COMPARATIVE STUDY ON LIQUEFACTION DETECTION METHODS USING STRONG MOTION RECORDS

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During the recent big earthquakes in Japan and USA a number of records from liquefied-soil site were obtained. Several methods for detection of liquefaction from the ground motion records were developed, based on particular ground motion parameters. This paper presents an alternative method and investigates the efficiency of the existing methods by processing a common data set from liquefied and non-liquefied sites. The results show that the occurrence of liquefaction could be reliably judged from the recorded three-component acceleration time histories.

Key Words: *liquefaction, strong ground motion record, ground motion parameters, Kobe earthquake*

1. INTRODUCTION

After the 1995 Hyogoken-Nanbu (Kobe) earthquake it was realized that real-time ground motion monitoring systems offer some possibilities for minimizing effects of liquefaction to lifelines. These systems make the observed ground motion records available shortly after an earthquake. Liquefaction occurrence could be judged from a distance by processing the records with a method for liquefaction detection. The method evaluates specific ground motion parameters, which capture the important features of the ground motion at liquefied sites and judges about the occurrence of liquefaction. Existing methods, however, do not perform well in some cases.

In this paper an alternative method for soil liquefaction detection from ground motion records is proposed. Then the feasibility of all methods is investigated by processing a common data set.

2. REVIEW OF EXISTING METHODS FOR LIQUEFACTION DETECTION USING GROUND MOTION RECORDS

(1) Method of Suzuki[1)]

The method uses the two horizontal acceleration components and considers following four parameters: peak ground acceleration (PGA), maximal spectral intensity (SI_{max}), which is obtained by rotating the direction of the horizontal acceleration, maximal horizontal displacement (D_c) and zero-crossing period ($T_{z,a}$). The occurrence of liquefaction is judged if all parameters exceed the following limit values:

- $PGA > 100$ cm/s^2
- $SI_{max} > 20$ cm/s
- $D_c = 2SI_{max}^2/PGA > 10$ cm
- $2T_{z,a} > 2$ s

The method is implemented into a new SI-sensor, developed by Tokyo Gas Co., Ltd.

(2) Method of Miyajima[2)]

This method analyzes the three components of an accelerogram. It distinguishes three possibilities for liquefaction. The method evaluates following four parameters: the maximal ratio of vertical to horizontal acceleration amplitude ($R_{VH,max}$), the ratio of low-frequency portion (up to 2 Hz) to the whole area of Fourier amplitude spectrum (R_L), the averaged predominant frequency ($F_{p,a}$), and the decrease rate of the predominant frequency (ΔF_p).

In case that any of the parameters exceeds a limit value, points are given as follows:

- $R_{VH,max} > 2.0$ - 1 point
- $R_L > 0.25$ - 1 point
- $F_{p,a} < 2$ Hz and $\Delta F_p > 1$ Hz/s - 1 point
- $F_{p,a} < 2$ Hz and $\Delta F_p < 1$ Hz/s - 0.5 point

If the sum of points is less than 2.0, the possibility for liquefaction is judged as low. If the sum of points is equal or greater than 2.0 but less

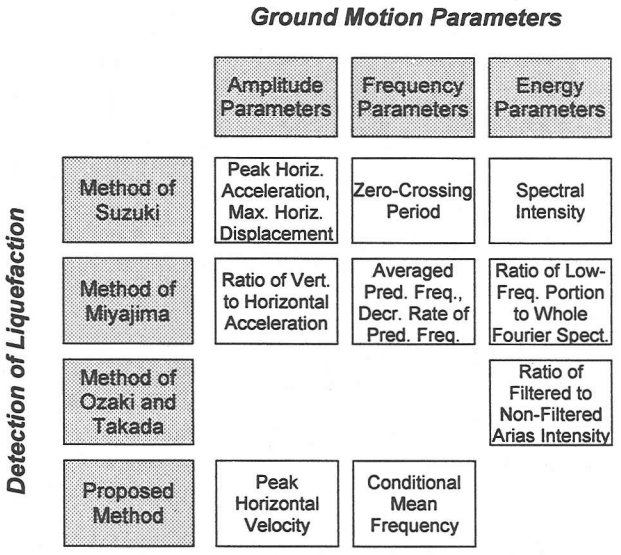

Fig.1 Ground motion parameters, used in the methods for liquefaction detection from earthquake records

than 3.0, the possibility for liquefaction is judged as high. If the sum of points is equal to 3.0, the possibility for liquefaction is judged as very high.

(3) Method of Ozaki and Takada[3, 4)]

This method processes the two horizontal acceleration components. It takes into account only one parameter - ratio of Arias intensity of filtered (low-pass at 1 Hz) to non-filtered acceleration time history (R_{AI}). According to the value of R_{AI}, the occurrence of liquefaction is judged as follows:

- $0 < R_{AI} < 0.3$ - no liquefaction
- $0.3 \leq R_{AI} < 0.6$ - possible liquefaction
- $0.6 \leq R_{AI} \leq 1$ - liquefaction

3. DESCRIPTION OF THE PROPOSED METHOD

Here an alternative method for liquefaction detection using ground motion records is proposed. The method considers two ground motion parameters:

1) Peak ground velocity (*PGV*). It is obtained by integration of acceleration time history. The integration by Fourier transform is used after filtering the original acceleration components with a band-pass filter.

2) Conditional mean frequency (*CMF*). It is defined as ratio of first to zeroth frequency moment of a time-frequency representation. *CMF* is a weighted average of all frequencies present at any moment and quantifies the instant frequency content of the ground acceleration. The short-time Fourier transform (also running spectrum) was used as time-frequency representation. It is a low-resolution one but it is computationally efficient. A window length of 256 points was accepted for time increment of 0.01 s and a proportional rule was applied for different increments in order to maintain similar frequency resolution.

Table 1 Liquefied and Suspicious Sites

No	Site	Earthquake	Liquefaction
1	Aomori-S (PHRI)	Tokachi Ohki 1968/05/16	Liquefied
2	Hachirogata (PWRI)	Nihonkai-Chibu 1983/05/26	Suspicious
3	Wildlife, GL	Superstition Hills 1987/11/23	Liquefied
4	Treasure Island	Loma Prieta 1989/10/17	Liquefied
5	Kushiro-G (PHRI)	Kushiro Ohki 1993/01/15	Suspicious
6	Amagasaki Bridge (PWRI)	Hyogoken Nanbu 1995/01/17	Suspicious
7	Amagasaki No. 3 P.S.	Hyogoken Nanbu 1995/01/17	Liquefied
8	Amagasaki-G (PHRI)	Hyogoken Nanbu 1995/01/17	Liquefied
9	Higashi-Kobe Bridge	Hyogoken Nanbu 1995/01/17	Liquefied
10	Kobe-JI-S (PHRI)	Hyogoken Nanbu 1995/01/17	Liquefied
11	Port Island, GL	Hyogoken Nanbu 1995/01/17	Liquefied
12	Port Island, GL-12	Hyogoken Nanbu 1995/01/17	Liquefied
13	Port Island, GL-28	Hyogoken Nanbu 1995/01/17	Suspicious
14	Rokko Island	Hyogoken Nanbu 1995/01/17	Liquefied
15	JR Takatori Station	Hyogoken Nanbu 1995/01/17	Suspicious
		Total Number of Liquefied Sites:	10
		Total Number of Suspicious Sites:	5

Figure 1 shows classification of the ground motion parameters used in the liquefaction detection methods. It should be noted that all frequency-related parameters are determined by the moving window technique, that is in common joint time-frequency analysis.

The proposed method uses three-component accelerograms. It determines three levels of liquefaction occurrence in accordance to the parameter values:

- $PGV > 20$ cm/s, $CMF_H < 2/3$ Hz and $CMF_V > 3$ Hz - liquefaction
- $PGV > 20$ cm/s, $CMF_H < 1$ Hz and $CMF_V > 3$ Hz - suspicion for liquefaction
- otherwise - no liquefaction,

Table 2 Earthquake events and corresponding number of records from non-liquefied sites

Earthquake	*Number of Records*
Tokachi Oki 1968/05/16	2
Miyagiken Oki 1978/06/12	1
Nihonkai Chibu 1983/05/26	1
Michoacan, Mexico City 1985/09/19	5
Superstition Hills 1987/11/23	1
Chibaken Toho Oki 1987/12/17	5
Loma Prieta 1989/10/17	10
Kushiro Oki 1993/01/15	7
Hokkaido Nansei Oki 1993/07/12	4
Northridge Earthquake 1994/01/07	10
Hokkaido Toho Oki 1994/10/04	4
Sanriku Haruka Oki 1994/12/28	1
Hyogoken Nanbu 1995/01/17	10
Kagoshimaken Hokuseibu 1997/05/13	4
Total Number of Non-liquefied Sites:	65

where the index H stands for any of the horizontal components and V stands for the vertical component of an accelerogram. CMF_H and CMF_V are considered simultaneously, within the first and last exceeding of 40 cm/s^2 of the resultant horizontal acceleration.

4. GROUND MOTION RECORD SET

A common data set of 80 free-field ground motion records from Japan, USA and Mexico was used to investigate the feasibility of the above methods. Records with *PGA* more than 150 cm/s^2 and *PGV* more than 20 cm/s are mainly presented in the set. The recording sites were divided into three groups as follows:

1) Liquefied sites - there were evidences seen (sand boils, ground fissures etc.) for liquefaction at the recording site, which were described in a report.

2) Suspicious sites - there were not clear evidences for liquefaction (it was difficult to judge about them) at the recording site.

3) Non-liquefied sites - liquefaction did not occurred at the recording site.

The liquefied and suspicious sites, which records were used, are shown in **Table 1**. In addition to them 65 free-field records from non-liquefied sites were processed. These include some records from the deep levels of the liquefied sites, which were not considered to be affected by the phenomena. **Table 2** displays the names of the

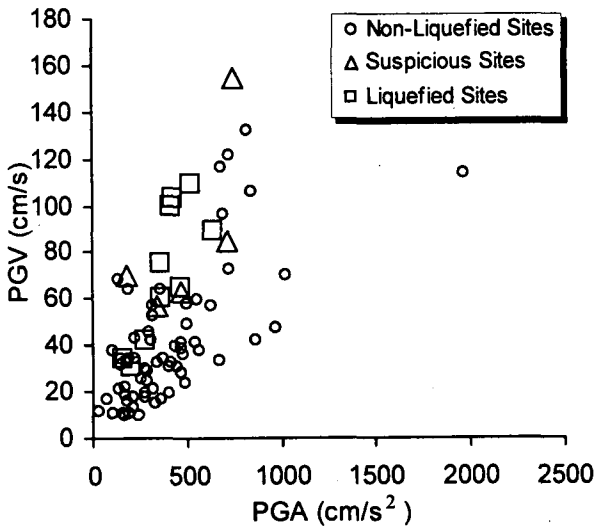

Fig.2 Peak ground acceleration and peak ground velocity of all earthquake records

earthquakes and the corresponding number of records from non-liquefied sites. **Figure 2** depicts the values of *PGA* and *PGV* of all records used in this study.

5. ASSUMPTIONS FOR COMPARISON

Some assumptions were made in order to provide equal conditions for all methods.

Liquefaction occurrence of level 1 is detected if liquefaction occurrence is judged by method of Suzuki, very high possibility is judged by method of Miyajima, liquefaction is judged by method of Ozaki and Takada and by the proposed method. Liquefaction occurrence of level 0.5 is detected if high possibility is judged by method of Miyajima, possible liquefaction is judged by method of Ozaki and Takada and suspicion for liquefaction is judged by the proposed method. Liquefaction occurrence of level 0 is detected if no liquefaction is judged by method of Suzuki, method of Ozaki and Takada and by the proposed method and low possibility is judged by method of Miyajima.

$R_{VH,max}$ from method of Miyajima was calculated form the occurrence of *PGA* to last exceeding of 50 cm/s^2 but for at least 10 s $F_{p,a}$ from the same method was calculated within the first and last exceeding of 5 cm/s^2 but for at least 10 s and its limit value was changed to 1 Hz.

The value of R_{AI} from method of Ozaki and Takada is determined as the bigger from the two ratios of the horizontal components.

6. RESULTS AND DISCUSSION

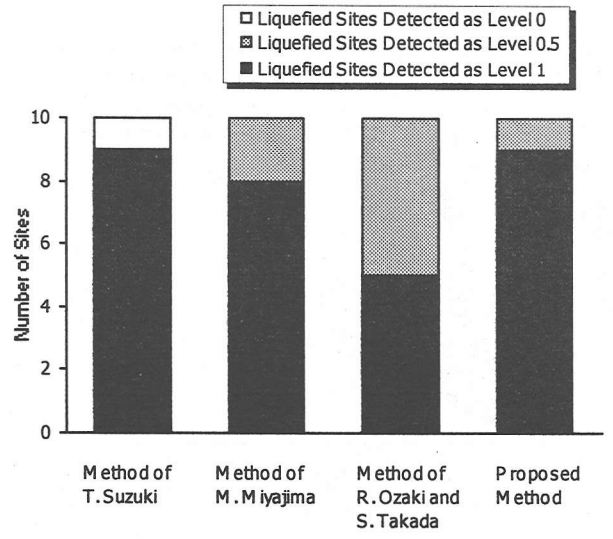

Fig. 3 Detection of liquefied sites

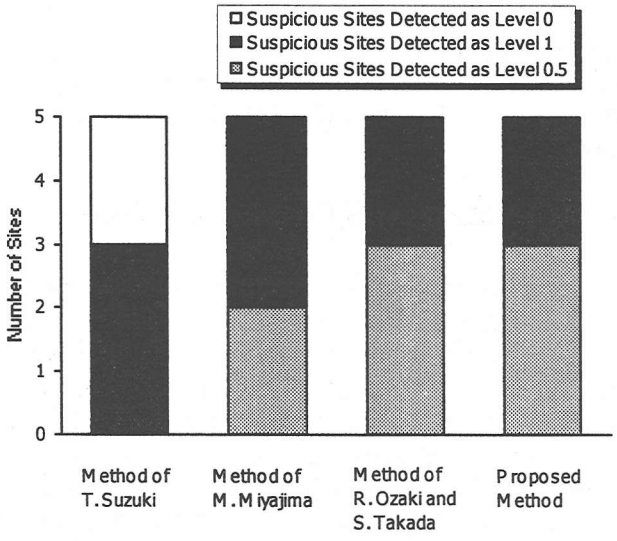

Fig. 4 Detection of suspicious sites

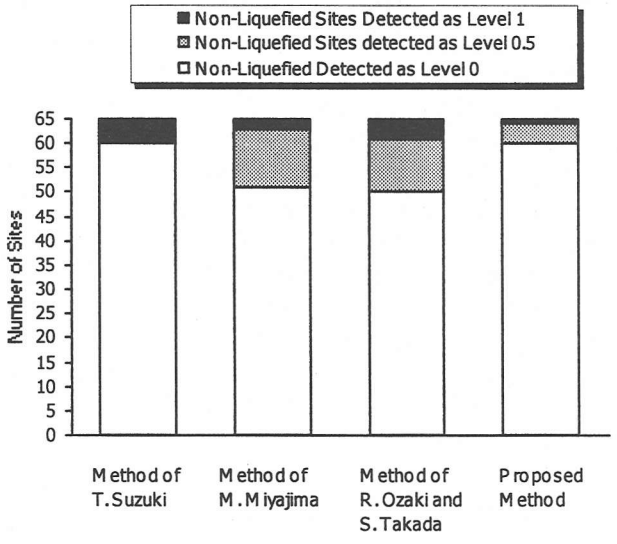

Fig. 5 Detection of non-liquefied sites

The results for each group records are given separately. **Figure 3** shows the judgements about the liquefied sites. All methods detect more than 90 percents of these sites either as level 1 or as level 0.5. **Figure 4** displays the detection of the suspicious sites. The method of Suzuki seems not to recognize some of them. The three-level methods do not distinguish the sites well even they aimed it. **Figure 5** depicts the judgements about the non-liquefied sites. The method of Miyajima and method of Ozaki and Takada perform not as good as the method of Suzuki and the proposed method in this case. One reason is that method of Ozaki and Takada does not employ amplitude parameters. The method of Suzuki recognizes the soft-soil sites with low-frequency ground motion from Mexico earthquake as liquefied.

The opinion of the authors is that future records from liquefied or suspicious sites might change some limit values of the ground motion parameters used and that there is no method giving hundred percent sure judgements.

7. CONCLUSIONS

An alternative method for detection of liquefaction from the ground motion records was proposed and a comparative study on the feasibility of all existing methods was conducted by processing a common data set. The results show that the methods detect the liquefaction occurrence in more than 90 percents of the cases.

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