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Seismic response of municipal solid waste landfills

S. Singh
Department of Civil Engineering, Santa Clara University, Santa Clara CA 95053, USA

ABSTRACT

A brief but critical evaluation of the seismic response of Municipal solid Waste Landfills (MSWL) have been presented.

Parametric studies on the dynamic response using range of values for shear modulus and damping characteristics of the refuse material were carried out. Results of seismic response analyses (for different levels of base motion) performed by the authors and other investigators are examined to evaluate the impact of stiffness and height of the refuse fill on the overall response. A strong influence by a moderate increase in dynamic strength (stiffness) properties on the response has been noted. Based on these analyses the influence of shear wave velocity is discussed. The importance of low and high frequency contents of the base motions is also addressed. Simplified procedures to estimate amplification of seismic ground motions by MSWL have been developed and are presented in this paper.

INTRODUCTION

The seismic response of Municipal Solid Waste Landfills are typically carried out using procedures developed for soil slopes or earth dams. Accordingly assessment of landfill stability under earthquake loading is carried out using deformational analysis. Typical deformation analyses employ a combination of one dimensional seismic response analyses, e.g. (SHAKE 1972) and Newmark [10] sliding block deformation procedures to evaluate permanent deformations which are assumed to take place along a sliding surface. An accurate estimation of the material properties, especially the dynamic strength properties are essential for use in the above analyses. The refuse is a highly heterogeneous material and its dynamic strength properties are yet to established through a reasonable set of data measured or observed. There are other aspects of the MSWL which differ from a well compacted homogeneous earth dam. For example the light weight of refuse and existence of layers of soils and liner systems. All these have raised concerns regarding the applicability of the conventional geotechnical earthquake engineering procedures to refuse slope.

This paper attempts to address the unique concerns related to the seismic response of MSWL and presents simplified procedures for preliminary assessment of the amplification effects of the refuse fill to base motions.

SEISMIC RESPONSE OF MUNICIPAL SOLID WASTE LANDFILLS (MSWL)

Factors that could influence seismic response of landfills include: (1) height of refuse, (2) stiffness (or shear wave velocity) of refuse, (3) dynamic properties of refuse, (4) presence of clay liner, (5) refuse geometry, and (6) characteristics of base motions.

Height and stiffness of the refuse influence the basic vibrating characteristics of the landfills. In a preliminary assessment of landfill response, these are the two most significant factors that should be considered. Shear wave velocity measurements in landfills are not that uncommon nowadays. Conventional methods of downhole and crosshole measurements have been successfully used at landfill sites. Although, all the aforementioned methods require drilling or puncturing a probe into the refuse, more recently, a new method of using surface wave measurements was successfully used to determine the shear wave velocity of refuse Kavazanjian et al. [6]. The benefit of this new technology is that this non-destructive method does not require puncturing any hole into the refuse, and more importantly the surface wave measurement uses a much larger volume of materials in determining the average stiffness of the extremely heterogeneous materials, as compared to crosshole and downhole methods.

Measurements made in landfills typically show that the shear wave velocity ranges between 500 to 1000 feet per second (fps). Although shear wave velocity in excess of 1000 fps have also been reported. The velocity profiles at some landfill sites show that the stiffness increases with depths. It should be noted that unlike conventional soil fills, the refuse fill compacts under its own weight with time, thus the stiffness and in turn the shear wave velocity also increase with time. Thus the velocity of a newly closed landfill may be significantly different when the measurements were made 10 or 20 years later. In the following section, the authors present simplified charts using the refuse height and the average shear wave velocity to assess the response of landfills.

SIMPLIFIED METHOD OF LANDFILL RESPONSE EVALUATION

The relationships shown in Figures 1 and 2 are derived from the authors' experience, publised results, and field instrumentation records on landfill response during earthquakes.

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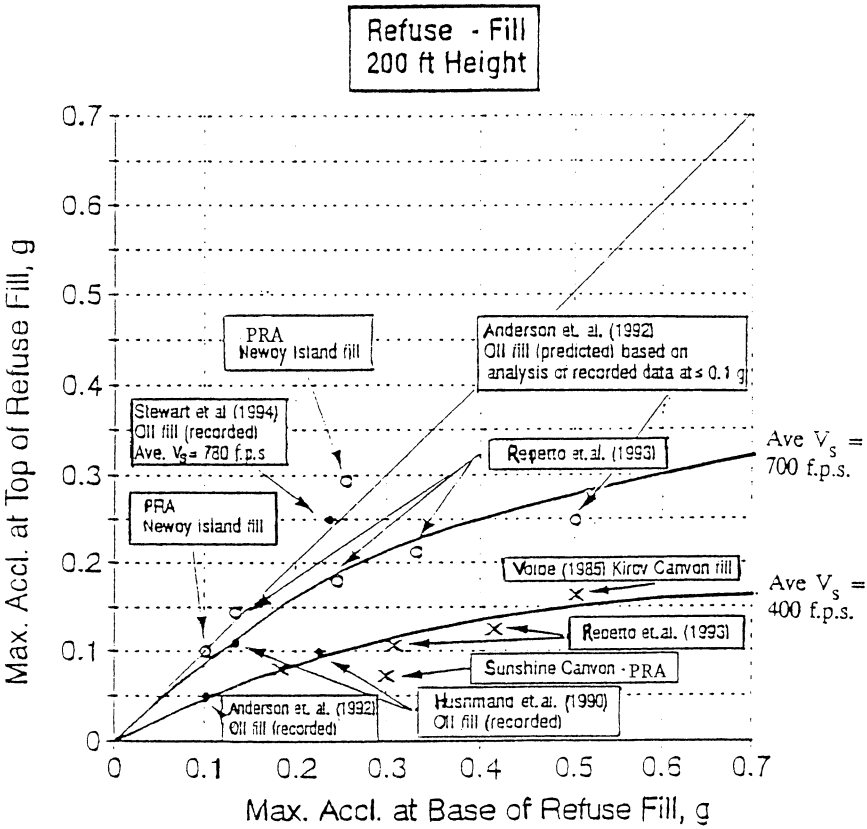

Fig. 1 Approximate Relationship Between Maximum Accelerations at the Base and Crest

The horizontal axis represents the anticipated ground motion at the toe or base of the landfill. In using these charts for preliminary design purposes, this can be determined either from conventional deterministic or probabilistic seismic hazard evaluation. The vertical axis represents the anticipated ground acceleration at the top or crest of the landfill.

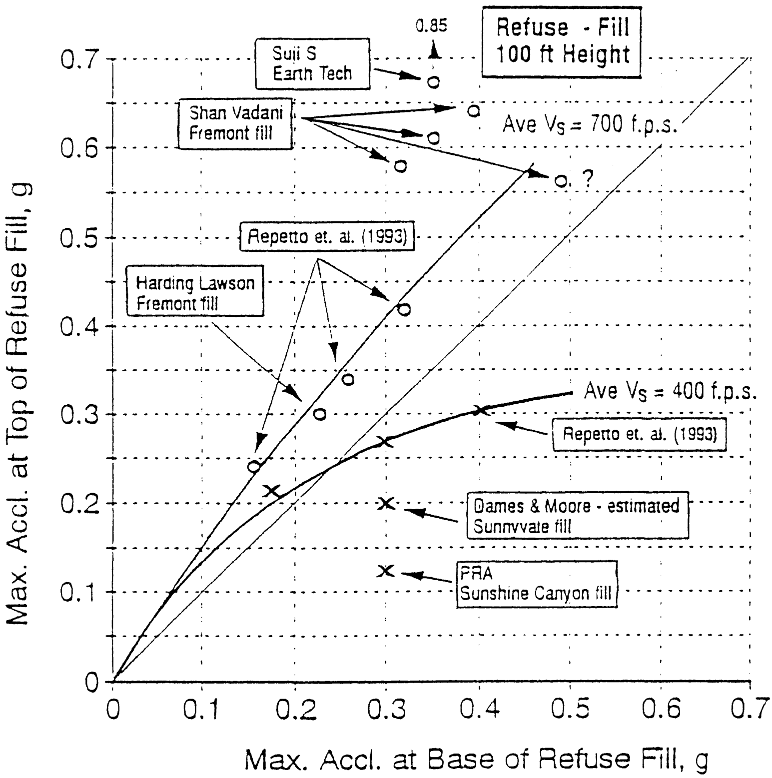

Fig. 2 Approximate Relationship Between Maximum Accelerations at the Base and Crest

As stated in the previous paragraph, the two key parameters used in these two charts and refuse height and refuse average shear wave velocity. Fig. 1 shows the response of 200-ft high landfill and Fig. 2 shows the response of a 100 ft. high landfill. In each plot, the authors developed two curves; they correspond to average refuse shear wave velocity of 400 fps and 700 fps (ft/sec).

It should be noted that due to the limited instrumentation on landfills, Figs 1 and 2 also incorporate some of the authors' analytical work as well as simulations presented by others.

Harder [3] presented a similar chart for earth dams, where he compared the acceleration recorded at the base (or abutment) of the dam with those recorded at the crest of the dam. The authors believe that he proposed upper bound correlation by Harder can be also viewed as an upper bound for response of landfills. The basis of this assessment are (1) the two dimensional geometry of a typical earth dam will respond more than that of a landfill which responds more in a one-dimensional manner, (2) the refuse will have a higher damping than that of an earth fill dam.

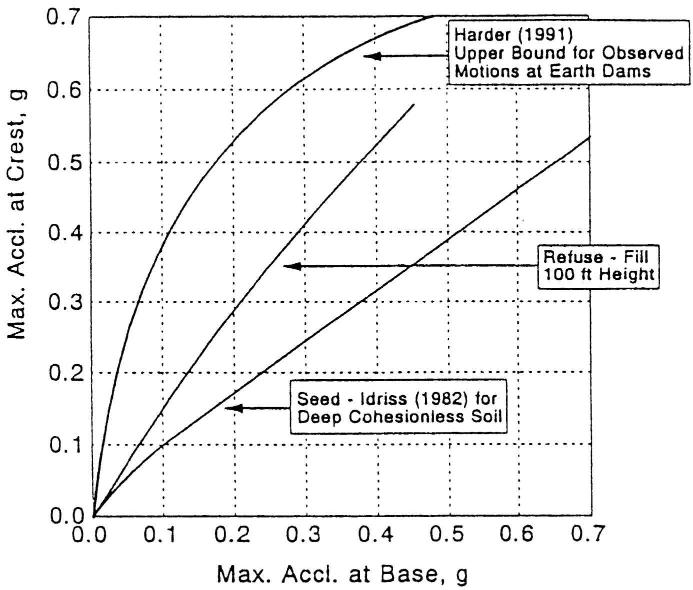

Fig. 3 Approximate Relationships Between Maximum Accelerations at the Base and Crest

Fig. 3 shows the comparison of Harder's proposed relationship with the 700 fps curve shown in Fig. 2. Also shown on Fig. 3 is the correlation proposed by Seed and Idriss [14] for deep cohesionless sites. It can be seen that all three curves are reasonably similar. It is the authors' opinion that on a preliminary basis the upper bound for the response of the MSWL should be between the Harder curve and the authors' 100 ft. curve in Fig. 3.

It should be pointed out that if one compares Figs. 1 and 2, it could easily be seen that the acceleration for 100 ft. landfill is much higher than the 200 ft. high landfill. However, one important aspect that these two charts do not show is the effect of straining. The reason that lower acceleration is anticipated for 200 ft. high landfill is that much of the motion is anticipated to be damped out before the motions can reach to the top with the accompanying strain. Thus the strain developed in the 200 ft. landfill is higher than the 100 ft. landfill.

Frequency dependence aspects of the response is also very important. It is now well known that the maximum response depends primarily on the fundamental period of the landfill and the frequency characteristics of the base motions, and typically high acceleration levels are associated with higher frequency motions. On the basis of several analyses made by the authors using SHAKE program and the Singh and Murphy [15] modules degradation and damping curves; and more recently analyses made by Hushmand Associates [5] and Stewart et al. [16], it appears that a MSWL with height over 200 ft. will have fundamental periods on the order of one second or more. Accordingly, it is likely that as the fill height increases, the high frequency high motion will be attenuated. This trend is evident from Figs. 1 and 2. It may be noted that on the basis of the evaluation of the recorded data at the base and the top of the OII Landfill in Monterey Park, in the Los Angeles area, during the Northridge earthquake, Stewart et al. [16] pointed out that "there was attenuation in the high frequency range, but at periods beyond approximately 0.6 seconds, there was amplification of the motions from the base to the top." The OII Landfill is located 48 km from the epicenter. Accordingly, if significant energy from a seismic shaking at an MSWL site is dominant in relatively low frequency, an amplification can be expected. In this context it appears that for a given peak acceleration at the base, the distinction between a near field and a far field seismic event is a significant consideration in evaluating the response of MSWL.

LANDFILL PERFORMANCE DURING RECENT EARTHQUAKES

An evaluation of the performance of solid waste landfills during the Loma Prieta Earthquake was reported by Orr and Finch, [11]. They examined ten solid waste landfills located in the area impacted by the earthquake. The landfill sites accelerations ranged from 0.10 to 0.45g. However, none of these landfills were equipped with liners, nor were any one of them instrumented. According to Orr and Finch [11], "The limited surface damage, given the peak horizontal accelerations estimated for the 10 solid waste landfills, suggests that the properties of the solid waste may tend to dampen or attenuate the effects of earthquakes." It also suggests that landfills behave more elastically than what we normally conceive and that damping may also play a significant role in the seismic response of MSWL. It is important to note, however, that the Buena Vista Landfill suffered minor slope cracking and minor cracking to a buried landfill gas header line. The two-foot gunit-lined drainage ditch at the Newby Island site was also damaged.

The solid waste landfills located in the Los Angeles area that were shaken during the Northridge earthquake have performed much better than expected (Kavanzanjian,[6] and Stewart et al., [16]. Compared to the very high levels of accelerations, the damage was relatively insignificant. Unfortunately, because of the lack of instrumentation, recorded data on the seismic response is available only for one landfill, the OII fill. Preliminary information, however, indicates that the MSWL has inherently moderate to strong energy absorption characteristics; especially for the high frequency motions. The existence of interlocking, large-strain capacity and the light-weight, appear to contribute to this response.

CONCLUSIONS

On the basis of the studies reported in this paper, the following conclusions may be drawn:

1. The height and stiffness (or shear wave velocity) of the refuse material in a MSWL are the significant factors which influence the basic vibrating characteristics of the landfills.
2. Results of seismic response analyses (for different levels of base motion) indicate a strong influence by a moderate increase in dynamic strength (stiffness) properties of refuse on the seismic response of MSWL.
3. Preliminary evaluation of landfill response which includes the influence of height and stiffness of refuse can be made from figures 1 and 2.

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