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RESIDENTIAL DAMAGE IN IBARAKI DURING THE GREAT EASTERN JAPAN EARTHQUAKE

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ABSTRACT: Damage in Ibaraki from the tsunami and liquefaction during the 3.11 earthquake was remarkable from a historical perspective. Regarding two issues, this study specifically examines the characteristics of damage to residential areas from tsunami and liquefaction. GIS-aided analysis reveals that tsunami-induced damage extends throughout coastal areas from north to south while liquefaction-induced damage is concentrated in southern areas. Future disaster reduction planning should be undertaken based on the results of analysis presented herein.

Key Words: Great Eastern Japan Earthquake, Ibaraki, Residence, Tsunami, Liquefaction, GIS, City planning

INTRODUCTION

Little attention has been devoted by mass media to the damage triggered by the 3.11 Eastern Japan Great Earthquake in Ibaraki prefecture because of the severity of its impact in the Tohoku region. Nevertheless, the damage in Ibaraki from the tsunami and liquefaction was remarkable from a historical perspective. Regarding two issues, this study specifically examines damage impact to residential areas from the tsunami and liquefaction. Data were collected from all local governments (cities, towns and villages) in Ibaraki by the Department of Emergency and Disaster, Ibaraki Prefectural Government. Results of investigations were obtained using Geographical Information System (GIS).

OUTLINE OF DAMAGE TRIGGERED BY THE 2011.3.11 EASTERN JAPAN GREAT EARTHQUAKE

As described above, although it has not strongly attracted public attention, the damage in Ibaraki was caused not only by strong earthquake motion but also by the subsequent tsunami triggered by the 3.11 earthquake, which was remarkable from a historical perspective in Ibaraki.

Table 1 Statistical data of damage in major areas in Tohoku and Kanto (at 02 Dec. 2011, after Fire and Disaster Management Agency)

		Human damage					Building damage					
		Death	Missing	Injury			Complete dstroy	Half destroy	Part destroy	Flood above floor	Flood under floor	Non-residence
				Serious injury	Minor injury	Total						
Touhoku	Aomori	3	1	16	45	61	311	852	832			1194
	Iwate	4666	1371			188	20189	4552	7316	1761	323	4148
	Miyagi	9506	1875			4013	82755	129211	211258	7900	11299	27786
	Fukushima	1605	219	20	161	181	19709	61369	141412	1053	340	1108
Subtotal		15780	3466	36	206	4443	122964	195984	360818	10714	11962	34236
Kantou	Ibaraki	24	1	33	674	707	3012	22786	162036	1715	700	14411
	Chiba	20	2	25	226	251	797	9731	42261	153	720	660
	Tokyo	7		14	7	90		11	257			20
Subtotal		¥51	3	72	907	1048	¥3,809	32528	204554	1868	1420	15091
Total		15843	3469			5890	127091	230896	652951	12917	13952	50351

(Shaded areas show the largest figures in respective columns)

Damage in Tohoku

Table 1 presents data related to human and structural damage in both Tohoku and Kanto, which are the major areas suffering from the earthquake. At a glance, damage to Tohoku is overwhelmingly greater than that in Kanto. Particularly, all figures indicate that damage in Tohoku is concentrated in Miyagi Prefecture because Sendai, the most populous city in Tohoku, is located there. It holds important infrastructure and buildings as a virtual capital of Tohoku. Damage to Miyagi is dominated by tsunami more than by the earthquake although that fact is not clearly apparent in statistical data presented in Table 1.

Damage in Kanto and Ibaraki

In contrast, damage in Kanto differs from that in Tohoku: the fatalities in Kanto were very few, as shown in Table 1. Among the Kanto areas, damage in Ibaraki stands out against that in Tokyo and Chiba.

Table 2 Statistical data related to damage in major areas in Ibaraki (at 02 Dec. 2011, after Fire and Disaster Management Agency)

		Human damage					Building damage					
		Death	Missing	Injury			Complete dstroy	Half destroy	Part destroy	Flood above floor	Flood under floor	Non-residence
				Serious injury	Minor injury	Total						
Northern	Mito	2		9	74	83	580	2848	22554	6	0	0
	Hitachi			6	162	168	417	3228	12505	569	162	0
	Hitachiohta	1			2	2	105	1211	4204	0	0	107
	Takahagi	1		1	18	19	204	1069	3891	10	18	98
	Kitaibaraki	5	1	1	187	188	186	1209	4680	522	117	1914
Subtotal		9	1	17	443	460	1492	9565	47834	1107	297	2119
Southern	Kajima	1					488	3058	2897	155	77	62
	Itako				6	6	88	2224	2620	0	0	541
	Inashiki				1	1	130	413	3281	0	0	376
	Kamisu				6	6	139	1775	3310	25	7	0
	Ubukata	2		1	4	5	103	453	2877	0	0	51
	Hokota			1	14	15	104	705	4674	43	13	156
Subtotal		3		2	31	33	1052	8628	19659	223	97	1186
Others		12	1	14	200	214	468	4593	94543	385	306	10806
Total		24	1	33	674	707	3012	22786	162036	1715	700	14411

One characteristic feature of damage in Ibaraki appears in relation to damage of buildings and facilities, as shown in Table 1. Details of structural damage in Ibaraki are presented in Table 2, showing figures of damage for every representative city, both in northern and southern Ibaraki. It is apparent from Table 2 that damage to buildings in Ibaraki is concentrated in Mito in the north and Kajima in the south. However, the main factors caused different damage in both cities. The former in Mito results from strong seismic motion. The latter in Kashima results from the severe tsunami.

FEATURES OF RESIDENTIAL DAMAGE IN IBARAKI

Distribution of damaged residences

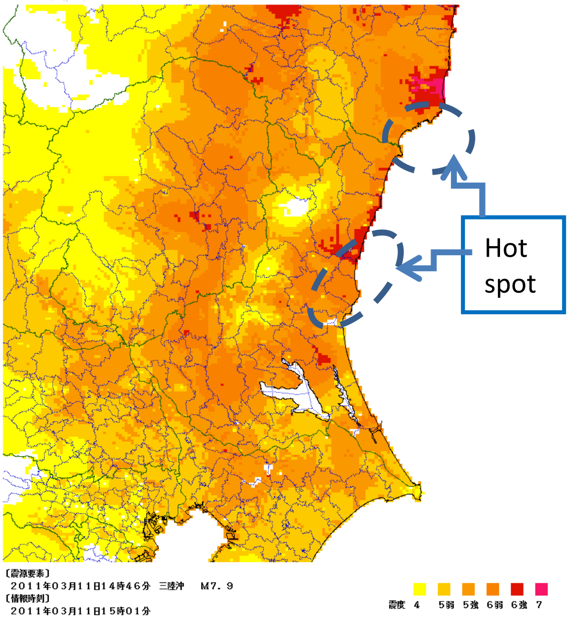


Fig. 1 Distribution of seismic intensity (JMA,2011).

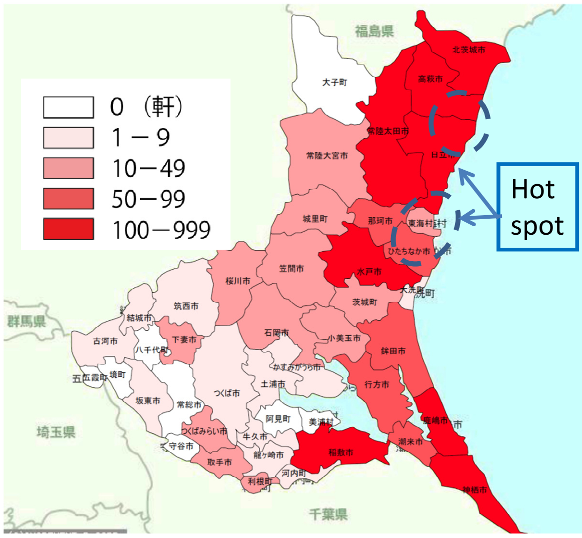


Fig. 2 Distribution of residences damaged by the earthquake.

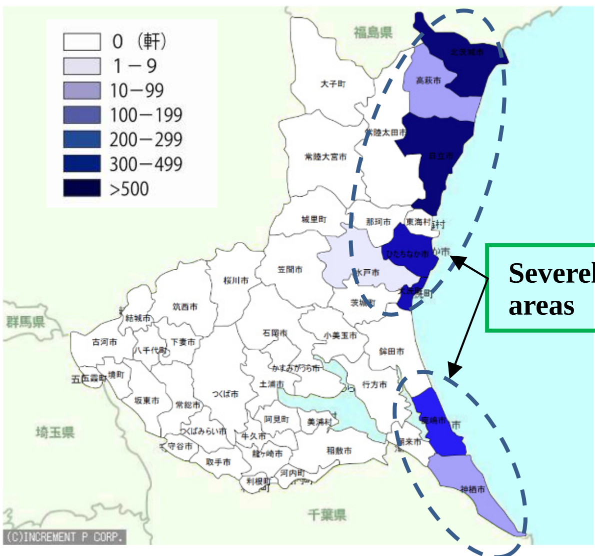


Fig. 3 Distribution of residences damaged by the tsunami.

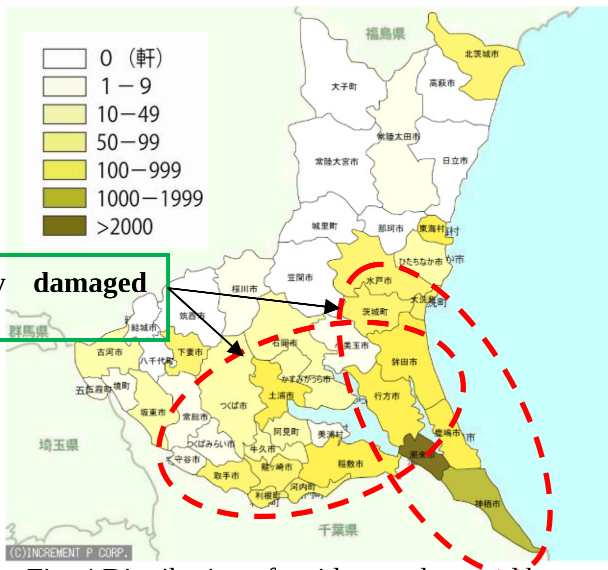


Fig. 4 Distribution of residences damaged by liquefaction.

Data related to the damage to residences in Ibaraki were collected from all local governments (cities, towns and villages) in Ibaraki by the Department of Emergency and Disaster, Ibaraki Prefectural Government. Using the Geographical Information System (GIS), the following analysis was mainly conducted based on data collated until 7 July 2011 at the department.

i) How are the damaged residences after earthquake distributed throughout the prefecture?
ii) Which earthquake-related cause mainly triggered the residential damage: tsunami or liquefaction?

Fig. 2 presents the distribution of damaged residences attributable to both tsunami and to liquefaction during the earthquake. Overall agreement is apparent between the severity of seismic intensity and the distribution of residential damage from the earthquake. Therefore, the larger the seismic intensity was, the severer the residential damage became. At the same time, it seems from Fig. 2 that the damage to residences is concentrated along the coastal region. Nevertheless, it is not distinguishable from Fig. 2 which of the tsunami or liquefaction was the dominant factor contributing to increased residential damage. Incidentally, neither the tsunami nor liquefaction affected a nuclear power station located along the coast in Tokai.

Roughly speaking, it can be inferred from Fig. 1 that two hot spots of strong seismic intensity exist. These two locations of the hot spot of the seismic magnitude in accordance with Fig. 1 are also denoted by dotted circles in Fig. 2. Once we indicate hot spots of the seismic intensity in the same locations in Fig. 2 showing the distribution of damaged residences, it is notable that no agreement can be found between hot spots of the seismic intensity and the most damaged locations of residences. Particularly, the number of damaged residences at Tokai village areas is not marked, although the seismic intensity was 6-strong, which is the largest. It is apparent from comparison between Fig. 3 and Fig. 4 that, rather in Tokai, the influence of liquefaction is more marked than that of the tsunami.

Conclusively, more than 174,000 residences were damaged in Ibaraki. Among them, completely damaged residences were 2667 as of 7 July 2011, which corresponds to approximately 14% of all damaged residences in Ibaraki Prefecture. Tsunami-induced damage is historically great on the northern coast in Ibaraki, even in comparison with that which occurred after the Chile earthquake of 1960.

Effects of geological characteristics on residential damage

Figure 5 presents the geological situation of Ibaraki. Roughly speaking, northern Ibaraki is mountainous and hilly with a spotted plain along the coast, whereas southern Ibaraki is a plain and in the lowlands in some areas. Comparison of the residential damage features in Fig. 2 with the geological situation depicted in Fig. 5 seems not to show that there is not clear agreement between the geological situation and the distribution of the damaged residences. To clarify this point, by superimposing the damage data on Fig. 5, we obtained Fig. 6. The results in Fig. 6 are characterized by the following.

1) Tsunami-induced damage is concentrated along the coast.
2) In inland areas, damage to residential area is more marked in lowland-like and lowland areas along the Kokai River and Kinu River, but it is less marked in table lands.
3) In the older geological deposits such as those of the Neocene period, damage was slight.

Those characteristics are, however, quite natural and understandable. This will be mentioned again in the following chapters.

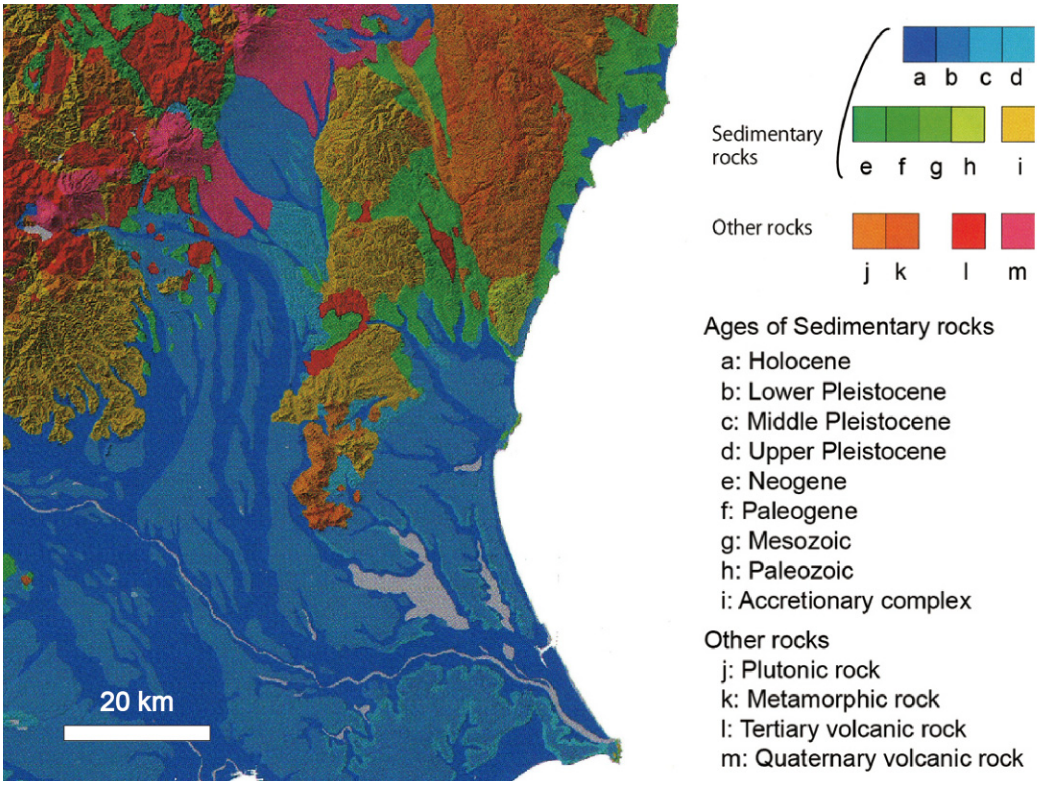


Fig. 5 Geological situation of Ibaraki Prefecture (Data Kaizuka et al., 2000).

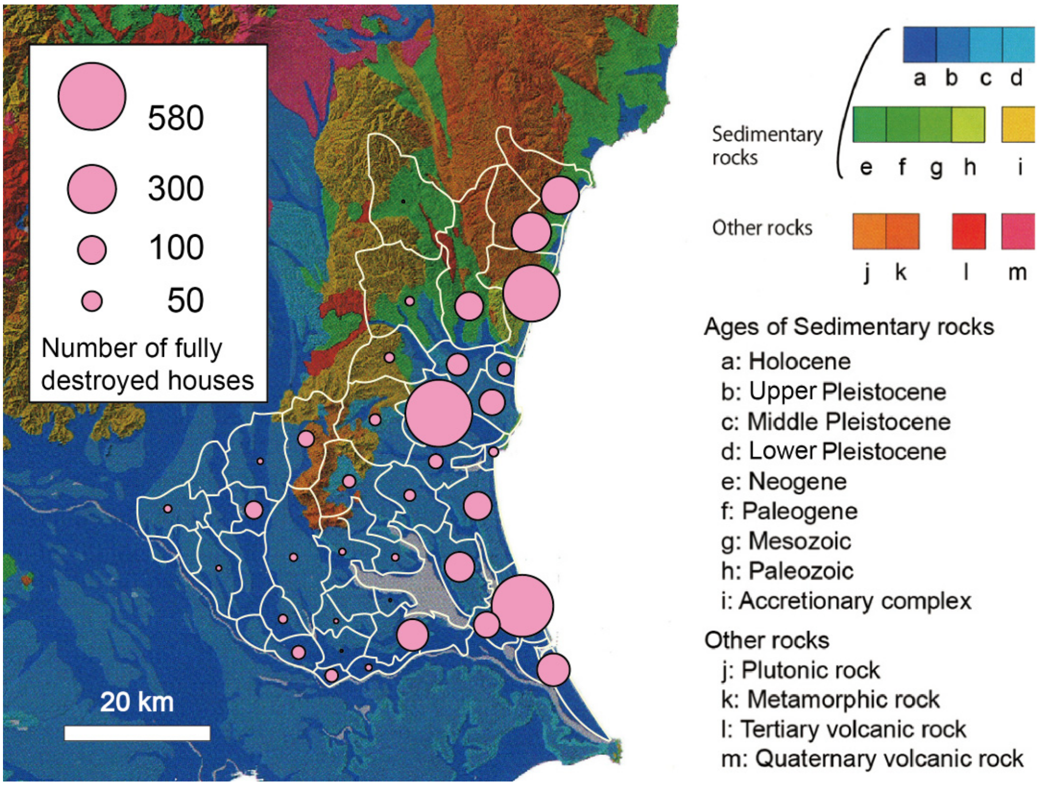
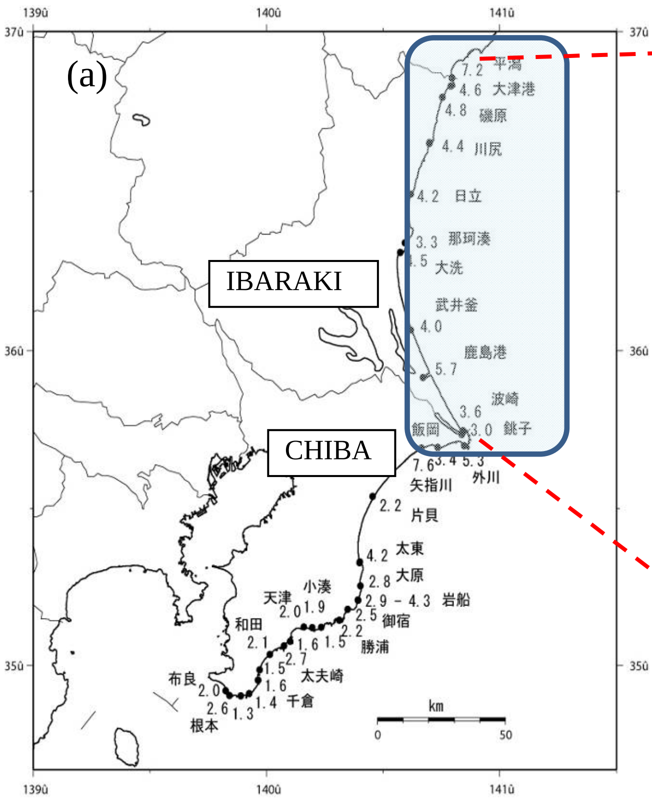


Fig. 6 Influence of geological conditions on features of residential damage in Ibaraki (After Ibaraki Pref. 2011 and Kaizuka et al., 2000).

INFLUENCE OF TSUNAMI ON RESIDENTIAL DAMAGE

In comparison with the situation in Tohoku, tsunami-induced damage in Ibaraki is considerably less. Figure 7 presents a distribution of the tsunami height along the coast in Ibaraki. Those results are based on an investigation conducted by Dr. Yoshinobu Tsuji, Earthquake Research Institute, The University of Tokyo, Japan. Fig. 7(a) includes distributions of both Ibaraki and Chiba, and Fig. 7(b) was enlarged from Fig. 7(a) for clarification of the tsunami height distribution in Ibaraki.



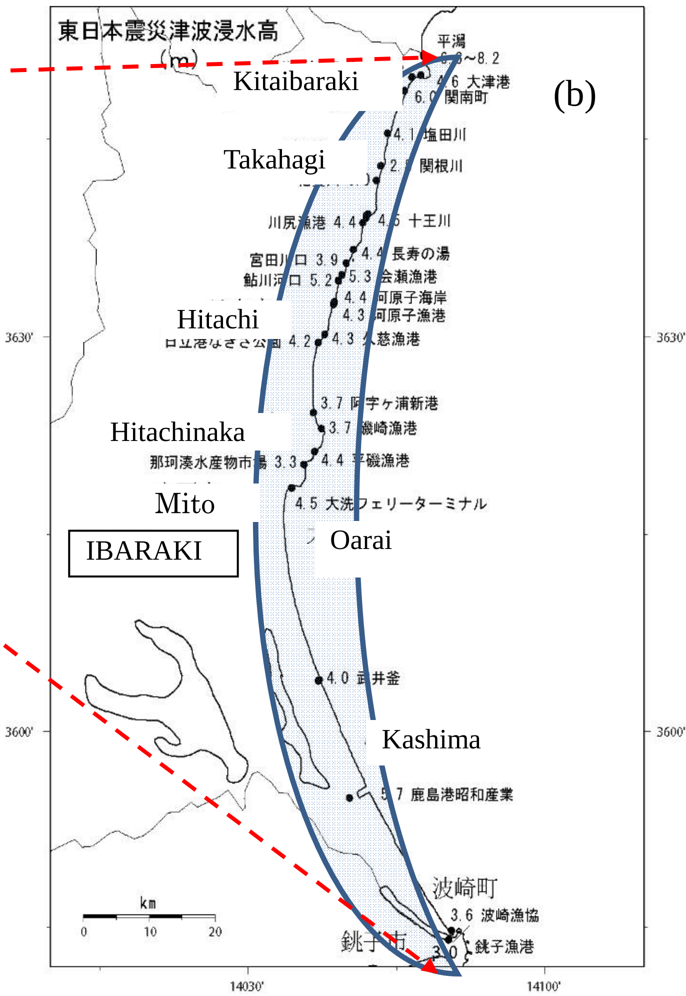


Fig. 7 Distribution of the tsunami height in in Ibaraki in (a) Kanto and (b) Ibaraki

(After Dr. Yoshinobu Tsuji, Earthquake Research Institute, The University of Tokyo, Tokyo, Japan).

(a) During the second attack of tsunami. (b) One month later

Fig. 8 Scenes of a railway embankment and its neighbors near Isohara Town of Kitaibaraki City during and one month after the second attack of tsunami (taken by Mr. Kazutami Shibata).

Tsunami-induced damage in Kitaibaraki presents an important example. Figs. 8(a) and 8(b) show scenes of a railway embankment and its neighboring areas near Isohara Town of Kitaibaraki City during and one month after the second attack of tsunami. This attacked area is less than 1 km distant from the coast. The approximately 4 m high railway embankment served as a barrier against the tsunami: no damage occurred in areas beyond the embankment. Furthermore,, investigation after tsunami indicated that the railway ballasts were not removed even by the drawing wave of the tsunami. In other words, it might be said that the wave force of the tsunami was not sufficiently strong to cause severe damage to the railway embankment and residences when the wave reached these areas.

CONSIDERATION OF INFLUENCES OF LIQUEFACTION ON RESIDENTIAL DAMAGE

Influence of Ibaraki micro-topography on liquefaction

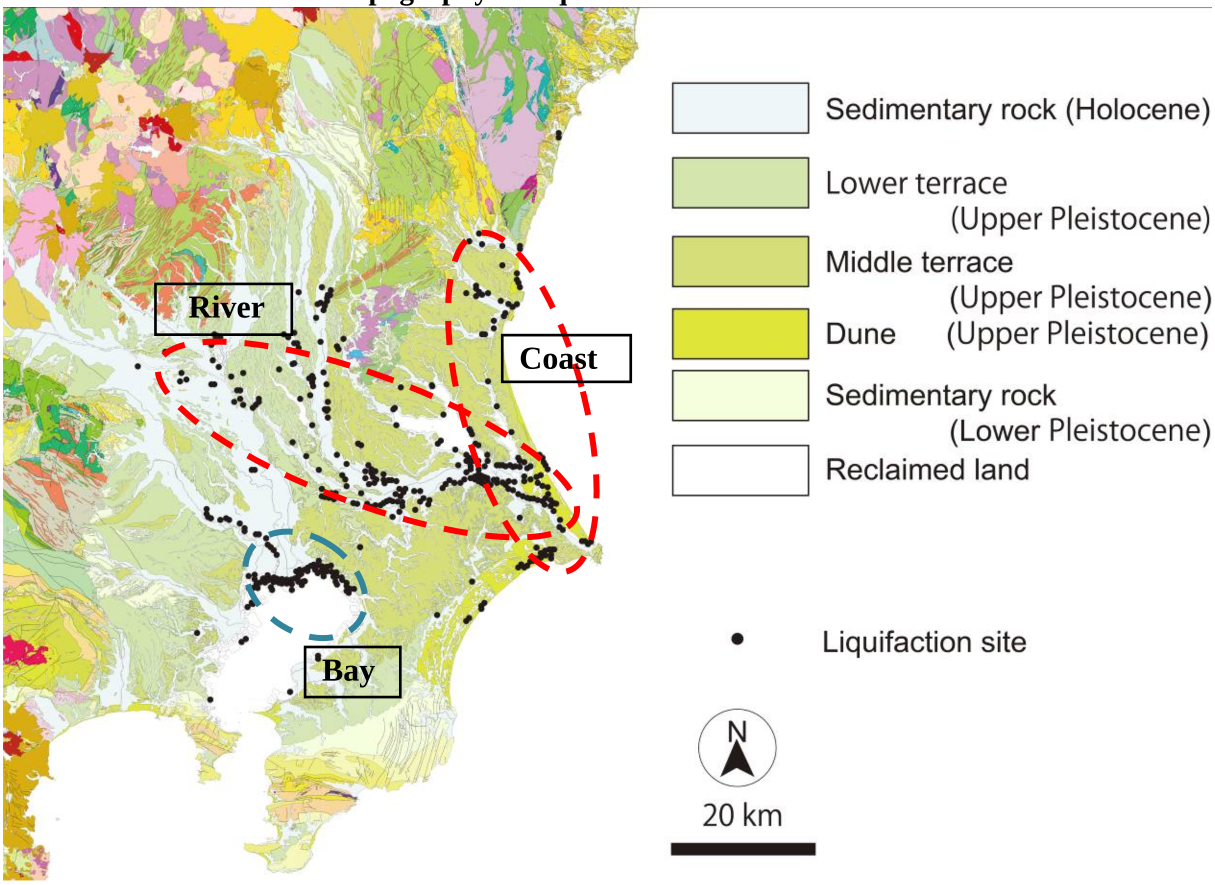


Fig. 9 Distribution of liquefied locations on a geological map of Ibaraki (after JGS, 2011and Wakita et al., 2009).

As portrayed in Fig. 4, liquefaction-damaged residences are more numerous in the southern parts of Ibaraki than in the northern parts. To clarify the influence of micro-topography on liquefaction, a comparison was made of Fig. 4 and Fig. 10, revealing that the micro-topographic conditions in Ibaraki indicating the locations of liquefaction with dotted circles. Information about liquefaction locations in red circles was investigated by Japan Geotechnical Society (JGS, 2011). The ranges of liquefaction shown in dotted circles in Fig. 10 show good agreement with tendency areas in Fig. 4 and Fig. 7, which shows the area and the effects of the geological situation of the liquefaction distribution in Ibaraki, respectively. The three circles in dotted red and blue covering Ibaraki, Chiba and Tokyo indicate that liquefaction mainly took place along the coast, river and bay.

Typical case history of severe liquefaction in residential areas in Ibaraki

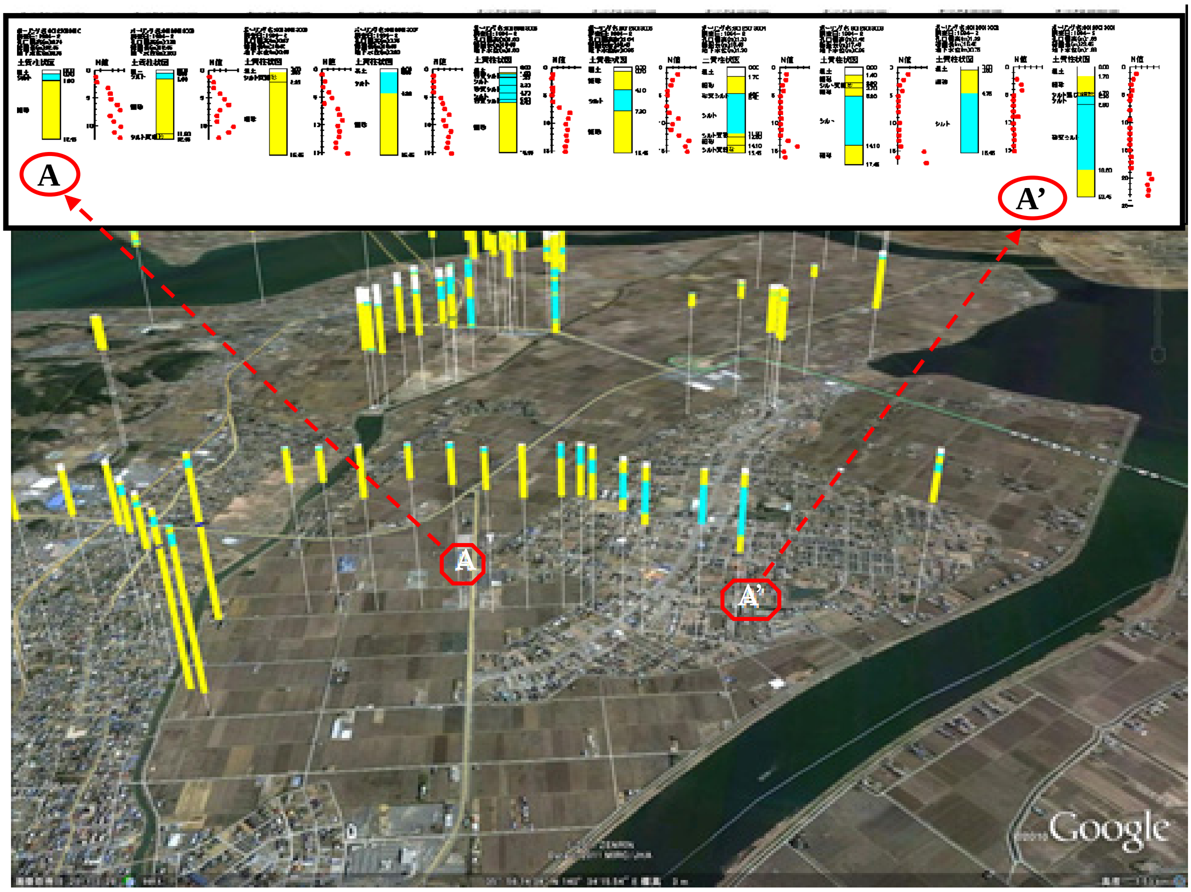


Fig. 10 Soil profile of Hinode Town in Itako City.

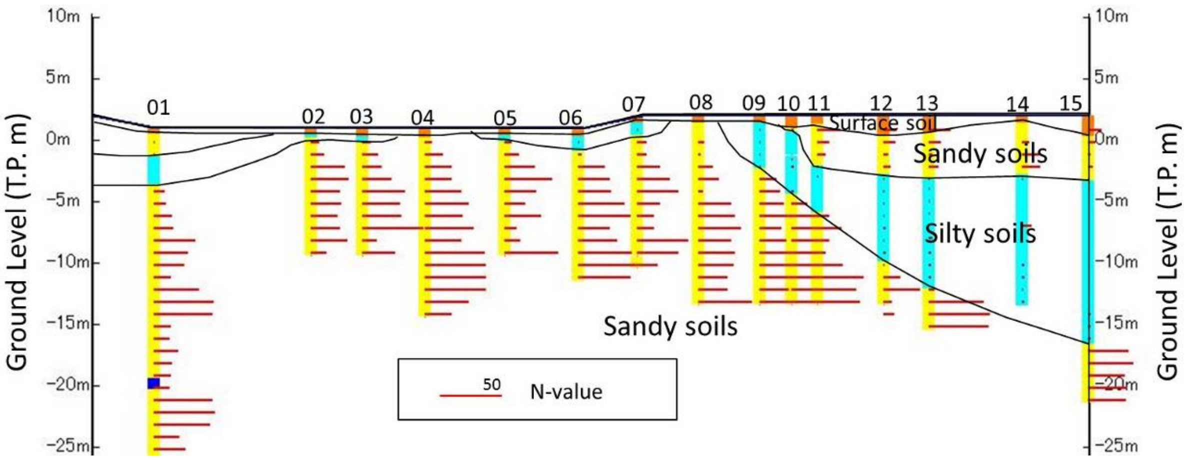


Fig. 11 Ground profiles at Hinode Town of Itako City (data from DB of Ibaraki Prefecture and Kunijiban of MLIT).

As indicated previously in Fig. 4 and Fig. 9, severe liquefaction took place in southern districts, particularly in the cities of Itako, Kajima, and Kamisu. However, the damage features in three cities mutually differ, particularly from the perspective of geography, topography, geology, and geotechnical engineering.

Here we take as an example the case history in Itako City, which suffered the severest damage in Ibaraki. Typical damage features in Kamisu and Itako after the Earthquake on 3.11 have frequently been introduced by mass media. The liquefaction situation of Hinode Town in Itako City is taken up as an example in the present paper. The land use and the typical subsoil profiles in Hinode Town of Itako are depicted in Fig. 10. The following tendencies are indicated from Figs. 10 and 11 if considering the cross section from A to A' in Fig. 10.

i) The ground consists of transported soils at the surface, sands below the surface, and silt beneath sand.

ii) The groundwater level is high, approximately 1 m from the surface.

iii) Both sandy and silty layers are of the small *N*-value from zero to several.

These conditions satisfy the high potential of liquefaction occurrence. In other words, the grounds in this area are well equipped by feasible liquefaction. Only one questionable issue exists of silty layers to some extent in every profile, although sand layers are expected to have played a role in triggering liquefaction. The role of silty layers in liquefaction was perhaps a trigger of the amplification of ground motion leading to increased liquefaction.

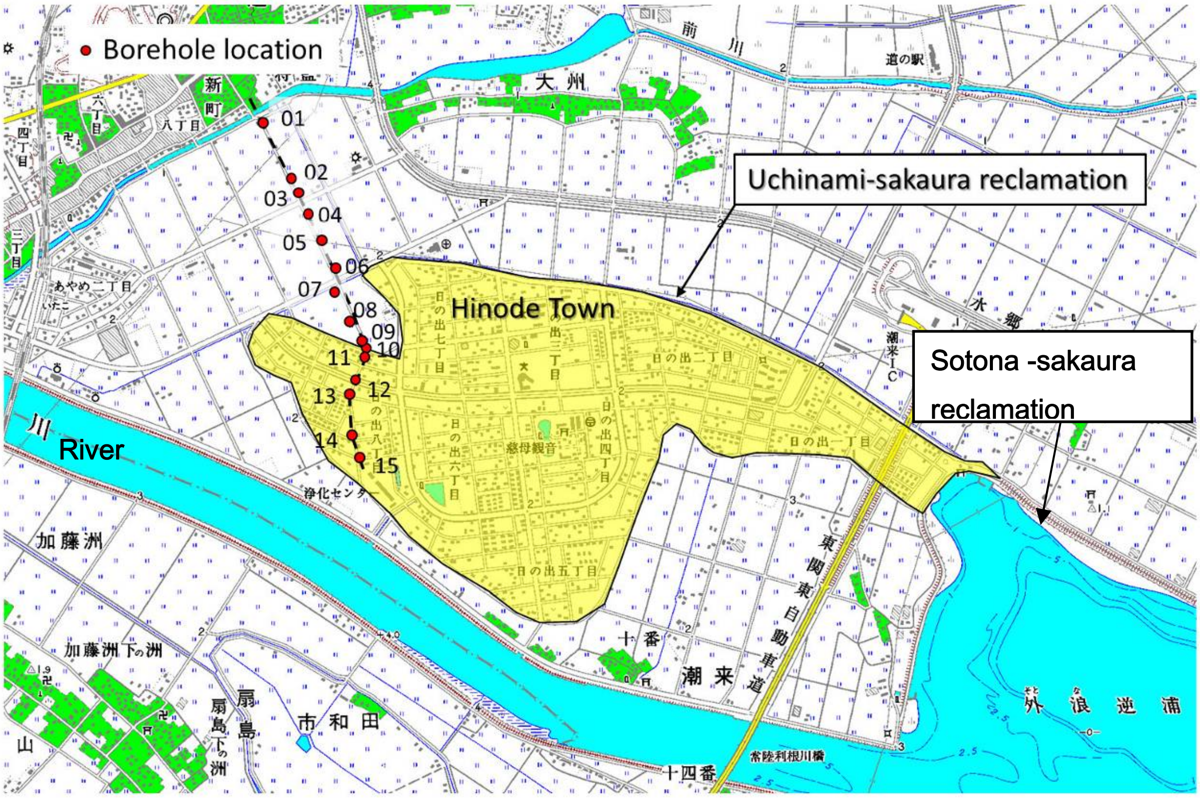


Fig. 12 Ground history of Hinode Town and its vicinity in Itako City
(modified from the map produced by Japan Map Center (JMC), 2011).

Fig. 12 shows the ground history of Hinode Town and its vicinity in Itako City. Figure from 1 to 15 in Fig. 12 correspond to the figures in Fig. 11. By reviewing the ground history of Hinode Town shown in Fig. 12, roughly speaking, the ground underwent the following before reaching the present situation.

i) Reclamation of *Uchinami-sakaura* for agricultural purposes during 1942–1950.

ii) Reclamation as land readjustment work during 1970–1974. Earthworks were conducted using dredged sands from *Uchinami-sakaura*.

The geomorphological configuration based on the situations described above is also responsible for amplification of seismic ground motion. It can be seen from Fig. 12 that the residences in Hinode Town are built upon the basined deposition by reclamation. This situation resembles that in Mexico City when the Michiokan Earthquake struck in 1985 (Mendoza and Auvinet, 1986), although sub-soils in Mexico City consist of highly plastic clay with high water contents, which differ from silty soils in

Hinode Town in Itako City. Presumably, the similarity of geometrical configuration of soil deposits with a bowl type of geomorphologic situation between Mexico City and Itako City is also related to the amplification of seismic motion.

CONCLUSIONS

Little attention has been given by the mass media to damage triggered by the 3.11 Eastern Japan Great Earthquake in Ibaraki prefecture because of the relative severity of effects in the Tohoku region. Nevertheless, the damage in Ibaraki from the tsunami and liquefaction was remarkable from a historical perspective in Ibaraki. Regarding two issues, this study specifically examines damage impacts to residential areas from the tsunami and liquefaction. Data were collected from all local governments (cities, towns and villages) in Ibaraki by the Department of Emergency and Disaster, Ibaraki Prefectural Government. Results from investigations were demonstrated using Geographical Information Systems. The following findings were obtained from the present investigation.
i) The tsunami damage was concentrated along the entire coastal area from north to south. Particularly those areas damaged by tsunami are concentrated on the northern coasts.
ii) Liquefaction damage occurred in more than 84% of all Ibaraki, not only in coastal areas but also in inland areas. However, the areas impacted by liquefaction were more severely affected in the southern parts of Ibaraki.
iii) Therefore, these characteristics of earthquake-induced damage in residences should be examined when planning cities that are robust and resilient against the coming great earthquakes in the future.

A review of the damage in residential areas in views of geotechnical engineering indicates possible cases in which liquefaction triggered an increase of the tsunami damage as a compound geo-disaster. This is an important issue to be pursued in further investigations in the future.

ACKNOWLEDGMENTS

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