Evaluating the Dynamic Characteristics of Municipal Solid Waste for Geotechnical Purpose

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Abstract*-In order to analyse the engineering behavior of refuse material subjected to dynamic loadings, it is essential to determine its dynamic modulus, Poisson's ratio, and strength. The shear modulus (G) is a major property in the evaluation of dynamic response of MSW, since it relates shear stress to shear strains. The dynamic shear modulus can be estimated from its mass density and shear wave velocity. The combination of shear wave and compression wave velocities are used to determine the Poisson's ratio. This paper presents the results of cyclic triaxial tests performed on municipal solid waste (MSW). One sample was collected from the Mavallipura landfill area and another sample was from a illegal dump around the same landfill area located in Bangalore. This illegal dump underwent substantial degradation with over a period of time. Dynamic properties of municipal solid waste for both dumped waste and drywaste (landfill) are obtained from laboratory cyclic triaxial shear tests using stress controlled cyclic triaxial tests. MSW degrades with time and its shear modulus and damping ratio are expected to vary with time and degradation. Dynamic shear modulus values for dumped waste varied from 0.8 MPa to 4.2 MPa and for dry waste varied from 2 MPa to 4.2 MPa. Dynamic shear modulus of the waste increases with increasing confining pressure and shear strains for both dry and dumped wastes. The increase is more with more confining pressure. The dynamic shear modulus slightly increases at a higher number of cycles of cyclic loading. Damping ratio varied from 14% to 32% for dumped waste. For dry waste damping ratio varied from 14% to 18%. Damping ratio decreases with increasing confining pressure. However, there is not much change with shear strain or number of cycles.

Keywords- Damping; Municipal Solid Waste; Shear Modulus; Poisson's Ratio

I. INTRODUCTION

An ability of engineer to evaluate the likely municipal solid waste (MSW) landfills for a seismic performance is limited currently by the lack of reliable data on the stress dependent dynamic properties of MSW. The required dynamic properties of the waste materials include the:

i. The MSW unit weight profile.

ii. Small –strain shear modulus(Gmax) or Shear wave velocity (Vs)

iii. The stress dependent normalized shear modulus reduction (G/Gmax) and material damping ratio realtionship.

Several attempts made in the past to determined the dynamic properties of MSW. The following is the summary of the earlier work carried out.

The decomposition of the municipal solid waste in open dump site changes the geotechnical characteristics of the waste it varies with aging, and there by increasing concern for waste stability. Since many of the open dump wastes are located in the vicinity of highly populated areas, these results in the increasing hazard potential associated with the failure of a municipal solid waste landfill. Due to this considerable attention has been focused on studying the geotechnical characteristics such as shear strength, permeability, moisture content, density and compressibility of wastes. The strength characteristics of municipal solid waste are intimately related to heterogeneous composition, and its physical and chemical properties. These properties changes significantly not only with time, but also with the degree of degradation . Gomes et al.,[7] has reported MSW shear strength parameters reported in literature varied widely, with a cohesion varying from 0 to 67 kPa, and friction angle ranging from 10° to 53°. Gabr [6] has performed a constant and falling head tests on triaxial compression specimen by measuring the flow rates through the saturated specimens before the consolidation phase. The observed values of the permeability from this testing were in the order of 10^{-7} to 10^{-5} m/s.

Dixon and Jones [5] has reported on measurement and interpretation of engineering parameters such as compressibility, shear strength, unit weight, lateral stiffness, insitu horizontal stress and hydrualic conductivity. Korner and Soong [13] studied the landfill failures, although not common, occur on a regular basis in countries around the world. Jones and Dixon [9] have investigated the potential development of post-peak shear strengths on side slope lining component interfaces resulting from solid waste settlement by using numerical modelling.

Zekkos et. al [17] evaluated the various relationship of MSW which included the material damping ratio, strain dependent normalized shear modulus reduction. Idriss et al. [4] and Matasovic and Kavazanjian [14] studied material damping realtionship for MSW and strain-dependent normalized shear modulus reduction (G/G_{max}). The combination of shear wave and compression wave velocities are used to determine the Poisson's ratio. Matasovic and Kavazanjian[10,11] have used shear and compressional waves to calculate the Poisson's ratio. Elgamal et al. [3] have presented material damping curves and shear modulus reduction for waste materials for use in practice.

Zekkos et al [18] has reported that specimens composed of larger-sized particles are attributed to a fibrous reinforcing effect that is mobilized when the municipal solid waste is sheared at an angle to the preferred orientation of particle and it continued increase in mobilized shear stress at very large strains in specimens due to upward curvature of the stress-strain response.

Matasovic and kavazanjian[14] have used shear and compressional waves to calculate the poisson's ratio. Kavazanjian[12] has reported the asumption poisson's ratio becomes a factor when it exceeds 0.4 and approaches 0.5, this occurs when the waste approaches saturation, as is the case of bioreactor landfills. Sharma et al.[15] reported a poisson's ratio of 0.49 from his studies on the San Pablo Bay landfill, Richmond, California.

Dimitrios Zekkos et. al [5] evaluated the various relationship of MSW which included the material damping ratio, strain dependent normalized shear modulus reduction. Idriss et al. [8] and Matasovic and Kavazanjian [14] studied material damping realtionship for MSW and strain-dependent normalized shear modulus reduction (G/Gmax). Elgamal et al. [3] have presented material damping curves and shear modulus reduction for waste materials for use in practice.

In MSW, limited laboratory investigations have been performed due to the difficulties in performing such tests. Such difficulties include the health issues associated with testing waste material, sample disturbance, and the large test specimens required to include the larger waste particles. Matasovic and Kavazanjian[14] performed large-diameter (457 mm) cyclic simple shear tests on waste from the OII landfill. Data were collected for shear strains larger than 10^{-2}%. Towhata et al. [16] perfomed a limited cyclic triaxial tests at shear strains of approximately 0.3% . This research, therefore, aims to presents the results of a cyclic triaxial tests performed on municipal solid waste (MSW) collected from a illegal dump around the bangalore city. This illegal dump underwent substantial degradation with time. Dynamic properties of municipal solid waste for dumped waste are obtained from laboratory cyclic triaxial shear tests using stress controlled cyclic triaxial tests. Still very little work has been carried out on dynamic properties of MSW. Hence, Dynamic properties of municipal solid waste (both for Dumped waste and Dry waste) are obtained from laboratory cyclic triaxial shear tests using stress controlled cyclic triaxial tests at different confining pressures and shear strains. MSW degrades with time and its shear modulus and damping are expected to vary with time and degradation.

II. SAMPLE PREPARATION

Fig. 1 Area map of Mavallipura site
(courstey:google earth images,https://maps.google.com/map)

The Landfill is situated at survey no.108, at Mavallipura village, Hesaragatta zone, Bangalore North, Karnataka state. This site has been used as processing site for the municipal solid waste generated from the Bangalore city. Fig. 1 shows the Google map with area map of Mavallipura landfill dump site. One sample was collected from the mavallipura landfill area another sample was from a illegal dump around the same landfill area located in Bangalore.

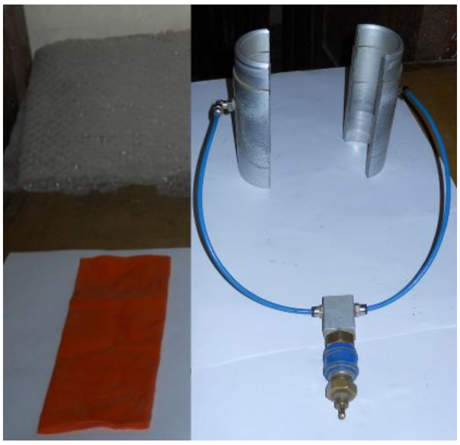
Composted MSW is then shifted to coarse segregation area having mechanical arrangements to segregate the rejects like plastic, cloth, metals, glass of the size above 14mm using rotary screen (trommel) of 35mm and 15mm sizes. Feeder, hopper and conveyer belts are provided with trommel for taking away rejects and semi-finished compost separately. Above semi-finished compost is then further shifted to curing section for further digestion. After curing, compost is shifted to refinement section which consists of vibratory screen or trommel of 4-6mm size. Disposal of reject material (Rejects like gravels, sand, stones, glass, metal and other inert materials above 4 mm are separated in this section). This reject material goes to landfill. From the landfill sufficient quantity of Dry waste (landfill waste) is collected and kept in closed bags and carried to the laboratory as shown in Fig. 2.

Fig. 2 Landfill waste (dry waste)

Illegal dumping of MSW is found next to Mavallipura landfill site area. This waste was brought in by the municipal and contract Lorries before the landfill was in operation. This waste includes newspaper, junk mail, today's meal scraps, pieces of bread, roti, waste rice, raked leaves, dust grass clippings, broken furniture, abandoned materials, animal manure, sewage sludge, industrial refuse or street sweepings etc. and this waste was dumped in the open site, for the past 10 years in the form of a heap (of approximately 2.5m wide and 2m height). The waste was found mixed with the local soil around due to many reasons such as wind, disturbance by animals, etc. From this heap sufficient quantity of Dumped waste (See Fig. 3) is collected and kept in closed bags and carried to the laboratory for testing.

The solid waste samples at different densities at different confining pressure were prepared into a cylindrical specimen of height 10cm and a diameter of 5cm, an aspect ratio of 2. All the solid waste samples tested under cyclic loading were prepared for different void ratio and water content. After the sample was prepared sample enclosed in an acrylic cell. The loading ram and load cell are aligned in coincidence with their respective vertical axis. In cyclic shearing phase, the specimens were subjected to repetitive loads of fixed load amplitude and frequency. In monotonic loading, the samples were sheared under a single constant strain rate of 0.6 mm/min. The values of shear modulus and damping ratios were calculated from ASTM D 3991-91[1].

Fig. 3 Illegal dumping of municipal solid waste (dumped waste)



(a) (b)

(c) (d)

Fig. 4 Materials used for sample preparation (a) Rubber membrane (0.3 mm thick), (b) Split mould (c) Solid waste sample enclosed in membrane (d) Sample inside the triaxial cell with applied confining pressure

A. Cyclic Stress (σ_{dc})

$$\pm\sigma_{dc} = \frac{\Delta P_c + \Delta P_e}{2A_c} \quad (1)$$

ΔP_c = Peak load in compression, ΔP_e = Peak load in extension, Ac = cross sectional area of specimen after consolidation.

B. Cyclic Stress Ratio (CSR)

$$CSR = \frac{\pm\sigma_{dc}}{2\sigma'_{3c}} \quad (2)$$

σ'_{3c} = Effective confining pressure (kPa)

C. Double Amplitude Axial Strain (ε_{da})

$$\varepsilon_{da} = \varepsilon_c + \varepsilon_e \quad (3)$$

$$\varepsilon_c = \frac{\delta_c}{H_c} \quad \text{and} \quad \varepsilon_e = \frac{\delta_e}{H_c}$$

ε_c = axial strain in compression, ε_e = axial strain in tension, δ_c = axial deformation in compression, δ_e = axial deformation in extension, H_c = Height of the specimen after consolidation.

D. Damping Ratio and Shear Modulus

The cyclic stress-strain behaviour of solid wastes were analysed to determine shear strain dependent shear modulus and damping ratio values. Solid waste under repetitive or cyclic loading undergoes degradation of shear modulus and increase in damping ratio with shear strain.

In a cyclic triaxial testing system, after considering the effects of system compliance and applicable corrections ASTM- D5311[2], a typical hysteresis loop obtained on solid waste sample is shown in the Fig 2. values of shear strain (%), shear modulus (MPa) and damping ratio (%) were estimated for each cycle of loading from the hysteresis loops obtained in stress controlled cyclic loading.

The methods followed to determine the shear modulus (G) and damping ratio from cyclic loading are depicted fig 5. From the plot of deviator stress v/s. axial strain. The dynamic Young's modulus (E) and hence shear modulus (G) of the solid waste sample were estimated using the equations (4), (5) and (6).

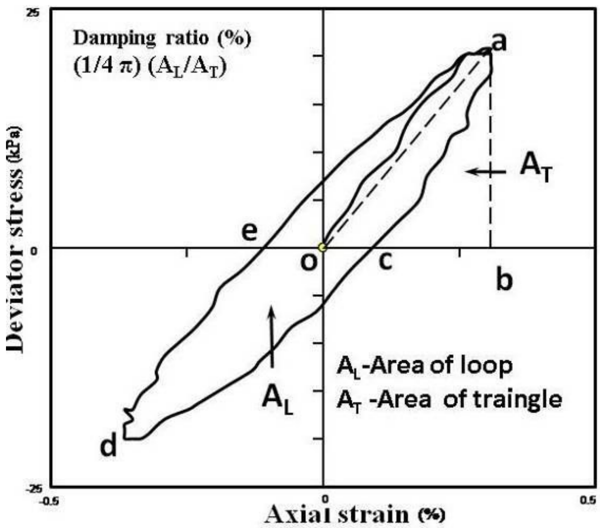


Fig. 5 Hysteresis curve for deviator stress and axial strain

$$E = \frac{\sigma_d}{\varepsilon} \quad (4)$$

$$\gamma = (1+\nu)\varepsilon \quad (5)$$

$$G = \frac{E}{2(1+\nu)} \quad (6)$$

Where, E is the dynamic Young's modulus, σ_d is the deviator stress, ε is the axial strain, γ is the shear strain(%), ν is the Poisson's ratio, and G is the shear modulus.

$$D = \frac{A_L}{4\pi A_T} \quad (7)$$

A_L is the area enclosed by hysteresis loop (total energy supplied), A_T is the area of triangle (percentage of energy lost). The estimation of damping ratio was done using the equation (7) for different axial strain amplitudes.

III. EXPERIMENTAL PROCEDURE

The laboratory studies were conducted under cyclic stress controlled conditions for confining pressure of 50, 100 and 200 kPa with Dumped waste and Dry waste specimen of void ratio of 0.7 and 0.9 respectively. To evaluate dynamic shear modulus and damping properties cyclic stress controlled load on the sample was applied at a frequency of 0.1 Hz with a sinusoidal loading wave form. All the standard requirements for conducting a cyclic triaxial testing on soils were followed as per the ASTM D5311[2] for testing procedure and ASTM D3999-91[1] for determination of shear modulus (G) and damping ratio (D).

The solid waste samples tested are:

1. Dumped waste sample having a water content of 30.59 % .
2. Dry waste sample a water content of 15.30%.

The Dumped and Dry solid waste sample which contained different amount of water contents and were not saturated completely, therefore both the samples were considered as partially saturated. Due to the partially saturated condition of the wastes, the value of Poisson's ratio considered was 0.3.

Details of testing programme and parameters selected for testing are presented in Table 1.

TABLE I TESTING PROGRAMME OF DUMPED WASTE AND DRY WASTE

Sample	γ_d g/cc	(e)	Ww %	σ_{3c} kPa	ampl kg	freq Hz	CSR	N
Dump Waste	0.982	0.17	30.59	50	4	0.1	0.20	10
	1.0	0.17	30.59	100	4	0.1	0.10	9
	1.0	0.17	30.59	200	4	0.1	0.05	9
Dry Waste	0.7	0.64	15.30	50	4	0.1	0.20	6
	0.7	0.64	15.30	100	4	0.1	0.10	5
	0.7	0.64	15.30	200	4	0.1	0.05	8

IV. SHEAR MODULUS AND DAMPING RATIO OF DUMPED AND DRY WASTE

A. Dumped Waste Samples

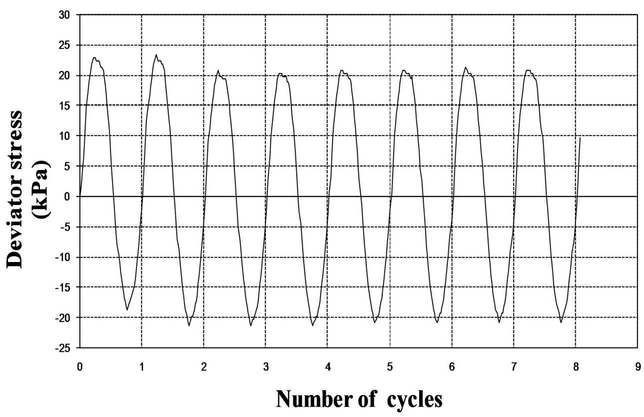


Fig. 6 Deviator stress vs. number of cycles

Fig. 6 & 7 shows that the Deviator stress is applied and axial strain measured with number of cycles.

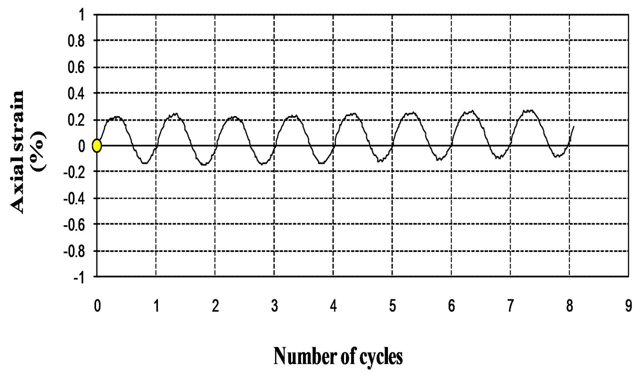


Fig. 7 Axial strain vs. number of cycles

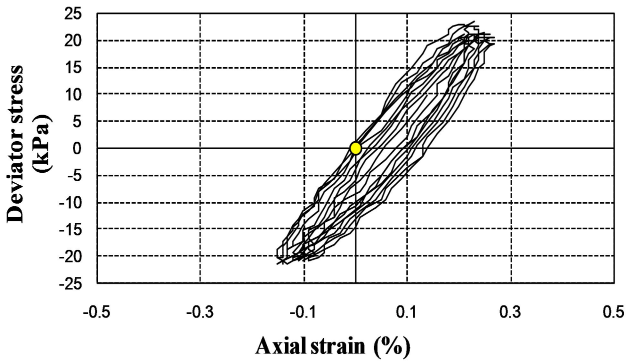


Fig. 8 Deviator stress vs. axial strain

Fig. 8 shows that the cycle hysteresis loops for Dumped waste sample. Fig. 9 shows that the shear modulus slightly increases with number of cycles and drastically with increasing confining stress for Dumped waste samples. Dynamic shear modulus values for Dumped waste varied from 0.8 MPa to 4.2 MPa.

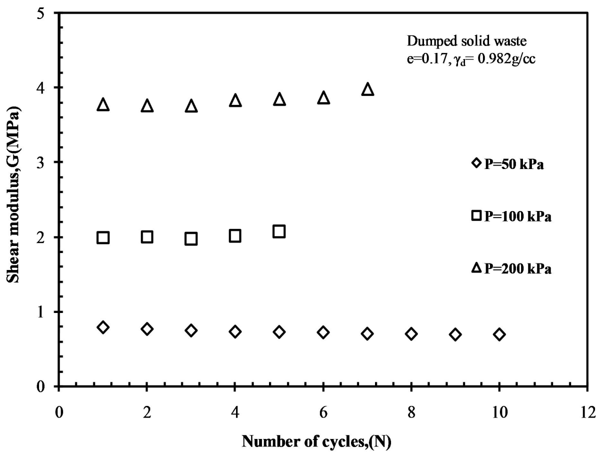


Fig. 9 Shear modulus variations with number of cycles

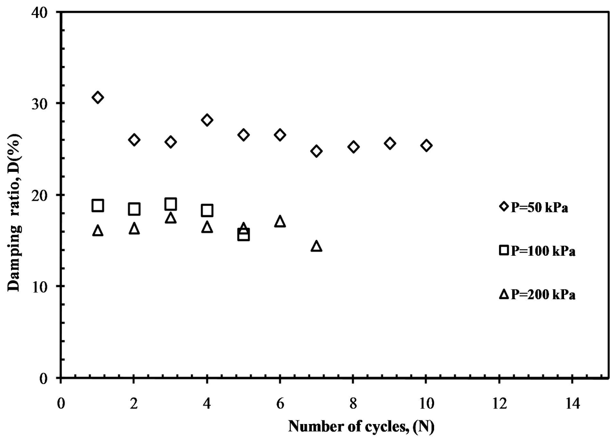


Fig. 10 Damping ratio variations with number of cycles

Fig. 10 shows the damping ratio decreases with increasing the confining pressure and however the results associates with number of cycles. Damping ratio varied from 14% to 32% for Dumped waste.

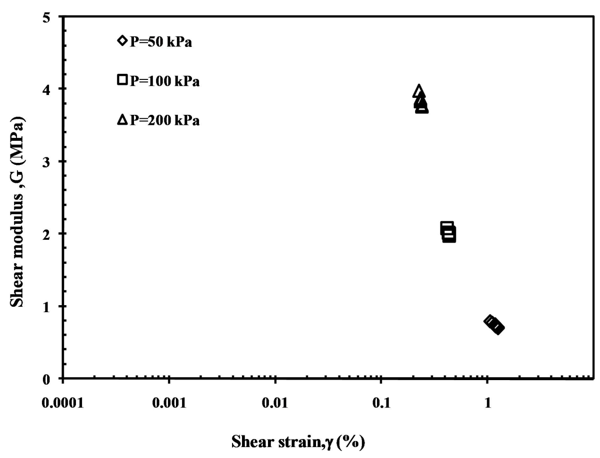


Fig. 11 Shear modulus variations with shear strain

Fig. 11 shows the shear modulus variations with shear strains applied, clearly indicating degradation with increase in shear strain. Fig. 12 shows the Damping ratio get increase with increase in shear strain.

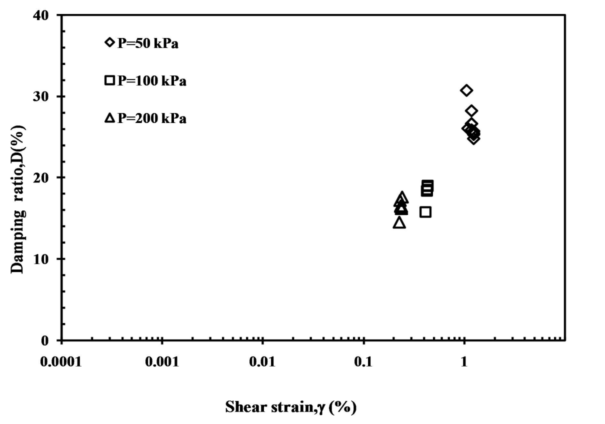


Fig. 12 Damping ratio variations with shear strain

B. Dry Waste Samples

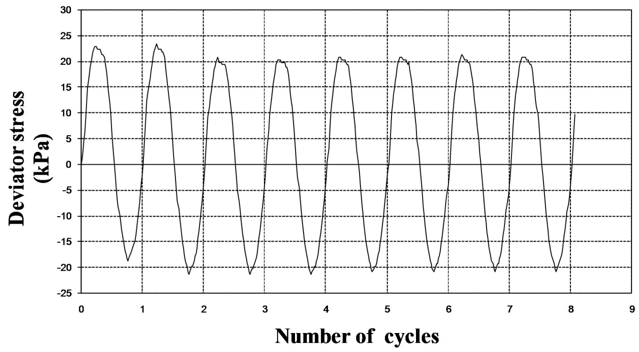


Fig. 13 Deviator stress vs. number of cycles

Fig. 13 & 14 shows that the Deviator stress is applied and axial strain measured with number of cycles.

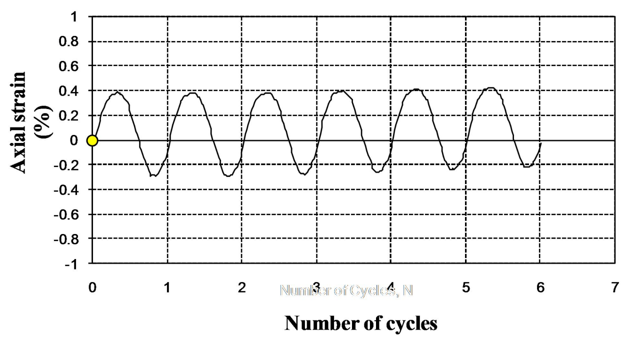


Fig. 14 Axial strain vs. number of cycles

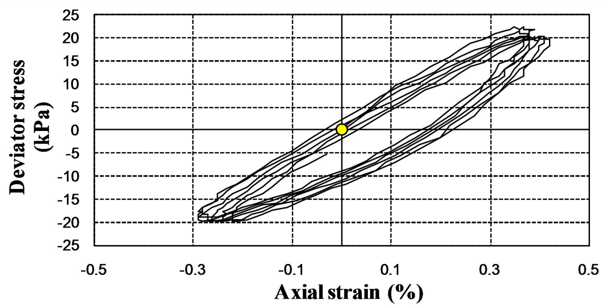


Fig. 15 Deviator stress vs. axial strain

Fig. 15 shows the hysteresis loop for Dry waste sample. Fig. 16 shows that the shear modulus slightly increases with number of cycles and drastically with increasing confining stress for Dry waste samples. Dynamic shear modulus values for Dry waste varied from 2 MPa to 4.2 MPa. Fig. 17 shows the damping ratio decreases with increasing the confining pressure and however the results decreases with number of cycles. Damping ratio varied from 14% to 18% for Dry waste.

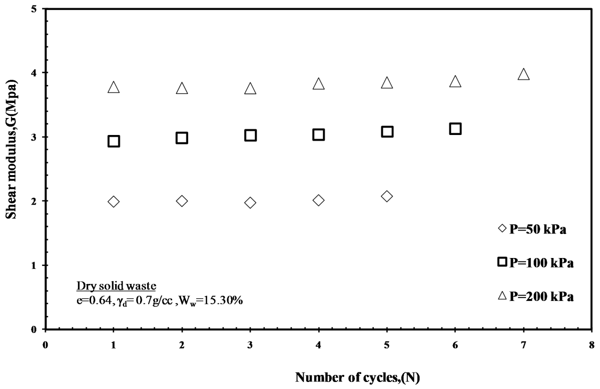


Fig. 16 Shear modulus variations with number of cycles

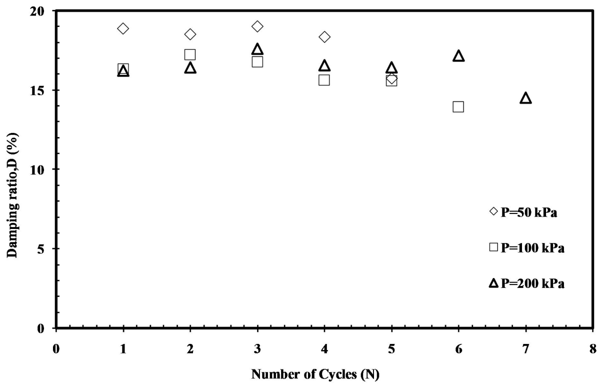


Fig. 17 Damping ratio variations with number of cycles

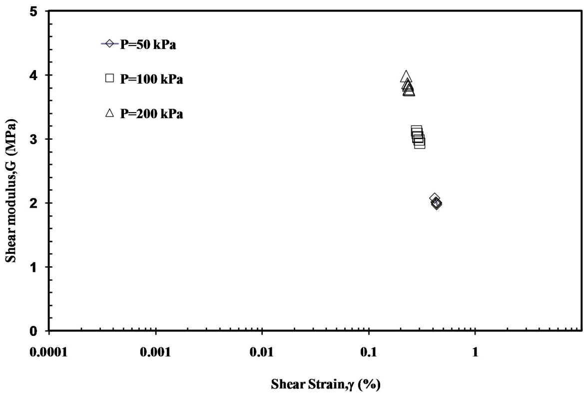


Fig. 18 Shear modulus variations with shear strain

Fig. 18 shows the shear modulus variations with shear strains applied, clearly indicating degradation with increase in shear strain. Fig. 19 shows the Damping ratio get increase with increase in shear strain.

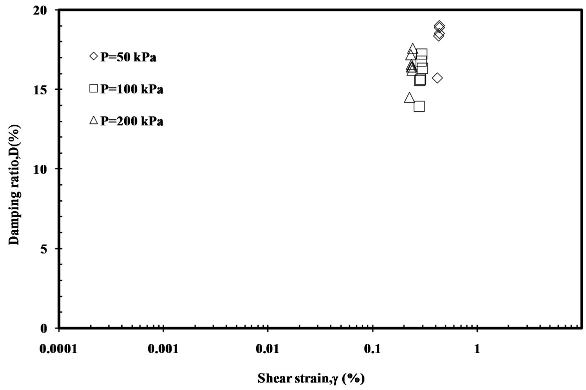


Fig. 19 Damping ratio variations with shear strain

V. CONCLUSIONS

Based on the studies conducted on waste samples collected from dump site and dry waste the following are typical values of cyclic triaxil test:

- Dynamic shear modulus values for Dumped waste varied from 0.8 MPa to 4.2 MPa and for Dry waste varied from 2 MPa to 4.2 MPa.
- Dynamic shear modulus of the wastes increases with increasing confining pressure and shear strains for both Dry and Dumped wastes.
- The increase is more with more confining pressure than shear strains.
- The dynamic shear modulus slightly increases at higher number of cycles of cyclic loading.
- Damping ratio varied from 14% to 32% for Dumped waste and for Dry waste, it varied from 14% to 18%.
- Damping ratio decreases with increasing confining pressure.However, there is not much change with shear strain or number of cycles. Similar trend of results have been reported by others.
- The scatter in the results of Dumped waste is more due to heterogeneity of wastes mixed with the soil and decomposition of waste with time. It should be noted that the dynamic properties of municipal solid waste are functions of time and decomposition.

REFERENCES

ASTM Designation: D 3999-91. Standard Test Methods for the Determination of the Modulus and Damping Properties of Soils using the Cyclic Triaxial Apparatus, *Annual Book of ASTM standards*, vol. 04. 08.

ASTM Designation: D 5311-92(Reapproved 1996). Standard test method for load controlled cyclic triaxial strength of soil.

Elgamal, A., Lai, T., Gunturi, R., and Zeghal, M.,"System Identification of Landfill Seismic Response,"*Journal of Earthquake Engineering*, vol. 8, no.4, pp. 545-566, 2004.

Dimitrios Zekkos., Jonathan D. Bray., and Michael F. Riermer., " Shear Modulus and Material Damping of Municipal Solid Waste based on Large-Scale Cyclic Triaxial Testing," *Can.Geotechinal Journal*, vol. 45, pp. 45-58, 2008.

Dixon, N., and Jones,D. R., "Engineering Properties of Municipal Solid Waste," *Geotextiles and Geomembranes*, vol. 23, pp. 205-233, 2005.

Gabr,M.A., and Valero,S.N., "Geotechnical Properties of Municipal Solid Waste", *Geotechnical Testing Journal*, vol. 18, No. 2, pp. 241-255, 1995.

Gomes,C., Lopes, M. L., and Lopes, M. G., "A study of MSW properties of a portuguese landfill," Proc.of Int'l workshop on Hydro-Physico Mechanics of landfills, LIRIGM, France, 2005.

Idriss, I.M., Fiegel, G., Hudson, M.B.,Mundy,P.k.,and Herzig, R., "Seismic Response of the Operating Indurstries Landfill. Earthquake Design and Performance of Solid waste landfills," *ASCE Geotechnical special publication* No.54, Edited by M.Y. Yegian, W.D. Liam Finn, pp. 83-118, 1995.

Jones, D.R.V., and Dixon, N., " The Long term Stability of Landfill side Slopes," Proc. 6th International landfill symposium, Sardinia,3: pp. 507-516, 1997.

Kavazanjian,E., Matasovic,N., Stoke,k., and Bray,J.D., "Insitu Shear Wave Velocity of Solid Waste from Surface Wave Measurements," *In Proceedings of the Second International Congress on Environmental Geotechnical*, 5-8 November, Osaka, Japan, pp. 97-102, 1996.

Kavazanjian, E., "Seismic Design of Solid Waste Containment Facilities," Proceedings of the 8th *Canadian Conference on Earthquake Engineering*, Vancouver, B.C.June, pp 51-89,1999.

Kavazanjian,E., Jr. "Evaluation of MSW properties using Field Measurements," Proc.,17th GSI/GRI Conference: Hot topic in *Geosynthetics-IV*,Las Vegas,Nevada,2003.

Koerner, R.M., and Soong, T-Y., "Leachate in Landfills: The Stability Issues,"Geotextiles and Geomembranes, vol.18, pp. 293–309, 2000.

Matasovic,N and Kavazanjian,E., "Cyclic characterization of OII landfill solid waste," *J.Geotechnical and Geoenvironmental Engineering*, ASCE, vol. 124, no. 3, pp. 197-210, 1998.

Sharma,H.D., Dukes,M.T., and Olsen,D.M. "Field Measurements of Dynamic Moduli and Poisson's Ratio of Refuse and Underlying soils at a Landfill site," *Geotechnics of Waste Fills-Theory and Practice*, STP 1070, ASTM, Philadelphia, PA,1990.

Towhata, I., Kawano, Y., Yonai, Y., and Koelsh, F. , "Laboratory tests on dynamic properties of municipal wastes," *In Proceedings of the 11th Conference in Soil Dynamics and Earthquake Engineering and the 3rd International Conference on Earthquake Geotechnical Engineering*, vol. 1, pp. 688–693,2004.

Zekkos.D, Bray,J.D., kavazanjian,E., Matasovic,N., Rathje, E., Riemer.M., and Stokoe,K., "Unit Weight of Municipal Solid Waste," *Journal of Geotechnical and GeoEnvironmental Engineering*, ASCE, vol. 132, no. 10, pp. 1250-1261, 2006.

Zekkos,D.,Bray,J.D., Stokoe,K., Kavazanjian,E., Rathji,E., Athanasopoulos,G.A., Riemer,M., Riemer,M., Matasovic,N., Lee,J.J.,and Seos,B., "Recent Findings on the static & Dynamic properties of MSW," *Geotechnics of Waste Management & Remediation*, *Geocongress*, vol. 9-12, pp . 176-183, 2008.

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