



# Soil liquefaction observed at the lower stream of Tonegawa river during the 2011 off the Pacific Coast of Tohoku Earthquake

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Received 4 April 2012; received in revised form 23 June 2012; accepted 1 September 2012

Available online 9 January 2013

## Abstract

Earthquake reconnaissance investigations were carried out at regions located along the lower stream of Tonegawa River where widely spread soil liquefaction and associated phenomena were observed following the main shock and aftershocks of the 2011 off the Pacific coast of Tohoku Earthquake. A multiple series of Swedish Weight Sounding tests were carried out at Sawara of Katori City, Hinode of Itako City, and Wanigawa and Fukashiba of Kamisu City. The soil profiles responsible for the damage inflicted by soil liquefaction were demonstrated along with the help of SPT data. At some locations where the soil samples of erupted sand boils were retrieved, the profiles of relative density and factor of safety against liquefaction with depth are estimated and discussed in detail. The use of Swedish weight sounding tests along with a help of SPT soil profiling proved an effective method for detecting liquefiable soil layers responsible for widespread soil liquefaction induced damage.

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*Keywords:* the 2011 off the Pacific Coast of Tohoku Earthquake; Soil liquefaction; Swedish weight sounding tests; Soil profiles; Tonegawa river

## 1. Introduction

Following the main shock of the 2011 off the Pacific Coast of Tohoku Earthquake of  $M_w=9.0$  that occurred at 14:46 on March 11, 2011, and the subsequent aftershocks, widespread soil liquefaction and associated phenomena have been observed in various regions on Kanto plain, inflicting immeasurable damage to lifelines, infrastructures and residential homes. As such, soil liquefaction has once again come into focus as one of the important issues in natural

disaster mitigation and reduction, as it was after the 1964 Niigata Earthquake. It is most noteworthy that tens of thousands of residential houses were subjected to liquefaction induced settlement and tilt over the ground surfaces covered by erupted sand boils located on reclaimed lands developed along Tokyo Bay, including some areas in Urayasu City and Chiba City. The areas affected by soil liquefaction were also found to extend along the lower stream of Tonegawa River.

When one looks at the regions along the lower stream of Tonegawa River as shown in Fig. 1, one needs to remember the aftershock that occurred off the coast of Ibaraki Prefecture at 15:15, about 30 min after the main shock on the same day. In Katori City, a seismic intensity of Shindo 5 strong was recorded for the main shock as well as the aftershock on the scale of Japan Meteorological Agency. In Itako City, the levels of seismic intensity were

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Peer review under responsibility of The Japanese Geotechnical Society.



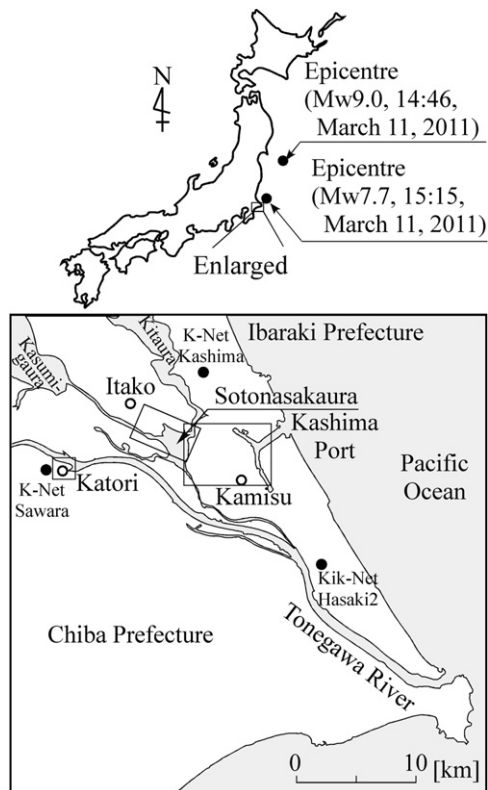


Fig. 1. Locations of regions investigated.

recorded as Shindo 6 weak and 5 strong, respectively, while those recorded in Kamisu City were 5 strong and 6 weak. Several K-Net stations were located around this region. At Sawara K-Net station, the seismic shaking continued for more than 2 min during the main shock, and the maximum acceleration of 301 Gal was recorded in the East–West component. The aftershock lasted again for over 2 min, with a maximum acceleration of 220 Gal recorded in the East–West component. At Kashima K-Net station, the maximum acceleration of EW 651 Gal and NS 494 Gal were recorded during the main shock, while those of EW 355 Gal and NS 408 Gal were recorded during the aftershock. At Hasaki-2 Kik-Net Station, the seismic shaking was weaker, with a maximum acceleration of EW 188 Gal and NS 216 Gal recorded during the main shock, while those of EW 228 Gal and NS 168 Gal were recorded during the aftershock.

In the present study, a multiple series of Swedish Weight Sounding (SWS) tests were carried out at Sawara of Katori City, Hinode of Itako City, and Wanigawa and Fukushima of Kamisu City, as shown in Fig. 1, and the results of the earthquake reconnaissance investigations are described in what follows.

## 2. Historical overview

To understand the widespread occurrence of soil liquefaction along the lower stream of Tonegawa River, it would be helpful to recognize the importance of recent geological history of this area. About one thousand years ago, the

current downstream area of Tonegawa River, which corresponds to the regions shown in Fig. 1, used to form an inner sea, and the old Tonegawa River used to run southwards on Kanto plain to pour into Tokyo Bay, (Tonegawa River Lower Stream Office, 2011). In the Edo era, about 400 years ago, in order to prevent floods in the centre of the old capital of Tokyo caused by the old abraded Tonegawa River, the course of the river was purposely changed to run eastwards to flow directly into Pacific Ocean, and the current stream of Tonegawa River was laid down. It took about 60 years from 1594 to 1654 to complete this extensive work. Following the continued flow of the river water and the gradual accumulation of loose river bed deposits, the sea water has progressively been replaced with fresh water around this area, and a series of the currently seen inner lakes called “Kasumigaura” were formed. However, abrading the current of Tonegawa River did not stop flooding along its stream. In the Meiji era, a series of river works were carried out from 1900 to 1930, which can be divided into three periods. In the first period from 1900 to 1909, the river improvement work consisting of river bed excavations and river embankment constructions was conducted in an area spanning from the estuary to the current Sawara district of Katori City. The river improvement work conducted during the second and third periods covered the areas from Sawara to the upper reach of the river. Therefore, it is most likely that at least part of Sawara district was reclaimed at that time with soils produced by excavations of the nearby river floor deposits. The river work from 1900 to 1909 should then have allowed dwelling to be extended to such wet lands. Since Sawara served as one of the major ports for ship loading and unloading, the local Onogawa River, which extends from the main Tonegawa River to the inner district of Sawara, was used as a ship canal. However, the use of the canal for this purpose came to a halt due to the decline of shipments along Tonegawa River.

## 3. Sawara of Katori city

Two series of SWS tests were carried out on August 4 and 5, 2011, along the two lines denoted as A–A' and B–B'–B'' in Fig. 2. The locations of SWS tests are denoted

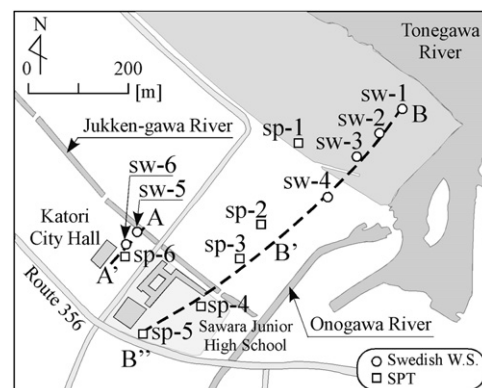


Fig. 2. Locations of SWS tests and soil sampling (Sawara in Katori City).

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