ESTIMATION OF THE JMA SEISMIC INTENSITY FROM LIQUEFIED RECORDS AND ITS CORRELATION WITH STRONG MOTION PARAMETERS

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The JMA seismic intensity and other ground motion indices (e.g., PGA, PGV and SI) were calculated using 17 liquefied records selected from 7 major earthquake events. The relationships between the JMA seismic intensity and PGA, PGV and SI were then derived performing a linear regression analysis. Results from the analysis show that the JMA seismic intensity shows higher correlation with SI than PGA or PGV, and it shows the highest correlation with the parameter such as the combination of PGA and SI. The obtained relationships are also compared with the ones obtained from non-liquefied records, and it will useful for the disaster management agencies in Japan and deployment of new SI-sensors, which monitor both PGA and SI.

Key Words : *JMA seismic intensity, seismometer, spectrum intensity, SI-sensor, strong motion records*

1. INTRIDUCTION

After the 1995 Kobe earthquake, the earthquake information and early damage assessment systems[1)] became popular in Japan, and it can predict structural damage due to the ground shaking, fire, soil liquefaction or tsunami. The JMA seismic intensity[2)] has been used as the most important index to estimate structural damage due to earthquakes in Japan. Other ground motion indices, e.g., PGA, PGV, SI, etc., are also used to describe the severity of an earthquake, for instance, Tokyo Gas Co. Ltd. uses the SI value (**Fig.1**) as a measure of strong shaking and has developed the SI-sensor.[3)] Hence, it is important to know the relationship between the JMA instrumental seismic intensity and other strong motion indices, e.g., PGA, PGV, and SI.[4)]

Since, liquefaction has been recognized as the main reason for the collapse of earth dams and slopes, failure of foundations, superstructures and lifelines, it is also necessary to know the relationships between the JMA seismic intensity and ground motion parameters of liquefied sites.[5)] In this objective, a strong motion data set was selected in

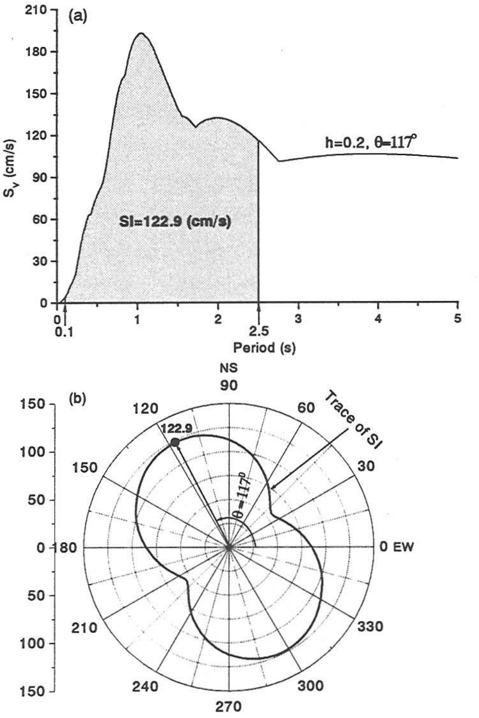

Fig.1 (a) Definition of *SI*, and (b) trace of *SI*, which is computed from the EW and NS components of acceleration records of the JMA Kobe station of the 1995 Kobe earthquake. The maximum value of *SI* is shown on the trace with a solid circle.

this study, which consists of seventeen (17) three-components liquefied records selected from seven (7) major earthquake events that occurred mostly in Japan and the United States. The JMA seismic intensity and other ground motion indices are calculated using the selected data set. The relationships between the JMA seismic intensity and PGA, PGV and SI are then derived performing a simple linear regression analysis. The obtained relationships are also compared with the ones obtained from non-liquefied records,[4] and it will useful for the disaster management agencies in Japan and deployment of new SI-sensors, which monitor both PGA and SI.

2. EARTHQUAKE DATA

Since the 1964 Niigata earthquake, a number of ground motion records from liquefied-soil sites have been obtained. The records show that the horizontal ground acceleration alterates uniquely after the onset of liquefaction-its frequency abruptly drops off to the range 0.5-1 Hz and its amplitudes decrease-while the vertical acceleration is rather stable. This alteration of the horizontal acceleration is triggered by the decreasing of the soil shear modulus as a consequence of the pore-water pressure buildup under undrained condition. An adequate description of the alteration can be used as a method for detection of liquefaction from seismic records. Such method can operate data from a seismometer network and identify the occurrence of the phenomenon immediately after an earthquake. It can also function as a standalone liquefaction sensor in combination with an accelerometer. Liquefaction has been recognized as the main reason for collapse of earth dams and slopes, failure of foundations, superstructures and lifelines and its early detection might be of great interest.[5] The fact whether a record is from a liquefied site is judged from a report about the site condition after a particular earthquake. Liquefaction occurrence is proved by field evidence like sand boils, ground fissures filled with sand, large permanent displacements or vertical settlements of soil, uplifting of pipelines or tanks, tilting of buildings, some foundation failures, etc. Seed *et al.*[6] pointed out that the liquefaction evidence takes different forms for different soils and suggested to consider two phenomena-'liquefaction' and 'cyclic mobility'. The former involves very large deformations while the latter involves limited amount of cyclic strain in the soil. Depending on the soil profile, however, some liquefaction evidence

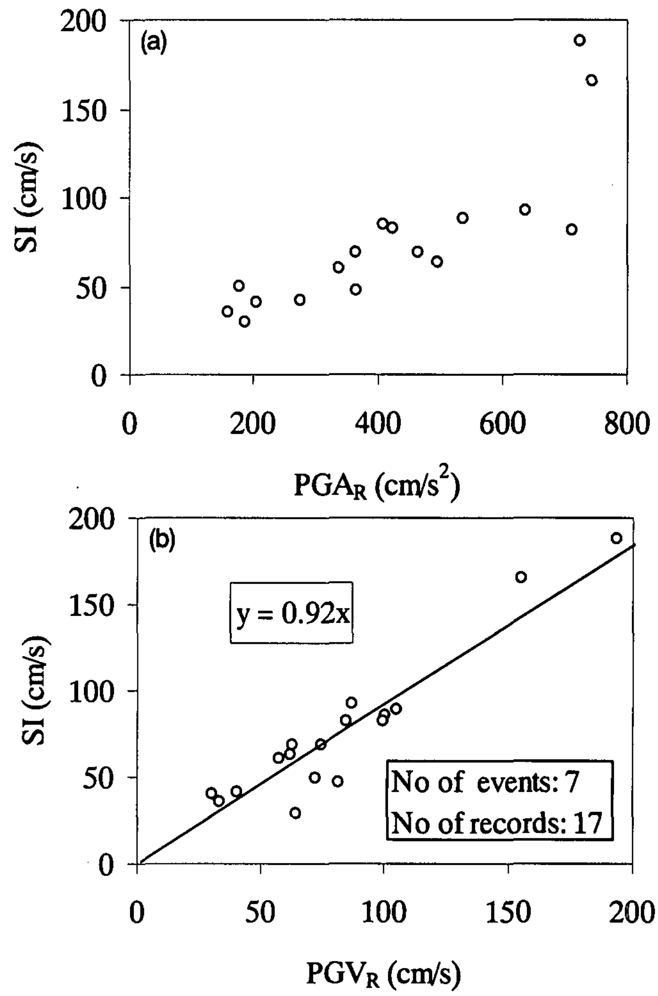

Fig.2 (a) Distribution of PGA_R and SI, and (b) relationship between PGV_R and SI for the 17 liquefied records used in this study.

such as sand boils may not be observed on the surface, when liquefaction occurs in depth.[7] In accordance with the above considerations, Kostadinov and Yamazaki[5] classified the recording sites with respect to the liquefaction occurrence due to a particular earthquake in the following three groups:

a) *Liquefied sites*: there was evidence seen for liquefaction at the recording site.

b) *Liquefaction-suspicious sites*: there was no evidence seen for liquefaction at the recording site, but it was observed in its vicinity (up to 50 m) or cyclic mobility at the site was confirmed by an analytical study.

c) *Non-liquefied sites*: there was no evidence for liquefaction at the recording site and its vicinity (up to 50 m) as well as no confirmation about the cyclic mobility at the site.

Based on the above classifications, a data set, which consists of seventeen (17) three-components acceleration records from both liquefied and liquefaction-suspicious sites was selected from seven (7) major earthquake events that occurred mostly in Japan and the United States. The data set was also used by Kostadinov and Yamazaki[5] for detection of soil liquefaction from strong motion records. **Figure 2** shows the distribution of PGA_R vs. SI and PGV_R vs. SI for the 17 liquefied records used in this study. The linear relationship between PGV_R and SI **(Fig.2** (b)) for the liquefied records is different from the one obtained for non-liquefied records.[8]

3. RESULTS AND DISCUSSIONS

The linear relationships between the JMA seismic intensity and *PGA*, *PGV*, and *SI* are derived for the liquefied records in this study as

$$I_{JMA} = 1.47 + 1.65\log_{10} PGA_R \quad (\sigma=0.200,\ R^2=0.778) \quad (1)$$

$$I_{JMA} = 2.64 + 1.64\log_{10} PGV_R \quad (\sigma=0.234,\ R^2=0.698) \quad (2)$$

$$I_{JMA} = 2.33 + 1.86\log_{10} SI \quad (\sigma=0.074,\ R^2=0.970) \quad (3)$$

In case of multiple ground motion indices, the linear relationships are derived as

$$I_{JMA} = 2.17 + 1.71\log_{10} SI + 0.17\log_{10} PGA_R \quad (\sigma=0.074,\ R^2=0.971) \quad (4)$$

$$I_{JMA} = 1.44 + 0.78\log_{10} PGV_R + 1.09\log_{10} PGA_R \quad (\sigma=0.172,\ R^2=0.848) \quad (5)$$

where I_{JMA} is the JMA intensity, PGA_R and PGV_R are the resultant of the two horizontal components, and *SI* is the maximum of *SI* calculated from 0 to 180 degree in the horizontal plane with one-degree interval **(Fig.1)**.

Figure 3 shows the comparison of the relationships between the JMA seismic intensity and PGA_R, PGV_R and *SI*, which are obtained in this study with the ones obtained from non-liquefied records[4]. One can see that the relationship between the JMA intensity and PGA_R **(Fig.3** (a)) obtained from liquefied records shows higher intensity comparing to the one obtained from non-liquefied records. Note that the correlation coefficient obtained between the JMA intensity and PGA_R shows higher value comparing to the one obtained for PGV_R. The common trend of liquefied site is that it has longer period, which may cause intensity to have higher value while estimating from PGA_R. However, with respect to both PGV_R and *SI* **(Fig.3** (b) and (c)), the relationships obtained from liquefied records show a very similarity with the ones obtained from the non-liquefied records.[4]

Midorikawa and Wakamatsu[9] calculated the JMA intensities of the ground motion at liquefied sites during past earthquakes by semi-empirical method taking into account the fault size and the soil profile at the site. They concluded that *PGV* is better correlated with the occurrence of liquefaction than *PGA* and suggested that soil liquefaction is likely to

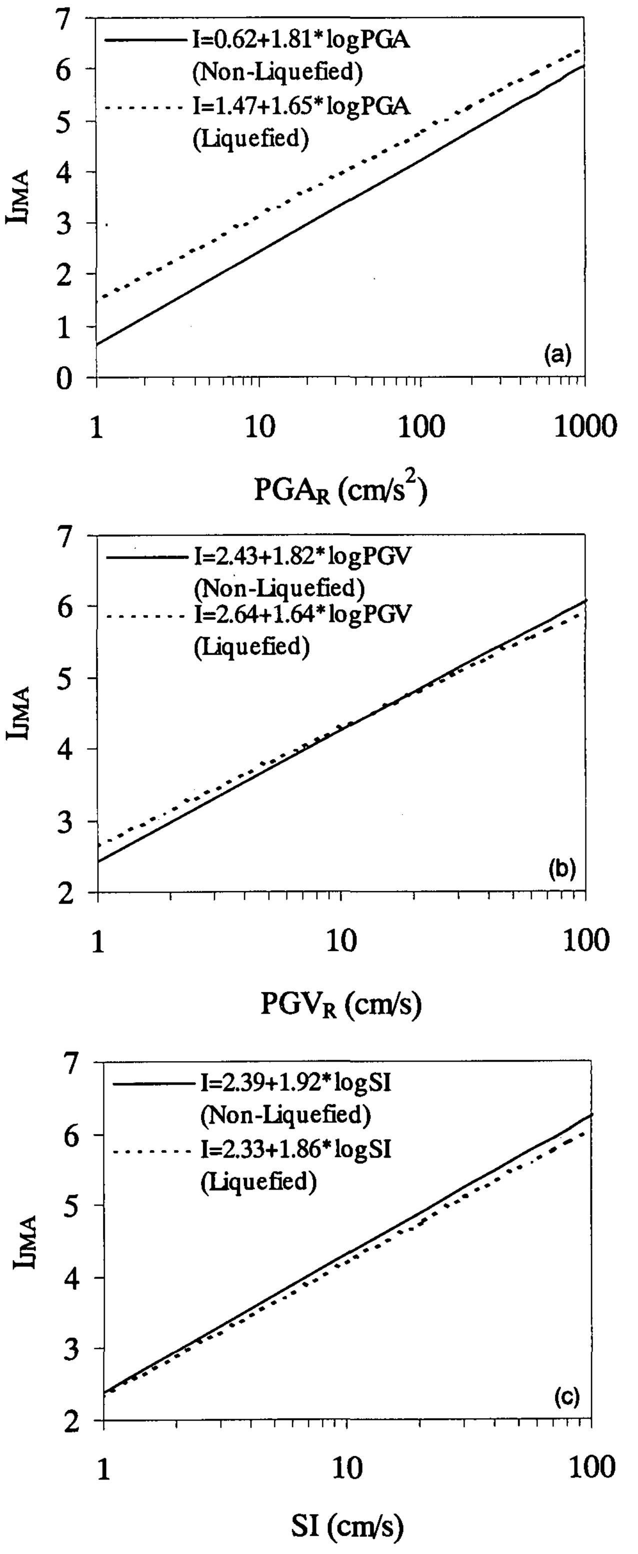

Fig.3 Comparison of the relationships between the JMA intensity and ground motion indices obtained from the liquefied and non-liquefied records.

occur when *PGV* exceeds 10-15 cm/s, which is supported by observation. Hence, for estimating the JMA intensity from liquefied records using single ground motion index, the choice of PGV_R or *SI* would be a better option than PGA_R.

Figure 4 shows the comparison of the linear relationship between the JMA intensity estimated from liquefied and non-liquefied records using both *SI* and PGA_R. The relationship is obtained as

$$I_{liq} = 0.99 I_{non-liq} \qquad (6)$$

It means, in case of multiple ground motion indices, i.e., *SI* and PGA_R, the JMA seismic intensity estimated from liquefied records is only 1 percent lower in magnitude than the JMA seismic intensity estimated from non-liquefied records. Although it was observed that when JMA intensity is estimated from liquefied records using only PGA_R, it shows higher value than non-liquefied records, however, when it is estimated using both *SI* and PGA_R, the JMA intensity shows only 1 percent lower in magnitude than the non-liquefied records. It means, if JMA intensity is estimated using both *SI* and PGA_R, then *SI* dominates to the contribution of estimating the JMA intensity than PGA_R. Moreover, if we look at the all relationships (Equations (1)-(5)) obtained for the liquefied records, then it can also be seen that the JMA intensity shows the highest correlation (R^2=0.971) with the parameter such as the combination of both PGA_R and *SI*, and it shows the second highest correlation (R^2=0.970) with *SI*. The similar trend was also observed in case of the non-liquefied records.[4)]

4. CONCLUSIONS

The JMA seismic intensity was calculated using 17 three-components liquefied records selected from 7 major earthquake events that occurred mostly in Japan and the United States. The relationships between the JMA seismic intensity and other ground motion indices, i.e., *PGA*, *PGV*, and *SI* were derived performing a linear regression analysis. The major findings are as follows:

1. The relationship between the JMA intensity and strong motion parameters obtained from liquefied records showed a very similarity with the one obtained from non-liquefied records with respect to both PGV and SI, however, some difference was observed with respect to PGA.
2. In case of multiple ground motion parameters, the relationship obtained from the liquefied records was also similar to the one obtained from non-liquefied records.
3. It was observed that the JMA intensity shows the higher correlation with both PGA and SI, and it shows the second higher correlation with only SI.

In case of implementation, according to the above findings, it can be concluded that the

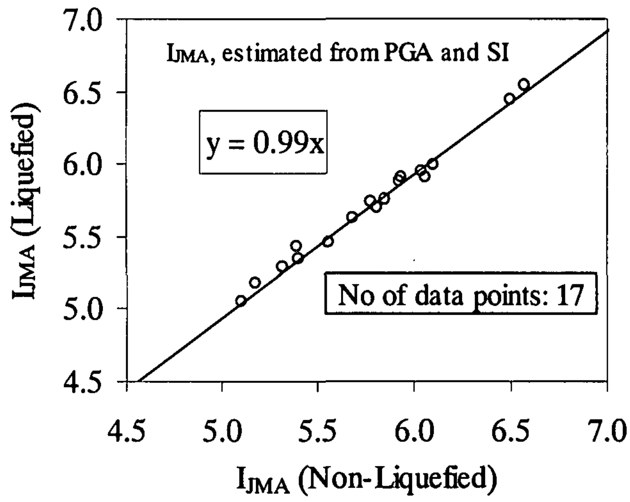

Fig.4 Comparison of the relationship between the JMA intensity and ground motion indices obtained from the liquefied and non-liquefied records with respect to both *PGA* and *SI*.

choice of SI or PGV would be better than PGA for single ground motion parameter, and the choice of PGA and SI would be better than PGA and PGV for multiple ground motion parameters.

REFERENCES

1) Yamazaki, F.: Earthquake monitoring and real-time damage assessment systems in Japan-developments and future directions, *Proc. of the 6th U.S.-Japan Workshop on Earthquake Resistant Design of Lifeline Facilities and Countermeasures Against Soil Liquefaction*, Technical Report NCEER-960012, pp. 727-740, 1996.
2) Japan Meteorological Agency (JMA) Report: Note on the JMA seismic intensity, *Gyosei*, 1996 (in Japansese).
3) Katayama, T., Sato, N. and Saito, K.: SI-sensor for the identification of destructive earthquake ground motion, *Proceedings of the 9th World Conference on Earthquake Engineering*, Vol. II, pp. 667-672, 1988.
4) Karim, K.R., Yamazaki, F. and Shabestari, K.T.: Correlation between the JMA instrumental seismic intensity and strong motion parameters, *Bull. of ERS*, IIS, University of Tokyo, No. 34, pp. 37-53, 2001.
5) Kostadinov, M.V. and Yamazaki, F.: Detection of soil liquefaction from strong motion records, *Earthquake Eng. Struct. Dyn.* Vol. **30**, pp. 173-193, 2001.
6) Seed, H.B., Tokimatsu, K., Harder, L.F. and Chung, R.M.: Influence of SPT procedures in soil liquefaction resistance evaluation, *Journal of Geotechnical Engineering*, Vol. 111, No. 12, pp. 1425-1445, 1985.
7) Kramer, S.: *Geotechnical Earthquake Engineering*, Prentice-Hall, Upper Saddle River, NJ, 1996.
8) Tong, H. and Yamazaki, F.: A relationship between seismic ground motion severity and house damage ratio, *Proc. of the 4th US Conference on Lifeline Earthquake Engineering*, ASCE, pp. 33-40, 1995.
9) Midorikawa, S. and Wakamatsu, K.: Intensity of earthquake motion at liquefied sites, *Soils and Foundations*, Vol. 28, No. 2, pp. 73-84, 1988.