Liquefaction damage by the 2011 off the Pacific coast of Tohoku Earthquake in Japan and land condition of damaged area detected by time serial geospatial information

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Abstract. The 2011 off the Pacific coast of Tohoku Earthquake in Japan caused liquefaction in large parts of the Kanto Region, especially in the Tokyo Bay side area and the lower reaches of the Tone River. Liquefaction was concentrated in areas of land reclamation and former river channels, where it is easy to recognize using time-series geospatial information such as olden topographic maps and olden aerial photographs. To determine the amount of land subsidence due to liquefaction in Urayasu City, the Geospatial Information authority of Japan (GSI) carried out a leveling survey and compared the differences between pre- and post-earthquake LiDAR survey data with the relative subsidence obtained by leveling.

Keywords: land condition, LiDAR, liquefaction, the 2011 off the Pacific coast of Tohoku Earthquake, time-series geospatial information

1. Introduction

"The 2011 off the Pacific coast of Tohoku Earthquake" caused heavy liquefaction damage to buildings, public facilities and lifelines in large parts of the Kanto District, especially in the Tokyo Bay area and the lower plains along the Tone River.

Conditions under which liquefaction occurs are as follows: strong earthquake motion, high ground water level and loosely deposited sand. Places with the high possibility of liquefaction are reclaimed land, former river channels, and lowlands between sand dunes and sandbars. To know the potential for liquefaction, it is important to determine the history of the land. The Geospatial Information Authority of Japan (GSI) has archived time-series geospatial information, such as olden topographical maps and olden aerial photos, and it provides these archived data to the general public. It is possible to understand the history of the land and liquefaction-prone locations from time-series geospatial information.

We surveyed the damage at the liquefaction sites and researched geographical conditions of areas remarkably damaged by liquefaction using time-series geospatial information. We mainly used time-series geospatial information, such as olden French-style maps (Japanese: jinsoku-sokuzu), olden topographical maps, previous aerial photos, land condition maps and landform classification maps for river improvement.

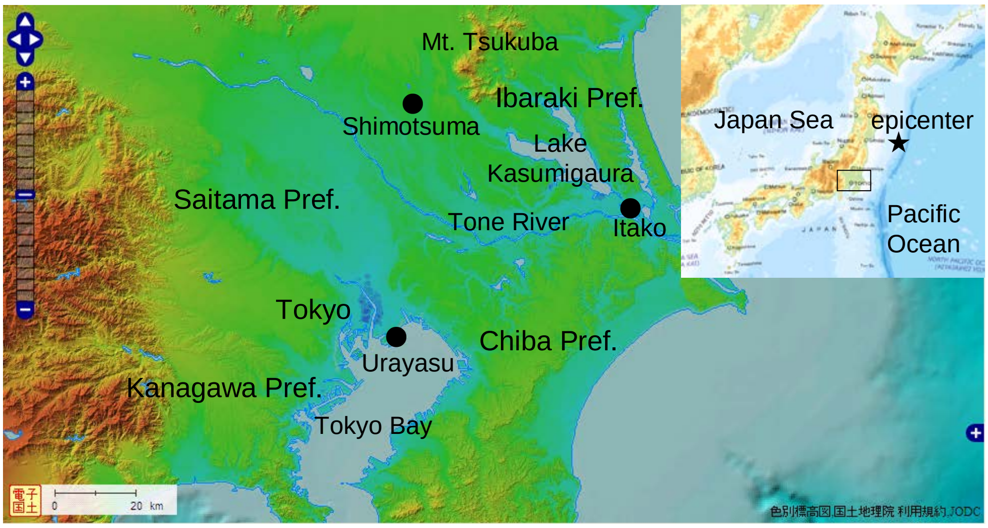


Figure 1. Index map of reported area (base map by Cyber Japan Web System).

2. Liquefaction damage on Tone River area by the 2011 off the Pacific coast of Tohoku Earthquake

2.1. Liquefaction damage in the Hinode area of Itako City, Ibaraki Prefecture

Although liquefaction occurred at many places in Itako City, Ibaraki Prefecture, which is in the lower reaches of the Tone River, liquefaction damage was especially serious in the Hinode area (Fig.1). Typical liquefaction damage of the Hinode area is shown in Fig.2. Although the main roads were restored to some extent by June 2011, leaning utility poles were left ‘‘as is’’ (Fig. 2A). The school buildings showed an apparent relative uplift of about 25 cm at Hinode Junior High school (Fig. 2B). The damage extended to be more severe in the southern area. Street gutters were deformed by lateral spreading; cave-in and other damage to the lid of a gutter are seen in Fig. 2C and Fig. 2D. The “jinsoku-sokuzu” map (Fig. 3) published by the Japanese army about 130 years ago shows that the Hinode area is land that was reclaimed by the drainage of a small bay, which means the area is susceptible to liquefaction.

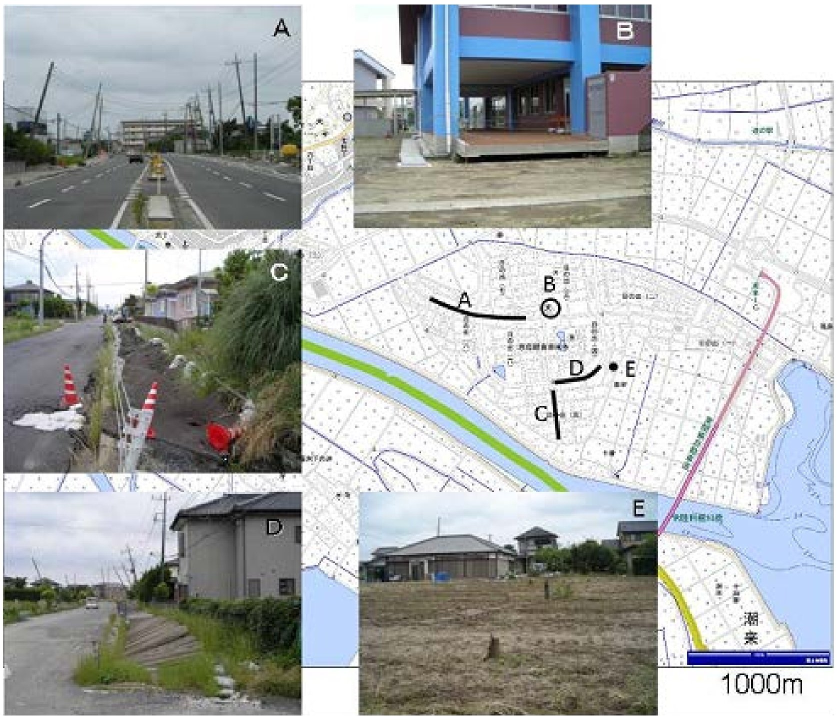


Figure 2. Liquefaction damages in Hinode area, Itako City.

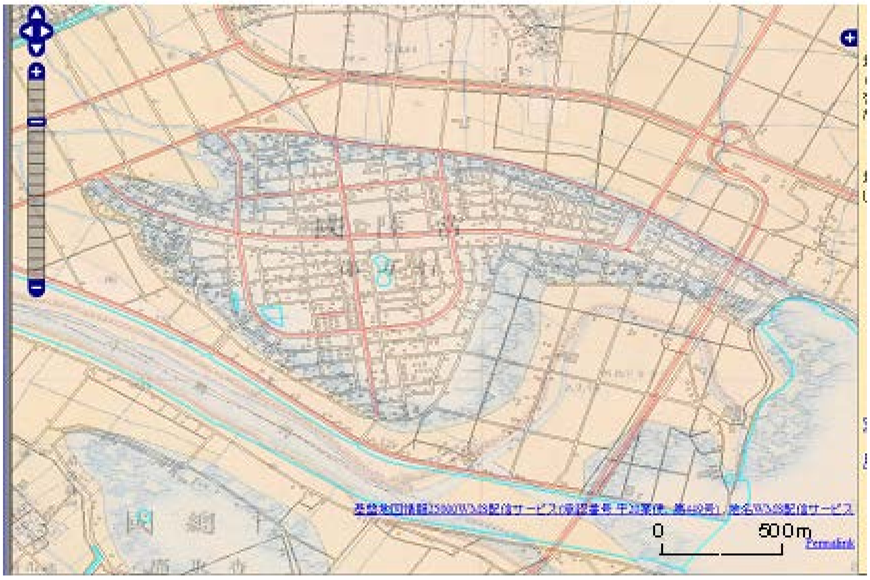


Figure 3. Overlay between “Jinsoku-sokuzu” and Fundamental Geospatial Data of Hinode area, Itako City (using the Historical Agricultural Environmental Inspection System by National Institute for Agro-Environmental Sciences).

2.2. Liquefaction damage in the Kinu area of Shimotsuma City, Ibaraki Prefecture

There is a low lying former river channel in a band across the Kinu area of Shimotsuma City, Ibaraki Prefecture (Fig. 1). This landform is shown on the ‘‘Mitsukaido’’ Land Condition Map published by the GSI. This former river channel sank, and land subsidence and relative ground water level rise are presumed. Service on neighboring roads was suspended as a result of intense cracking and undulation of the road (A in Fig. 4). Liquefaction damage, such as cracking, differential settlement and the tilting of buildings occurred even in the new residential area in the former river channel. The houses were destroyed by the severe subsidence of reclaimed land and the collapse of foundations (B in Fig. 4). The main stream of the Kinu River was shown as meandering in a jinsoku-sokuzu map from about 130 years ago (Fig. 5a). A new river channel was under construction in the olden topographic map (1:50,000 scale) published about 75 years ago (Fig. 5b). In the U.S.Army aerial photo, it is clear that the former river channel turned to be a paddy field about 65 years old(Fig. 5c).

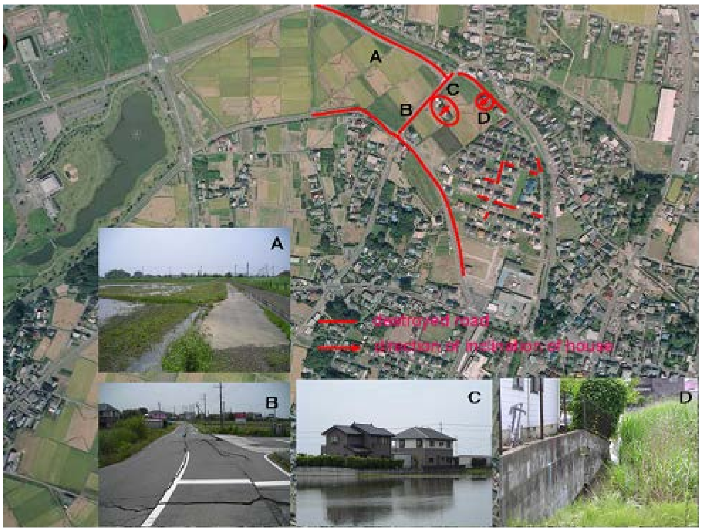
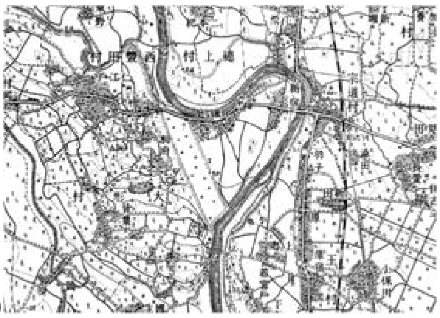


Figure 4. Liquefaction damage in Kinu area, Shimotuma City (Base image is aerial photo taken by GSI in 2008 (CKT2008-2 C3-36).

(a) 

(b) 

(c) 

Figure5. (a) "Jinsoku-sokuzu" of Kinu area, Shimotuma City, Ibaraki Prefecture, (b) Part of 1:50,000 scale olden topographical map "Mitsukaido" published by Japanese Army in 1934, (c) Aerial photo of Kinu area taken by US Army in 1947 (USA-R388-61).

3. Liquefaction in Urayasu City

Urayasu City, Chiba Prefecture, is one of the areas that were most severely affected by liquefaction caused by the strong motion of the Tohoku Earthquake (Fig. 1). We carried out a leveling survey in Urayasu City and compared the results with the differences in LiDAR (Light Detection and Ranging) survey data measured pre- and post-earthquake, and relative upward displacement values of piled buildings to determine surface subsidence by liquefaction.

3.1. Results of the leveling survey near Shin-Urayasu Station

Since the liquefaction damage of Urayasu City in the Tokyo Bay area was severe, the amount of land subsidence caused by liquefaction was surveyed by leveling, and the authors analyzed the severity of liquefaction. Leveling was carried out using the block reference points near Shin-Urayasu Station on the JR Keiyo Line in August 2011. The leveling route was set perpendicular to the coastline. The results were compared with the observation results of the block reference points in November and December 2006. Assuming that the subsidence at point A is zero where liquefaction was not observed relative subsidence in the area after 2006 was computed. The leveling survey results are shown in Fig. 6.

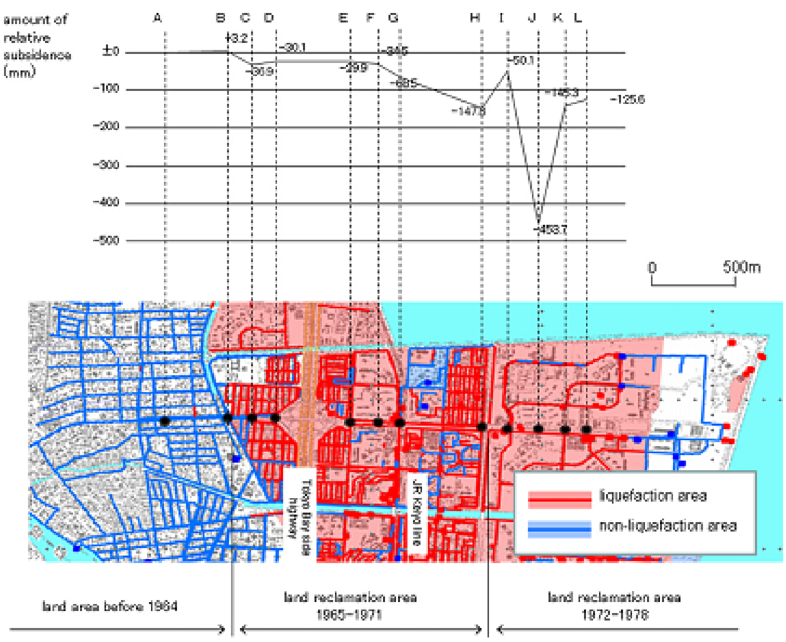


Figure 6. Results of leveling survey in Urayasu City.

Subsidence in the liquefaction area ranged from several centimeters to several tens of centimeters. A tendency was seen for the subsidence of recently reclaimed land near the coastline to be large and for the subsidence of old reclaimed land to be small. Near point H, land subsidence of about 4 cm was observed for the five years from 2004 to 2009 by leveling survey. The subsidence in Fig. 6 contains not only that from liquefaction but also that from pre- earthquake consolidation.

3.2. Comparison of the difference between pre- and post- earthquake LiDAR data, and leveling survey data

To understand ground deformation produced by earthquake-generated liquefaction, Urayasu City (2011) released an elevation difference map on its website. This map was created by comparing two seasons of airborne laser survey data (LiDAR data). Pre-earthquake LiDAR data were surveyed in December 2006; post-earthquake LiDAR data were surveyed in April 2011.

An overlay of the change of elevation produced by determining the difference between pre- and post- earthquake LiDAR data and the data from the leveling survey is shown in Fig. 7. It is thought that the results also include fundamental subsidence for the previous five years. Land subsidence is observed in whole area; deeper subsidence was observed in the area on the south side of the Tokyo Bay Highway. Crustal deformation from the Tohoku Earthquake is shown to have caused about 4 cm of subsidence in the Tokyo Bay area, and about 4 cm of fundamental land subsidence in five years. The vertical accuracy of the LiDAR survey is about 15 cm. Because depression of 30 cm or more is considered significant with respect to LiDAR data, only depressions of 30 cm or more are judged to be significant for the following discussion.

A large amount of sedimentation is particularly apparent at Imagawa, Meikai and Hinode. Notable land subsidence due to liquefaction is found along the line a–b–c–d and b–e–f in Fig.7. When field survey was performed, severe sand volcanoes and ground deformation were found to have occurred. Near point J, where the leveling survey shows about 45cm of subsidence, an area with large subsidence has the shape of a circle. About 40cm of uplift for buildings was measured at several apartments near point J by field survey. Therefore, it can be considered that the subsidence of a block reference points properly reflects the surrounding land subsidence. The relationship between subsidence at a block reference points as determined by leveling survey and subsidence by the average value of the difference of LiDAR data in nine meshes near the block reference points are shown in Fig.

8. Since the amount of lowering as determined by the difference in the two LiDAR data is large in places where large amounts of subsidence as determined by leveling occurred, it can be judged that the correspondence between the data is generally good. However, absolute value correspondence is not necessarily good. In Fig. 8, the amount of lowering as determined by the difference of the two LiDAR data tends to be larger than that determined by leveling. Although a problem remains in the absolute value of the difference of LiDAR data, LiDAR data are sufficiently accurate for judging relative amounts of lowering, such as the degree of subsidence, and for seeing the tendency of overall subsidence distribution. The result is considered effective toward finding out the amount of land subsidence accompanying liquefaction in Urayasu City.

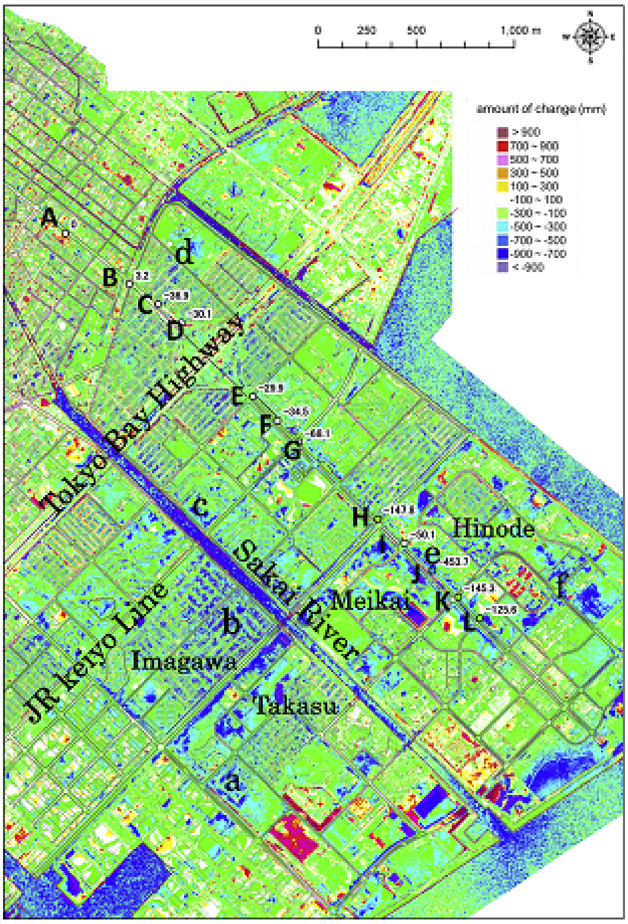


Figure 7. Overlaying the amount of change by the difference of two LiDAR data and results of leveling.

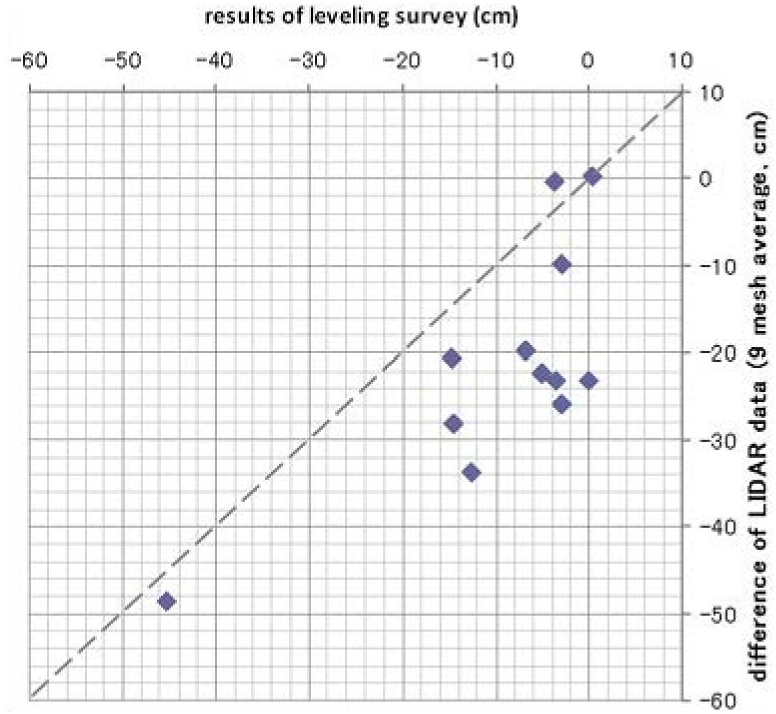


Figure 8. Relationship between results of leveling and difference of LiDAR data.

3.3. Comparison between the difference between pre- and post-earthquake LiDAR data and the uplift value for large buildings

Research Institute of Environmental Geology, Chiba (2011) measured the amount of relative uplift of structures with a stake foundation (from which the amount of land subsidence that can be found) and provide the results to the public on their website. The data excluded the factors of relative uplift of buildings caused by consolidation settlement as much as possible, with the aim of measuring only the apparent relative uplift of buildings caused by the earthquake. The data were measured with high density except in the single-family house areas and areas without buildings. The amount of surface subsidence by liquefaction is expected to be measured quite accurately, since neither the amount of subsidence by crustal deformation or consolidation settlement is included. This data is considered very useful for calculating the regional subsidence by liquefaction. An overlay of the values of relative uplift of buildings and the difference in DEM by two period LiDAR data shows that relative uplift of buildings is greater in the area on the south side of the Tokyo Bay Highway. This distribution qualitatively agrees with the area where the amount of lowering as determined by the difference in LiDAR data tends to be large.

4. Conclusion

The 2011 off the Pacific coast of Tohoku Earthquake in Japan caused liquefaction in large parts of the Kanto Region, especially in the Tokyo Bay side area and the lower reaches of the Tone River. The most severely areas affected by liquefaction were reclaimed land such as former river channels, which can be recognized from olden maps and olden aerial photos. The comparison of LiDAR survey data measured pre- and post-earthquake is effective to detect the amount of land subsidence due to liquefaction.

Acknowledgements

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