

COMPOSITIONAL AND LOADING RATE EFFECTS ON THE SHEAR STRENGTH OF MUNICIPAL SOLID WASTE

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ABSTRACT

Large scale triaxial compression and direct shear tests were performed on Municipal Solid Waste (MSW) collected from the Tri-Cities landfill to evaluate the monotonic stress-strain (or stress-displacement) response of MSW. The results indicate that the drained shear response may differ significantly depending on the specimen waste composition and the mode of shearing. Staged tests with varying shearing rates performed using triaxial and direct shear testing devices indicated that the response of MSW is significantly affected by the rate of shearing. Thus, the dynamic shear strength of MSW can be significantly higher than its static shear strength.

Keywords: Municipal Solid Waste, laboratory testing, seismic shear strength, strain rate effects

INTRODUCTION

Over the last two decades Municipal Solid Waste (MSW) landfills have evolved from uncontrolled waste disposal sites to engineered systems with stringent criteria for their location, operation, and closure. The evaluation of the static and seismic stability of MSW landfills is an important design consideration. The use of representative MSW material properties is required if stability analyses of landfills are to provide a reliable assessment of potential landfill performance. In particular, for dynamic analyses, these properties are required:

- MSW unit weight profile.
- Shear wave velocity (V_{so}) or small-strain shear modulus (G_{max}).
- Strain-dependent normalized shear modulus reduction (G/G_{max}) and material damping relationships.
- Dynamic shear strength.

In this paper, a concise review of the dynamic properties of MSW, incorporating recent findings of a collaborative NSF-funded research project, is first presented. Subsequently, the stress-strain response of MSW under slow and rapid monotonic loading is investigated. Preliminary recommendations on the dynamic shear strength of MSW are made based on the test data presented in this paper.

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REVIEW OF DYNAMIC PROPERTIES OF MSW

MSW unit weight

The selection of the MSW unit weight (γ) profile can significantly impact the results of dynamic analyses of landfills. Zekkos et al. (2006) presented in situ unit weight data and a comprehensive framework for developing a landfill-specific profile MSW unit weight versus depth within a landfill. Generalized MSW unit weight profiles that depend primarily on waste composition and compaction effort during placement of waste were also provided for use in preliminary analysis.

Small-strain shear modulus and shear wave velocity

The small-strain shear modulus (G_{\max}) is related to the shear wave velocity (V_{so}). The low-amplitude shear wave velocity of waste materials in a landfill can be measured in situ by various seismic methods. The Spectral Analysis of Surface Waves (SASW) method has become particularly popular in landfills, because it is reliable, non-intrusive, and cost-effective. For preliminary purposes and when landfill-specific data are not available, Kavazanjian et al. (1996) recommended typical low-amplitude shear wave velocity profiles for Southern California MSW landfills. Based on a review of additional data presented in the literature, Kavazanjian (1999) stated that these recommended shear wave velocity profiles provided reasonable estimates of V_{so} for MSW landfills in temperate and arid climates.

Zekkos (2005) and Zekkos et al. (2006) performed an extensive large-scale cyclic triaxial laboratory investigation to examine systematically the factors that affect the engineering properties of MSW. More than 90 cyclic triaxial tests were performed on 300 mm-diameter specimens from three different sample groups of solid waste collected from the Tri-Cities landfill, which is located in Northern California. Among other things, the small-strain shear modulus G_{\max} of MSW was found to be affected significantly by waste composition and confining stress. MSW unit weight, time under a sustained confining stress, and to a lesser degree loading frequency also affect G_{\max} of MSW.

Strain dependent normalized shear modulus reduction and material damping relationships

Normalized shear modulus reduction and material damping relationships for MSW have been recommended by various researchers (e.g., Idriss et al. 1995, Matasovic and Kavazanjian 1998, Augello et al. 1998b, and Elgamal et al. 2004). These recommendations are primarily based on back-analyses of the seismic response of the OII landfill located in Southern California. However, the OII landfill is a particular case of landfill, because it includes significant amounts of soil material as well as commercial and industrial waste (Matasovic and Kavazanjian 1998). In addition, there are important differences among the recommended curves.

The parameters that affect the strain dependent normalized shear modulus reduction and material damping relationships of MSW were also investigated as part of the collaborative study cited previously (e.g., see Zekkos, 2005). As presented in Zekkos et al. (2006), the strain-dependent normalized shear modulus reduction and material damping relationships are affected primarily by waste composition (i.e., amount of fibrous material larger than 20 mm) and confining stress. The normalized shear modulus reduction curves shift to the right (i.e., the threshold strain increases) as the amount of material larger than 20 mm increases or as confining stress increases. Correspondingly, material damping reduces at larger strains as the amount of fibrous material that is larger than 20 mm increases or as confining stress increases. The strain-dependent curves are not significantly affected by reasonable variations in MSW unit weight, time under confinement, or loading frequency.

The laboratory test results shown in Zekkos et al. (2006) were found to be in good agreement with the limited large-scale laboratory and in situ test results available in the literature and to some degree consistent with some of the recommended relationships estimated through back-calculation of the seismic response of the OII landfill. A set of strain-dependent normalized shear modulus reduction and material damping ratio relationships for MSW, which are a function of waste composition and confining stress, are recommended for the performance of dynamic analyses of MSW landfills. An

important advantage of the Zekkos et al. (2006) relationships is that they provide a sound basis for the selection of the most appropriate shear modulus reduction and damping relationships of MSW at selected depths within a particular landfill based on waste composition and confining stress.

Dynamic shear strength of MSW

Relatively less is understood regarding the dynamic shear strength of MSW. In practice, the seismic shear strength of MSW is often assumed to be equal to its static shear strength. Anderson and Kavazanjian (1995) commented that the use of the static shear strength for seismic conditions is probably conservative, because under short-term loading conditions less creep and relative displacement of the waste constituents will occur in the refuse, resulting in larger short-term stiffness and resistance to loading. Augello et al. (1998a, 1998b), following the 1994 Northridge earthquake, evaluated the seismic performance of five landfill facilities including four unlined waste units (OII, Toyon Canyon, Sunshine Canyon, and Lopez Canyon) and two geosynthetic-lined waste units (Chiquita Canyon and Lopez Canyon). The authors concluded that a reasonable range of dynamic friction angles of the MSW from these landfills is 33° to 38° . This paper presents data that provide additional insight on this important dynamic property of MSW.

WASTE CHARACTERIZATION & TESTING PROGRAM

Municipal Solid Waste material was collected from the Tri-Cities landfill located in the San Francisco Bay Area. Two boreholes extending to a depth of 9 m and 32 m were performed using a 760 mm bucket auger. Bulk material representative of fresh waste and older waste was sampled and placed in 39 55-gallon sealed drums. In addition, in situ unit weight tests (Zekkos et al. 2006) and shear wave velocity measurements (Lin et al. 2004) were performed. Information regarding the field activities at the Tri-Cities landfill is provided in Zekkos (2005).

Waste characterization procedures were developed to characterize the sampled waste. Based on the results of the waste characterization procedures, three sample groups were selected for large-scale laboratory testing. The characteristics of the sample groups are provided in Table 1. Group A3 is material sampled from a relatively large depth and was 15 years old at the time of drilling. Group C6 is material sampled from a different location of the landfill at relatively shallow depths and was 2 years old at the time of drilling. Group C3 was selected based on the waste characterization information as the most different sample group than the previously tested sample groups A3 and C6.

Samples from all three groups were tested using a large-scale triaxial test device ($d = 300$ mm, $h = 600$ - 630 mm) located at the Richmond Field Station of the University of California at Berkeley. Material from the A3 sample group was also transported to the University of Patras, Greece and was tested using a large-scale direct shear test device. The direct shear box has a square plan view with a side dimension of 300 mm and a total height of 180 mm.

Specimens were reconstituted in layers using a 100 N weight that was dropped repeatedly from a constant height to achieve a target unit weight. Specimens were prepared with material 100%, 62-76%, and 8-25%, by weight, smaller than 20 mm. The material was divided in the smaller and larger than 20 mm fraction based on the methodology of waste characterization, which is presented in detail in Zekkos (2005). Briefly, the material with particle size smaller than 20 mm consists primarily of soil-like material and includes the daily soil cover, soil materials and some fine waste inclusions. The fraction with particle size greater than 20 mm includes the waste fraction, which based on the waste characterization, consists primarily of paper, soft plastics, wood and small amounts of gravel. The larger than 20 mm fraction is primarily fibrous in nature and has a lower particle unit weight than the smaller than 20 mm fraction. Additional advantages of this segregation is that the finer fraction can be characterized according to geotechnical engineering practices and can also be tested in typical geotechnical laboratory testing devices. The waste characterization of the Tri-Cities landfill suggested that 50-75% of the combined MSW material by weight has particles smaller than 20 mm.

DIRECT SHEAR TESTING INVESTIGATION

Static response

Direct shear tests have been performed on MSW specimens from the A3 sample group that included 100%, 62%, and 12% material with particles smaller than 20 mm. The presence of material with particles larger than 20 mm is typically identified as the main cause for the relatively large shear strength of MSW, because this larger, fibrous material is thought to act as internal reinforcement within the waste. Tests were performed at 5 normal stresses and the results, summarized in Figure 1, indicate that the shear strength of waste that contains 100%, 62%, and 12% <20 mm material is not significantly different, i.e. the increased amount of fibrous material does not appear to increase the shear strength of MSW in direct shear. This response is a function of the manner in which the waste material is prepared and the orientation of shearing during the test. For the test results shown in Figure 1, the waste material was compacted with a drop hammer (Zekkos, 2005) so that the fibrous material within the MSW tends to be aligned in a nearly horizontal orientation. This specimen preparation method was employed, because it mimics the waste placement operations commonly observed in the field (e.g., Matasovic and Kavazanjian, 1998). Thus, in direct shear testing, the fiber orientation is approximately parallel to the direction of shearing and the fibrous materials do not contribute significantly in the shear resistance of the MSW. A unique non-linear shear strength envelope can be defined for all tests regardless of the amount of fibrous material present in the MSW. As shown in Figure 2, the secant friction angle reduces with increasing confining stress, similar to what is observed for many soils (e.g., Duncan and Wright, 2005). The direct shear total strength envelope for the Tri-Cities landfill waste, which is shown in Figure 1, can be described by:

$$\tau = c + \sigma_n \cdot \tan(\phi) \quad (1)$$

where:

τ is the shear strength of Tri-Cities MSW in direct shear;

σ_n is the total normal stress;

c is the cohesion intercept, which is equal to 15 kPa; and

ϕ is the friction angle given by $\phi = \phi_o - \Delta\phi \cdot \log\left(\frac{\sigma_n}{p_a}\right) = 41^\circ - 12^\circ \cdot \log\left(\frac{\sigma_n}{p_a}\right)$

so that $\phi_o = 41^\circ$ is the friction angle at a normal stress of one atmosphere (i.e., $p_a = 101.3 \text{ kPa}$), and $\Delta\phi = 12^\circ$ is the change of the friction angle over one log-cycle change of normal stress.

Table 1: Characteristics of tested MSW sample groups

	A3	C6	C3
Borehole	BH-2	BH-1	BH-2
Depth, m	25.6-26.2	7.6-9.6	3.5-4.5
% moisture content ¹	12	13	23
% organic ¹	15-30	10-16	20-36
Age (years)	15	<1	2

¹Information for the smaller than 20 mm material.

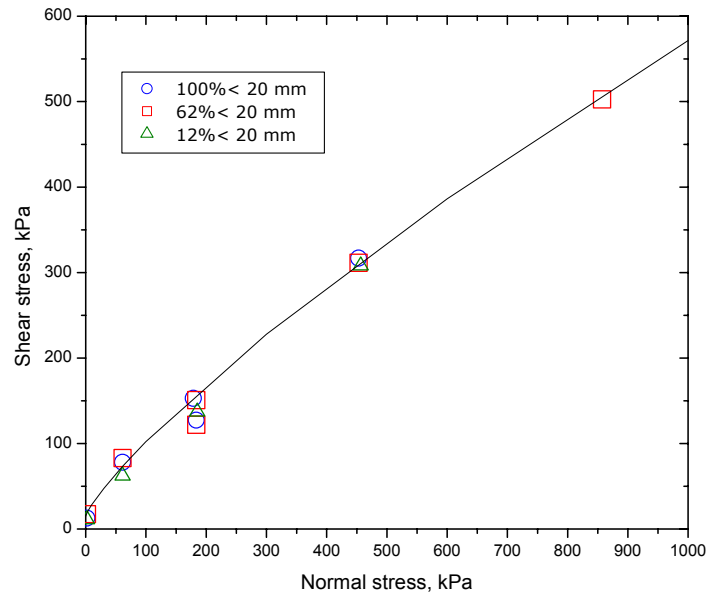


Figure 1. Shear strength of Tri-Cities landfill MSW with varying waste composition.

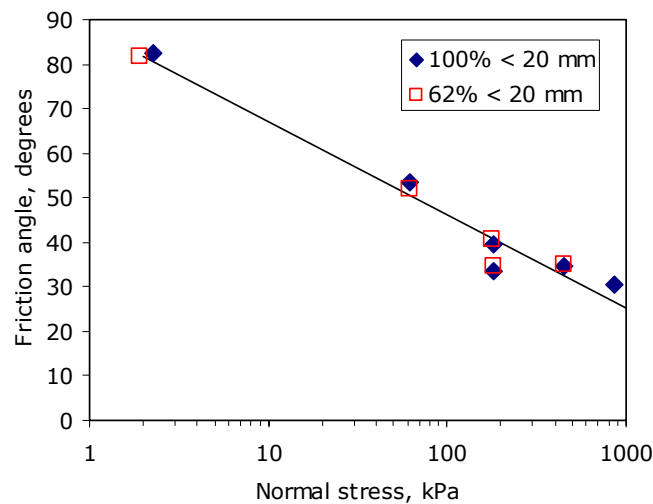


Figure 2. Effect of normal stress on the secant friction angle of MSW (assuming $c = 0$).

Recognizing that shearing occurred parallel to the fibers in these tests, and thus the fibers do not appear to contribute to the shearing resistance of waste material, a series of direct shear specimens were prepared with identical composition in a specially designed split preparation mold. The mold has a plan view with dimensions 180 mm x 300 mm and a height of 300 mm. Specimens were prepared in this mold in the same manner as the specimens that were prepared in the direct shear box. Once the specimen preparation was completed, the mold was disassembled and the specimen was placed sideways in the shear box. As a result, fibers were now oriented roughly perpendicular to the horizontal shear surface imposed in the direct shear box (i.e., the shear surface is forced to occur at approximately 90 degrees to the initial fiber orientation).

The shear stress-displacement response of two specimens with identical composition (62% smaller than 20 mm material) at the same normal stress of 2 kPa and approximately the same unit weight is compared in Figure 3. The only difference between the two specimens is that in specimen UP-10 the fibers are horizontally oriented, parallel to the shear failure surface; whereas in specimen UP-15, the fibers are oriented perpendicular to the horizontal failure surface. The stress-displacement response is significantly different for these two specimens. Specimen UP-15 exhibits initially a softer response,

but then an upward curvature is observed until the termination of the test at a horizontal displacement of 57 mm. This upward curvature is attributed to the progressive contribution of the fibrous materials in the shear resistance of the MSW. At a horizontal displacement of 55 mm, the mobilized shear stress of specimen UP-15 is about 2.1 times higher than the mobilized shear stress of specimen UP-10, which includes horizontally oriented fibers. Thus, it is clear that the shear resistance of MSW is anisotropic and that the shear resistance of MSW measured in typical direct shear testing is representative of the shear resistance along the weakest orientation of the material where the contribution of the fibrous waste materials is minimal (i.e. parallel to the fiber orientation).

Displacement-rate effects

Staged direct shear tests were performed to evaluate displacement rate effects on the strength of MSW and to provide insight for estimating the dynamic strength of MSW. The shearing rate was modified during the same test to eliminate scatter due to specimen variability. Tests were performed at displacement rates of 0.1 mm/min and 5 mm/min. An example of the results from these tests is shown in Figure 4 for a specimen with 62% <20 mm material and fibers oriented parallel to the horizontal failure surface. The stress-displacement response suggests that as the displacement rate increases, the mobilized shear stress increases. Similar results were observed for two additional specimens with 12% <20 mm material. One of these tests included horizontally oriented fibers whereas the second one included vertically oriented fibers. The results are summarized in Figure 5. The displacement-rate effects for the specimens with horizontally oriented fibers were similar. The specimen with vertically oriented fibers (i.e., fibers oriented perpendicular and across the shearing surface) yielded more pronounced displacement-rate effects.

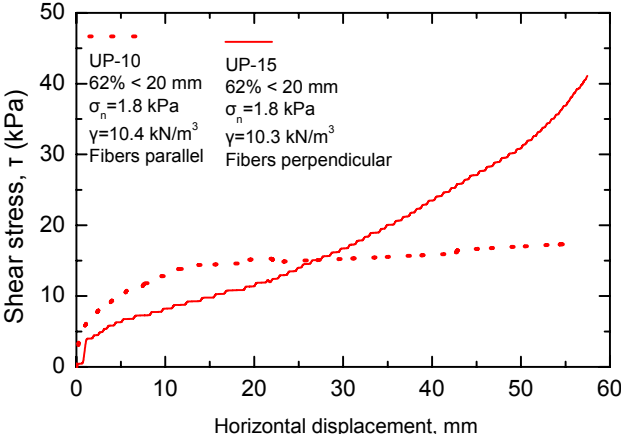


Figure 3. Comparison of the responses of MSW in direct shear testing for specimens where fibers are oriented parallel or perpendicular to the horizontal shear surface.

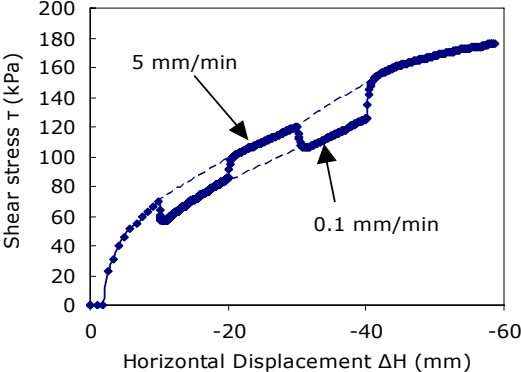


Figure 4. Response of MSW in direct shear testing sheared at two displacement rates ($\sigma_n=150$ KPα, $\gamma_t=12.0$ kN/m³, 62%<20 mm material).

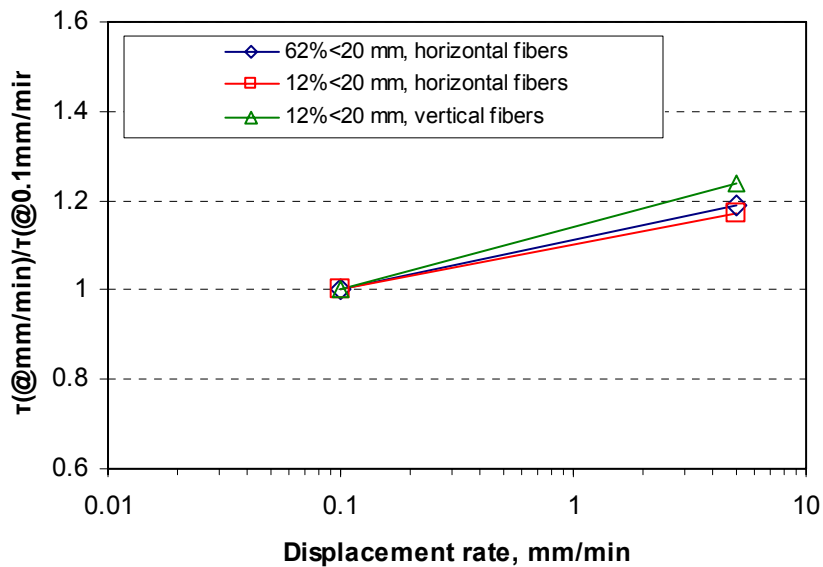


Figure 5. Summary of direct shear tests sheared at two displacement-rates.

TRIAXIAL COMPRESSION TESTING INVESTIGATION

Static monotonic testing

A total of 21 large-scale triaxial compression tests have been performed to investigate the monotonic triaxial response of MSW. The effects of compaction effort, composition, confining stress, unit weight, and strain rate were investigated. Detailed discussions of the procedures and results are presented in Zekkos (2005).

Figure 6 illustrates the stress-displacement response of three specimens compacted with the same compaction effort and sheared at a confining stress of 75 kPa with a strain rate of 0.5%/min. Specimen A3-2L includes 100% <20 mm material, specimen A3-7L includes 62% <20 mm material and specimen A3-12L includes only 14% <20 mm material. Specimen A3-2L reaches peak shear stress conditions at an axial strain of about 22% and then exhibits a post-peak reduction in shear resistance. When fibrous, >20 mm material is included (i.e., Specimen A3-7L) the specimen exhibits initially a softer response, but at larger strains exhibits progressively an upward curvature without reaching peak shear stress conditions. Similarly, specimen A3-12L, which includes 14% <20 mm material by weight, exhibits a more pronounced upward curvature. The upward curvature of the stress-strain curve in triaxial testing has been reported by previous researchers (e.g., Jessberger and Kockel 1993, Grisolia et al. 1995), but to the authors' knowledge there has been no satisfactory explanation for the triaxial compression response and the apparent inconsistency with the shearing response typically observed in direct shear testing.

The upward curvature observed for MSW specimens with >20 mm material can be attributed to waste composition. This is consistent with the findings of the direct shear test results where the upward curvature was observed only when the relative orientation of the fiber and shear failure surface allowed the mobilization of fibrous materials. In triaxial testing the failure plane would be oriented at approximately an angle of $45^\circ + \phi/2$. For a friction angle of 30 to 40 degrees, the failure plane would be at an angle of 60 to 65 degrees from the horizontal. As a result, in triaxial testing the failure surface is at an angle of about 60 degrees from the fiber orientation. Previous studies (e.g., Jewel and Roth, 1987) in reinforced soils suggest that when the failure surface is oriented about 60 degrees to the fiber orientation, the reinforced material exhibits the highest shear strength. Zekkos (2005) systematically

studied the triaxial compression test results of the present investigation along with the data in the literature and by implementing a limiting strain criterion and accounting for the loading stress paths in triaxial testing concluded that a reasonable friction angle of MSW in triaxial compression testing ranges between 34 and 44 degrees with 39 degrees being representative of the data overall.

Strain-rate effects

Variable strain-rate monotonic tests were performed on three specimens from the three waste groups and of varying waste composition. Specimen C3-1L included 100% <20 mm material and was sheared in stages at strain rates of 0.5%/min, 5%/min, and 50%/min. Specimen C6-4L included 62% <20 mm material and was sheared in stages at strain rates of 0.5%/min and 50%/min. Specimen C3-3L included 20% <20 mm material and was sheared in stages at strain rates of 0.5%/min and 50%/min. Results are shown in Figure 7. The complete stress-strain response for each specimen at each strain rate can be estimated from these staged tests with reasonable accuracy. The ratio of the mobilized shear stress at any strain rate divided by the mobilized shear stress at a strain rate of 0.5%/min was estimated and is shown in Figure 8. For all specimens, the mobilized shear stress increases with increasing strain rate. However, strain rate effects appear to be more pronounced for specimens with higher amounts of >20 mm material (C3-3L) than specimens with lower amounts of >20 mm (C6-4L).

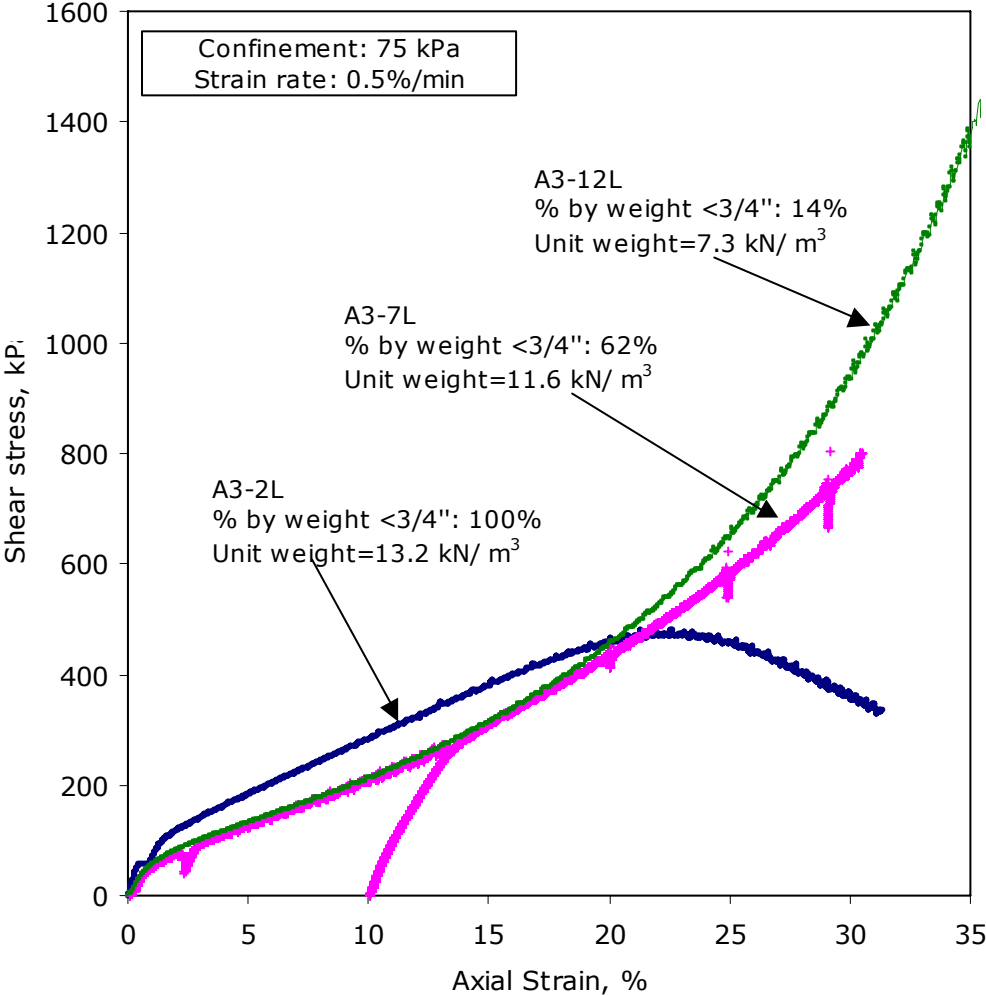


Figure 6. Responses of MSW in monotonic triaxial compression testing for specimens with varying waste compositions.

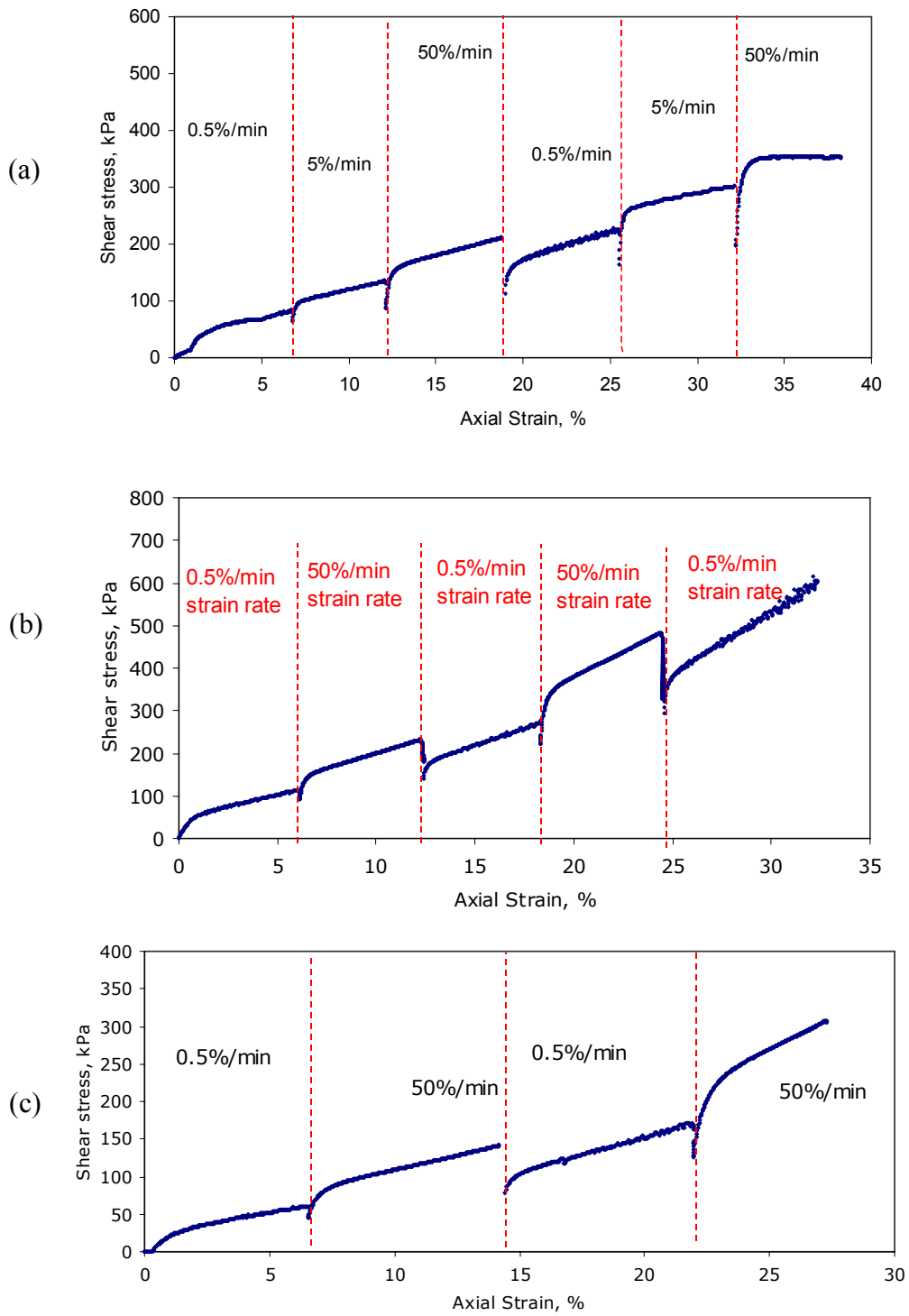


Figure 7. Responses of specimens tested with varying strain rate. a. Specimen C3-1L with 100% <20 mm, b. Specimen C6-4L with 62% <20 mm, c. Specimen C3-3L with 20% <20 mm.

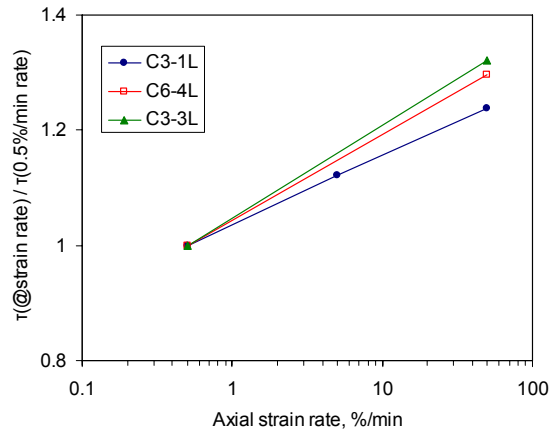


Figure 8. Strain rate effects for specimens with varying waste compositions. Specimen C3-1L has 100%, Specimen C6-4L has 62%, and Specimen C3-3L has 20% < 20 mm material.

DISCUSSION OF RESULTS

Triaxial and direct shear test results indicate that the shearing rate affects the mobilized shear resistance of MSW. Although the strain rate in direct shear is not known, it is reasonable to assume that if the displacement rate increases by a factor of 50 (i.e. from 0.1 mm/min to 5 mm/min), the unknown strain rate will also increase by the same factor. With this assumption the direct shear test results can be compared directly with the triaxial shear test results as shown in Figure 9.

The results of the variable strain rate direct shear tests for specimens with fibers oriented parallel to shear (with 62% and 12% <20 mm material) are in good agreement with the triaxial test for a specimen with 100% <20 mm material. This is consistent with the previous observation that there is a negligible influence of the fibers for samples with fibrous materials oriented parallel to the failure surface. The strain-rate effects of the direct shear specimen with 12% <20 mm material and fibers oriented perpendicular to the failure surface are higher than the direct shear specimens with fibers oriented parallel to the failure surface, which is similar to the trends observed in triaxial testing. However, the strain-rate effects in direct shear appear to be less pronounced than in triaxial testing. This may be due to the orientation of the fibers to the shearing failure surface, which is about 60 degrees in triaxial testing as opposed to 0 or 90 degrees in direct shear testing).

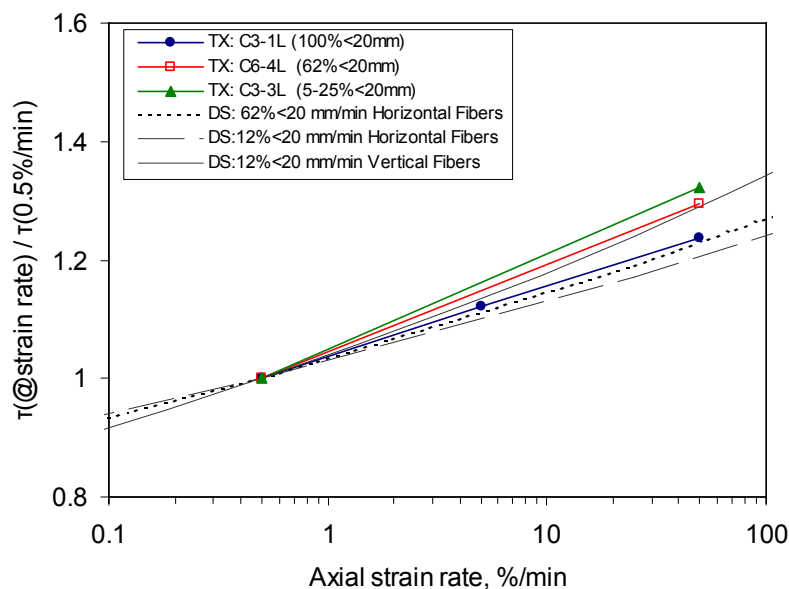


Figure 9. Strain rate effects observed in large-scale triaxial and direct shear tests on MSW

In Figure 9, for a 100-fold strain rate increase (from 0.5%/min to 50%/min), the mobilized shear stress increase is about 25% for specimen C3-1L (100% <20 mm material), about 30% for specimen C6-4L (62% <20 mm material), and 32% for specimen C3-3L (20% <20 mm material). These observations indicate that the dynamic strength of MSW can be significantly higher than its static shear strength. From numerical analyses, the strain-rate of strong earthquake ground motions is estimated to be approximately 3000%/hr or 33%/min. which is approximately 100 times higher than the strain rate of 0.5%/min that is commonly used to estimate static shear strength. Based on these considerations and the results of these investigations, the dynamic shear strength of MSW is estimated to be about 30 percent greater than its static shear strength (i.e. loading rate factor of 1.3). Because of the scarcity of the data, a conservative estimate for use in practice would be that the dynamic shear strength is about 1.2 times its static shear strength. These findings are somewhat consistent with the recommendations of Augello et al. (1998) discussed previously and the finding that the seismic performance of landfills during previous earthquakes has generally been satisfactory. Finally it should be noted that the results presented in this paper are representative of waste material at moisture contents of 10-20%. As a result, strength degradation due to pore pressure increase, as has been observed for saturated clay soils, was not considered.

CONCLUSIONS

A series of large-scale direct shear and triaxial compression tests have been performed on MSW collected from the Tri-Cities landfill located in the San Francisco Bay Area. The results indicate that:

- Large-scale direct shear tests on MSW provide an assessment of the shear strength of MSW along the weakest orientation of the waste material. Shearing typically occurs parallel to the the orientation of fibrous materials within the waste, and thus, the contribution of the fibrous materials is minimal.
- Direct shear tests performed with waste fibers oriented perpendicular to the shear failure surface yield an upward curvature in the stress-displacement response, which is attributed to the progressive mobilization of the fibrous materials within the waste matrix.
- The stress-strain response in triaxial compression tests is strongly dependent on waste composition. The upward curvature observed in the triaxial compression tests of this study as well as the tests available in the literature can be explained by the progressive mobilization of fibrous materials during shearing. Shearing in triaxial compression occurs at an angle of about 60 degrees from the horizontal orientation of the fibers. As a result, the shear resistance of MSW in triaxial compression is higher than that observed in direct shear where the fibers are typically oriented parallel to the shear surface.
- Variable strain rate direct shear and triaxial compression tests on waste of varying composition indicate that strain rate effects on the strength of MSW are important. The shear resistance of MSW was found to increase with increasing strain rate. The dynamic shear strength of MSW is expected to be about 20% greater than its static shear strength.

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REFERENCES

- Anderson DG and Kavazanjian E. "Performance of Landfills Under Seismic Loading," Proc. Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics. Vol. 3, St. Louis, Missouri, 1557-1587, 1995.
- Augello AJ, Bray JD, Seed RB, Matasovic N, and Kavazanjian E. "Performance of Solid-Waste Landfill During the Northridge Earthquake", Proc., NEHRP Conf. on Research on the Northridge, California Earthquake of January 17, 1994, CUREe, Los Angeles, CA, pp. II-71 to II-80, 1998a.
- Augello AJ, Bray JD, Abrahamson NA and Seed RB. "Dynamic properties of solid waste based on back-analysis of OII landfill". ASCE Journal of Geotechnical and Geoenvironmental Engineering, 124 (3): 211- 222, 1998b.
- Duncan, J. M., Wright, S. G. Soil strength and slope stability, John Wiley & Sons Inc, 2005.
- Elgamal A, Lai, T, Gunturi R. and Zeghal M. "System identification of landfill seismic response". Journal of earthquake engineering, 8 (4): 545-5666, Imperial College Press, 2004.
- Grisolia M, Napoleoni Q and Tangredi G. "The use of triaxial tests for the mechanical characterization of municipal solid waste", Proc. of the 5th International Landfill Symposium - Sardinia '95, 2: 761-767. Cagliari (I): CISA, 1995.
- Idriss IM, Fiegel G, Hudson MB, Mundy PK and Herzig R. "Seismic response of the Operating Industries landfill. In Earthquake design and performance of solid waste landfills", ASCE Geotechnical Special Publication No.54, editors M.Y. Yegian, W.D. Liam Finn, pp.83-118, 1995.
- Jessberger HL and Kockel R. "Determination and assessment of the mechanical properties of waste". Waste disposal by landfill - Green '93. R.W. Sarsby (edit). pp. 313-322. Rotterdam- Balkema, 1993.
- Jewell RA and Wroth CP. "Direct shear tests on reinforced sand", Geotechnique, 37, No. 1, pp. 53-68, 1987.
- Kavazanjian E, Matasovic N, Stokoe KH and Bray JD. "In situ shear wave velocity of solid waste from surface wave measurements". Proc. Environmental Geotechnics, Kamon, (editor), Balkema, 1, pp. 97-102, 1996.
- Lin Y-C, Rosenblad B and Stokoe KH. "Data Report on Shear Wave Velocity Profiles Determined by SASW Method at: Altamont Landfill, Redwood Landfill, and Tri-Cities Landfill". Geotechnical Engineering Report GR04-3, Geotechnical Engineering Center, Civil Engineering Department, The University of Texas at Austin, October 29, 2004.
- Matasovic N and Kavazanjian E. "Cyclic characterization of OII landfill solid waste". Journal of Geotechnical and Geoenvironmental Engineering, March, 124 (3), pp. 197-210, 1998.
- Kavazanjian E. "Seismic Design of Solid Waste Containment Facilities. In Proceedings of the Eight Canadian Conf. on EQ Engrg., Vancouver, BC, June, pp. 51-89, 1999.
- Zekkos (Zeccos) DP. "Evaluation of static and dynamic properties of Municipal Solid-Waste". Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Department of Civil and Environmental Engineering, University of California, Berkeley, Fall. 2005 (Also available at <http://waste.geoengineer.org>).
- Zekkos D, Bray JD, Riemer M, Kavazanjian E, Matasovic N, Rathje E and Stokoe KH. "Unit Weight of Municipal Solid-Waste". ASCE Journal of Geotechnical and Geoenvironmental Engineering, 132 (10), pp.1250 -1261 2006.
- Zekkos D, Bray JD and Riemer MF. "Shear modulus reduction and material damping relationships for Municipal Solid-Waste", Proceedings of the 8th U.S. National Conference on Earthquake Engineering, April 18-22, 2006, San Francisco, California, USA, Paper No. 1324, 2006. (Also available at <http://waste.geoengineer.org>)