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LIQUEFACTION DAMAGE OF THE TONEGAWA BASIN CAUSED BY THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE

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ABSTRACT: By the 2011 off the Pacific coast of Tohoku Earthquake, a large number of liquefaction occurred in the Tone river basin. By this liquefaction, serious damage including the cutoff of the lifeline, the destruction of the house basics and the nonequivalent subsidence occurred. The liquefaction damage taken up by the news was a small portion. Then we carried out a local survey for the purpose of catching perspective of the liquefaction damage in the Tone river basin. It was almost the artificial ground where filled up pond and river that intense liquefaction was seen. The ground hazard by liquidizing was known from of old. It was recognized again to cause an extensive ground hazard by liquidizing in this earthquake. It is thought that liquidizing is generated by the earthquake in the future again. Next, we compared our data with the liquefaction locations, the geomorphologic classification of the regions, seismic intensity distribution, and liquefaction probability value in the Kanto district in the report published by the Committee for Analysis of Liquefaction in the off the Pacific coast of Tohoku Earthquake, chaired by the author and organized by the Ministry of Land, Infrastructure, Transport and Tourism. It was calculated by the method of judging the liquefaction studied until now. Furthermore, the long continuation time of the earthquake ground motion which is the feature of this earthquake investigated the influence which causes liquefaction. Moreover, about the HINODE area in Itako city whose liquefaction damage was serious, creation of a detailed structure model and microtremor observation were performed. The scale of liquefaction was harmonic when the structure model of this study was compared with the damage report information on a city office.

Key Words: Liquefaction damage, The Tonegawa basin, Artificial ground, residential land, secondary disaster, Liquefaction probability, Microtremor observation

INTRODUCTION

The off the Pacific coast of Tohoku Earthquake that occurred on March 11, 2011, caused liquefaction damage over an extremely large region extending from the Tohoku district to Kanto district. However, the details of the liquefaction damage have not yet been fully clarified, even though half a year has passed

since the outbreak of the earthquake.
This is because initially, survey of the damage was greatly delayed owing to planned power outage and gasoline shortage and also because the damaged areas were spread extensively. The region damaged by liquefaction was spread across five prefectures in the Tohoku district (Miyagi, Fukushima, Aomori, Yamagata and Iwate Prefectures), six prefectures in the Kanto district (Tochigi, Gunma, Ibaraki, Saitama, Chiba, and Kanagawa Prefectures), and the Tokyo Metropolitan area according to survey information released by academic societies, information on the municipality websites, and our field survey. (Fig. 1)

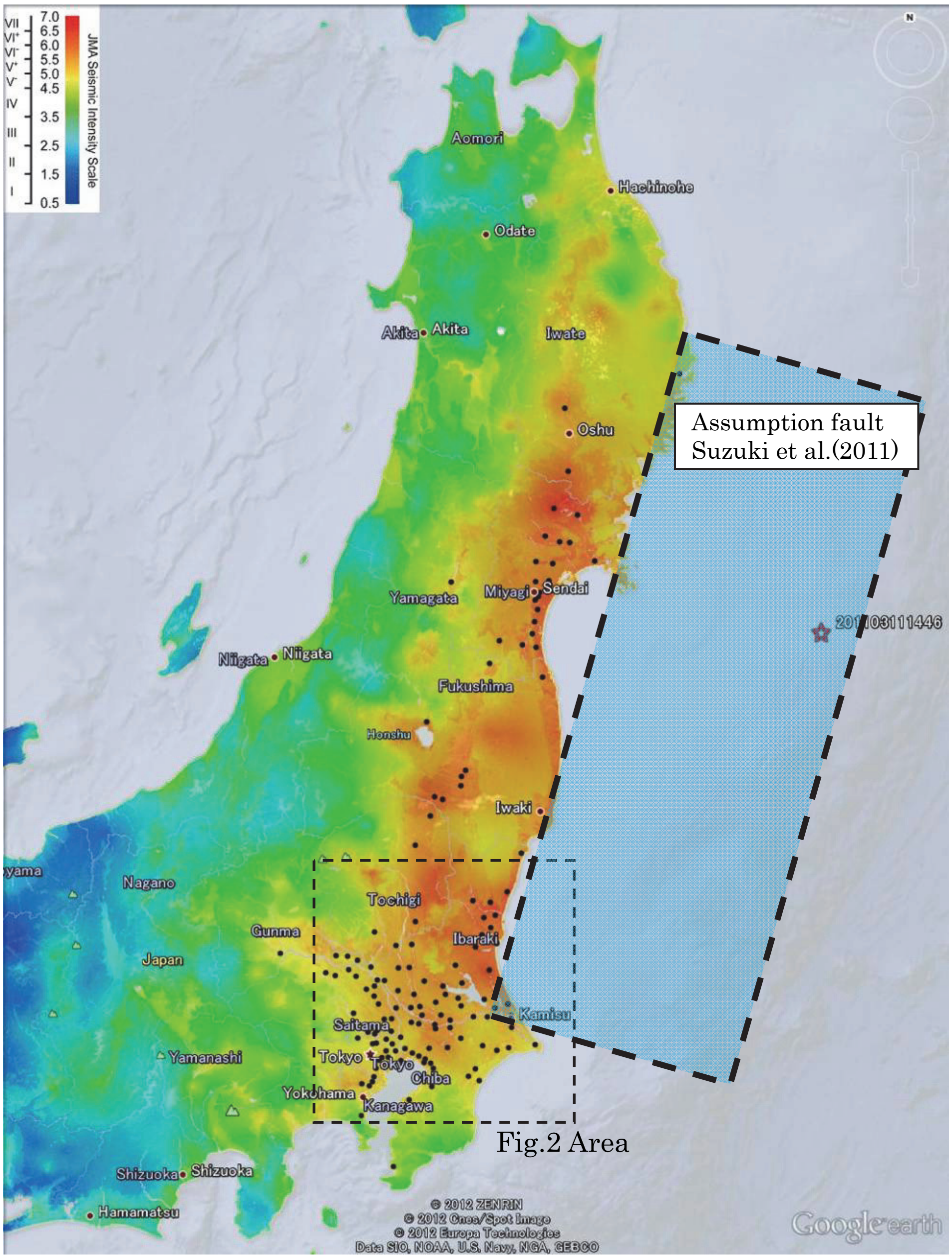


Fig. 1 The distribution of seismic intensities(JMA) in the municipalities that suffered liquefaction damage in the 2011 off the Pacific coast of Tohoku Earthquake

In the Tohoku district, regions other than four prefectures mentioned above, liquefaction occurred in lowlands and in reclaimed lands in the areas for which a seismic intensity higher than 5 was recorded. Of the prefectures in the Kanto district, Chiba and Ibaraki Prefectures recorded a large number of cases of liquefaction damage. As will be described later, liquefaction occurred over a very wide region with high density mainly in the reclaimed lands in these two prefectures. (See Fig. 2) However, liquefaction occurred in fewer locations in Miyagi Prefecture, which is located near the epicenter of the main earthquake, than in the Kanto district. This could be because the tsunami that attacked the coast of Miyagi Prefecture removed all traces of liquefaction damage, or because the Sendai Plain has a smaller area of lowland created by alluviation by big rivers and reclaimed land. We discuss the liquefaction damage in 28 municipalities mainly in the Tonegawa basin (including the Pacific coast and the basins the subsidiary streams of Tonegawa) in the Kanto district that reported a very large number of liquefaction damage cases.

SUMMARY OF THE FIELD RESEARCH

We conducted field research for two days, on April 7 and 8, 2011. Figure 1 shows the 28 municipalities, all of which are in Ibaraki Prefecture, covered in the field survey. These municipalities are located in the basins of the Tonegawa and its subsidiary steams Kinugawa and Kokaikawa; the field survey also includes Kashima City and Namegata City, both of which are on the coast of Kitaura Lake, which is part of Kasumigaura Lake. Because of the limits of the survey schedule, we did not cover Inashiki City in Ibaraki Prefecture in the Tonegawa basin or Noda City in Chiba Prefecture. We tried to capture the locations and scale of liquefaction as exhaustively as possible. After collecting information on the sites of liquefaction from each municipality office, we conducted the field survey. Hence, we did not conduct the field survey in two municipalities (Moriya City and Narita City) for which we did not have any information on liquefaction by the time we started the field survey.The following three groups conducted the field survey.

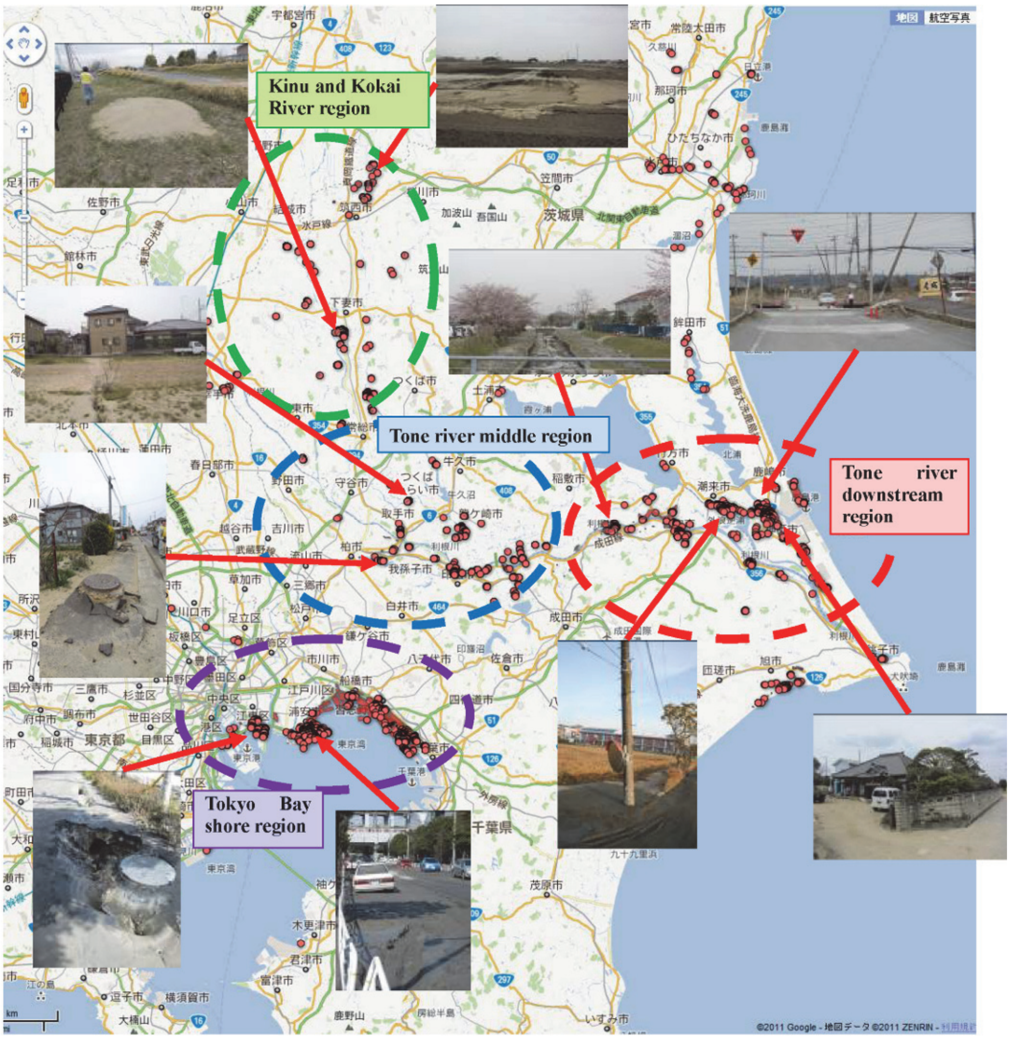
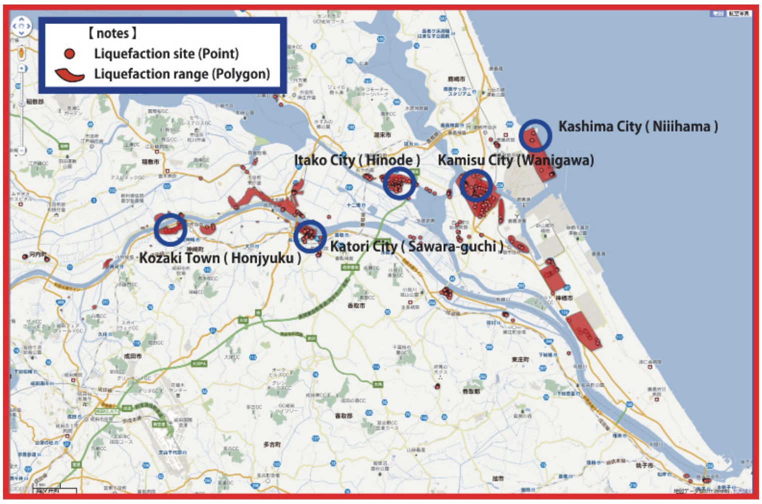


Fig. 2 Distribution map of liquefaction locations and photographs showing liquefaction damage in the Kanto district (Information on the liquefaction points and areas was provided by the Committee for Analysis of Liquefaction in the off the Pacific coast of Tohoku Earthquake)

① Downstream basin of Tonegawa (including the Pacific coast)



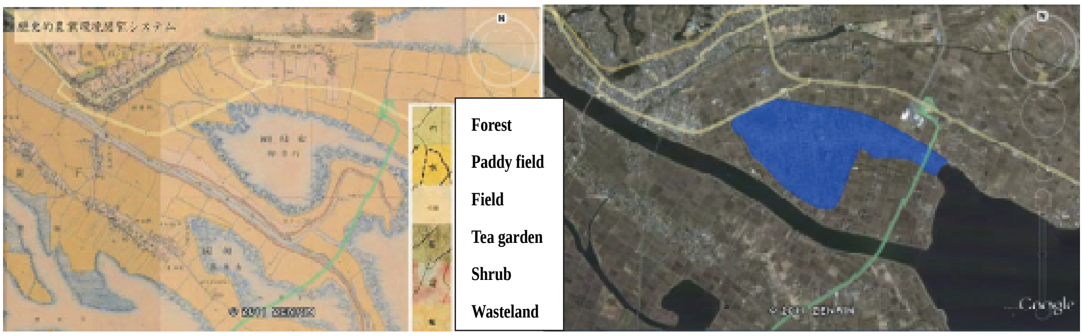


Fig. 3 Meiji era (left) and present (right) topographic maps of the region near Hinode in Itako City

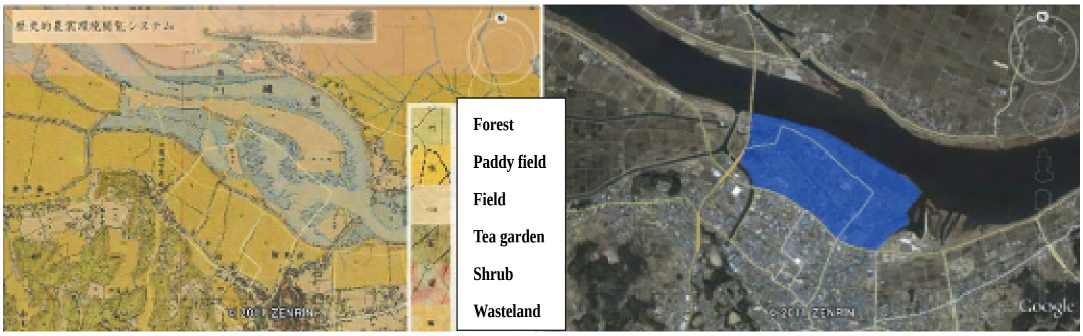
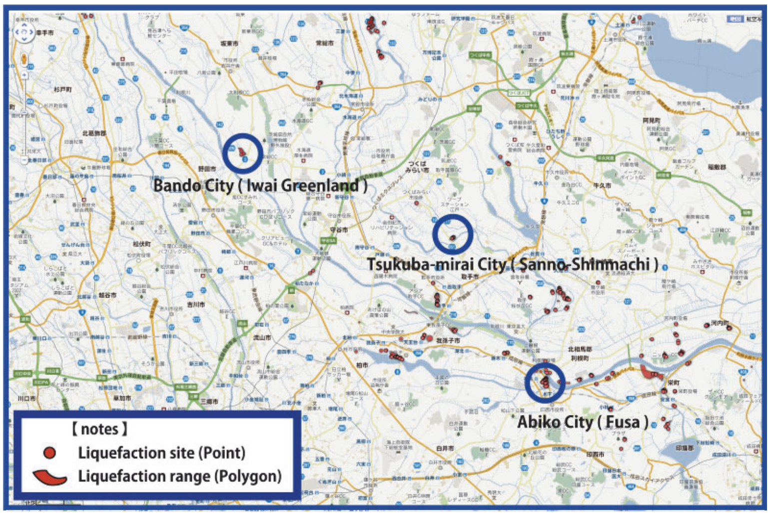


Fig. 4 Meiji era (left) and present (right) topographic maps of the region near Sawara in Katori City

Photo 1 A large volume of sand boil was observed, and many telephone poles became slanted. The telephone pole standing straight was installed after the earthquake. (Hinode, Itako)

Photo 2 The ground in front of Katori Health Center subsided, and a depression of about 50 cm was created. (Sawara, Katori)

② **Midstream basin of Tonegawa**



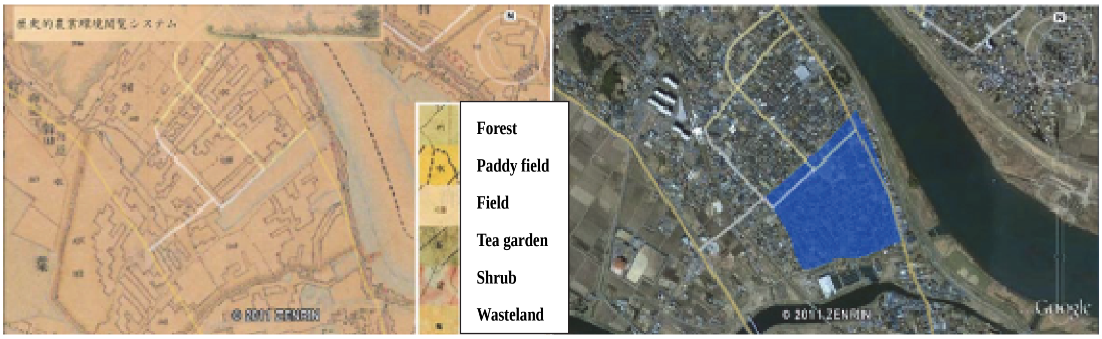


Fig. 5 Meiji era (left) and present (right) topographic maps of the region near Fusa in Abiko City

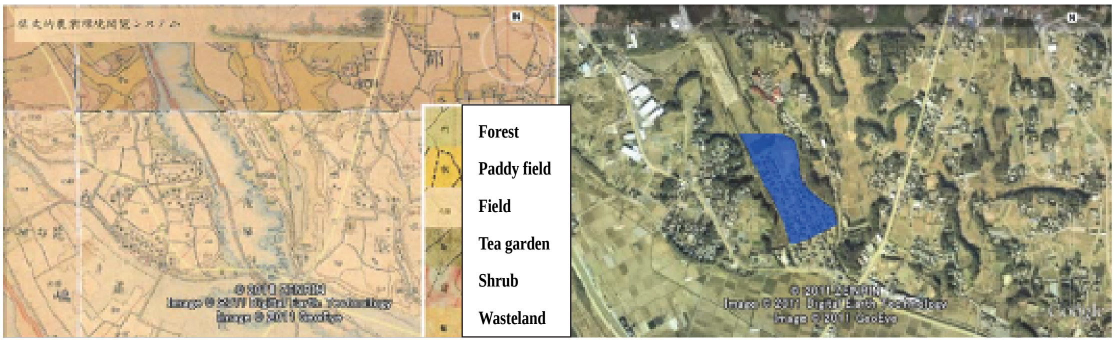
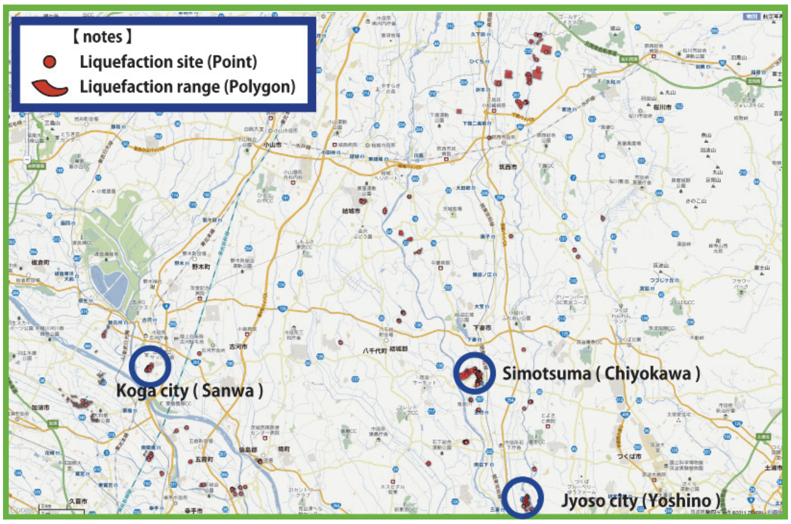


Fig. 6 Meiji era (left) and present (right) topographic maps of the Iwai Greenland in Bando City

Photo 3 Large-scale liquefaction occurred, and many telephone poles became slanted. (Fusa, Abiko)

Photo 4 Traces of sand boils spreading on the road (Iwai Greenland, Bando)

③ Basins of Kinugawa and Kokaigawa



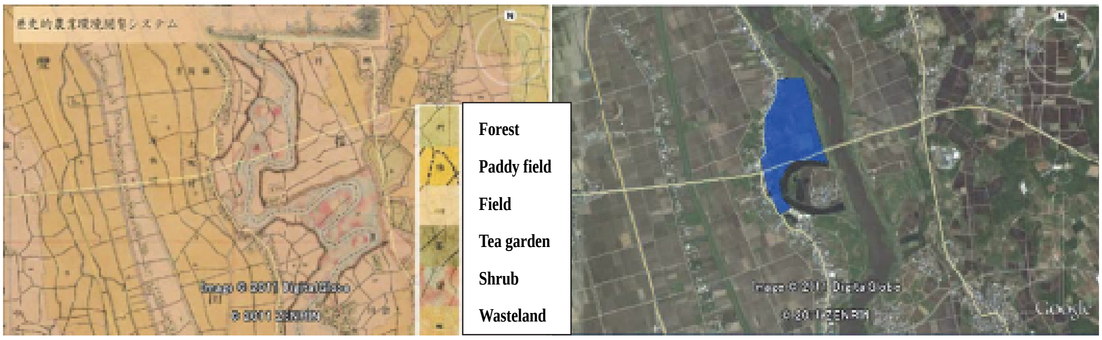


Fig. 7 Meiji era (left) and present (right) topographic maps of the region near Yoshino in Joso City

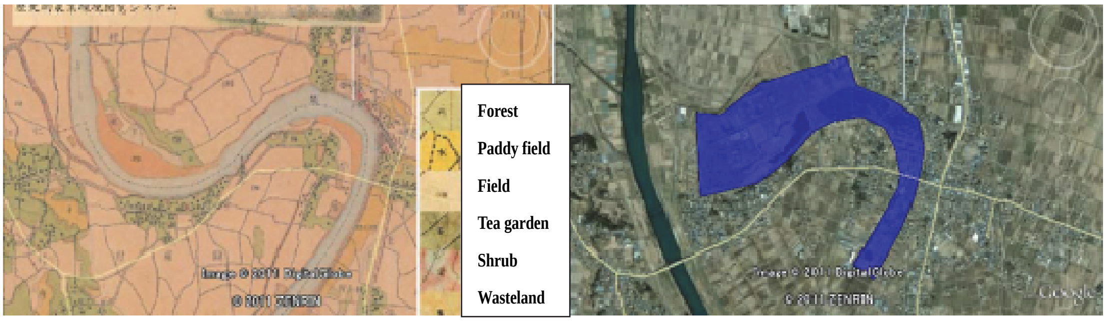


Fig. 8 Meiji era (left) and present (right) topographic maps of the region near Chiyogawa in Shimotsuma City

Photo 5 Sand boils and subsidence (Yoshino, Joso)

Photo 6 Sand boils occurred over a wide area. (Chiyogawa, Shimotsuma)

THE SUMMARY OF ANALYSIS RESULTS

Because the data we collected on the liquefaction locations cover only part of the Tonegawa basin, as shown in Fig. 2, we compared our data with the liquefaction locations, the geomorphologic classification of the regions, seismic intensity distribution, and liquefaction probability value in the Kanto district in the report[4] published by the Committee for Analysis of Liquefaction in the off the Pacific coast of Tohoku Earthquake, chaired by the author and organized by the Ministry of Land, Infrastructure, Transport and Tourism. We have indicated the liquefaction locations as points on the aerial photograph of the Kanto district showing Chiba and Ibaraki Prefectures in Fig. 9. Similarly, we show on a background map, the geomorphologic classification provided by Wakamatsu, et al. (2005)[5] in Fig. 10 and the distribution of estimated surface seismic intensities in Fig. 11. The liquefaction probability values calculated by Matsuoka et al. (2011)[6] are shown in Fig. 12.

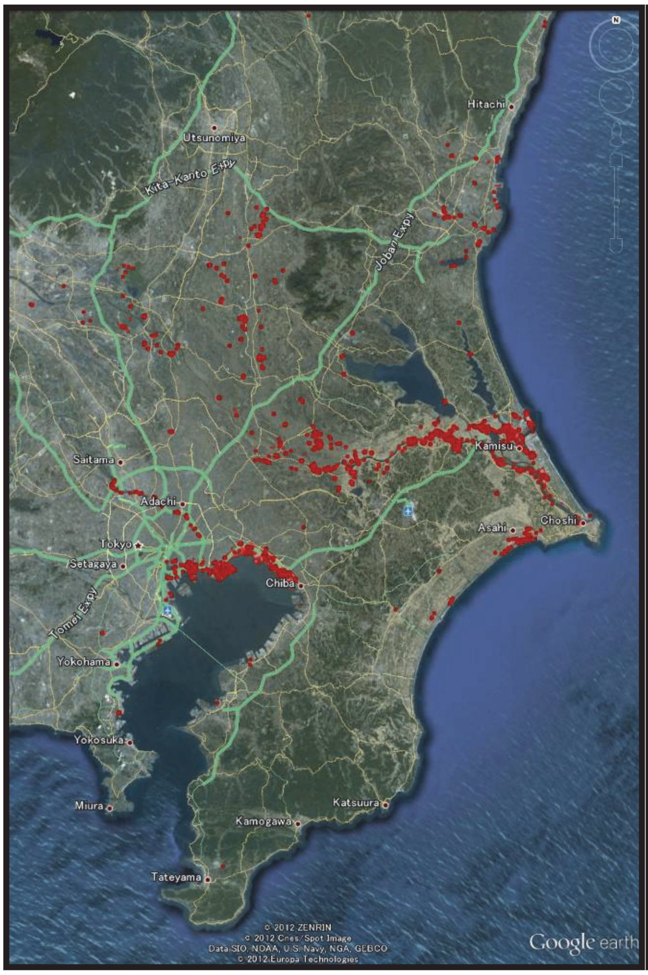


Figure 9 Distribution of liquefaction locations in the Kanto district

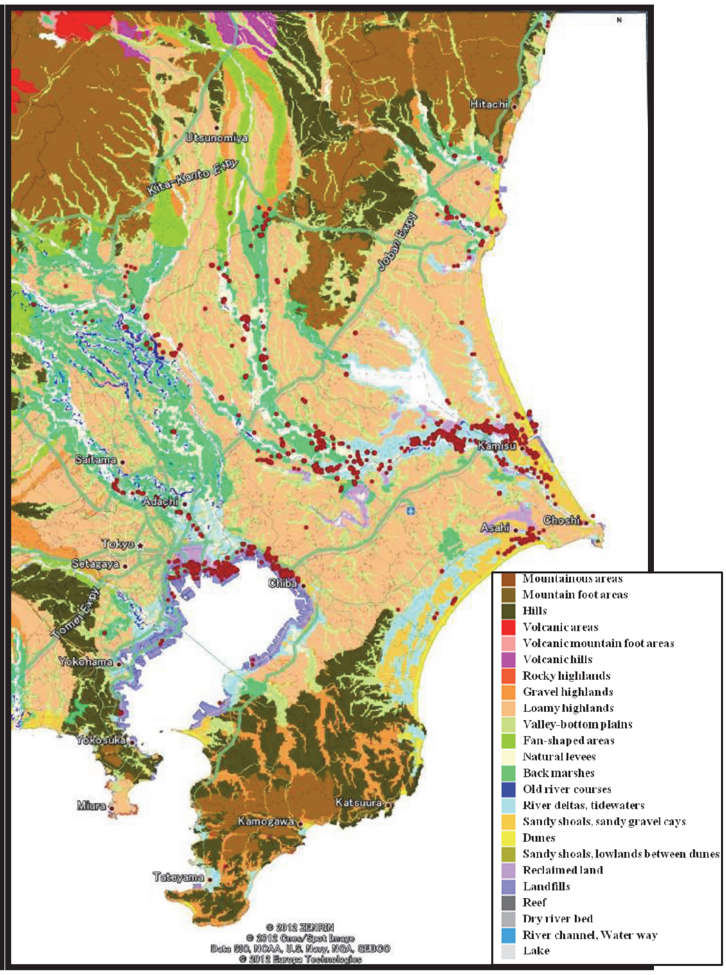


Figure 10 The liquefaction locations in Kanto district and geomorphologic classification of the region

To study the distribution of estimated seismic intensities on the ground surface, we considered the instrumental seismic intensity; thus, a significant amount of the instrumental seismic intensity data can be obtained from many seismometers, as proposed by Matsuoka et al. (2011)[6]. First, we calculated the instrumental seismic intensity from the observational data of strong earthquake motions. However, because this data reflects the S-wave velocity that corresponds to the location of the seismometer, we have to isolate the contribution of the ease with which seismic waves travel through the surface, and eliminate it from the probability values. We calculated the degree of amplification of the instrumental seismic intensities by considering the average S-wave velocity (Vs30)[7] in the ground; the velocity data are available from the

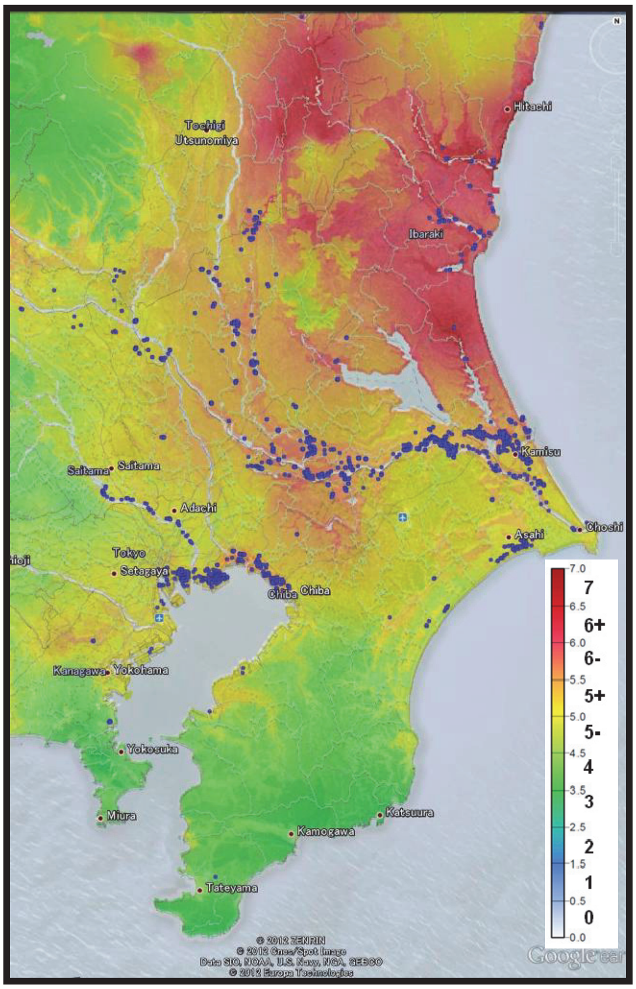


Fig. 11 Liquefaction locations and seismic intensity distribution in the Kanto district

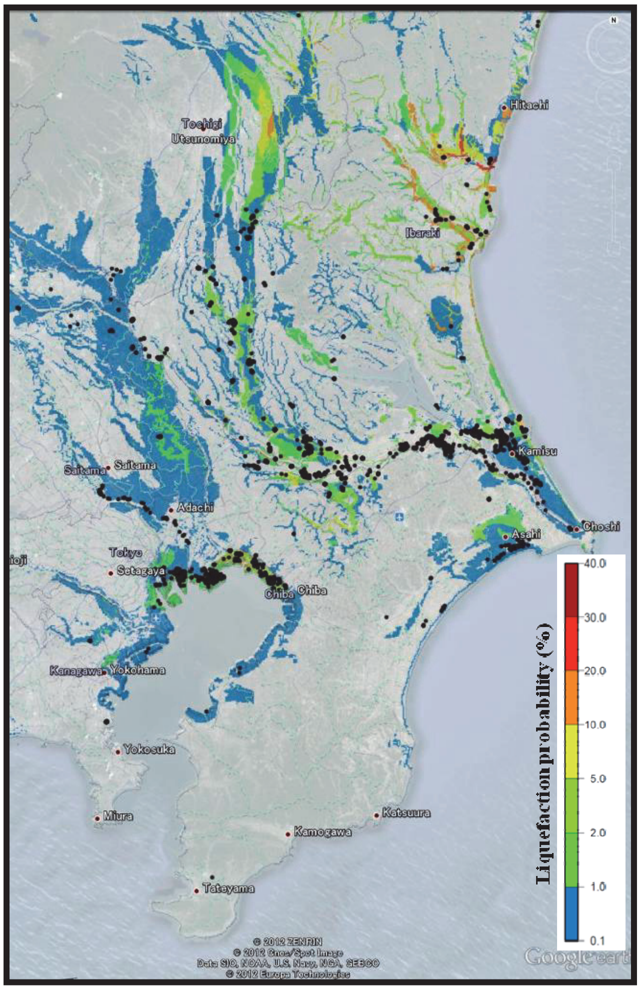


Fig. 12 Liquefaction locations and probability distribution of liquefaction (from Matsuoka, et al. (2011))

250 m mesh map showing the geography and ground classification. We estimated the instrumental seismic intensities on the hard ground (Vs30 = 600 m/s). Thereafter, we calculated the distribution of seismic intensities on the ground surface using the Simple Kriging interpolation[9] that uses the distance decay formula for the epicenter[8] as the trend component; we obtained the distribution map of instrumental seismic intensities on the ground surface by adding the amplification degrees to each 250m cell of the mesh (Figure 11). For the calculations, we used the records of K-NET and Kik-net of National Research Institute for Earth Science and Disaster Prevention (NIED) and the seismometer records obtained from the municipalities. Liquefaction damage is mostly observed in locations on the land reclaimed from old river channels and lakes. In the inland area, liquefaction damage occurred in many areas that experienced a seismic intensity of 5-upper as well as in the areas that experienced a seismic intensity of 5-lower.

Table 1 shows the correspondence relationship between geomorphologic classification and liquefaction locations that are listed. Figure 13 shows the percentage of liquefaction events in locations classified according to geography and ground types. This figure shows that most liquefaction events, i.e., about 35% occurred in the reclaimed land, followed about 16% each in delta and coast lowland, and about 8% in backswamps. The geomorphologic classification of the Kanto district shows that the percentage of liquefaction events is the highest, i.e., about 20% in reclaimed land. This is followed by old river channels where about 10% of the liquefaction events occurred and drained land where about 7% of the liquefaction events occurred; this indicates that liquefaction occurred in artificially altered lands and low marshlands.

Figure shows the comparison of the probability values obtained from the intensity distribution shown in Fig. 11 by using the relational formula developed by Matsuoka, et al. (2011)[6]; Table 2 lists the detailed results.

Table 1 Relationship between the liquefaction locations in the 250 m mesh and the geomorphologic classification

No.	Name of geomorphological configuration	The number of liquefaction meshes	The total number of meshes of the Kanto Area	Liquefaction mesh rate (%)	The rate to all the liquefaction points (%)	Liquefaction ranking
20	Landfills	1171	5806	20.17%	35.14%	1
14	Old river courses	244	2338	10.44%	7.32%	2
19	Reclaimed land	257	3432	7.49%	7.71%	3
15	River deltas, tidewaters	538	11868	4.53%	16.15%	4
17	Dunes	104	2764	3.76%	3.12%	5
16	Sandy shoals, sandy gravel cays	254	8307	3.06%	7.62%	6
22	Dry river bed	107	4098	2.61%	3.21%	7
12	Natural levees	222	10299	2.16%	6.66%	8
23	River channel, Waterway	4	207	1.93%	0.12%	9
13	Back marshes	282	27477	1.03%	8.46%	10
18	Sandy shoals, lowlands between dunes	15	1748	0.86%	0.45%	11
10	Valley-bottom plains	39	25122	0.16%	1.17%	12
9	Loamy highlands	92	104650	0.09%	2.76%	13
11	Fan-shaped areas	2	17065	0.01%	0.06%	14
3	Hills	1	40094	0.00%	0.03%	15
1	Mountainous areas	0	146454	0.00%	0.00%	-
2	Mountain foot areas	0	4271	0.00%	0.00%	-
4	Volcanic areas	0	17804	0.00%	0.00%	-
5	Volcanic mountain foot areas	0	18804	0.00%	0.00%	-
6	Volcanic hills	0	8024	0.00%	0.00%	-
7	Rocky highlands	0	75	0.00%	0.00%	-
8	Gravel highlands	0	32654	0.00%	0.00%	-
21	Reef	0	205	0.00%	0.00%	-
24	Lake	0	3219	0.00%	0.00%	-
Total	-	3332	496785	0.67%	100.00%	-

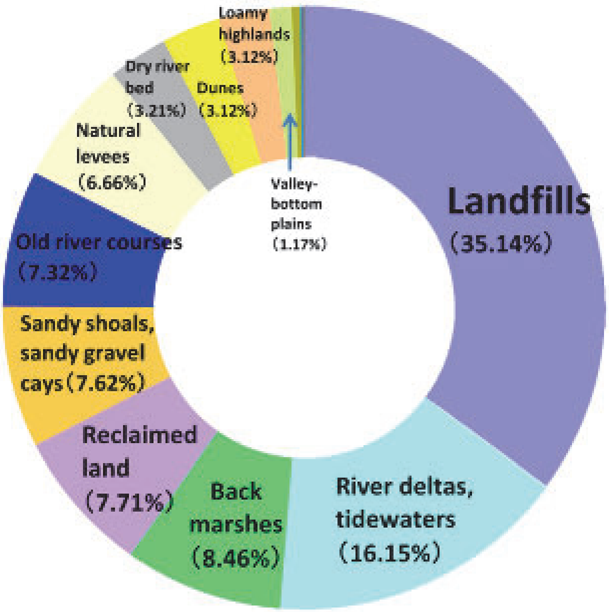


Fig. 13 Percentage of liquefaction events in locations classified according to geography and ground types

Table 2 Probability distribution of liquefaction events according to geomorphologic type of land and the average probability values (matsuoka et al.(2011)).

No.	Name of geomorphological configuration	The number of liquefaction	5%≦	2%≦ <5%	1%≦ <2%	0.1%≦ <1%	0.1% >	Average probability (%)	Probability Ranking	Actual probability(%)
20	Landfills	1171	8.1%	52.2%	30.8%	7.3%	1.6%	3.1%	1	20.17%
14	Old river courses	244	0.4%	52.0%	30.0%	12.0%	5.6%	2.4%	2	10.44%
12	Natural levees	222	8.3%	22.7%	33.0%	23.0%	13.0%	2.2%	4	4.53%
19	Reclaimed land	257	4.0%	26.0%	40.0%	22.0%	8.0%	2.0%	3	7.49%
13	Back marshes	282	9.2%	16.0%	22.0%	40.0%	12.8%	2.0%	5	3.76%
15	River deltas, tidewaters	538	0.0%	6.1%	17.3%	61.0%	15.6%	0.8%	6	3.06%
16	Sandy shoals, sandy gravel cays	254	0.0%	0.0%	18.0%	41.0%	41.0%	0.5%	7	2.61%
17	Dunes	104	0.0%	0.0%	5.0%	76.0%	19.0%	0.5%	8	2.16%
10	Valley-bottom plains	39	0.0%	2.0%	7.0%	47.0%	44.0%	0.4%	9	1.93%
18	Sandy shoals, lowlands between dunes	15	0.0%	0.0%	7.0%	14.0%	79.0%	0.2%	10	1.03%
23	River channel, Waterway	4	0.0%	0.0%	0.0%	0.0%	100.0%	0.1%	11	0.09%
22	Dry river bed	107	0.0%	0.0%	0.0%	0.0%	100.0%	0.1%	11	0.86%
11	Fan-shaped areas	2	0.0%	0.0%	0.0%	0.0%	100.0%	0.1%	11	0.01%
9	Loamy highlands	92	0.0%	0.0%	0.0%	0.0%	100.0%	0.1%	11	0.16%
3	Hills	1	0.0%	0.0%	0.0%	0.0%	100.0%	0.1%	11	0.00%

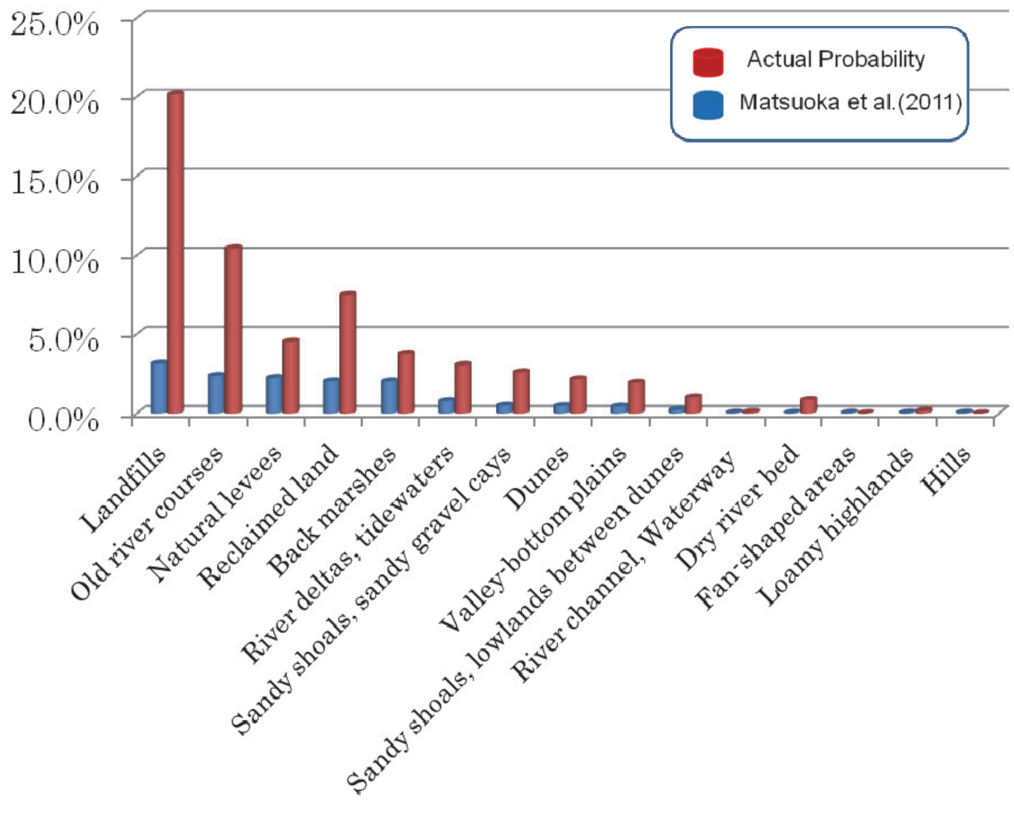


Fig. 14 Probability distribution of liquefaction events according to geomorphologic type of land and the average probability values (matsuoka et al.(2011)).

Table 2 lists and Fig.14 figure the calculation results of the average probability of liquefaction. From the list, it is seen that the reclaimed land has the highest liquefaction probability of 1.73%, followed by old river channel with a probability of 1.63%, and drained land with a probability of 1.51%. These probabilities agree with the ranking of liquefaction in the entire Kanto district listed in Table 1. The method used by Matsuoka et. al (2011) reflects the extensive distribution of the liquefaction phenomena very faithfully.

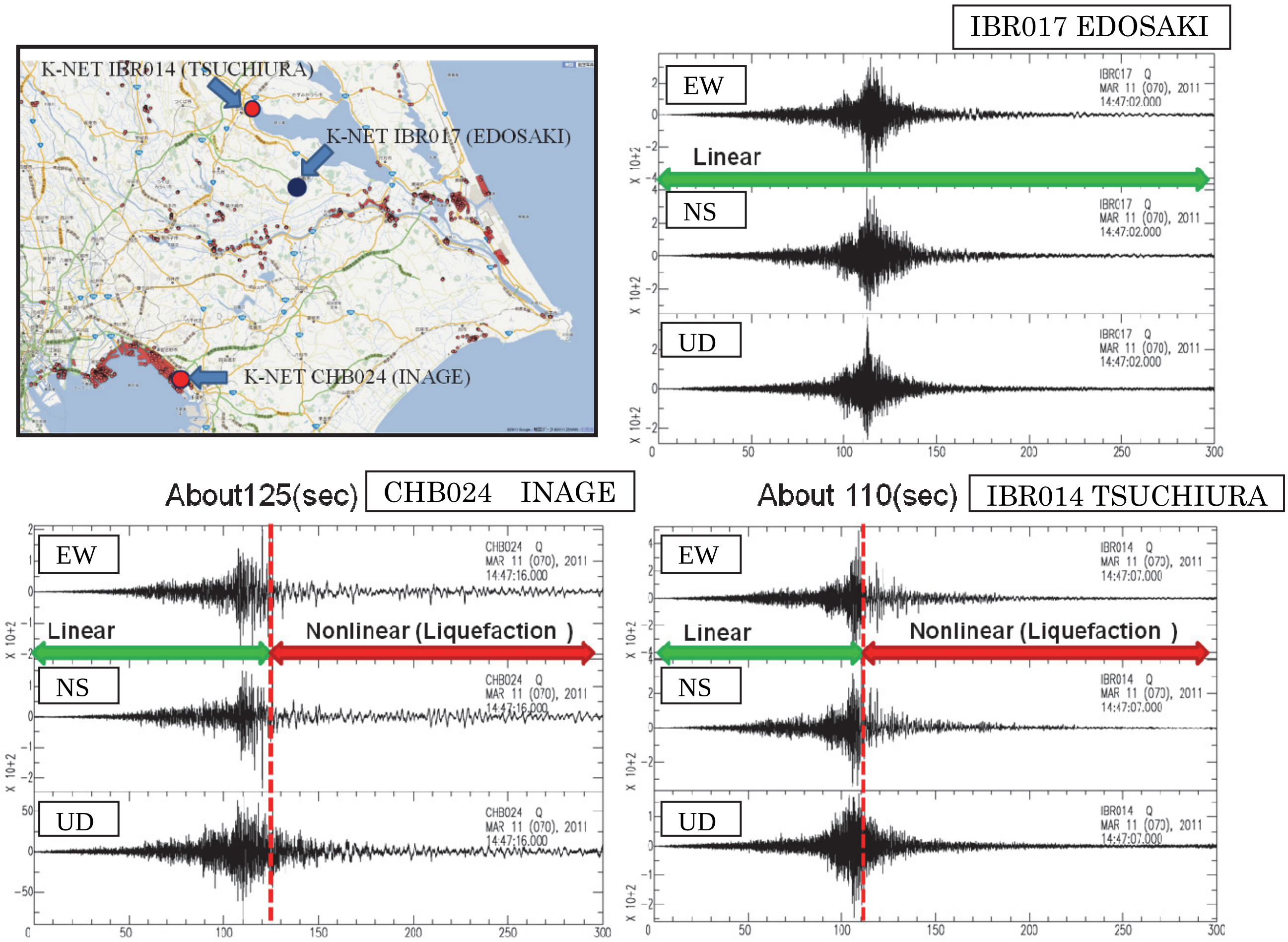


Fig. 15 NIED observation points for the 2011 off the Pacific coast of Tohoku Earthquake. Solid red circles indicate the locations where liquefaction occurred, while solid black circles indicate the locations where liquefaction did not occur (A waveform is an acceleration(gal))

CONCLUSIONS

We summarize the relationship between the occurrence of liquefaction and geomorphology, as observed from our research on three regions, namely, the Pacific coast of the Kanto district, downstream basin Tonegawa, and midstream basin of Tonegawa.

(1) The Pacific coast of the Kanto district (Kamisu City, Kashima City, and Choshi City)

Severe liquefaction was observed not only in lands artificially reclaimed from gravel plants and ponds but also in natural lands such as dunes.

(2) The downstream basin of Tonegawa (Itako City, Namegata City, Tohnosho town, Katori City, Kozaki town, Kawachi town, and Tone town)

In this area, liquefaction mainly occurred in artificial lands reclaimed from ponds and rivers. Liquefaction may have occurred in natural grounds such as valley lowlands and backswamps. However, liquefaction in the artificial lands was so severe that no municipal office in this area received reports on liquefaction in the natural lands in this area.” Please revise the highlighted text suitably.

(3) Midstream basin of Tonegawa (Municipalities other than those mentioned above)

Nearly all of the severe liquefaction events occurred in the artificial lands reclaimed from ponds and rivers. Liquefaction was also observed in natural grounds (the geomorphological types being natural levees, valley lowlands, sandbanks, and gravel sandbanks). However, most areas where liquefaction occurred are paddies in terms of land use, and these are catchment areas such as narrow valleys geographically.

By interviewing residents, we learnt that severe sand boils occurred during the aftershock at 15:15 than during the main earthquake at 14:46 on March 11 in the eastern regions of Ibaraki and Chiba Prefectures, along the Pacific coast; this includes Itako City, Kamisu City, Kashima City, and Kozaki City. This suggests the possibility that the maximum acceleration was relatively high along the Pacific coast in Ibaraki and Chiba Prefectures near the point of the aftershock and that the excessive interstitial water unreleased during seismic motions in short intervals that created a great earthquake worsened the liquefaction damage there.

ACKNOWLEDGMENTS

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