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Research Paper

A constitutive framework to model the undrained loading of municipal solid waste

Sandro Lemos Machado [a,*], Orencio Monje Vilar [b], Miriam de Fátima Carvalho [c], Mehran Karimpour-Fard [d]

[a] Dept. of Materials Science and Technology, Federal University of Bahia, 02 Aristides Novis St., Salvador, BA 40210-630, Brazil
[b] Geotechnical Department, University of São Paulo, 1465 Dr. Carlos Botelho Av., São Carlos, SP 13560-250, Brazil
[c] School of Engineering, Catholic University of Salvador, 2589 Pinto de Aguiar Av, Salvador, BA 40.710-000, Brazil
[d] Faculty of Civil Engineering, University of Guilan, Rasht 41635-1477, Iran

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ABSTRACT

This paper proposes a model to represent the MSW undrained mechanical behavior, which is an extension of the previous models developed by the authors. A more comprehensive formulation for effective stress is adopted taking into account the compressibility of waste particles and the concepts embraced in the Skempton's equation for effective stress. The model reproduces the main MSW features such as high pore water pressure generation, concave upward curves and high shear strength values, even for $u = \sigma_3$ (zero net confining stress). Model predictions showed good adherence to experimental results. MSW samples of different sources were used in the simulations.

1. Introduction

The most commonly used method for final deposition of Municipal Solid Waste (MSW) continues to be landfilling, despite the many management processes available to reduce the amount and type of waste disposed of. Although the current strategy is disposing of only worthless matter that cannot be composted or recycled, in many countries the waste stream that reaches the landfill is heterogeneous and composed of parts as different as easily degradable organics, soil-like materials and plastics, often with a high moisture content. Stringent regulations and public rejection of landfills make it difficult to find adequate new sites for landfills and this compels engineers to enlarge the few available areas and to increase the height of already disposed waste resulting in piles which are frequently higher than 100 m. As a result, such structures require detailed design and particular attention to points usually addressed by geotechnical engineers such as slope stability. Many slope failures in landfills have highlighted the importance of adequately determining MSW shear strength and defining the conditions of pore fluid drainage control rupture. Some failure reports, especially those associated with landfills with a high moisture content and/or high gas pressure have suggested the possibility of undrained forms of failure such as in Bandeirantes landfill located in São Paulo, Brazil, [2] and Doña Juana, in Columbia, [6,5], among other examples available in the literature. In addition, issues associated with the definition of stresses, fluid pressures and strain within the landfill require a knowledge of stress-strain behavior.

This paper presents the development of a theoretical framework to model the undrained stress-strain and associated pore fluid pressures responses of MSW. The model is an extension of previous models presented by [13] that mainly dealt with drained stress-strain and Machado et al. [14] which incorporated the effect of waste degradation on the mechanical behavior of MSW. In essence the proposed model separates MSW in two main components, fibers (plastics, textiles and similar materials) and nonfibrous components or paste (organic compounds, wood, soil-like materials, etc.), which are represented by different models, a perfectly plastic model (Von Mises) and critical state framework (modified Cam-Clay), respectively. In addition, the model incorporates an alternative effective stress law that takes into account the compressible nature of many MSW components.

The hypothesis and the development of the model are presented together with the MSW parameters which are used to model results from undrained triaxial tests available in the literature.

* Corresponding author.
E-mail addresses: smachado@ufba.br (S.L. Machado), orencio@sc.usp.br (O.M. Vilar), miriam@ucsal.br (M.F. Carvalho), mehran.karimpour@guilan.ac.ir (M. Karimpour-Fard).

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2. Fundamentals

The mechanical properties of MSW, especially shear strength, are usually obtained from back analysis of slope failures in landfills and from laboratory tests commonly performed with reconstituted samples. As known, MSW is made up of components of different sizes and characteristics, varying from organic compounds with different rates of degradation; solid non-degradable materials, such as glass, metals and soil; plastic, papers and fibers and fluids such as infiltrating water combined with the moisture released from degradation processes. To overcome the difficulty associated to component size, large dimension specimens have been used. The response of MSW to shearing revealed a peculiar behavior in both drained and undrained approaches, although differences arise when comparing results from different stress path tests, especially where peak stresses are concerned [4]. Fig. 1 shows typical stress-strain curves of isotropically consolidated drained triaxial tests (CID) reported by [8].

As can be seen, stress increases with strain according to different shaped curves, which depend on strain. For higher strains there is an upward curvature in strain hardening behavior without defining a peak shear stress. This peculiar behavior has been attributed to the reinforcement effect of fiber materials, such as plastics, which are mobilized as strain increases. As no sign of rupture is detected, usual practice has been to define shear strength according to Mohr Coulomb failure criterion and consider the strength mobilized at some strain, for instance, 5%, 10% and 20%. In spite of the large variance reported in shear strength parameters of MSW, the analysis of available data has led some authors to propose practical shear strength envelopes, for instance, [11] who proposed for normal stress lower than 30 kPa, $c = 24$ kPa and $\phi = 0$ and for stress larger than 30 kPa, $c = 0$ and $\phi = 33^{\circ}$.

As far as volumetric strains are concerned, they increase almost linearly with strain and an intriguing point worth mentioning arises. This is that volumetric variation tends to be larger for the lower confining stress as opposed to what is typically observed in soils.

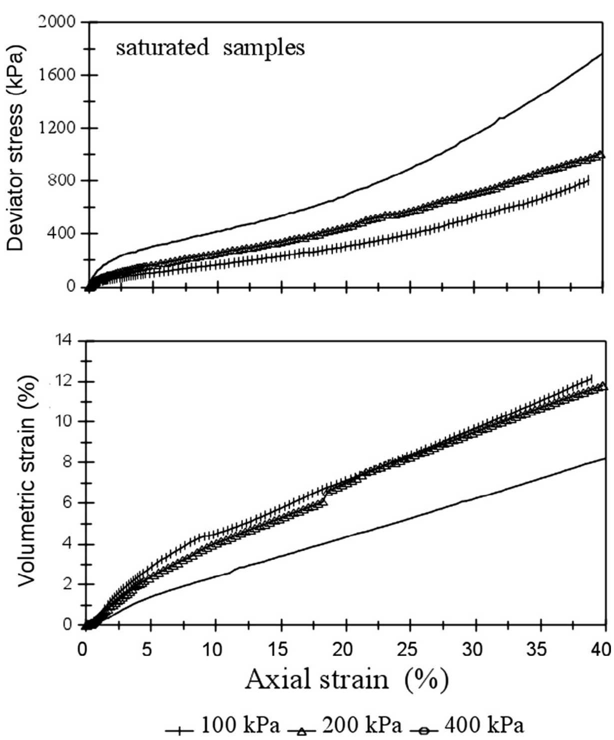

Fig. 1. Typical results from drained triaxial compression tests (CID) of 20 × 40 cm MSW samples. Unit weight of 12 kN/m^3 and initial degree of saturation of 72% [8].

Considering the MSW undrained behavior, Fig. 2 presents the undrained response of supposedly saturated MSW specimens obtained by [7] from isotropically consolidated undrained (CIU) triaxial compression tests. According to the authors, the samples were first submitted to upward flow until no air bubbles were detected in the outlet water. After that, the samples remained with confined and pore water pressures of 80 kPa and 70 kPa, respectively, for a period of a day, minimum. Back pressure procedure was then applied. The obtained Skempton's B parameter ranged from 0.86 to 0.98. Because of the presence of fibrous material such

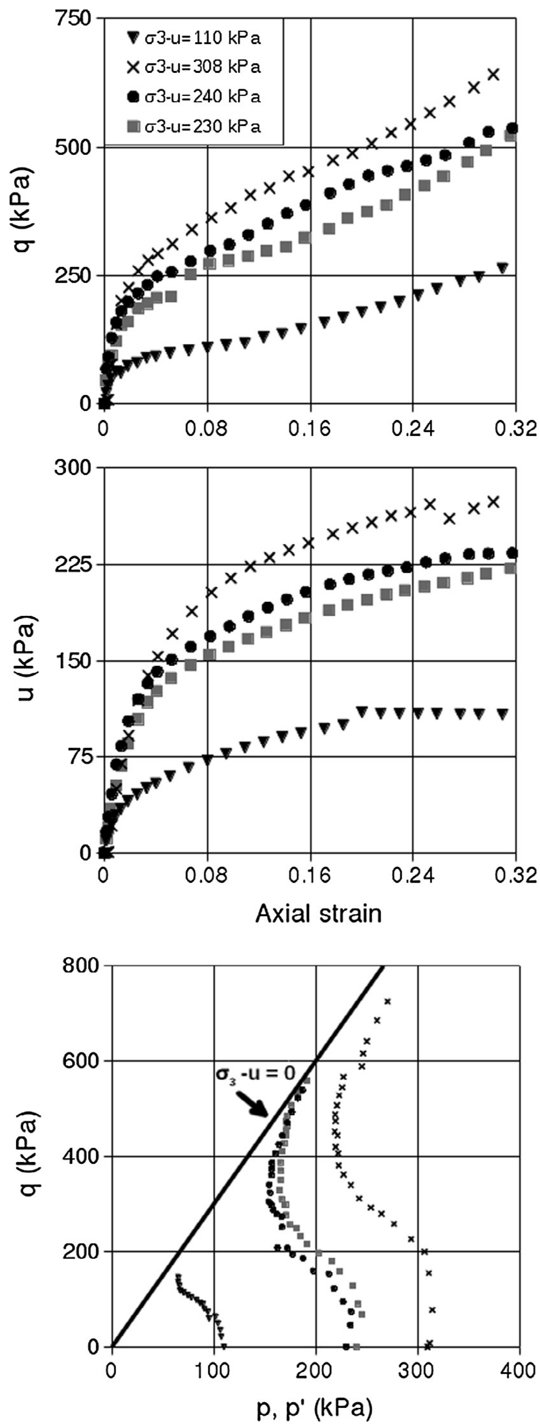

Fig. 2. Typical MSW undrained behavior of saturated 20 × 40 cm MSW samples. Initial Unit weight of 12 kN/m^3 [7].