土木学会第54回年次学術講演会（平成11年9月）

I－B107 Ground Motion Characteristics at Liquefied Soil Sites

Mladen KOSTADINOV, Student Member, Institute of Industrial Science, The University of Tokyo
Fumio YAMAZAKI, Regular Member, Institute of Industrial Science, The University of Tokyo
Ken SUDO, Regular Member, Institute of Industrial Science, The University of Tokyo

1. Introduction

Soil liquefaction has been recognized as one of the main hazards for lifeline systems during an earthquake. The ground motion records from liquefied soil sites from the 1995 Hyogoken Nanbu earthquake in addition to the previously obtained ones have made possible the quantitative characterization of the phenomena. As a result methods for soil liquefaction detection using strong motion records have been developed. Such methods are employed in the real-time earthquake monitoring systems for preliminary estimation of the lifeline system damages.

Towhata *et al.* (1996) studied spectral intensity (SI) and SI-derived displacement from liquefied soil sites. Suzuki *et al.* (1998) investigated some types of periods and related displacements. Miyajima *et al.* (1997,1998) examined ratio of vertical to horizontal ground motion, low-frequency portion of the Fourier spectrum and predominant frequency. Takada and Ohzaki (1997) considered ratio of Arias intensity between surface and depth and predominant period. However these parameters are not always successful. An example is the record at SG&T, 1985 Mexico City earthquake (Fig. 1). In addition, not all of the available liquefied soil records were processed.

In this study alternative ground motion parameters are proposed in order to characterize more precisely the strong ground motion at liquefied soil sites.

2. Character of the Ground Motion at Liquefied Soil Sites

The decrease of the soil shear modulus on occurrence of liquefaction causes considerable change in the amplitude and frequency content of the ground motion. In such a case it is observed that the frequency of the horizontal ground acceleration abruptly alternates towards the low range (1-2 Hz). Besides, the acceleration amplitudes decrease still producing large displacements. These changes are identified by several ground motion parameters.

3. Strong Motion Parameters

It is acquired by now that there is no single parameter that reflects perfectly the liquefaction-induced alternation of the ground motion. Therefore a combination of a few ground motion parameters is used. Mainly they are frequency- and energy-related parameters. The ground motion parameters proposed in this study are described as follows:

a. Peak ground horizontal displacement (PGD_H): It is obtained by double integration of acceleration time history. The integration by Fourier transform is used after filtering the original acceleration components with a band-pass filter.

b. Cumulative absolute velocity (CAV): It is defined as the area under the absolute value of the acceleration. Accelerations with predominant low-frequency content are supposed to have larger CAV. To eliminate the influence of the surface waves the bracketed duration of acceleration is considered. Frequencies above 2 Hz are filtered out before the computation, similarly to Benjamin and Associates (1988). Since CAV could be calculated for one direction only, the maximal value of CAV is obtained by rotating the direction of the horizontal acceleration as practiced by Suzuki (1998).

c. Deformation spectral intensity (DSI): It is the area under the deformation response spectrum of linear SDOF system with damping ratio 20 % between periods of 1.5 sec. and 4.5 sec., divided to that period interval. The latter is the vibration range of acceleration after occurrence of liquefaction. For large periods DSI approaches the peak ground displacement.

d. Conditional mean period (CMP): It is the reciprocal of conditional mean frequency (CMF), which is defined as ratio of first to zeroth moment of frequency of a time-frequency representation. Because CMF is a weighted average of all presented frequencies at any moment, it could give more information about the instant frequency content of the ground acceleration. The time-frequency representation widely used in the earthquake research is short-time Fourier transform (STFT). It possesses poor resolution but it is computationally simple and fast. The choice of window length and type is however rather subjective. Therefore a more advanced time-frequency method – adaptive spectrogram (see Qian and Chen (1996)) – is used to calibrate STFT.

Key words: *Ground Motion Parameters, Soil Liquefaction, Strong Motion Records*
Contact Address: *4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Tel. 03-3485-7624, Fax: 03-3485-7796*

4. Strong Motion Record Set

A set of 103 strong motion records from sites in Japan, USA and Mexico was processed. Among them 17 records from liquefied or nearly liquefied sites were identified. This pretend to be the most completed collection of such records examined by now.

5. Results and Discussion

The ground motion parameters presented in section 3 were computed for the described strong motion record set. It was found that those, obtained from the liquefied site records, have the following properties:

- the peak horizontal displacement exceeds 10 cm
- the maximal cumulative absolute velocity exceeds 5 m/sec.
- the deformation spectral intensity exceeds 6 cm
- the conditional mean period exceeds 1.0 sec. for the horizontal components and does not exceed 0.33 sec. for the vertical component on occurrence of liquefaction.

Fig.2 and Fig.3 show the values of maximal CAV and DSI plotted against these of PGA_H correspondingly.

It should be noted that the quantitative studies depend on the data used. A comparative investigation on the feasibility of the existing methods for liquefaction detection should be carried using a common record set.

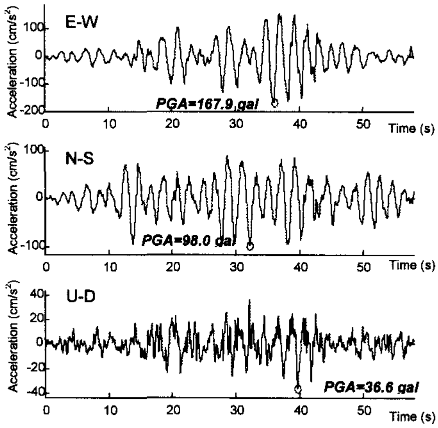

Fig. 1 Acceleration record from SC&T, 1985 Mexico City earthquake

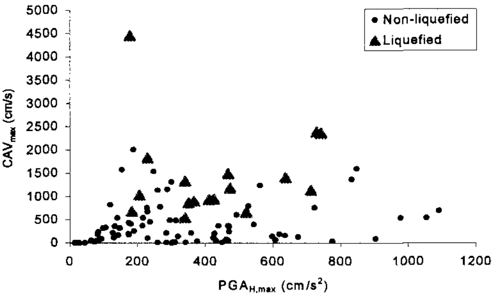

Fig. 2 Maximal Cumulative Absolute Velocity

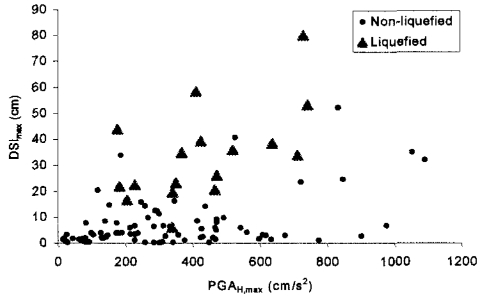

Fig. 3 Maximal Deformation Spectral Density

References:

Benjamin J.R. and Associates (1988) "A Criterion for Determining Exceedance of the Operating Basis Earthquake", *EPRI report NP-5930, Electric Power Research Institute, Palo Alto, California*

Miyajima M., Nozu S., Kitaura M. (1997) "A Detection Method for Liquefaction Using Strong Motion Records", *Proceedings of 24th JSCE Earthquake Engineering Symposium* (in Japanese)

Miyajima M., Kitaura M., Nozu S. (1998) "Detective Method of Liquefaction Using Strong Ground Motion Records", *Proceedings of Third China-Japan-US Trilateral Symposium on Lifeline Earthquake Engineering*

Qian Sh., Chen D. (1996) "Joint Time-Frequency Analysis", *Prentice Hall PTR*

Suzuki T., Shimizu Y., Nakayama W. (1998) "Characteristics of Strong Motion Records at the Liquefied Sites and Judgement for Liquefaction", *Proceedings of 11th ECEE*

Suzuki T. (1998) "A Method for Judgement of Liquefaction Based on Observed Waves", *Studies on Development of a Real-time Earthquake Emergency System* (in Japanese)

Takada S., Ozaki (1997) "A Judgement for Liquefaction Based on Strong Ground Motion", *Proceedings of 24th JSCE Earthquake Engineering Symposium* (in Japanese)

Towata I., Park J. K., Orense R. P. , Kano H. (1996) "Use of Spectrum Intensity for Immediate Detection of Subsoil Liquefaction", *Soils and Foundations Vol.36, No.2*