LOADING RATE EVALUTION ON THE MECHANICAL BEHAVIOR OF SATURATED MSW MATERIALS

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SUMMARY: Landfill catastrophic failure in last decade indicates that the knowledge level of these materials behaviour in the geotechnical point of view is not properly adequiet however many attempts and researches in this way have been made. In the region with high seismic activity, mechanical response of MSW materials under quick and dynamic loading condition is one of the issues which should be addressed however there are some evidences concerning the higher resistance of MSW materials under dynamic loading condition. As a part of an extensive research, using large triaxial apparatus and triaxia test in undrained condition, the effect of loading rate on the level of shear strength and pore water pressure generation pattern under different loading rate were evaluated. The loading rates were changed from a base value achived according to head (1980) relationship to higher values representing ground motions. The results confirmed the achievement of Augello et al (1995, 1998), Zekkos (2005) and Zekkos et al. (2007) concerning higher level of shear resistance of MSW materials under dynamic loading condition.

1. INTRODUCTION

In the regions with high seismic activitry, the stability issues during strong ground motions is a matter of concern and because of this reason the mechanical respnse of MSW materials under dynamic loading condition should be considered. Especially in cases which the leachate collection system is not included in the lanfill construction, the MSW materials state will be saturated. The pore water pressure generation during quyick loading is one of the issues which should be considered due to its effect on the stability issues.

Augello et al. (1995) using Kavazanjian et al. (1995) recommendations for estimation of unit weight and shear strength, evaluated the seismic performance of landfills during the 1994 Northridge earthquake. They also employed the average shear modulus reduction and material damping curves recommended by Kavazanjian and Matasovic (1995) and those by Vucetic and

Dobry (1991). According to their achievments static and dynamic friction angles for a factor of safety equal to 1.2 to range between 19 and 35 degrees and 30 and 40 degrees, respectively. They concluded that the dynamic strength of the waste fill is higher than the shear strength of MSW materials in static condition.

Augello et al. (1998) using the shear wave velocity and unit weight of MSW recommended by Kavazanjian et al. (1996) revised their former evaluation of the seismic performance of solid-waste landfills during the 1994 Northridge earthquake. Choosing a more conservative level of stability in static condition with assuming a factor safety of 1.3, they estimaed static and dynamic values of internal friction angle from 25 to 41 and 27 to 45 degrees, respectively. These findings indicated that the dynamic strength of waste fill is higher than the conservative estimates of static strength. The authors suggested the middle values of this range, 33 degrees to 38 degrees, to be appropriate for use in design and analysis.

Zekkos (2005) stated that the strain-rate of strong earthquake ground motions from numerical analysis is estimated to be approximately 2000%/hr or 33%/min. According to these values this researcher performed several large scale triaxial tests on MSW samples with different fiber content under various strain rate changing from 0.5%/min to 50%/min. The results suggested that as the strain-rate increases the material becomes stiffer. The increase of shear strength level of MSW materials depending on the fiber content changed from 25% to 32% for a 100-fold strain rate increase (Figure 1.).

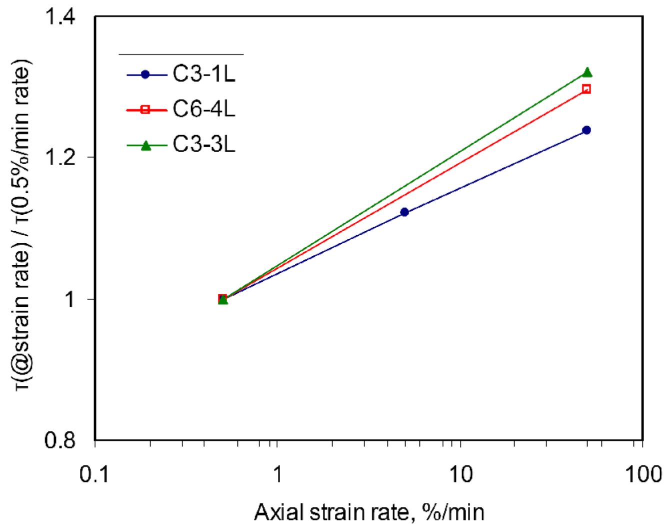

Figure 1. Strain rate effects on the mechanical response of MSW materials with different fiber content (Zekkos, 2005)

Based on the results of these investigations this researcher concluded that the dynamic shear strength of MSW is larger than the static shear strength by a factor of 1.25 to 1.3 which due to the scarcity of the data a factor of 1.2 was suggested to estimate a conservative level of dynamic shear strength from static shear strength.

Zekkos et al. (2007) reported the results of staged direct shear tests on MSW materials with different fiber content and fiber orientation and under different values of displacement rate. Tests were performed at displacement rates of 0.1 mm/min and 5 mm/min. The stress-displacement response suggests that as the displacement rate increases, the mobilized shear stress increases.

The results of this research are illustrated in Figure 2. The displacement-rate effects for the specimens with horizontally oriented fibers were similar. The specimen with vertically oriented fibers yielded more pronounced displacement-rate effects.

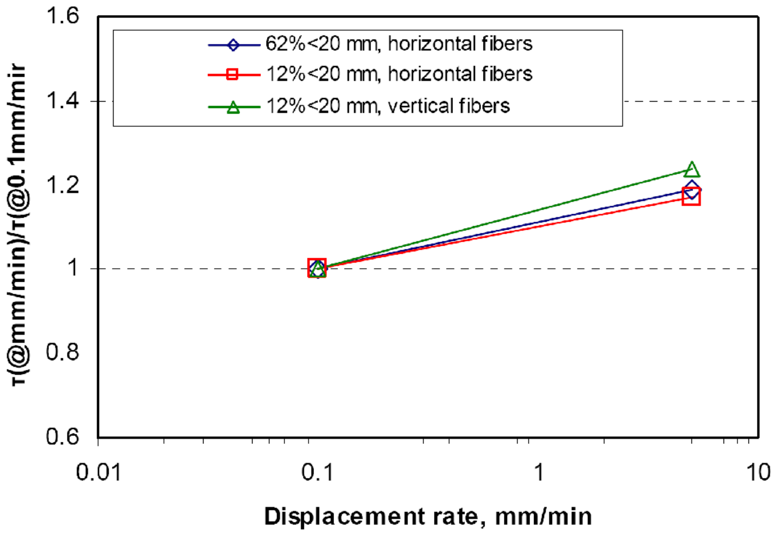

Figure 2. Displacement rate effects on the mechanical response of MSW materials with different fiber content and fiber orientation (Zekkos et al., 2007)

As could be observed in this Figure, increasing the dispalacement rate from 0.1 to 5 mm/min, increases the level of shearing strength up to 20% which is relatively lower than the values reported by Zekkos (2005). This difference could be due to difference in shearing mechanisams.

2. EXPRIMENTAL PROGRAM

A large triaxial test apparatus was employed to evaluate the loading rate factor on the mechanical behaviour of MSW materials. This apparatus includes a loading frame with a capacity up to 300 kN manufactured by EMIC company which was capable to apply load with a wide range of rates changing 1 to 1000 mm/Min. The loading frame also had a load cell with precision of 1 N. (Figure 3.).

The loading frame was controlled with software named TESC which also represented the loading graph in the form of force-displacement. Another software named VEGA controlled the different aspects of triaxial test approach like applying confining pressure, back pressure in conventional manner and different stress paths as well using a servo control system.

The waste materials used in this research was fresh. The density of samples was around 8 kN/m^3 and the water content of samples was 115%. The fiber content of materials also was around 10% by weight.

The samples which was used in this research were collected from Metropolitan landfill of Salvador, Brazil that in the landfilling stage, daily cover is not used and the soil content of waste materials is almost zero therefore the collected samples did not contain soil fragments.

To compact the sample the loading frame of triaxial apparatus was used and all samples compressed up to 8 kN for 2 hours. The sample's height was limited to 30 cm during compaction stage but because of rebound tendency of sample the average height of samples was around 35 cm.

After preparation of sample and filling the chamber, with a low value of back and cell pressure leading to a confining pressure of 10 kPa, a flow was applied to sample for at least 2 houre. The target value of skempton coefficent to check the level of sample's saturation was chosen 0.95, however there are some debate concerning the suitability of this factor as a criterion of MSW materials satuation.

Figure 3. A view of employed loading frame and triaxial chamber

After flow saturation and checking the B value, in the case of low saturation degree, the saturation was continued by increasing the back and cell pressure parallely and with 50 kPa increament to reach the saturation target.

After saturation stage, the samples were consolidated. The consolidation period was up to 24 hour which the volume change of sample was almost constant.

The base value for the loading rate in the shearing stage was evaluated using the equation suggested by Head (1984):

$$v = \frac{\varepsilon_a . h}{\psi . t_{100}} \qquad (1)$$

Where, ν: loading rate, ε_a: maximum axial strain, h: sample's height, ψ: a constant which in the case CD test is 8.5 and 14 depending on the drainage path and in the case of CU test is 1.8, t_{100}: is estimated from intersection point of two semi line part of variation of valume change to square of time.

According to this equation the loading rate was chosen 0.8 mm/min. This value is compatible with the loading rate reported by Carvalho (1999), 0.7 mm/min, and Jessberger & Kockel (1993), 1 mm/min.

To evaluate the effect of loading rate two other loading rates were chosen 2.5 and 7.5 mm/min. According to average height of samples before shearing stage, these two values are 1 and 3%/min which are lower than upper bond values reported by Zekkos (2005). The reason of choosing such a relatively low value of loading rate comparing strain rate imposed to soil in strong motion are, (1) limitation due to loading rate in the case of CU tests and (2) Since the employed waste materials were fresh with high values of non-homogeneity, the samples were susceptible to buckling during shearing phase especially in higher values of loading rate and (3) the rate of data acquisition was not enough to record data in high values of loading rate. The list of performed tests are summarized in Table 1.

Table 1. List of performed tests

No.	Confining pressure (kPa)	Loading rate (mm/min)	Saturation Condition
1	50	0.8	Saturated
2	150	0.8	Saturated
3	300	0.8	Saturated
4	50	0.8	Saturated
5	150	0.8	Saturated
6	300	0.8	Saturated
7	50	0.8	Un-saturated
8	150	0.8	Un-saturated
9	300	0.8	Un-saturated
10	50	2.5	Saturated
11	150	2.5	Saturated
12	300	2.5	Saturated
13	50	7.5	Saturated
14	150	7.5	Saturated
15	300	7.5	Saturated

As could be observed in Table.1, all series of tests have been conducted under three confining pressure of 50, 150 and 300 kPa. Except one series all samples were saturated before consolidation stage and all of the tests were performed under un-drained condition.

2. TEST RESULTS

The results of CU triaxial tests on saturated samples and with loading rate of 0.8 mm/min represented in Figure 4. The main characteristics of the MSW mechanical behavior can be observed in this graph: the upward concave in deviatoric stress x axial strain curve and the pronounced increase of the pore water pressure during the shearing process.

The mechanical response of MSW materials under shearing has been reported by researchers such as Jessberger & Kockel (1993), Grisolia & Napoleoni (1995), Carvalho (1999), Machado et al. (2002, 2008), Towhata et al. (2004), Zekkos (2005) and Nascimento (2007).

Researchers like Vilar & Carvalho (2002) and Towhata et al. (2004) believed that the existence of the fibrous material in waste (papers and plastics) is the source of such a pronounced starin hardening. Zekkos (2005) stated that during triaxial compression, under the increasing vertical load and the increasing anisotropic conditions, the initial horizontal structure of the specimen will become even more pronounced and this could lead to a further increase in strength.

The pattern of pore water pressure generation is compatible with the reported results by Carvalho (1999) and Nascimento (2007). The pattern of pore water pressure generation is similar to that observed in peat materials, as reported by Oikawa & Miyakawa (1980), Yamaguchi et al. (1985), Cola & Cortellaszzo (2005) and Mesri & Ajlouni 2007.

It is believed that the waste particles compressibility plays a very important role in this behavior which during the shearing phase the waste particles were squeezed leading a decrease in voids intra and inter particles and cause accumulation of water in the space between sample boundaries and membrane

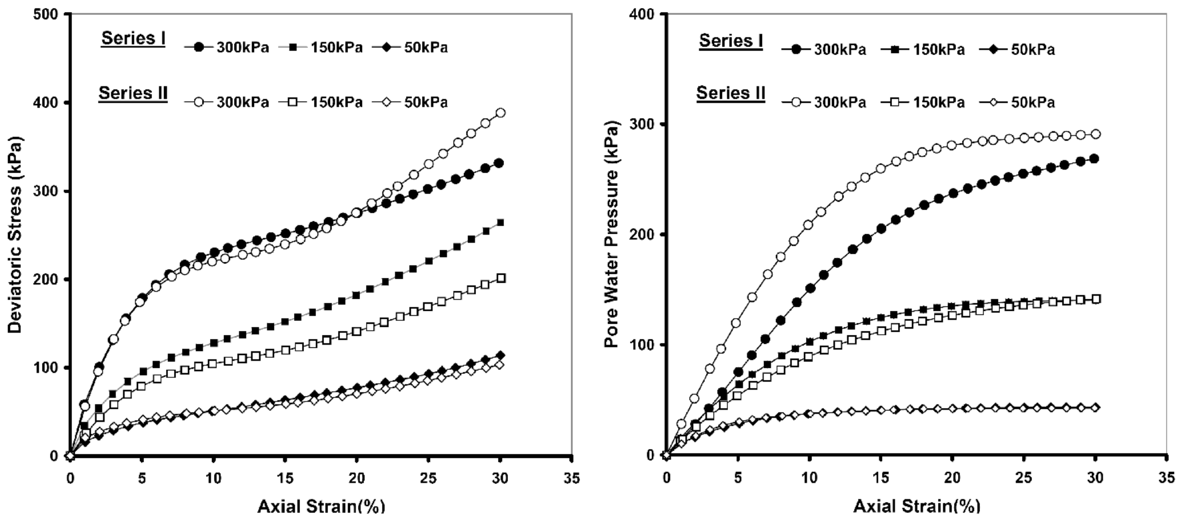

Figure 4. Results of triaxial tests on saturated samples sheared at 0.8 mm/min

The results of tests on the samples without preliminary saturation are presented in Figure 5. As could be observed in this graph the trend of pore water pressure generation is similar to saturated samples and irrespect to the saturation condition of samples approach to confing pressure level. The reason could be attribured to high water content and compressibility of materials which during consolidation stage, the water content will approach to saturation state.

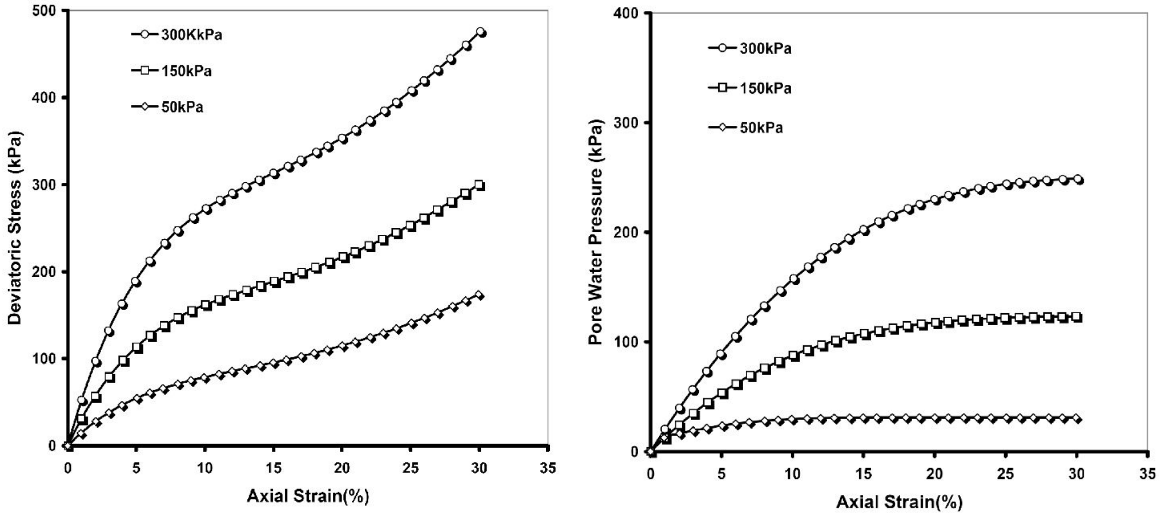

Figure 5. Results of triaxial tests on un-saturated samples sheared at 0.8 mm/min

In Figure 6 the results of triaxal tests on saturated samples sheard at different loading rate are presented. As could be observed increasing the loading rate leads to increase in the shear strength of samples. It is also clear that stiffness of sample with inceasing the loading rate becomes higer which is compatible with Zekkos (2005) achievements.

The final level of pore water pressure generated in testd samples under higher level of sloading rate is the same as samples tested at 0.8 mm/min, however the rate of pore water pressure generation seems that decrease with the loading rate. The reason of such a lower rate of pore water pressure under higher loading rate could be due to time which the pore water need to be stabilized.

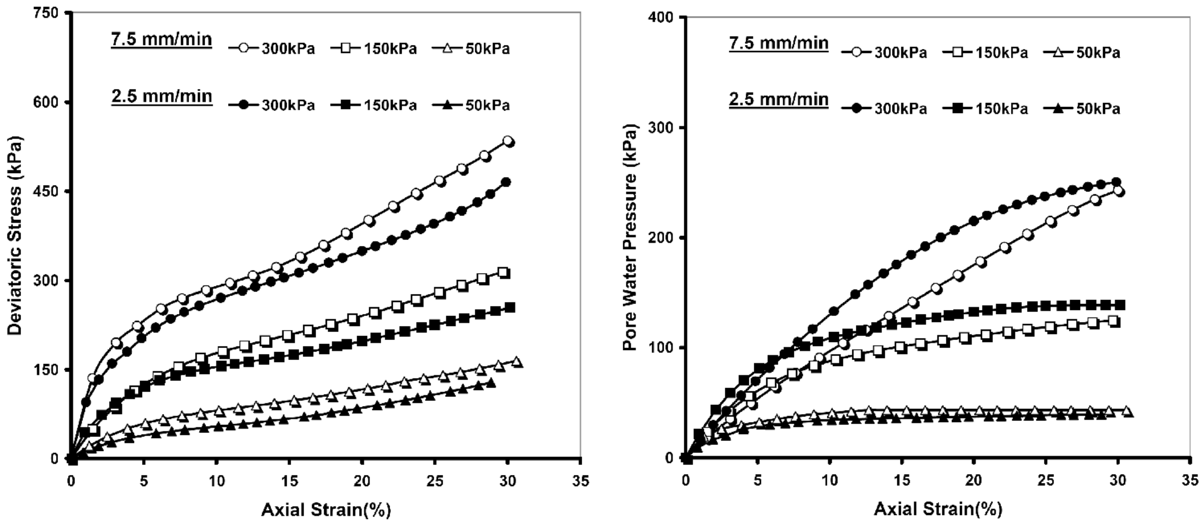

Figure 7. Results of triaxial tests on samples sheared at 2.5 and 7.5 mm/min

3. ANALYSIS AND DISCUSSION

Interpretation of triaxial and direct shear tests performed on MSW materials based on the Mohr-Coulomb constitutive model is very common in the litatuire; however compressibility of MSW materials componenets and also existing foil like reinforcing element leads to the situation which these type of materials do not follow the frame work represented by this model.

Because of upward concave in the mechanical response of MSW materials under triuaxial loading condition, all of the researchers are agree that a MSW failure criterion should be strain dependent, but the level of shear strain to be considered is still the source of debates.

Using Mohr-Coulomb constitutve model which is the most poular model to predict geo-materials, the results of performed test were analyzed. Achieved internal friction angle and cohesion intercept factor in 5% increment of axial strain up to 20% has been represented in Figure 8.

The resean of choosing an upper limit of 20% to estimate strength parameter of MSW materials was ommiting the risk of cap and pedestal effect on the strength level of samples.

It could be clearly observed that with increasing of axial strain level both shear strength facyor will increase and this is the exact issue which force researcher to choose stran dependent criteria for interpretation of MSW materials.

According tothese graphs, with increasing loading rate the level of internal friction angle will increase slightly however in the case of cohesion intercept there is not any clear trend.

It seems also with saturation the sample both of strength parameter of MSW materials will decrease.

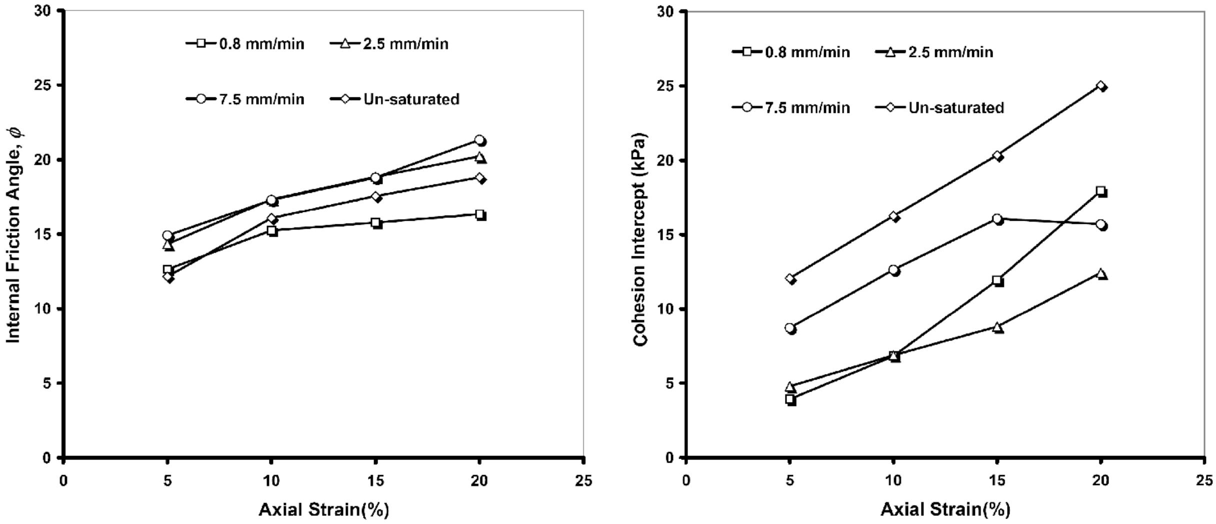

Figure 8. Variation of shear strength parameter of MSW materials with loading rate and satuation

To evaluate the effect of ooading rate on the shear strength level of MSW materials shear envelope of these materials achieved at 20% of axial strain is represented.

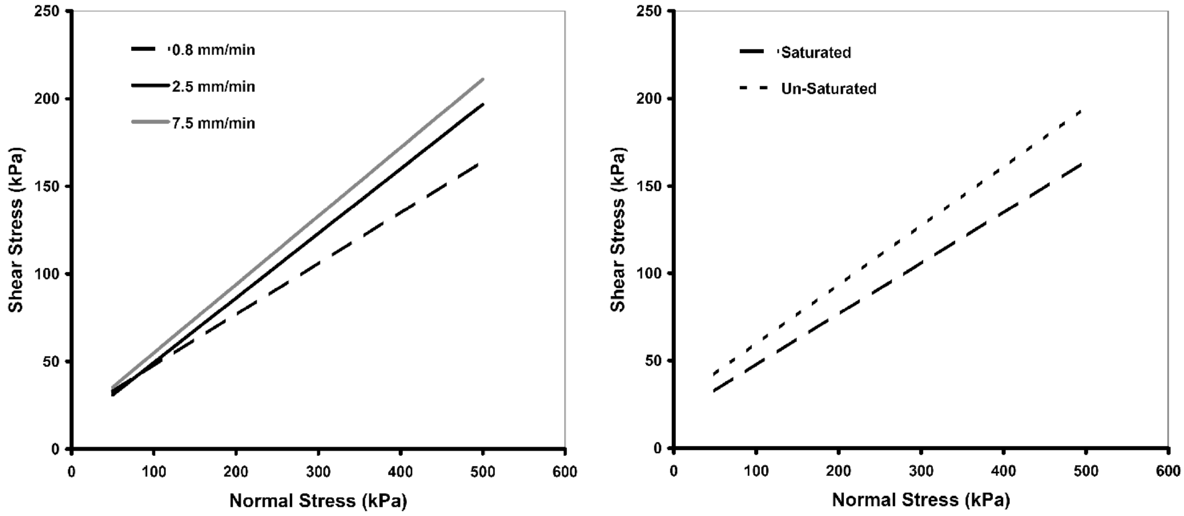

Figure 8. Shear strength envelope of MSW materials at different condition

The trends are completely clear. With increasing loading rate the level of shear strength will increase which is compatible with the findings of Augello et al. (1995, 1998) and zekkos (2005).

Accrding to achieved shear strength envelopes at different loading rate, with increasing of this factor from 0.8 to 2.5 and 7.5 mm/min, the level of shear strength averagely will increase 10 and 15% respectively. However the level of increase is not compatible with Zekkos (2005) but it shouhld be noticed that the level of loading rate at its upper limit was 10 times higher than base level which was 50 in the case of Zekkos (2005, 2007) reports.

This increment in the case of unsaturated samples was averagely around 20% which in considarable. It means that effective performance of leachate collection systems could help to increase the level of safety factor of general failure.

5. CONCLUSIONS

The mechnical response of MSW materials under quick loading condition during ground motions is one of the issues which has not addressed properly yet especially in the case of saturated samples that pore water pressure generation could affect stability issues.

As a part of a comperehensive research on the mechanical response of MSW materials under different condition the effect of loading rate on the mechanical response of these materials was evaluated.

The results emphasized that with increasing the loading rate the level of shear strength will increase which is compatible with Augello et al. (1995, 1998) and Zekkos (2005) and Zekkos et al. (2007). According to these analyses of the test results with increasing the loading rate for a base value of 0.8 mm/min achived by head (1985) approach to 2.5 and 7.5 mm/min, the laval of shear strength will increase 10 and 15% respectively.

The rate of pore water pressure generation decreased by increasing the loading rate however that final value of pore water pressure was the same in all saturated samples and equal almost to confing pressure. It seems that lower rate of pore water pressure generation in the cas of higher loading could be attributed to time which water needs for pressure stabilization, however because of stress dependency of MSW materials hydraulic conductivity, the permeability of

MSW materials at higher loading rate which higher level of mean pressure will be applied on the sample was lower.

Increasing the loading rate increase the level of internal friction angle however any clear trend was not observed in the case of cohesion intercept factor.

The saturation of samples leads to decrease the shear trength level of MSW materials up to 20%. Both the internal friction angle and cohesion interept decrease with saturation.

According to the results of this reaserch it could be concluded that stability of waste fills which are stable at static loading condition even in the case of high level of leachate inside the fills, could not be a matter of concern however more sophisticated laboratoary and field tests should be performed to address this issue.

Also the effective perofomance of leachate collection system could increase the level of safety factor of waste fills with increasing the shear strength of MSW materials.

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