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Field and large scale laboratory studies on dynamic properties of emplaced municipal solid waste from two dump sites at Delhi, India

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ABSTRACT

Dynamic properties of municipal solid waste (MSW) from two dump sites located at Delhi, India are evaluated from field and large scale laboratory tests. Shear wave velocity (V_s) profiles of MSW, measured at these two sites using surface wave techniques, are in range of V_s data reported for MSW landfills worldwide. Representative bulk MSW samples were collected from large test pits excavated at the two dump sites to determine the near surface unit weight. Large scale undrained cyclic triaxial (CTX) tests were conducted on reconstituted MSW specimens to investigate the effect of various parameters such as composition, confining pressure, number of loading cycles, loading frequency and saturation on the dynamic properties. Undrained CTX tests, conducted on the specimens with and without fibrous materials demonstrated the effect of fibrous waste constituents on the stiffness and damping behavior of MSW. Specimens consisting of fibrous waste constituents such as plastics and textiles exhibited significantly less modulus reduction compared to specimens with negligible amount of fibrous content. The modulus reduction (G/G_{max}) and material damping ratio curves derived from the present study are in the range reported for MSW in the literature. The G/G_{max} curves from present study are in good agreement with curves recommended for MSW at Tri-Cities landfill in USA and Tianziling landfill in China. Dynamic properties evaluated from the present study add to the growing database of the worldwide dataset and can be useful for evaluating the seismic stability and associated permanent deformations of the existing dumps in and around Delhi.

1. Introduction

Stability and integrity of the containment system of a municipal solid waste (MSW) landfill must be ensured during strong ground shaking. Seismic performance of solid waste landfills, in general, was observed to be satisfactory. However, significant cracking in the soil cover and tears in geomembrane of containment system at some landfills during Northridge earthquake were also documented [1–3]. In addition, the potential of solid waste for amplifying the ground motions was also observed from the ground motions recorded at Operating Industries Inc. (OII) landfill, California [4,5]. This amplification phenomenon has direct implication on the stability and or the permanent displacements of landfill final cover system [6,7].

Municipal solid waste forms the largest portion of a waste disposal (landfill) system. Hence seismic response of an MSW landfill is largely governed by the cyclic properties of the MSW. In addition to the unit weight of MSW, dynamic properties required for seismic response analysis of an MSW landfill using the equivalent linear method include:

- Small strain shear modulus (G_{max}) or the shear wave velocity (V_s)
- Modulus reduction (G/G_{max}) with shear strain (γ)
- Material damping ratio (λ) with shear strain.

Evaluation of the G/G_{max} and material damping ratio curves for MSW has started in the last two decades or so [8–28]. Significant insights have been gained on the fundamental aspects of the seismic behavior of solid waste landfills and various parameters influencing their cyclic behavior through the analyses of data from the field and large scale laboratory tests. Results of the parametric analyses by Bray et al. [29] and Bray and Rathje [30] emphasize the importance of using site specific dynamic properties of MSW for reliable seismic response evaluation of MSW landfills. Although there is an incremental progress in the accumulation of the database on G/G_{max} and λ curves of MSW, it is still insignificant

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compared to that of soils. A thorough literature review indicated that the secant shear modulus (G) or G/G_{max} and λ curves reported for MSW till date corresponds to just nine landfills from four countries [9–17,19–28]. In addition, no such data has been reported for MSW from landfills in India. Furthermore, research work on the cyclic behavior of MSW under undrained conditions is particularly sparse [16]. Cyclic behavior of MSW under undrained conditions may be important for uncontrolled dumps and bioreactor landfills located in areas of moderate to high seismicity, in which MSW may be in saturated or near saturated condition.

This article presents the results of field and large scale laboratory studies conducted to evaluate the dynamic properties of emplaced MSW at two dump sites in Delhi, India. Surface wave based geophysical methods such as spectral analysis of surface wave (SASW) technique, multichannel analysis of surface wave (MASW) method and microtremor analysis method (MAM) were adopted at the two dump sites to measure the V_s of MSW. Undrained cyclic triaxial (CTX) tests were conducted on large scale MSW specimens reconstituted using the bulk representative samples retrieved from different locations of the two sites. Influence of parameters such as composition, confining pressure, number of loading cycles, loading frequency and saturation on the cyclic behavior of MSW was studied. Dynamic properties of MSW obtained from this study are compared with the data reported for MSW in the literature. Results generated from this study add to the limited database on dynamic properties of MSW worldwide and can be useful for preliminary seismic analysis of MSW dump site/landfills in and around Delhi.

2. Previous work on dynamic properties of MSW

2.1. Small strain shear modulus or shear wave velocity

Small strain shear modulus is one of the basic input parameters required for seismic analysis of any geotechnical structure [31]. In practice, G_{max} is generally derived from V_s and the mass density (ρ) of the material using the following relationship:

$$G_{\max} = \rho V_S^2 \tag{1}$$

Several field and laboratory techniques that are used to measure the V_s or G_{max} of soils are also employed for measuring these small strain properties of MSW. List of various in situ methods adopted for V_s profiling at MSW landfills suggests that the surface wave methods such as SASW, MASW and MAM (or Refraction microtremor, ReMi) are among the most popular techniques adopted for measuring the V_s of MSW landfills [32]. This popularity is attributed to their non-invasive nature and rapid rate of testing, which makes them relatively inexpensive compared to other methods, and in particular with methods requiring borehole drilling [33,34]. Ramaiah et al. [32] compiled a large database of in-situ V_s of MSW and observed a wide range of V_s with depth which may be attributed to the differences in composition, operational practices and climatic conditions of different landfills. However, at a given landfill, a fairly consistent and less variability of V_s with depth can be observed, which emphasizes the importance of using site specific V_s data whenever possible [35].

Reported laboratory studies to measure either the V_s or G_{max} of MSW are currently very limited [35]. Extensive large scale laboratory studies on MSW retrieved from Tri-Cities landfill, California provided insights on the influence of various parameters such as composition, density, confining pressure, time under confinement and excitation frequency on the G_{max} or V_s [17,19,20,23]. The results of these studies revealed a systematic increase in V_s and G_{max} with the increase in confining pressure and unit weight for a given composition. Zekkos et al. [34] reported that the V_s of MSW changed from 80 to 150 m/s as the composition of MSW specimens changed from waste-rich (with 18% of the < 20 mm fraction) to soil-rich (with 100% of the < 20 mm fraction).

2.2. Modulus reduction and material damping ratio curves

Efforts made by previous investigators to generate the modulus reduction and material damping ratio curves for MSW can be broadly categorized into the following three techniques:

- Back analyses using recorded ground strong motions (at only OII landfill till date) [9–14]
- Laboratory testing of reconstituted MSW [11,15–17,19–23,28]
- In-situ testing using mobile field shakers [24–27]

However, the above three techniques provide the G/G_{max} and λ curves for different strain ranges. A summary of the G/G_{max} and λ curves reported for MSW by previous investigators is given in Fig. 1. It can be seen from Fig. 1 that there is significant scatter in the curves which may be attributed to the differences in method of analyses/type of testing apparatus, composition of MSW, drainage conditions, range of shear strain amplitude, age or degradation etc. Significant findings observed from the work of previous researchers on MSW include:

- Similar to regular soils, the G/G_{max} decreased and the material damping ratio increased with increasing shear strain amplitude [9,11,12,15–17,19–28].
- Composition is reported to have significant influence on the stiffness and material damping ratio of MSW. The MSW with higher percentage of fibrous materials (plastics, textiles, paper, wood, leather etc.) responded more linearly compared to MSW with lower percentages of fibrous materials i.e., the G/G_{max} curve shifts towards right. At large shear strains, the damping ratio of MSW with higher fibrous fraction is lower compared to MSW consisting of less fibrous fraction [15,19,20,22,23,25–27].
- Confining pressure also influenced the G/G_{max} and damping ratio of MSW. At a given shear strain amplitude, as confining stress increases, the G/G_{max} curve shifted towards right indicating a more linear response. The material damping ratio reduced with increasing confining stress [20,25–27]. However, some researchers (Feng et al. [16] and Towhata and Uno [22]) did not observed any systematic difference (increase or decrease) in material damping ratio with increase in confining pressure (over the range of 15–400 kPa).
- Unit weight (or initial void ratio), loading frequency and time under confinement did not have significant impact on the modulus reduction and material damping behavior of MSW [16,20]. However, Morochnik et al. [13] reported that the damping ratio of MSW is frequency dependent over the range of 0.1–10 Hz based on the back analysis from recorded ground motions using system identification technique.
- Material damping ratio appears to be dependent on the type of testing device employed. Yuan et al. [23] from cyclic simple shear (CSS) tests observed about 50% higher material damping ratio than that evaluated using cyclic triaxial (CTX) apparatus [20] for an identical composition of MSW. They attributed the relatively high damping ratio from CSS tests could be due to a higher slippage and relative displacement occurring among the waste constituents than in CTX tests.

3. Description of MSW dump sites

Two MSW dump sites selected for the present study are the