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Dynamic strength and stability of refuse landfills during earthquakes

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ABSTRACT: The paper presents results of research made to provide answers to basic questions on the dynamic strength properties of refuse, the applicability of slope stability techniques, and the seismic response of refuse landfills. The applicability of the deformation analysis approach for evaluating dynamic stability of sanitary landfills was examined, parametric studies on the dynamic response of refuse landfills using range of values for shear modulus and damping characteristics of refuse material were made.

The results of the studies suggest that the dynamic strength characteristics of the refuse material are not yet adequately defined. There is a large scatter on the data estimated from laboratory testing and in-situ testing. The application of the soil mechanics principles to refuse material strength and stability evaluation should be viewed with caution because of the incompatibility of strains that produce a shear failure in soils and those that would produce shear failure in refuse. The response analyses indicate that the properties of the refuse are such as to absorb, dampen or attenuate the effects of earthquakes. This is due to the mismatching of the very low frequency of vibration of a solid waste landfill with that of earthquake motions and to the inherent energy absorption mechanism of the landfill material. Furthermore, because of the complex and heterogeneous structure of refuse material and the lack of test data, it is recommended that a range of values of dynamic strength characteristics should be used in the pseudostatic or deformation analysis approach.

1. INTRODUCTION

In almost all major cities of the United States, solid waste landfill capacity and available new landfill sites are declining. In some cases, the demand for increased capacity has been achieved by building landfills to greater heights. This has raised concerns regarding the stability of high refuse fills, particularly for the landfills which are located in areas where a potential for seismic loading exists. The behavior of a refuse landfill to earthquake loading conditions is far from having been understood; this is because of the complexities in estimating the dynamic strength properties of the refuse. The modulus (or stiffness) and the damping properties of a highly heterogeneous material such as refuse are extremely difficult to characterize. As a result, systematic studies on the seismic response analysis of a refuse fill are strikingly lacking or have not been reported. A reasonable seismic response analysis must use reasonable dynamic strength properties which are not available. The questions have also been raised on the application of soil mechanics principles to the evaluation of the strength and stability of refuse. Data from field monitoring of seismic responses Hushmand, et al (1990) is yet too meager to warrant any conclusions. Accordingly, research efforts were made to seek answers to the basic questions on the dynamic strength properties of refuse material, the applicability of the stability techniques of soil mechanics, and the seismic response of refuse landfills.

2. DYNAMIC STRENGTH CHARACTERISTICS OF REFUSE MATERIAL

In order to understand the engineering behavior of a refuse fill when subjected to dynamic or earthquake loading conditions, an analytical approach such as seismic response analysis must use appropriate dynamic strength properties of the refuse material required for response analyses.

Dynamic strength properties of a material such as soil are determined by either laboratory testing or from field test methods. Laboratory test methods include Cyclic Triaxial Compression Test, Cyclic Simple Shear Test, and Resonant Column Test. In each of these tests, an appropriate and a representative sample is tested. Because of the highly heterogeneous composition of the refuse and the difficulty in obtaining representative samples of the in-place refuse, laboratory test data on the dynamic strength characteristics of refuse material has been seriously lacking.

Until recently, the shear modulus and damping characteristics of refuse were assumed to be similar to peat because of the low unit weights, high void ratios and high compressibilities of both peat and refuse materials. Seed and Idriss (1970) developed shear modulus and damping curves for peat on the basis of static and dynamic laboratory tests. This data was used by several authors Volpe (1985), EMCON (1986), Purcell, Rhoades & Associates, (1987), Earth Tech, Inc., (1988) in the response analyses made for sanitary landfills in

California. Volpe (1985) estimated shear wave velocity for refuse based on the static load settlement results from the full scale load test performed by Converse et al., (1975) at the Operating Industries Landfill in Monterey Park, California. The computed average of shear wave velocity was 26 m/sec (85 ft/sec). The range of shear wave velocity for peat reported by Seed and Idriss (1970) was 21.6 to 43.3 m/sec (71 to 142 ft/sec).

More recently, test data based on field shear wave velocity tests have been reported by the Earth Technology Inc. (1988). An average shear wave velocity of about 274 m/sec (900 ft/sec) has been estimated by Earth Technology, Inc. on the basis of geophysical cross-hole and downhole shear wave velocity tests. Results of seismic survey by downhole shear wave velocity tests carried out for EMCON (1989) by Redpath Geophysics and by Portola Geophysics at West Richmond Fill and at Redwood Fill indicate respectively, average shear wave velocities of 213 m/se (700 ft/sec) and 91 m/sec (300 ft/sec). A value as low as 31.4 m/sec (103 ft/sec) has also been reported at the Redwood Refuse Fill. These values are much higher than those estimated on the basis of test on peat or field load test. Apparently, as more test data on refuse will accumulate, representative values for shear modulus and its damping for the refuse material at various stages of decomposition should emerge. In the meanwhile, the use of the static stress-strain data or the downhole shear wave velocity data to estimate dynamic shear modulus of refuse may be used with caution because of the highly compressive nature of the refuse and its non-soil like strength deformation characteristics.

In soils, both dynamic stiffness and damping values are strain dependent. In other words, non-linear behavior of the soils are important in the response analyses. Accordingly strain dependent modulus and damping values are used in the analyses. Tests on peat has shown it to be highly compressible Seed and Idriss (1970). Field tests provide dynamic properties at very low stains and there are no laboratory test results on refuse to provide values at higher strains. The incompatibility of strains that produce shear failure in soils and those that would produce shear failure in refuse raises serious questions on the applicability of soil mechanics principles to refuse. In other words the extension of dynamic stiffness and damping curves for refuse from low strain values to higher strain values should be done with caution. Satisfactory performance of relatively steep slopes (1 3/4:1; H:V) of high refuse fills in southern California and of several other refuse fills in northern California Orr and Finch (1990) during earthquakes seems to suggest that the refuse materials exhibit a very high damping coefficient and thus will attenuate bedrock accelerations as they propagate up through the fill. Recent data from seismic monitoring records Hushmaud et al., (1990) suggest that higher frequency energy (>3HZ) is attenuated, but lower frequency energy amplified significantly. More results from monitoring studies should provide check on the analytical predictions based on assumed dynamic properties. In the meanwhile, the writer suggests that a range of values as shown in Fig. 1 may be used.

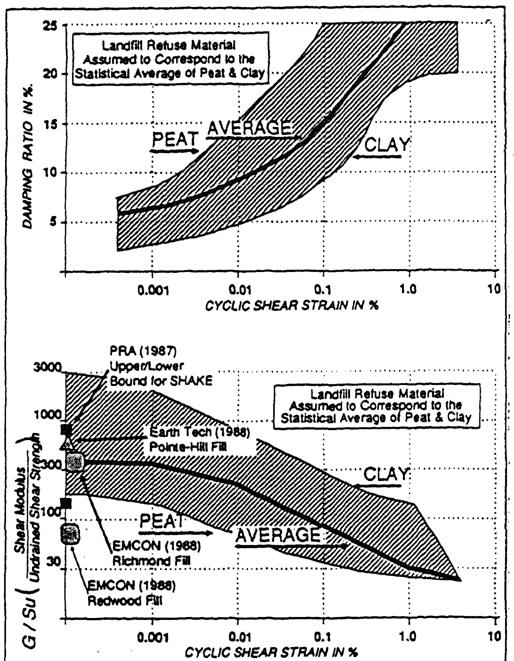

Fig 1 - Modulus and Damping for Refuse Material

Note: Data Points are estimated average values from shear wave data for Su=143 KN/m^2

3. Dynamic Stability Analyses

It has been believed that the principles for seismic design of landfill slopes are similar to those used in the design of soil slopes.

Analysis of soil slope stability under earthquake loading has been carried out using pseudo-static and deformational analysis. The deformational analysis approach is based on the works of Newmark (1965), Seed (1979) and Makdisi and Seed (1978). This approach has also been used for analyzing the dynamic stability of sanitary landfills. According to these analyses, both the simplified and the rigouous method of estimating time history of accelerations and shear stress, requires representative data on the dynamic strength properties of the material at different points within the fill. Obtaining dynamic strength properties of soil through equivalent linear or non-linear models has not been easy and as pointed out in the previous section, there is hardly any test data on the dynamic strength properties of refuse material.

Because of the foregoing reasons, the author carried out parametric studies on the dynamic response of landfills using a range of values for shear modulus and damping characteristics shown in Fig. 1 of the refuse material. Based on the assumption that the strength properties of the refuse are more cohesive than frictional, the range of values chosen were similar to that of peat and clay. Figure 1 shows the modulus and damping curves used in the SHAKE analyses made to evaluate the response of 122 m (400-foot) high sanitary landfill.

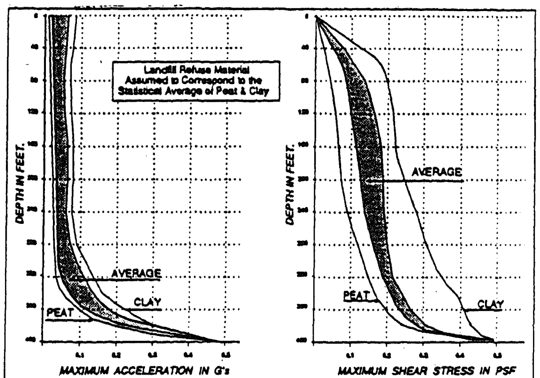

Fig 2 - Results of Response Analysis by SHAKE for 400 ft. High Landfill

Significant attenuation of baserock motions is evident in each case (see Figure 2). Apparently, the influence of varying the shear modulus and the damping values is not significant for the range of values considered. In view of the limited recorded data on earthquake motion attenuation on refuse fills, and the satisfactory performance of sanitary landfills to relatively strong earthquake motions in California, it can be argued, on the basis of the physical makeup of the refuse, that the refuse inherently has strong energy absorption mechanisms.

The result of SHAKE analyses are most significant in showing that the maximum bedrock accelerations were considerably reduced as they propagated up through the height of the landfill. This is quite different from what one could expect from the response of an earth dam subjected to similar motions. The results showed that the maximum bedrock acceleration was reduced from 0.5g at the bedrock level to average values of 0.06g or less at crest level. This is due to the low modulus, high damping and light weight of the fill.

These factors were probably also responsible for the natural period estimated by SHAKE analysis to be relatively high (12 to 16 seconds). Accordingly, amplification of energy may only be expected for frequencies less than one Hz. The effect of damping on motions as they propagate upward was noted in the filtering out of the high frequencies. However, more data on the dynamic response of refuse fills is needed to confirm these results.

4. CONCLUSIONS

As a result of the studies presented in this paper, the following conclusions may be drawn:

1. Dynamic strength characteristics of the refuse material are not yet adequately defined. There is a large scatter on the dynamic strength data obtained by in-situ testing reported in the literature. Results from recent but limited shear wave velocity test indicate shear moduli values to be somewhere between that of clay and peat.

2. The application of the soil mechanics principles to refuse material dynamic strength and stability evaluation should be viewed with caution because of the incompatibility of stains that produce a shear failure in soils and those that would produce shear failure in refuse. The Mohr-coulomb theory may not adequately account for the large deformations a refuse material undergoes without failure.

3. Results of SHAKE analysis indicate significant attenuation of bedrock motion as they propagate up through the refuse fill. The use of the pseudostatic and deformation analysis approach for dynamic stability analysis should consider the energy absorption mechanism of the refuse material.

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