Liquefaction Damage Distribution in Mihama Ward of Chiba City during 2011 Tohoku Earthquake

T. Sekiguchi & S. Nakai
Chiba University, Japan

SUMMARY:
Extensive soil liquefaction occurred in the reclaimed ground along Tokyo Bay during the 2011 Tohoku earthquake, causing floor incline damages to a huge number of houses. The liquefaction damage distribution was surveyed on public roads immediately after the earthquake in Mihama ward of Chiba city which consists entirely of reclaimed ground. In order to evaluate the effects of surface soil structure and the amplification characteristics on the liquefaction damage in the ward during the earthquake, microtremor measurements were conducted. The shear wave profile models of divided 50m square grids in the ward were estimated based on lots of boring logs. The equivalent linear analysis was conducted using the estimated profiles and the seismic ground motion record of the main shock. The distribution of estimated maximum shear strains of sand layers shows good agreement with the liquefaction damage distribution.

Keywords: liquefaction, surface soil, strong motion, microtremor measurement

1. INTRODUCTION

The 2011 Tohoku earthquake (M_W 9.0) that struck the east area of Japan on March 11 caused Tsunami and extensive damage. In Mihama ward of Chiba city that is located in the east of Tokyo, more than 300 km away from the epicenter and consists entirely of reclaimed ground along Tokyo Bay, a huge number of liquefaction damage, such as sand boiling, ground deformation and floor incline of buildings including 21 fully destroyed houses, occurred, and strong motions at the grounds with peak ground accelerations (PGA) of more than 3 m/s^2 were recorded.

Although small sand boiling was found on the main road, narrower streets inside a block were almost completely covered with sand boiling as thick as 45 cm. One of the interesting phenomena, however, is that there are some no-damage blocks right next to heavily damaged blocks.

The objective of this study is to evaluate the effects of the surface soil structure and the amplification characteristic on the liquefaction damage distribution in Mihama ward of Chiba city during the 2011 Tohoku earthquake based on the damage investigation immediately after the earthquake, microtremor measurements and dynamic response analysis using the boring data.

2. INVESTIGATION OF LIQUEFACTION DAMAGE DISTRIBUTION

Figure 1 shows the map of Mihama ward with the districts. Mihama ward is located in the western part of Chiba city along the coast of Tokyo Bay and consists entirely of the reclaimed ground. It was reclaimed by dredge soil consisting of sand or sandy silt from the sea bed of Tokyo Bay sequentially from the south-eastern side from 1960s to mid-1980.

A huge number of sand boiling due to soil liquefaction occurred in Mihama ward during the

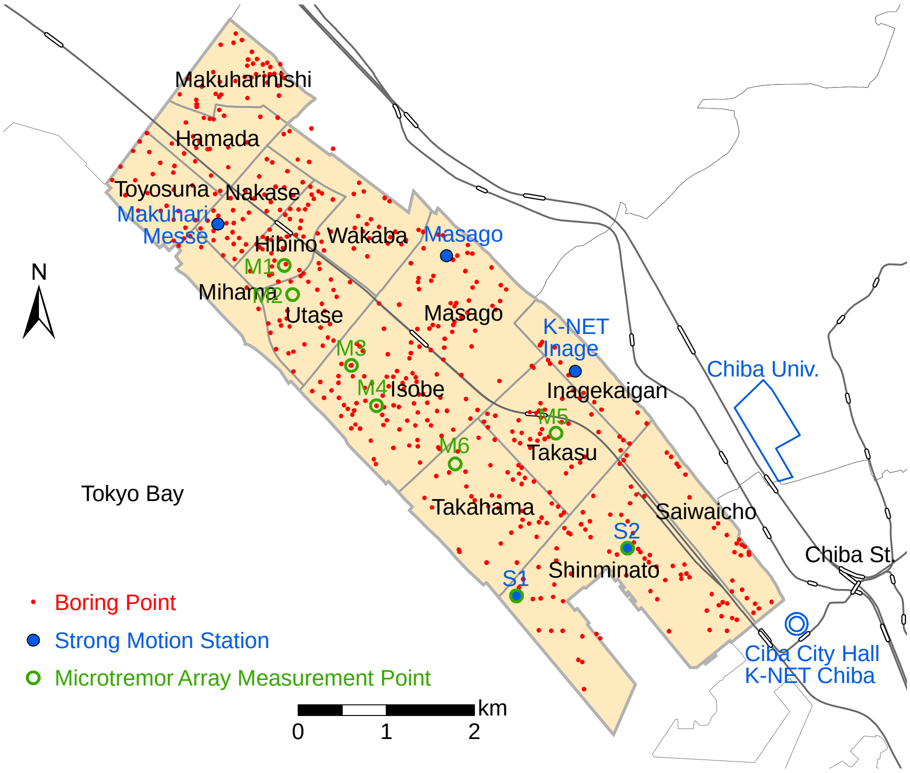

Figure 1. Map of Mihama ward with strong motion stations, microtremor measurement points and boring spots

earthquake. Sand boiling was hardly found on the main road and small sand boiling was found at the edge of the asphaltic pavement or the sidewalk of the main road. On the other hand, some narrower streets inside a block were almost completely covered with sand boiling as thick as 45 cm. The sand which spouted out on the roads was removed by Chuo-Mihama civil engineering office of Chiba city in one week just after the earthquake. The amount of the removed sand reached 8,500 m^3.

The liquefaction damage distribution was surveyed on public roads in Mihama ward immediately after the earthquake from March 12 to 20. The target area of the investigation is all the public roads and parks which could be entered in Mihama ward. The damage of sand boiling is classified into 3 levels ; heavy, minor and none. The case that the overflow area of the sand boiling found in the spot is more than about 1 m is classified as 'heavy'. The case that the overflow area is less than about 1 m is classified as 'minor'. The case that no sand boiling was found is classified as 'none'.

Figure 2 shows the distribution of sand boiling using 50 m square grids together with the locations of emergency restoration of road conducted by the Chuo-Mihama civil engineering office. White grids mean the areas which could not be entered. Heavy sand boiling and road restoration locations are densely distributed in the coastal area when compared to the inland area. Many spots with minor sand boiling are found in the inland area. The districts where widespread heavy sand boiling was found are Hibino, Isobe, Takasu, Takahama and western part of Shinminato shown in Figure 1. On the other hand, there are some districts where little sand boiling was found in areas such as Utase, the area between Isobe and Takahama and the inland part of Shinminato.

3. MICROTREMOR MEASUREMENTS

In order to estimate the seismic ground motion amplification characteristics of the surface soil, one point microtremor measurements with a three-component sensor at 163 sites and microtremor array measurements with 5 sensors at 8 sites were conducted in Mihama ward. The H/V spectra were

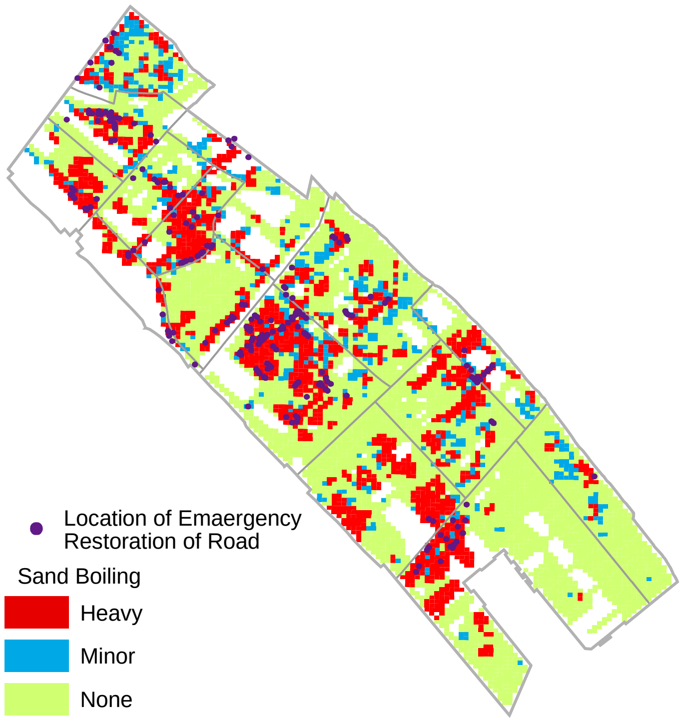

Figure 2. Distribution of sand boiling

calculated from the three-component motions at the 163 sites. At the array measurements, circular arrays of a radius of 50 cm were formed with a sensor at the center and five sensors on the circumference of vertical component. Based on CCA method (Cho et al. 2008), dispersion characteristics of surface wave at the 8 sites were computed from the vertical component motions.

Figure 3 shows the peak periods of H/V spectra and contour lines of basement depth of alluvial deposit (Journal of Environmental Laboratories Association, 2012). The peak periods of microtremor H/V spectra are in good agreement with the basement depth of alluvial deposit. The peak periods in the coastal area tend to be longer than those in the inland area. The peak periods at the districts of Nakase, Isobe, Takahama and the western part of Shinminato with heavy sand boiling tend to be longer than those at the other districts. In addition, the peak periods at Utase district with small sand boiling are short. But little sand boiling was found at the area between Isobe and Takahama in spite of the long peak periods of microtremor H/V spectra.

Figure 4 shows the dispersion characteristics at 8 sites shown in Figure 1 in which the computed phase velocities are plotted against periods by black circles. In the vicinity of the sites named by odd numbers (on upper line in Figure 4), heavy sand boiling was found. In the vicinity of the sites named by even numbers (on lower line in Figure 4), little sand boiling was found. The phase velocities at short period range at all the sites are low of about 100 - 150 m/s.

Based on the dispersion characteristics and the H/V spectra, the shear wave velocity profiles at the sites were estimated. The theoretical dispersion curve which is consisting of multiple modes presented by Tokimatsu et al. (1992) for the estimated profiles are shown in Figure 4 by red line.

Figure 5 shows the estimated shear wave profiles at the 8 sites together with the boring logs in each vicinities. At M1, M2, M5 and S2 sites, PS logs are also shown. At these sites, the estimated shear wave velocities are in good agreement with those of PS logs. At M1, M3, M5 and S1 sites where heavy sand boiling was found, the shear wave velocities of the surface layers to a depth of about 10 m which seem to be filling layers are low with about 100 m/s, and the layers mainly consist of fine sand with low *N*-value. On the other hand, the shear wave velocities of the surface layers at M4 site are

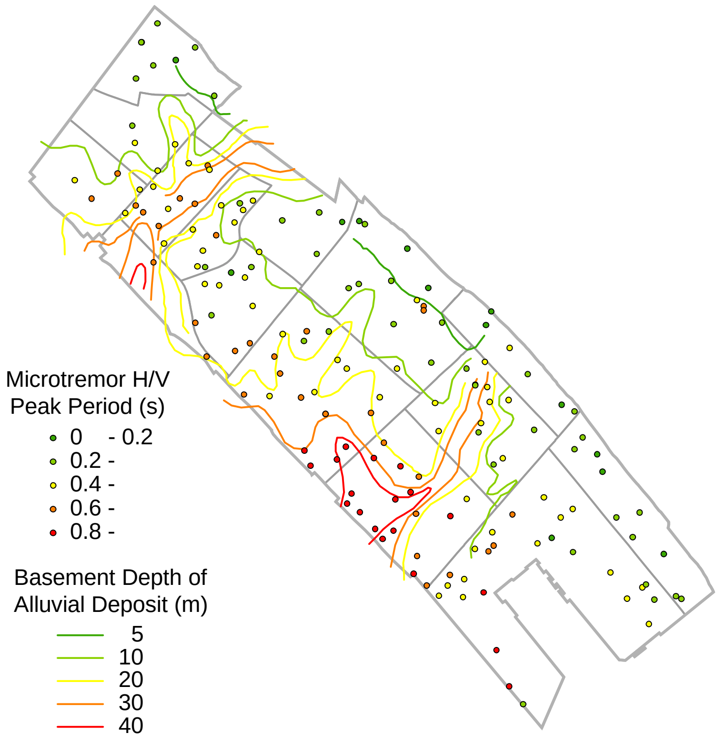

Figure 3. Distribution of microtremor H/V peak periods and contour lines of basement depth of alluvial deposit

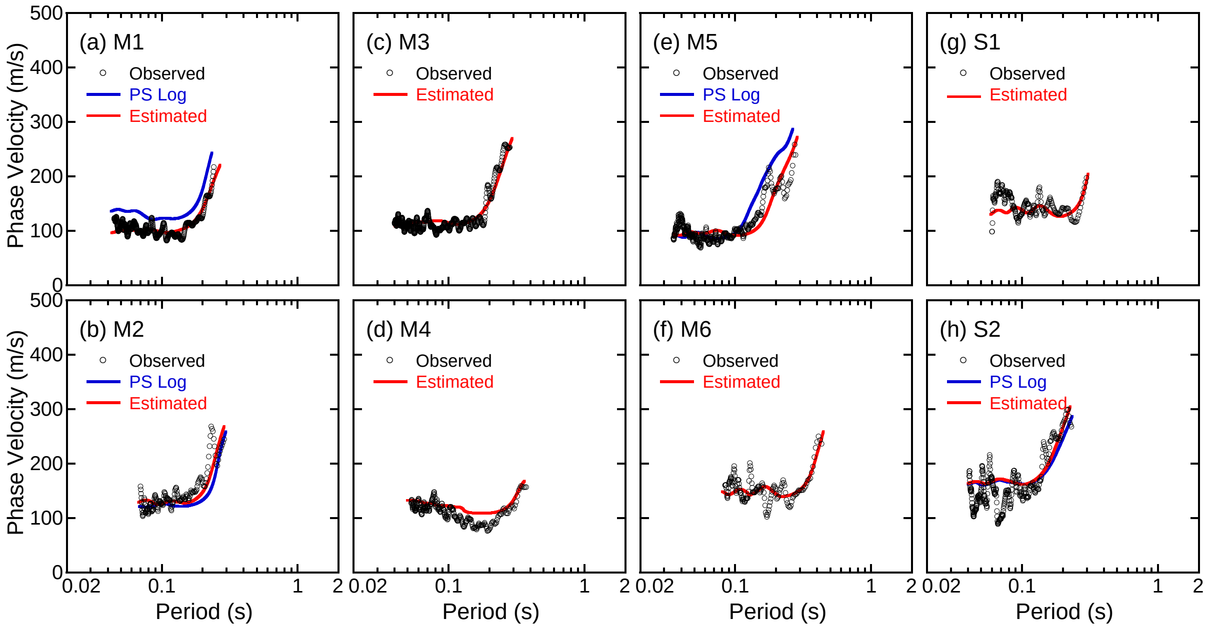

Figure 4. Dispersion characteristics of surface wave

estimated to be about 100 m/s, but the surface layers at M2, M4 and M6 sites with small sand boiling mainly consist of silt. At S2 site with small sand boiling, the surface layers mainly consist of fine sand, but the shear wave velocities are high with more than 160 m/s.

The above finding indicates that the soil types of the surface soils which seem to be filling layers vary widely in response to sites in spite of reclaimed land of same ward.

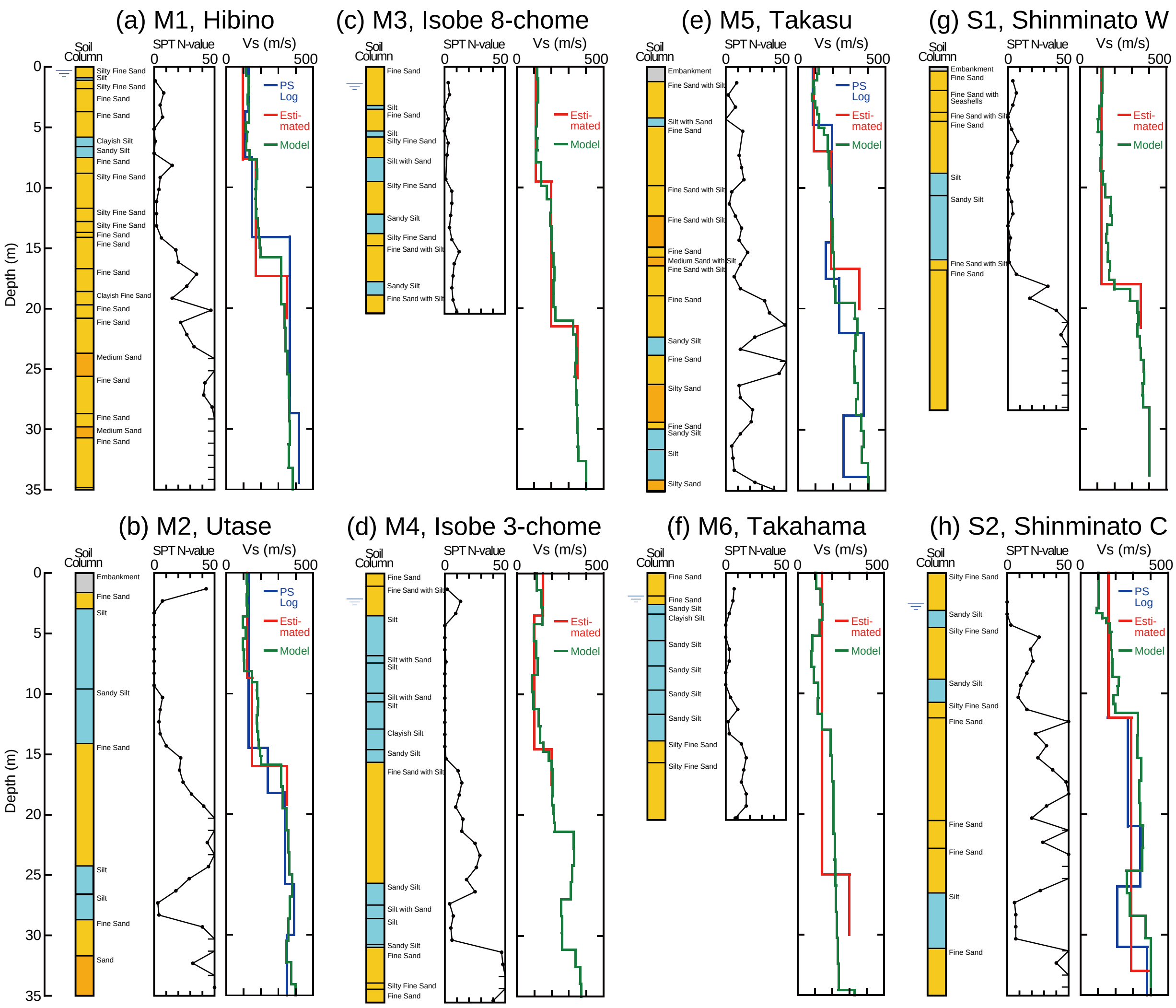

Figure 5. Boring logs, estimated shear wave velocity profiles and PS logs

4. EVALUATION OF SURFACE SOIL AMPLIFICATION CHARACTERISTICS BASED ON BORING LOGS

The shear wave velocity structure models of surface soils in Mihama ward were made using boring logs. The ward was divided to 7439 square grids with a size of about 50 m. The one-dimensional shear wave velocity profiles to a depth of engineering bedrock at each grids were estimated based on boring logs. 540 boring logs were used, and the positions are shown in Figure 1.

The soil types and SPT *N*-values were estimated by interpolation using 8 boring logs in the vicinities. The shear wave velocities were estimated from the soil types and *N*-values by empirical equations in Chiba prefecture (Nagata et al. 2008).

4.1. Validation of Estimated Model

The estimated shear wave velocity profiles of the grids near the sites where microtremor measurements were conducted are also shown in Figure 5 by green lines. The estimated profiles are in good agreement with those of estimated ones based on microtremor measurements and PS logs.

The linear theoretical transfer functions, defined as the spectral ratio between the ground surface and the engineering bedrock layer, were calculated using the estimated shear wave profiles with a damping

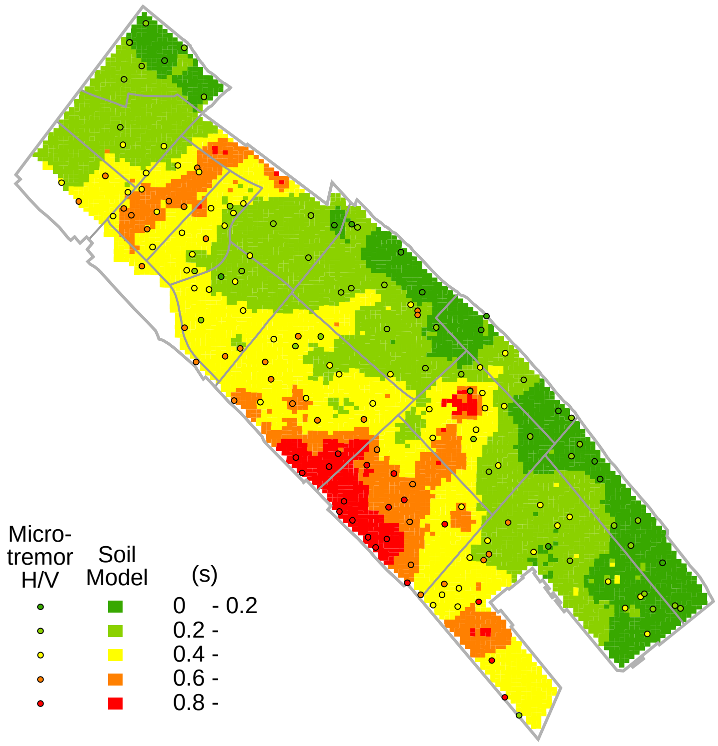

Figure 6. Distribution of microtremor H/V peak periods and estimated natural periods of surface soils

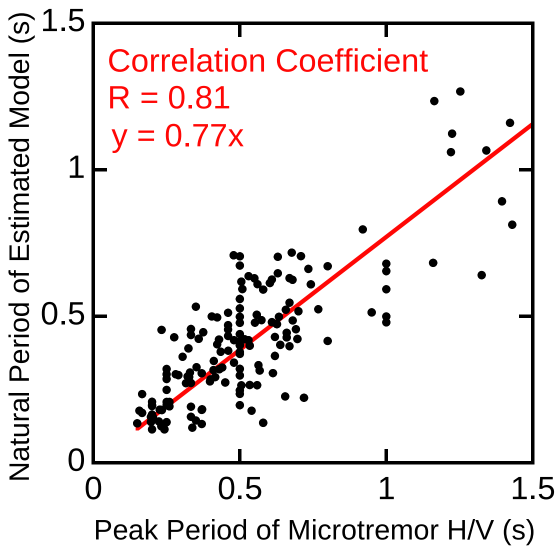

Figure 7. Comparison between peak periods of microtremor H/V spectra and estimated natural periods

ratio of 2 % at each grids. Figure 6 shows the distribution of the first peak periods of the calculated transfer functions, which correspond to the natural periods of the surface soils, in Mihama ward together with the peak periods of microtremor H/V spectra shown in Figure 3. The natural periods in the coastal area tend to be longer than those in the inland area, corresponding to the basement depth of alluvial deposit shown in Figure 3, in the same way as the peak period of H/V spectra.

Figure 7 shows the comparison between the peak periods of microtremor H/V spectra and the estimated natural periods at the grids in the vicinities. The correlation coefficient is high with a value

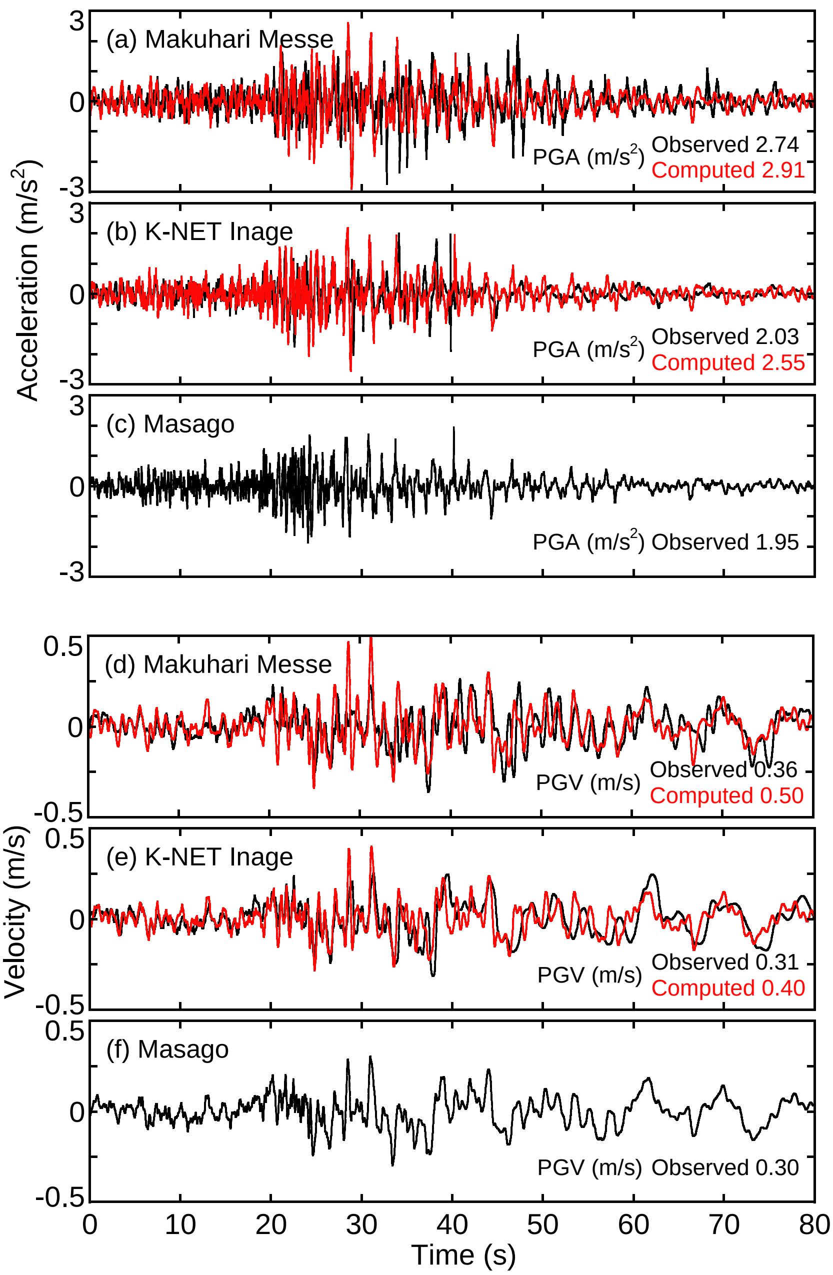

Figure 8. Acceleration and velocity time histories

of 0.81.

4.2. Dynamic Response Analysis

One-dimensional equivalent linear dynamic response analyses with frequency dependent damping (Schnabel at al., 1972, Sugito et al., 1993) were conducted using the estimated soil profiles of all the grids. The nonlinear dynamic soil properties used for the analysis are based on the study by Imazu and Fukutake (1986). The acceleration record of the EW component at Masago station shown in Figure 1 during the Tohoku earthquake was used as the input ground surface motion to compute the outcrop bedrock motion at the engineering bedrock layer. The computed bedrock motion was used as the input outcrop motion to the engineering bedrock layer at each grids.

Figure 8 compares the computed time histories of the ground surface acceleration and velocity integrated from the acceleration with those observed at Makuhari Messe and K-NET Inage stations

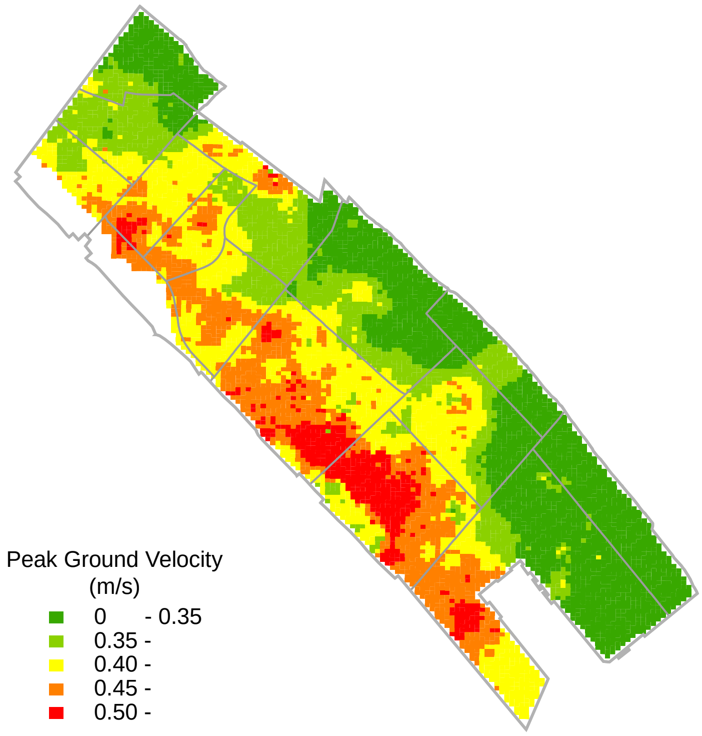

Figure 9. Distribution of computed peak ground velocities

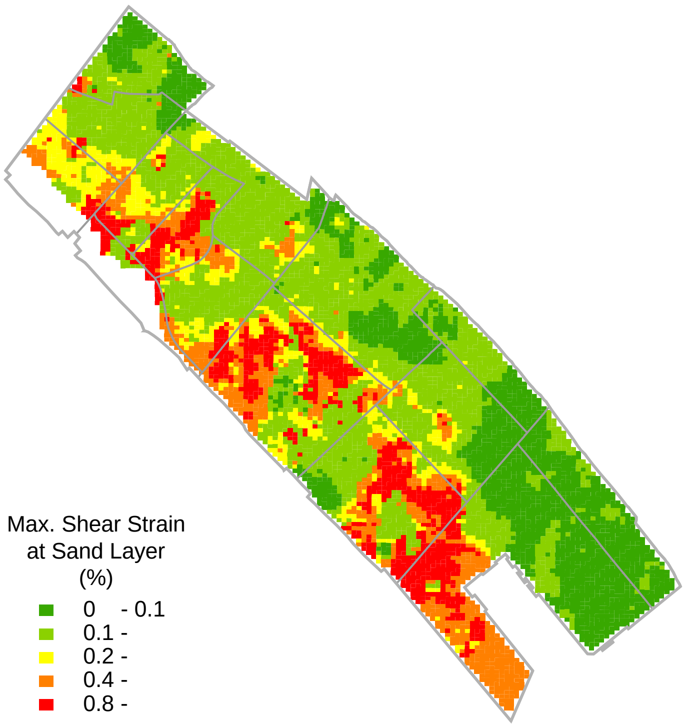

Figure 10. Distribution of computed maximum shear strains of sand layers

shown in Figure 1, and shows the record at Masago station as well. The time histories of the computed ground surface motions near those stations are roughly consistent with those observed at the same stations.

Figure 9 shows the distribution of the computed peak ground velocities. The peak ground velocities in the coastal area tend to be larger than those in the inland area, corresponding to the basement depth of alluvial deposit. The results are in roughly good agreement with the distribution of sand boiling shown in Figure 2, but the peak ground velocities at Utase and the area between Isobe and Takahama are high in spite of the small sand boiling.

Figure 10 shows the distribution of the computed maximum shear strains of sand layers. The distribution are fairly consistent with those of sand boiling such as Utase and the area between Isobe and Takahama with small sand boiling.

The above finding indicates that it is possible to explain the distribution of sand boiling in Mihama ward during the Tohoku earthquake by evaluating the shear strains of sand layers based on the dynamic analysis to the estimated model from the boring logs.

5. CONCLUSIONS

The effects of the surface soil structure and the amplification characteristic on the liquefaction damage distribution in Mihama ward of Chiba city during the 2011 Tohoku earthquake were examined based on the damage investigation immediately after the earthquake, microtremor measurements and dynamic response analysis using the boring logs. The following conclusions can be made through this study:

1. Heavy sand boiling was densely distributed in the coastal area when compared to the inland area. However, there are some districts where little sand boiling was found in the coastal area.

2 The soil types of the surface soils which seem to be filling layers vary widely in response to sites in spite of reclaimed land of same ward.

3 It is possible to explain the distribution of sand boiling in Mihama ward during the Tohoku earthquake by evaluating the shear strains of sand layers based on the dynamic analysis to the estimated model from the boring logs.

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