimensional compaction of unsaturated soils. It focuses on anisotropic behaviour. The testing programme was carried out in a new automated oedometer apparatus that allows measurement of axial strain, radial and axial stresses, suction, and water content during tests.

The laboratory component used in this study involves kaolin compacted with different water contents. After compaction, the soil was subjected to wetting while the volumetric changes and stress paths were being examined. The results were interpreted within an anisotropic elasto-plastic framework. The proposed methodology provides new insights into the behaviour of unsaturated soils during compaction and wetting.

1. Introduction

Throughout the world compacted soils are used as construction materials in numerous geotechnical contexts. In spite of huge advances in unsaturated soil mechanics in the last 20 years, there continues to be a disconnection between the current design of geotechnical earthworks based on Proctor's ideas and the fundamental principles of unsaturated soil mechanics. Two reasons may explain this disconnection: (i) the simplicity of Proctor's tests compared to the high complexity of tests on unsaturated soils with controlled suction; and (ii) the absence of well-understood constitutive laws of how stress and suction during compaction are related to the post compaction behaviour of soils. These two difficulties could be overcome by combining the development of new laboratory apparatuses which would allow the study of compaction by measuring the state variables of the unsaturated soil (including stresses, matric suction, water content and void ratio) with the use of constitutive models adapted to compacted soils.

To include unsaturated characteristics in the understanding of compacted soils, Toll (1988), Schreiner (1988), Maswoswe et al. (1992), Li (1995), Delage and Graham (1996) and Alonso (1998), among others, have characterised the post-compaction suction and microstructure of soils compacted using oedometric paths. However, most of these works were carried out after compaction without controlling the history of stresses and phase variables during compaction. The possibility of following the stress and phase variables paths during compaction has recently become possible with the development of suction measurement systems based on psychrometers (Zerhouni, 1995; Blatz and Graham, 2000, 2003; Caicedo et al., 2008) or on high capacity tensiometers (Ridley and Burland, 1993; Jotisankasa et al., 2007; Tarantino and Tombolato, 2008).

Concerning constitutive laws for compacted soils, Cui and Delage (1996), Leroueil and Barbosa (2000) and Ghorbel and Leroueil (2006) have all shown the essentially anisotropic behaviour of compacted soils, in particular in terms of yielding. Moreover, Tarantino and De Col (2008) studied the microstructure of compacted soils at different water contents and presented a one dimensional mechanical model adapted to reproducing soil behaviour during compaction.

The purpose of this paper is to present a methodology to investigate the stress/strain, and suction/water content paths during oedometric compaction of unsaturated soils. The results are interpreted in an anisotropic elastoplastic framework combining the characteristics of the models presented by Cui and Delage (1996), Leroueil and Barbosa (2000) and Ghorbel and Leroueil (2006). The proposed methodology

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http://dx.doi.org/10.1016/j.enggeo.2014.03.014
0013-7952/

provides new insights into the behaviour of unsaturated soils during compaction and subsequent wetting.

2. Compaction interpreted within the framework of unsaturated soil mechanics

Fig. 1 presents the description of the stress path of a soil subjected to oedometric compaction in a plane of radial total vs axial total stresses (σ_r, σ_a), Alonso (1998). It shows the critical state lines, CSLs, in compression and in extension for zero and positive suction value, and it shows the K_0 line, which is defined as the relationship between radial and axial stresses during one dimensional compression under zero radial strain. Oedometric compaction could be described as follows. First the soil is mixed and prepared in unsaturated conditions. In this initial state the soil is represented by an unsaturated yield surface (F_1). Next, if an axial stress is applied, radial stress increases within the elastic domain to the surface F_1 (paths A to B). After the stress path continues in the plastic domain following the anisotropy line up to a second yield surface (F_2) (paths B to C). If the soil is then unloaded, the axial and radial stresses decrease in the elastic domain and the CSL in extension may be attained. If it is, the path will follow this CSL until the axial stress equals zero (paths C, D, E). It is important to note that when zero axial stress is reached, a radial stress remains within the unsaturated soil (point E). On reloading, the stress path remains within the elastic domain up to the F_2 yield surface; afterwards the path follows the anisotropy line and defines a new and larger yield surface. On the other hand, if after unloading there is a change in suction, as for example saturation of the soil under zero axial stress, the radial stress goes to zero (paths E to O), and swelling or collapse occurs, depending on the position of the loading collapse surface.

It is important to keep in mind that the previous explanation is a simplified approach to in situ compaction. In fact, oedometric compaction allows obtaining similar compaction curves than the Proctor's procedure, Biarez (1980). However, moving loads due to in situ compaction produces cyclic loads and rotation of stresses that create stress paths different from the oedometric stress path used in this study, Caicedo et al. (2012). These effects must be included in further researches.

3. Materials and equipment

3.1. Oedometric cell for K_0 measurement

The oedometric cell used in this research was designed to reproduce soil compaction by increasing the axial stress under one dimensional compression while measuring the axial and radial stresses, suction, void ratio and water content during compaction. To accomplish this, the cell includes the following features (see Figure 2):

(1) The compression piston in the cell has a large displacement capacity. This allows it to perform compaction tests starting with soils in a loose state and finishing with soils having dry unit weights similar to those obtained in Proctor's tests (The initial size of the sample is 78 mm in height and 70 mm in diameter, the final height of compacted samples varies between 53 mm and 43 mm depending on the water content).
(2) The large displacement of the soil produced by one moving piston can result in significant variation in dry density across the sample due to the friction between the soil and the mould. This friction can be reduced either including two moving pistons or reducing friction with an internal Teflon cylinder. The second option has been included in the oedometric cell. The effectiveness of this solution was confirmed verifying that the dry density for samples located at the top and the bottom of the soil varies in less than 2%.
(3) The cell is equipped with a capacitive sensor to measure the water content in the soil during compaction. For this reason plastic materials were used in most of the cell design. However, to avoid undesirable radial displacement the cell was conceived with a thick cylinder wall (32 mm) of composite material (phenolic resin reinforced with glass fibres).

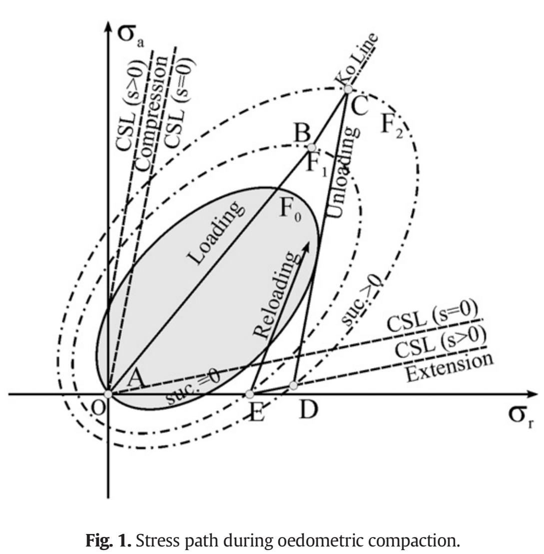

Fig. 1. Stress path during oedometric compaction.

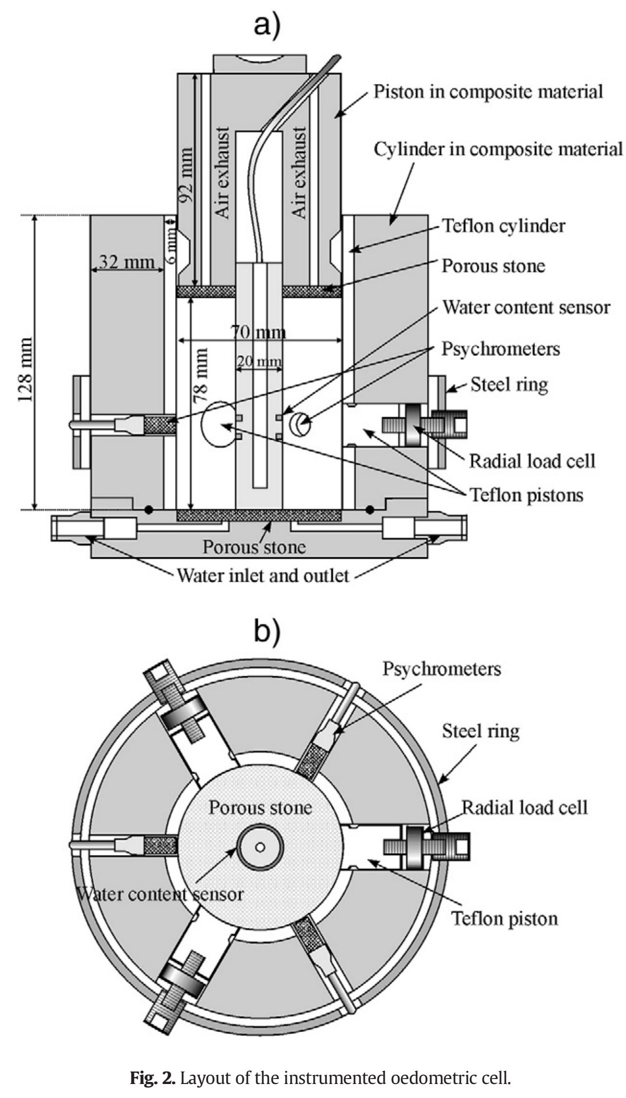

Fig. 2. Layout of the instrumented oedometric cell.