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Laboratory studies on effect of fiber content on dynamic characteristics of municipal solid waste

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ABSTRACT

The dynamic characterization of municipal solid waste (MSW), especially in regions with high seismicity, is of considerable importance in the stability assessment of landfills. Additionally, findings indicated that the response of MSW under dynamic loadings is significantly affected by fibrous material. Therefore, a comprehensive strain-controlled cyclic triaxial testing program was performed on MSW samples retrieved from a landfill in the Kahrizak area, Tehran province. The tests were conducted on fresh MSW specimens (with a diameter of 100 mm) with different percentage of fibers in the consolidated undrained condition. The potential reinforcing capability of fibers and their impacts on changes in the MSW composition were investigated under variations of different factors including confining pressure, loading frequency, Poisson's ratio, and loading cycles. From the results of the study, increasing fiber content in specimens resulted in improved elastic behavior of MSW under dynamic loadings, irrespective of the test conditions, such that the normalized shear modulus reduction curves shifted to the right, while the damping ratio curves exhibited no specific trend. However, it is necessary to simultaneously consider the impact of fiber contents, confining stress and shear strain on the variation rates of normalized shear modulus reduction values. This trend is attributed to the greater values of stiffness from changing the composition when compared with the one generated by obtained reinforcement within the studied strain range. Given the lack of systematic evaluations on the effect of the fibrous waste materials on the dynamic response of MSW, the results of this study provide additional insight into the seismic analysis of landfills.

1. Introduction

The design and analysis of waste fills in earthquake prone areas are highly dependent on the reliable estimation of the dynamic properties of Municipal Solid Waste (MSW). Recent worldwide landfill failures and performance problems have resulted in the increasing importance of proper determination of the dynamic properties, including small-strain shear modulus, shear strain-dependent shear modulus reduction and damping ratio. Several studies reported the importance of the reinforcing effect of the fibrous waste constituents in enhancing the strength of MSW compared to the organic material of MSW (Athanasopoulos et al., 2008; Kavazanjian et al., 1999). It should be noted that the majority of published technical studies do not consider the direct impact of fiber content on the dynamic response of MSW, while several studies only evaluated the direct effect of fibers on the static response of MSW. However, the results indicated a substantial effect of fibrous materials on the static behavior of MSW, without any direct evidence to show any substantial effect on the dynamic properties (Shariatmadari et al., 2011, 2010; Zekkos, 2005). Despite numerous advances in the understanding of MSW properties, many of the factors affecting the dynamic response of MSW remain largely unknown. Additionally, in the seismic analysis of landfills, site-specific data are always preferable to general recommendations and experience. This is because waste materials may differ for a number of reasons, including weather conditions and culture (Zekkos et al., 2008).

To address the abovementioned problems, this study includes the results of more than 60 cyclic triaxial tests, and is a continuation of previous studies conducted by the authors at the Iran University of Science and Technology (IUST). The aim of the study is to experimentally quantify the effect of fibrous materials on the dynamic properties of MSW, and demonstrate the potential effects of aging on MSW samples. Additionally, bender element (BE) and large-scale oedometer tests were conducted at the IUST

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geotechnical research center to evaluate the shear wave velocity and Poisson's ratio of MSW, respectively.

1.1. Recent studies on dynamic properties of MSW

The dynamic response of an MSW landfill subjected to cyclic loading depends to a large extent in the cyclic stress-strain characteristics of MSW. The required properties for seismic response analysis of an MSW landfill by using the equivalent linear method include the following:

- Shear wave velocity (V_s) or small-strain shear modulus (G_{max}).
- Strain-dependent material damping ratio (λ).
- Strain-dependent normalized shear modulus reduction ($G/G_{\max}$).

The following summarizes the current understanding of the above-mentioned parameters. However, despite several attempts, there is a lack of reliable data on the dynamic properties of MSW (Naveen et al., 2014).

The $G_{\max}$ is one of the basic parameters required for much of the engineering analysis of the geomaterials. Based on the elasticity theory, the G_{max} is related to the V_s and the mass density (ρ) of the material as follows (Zekkos et al., 2008):

$$G_{max} = \rho . V_s^2 \quad (1)$$

The shear wave velocity of MSW has been measured using different laboratory and in situ techniques. The spectral analysis of surface waves (SASW), multichannel analysis of surface waves (MASW), and microtremor analysis method (MAM) are gaining popularity because of their nonintrusive nature and rapid rate of testing, compared to other in situ methods, such as the downhole and crosshole methods (Ramaiah et al., 2015). The in situ methods typically determine a shear wave velocity of MSW materials based on the variation of landfill depth. Following the Northridge earthquake, Kavazanjian et al. (1996) proposed a recommended curve for the shear wave velocity of southern California landfills based on the SASW method (Kavazanjian et al., 1996). Pereira et al. (2002) measured the shear wave velocity using the SASW method in a landfill near Madrid, Spain, and reported a range of 100–250 m/s (Pereira et al., 2002). Khaleghi (2011) performed a series of Continuous Surface Wave System (CSWS) tests and reported on the shear wave velocity profile of the Kahrizak landfill (Khaleghi, 2011). Ramaiah et al. (2015) proposed an empirical linear model for V_s of landfills with a maximum depth of 30 m based on statistical analysis of 146 in situ shear wave velocity profiles from 37 MSW landfill sites worldwide (Ramaiah et al., 2015). In addition to the wide use of in situ methods, laboratory methods are becoming increasingly applicable when the assessment of different factors, including waste composition, and confining pressure on shear wave velocity is critical. Many researchers evaluated the shear wave velocity of MSW materials by performing laboratory tests, such as the BE and resonant column (RC). Hossain et al. (2010) reported that the decomposition of waste has an increasing effect on values of small strain shear modulus based on a series of Resonant Column (RC) tests (Hossain et al., 2010). Yuan et al. (2011) estimated V_s and subsequently the small-strain shear modulus in a laboratory by using a BE that was installed on a large simple shear apparatus (Yuan et al., 2011). The author reported the significant role of waste composition on V_s values. Zekkos, (2005) conducted several tests to compare the laboratory data with field data. He reported that the laboratory-derived values are highly dependent on composition and time under the confinement of specimens (Zekkos, 2005).

The material damping ratio and shear modulus are the parameters required for the seismic response analysis of landfills. The shear modulus describes the stiffness of MSW, while the damping ratio represents the loss of energy during seismic loads. Different factors such as shear strain, number of cycles, and confining pressure can change the values of the parameters. The cyclic shear strain is accepted as the most important and influential of the factors. Because of this dependence, the abovementioned geotechnical parameters for dynamic analysis are typically depicted relative to the shear strain values.

The majority of available recommendations on strain-dependent normalized shear modulus reduction and material damping curves of MSW are based on back analyses of recorded ground motions of the OII[1] landfill using different analytical techniques (Zekkos, 2005). Various researchers proposed recommended curves based on back analysis although important differences were observed between the curves (Augello et al., 1995; Elgamal et al., 2004; Idriss et al., 1995; Matasović et al., 1995; Morochnik et al., 1998). However, the necessity of dynamically assessing of MSW worldwide is recognized owing to site-specific characterization of MSW, and these types of data are always preferred to generalized data (the OII landfill is a specific case of landfill). The abovementioned discussion resulted in several laboratory and field test assessments. Large-scale tests, including cyclic triaxial, cyclic simple shear and RC tests, are of great interest. However, there is a lack of field and laboratory data, given the difficulties including health issues associated with testing waste material and sample disturbance.

One of the first laboratory studies on the dynamic properties of MSW was conducted based on a large- diameter cyclic direct simple shear testing program by Matasović and Kavazanjian (1998). The test included testing at uniform cyclic shear strains corresponding to 0.1%, 0.3%, 1%, 3%, and 5% at a frequency of approximately 0.1 Hz, on waste recovered from the OII landfill. The data showed good agreement in the dynamic properties of the OII landfill between the laboratory and back-calculated curves (Matasović and Kavazanjian, 1998). Towhata et al., (2004), performed cyclic triaxial and shaking table tests on organic waste bio-treated both with, and without, plastics. The results confirmed that plastic sheets and other fiber components generate shear strength in waste specimens. They also reported that the material damping of specimens without plastic exhibited greater values when compared to containing specimens with plastic (Towhata et al., 2004). Zekkos (2005) conducted more than 80 large-scale cyclic triaxial tests on 25 specimens with varying waste composition, confining stress, loading frequency and density. The author reported that the waste composition is the most critical factor for the stiffness and material damping ratio of MSW. Based on the results, an increase in the larger fraction and fiber materials shifted the normalized shear modulus curve to the right and they exhibited greater elastic behavior (Zekkos, 2005). Towhata and Uno (2008), assessed the influence of confining stress on waste samples collected from a landfill in Japan. The results indicated that the shear modulus increases with increasing confining pressure while the effect of confining stress on the damping ratio was not clear. The author also stated that the dynamic behavior of MSW under strains less than 0.01% is uncertain (Towhata and Uno, 2008). Yuan et al. (2011), performed 15 large-scale cyclic simple shear tests on reconstituted specimens of MSW from the Tri-Cities landfill. The test results clearly showed a strong dependence of shear wave velocity and small strain shear modulus on unit weight as well as a dependence on the composition ratio (Yuan et al., 2011). Ramaiah et al. (2016a, 2016b) and Keramati, et al. (2016) and Keramati et al. (2017a, 2017b also conducted a

[1] A landfill site located in Monterey Park, California