Chapter 5
Dynamic Properties of Municipal Solid Waste and Amplification of Landfill Site

P. Anbazhagan, P. Lakshmikanthan, and G.L. Sivakumar Babu

Abstract Understanding of the dynamic properties of municipal solid waste (MSW) and the response of waste landfill for cyclic loads are important for safe seismic design and ensuring sustainability of landfills. This study presents estimation of the dynamic properties through field and laboratory tests of MSW landfill and dynamic response of Mavallipura landfill in Bangalore. Both field tests and laboratory tests are used to develop model to represent variation of shear modulus and damping ratio for different strain levels. Ten ground motions are selected based on regional seismicity of landfill site, and detailed site response analysis was carried out considering one-dimensional nonlinear analysis in DEEPSOIL programme. Surface response parameters have been estimated; the surface spectral response varied from 0.6 to 2 g and persisted only for a period of 1 s for most of the ground motions. The minimum and maximum amplifications are 1.35 and 4.05. This study shows that Indian MSW has less shear stiffness and loose filling, may be subject to more amplification for moderate earthquake ground motions, which need to be accounted for seismic design of landfills.

Keywords Shear modulus • Damping ratio • Cyclic triaxial tests • Municipal solid waste • Landfills

---

P. Anbazhagan • G.L. Sivakumar Babu
Department of Civil Engineering, Indian Institute of Science (IISc),
Bangalore, Karnataka 560012, India
e-mail: anbazhagan@civil.iisc.ernet.in; gls@civil.iisc.ernet.in

P. Lakshmikanthan (✉)
Centre for Sustainable Technologies, Indian Institute of Science (IISc),
Bangalore, Karnataka 560012, India
e-mail: lakshmikanth@astra.iisc.ernet.in

G.L. Sivakumar Babu et al. (eds.), *Geoenvironmental Practices and Sustainability*, Developments in Geotechnical Engineering,
DOI 10.1007/978-981-10-4077-1_5

5.1 Introduction

Landfills can be subjected to cyclic loads due to earthquakes, and the dynamic response under such loads depends on the cyclic stress-strain characteristics of the MSW. The evaluation of dynamic properties of municipal solid waste (MSW) is important for proper seismic response analysis, modelling and efficient design of landfills. It is essential to determine the dynamic parameters (small-strain shear modulus (Gmax), normalised shear modulus reduction (G/Gmax) and damping ratio (D)) in order to analyse the engineering response of MSW subjected to dynamic loadings. Shear stresses are related to shear strains by the shear modulus (G) of the material. The shear modulus is simply related to the velocity of shear waves; hence, measurements of shear wave velocity provide a convenient method for measuring stiffness. In this study shear modulus for low strain is obtained from field seismic test, and shear modulus and damping for high strain are measured by laboratory tests (cyclic triaxial tests). These values are further used to develop the normalised shear modulus reduction and damping relationships for MSW from India. These results are used as inputs along with recorded ground motions to perform nonlinear one-dimensional seismic response analysis of landfill site and site-specific amplification are estimated.

5.2 Site and Sample Description

The MSW used in this study is the compost reject collected from the Mavallipura Landfill site, Bangalore, India, and is referred to as MSW in this paper. The site is spread over 30 acres and is divided into cell 1 (6 acres) and cell 2 (2 acres). The height of the landfill is 10 m. Composting has been adopted as a potential pretreatment method. Hand sorting of recoverable waste was followed by aerobic windrow composting for a period of 2 months. The compost reject had particle sizes varying from 4 to 35 mm. The particles of size >20 mm, mostly consisting of large plastics, rubber shoes, leather bags and other inert materials, were hand sorted or removed by other mechanical procedures. As it was difficult to separate particles <20 mm, these were filled directly. Therefore, particles of size <20 mm were used in the laboratory for characterisation and testing. The compost reject contained 6.34% clothes, 28% plastics, 1.28% glass, 0.8% leather, 5.56% coconut, 1.96% stones, 0.88% rubber, 0.16% wood and 54.2% organic matter. The moisture content of the waste was calculated as the ratio of the weight loss of the weight that remained after heating at a temperature of 60°C until the specimen has dried to a constant mass. The natural water content of the sample was found to be 20%. The test for total volatile solids was performed according to the APHA 1965 (American Public Health Association) standard methods. The organic content of the compost reject <10 mm particle size was calculated as the ratio of the weight loss of the initial specimen weight after heating to a temperature of 550 °C in a muffle furnace. The initial decomposable organic content of the waste was found to be 55% and the inerts constituted 45%.

5.3 Materials and Methods

5.3.1 Field Tests

In the present study, the multiple channel analysis of surface waves (MASW) method is used to measure shear wave velocity (*V*s) of in situ MSW. The MASW testing was done at the Mavallipura landfill site which is situated in the outskirts of Bangalore. More details about testing, data processing and results can be found in Anbazhagan et al. (2016). The G_{max} at low strain was calculated from the shear wave velocity measured at the site using the following Eq. (5.1):

$$G_{max} = \rho * V_s^2 \tag{5.1}$$

where *V*s is the shear wave velocity in m/s and ρ is the density in g/cc.

5.3.2 Laboratory Determination of Dynamic Properties

Cyclic triaxial compression method has been adopted as the test method in this study for the analysis of the dynamic properties of MSW in the laboratory. Shear strains in the range of 1%–10^{-3}% can be measured in the cyclic triaxial apparatus. Reconstituted MSW samples (50 mm × 100 mm) of particle size <20 mm and moisture content of 44% were used for testing in the laboratory. The loading was done in a sinusoidal pattern and the tests were stress controlled. More than 40 cyclic triaxial tests were conducted in laboratory, and the shear modulus and damping ratios were calculated according to ASTM D 3991-91 and ASTM D 5311-92. The G_{max} values from the field test and lab tests are combined to develop the G/G_{max} curves for MSW.

5.4 Results and Discussions

5.4.1 Field Tests

The MASW tests were conducted at selected locations at the landfill site, and the typical shear wave velocity profiles are presented in Fig. 5.1. Based on the total station survey and the previous available data, the depth of the landfill was arrived at

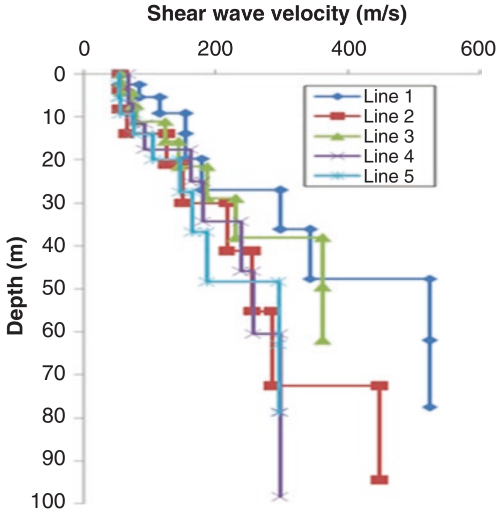

Fig. 5.1 Field measurements of shear wave velocities of municipal solid waste at Mavallipura landfill

9–10 m with *V*s values of 56 m/s. The waste below the depth of 10 m was composites of waste and soil with higher shear wave velocity.

5.4.2 Laboratory Tests

5.4.2.1 Normalised Shear Modulus Reduction and Damping Ratio Curves

Figure 5.2 shows the results of cyclic triaxial tests conducted on waste samples. The shear modulus increased from 4 to 6 MPa with the increase in frequency from 0.1 to 1 Hz. Similar increasing trends were found in the published literature for strains less than 0.05%.

The normalised shear modulus reduction values obtained from laboratory are presented in Fig. 5.3. Most of the values fall below the upper bound of the curves recommended by Matasovic and Kavazanjian (1998). The results closely match Zekkos et al. (2008). Idriss et al. (1995) and Augello et al. (1998) back-calculated the strain-dependent shear modulus reduction and material damping curves using the time histories recorded on top of OII landfill from earthquakes. MSW degrades with time, and therefore the shear modulus and damping ratio are likely to change which should be considered while developing modulus reduction curves. Though the results are obtained from limited laboratory and field tests in this study, a modulus reduction curve close to the lower bound can be recommended for MSW of Indian origin for seismic analysis. However, further studies including the effect of water content, particle size, sample size and composition of MSW on the modulus reduction curves can provide further details in understanding and developing the dynamic parameters.

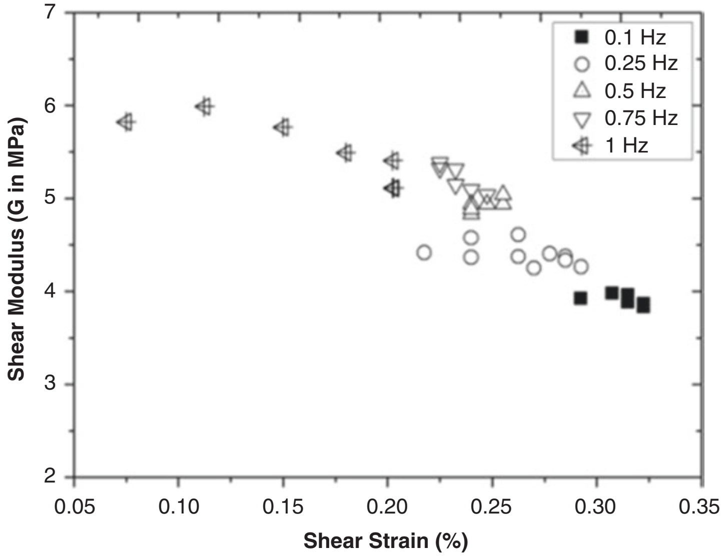

Fig. 5.2 Variation of shear modulus with shear strain

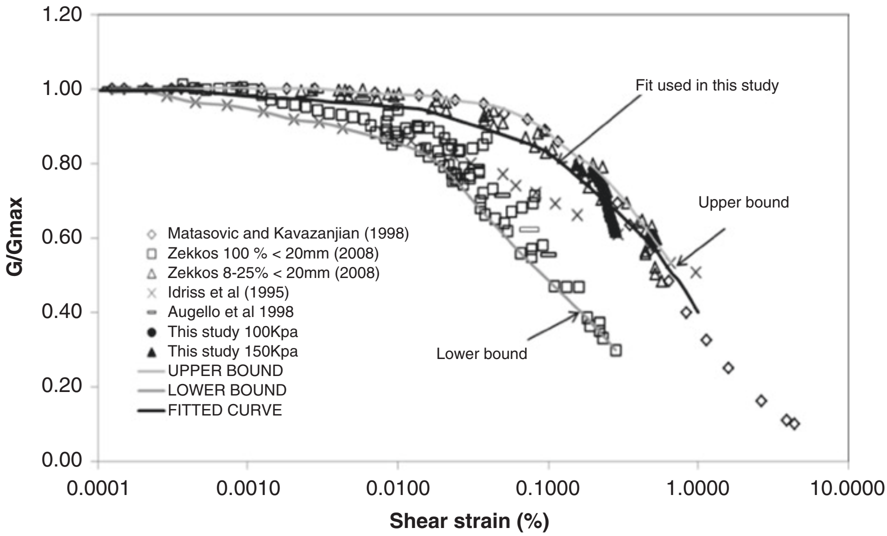

Fig. 5.3 Normalised shear modulus reduction curves from previous studies and the present study

Similarly the damping values of the MSW were calculated, and damping curve is developed for the MSW (Anbazghagan et al. 2016). The damping values varied from 10% to 17% in all the tests. Matasovic and Kavazanjian (1998) and Zekkos et al. (2008) observed high damping values in the range 20–30% compared to Augello et al. (1998) and Idriss et al. (1995) who reported values less than 15%.

5.4.3 Seismic Response Analysis of MSW

Site response analysis is used to predict the response of each subsurface layer subjected to an earthquake ground motion. MSW landfill site consists of MSW fill followed by filled soil layer and hard stratum. Site-specific data are modelled in DEEPSOIL to get one-dimensional (1-D) nonlinear response parameters. Fully nonlinear analyses are performed in the time domain, where shear modulus (G) and damping (ξ) vary throughout the duration of loading. The seismic response is studied by examining surface acceleration time history, response spectra and the maximum strain of the each location in the landfill. The input ground motion and estimated surface acceleration time history are used to predict amplification of MSW. Typical response spectrum for selected input motions is shown in Fig. 5.4. It can be observed that input motion has undergone considerable amplification and change in amplitude, frequency and duration are noticed. The peak spectral acceleration is noticed before 0.5 s in the input as well as in surface. A few input motions show multiple spectral peaks at the surface due to shallow hard stratum reverberation. This study shows that amplification and spectral signature of MSW fill is different from that of soils, which need to be accounted in seismic design of MSW landfill sites.

5.5 Conclusions

The cyclic characteristics of the MSW were established based upon field and laboratory testing. The shear wave velocity profile for the solid waste was measured using MASW survey. Cyclic triaxial test were carried out on MSW samples, and shear modulus and damping values were measured for strain values of 1%–10^{-3}%. The normalised shear modulus reduction and damping curves for waste were developed based on a combination of laboratory cyclic triaxial test results and literature. One-dimensional nonlinear site response study was carried out at five MSW columns at Mavallipura landfill. Ten input motions were selected considering seismicity of study and area of Bangalore and were used for site response analysis. This study shows that shallow MSW fill undergoes considerable seismic amplification for ground motion less than 0.2 g. The results indicate the potential of amplification of ground motions by the waste situated above a composite layer of soils and rock bed at the bottom. Hence, the site-specific amplifications need to be accounted for sustainable landfill design.

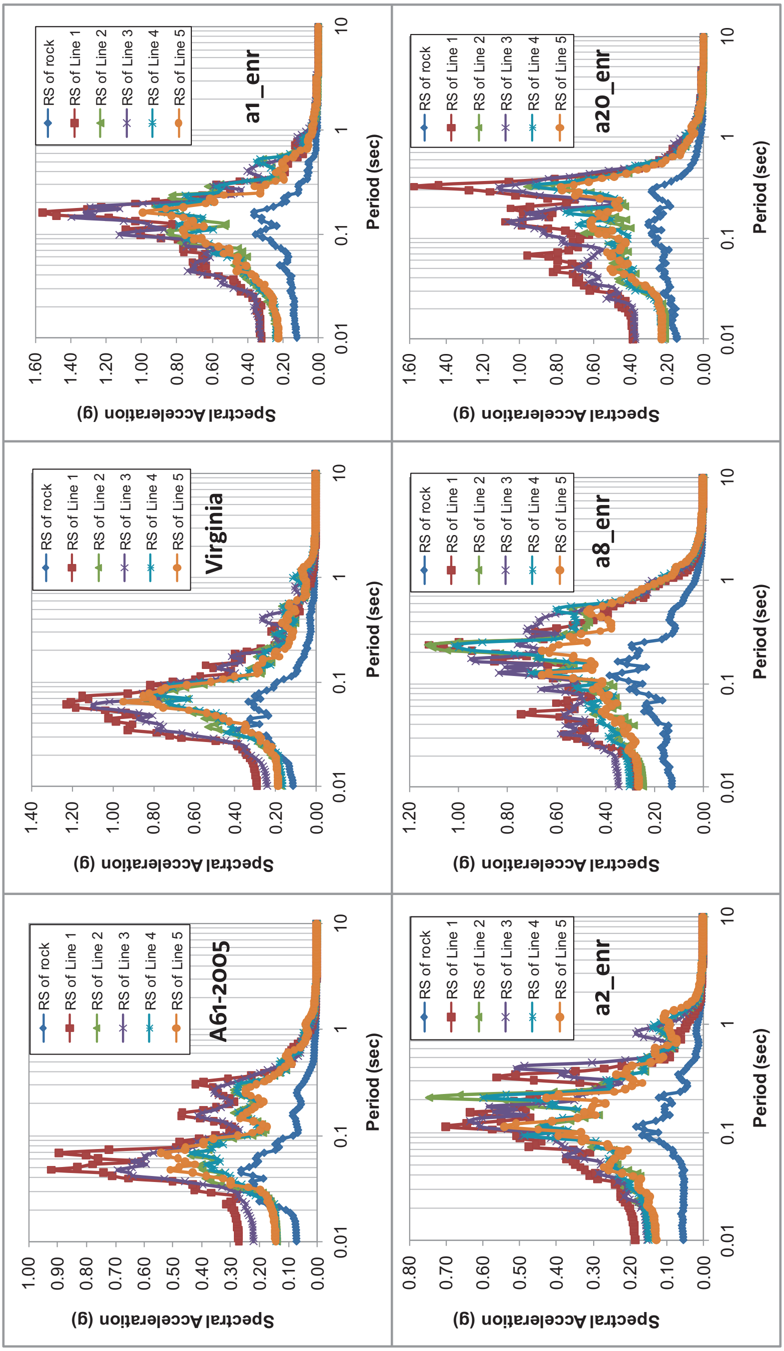

Fig. 5.4 Input and surface response spectrum for MSW sites

References

Anbazhagan P, Sivakumar Babu GL, Lakshmikanthan P, Vivek Anand KS (2016) Seismic characterization and dynamic site response of a municipal solid waste landfill in Bangalore, India. Waste Manag Res 34(3):205–213. doi:10.1177/0734242X15622814

Augello AJ, Bray JD, Abrahamson NA, Seed RB (1998) Dynamic properties of solid waste based on back-analysis of OII landfill. ASCE J Geotech Geoenviron Eng 124(3):211–222

Idriss IM, Fiegel G, Hudson MB, Mundy PK, Herzig R (1995) Seismic response of the operating industries landfill, earthquake design and performance of solid waste landfills, ASCE Geotech J Earthq Eng 8(4):545–566, Imperial College Press

Matasovic N, Kavazanjian E Jr (1998) Cyclic characterization of OII landfill solid waste. J Geotech Geoenviron 124(3):197–210

Zekkos D, Bray JD, Riemer MF (2008) Shear modulus and material damping of municipal solid waste based on large-scale cyclic triaxial testing. Can Geotech J 45(1):45–58