Liquefaction caused by the 2011 off the Pacific Coast of Tohoku Earthquake and the Result of the Prior Microtremor Measurement

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SUMMARY:
The 2011 off the Pacific coast of Tohoku Earthquake caused severe damage in a wide sphere. Even in Tokyo metropolitan area liquefaction was observed. The basic and proper countermeasure for earthquake disaster is to make all the structure earthquake resistance. For this purpose, it is important to grasp the vulnerability from the inventory survey before the expected event. This paper explains the vulnerability index Kg value and compares the liquefaction caused by this earthquake with the results of the microtremor measurement in 1990. For example, at Maihama area we had 4 measurement points. In this area, Kg value was 9.8 to 34.9 (micro strain/Gal) and it corresponds to the shear strain at the surface ground layer caused by this earthquake is estimated 700 to 2300 micro strain. So, two points of this measurement are possible to be suffered liquefaction damage. This agrees with the field investigation.

Keywords: The 2011 off the Pacific coast of Tohoku Earthquake, Microtremor Measurement, K Value, H/V Spectral Ratio, Liquefaction

1. INTRODUCTION

The 2011 off the Pacific coast of Tohoku Earthquake (hereafter the 3.11 earthquake) caused severe damage in wide sphere focusing mainly around eastern Japan area. And even in Tokyo metropolitan area, more than 200 to 300 km far from the epicentral area, liquefaction was observed in many places.
By the way, the ultimate and proper countermeasure for earthquake disaster is to make all the structure earthquake resistance. For this purpose, it is important to grasp the vulnerability from the inventory survey before the expected event.
This paper explains the vulnerability index Kg value derived from the result of microtremor measurement and adopts Kg value for the microtremor measurement in 1990 to estimate the possibility of liquefaction. Then Kg value compares the liquefaction situation caused by the 3.11 earthquake.

2. VULNERABILITY INDEX KG VALUE FOR GROUND

Vulnerability index K value is proposed as an index to estimate the strain of ground or the focused part of the structure against estimated earthquake motion, derived from the predominant frequency F and its amplification factor A of microtremor, and the dimensions of the structure. The common estimating equation of the strain γ or ε is as follows.

$$\gamma \text{ or } \varepsilon = K \times a \qquad (2.1)$$

Here, K and a are K value and the acceleration value at the base ground, respectively.
In case of ground, Kg value, K value for ground, is defined as follows;

$$
\begin{aligned}
\gamma &= eAd / h \\
&= eAa / \omega^2 / h \\
&= eAa / (2\pi F)^2 (4F / Vs) \\
&= eAa / (2\pi F)^2 (4FA / Vb) \\
&= eA^2 / F / (\pi^2 Vb) \\
&= A^2 / Fe / (\pi^2 Vb) a
\end{aligned} \tag{2.2}
$$

Here, e is input efficiency and Vb and Vs are the velocity of the base ground and surface layer, respectively. Also d is displacement at ground surface and h is depth of the surface ground. Hence,

$$\gamma_e = \beta \times Kg \times a \tag{2.3}$$

Here, $Kg = A^2/F$ and $\beta = e/(\pi^2 Vb)$. Vb can be assumed 600m/s in Japan. If input efficiency e is assumed 0.6, numerical value of β is about 1.0 and then,

$$\gamma_e = Kg \times a \tag{2.4}$$

It seems that the input efficiency e can be fluctuated by the input earthquake motion. In case of the shot duration like pulse wave, large acceleration is required to cause large strain so the input efficiency e will be small. However this earthquake has very long duration, so input efficiency e can be set 1.0 and then β becomes 1.7. Thus,

$$\gamma_e = 1.7 \times Kg \times a \tag{2.5}$$

The trial on the determination of liquefaction occurrence using Kg value will be described below.

3. RESULT OF MICROTREMOR MEASUREMENT AND LIQUEFACTION OCCURRENCE

This paper uses the result of microtremor measurement conducted in 1990. The instrument for this measurement was PIC, Portable Intelligent Collector, a microtremor measuring tool with a three-component sensor and data logger units. The microtremor was repeatedly recorded for 40.96 seconds (4,096 data in 100 Hz sampling) at every measurement site, and a 10.24 seconds length data was chose from a viewpoint of less artificial noise. Then the selected data was Fourier transformed. After that, the horizontal to vertical spectrum ratio was calculated for each component of every measurement and finally H/V spectrum ratio was derived as an averaged spectrum ratio (Nakamura, 1989). Predominant frequency F and its amplification factor A are read from the H/V spectral ratio. These procedures had been done in 1990.

This paper calculates the Kg value from this result in 1990 and estimates the strain in the surface ground layer with the acceleration value at the time 0f 2011 event observed nearby sites. Then the proposed index and method are verified their validity with comparing the estimated strain with the actual liquefaction situation.

3.1. Maihama area

Maihama is a reclaimed area filled in 1970s and locates at eastern side of Tokyo metropolitan area. Tokyo Disney Land built on it. In 1990, microtremor measurement was conducted at four corners of a reclaimed land, MH01 to MH04 as Figure 3.1. Kg value is calculated from predominant frequency F and its amplification factor A in 1990. Kg value ranges 9.8 to 34.9 μ/Gal (=micro strain/(cm/s/s)) for MH01 to MH04 as shown in Figure 3.2. A nearby strong motion station, K-NET Urayasu, recorded 164 Gal (= cm/sec/sec) as maximum acceleration. Here this maximum acceleration value is 5HzPGA, 5Hz low passed peak ground acceleration to restrict the acceleration value to explaining the damage situation properly. And because the amplification factor is assumed about 4 times for the ground in this area, maximum acceleration at base ground can be assumed 41 Gal. In view of a considerable long duration time of the 3.11 earthquake, as described before, the input efficiency e set 1.0 for the discussion below.

If input efficiency e is 1.0, the strain in the surface ground is estimated roughly 1050, 1100, 700 and 2300 μ for MH01 to MH04, respectively. If a strain more than 1000 μ causes liquefaction as it is often expressed, it seems that liquefaction occurs at MH01 and MH02, does not occur at MH03 and severely occurs at MH04. Figure 3.1 also shows the result of the field survey of the liquefaction situation after Yasuda, 2011. We can see that the Kg value distribution agrees with the liquefaction situation.

Figure 3.1. Measurement Point and Liquefaction Situation at Maihama Area

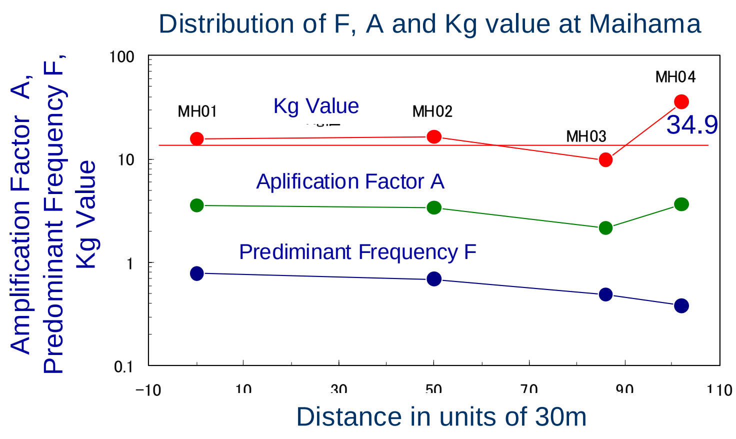

Figure 3.2. Distribution of Kg value, Predominant Frequency F and Amplification Factor A at Maihama Area

3.2. Omori and Oi area

Omori and Oi area locate in south west part of Tokyo Metropolitan area and the main part of Oi had been filled up in before 1940s. Measurement points were set along EW line between a park west side of JR Omori station and Oi container wharf, and along NS line in the center of Oi pier (see Figure 3.3). Figure 3.4 shows the Kg value distribution based on the 1990 measurement. This figure shows that Kg value exceeds 15 around the wharf and a park in the west side of the reclaimed land. After Tokimatsu 2011, liquefaction occurs around the pier, and also a park in the center of reclaimed land temporary closed a baseball ground because of liquefaction and informed damage as crack at artificial shore. There is no more information of damage for this area.
Kg values corresponding to this damage information are small value around 10 except more than 23 at the pier and more then 15 around the park. It shows that liquefaction must be caused more than 60 Gal of the acceleration at the base ground if the input efficiency is assumed 1.0. Thus it seems to be hard to occur liquefaction in case of less than 100 Gal from the ordinary event with common duration time. So Kg value distribution gives proper result for the possibility investigation of liquefaction.

Figure 3.3. Distribution of Measurement Point and Reported Damage at Omori and Oi Area
(★ : Reported Damage)

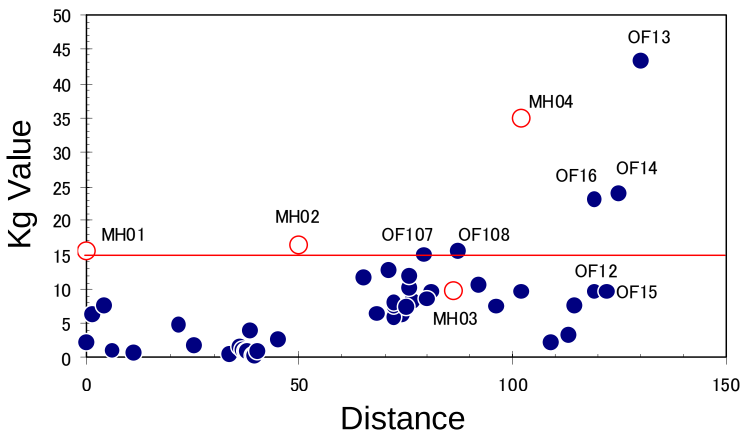

Figure 3.4. Distribution of Kg Value at Omori and Oi Area

3.3. JR Keiyo-line

JR Keiyo-Line is running along coastal line of Tokyo bay. Microtremor measurement in 1990 was conducted every 100m for 22.5km between Nishi-Funabashi station and Soga station (see Figure 3.5).

Figure 6 shows distribution of Kg value for the distance from Nishi-Funabashi station, the western end of the measured area. An area marked dark pink and light blue indicates a portion of liquefaction and not liquefaction, respectively, after Yasuda, 2011. Also light pink indicates liquefaction after Chiba Prefectural Environmental Research Center, 2011. After 7km, purple part indicates a possible area with liquefaction from comparing Google Earth photos before and after the earthquake.

It seems that distribution of Kg value in Figure 3.6 agrees with the result of reconnaissance survey. And at the area of liquefaction occurence, Kg value is mostly more than 10. Maximum acceleration around this area can be estimated about 50 Gal because observed acceleration was around 200 Gal and amplification factor is assumed 4. With considering long duration time, input efficiency can be assumed 1.0, and the strain is estimated about 1000 μ when Kg>12. It is able to be thought that the liquefaction judgment is almost proper.

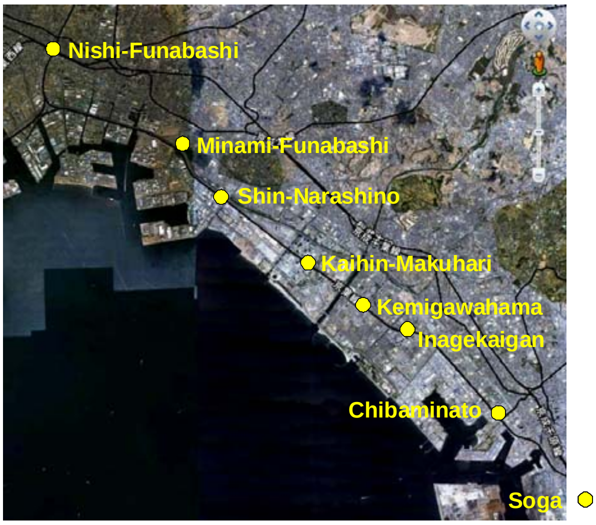

Figure 3.5. Distribution of Measurement Points for JR Keiyo-line

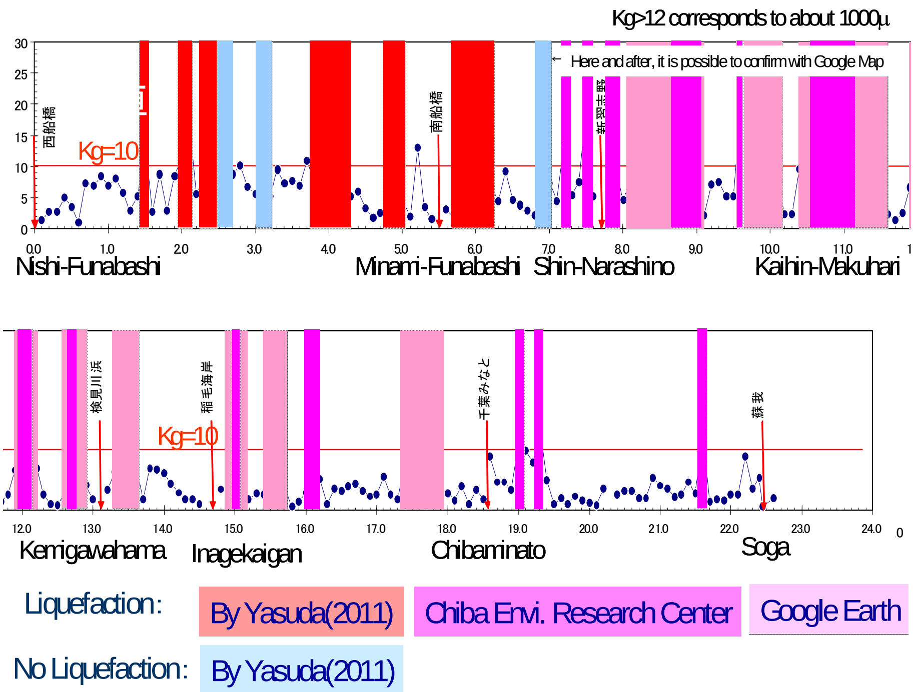

Figure 3.6. Distribution of Possible Damage and Kg Value for JR Keiyo-line

3.4. JR Kashima-line

JR Kashima-Line is running through marsh land in northern greater Tokyo area. Microtremor measurement in 1990 was conducted every 100m from south to north between JR Katori station and JR Kita-Kashima station (current Kashima Soccer Stadium station). In this area, we have no information of liquefaction occurrence totally along the railway line. So we have compared aerial photos opened by Google Earth to find out differences between before and after the earthquake. Figure 3.7 shows distribution of Kg value for the distance from Katori station, the southern end of the measured area. An area marked pink and brown indicates a possible area with liquefaction and damage for embankment, respectively, from comparing Google Earth photos. Although this is not a result of reconnaissance survey, it seems that the damage relates to the change of Kg value and threshold level for damage occurrence is little more than 10 of Kg.

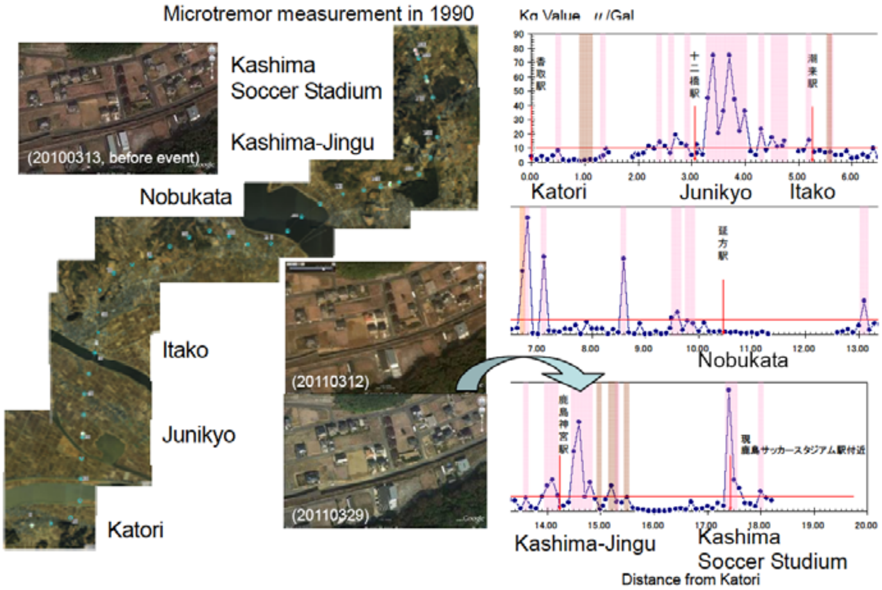

Figure 3.7. Distribution of Measurement Point, Possible Damage and Kg Value for JR Kashima-line

4. CONCLUSIONS

This paper adopted the proposed index for liquefaction occurrence based on the result of microtremor measurement for the measurement conducted in 1990, and then compared between the result of determination of the liquefaction possibility and the actual liquefaction situation at the time of 3.11 Earthquake. As a result, it confirmed that liquefaction occurred at the site with Kg value more than 12. This high Kg value corresponds around 1000 μ of a shear strain for a surface ground caused by an input earthquake motion, if the input efficiency assumed 1.0 in light of the long duration time for this 3.11 event. And also the possible damaged area only from the change of the aerial photographs before and after the earthquake on Google Earth agrees with the result of the microtremor measurement along the railway in 1990.

In this way it recognized that it is possible to evaluate accurately the possibility of the liquefaction and other earthquake damage occurrence for supposed earthquake motion from microtremor measurement beforehand. The validated technique here is a simple technique to measure microtremor and it can realize an inventory survey. So it will be possible to take a proper countermeasure based on the ordinary investigation technique in detail for an area fell out by this proposed technique. And also it is possible to confirm an effect the countermeasure work with a change of microtremor characteristics before and after the work.

We will be happy if the proposed technique can contribute a countermeasure for liquefaction.

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