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The behavior of compression and degradation for municipal solid waste and combined settlement calculation method

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ABSTRACT

The total compression of municipal solid waste (MSW) consists of primary, secondary, and decomposition compressions. It is usually difficult to distinguish between the three parts of compressions. In this study, the odeometer test was used to distinguish between the primary and secondary compressions to determine the primary and secondary compression coefficient. In addition, the ending time of the primary compressions were proposed based on municipal solid waste compression tests in a degradation-inhibited condition by adding vinegar. The amount of the secondary compression occurring in the primary compression stage has a relatively high percentage to either the total compression or the total secondary compression. The relationship between the degradation ratio and time was obtained from the tests independently. Furthermore, a combined compression calculation method of municipal solid waste for all three parts of compressions including considering organics degradation is proposed based on a one-dimensional compression method. The relationship between the methane generation potential L_0 of LandGEM model and degradation compression index was also discussed in the paper. A special column compression apparatus system, which can be used to simulate the whole compression process of municipal solid waste in China, was designed. According to the results obtained from 197-day column compression test, the new combined calculation method for municipal solid waste compression was analyzed. The degradation compression is the main part of the compression of MSW in the medium test period.

1. Introduction

The deformation of municipal solid waste (MSW) is composed of the primary and secondary compressions under loads as well as the volume reduction and mass loss due to organics degradation. It is difficult to distinguish between the quantities of primary, secondary and degradation settlement and the demarcation point of time from the compression curves of laboratory and field tests. Several calculation models related to MSW compression have been reported in literature to predict MSW landfill settlement. These models can be classified into: (1) traditional soil mechanics models (Sowers, 1973); (2) expanded rheological models (Zimmerman et al., 1977); (3) empirical models based on monitoring curves (Yen and Scanlon, 1975); and (4) combined calculation models (Park and Lee, 1997).

Sowers (1973), Deutsch et al. (1994), and Rao et al. (1977) divided compression deformation of MSW into the primary and secondary compressions. They used traditional soil mechanics model to estimate the MSW settlement. Zimmerman et al. (1977) and Edil et al. (1990) used rheological element to simulate the long-term compression characteristics of MSW, and then established the expanded rheological models to predict MSW settlement. Yen and Scanlon (1975), Edil et al. (1990) and Ling et al. (1998) presented logarithmic function and hyperbolic function based on field case studies. Gourc et al. (2010) established new secondary settlement model considering the mechanical settlement and the biochemical settlement due to creep and the degradation of the organic matter respectively. Staub et al. (2013) presented settlement model including mechanical and biochemical as well as hydrological parts. Park and Lee (1997, 2002), Chen et al.

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(2010) and Bareither et al. (2013) proposed new settlement models considering primary, secondary and time-dependent degradation compressions. First-order kinetic equation was used to calculate the settlement caused by waste degradation and then a combined method was established to estimate MSW settlement. Bareither and Kwak (2015) indicated a new method to calculate the immediate compression used critical state soil mechanics.

LandGEM equation (USEPA, 1997) and kinetic order model (Findikakis and Leckie, 1979; Marticorena and Attal, 1993; Arigala et al., 1995; Amini et al., 2012) are applied widely in landfill gas production models. Lamborn (2012) introduced two gas production tests for MSW specimen mixed sludge under different loads in 919 days. It is indicated that the gas production due to waste degradation increased gradually within 50 days and then tended to steady after 400 days. Chen et al. (2010) applied first-order kinetic equation to simulate degradation of waste organics. Liu et al. (2011) suggested that degradation behavior of MSW can be described as the quantity of organics degradation divided by the total mass (degradation ratio).

Since the ending time of the primary compression cannot be determined directly from compression curves of MSW, it is difficult to determine the primary and secondary compression coefficients based on traditional soil mechanics knowledge. The secondary compression coefficient of MSW is greater than soft clay (Qian et al., 2002). The proportion of secondary compression in total compression of MSW will be much higher. When load is applied, the primary and secondary compression occur simultaneously (Yin and Graham, 1989, 1994). According to the existing methods, the primary and secondary compression coefficients may not be determined correctly. It is necessary to develop a more reasonable method to calculate the primary and secondary compressions of MSW as well as the organics degradation compression associated with degradation behavior of MSW.

The objectives of this work are to establish a method to: (1) divide the primary and secondary compression stage by the odeometer test in a degradation-inhibited condition, (2) determine the ending time of the primary compression, (3) calculate the primary and secondary compression coefficients of MSW, (4) develop a combined calculation method to calculate the primary and secondary compressions value of MSW as well as the organics degradation compression. A column compression test undertaken here is to provide insight into relationships of primary, secondary and degradation compressions.

2. MSW compression calculation method

In the existing calculation methods for MSW compression, it is assumed that the secondary compression starts from the end of the primary compression. However, the primary and secondary compressions actually start at the same time.

The primary compression calculation method is proposed traditionally by Sowers (1973) and given by

$$\Delta e_1 = C_c(\lg \sigma - \lg \sigma_0) \tag{1}$$

where C_c is primary compression index, the tangent of the e-log$p$ curve; σ is the effective stress; and σ_0 is pre-consolidation stress.

The secondary compression model proposed by Yin and Graham (1989, 1994) is adopted in this paper. The secondary compression will be calculated from the time of load application.

The secondary compression Δe_2 can be expressed as:

$$\Delta e_2 = C_\alpha \lg\left(1 + \frac{t}{t_0}\right) \tag{2}$$

where C_α is the secondary compression index; t is the duration time of the secondary compression, counted from the starting time of load application; and t_0 is the modified parameter, not the ending time of the primary compression. It can be calculated by using compression curve and the least square method according to Eq. (2).

The change of the total void ratio induced by the applied load is composed of both the primary and secondary compressions. Therefore, the total compression by the load can be calculated from Eqs. (1) and (2), which can be expressed as follows:

$$\Delta e = C_c(\lg \sigma - \lg \sigma_0) + C_\alpha \lg\left(1 + \frac{t}{t_0}\right) \tag{3}$$

Fig. 1 shows the volume change of a MSW specimen before and after degradation compression. The compression of MSW is considered as one-dimensional direction.

In Fig. 1, h_0 is the height of MSW specimen before organics degradation; h is the height of MSW specimen after degradation compression at a certain time; v_{v0} and m_{v0} are the initial void volume and mass of MSW specimen; v_{s0} and m_{s0} are the initial solid volume and dry mass; v_v and m_v are the void volume and mass after degradation compression at certain time; v_s and m_s are the solid volume and dry mass after degradation compression at the same time.

According to the height of MSW specimen before and after degradation, the compression can be known as follows:

$$\Delta h = h_0 - h \tag{4}$$

Under the one-dimensional condition,

$$\frac{v_{s0} + v_{v0}}{h_0} = \frac{v_s + v_v}{h} \tag{5}$$

Initial void ratio and the void ratio after degradation compression can be expressed as follows:

$$e_0 = \frac{v_{v0}}{v_{s0}} \tag{6}$$

$$e = \frac{v_v}{v_s} \tag{7}$$

ρ_{s0} and ρ_s are the specific gravity of dry matter before and after degradation, then:

$$v_{s0} = \frac{m_{s0}}{\rho_{s0}} \tag{8}$$

$$v_s = \frac{m_s}{\rho_s} \tag{9}$$

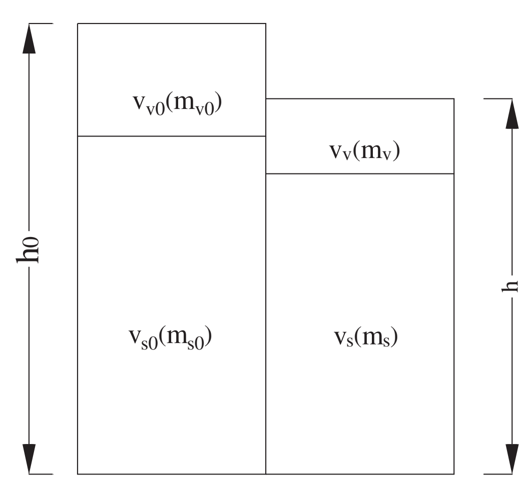

Fig. 1. Diagram of MSW compression.