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EVALUATION OF VELOCITY POWER SPECTRUM INTENSITY WITH VERY HIGH DENSE SPATIAL LOCATION IN RESIDENTIAL VALLEY-FILLING AREA DURING A FUTURE LARGE-SCALE EARTHQUAKE

Y. Hata[(1)], F. Minato[(2)], T. Ikeda[(3)], Y. Fukushima[(4)] and K. Tokida[(5)]

[(1)] *Assistant Professor, Graduate School of Engineering, Osaka University, hata@civil.eng.osaka-u.ac.jp*
[(2)] *Graduate Student, Graduate School of Engineering, Osaka University, fminato@civil.eng.osaka-u.ac.jp*
[(3)] *Professor, Department of Civil and Environmental Engineering, Nagaoka University of Technology, ikeda@vos.nagaokaut.ac.jp*
[(4)] *Project Leader, Earthquake Resistant Group, Eight-Japan Engineering Consultants Inc., fukushima-ya@ej-hds.co.jp*
[(5)] *Professor, Graduate School of Engineering, Osaka University, tokida@civil.eng.osaka-u.ac.jp*

Abstract

The 2011 off the Pacific coast of Tohoku, Japan, earthquake caused significant damage, not only due to tsunamis but also due to strong motions. The damage to housing may be classified into tsunami-related damage, damage due to ground liquefaction on newly reclaimed land, and that caused by the instability of slope sand fill embankments developed for residential use. Nowadays, many approaches which simulate the slope failure based on numerical analysis are carried out. On the other hand, it is very important to predict and evaluate the seismic response characteristics of residential valley-filling area during a future large-scale earthquake based on the obtained moderate earthquake observation record.

Regarding this indication, we have already focused on the damaged one to housing lots on hillside embankments. Emphasis is placed on the damage and failure of the housing lots on the hillside embankments in Sendai City, a city with a population in excess of one million, making it one of the largest cities in East Japan. We have then succeeded in clarifying the landslide mechanism of the residential fill slopes due to the 2011 off the Pacific coast of Tohoku Earthquake. It is important to use efficiently the obtained findings in the prediction and evaluation of damage and failure of a residential fill embankment during a future large-scale earthquake.

At present, in Japan, event probability of a large-scale earthquake whose epicenter has Tokyo Metropolitan Area is increasing. Yokohama City, a city with a population in excess of three million, located in the metropolitan area has the greatest residential land in Japan. A large part of the residential land consists of cutting or banking site of valley-filling. Due to the 1978 off Miyagi Prefecture Earthquake, the 1995 Southern Hyogo Prefecture Earthquake, the 2004 Mid Niigata Prefecture Earthquake and the 2011 off the Pacific coast of Tohoku Earthquake, serious damage are reported at the banking site of valley-filling in Sendai City, Kobe City and so on. Thus, during the future Tokyo Metropolitan Earthquake represented by the Northern Tokyo Bay Earthquake by Japanese Cabinet Office, the similar damage at a banking site of valley-filling in Yokohama City can imagine without difficulty.

In this paper, seismic response characteristics of the residential land in Yokohama City are evaluated based on temporary earthquake observation records. In particular, first, a lot of seismograph installed with very high dense spatial location at not only cutting but also banking sites of residential valley-filling in Kanagawa Ward, Yokohama City, Japan. Seismic waveform records are then obtained simultaneously at the created observation station sites during some moderate earth-quakes. Based on the analysis consequence of the observed seismic waveforms, furthermore, difference of the seismic response characteristics between the cutting sites and the banking sites was evaluated. Finally, ground motion estimation was carried out during the Northern Tokyo Bay Earthquake based on the evaluated local site effects. At that time, as an index of ground motion, we took into consideration the velocity power spectrum intensity (PSI) value with strong relation with the past seismic damage of residential fill embankment. Our related discussion and obtained findings will be useful in future evaluation of seismic performance of a residential fill embankment.

Keywords: seismic observation, valley filling, landslide, the Northern Tokyo Bay Earthquake, site effect

1. Introduction

The serious damage due to a strong motion with the 2011 off the Pacific coast of Tohoku Earthquake (M_W9.0) is reported at a lot of sites in residential area. With respect to this point, Hata *et al*. [1-9] have already carried out the strong motion estimation during the 2011 main shock *etc*. at damage and non-damage sites in the residential area. In these case studies on the strong motion estimation, the occurred large-scale earthquakes (*e.g*., principal historical earthquakes) were focused on. It is very significant to use efficiently the findings obtained by these strong motion estimations in the strong motion prediction during a future large-scale earthquake (*e.g*., the Northern Tokyo Bay Earthquake [10]), in order to improve seismic performance evaluation for a residential land.

On the other hand, in the seismic performance evaluation, it is important to better understand ground shaking characteristics of the residential land. However, there are few study based on ground investigation, such as earthquake observation and microtremor measurement *etc* [11]. It is important to evaluate the ground shaking characteristics in the residential land based on the record obtained by temporary earthquake observation at the site of interest.

In this paper, we carried out temporary earthquake observations with high dense spatial location in residential land in Kanagawa Ward, Yokohama City, Japan, (see Fig. 1). Based on the obtained observation records, site amplifi-cation factors and site phase effects focused on Tokyo Bay Area were then evaluated. Finally, strong ground motion during the Northern Tokyo Bay Earthquake was estimated based on the SMGA models [12] considering the empirical site amplification and phase effects.

2. Residential land of interest

Fig. 2 is a plan view of the residential land of interest in Kanagawa Ward with the shape of valley-filling for prewar and postwar based on results of condition survey of large-scale banking by Yokohama City [13]. The distribution of temporary earthquake observation sites in the residential land of interest (see Chapter 3) was also illustrated in Fig. 2. In Fig. 2, the created density of the temporary earthquake observation sites in this study is clearly higher than the official density of the permanent station sites for strong motion observation (the interval between SK-net Civil Engineering Office site and SK-net Fire Station site) by Yokohama City [14]. Thus, we will hereafter be called ‘the temporary earthquake observation with “very” high dense spatial location’.

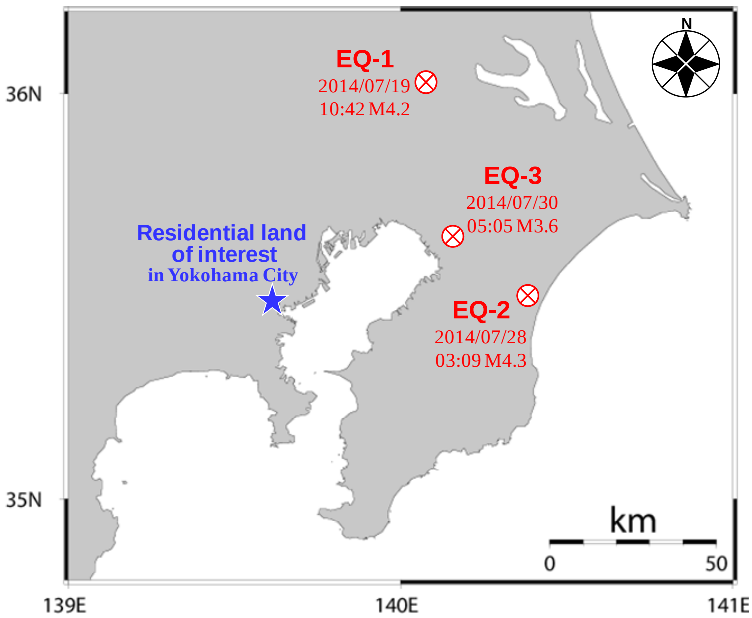

Fig. 1 – Location of the target site in Tokyo Bay Area

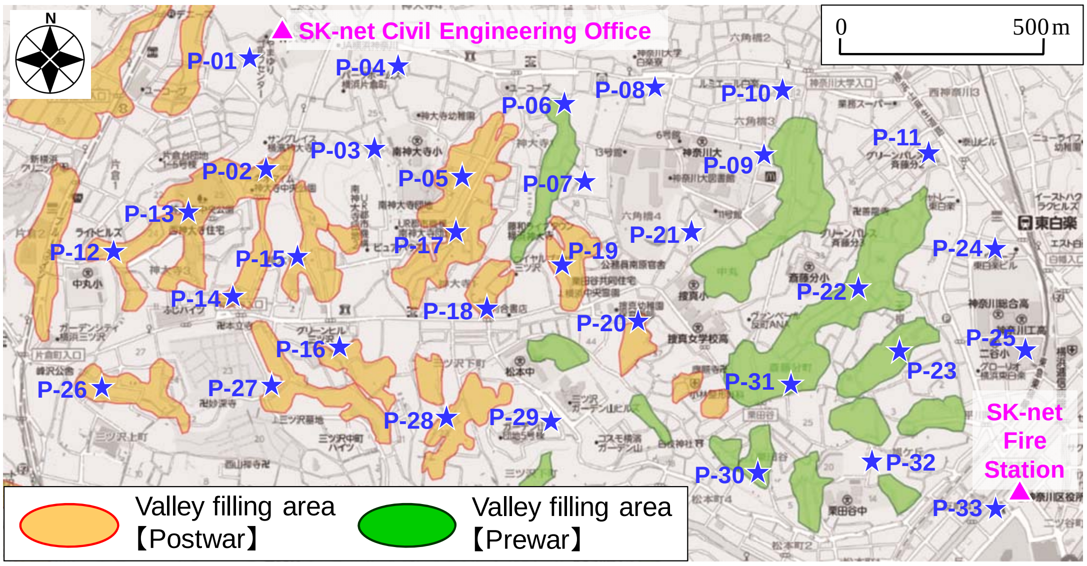

Fig. 2 – Distribution of the created 33 sites for temporary earthquake observation

3. Array earthquake observation

We created 33 sites for array earthquake observation (from P-01 to P-33 sites: see Fig. 2) in the residential land of interest. In particular, we adopted the array observation with the created 33 sites of interest in order to evaluate directly the difference in the ground shaking characteristics (the empirical site amplification and phase effects) in the residential land of interest based on some observation records due to a same earthquake. Note, number of the temporary earthquake observation sites in this study (total 33 sites) was increased rapidly with respect to number of the sites in previous study (total 5 sites [6]).

The accelerometers (JU210 or SA-355CT) were acceptance for the array earthquake observation considering coordination with the strong ground motion prediction. The specifications of the instrument for the observation can be found in Senna *et al*. [15] or Hata *et al*. [16]. The adopted data logger is LS-7000XT manufactured by Hakusan Corporation. The observation period is about 1 month from July 13 to August 10 of 2014. The installed depth is almost ground surface at the sites of interest. Sampling frequency is 100 Hz. Observation directions are N-S, E-W, U-D components. Here, the above observation systems and conditions are common at the created 33 sites.

As a result, record due to 3 moderate earthquakes (see Fig. 1) shown in the following were obtained simultaneously at the created 33 sites in the residential land of interest.

- EQ-1: Southern Ibaraki Prefecture Earthquake (2014/07/19 10:42 63km M_J4.2)
- EQ-2: Northeastern Chiba Prefecture Earthquake (2014/07/28 03:09 64km M_J4.3)
- EQ-3: Northwestern Chiba Prefecture Earthquake (2014/07/30 03:05 69km M_J3.6)

Note, unfortunately, the seismic waveform records due to EQ-1, EQ-2 and EQ-3 were not observed at SK-net Civil Engineering Office site and SK-net Fire Station site (see Fig. 2).

4. Evaluation of site effects

4.1 Site amplification factors

In Fig. 2, SK-net Civil Engineering Office and SK-net Fire Station are the closest permanent station to the created 33 sites. No records are available for the 2 station sites, however, during the period of temporary earthquake observation at the created 33 sites. Therefore, the ratio of site amplification factors cannot be evaluated directly with respect to SK-net Civil Engineering Office and SK-net Fire Station. On the other hand, the seismic waveform records due to EQ-1, EQ-2 and EQ-3 were observed not only at the created 33 sites but also at K-NET Yokohama [17].

Therefore, the ratios of Fourier amplitude spectra between the created 33 sites and K-NET Yokohama are calculated for EQ-1, EQ-2 and EQ-3. To obtain the spectral ratios, the composition of two horizontal components was used and the spectra were processed through a Parzen window with a bandwidth of 0.05 Hz. In addition, the spectral ratios were corrected for the difference of hypocentral distance for the two stations [18], [19]. In this process, the mean of the spectral ratios due to EQ-1, EQ-2 and EQ-3 was accepted. The horizontal site amplification factors at the created 33 sites were evaluated by multiplying conventional site amplification factor at K-NET Yokohama [20] with the mean ratio. The site amplification factors from seismological bedrock to ground surface at the created 33 sites are shown in Fig. 3.

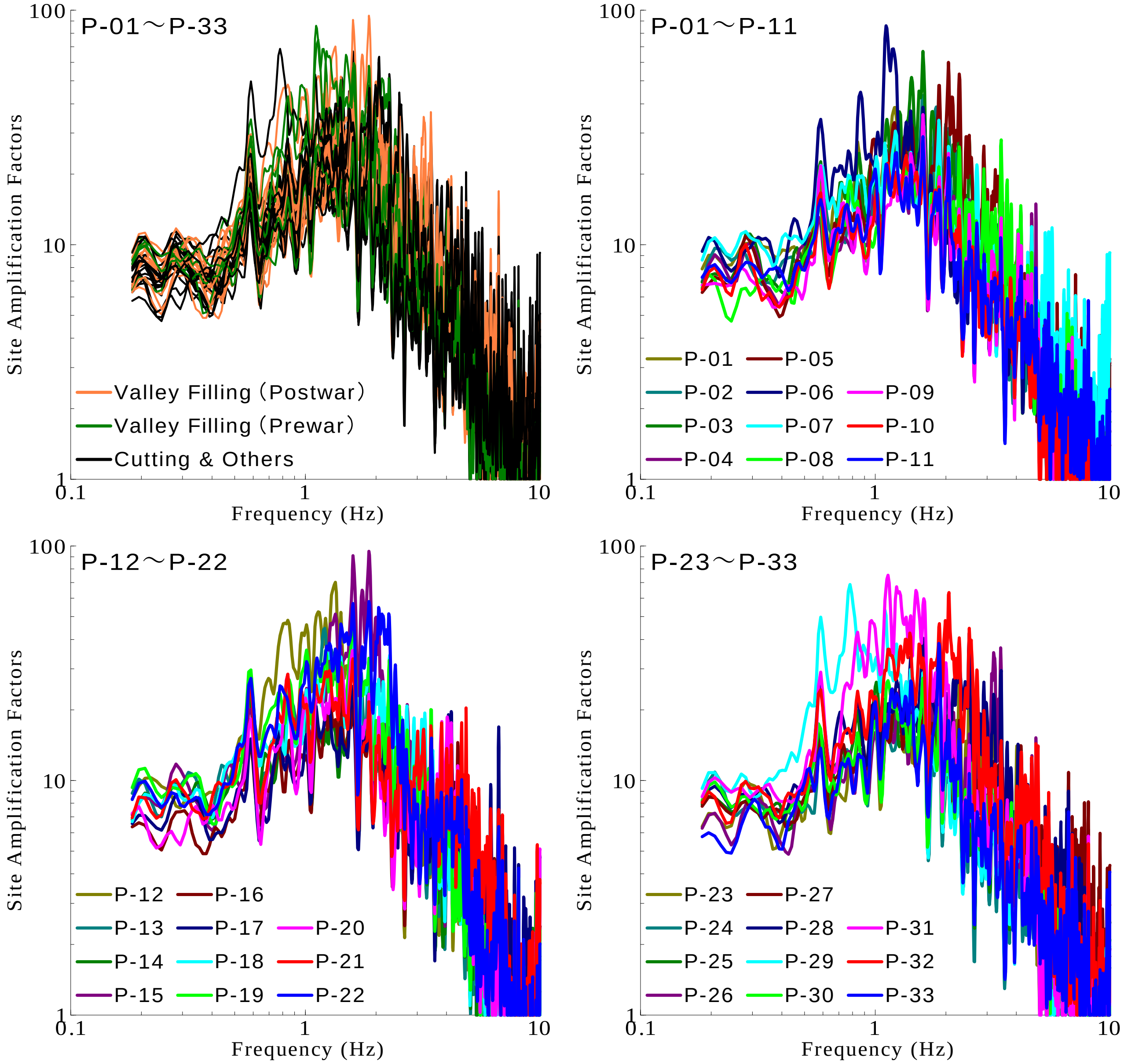

Fig. 3 – Comparison of the evaluated site amplification factors in residential land of interest

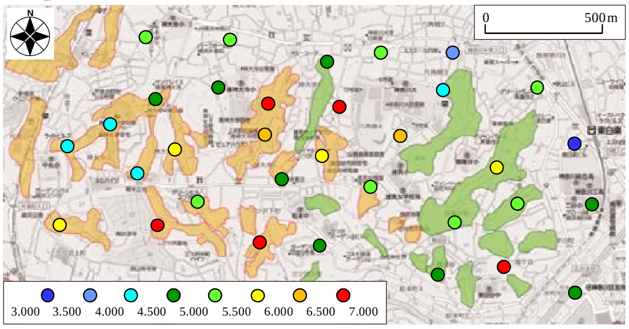

Fig. 4 – Distribution of *SAF* value focused on 0.1–10Hz

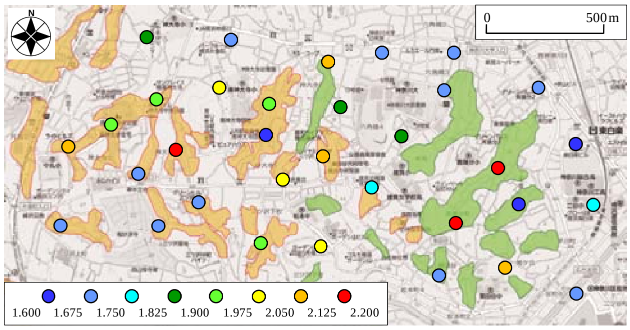

Fig. 5 – Distribution of *SAF* value focused on 0.5–2Hz

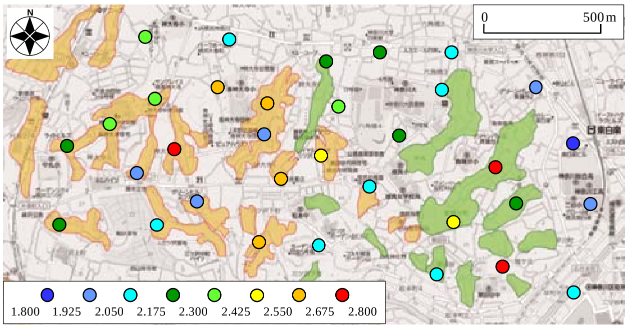

Fig. 6 – Distribution of *SAF* value focused on 1–3Hz

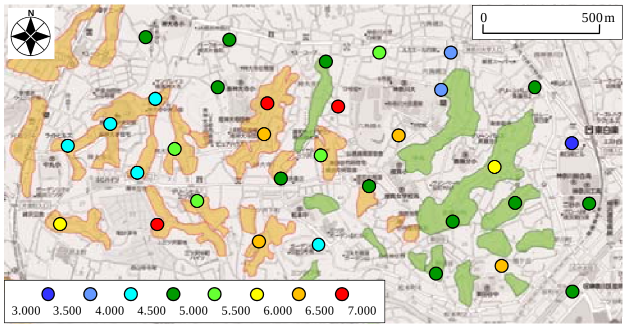

Fig. 7 – Distribution of *SAF* value focused on 0.4–10Hz

In Fig. 3, we can find a significant difference with the feature of the evaluated site amplification factor (*e.g*., peak frequency and spectral shape *etc*.) at the created 33 sites in the residential land of interest. On the other hand, we cannot confirm a clarify difference in the evaluated site amplification factor between valley filling sites and cutting & other sites. Furthermore, in the same valley filling sites, difference in the site amplification factor is not clarified between postwar and prewar.

Figs. 4, 5, 6 and 7 are distribution of *SAF* value [21] in the residential land of interest. *SAF* value is calculable using following equation.

$$SAF = \sum \log\left(\frac{G(f)}{B(f)}\right) \cdot \Delta f \tag{1}$$

Here, $B(f)$ is value of the site amplification factor at seismological bedrock (=1), $G(f)$ is value of the site amplification factor at ground surface and Δf is frequency interval with the corresponding site amplification factor (=0.012207). In this study, as an integral frequency range, the illustrated range (from 0.2 Hz to 10 Hz: see Fig. 4), the range around 1 Hz (from 0.5 Hz to 2 Hz [22]: see Fig. 5), the affected range to seismic damage of soil structure (from 1 to 3 Hz [23]: see Fig. 6) and the range focused on *SI* value (from 0.4 to 10 Hz [24]: see Fig. 7) were accepted respectively.

In Figs. 4, 5, 6 and 7, distributions of *SAF* value are not uniform in the determined 4 frequency ranges. Furthermore, *SAF* value at valley-filling sites is larger than that at cutting & other sites. This finding suggests that characteristics of the predicted ground motion are various in the residential land of interest, especially, the predicted ground motion at valley-filling sites are larger than that at other sites.

4.2 Site phase effects

In EQ-1, EQ-2 and EQ-3, EQ-3 has a hypocenter near the northern part of Tokyo Bay (see Fig. 1). Thus, the observed waveforms during EQ-3 at the created 33 sites are utilizable as site phase effects in the strong motion prediction considering back azimuth with respect to focal area of the Northern Tokyo Bay Earthquake.

Figs. 8 and 9 show the observed accelerograms in N-S and E-W components during EQ-3 at the created 33 sites. In Figs. 8 and 9, we can understand that difference in not only acceleration amplitude but also wave-form in the residential land of interest. Thus, these findings suggested that the difference in not only the site amplification factors but also the site phase effects is significant in the residential land of interest.

5. Strong motion predictions

5.1 Calculation method

To evaluate strong ground motions based on a characterized source model, Kowada's method [25, 26, 27] was used, which takes into account the effect of sediments on both the Fourier amplitude and Fourier phase of strong ground motions. Details of the Kowada's method are given below. First of all, the ground motion for a small earthquake (Green's function) was evaluated. The Fourier amplitude of the Green's function was evaluated as a product of the source spectrum $|S(f)|$, the path effect $|P(f)|$ and the site amplification factor $|G(f)|$. The source spectrum was assumed to follow the ω^{-2} model [28]. As for the path effect, geometrical spreading and nonelastic attenuation were considered. As for the site amplification factor, the empirical site amplification factors from the seismological bedrock to the ground surface were used (see Fig. 3). As for the Fourier phase of the Green's function, the Fourier phase of EQ-3 record (see Figs. 8 and 9) were used with the location of the determined rupture starting points in the focal area of the Northern Tokyo Bay Earthquake (see Fig. 10).

Thus, we can obtain a time domain Green's function which incorporates the effects of sediments both on Fourier amplitude and Fourier phase. The Green's function in the frequency domain can be written as follows:

$$|S(f)|\,|P(f)|\,|G(f)|\,O_s(f)\,/\,|O_s(f)|_p, \quad (2)$$

where $O_s(f)$ is the Fourier transform of the record at the site used for the quantification of Fourier phase, and $|O_s(f)|_p$ is its Parzen-windowed amplitude (band width of 0.05 Hz) to incorporate causality [26, 27]. Finally, the Green's function is used for superposition similar to the procedure in the empirical Green's function method. Fig. 10 shows the characterized source model (Strong Motion Generation Area (SMGA) models) by Japanese Cabinet Office [29]. The lists of the parameters of the source model refer to Japanese Cabinet Office [29] and Hata *et al*. [21]. Note, the construction of the characterized source model is focused on the reproducibility of JMA seismic intensity [30] in Tokyo Metroplitan Area including Yokohama City due to the large-scale historical earthquakes along the Philippine Sea Plate. Strong ground motions at the created 33 sites in the residential land of interest were calculated based on this source model and Kowada's method.

5.2 Distribution of ground motion indices

Fig. 11 shows distributions of the JMA seismic intensity [30] based on the estimated acceleration waveforms at the created 33 sites in the residential land of interest during the Northern Tokyo Bay Earthquake. In Fig. 11, the estimated JMA seismic intensity does not uniform significantly for the heterogeneity of the evaluated site amplification factors and site phase effects in the residential land of interest (see Figs. 3, 8 and 9). In gerneral, the estimated JMA seismic intensity at valley-filling sites are then larger than that at cutting & other sites. In particular, at valley-filling sites in the residential land of interest which consists of embankment, as compared with at cutting & other sites, the JMA seismic intensity are large as much as 10%.

In this paragraph, we also discussed the effect which the estimated strong motion has on seismic damage of the residential land of interest. Figs. 12 and 13 show distributions of the estimated velocity PSI value at the created 33 sites in the residential land of interest. As an index indicating the effect, we focused on velocity PSI value. In particular, the index is calculable with square root value for the square integration along the time history of the estimated velocity waveform [31, 32]. In Figs. 12 and 13, the estimated velocity PSI values differ significantly in the residential land of interest. The estimated velocity PSI values at valley-filling sites are then

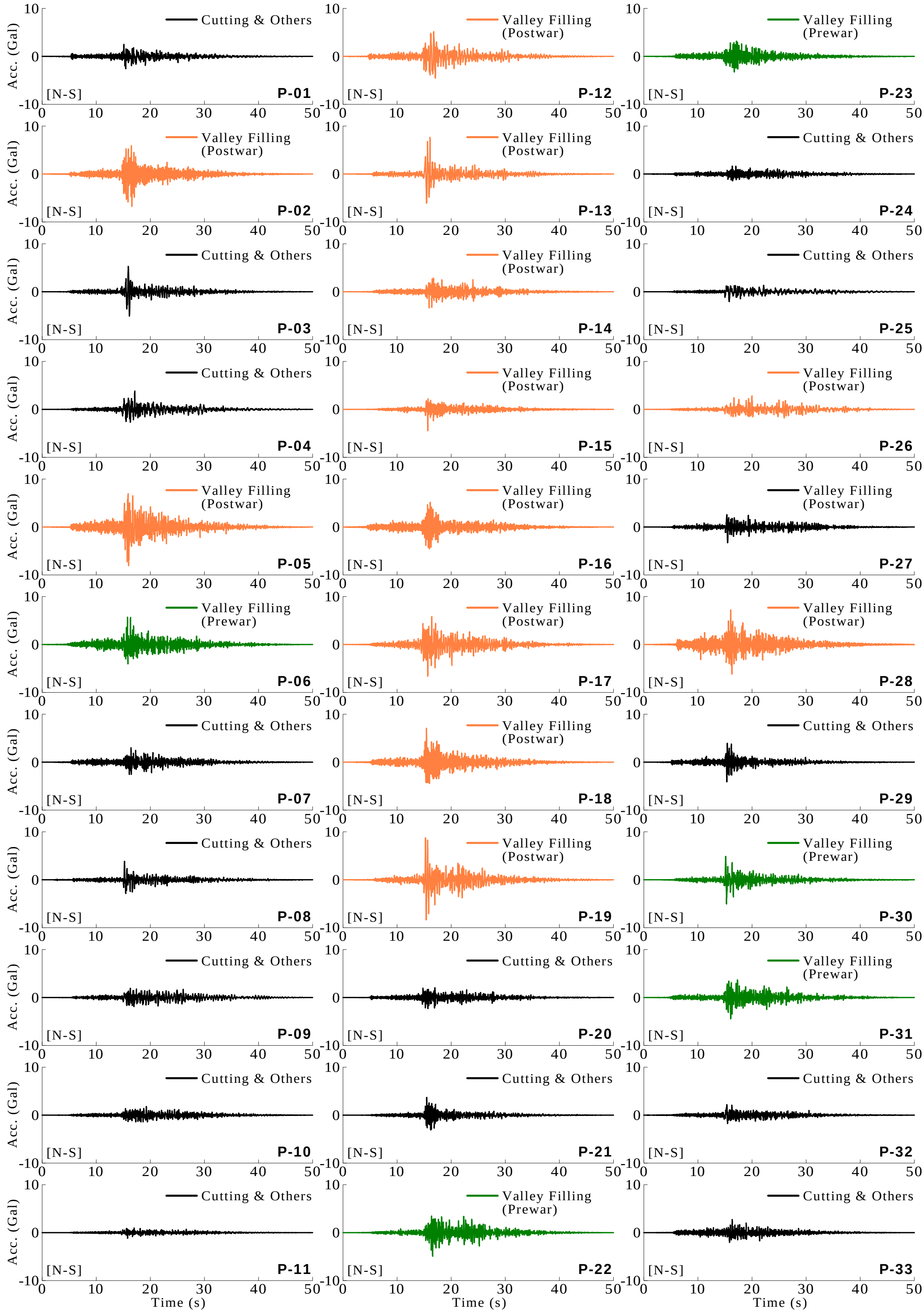

Fig. 8 – Comparison of the observed accelerograms at the created 33 sites in the residential land of interest [N-S].

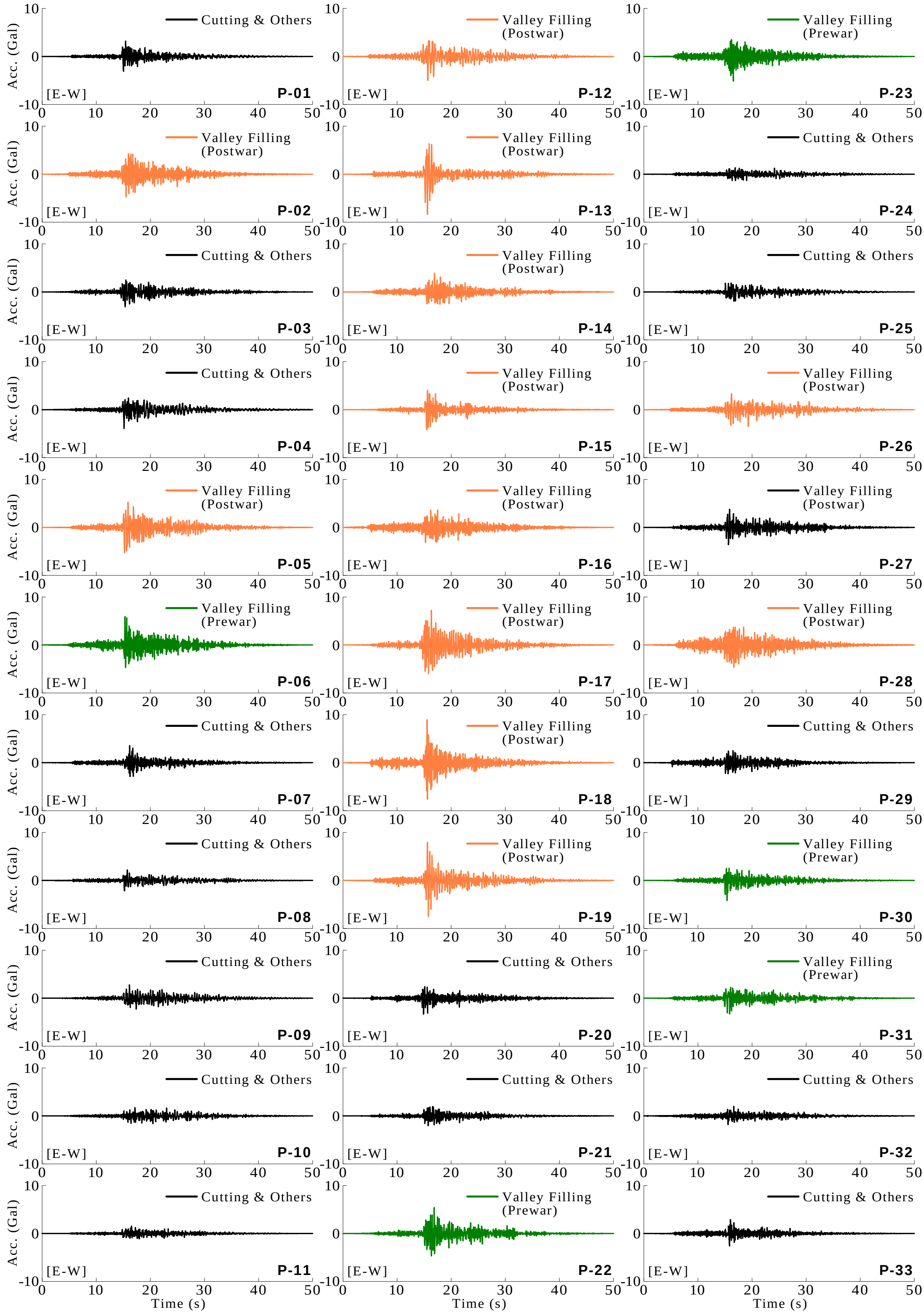

Fig. 9 – Comparison of the observed accelerograms at the created 33 sites in the residential land of interest [E-W].

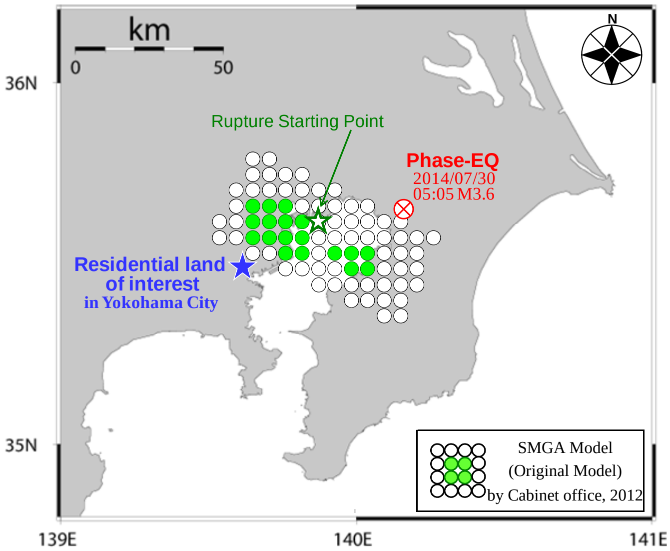

Fig. 10 – Charaterized source model for the Northern Tokyo Bay Earthquake

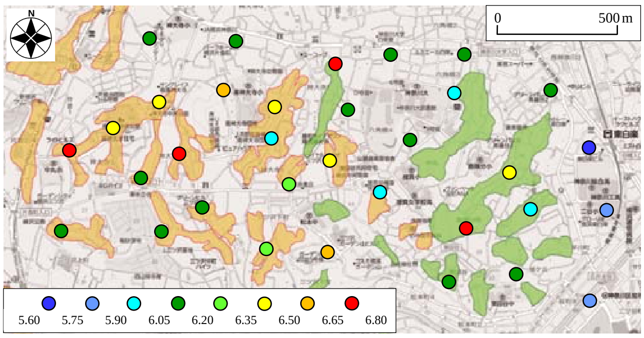

Fig. 11 – Distribution of the estimated JMA seismic intensity in the residential land of interest

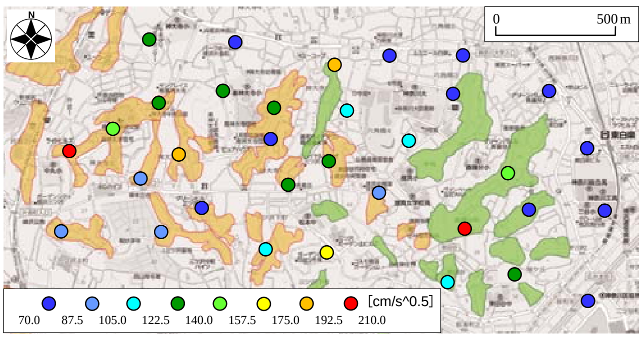

Fig. 12 – Distribution of the estimated velocity PSI value at N-S component

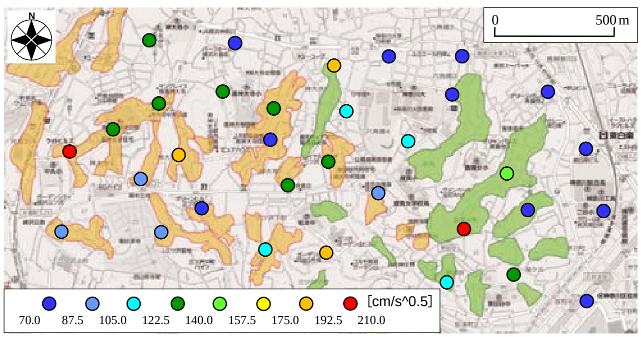

Fig. 13 – Distribution of the estimated velocity PSI value at E-W component

generally larger than that at cutting & other sites. Furthermore, the inclination obtained by the calculation result in this study agree well with an actual result of seismic damage of a residential land due to a historical large-scale earthquake. Thus, these results due to the relative discussion have suggested that seismic performance of the residential land of interest has a difference.

6. Conclusions

In this study, strong motion at valley-filling sites but also at cutting & other sites in the residential land in Kanagawa Ward, Yokohama City, Japan, due to the Northern Tokyo Bay Earthquake with M_J7.3 along the the Philippine Sea Plate was predicted with very high dense spatial location based on empirical site amplification and phase effects. At the current stage of the study, the following conclusions were obtained.

(1) In the residential land of interest in Kanagawa Ward, Yokohama City, since significant variation can be confirmed with the obtained records at the created 33 sites based on the temporary earthquake observation at the same time with very high density, the ground shaking characteristics are not uniform.

(2) Based on the results of spectral analysis, The valley-filling sites of *SAF* value indicated as an integration value of the evaluated site amplification factors in optional frequency range is larger than cutting & other sites. Moreover, Since a significant difference can be confirmed clearly in the observed waveform at the created 33 sites in the residential land of interest, the site phase effect is also different.

(3) In the residential land of interest, the predicted distribution of JMA seismic intensity is heterogeneous because of the difference in the evaluated ground shaking characteristics.

(4) The distribution of the recommend velocity PSI value based on the square root value for the square integration along the time history of the estimated velocity waveform is different significantly, *i.e.*, the seismic performance of the residential land of interest has a difference.

As a future study, we would like to adopt the estimated ground motions as a multi-input earthquake motion in 3-dimensional dynamic FEM analysis [33] for the residential land of interest.

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