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Assessing confined and semi-confined compression curves of highly calcareous remolded soil amended with farmyard manure

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Abstract

Confined and semi-confined compression curves of a highly calcareous remolded soil amended with farmyard manure (FYM) from dairy cattle were investigated. The samples were collected from the topsoil of the experimental plots where FYM had been added to the soil at four application rates (0, 25, 50 and 100 Mg ha^{-1}) for 7 years. Large remolded specimens were prepared by applying 100 kPa load at 17.1% and 20.9% dry basis moisture contents. The center section of the preloaded soil specimen was firstly submitted to a 50 mm diameter plate for plate sinkage test (PST). One cylindrical sample was also immediately cored for confined compression test (CCT). The S-shaped curves were observed with the CCT, whereas the bi-linear form was obtained with the PST. In the CCT, the S-shaped form was more obvious at the higher moisture content. The results revealed that the moisture content and the application rate of FYM influenced the start and end points and precompaction stress of compression curve for PST. Moreover, the moisture content and the application rate of FYM affected the end point and the compression index (C_c) in the case of CCT. However, it was concluded that the overall trend in compression curve only depends on the type of test conducted.

Keywords: Confined loading test; Plate sinkage; Pre-compaction stress; Compression index

1. Introduction

Soil compaction by wheeling of agricultural machines is one of the main processes that modifies the structure of cultivated soils and thus, affects crop production and environment [1]. The extent of the soil compaction problem is a function of soil type and water content, vehicle weight, speed, ground contact pressure and number of passes, as well as their interactions with cropping frequency and farming practices [2,3]. Compaction impacts the soil pore space and thus, affects soil physical properties. For example, saturated hydraulic conductivity [4–6] and air permeability [7,8] can be reduced. This in turn may lead to increased surface runoff and erosion [9,10]. Compaction also impacts soil mechanical properties. For instance, compression index and bulk density of the soil increased significantly with double passes of the tractor [11].

Through investigating the soil compaction processes, Horn et al. [12] stated that soils, as a three-phase system, encounter changes while the applied external stresses goes beyond the internal soil strength. As stress increases, the soil volume is decreased which firstly involves the air-filled pores. Then, the pore-water pressure and the pore-air pressure are increased and reduced with time, as a result of the dissipation process. This process depends considerably on the soil sample air permeability which itself reduces during compaction.

Soil compression curves are commonly used to understand the process of compression [13]. By determining the form of compression curve, influence of moisture content and manure application rate on the curve, as well as the

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information obtained from the curve such as pre-compaction stress and compression index, we can use the appropriate physical conditions and load applied by the vehicles in order to prevent a non-recoverable (plastic) compaction. In addition to a uni-axial compression (Oedometer) test, two other constant-rate tests for determining soil compressibility are the confined compression test (CCT) and the plate sinkage test (PST) [14]. In order to derive the compression properties (pre-compaction stress and compression index) of a soil from the compression curves, two types of models are usually fitted to the experimental data [15]: (i) elasto-plastic models, and (ii) S-shaped models. According to the elasto-plastic models (bi-linear form) (Fig. 1), the compression curve, i.e. the void ratio (e) versus the logarithm of vertical stress ($\log \sigma_v$), can be divided into two parts: an elastic rebound curve at low stress, termed the recompression or swelling line (RCL), and a linear virgin compression curve at higher stress, termed the virgin compression line (VCL). The transition point between RCL and VCL is known as the soil pre-compaction stress and the slope of the VCL is termed as the compression index (C_c). In the S-shaped model, the compression curve is allowed to deviate at high stresses.

Many factors affect the shape of compression curves including plasticity index, water content, type of soil sample (undisturbed or remolded), and clay content [16]. The S-shaped compression curves have been observed on soils with high plasticity index, while bi-linear compression curves have been observed on soils with low plasticity index, and the two forms of compression curves have been observed on soils with medium plasticity index. It was reported that the S-shaped compression curves were more frequently observed when the clay content or the initial water content, or both were high. In addition, the S-shaped curves were more frequently observed on remolded soils than on undisturbed soils [16]. Tang et al. [16] explained the observed S-shaped curves by the difference between the compression of air-filled pores and that of meso-pores storing water subjected to high capillary forces.

The objective of the research reported here was to characterize the effect of farmyard manure (FYM) at different application rates (0, 25, 50, and 100 Mg ha^{-1}) and at two moisture contents (MCs) (17.1% and 20.9%, dry basis) on the form of compression curves derived from PST and CCT for remolded samples of a highly calcareous soil.

2. Materials and methods

2.1. Soil

This study was conducted on the topsoil of the experimental research site of Isfahan University of Technology located in central Iran. The experimental site has an arid climate with mean annual precipitation and temperature of 140 mm and 14.5 °C, respectively. The texture of the soil was silty clay loam. The soil was highly calcareous classified as fine-loamy, mixed, thermic *Typic Haplargids* [17] and Calcaric Cambisols (FAO). It has developed on alluvial sediments of the Zayandehroud River initially low in organic matter (<0.5%), and with a history of intensive conventional tillage practices. The soil had received farmyard manure from dairy cattle at three application rates (25, 50 and 100 Mg ha^{-1} (2.5, 5 and 10 kg m^{-2})) for 7 years successively with a cropping rotation of irrigated wheat (*Triticum aestivum* L.) – silage corn (*Zea mays* L.). Manures had been applied and mixed to the 0–20 cm soil layer (topsoil) in fall during land preparation for wheat planting. There was also an unfertilized control treatment. Mixing the manures with the soil and also seed planting were performed manually, therefore there was no machinery traffic on the experimental plots. Irrigation consisted of flooding level basins for wheat and furrow irrigation for corn. The treatments were replicated three times in a randomized complete block design. Chemical properties of decayed farmyard manure are shown in Table 1. Moreover, some physical and consistency limits of the unfertilized soil and the soil to which farmyard manure had been applied the previous seven years are presented in Table 2 [18].

2.2. Soil sample preparation

From topsoil (0–20 cm depth), we collected soil samples of suitable water content, i.e. between the plastic limit (PL) and the liquid limit (LL), from plots to which manures

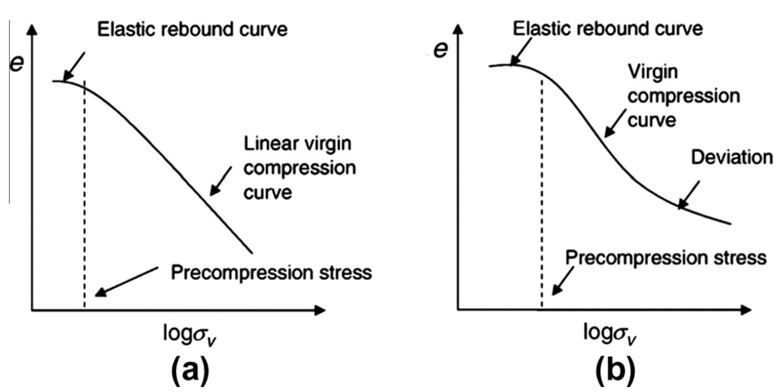

Fig. 1. Two main forms of confined uni-axial compression curve: (a) bi-linear curve; (b) S-shaped curve [3]; σ_v is the vertical stress.