A New Approach for Characterizing Shear Strength of Municipal Solid Waste for Land Fill Design

Une nouvelle approche pour la caractérisation de la résistance au cisaillement des déchets urbains pour la conception des décharges

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ABSTRACT: Many researchers have characterized shear strength properties of municipal solid waste (MSW) by proposing Mohr-Coulomb strength envelopes derived from their experimental data. Still others reported results in terms of the same parameters after obtaining the data from back-calculations of failed landfills. A factor which has not been paid much attention to is the highly compressible nature of MSW. Variability in the unit weights, due to high compressibility of MSW, observed in the samples tested at increasing confining pressures invalidate the use of a common Mohr-Coulomb envelope for these samples. This paper critically examines the impact of the high compressibility of MSW on the development of Mohr-Coulomb strength parameters. It is argued that a single Mohr-Coulomb envelope does not account for the high compressibility of MSW. A new approach based upon the use of 'Strength versus Depth' plot has been proposed.

RÉSUMÉ : De nombreux chercheurs ont caractérisé les propriétés de résistance au cisaillement des déchets urbains (MSW) en proposant des enveloppes de résistance de type Mohr-Coulomb issues de leurs données expérimentales. D'autres encore ont présenté des valeurs obtenues par analyse inverse de ces mêmes paramètres, à partir de cas de glissements observés dans des décharges. Un facteur auquel n'a pas été accordé beaucoup d'attention est la nature hautement compressible des déchets. La variabilité massique, du fait de la forte compressibilité des déchets, qui est observée dans les échantillons soumis à une pression de confinement croissante invalide l'utilisation d'une enveloppe de Mohr-Coulomb pour ces échantillons. Cet article examine de manière critique l'impact de la forte compressibilité des déchets sur le développement des paramètres de résistance de Mohr-Coulomb. Une enveloppe unique de Mohr-Coulomb ne permet pas de tenir compte de la forte compressibilité des déchets. Une nouvelle approche basée sur la dépendance de la résistance avec la profondeur est proposée.

KEYWORDS: Municipal Solid Waste, Shear Strength, Mohr-Coulomb concept.

1 INTRODUCTION

Every day, the United States alone generates millions of tons of municipal waste solid waste (MSW) that must be processed. Landfilling is the least expensive method of waste disposal and landfills are being built to unprecedented heights. Landfill failures can expose the public to a variety of health hazards and can also create ecological and environmental disasters. These and other reasons make the determination of design parameters for landfills a growing field of interest. Geotechnical parameters are important for the design of each of the subsystems such as waste mass slope and height and the containment systems.. The parameter of shear strength is important for both seismic and static slope stability. Over the past decade, there have been several publishing's on shear strength of MSW as it pertains to seismic and static slope stability. The data presented in these publishings, however, reflects the variability of MSW in regards to constituents and location. . Many question the applicability of Mohr Coulomb concept with MSW and the effect of age and compressibility on the evaluation of its strength parameters still remains unanswered. Nearly vertical slopes in the MSW landfills observed all over the world cannot be explained by the frictional strength envelopes derived using Mohr-Coulomb Approach. Accordingly, no clear cut way for characterizing the shear strength of MSW has emerged. This paper attempts to progress in this direction.

2 ALTERNATIVES FOR CHARACTERIZING STRENGTH OF MUNICPAL SOLID WASTE

In the slope stability analysis of Municipal Solid Waste (MSW) landfills, shear strength properties of the MSW are of high importance. There have been different approaches to characterize the shear strength properties of MSW. Fassett, et al. (1994) presented a summary and analyses of MSW strength properties and brought into focus the limitation of existing approaches used to characterize shear strength properties of MSW. Characterization has essentially been attempted in two ways. Singh and Murphy (1990) summarized existing data from laboratory test back-calculations and from in-situ testing and recommended a range of strength parameters for MSW; cohesion (*c*) and internal friction angle (Φ). Howland and Landva (1992) used an alternate method and expressed MSW strength in terms of mobilized shear strength (τ_m) and normal stress (σ_n). Howland and Landva considered the strength of MSW to be primarily frictional in nature. In terms of Mohr-Coulomb parameters, the relationship between shear strength and normal stress developed by Howland and Landva gave a *c* equal to 10 kPa and Φ equal to 23 degrees as a lower bound to their data. Howard and Landva summarized MSW strength data reported in the literature on four cases (New Jersey Landfill Failure, California Landfill Load Test, Laboratory Direct-Shear Tests and Field Direct Shear Tests). The data (figure 3 of their paper) was plotted as mobilized shear strength and average normal stress. Only the lower bound values were reported. No upper bound values were estimated or reported. Kavazanjian, et al. (1995) used an approach similar to that of Howland and Landva, however, Kavazanjian relied more on back calculationed data from case histories and in-situ testing than they did on laboratory data. Kavazanjian adopted a bilinear representation of the MSW shear strength using Mohr-Coulomb parameters. Their data suggested that up to the normal stress of 30 kPa no increase in the shear strength was noted. Accordingly, they suggested that at normal stress below 30 kPa, the Mohr-Coulomb parameters were $\Phi = 0$ and $c = 24$ kPa, and above normal stress of 30 kPa, the parameters were $c = 0$ and $\Phi = 33°$. More recently, Kavanzanjian, 1999, Zekkos, 2005, and Bray et al., (2009), have characterized shear strength properties by proposing Mohr-Coulomb strength envelopes derived from their experimental data (Fig. 1).

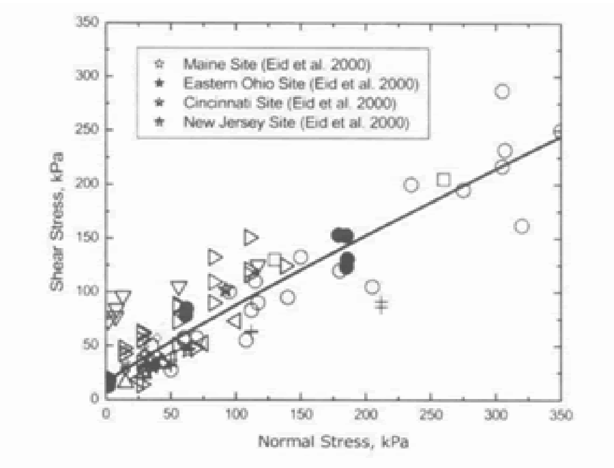

Figure 1 Recommended static shear strength of MSW based primarily on direct shear tests and field observation of slope stability. Bray et al. (2009)

Still others reported results in terms of the same parameters after obtaining data from back calculations of failed landfills (Kavazanjian, 2001, Eid, et al. 2000). Figure 2 presents data from various sources.

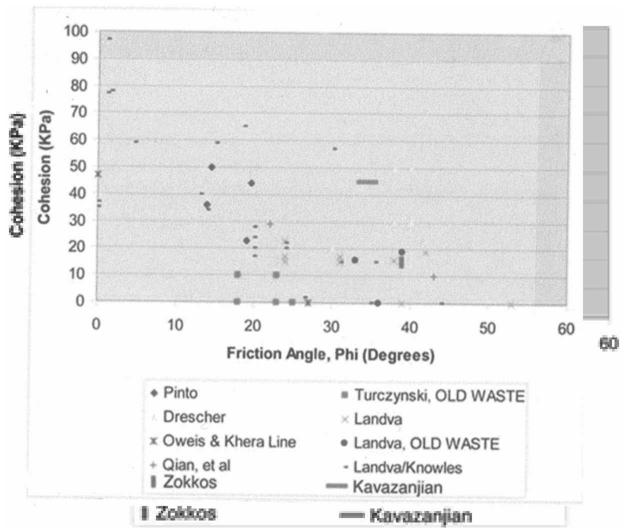

Figure 2 Lab Test or Institute Testing on MSW

Other researchers believed the variability they observed in their samples was too great for Mohr-Coulomb parameters to be usefully developed for each sample tested (Siegel, et al., 1990). For example, Siegel, et. al, (1990) tested samples from the OII landfill, perhaps the most studied landfill, in Monterey Los Angeles area and made the observation that given the refuse variability, deriving Mohr-Coulomb angles of internal friction and cohesion intercepts for individual samples was inappropriate. Singh and Murphy (1990) suggested that Mohr-Coulomb's theory might not be applicable to characterizing the shear strength of MSW.

The cause of this controversy is that while shearing, the strength mobilization rates for MSW and soils are quite different. The MSW behaves as a strain hardening material, i.e., even at large shear strains, it will continue to mobilize additional shear stress without exhibiting a leveling off or drop in shear stress or developing a failure plane typical of soils. In limit equilibrium analyses, such as what is used in slope stability analysis, the basic assumption is that the peak strength mobilization occurs at the same time along the entire failure surface. Because of the incompatibility of strains at which peak strength is mobilized in MSW, in soils, and along liner interfaces, the limit equilibrium analyses need to use reduced shear strength of MSW or the residual strength of soil and the interfaces (Mitchell et al. 1995).

3 COHESIVE PROPERTIES OF MUNICIPAL SOLID WASTE

The shear strength of the MSW is similar to a soil in many ways. It can be thought of for conceptual purposes (and many argue for other purposes as well) as a fibrous soil (Zekkos, 2008). Direct shear tests by Landva and others have shown that the shear strength of MSW depends on the nature of the test (Qian et al., 2002).

MSW can exhibit a kind of behavior while shearing, which is typically cohesion, but is seen by others as only apparent cohesion. Some call this apparent cohesion-'adhesion' (Qian et. al., 2002). This behavior comes about mainly because MSW is a hodgepodge of different materials with different shapes. The interlock of these odd-sized 'grains' causes the MSW to exhibit behavior similar to what is called cohesion in clay soils. In clay, cohesion is the result of water and associated electrical charges, although the critical state concept considers cohesion even in clays resulting from interlocking (Schofield, 2005). The cohesion in the MSW is the result of mechanical interlock. As MSW degrades with age the effect of the interlock would decrease and the cohesion should drop. Accordingly, cohesion in MSW cannot be treated as a constant parameter. Though, the root cause of the behavior differs from that in soils, the observed behavior is quite similar. Cohesion is observed in MSW although it can be correctly termed apparent cohesion. Cohesion has been observed in data on actual waste than in model wastes. The cohesive behavior of MSW is also reinforced in practice by the abundance of incidents in which vertical or nearly vertical cuts remain stable for years without any signs of failure (Qian et. al., 2002).

4 DATA FROM MODEL WASTE EXPERIMENTS

Testing of artificial waste and model waste provided data points with no cohesion (Thusyanthan et al, 2004).

5 DATA FROM CASE HISTORIES

As was mentioned earlier, another method of collecting shear strength data is back-calculations based on case histories. In almost all of the cases, the shear strength data was obtained after a landfill failure. The most common method was to assume a factor of safety equal to unity and back-calculate the shear strength of the MSW involved using standard geotechnical analysis. In this study, only case studies using a factor of safety equal to one for failure analysis were reported. Other case studies estimate the factor of safety and then back-calculate shear strength parameters. However, the shear strength values are very sensitive to changes in the factor of safety, and the factor of safety can't be known with certainty unless failure occurs. The most common details presented by the researchers, and the techniques used to calculate the shear parameters are given in Qian, et al., 2002 and Zekkos (2005) among others.

It is of interest that every case history for which shear strength was found, yielded data with cohesion. It should also be noted that the lowest cohesion is reported by Seed and Boulanger (1992), and it is the lower bound for five case studies reported by Howland and Landva (1992). All the case history data led to the determination that MSW does indeed have cohesive properties. However, no clear trendline emerged from the data, although a general decrease in cohesion as the friction angle increases was observed.

6 COMPRESSIBLITY OF MSW

An additional factor which has not been paid much attention is the highly compressible nature of MSW. Most of the test data on the shear strength of MSW has been presented without accounting for the significant volume changes that take place associated with high confining pressures. Tests at high confining pressures by Chen et al. (2008) (fig 3) showed that owing to the high compressibility of MSW, volume changes at high confining pressures are significant. Accordingly, these high volume changes should result in changes in the unit weight and hence in the shear strength. Bray et al. (2009) noted that the effect of unit weight on the shear strength is significant. Accordingly, the large compressibility of MSW would invalidate the attempt to use a single Mohr Coulomb envelope to tests on samples at widely varying unit weights at high normal stresses.

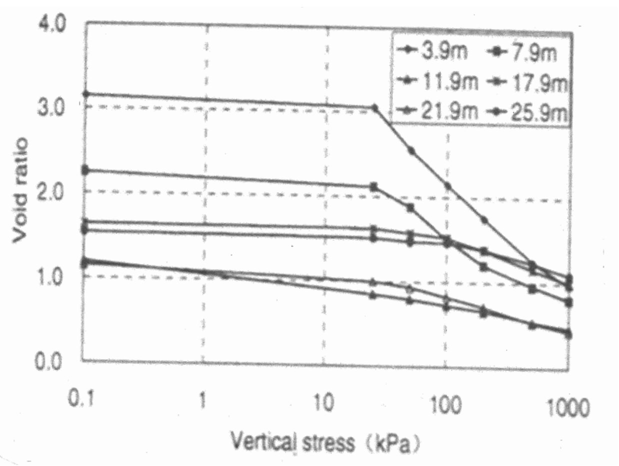

Figure 3 Compression curves for the samples taken from BH5 (chen et al, 2008).

It is therefore suggested that for high landfills, a plot of shear strength verses depth can better represent the effect of compressibility, unit weight, and high confining pressures than a single Mohr Coulomb envelope. Also, field measurements of density and shear strength supplemented with back calculation of well documented case histories appear to be the most logical mean of obtaining MSW strength information. These are some of the important issues which should be considered when applying geotechnical considerations in characterization of shear strength of MSW.

6 CONCLUSIONS

1. It is suggested that due to the large compressibility of MSW at high normal stresses, a single Mohr Coulomb shear envelope for a landfill may not be applicable.

2. The use of strength versus depth plot is more appropriate for characterizing shear strength of MSW, especially for high landfills.

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