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DETECTION OF GROUND FAILURE BY USING STRONG GROUND MOTION RECORDS

Masakatsu MIYAJIMA[1], Seiji INAGAKI[2], Hayato NISHIKAWA[3] and Masaru KITAURA[4]

SUMMARY

The present study is focusing on detection of ground failures such as liquefaction, large ground displacement induced by fault movement. This paper tries to use strong ground motion records for detection of the ground failures. We have proposed two indices for detection of liquefaction concerning with amplitude characteristics and frequency ones of acceleration records. These indices were verified by using the acceleration records obtained by the 2003 Tokachi-oki Earthquake, Japan. For a large ground displacement induced by fault movement, a new index is proposed by using velocity obtained by integration of acceleration records. The records of the 1999 Chi-Chi earthquake, Taiwan, verify this new index.

INTRODUCTION

It is well known that ground failure such as liquefaction, large ground displacement induced by fault movement is one of the serious causes of damage to buried lifeline facilities. Therefore establishment of a detection method of the ground failures using strong ground motion records was attempted in this study. There are few studies concerned with liquefaction detection by using strong ground motion records. Ozaki and Takada [1] proposed the ratio of Arias intensity of filtered to non-filtered acceleration time history by using the horizontal accelerations. Kayen and Mitchell [2] also used Arias intensity for his detection method of liquefaction. Suzuki's method [3] considered the following four parameters: peak ground acceleration, maximum spectral intensity, maximum horizontal displacement and zero-crossing period. Kiyono et al. [4] improved the existing techniques by taking account the period characteristics of the up-down component of ground acceleration. Kostadinov et al. [5] also proposed an alternative method. Their method used peak ground velocity and conditional mean frequency.

[1] Professor, Kanazawa University, Kanazawa, Japan, E-mail:miyajima@t.kanazawa-u.ac.jp
[2] Graduate Student, Kanazawa University, Kanazawa, Japan, E-mail:inagaki@pbousa9.ce.t.kanazawa-u.ac.jp
[3] Graduate Student, Kanazawa University, Kanazawa, Japan, E-mail:nishikawa@pbousa9.ce.t.kanazawa-u.ac.jp
[4] Professor, Kanazawa University, Kanazawa, Japan, E-mail:kitaura@t.kanazawa-u.ac.jp

The present study is focusing on detection of liquefaction and large ground displacement induced by fault movement. First, amplitude characteristics of strong ground motion records were investigated. Time histories of ratio of vertical ground acceleration to the horizontal one was calculated from ground acceleration records at ground surface. Next, frequency characteristics of the ground acceleration records were studied. The average predominant period of the strong motion was calculated here. Then these indices were verified by using more than one hundred acceleration records at ground surface in the 2003 Tokachi-oki Earthquake in Japan. The velocity of strong ground motion obtained by integration of acceleration is used for a new index to detect a large ground displacement induced by fault movement. As a result, the new index using the velocity waveform obtained from strong ground motion records within few kilometers from fault rupture identifies occurrence of a large ground displacement induced by fault movement.

DETECTION OF LIQUEFACTION

Indices for detection of liquefaction

Index on amplitude characteristics

It is well known that horizontal ground acceleration decreases but the vertical one does not decrease when liquefaction occurs. The time histories of ratio of vertical ground acceleration to the horizontal one were calculated from the acceleration records at ground surface in liquefied and non-liquefied areas. Strong ground motion records are usually digital values with time step of 0.01 second in Japan. If the ratio of vertical ground acceleration to the horizontal one is calculated at each time step, the ratio is remarkably great when the horizontal ground acceleration is close to zero instantaneously. Therefore, the ratio is calculated from the maximum accelerations in each direction for every 0.3 second in order to avoid the instantaneous great value.

Figs. 1, and 2 illustrate the acceleration records and the ratio of vertical ground acceleration to the horizontal one at Port Island and Kakogawa observation stations during the 1995 Hyogoken Nambu earthquake, Japan. Heavy liquefaction occurred at Port Island during the earthquake and there was no report of liquefaction at Kakogawa. The arrows illustrated in the figures indicate the time of occurrence of the peak horizontal acceleration in each direction. The large values of the ratio appear before the peak horizontal acceleration according to these figures. It is considered as the effect of primary wave.

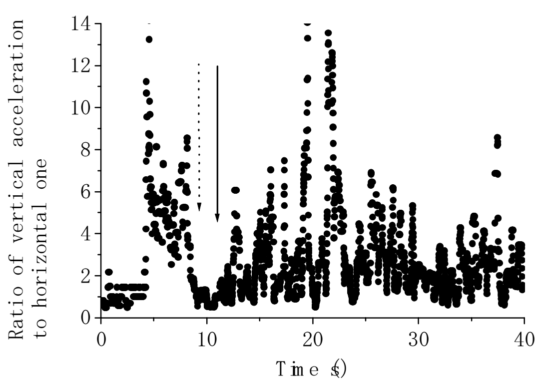

Fig. 1 Time history of the ratio of vertical ground Acceleration to the horizontal one (Port Island, 1995 Hyogoken Nambu EQ.)

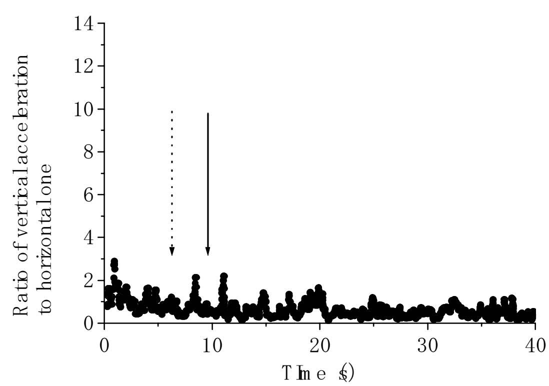

Fig. 2 Time history of the ratio of vertical ground Acceleration to the horizontal one (Kakogawa, 1995 Hyogoken Nambu EQ.)

Although the great values of the ratio appear in the record of Port Island after the peak horizontal acceleration, there is no large value in Kakogawa. The ratio, therefore, seems to be related to the liquefaction of the observation station.

The similar analysis was conducted for many strong ground motion records. The results seem to show that the possibility of liquefaction is great when the maximum ratio of vertical ground acceleration to the horizontal one after the peak horizontal acceleration is greater than 5.0 [6,7]. The ratio, therefore, seems to be one of the indices of detection of liquefaction.

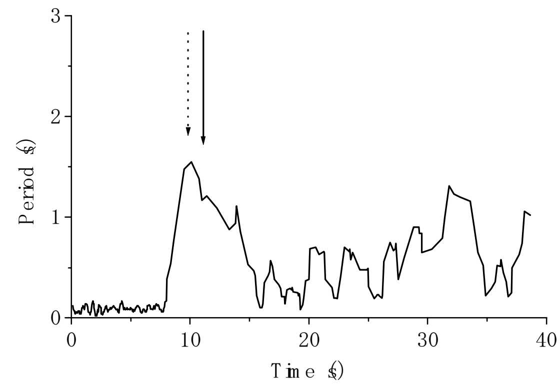

Fig. 3 Time history of average predominant period (Port Island, 1995 Hyogoken Nambu EQ.)

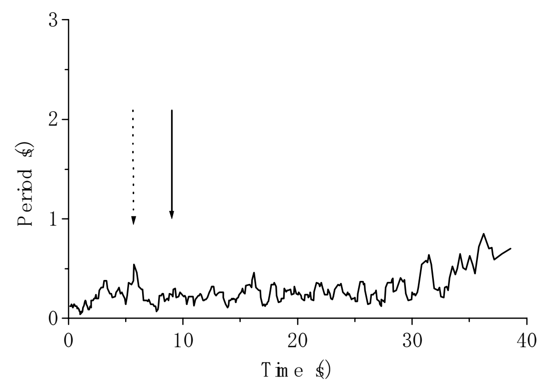

Fig. 4 Time history of average predominant period (Kakogawa, 1995 Hyogoken Nambu EQ.)

Index on frequency characteristics
It is well known that a predominant period of ground for shear vibration increases after occurrence of liquefaction. A time history of predominant period of horizontal ground acceleration was calculated by using the average of five zero-crossing periods. Figs. 3 and 4 indicate the time histories of the predominant period at Port Island and Kakogawa observation stations during the 1995 Hyogoken Nambu earthquake, respectively. The arrows in the figures also mean the time of the peak horizontal acceleration in each direction. According to Fig. 3, the predominant period rapidly increases at about 7 seconds, then kept a similar value, more than 1.0 second. There is, however, no great change before and after the peak horizontal acceleration in Kakogawa shown in Fig. 4. This change seems to explain the effect of occurrence of liquefaction.

The similar analysis was conducted for many strong ground motion records. The results seem to show that the possibility of liquefaction is great when predominant period of horizontal ground acceleration after the peak horizontal acceleration is greater than 1.0 second [6,7]. The ratio, therefore, seems to be one of the indices of detection of liquefaction.

Verification in the 2003 Tokachi-oki Earthquake, Japan

Tokachi-oki Earthquake occurred off Tokachi region in the east part of Hokkaido in September 26, 2003. The magnitude of the main shock and maximum aftershock were 8.0 and 7.1, respectively. Many strong ground motion records were obtained at JMA, K-NET and KiK-net observation stations. The maximum horizontal acceleration of 972 cm/s^2 was recorded at Hiroo station in the main shock. Liquefaction was occurred and structural damage induced by liquefaction was also caused. The records of the maximum aftershock were also used in this study because the magnitude was big and liquefaction happed in the maximum aftershock. One hundred thirty five acceleration records more than 80 gal of the peak ground acceleration were used for verification of the indices.

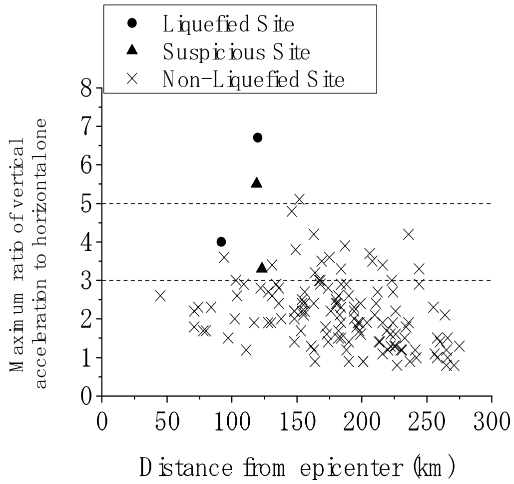

Fig. 5 Maximum ratio of vertical ground acceleration to the horizontal one.

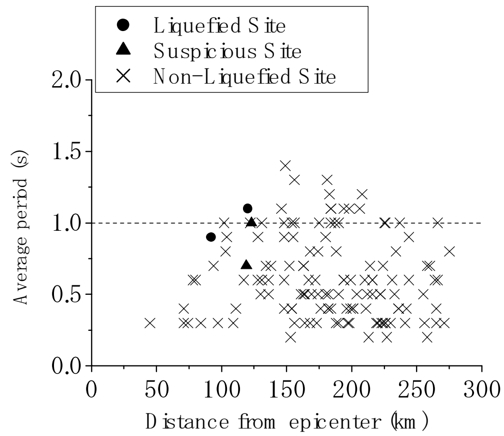

Fig. 6 Average predominant period.

Fig. 5 indicates the maximum ratio of vertical ground acceleration to the horizontal one in relation to the distance from the epicenter to each station. The past studies done by the authors [6,7] showed that the possibility of liquefaction was great when the maximum ratio of vertical ground acceleration to the horizontal one after the peak horizontal acceleration is greater than 5.0. It can be seen from this figure that the ratios at one liquefied and one suspicious site are greater than 5.0 but ratios of another liquefied and suspicious sites are less than 5.0. All of sites, which the ratio is less than 3.0, are non-liquefied.

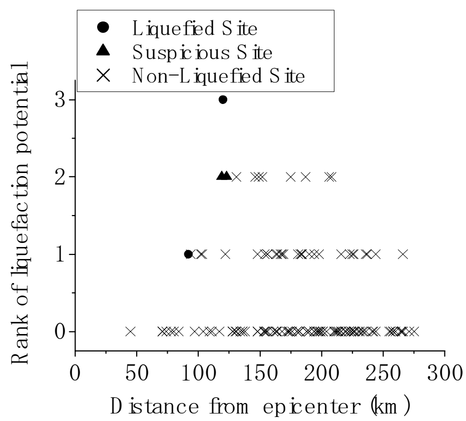

Fig. 7 Rank of liquefaction potential and condition of liquefaction.

Fig. 6 illustrates the average predominant period of the strong ground motion records. The past studies done by the authors [6,7] showed that the average predominant periods at liquefied sites were more than 1.0 second and most of those at suspicious sites were also more than 1.0 second. It can be seen from this figure that some average periods recorded at the non-liquefied site are more than 1.0 second, however. Since a peat layer widely exists at the subsurface ground of Tokachi region, predominant period of ground at many sites seems to be long despite non-liquefied ground.

Fig. 7 shows a rank of liquefaction potential estimated by the two indices proposed here. If the maximum ratio of vertical ground acceleration to the horizontal one exceeds 5.0, the rank of liquefaction is two and if it exceeds 3.0 but less than 5.0, the rank of liquefaction is one. Moreover, if the predominant period of horizontal ground acceleration after the peak horizontal acceleration is greater than 1.0 second, the rank of liquefaction is added one. Therefore the rank of liquefaction potential is estimated by four ranks, zero to three. According to Fig. 7, the ranks at one liquefied site and two suspicious sites are estimated as more than two and most of the ranks at non-liquefied sites are zero.

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DETECTION OF LARGE GROUND DISPLACEMENT INDUCED BY FAULT MOVEMENT

Index for detection of large ground displacement

Fig. 8 illustrates an acceleration waveform recoded at an observation station close to the surface fault rapture in the 1999 Chi-Chi Earthquake, Taiwan. Ground movements of about 8m in horizontal direction and about 5m in vertical direction were observed there. It can be seen from this figure that an abrupt change of the waveform appears at about 35 seconds. Fig. 9 shows a time history of predominant period of horizontal ground acceleration obtained from the average of five zero-crossing periods. The time of the abrupt change of waveform shown in Fig. 8 coincides with the long period of Fig. 9. Increase of predominant period of acceleration waveform recorded near a surface ground rupture is similar to that at a liquefied site. Only this index cannot be distinguished the liquefaction and large ground displacement induced by fault movement.

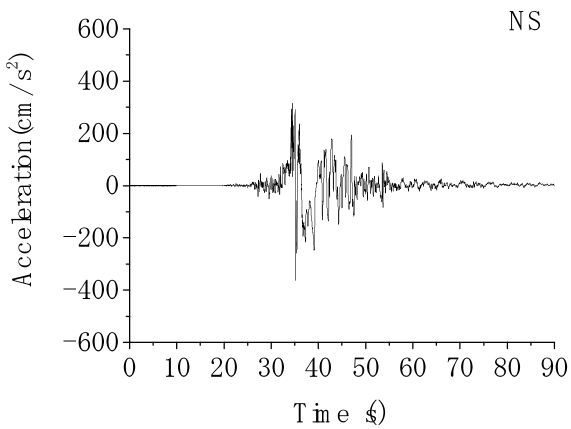

Fig. 8 An acceleration waveform recoded at an observation station near a surface fault rapture in the 1999 Chi-Chi Earthquake, Taiwan (Shih-Kang).

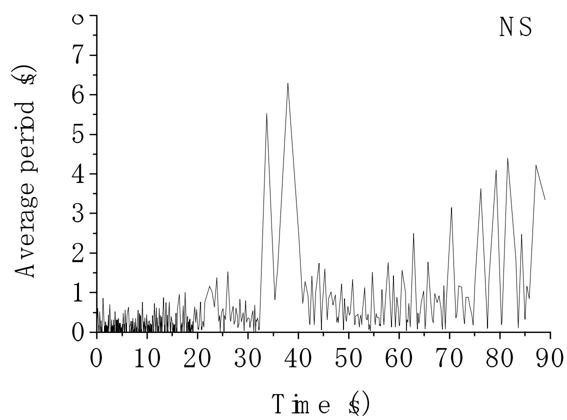

Fig. 9 Average predominant period of the acceleration waveform shown in Fig. 8.

Fig. 10 shows a velocity waveform obtained by integration of acceleration record shown in Fig. 8. The abrupt change at about 35 seconds is clearer than that in Fig. 8. We propose a new index for detection of large ground displacement induced by fault movements using a velocity waveform. The peak ground velocity divided by the area between horizontal axis and velocity waveform defines the new index here. This area of the waveform included long period pulse, such as Fig. 10 is larger than that of cyclic long period wave like liquefaction. And a peak ground velocity (PGV) near a surface fault rupture is larger than that at a liquefied ground in general. This index, therefore, seems to be classified into the waveform recorded near a surface fault rupture and at a liquefied ground.

Verification in the 1999 Chi-Chi Earthquake, Taiwan

Fig. 11 shows a peak ground velocity divided by an area of velocity waveform in relation to the distance from surface fault line to each station. According to this figure, this index at hanging wall side is larger than that at footwall side in same distance from the surface fault line. The values of liquefied site are smaller than those at hanging wall side. Since the fault of the 1999 Chi-Chi Earthquake was reverse type, surface ground at the hanging wall side moved. Therefore, this index seems to detect the ground movement induced by fault movement and distinguish it from liquefaction. Roughly speaking, the surface displacement was more than 2m within 2.5 km from the surface fault line in this earthquake. So this value seems to be one of indices for large ground displacement induced by fault movement because almost all stations within 2.5 km are larger than 0.15 of PGA/area of velocity waveform. The values, however, are also greater than 0.15 at hanging wall side far from the surface fault line. Further study is needed at this point.

CONCLUDING REMARKS

Establishment of detective method of ground failure such as liquefaction and large ground displacement induced by fault movement using strong ground motion records was attempted in this study. The following indices for detection of ground failures were proposed, that is, the maximum ratio of vertical ground acceleration to the horizontal one and the average predominant period of horizontal ground acceleration for detection of liquefaction, and a peak ground velocity divided by an area of velocity waveform for detection of large ground displacement induced by fault movement.

The indices for liquefaction were verified by the acceleration records obtained in the 2003 Tokachi-oki Earthquake, Japan. A rank of liquefaction potential estimated by the two

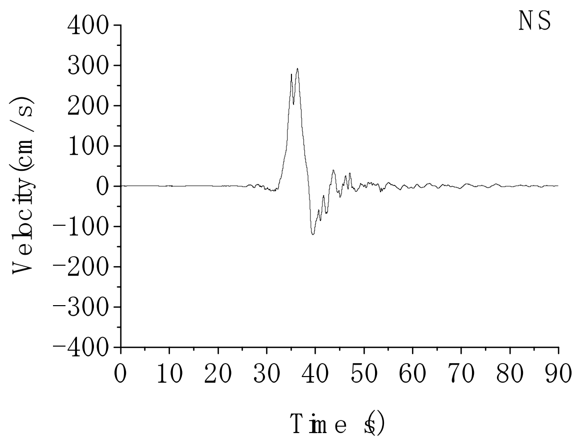

Fig. 10 A velocity waveform obtained by integration of acceleration record shown in Fig. 8.

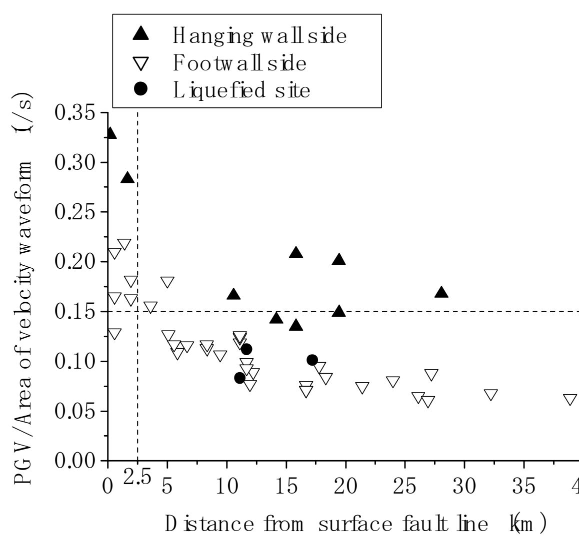

Fig. 11 A peak ground velocity divided by an area of velocity waveform in relation to the distance from surface fault line to each station.

indices proposed here distinguishes the liquefied and non-liquefied sites in certain extent. Further study on a soft ground condition such as a peat layer is needed because ranks of two and three cannot distinguish the liquefied and non-liquefied sites clearly.

The strong ground motion records obtained in the 1999 Chi-Chi Earthquake, Taiwan, verified the new index proposed in this paper, the peak ground velocity divided by an area of velocity waveform. This index seems to be classified into the ground motion waveform recorded near a surface fault rupture and at a liquefied ground. Since the value of this index depends on duration of waveform, a generalization is needed in the future to use another earthquake records.

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