Proceedings of the Twenty-second (2012) International Offshore and Polar Engineering Conference
Rhodes, Greece, June 17–22, 2012

ISBN 978-1-880653-94–4 (Set); ISSN 1098-6189 (Set)

www.isope.org

Survey Report of Liquefaction Damage of Urayasu Area

Chol-Ho Kim
Department of Engineering, Hokoku Engineering Co., Ltd
Edogawa, Tokyo, Japan
Mamoru Fujii
Department of Architecture and Building Engineering, Tokai University
Hiratsuka, Kanagawa, Japan
Kyoichi Shinagawa
Institute of Soil Exploration and Investigations, Lasting Co., Ltd
Hamamatsu, Shizuoka, Japan
Masahiro Ogawa
Department of Engineering, Hokoku Engineering Co., Ltd
Edogawa, Tokyo, Japan

ABSTRACT

The east Japan great earthquake struck from the northeast of Japan to the whole area of Kanto with a magnitude of 9.0 and maximum seismic intensity of 7 on March 11, 2011. Seismic hazard such as liquefaction has especially affected a number of detached houses. From the results of in-situ investigation, the authors found that the liquefaction damage is apparently concentrated on newly reclaimed land, and closely related to the thickness of weak soil, soil types and groundwater level. In addition, where ground improvement method had been already carried out, damage to buildings, facilities and detached houses located even in the newly reclaimed land were found to be very small. In order to predict and prepare for liquefaction, information of the soil classification and groundwater level as well as soil strength and density are important parameters, and these kinds of information also become necessary for considering the rational countermeasures to liquefaction.

KEY WORDS: Earthquake, Liquefaction, Subsidence, Groundwater level, Detached Houses

INTRODUCTION

The east Japan great earthquake struck from the northeast Japan to the whole area of Kanto with a magnitude of 9.0 and maximum seismic intensity of 7 (Kurihara city, Miyagi Prefecture) on March 11, 2011. Seismic hazards such as tsunami and liquefaction have especially affected detached houses. At present, in spite of announcement #1113 of the Ministry of Land, Infrastructure, Transportation and Tourism which addresses the possibilities of liquefaction, organized/systematic measure of liquefaction has hardly been accomplished for detached houses. The authors investigated the damage caused by liquefaction in the Urayasu area, Chiba Prefecture, where severe liquefaction damage has occurred.

OUTLINE OF THE EARTHQUAKE DAMAGE IN URAYASU AREA

Extensive damage has occurred in northeast Japan by the east Japan great earthquake, from Aomori to Kanagawa prefectures, especially where the seismic intensity of more than 5+ was observed. In addition, liquefaction caused severe damage in the Tokyo Bay, including Urayasu city. In Urayasu city, it is reported that the number of people who suffered damage was 96,473 (37,023 households), and the total area and the volume of boiling sand by liquefaction were assumed to be about 14km^2 (more than 80% of total area of Urayasu city) and 100,000~150,000m^3 respectively. Among 73,000 detached houses in the city, the water service of 33,000 households and the sewer service for 11,000 households could not be used, and more than one month was needed for the temporary restoration of the lifelines. Same as the damage in Kobe bay of the Great Hanshin Earthquake, as shown in Fig.1(a), liquefaction in the reclaimed land caused extensive damage to infrastructures and detached houses in Urayasu area, and it is necessary to consider an effective countermeasure for preventing not only liquefaction but also re-liquefaction for the future in the area. By surveying locations in detail where liquefaction occurred in Urayasu bay area, the authors have estimated the possibility of liquefaction and re-liquefaction of the area as the Liquefaction Warning Hazard Map, as shown in Fig.1(b).

DAMAGE BY LIQUEFACTION IN URAYASU AREA

Although severe damage by liquefaction was observed in the reclaimed land area from Route 357 to Tokyo Bay, as shown in Fig.1(b), Photo.6 and Fig.2, very little liquefaction has been reported in the original old land area in Urayasu city. Photo 1～3 show damage of roads, sidewalks and ground surface which was covered by the boiled sand due to liquefaction. Photo.4 shows a manhole which was found to protrude the ground surface after the earthquake.

Photo.6 and Fig.2 show the boundary between Tohno area (right side; newly reclaimed land area) and Fujimi area (left side; original old residential area), and also the cross section of these two areas respectively. Right side of the road located in Tohno area was reclaimed with the same height to the old levee, and difference of road height between the right and left sides was about 80cm. As shown in Photo 6, damage level caused by liquefaction apparently depends on the ground condition where sand boiling was observed on the sidewalk of Tohno area (right side; reclaimed land area), and contrarily, was not observed at all in the Fujimi area (left side; old residential area).

Photo.1 An electricity pole filled with boiled soil (Chidori area)

Photo.2 Ground surface covered by boiled sand (Chidori area)

Photo.3 Difference of sidewalk height (right side: old levee) (Imagawa area)

Photo.4 A protruding manhole in sidewalk (Hinode Area)

Photo.5 Sinking of soil near old levee (Hinode area)

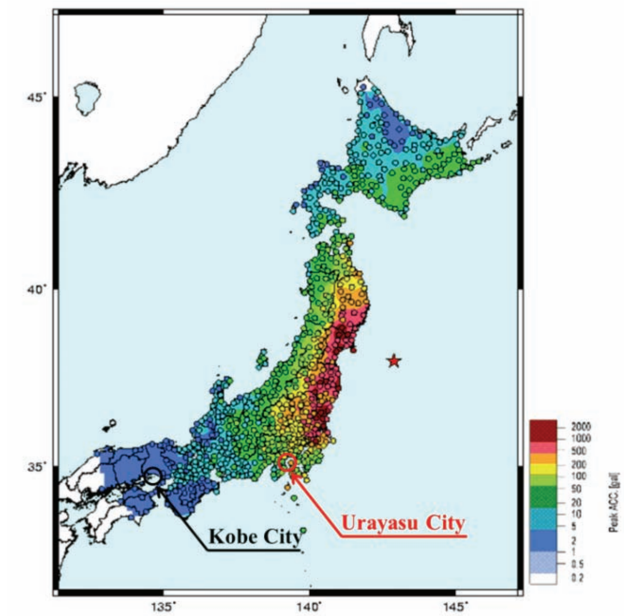

Fig.1(a) Location of Urayasu and Kobe (from K-net)

Fig.1(b) Liquefaction Warning Hazard Map in Urayasu city (Damaged area indicated by the hatched portion)

Photo.6 Boundary of newly reclaimed land and old residential areas in the Route 357 (small retaining wall just located in the center)

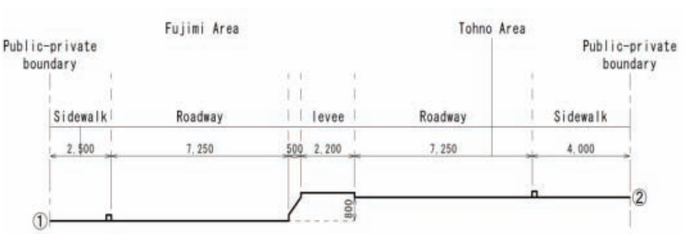

Fig.2 Cross section of boundary of newly reclaimed land and old residential area in the Route 357 (refer to Fig.3)

Fig.3 Location of newly reclaimed and old residential areas (by Google Map)

DAMAGE BY LIQUEFACTION TO BUILDINGS AND DETACHED HOUSES

Similar to the roads and sidewalks already described, damage levels caused by liquefaction to buildings and detached houses were closely related to the location. Photo 7 and 8 show Tomioka police box with part of its door filled with soil due to sand boiling and subsidence, and an inclined and damaged outer wall of a factory, respectively. From these photos, negligible uneven settlement of foundations and a large quantity of boiled sand caused by liquefaction can be easily observed. On the other hand, despite the world's largest earthquake with 9.0 of magnitude and level 7 of maximum seismic intensity (level 5 + in Urayasu area), damage to buildings and detached houses by the seismic (inertial) force was found to be small compared to that by liquefaction. Based on results of the spectrum analysis, it is reported that damage from the seismic wave of 1～2 second period, a range considered to increase damage to buildings by seismic force, was not significant in the earthquake. For example, in Sendai city, where level 6+ of maximum seismic intensity was reported, the observed seismic wave of 1～2 second period was only 20～30% of that of the Hanshin great earthquake (1995) where many more instances of total or partial destruction of 300,000 detached houses was reported. In the east Japan great earthquake, as the range of seismic waves less than 1 second period was relatively dominant, damage to building structures was far less than the Hanshin great earthquake. On the contrary, duration time of more than 300 seconds and large seismic force of the east Japan great earthquake are considered to enormously increase the total area of liquefaction and damage to the buildings and detached houses. Fig. 4 shows the seismic wave observed in Urayasu city for reference, in which the maximum acceleration and duration time are about 157 Gal and more than 5 minutes respectively.

Photo.7 Uneven settlement observed at a police box

Photo.8 Inclined outer wall of a factory caused by sand boiling and subsidence

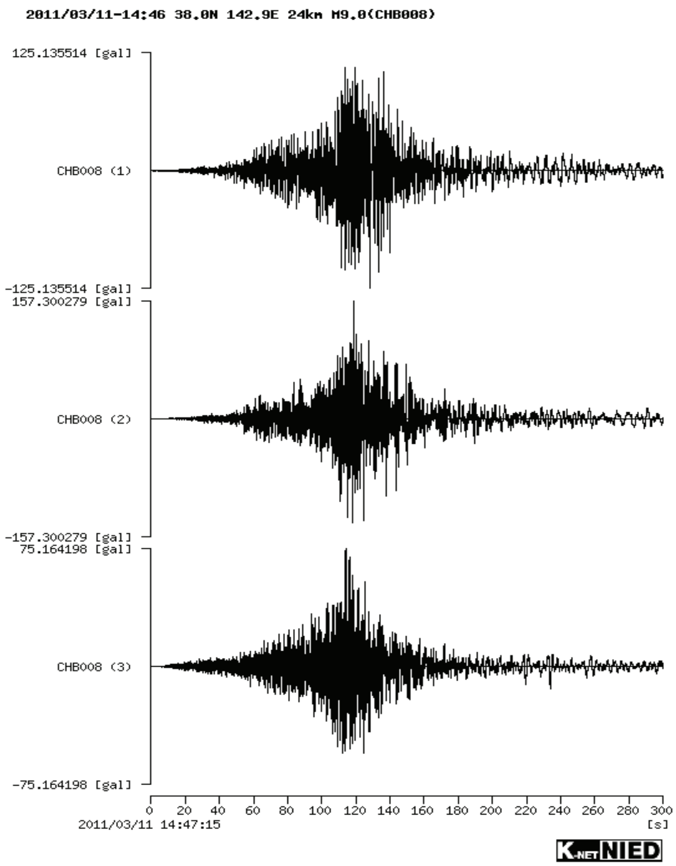

Fig.4 Seismic wave observed in Urayasu City (from K-net)

Although some traces of sand boiling were observed in the surrounding roads, shopping malls in the Irifune area suffered only small subsidence with effect of the sand compaction pile (SCP) method. On the other hand, although shopping malls reinforced with piles at Meikai area suffered very small damage, large differential subsidence of the ground surface was observed in the site. These results may indicate that the SCP is an effective method as the countermeasure to liquefaction.
Serious damage of detached houses such as inclined outer walls was observed in the residential areas, especially in the Imagawa, In the Benten and Imagawa areas, many detached houses were inclined toward the opposite side of roads, as shown in Fig.5. On the other hand, very small damage was observed in apartment houses built by the Housing Corporation in the Benten area, due to the fact that the apartment houses had already been reinforced by ground improvement methods.

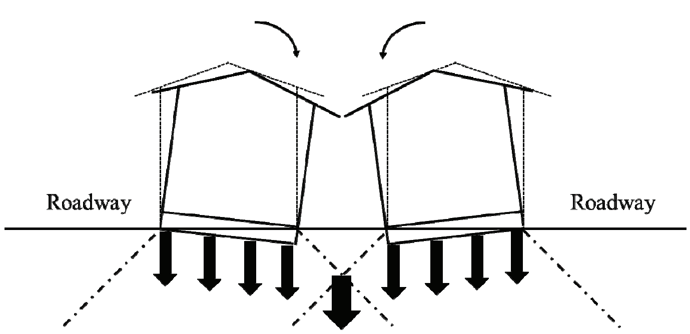

Fig.5 Inclination of detached houses

GROUND CONDITION OF URAYASU CITY

As shown in Fig.6, geographical features of Urayasu city are roughly classified into the Urayasu lowland, newly reclaimed land and embankment.

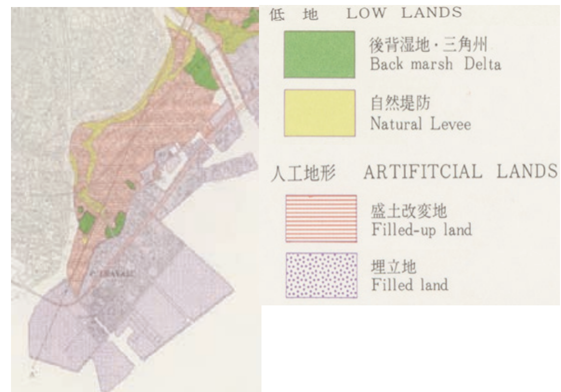

Fig.6 Geographical map of Urayasu city (by the Ministry of Land, Infrastructure, Transport and Tourism Website)

Fig.7 shows results of the Swedish Weight Sounding (SWS) tests in the Imagawa area where the damage caused by liquefaction was comparatively serious. The SWS tests were carried out in very close locations before (blue-line) and after (red-line) the earthquake, September 2010 and April 2011 respectively.
The SWS test is a popular and simple method for evaluating the soil layers and ground bearing capacity of detached houses by monitoring the vertical loading, penetrate resistance and torque. The apparatus ~~is~~ mainly consists of weight, rod, handle and screw point, and the vertical loading of 1kN maximum and torque are applied into in-situ ground through the screw point.

From Fig.7, relatively dense sand is observed from ground surface to 2m deep, and this sand layer is considered to be newly reclaimed soil. Between 2m and 5.5m deep, weak soil layer is observed continuously, and it is supposed that liquefaction occurred in this layer. Very dense soil layer appeared lower than 10m deep, and penetration of the SWS test rod was impossible at that point. The groundwater level was measured by the Alternating Current resistivity sensor using the SWS test holes simultaneously with the SWS tests, and was found to exist at a very shallow depth (1.10m deep from the ground surface). It is also understood by the SWS test results that although there is no noticeable difference, the soil after the earthquake gives a little more strength compared to before the earthquake.

Table.1 Result of the grain size test

Number of sample		boiled soil	P1	P2	P3	P4
Sampling depth(GL m)		–	-1.15 ～-1.45	-3.15 ～-3.45	-4.15 ～-4.60	-5.15 ～-5.45
Strata		–	Yu-c	Yu-s	Yu-c	Yu-s
Soil type		silty sand	sandy silt	silty fine sand	sandy silt	silty fine sand
Density of grain		2.695	2.685	2.685	2.690	2.742
Natural water content Wn (%)		20.8	40.2	38.7	47.7	36.9
Grain distri-bution	gravel (2～75mm) %	0.6	0	0.1	0	0.5
	sand(75μm～2mm) %	65.7	38.6	77.5	37.9	76.8
	silt (5～75μm) %	23.8	53.4	15.9	43	16.2
	clay (5μm～) %	9.9	8	6.5	19.1	6.5
Soil classification		SF	CsS	SF	CsS	SF

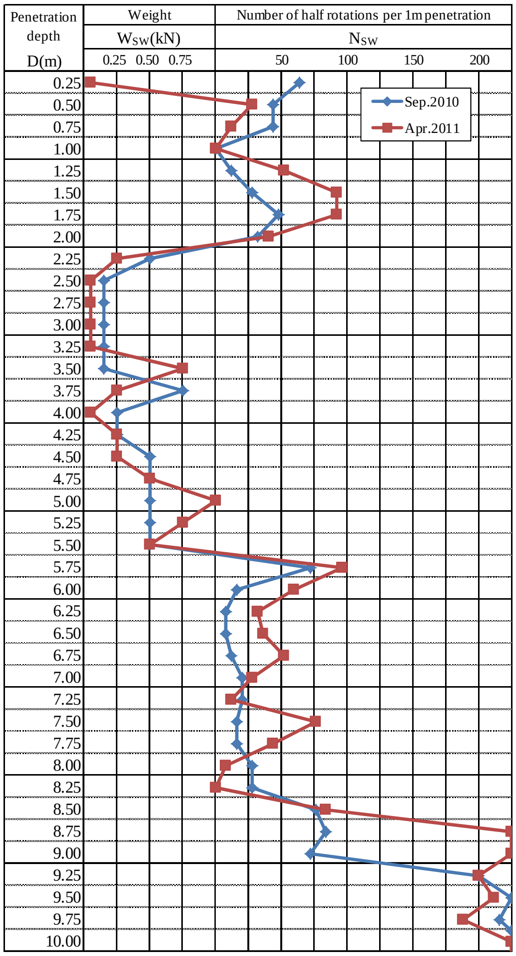

Fig.7 Result of the SWS test (Imagawa Area)

Table.2 Result of the fine fraction content test of the boiled sand

Number of sample	boiled soil	P1	P2	P3	P4
Sampling depth(GL m)	―	-1.15 ～-1.45	-3.15 ～-3.45	-4.15 ～-4.60	-5.15 ～-5.45
Strata	―	Yu-c	Yu-s	Yu-c	Yu-s
Soil type	silty sand	sandy silt	silty fine sand	sandy silt	silty fine sand
Coarse grained portion(%)	66.3	38.6	77.6	37.9	77.3
Fine grained portion(%)	33.7	61.4	22.4	62.1	22.7

Number of sample	P5	P6	P7	P8	P9	P10
Sampling depth(GL m)	-8.15 ～-8.45	-10.15 ～-10.45	-11.15 ～-11.45	-12.15 ～-12.45	-14.15 ～-15.45	-18.15 ～-18.60
Strata	Yu-s	Yu-s	Yu-c	Yu-s	Yl-c	Yl-c
Soil type	silty fine sand	silty fine sand	sandy silt	silty fine sand	sandy silt	clayey silt
Coarse grained portion(%)	54.3	91.8	47.9	56	22.9	1.7
Fine grained portion(%)	45.7	8.2	52.1	44	77.1	98.3

As the boiled sand observed in the site was classified into silty sand from result of the grain size test, the silty sand layer was supposed to be deposited in 3.15～3.45m (No.P2) and 5.15～5.45m deep (No.P4) from the ground surface, as shown in Table 1. When liquefaction and sand boiling occurred, however, it may be assumed that soils of large grain size such as gravel and sand are likely to remain as it was on the ground surface, and soils of small grain size with large specific surface area such as silt and clay are considered to be easily run out on the ground surface. In this point of view, the boiled sand (No.P2 and No.P4 in Table 1) included only less than 10% of clay, and is assumed to be flowed off with water on the ground surface. In the Tokachi-Oki Earthquake (2003), as similar results such as large amounts of silt contained in boiled sand was reported, the authors will continue to investigate the property of boiled sand caused by liquefaction.

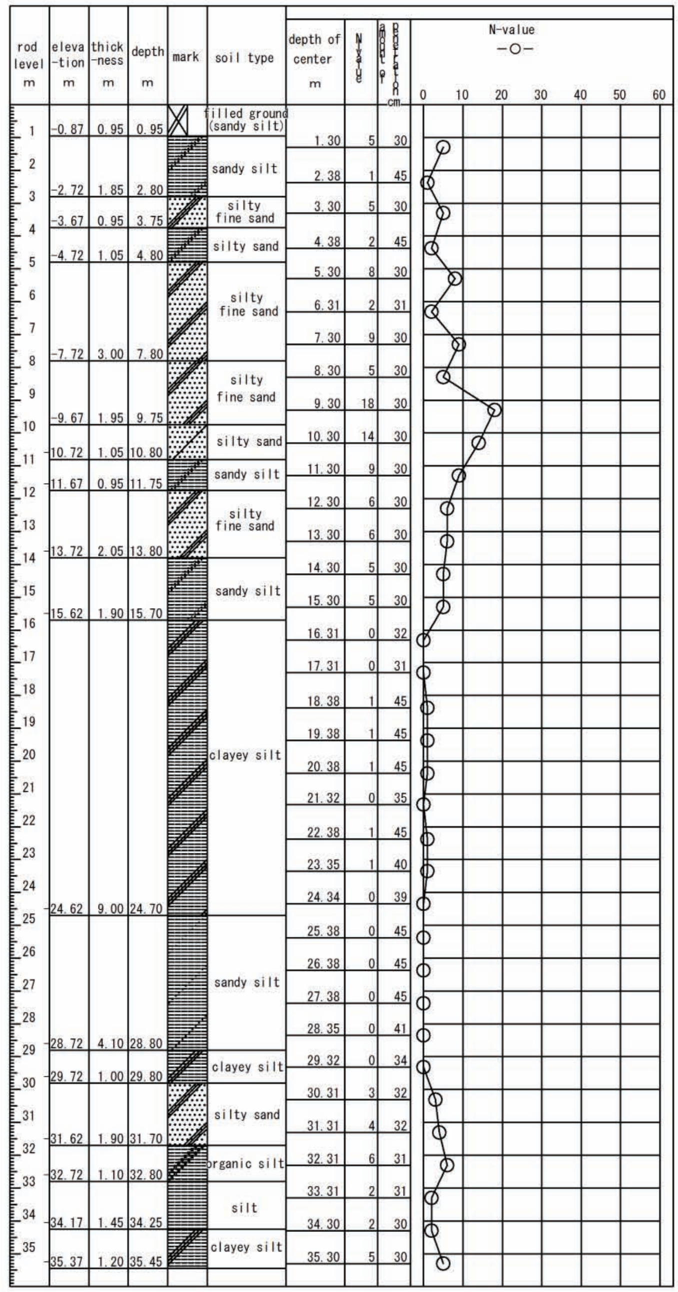

Fig.8 Soil boring log at Imagawa Area

Judgment of liquefaction possibility based on the “Design Manual for Building Foundation in Japan” was carried out using the boring log data as shown in Fig.8. PL value of 7.90, which means “possibility of liquefaction is large”, was calculated when 160 gals of the maximum horizontal acceleration and Magnitude 9 were assumed based on the observed seismic wave near the site. On the other hand, as it has been pointed out that the grain size distribution and relative density of soil may be changed before and after liquefaction and sand boiling, care is necessary when evaluating the possibility of liquefaction using boring log data obtained after the earthquake. Since the soil condition may become a little denser after liquefaction, as shown in Fig.7, possibility of liquefaction will be underestimated when using the boring log data after the earthquake. In addition, as the re-liquefaction of soil may take place when the next earthquake occurs, it is worthwhile to investigate an effective countermeasure to liquefaction in advance. When considering the foundation types and reinforcement methods with regard to the ground condition for detached houses, it is an important reminder that the result of the conventional judgment for liquefaction possibility may not be always on the safe side.

SUMMARY

From the results of in-situ investigation in Urayasu area, the authors found that the liquefaction damage is apparently concentrated on newly reclaimed land, and closely related to the thickness of weak soil, soil types and groundwater level. Where ground improvement method had been already carried out, damage to buildings, facilities and detached houses located even in the newly reclaimed land were found to be very small.

In order to predict and prepare for liquefaction, information of the soil classification and groundwater level as well as soil strength and density are important parameters, and in addition, these kinds of information also become necessary for considering the rational countermeasures to liquefaction.

For these purposes, the authors have been investigating
(a) The simple and accurate groundwater measurement technique using the SWS test holes
(b) The simple soil classification technique using the Alternating Current resistivity sensor

It is also found that the conventional soil parameters which have been proposed for liquefaction judgment may not be always on the safe side, and the ground improvement method such as the sand compaction pile method may be an effective countermeasure to liquefaction.

In the next step, we will investigate the relationship between types of ground improvement method and the damage level of detached houses when liquefaction occurred.

REFERENCES

Fujii, M (2003), etc. “Ground Evaluation by Swedish Weight Sounding for Detached House Construction” *Geotechnical Engineering in Urban Construction, Tsinghua University Press*, pp.375-382.

Ministry of Land, Infrastructure, Transport and Tourism Website , (http://tochi.mlit.go.jp/tockok/tochimizu/F3/ZOOMA/1218/index.html).

Mori, S (1984). etc. “Properties of boiled sand caused by liquefaction in reclaimed land”, *Soils and Foundations*, Japanese Geotechnical Society Vol.32, No.2, pp.17-22.

Nationwide strong motion network (2011). “National Research Institute for Earth Science and Disaster Prevention”, (http://www.k-net.bosai.go.jp/k-net/quake/).

Sakai, Y (2011). “Characteristics of the earthquake – The east Japan great earthquake 2011”, (http://www.kz.tsukuba.ac.jp/~sakai/113g.htm).

Urayasu City Website (2011),"Changes of reclaimed land use / Urayasu city” ,(http://www.city.urayasu.chiba.jp/menu3189.html).