Proceedings of the International Symposium on Engineering Lessons Learned from
the 2011 Great East Japan Earthquake, March 1-4, 2012, Tokyo, Japan

SOIL LIQUEFACTION OBSERVED AT KATORI CITY LOCATED ALONG THE LOWER STREAM OF TONEGAWA RIVER DURING 2011 GREAT EAST JAPAN EARTHQUAKE

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ABSTRACT: The earthquake reconnaissance investigations were conducted at Sawara district of Katori City, Chiba, located along the lower stream of Tonegawa River, where the extensive soil liquefaction and associated phenomena were observed following the main shock of 2011 Great East Japan Earthquake of M = 9.0 that occurred at 14:46 on March 11, 2011, and also the subsequent aftershocks. A series of Swedish weight sounding tests were carried out at the site subject to damages inflicted by lateral spreading, and the soil profiles responsible for such damages were identified. Another series of Swedish weight sounding tests were carried out at the dry river bed of Tonegawa River, and the soil profiles spanning from Sawara district to Tonegawa River were demonstrated along with a help of SPT data. The soil profiles responsible for widely spread soil liquefaction were discussed in detail.

Key Words: Great East Japan earthquake, Soil liquefaction, Swedish weight sounding tests, Soil profiles, Tonegawa river

INTRODUCTION

Following the main shock of 2011 Great East Japan Earthquake of M = 9.0 that occurred at 14:46 on March 11, 2011, and also the subsequent aftershocks, widely spread soil liquefaction and associated phenomena have been observed in various regions on Kanto plain, inflicting numerous damages on lifelines, infrastructures and residential houses. Most notably, tens of thousands of residential houses, located on reclaimed lands developed along Tokyo Bay, have been subject to post-liquefaction settlement and tilt over the ground surfaces covered by erupted sand boils. The areas affected by soil liquefaction were also found to extend along Tonegawa River.

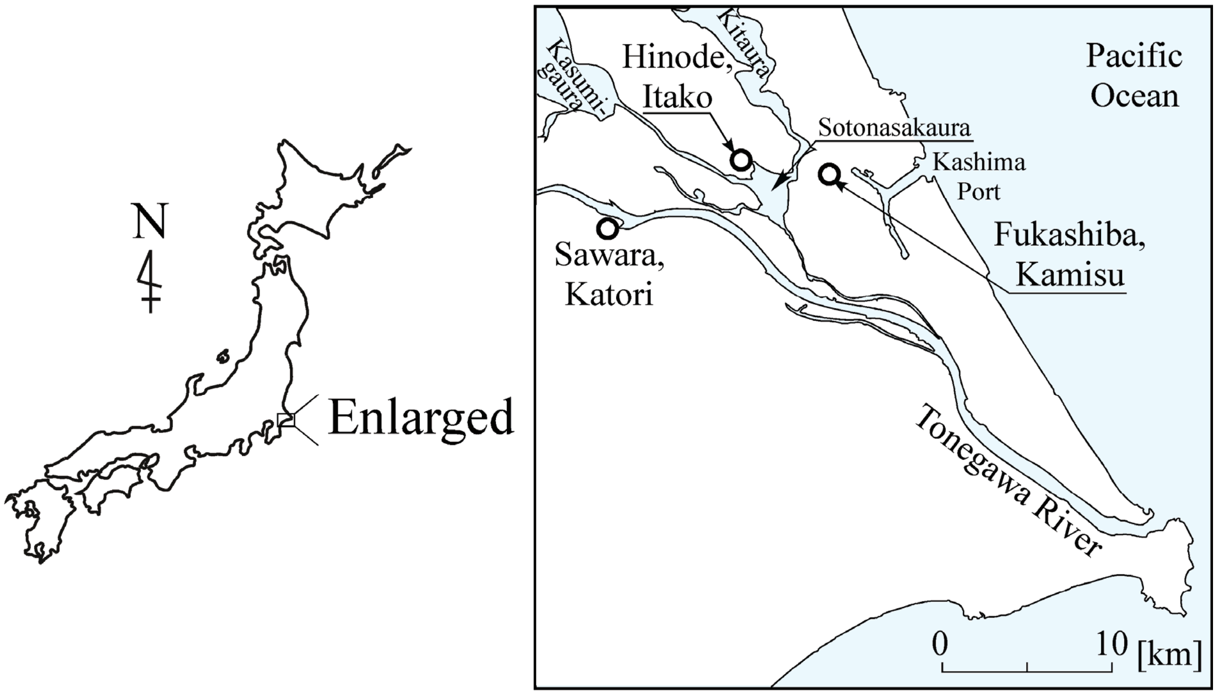

Fig. 1 Location of Sawara, Katori City, Chiba

The authors had some opportunities to conduct multiple series of field Swedish weight sounding tests at some areas located in the lower stream of Tonegawa River, including Sawara of Katori City, Hinode of Itako City, and Fukashiba of Kamisu City, as shown in Fig. 1. The results of the earthquake reconnaissance investigations conducted at Hinode of Itako City and Fukashiba of Kamisu City are described in the accompanying paper by Tsukamoto et al. (2012). In the present study, the results of the earthquake reconnaissance investigations carried out at Sawara of Katori City, Chiba, are described in what follows.

BACKGROUND

In ancient history that just dates back to about one thousand years ago, the current downstream area of Tonegawa River, which corresponds to the area 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 Edo era of about four hundred years ago, in order to prevent floods at 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, that took about 60 years from 1594 to 1654 to complete its extensive works. Following the gradual accumulation of loose river bed deposits, a series of the currently seen inner lakes called “Kasumigaura” were formed. However, the abraded current Tonegawa River could not help stop causing floods along its stream. From a close look at the old map of 1880’s (TRLSO 2011), the area of Sawara district shown in Fig. 2, which was currently bounded by the route 356 and the right bank of Tonegawa River, corresponded to part of the river bed or easily inundated dry river bed. In 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 works consisting of river bed excavations and river embankment constructions were conducted at the areas spanning from the estuary to the current Sawara district of Katori City. The river improvement works 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

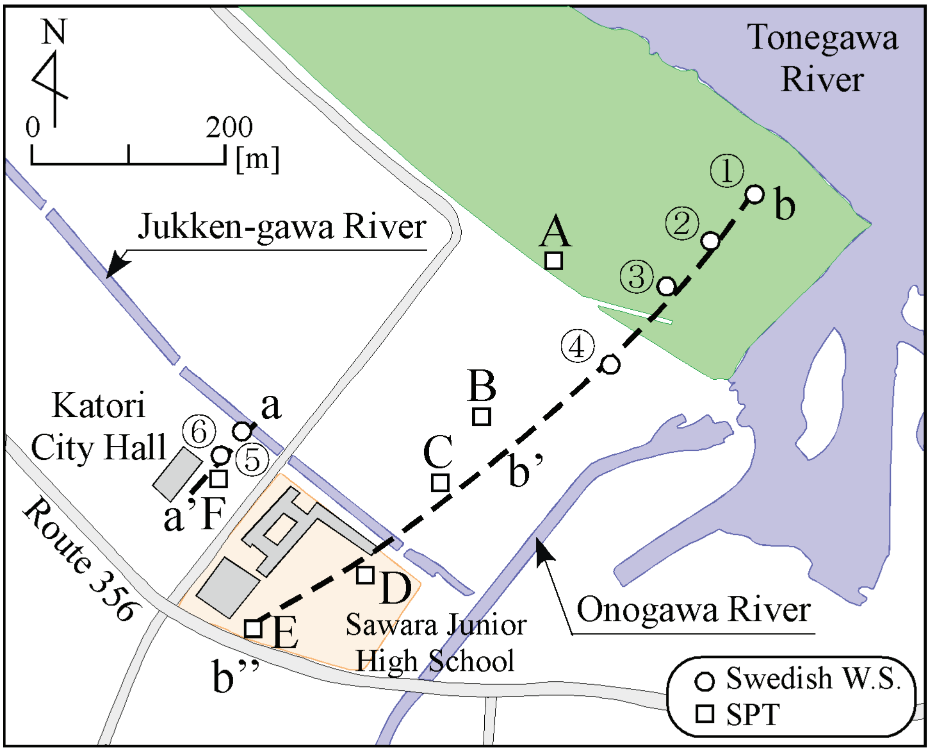

Fig. 2 Locations of Swedish weight sounding tests

with soils produced by excavations of the nearby river floor deposits. The river works from 1900 to 1909 should then have allowed dwelling to be extended to such wet lands. Since Sawara was one of the major ports for ship loading and unloading, local Onogawa River extending from main Tonegawa River to the inner district of Sawara was used as a ship canal. However, such functions for shipment came to a halt due to the decline of shipment along Tonegawa River.

OVERVIEW

The authors had some opportunities to conduct earthquake reconnaissance investigations at Sawara district of Katori City, Chiba. This area was found to be one of the sites where soil liquefaction was observed in the past earthquakes.

The acceleration records of the main shock at 14 : 46 were observed at Sawara station of K-Net, which is 323 km away from the epicenter, as shown in Fig. 3. The seismic shaking continued for more than 2 minutes, with the maximum acceleration of 301 Gal, among which the seismic shaking measuring over 50 Gal even lasted for about 60 seconds. The large aftershock of M = 7.7, then struck the region at 15 : 14. The epicenter was off the coast of Ibaraki Prefecture, which was 73 km away from Sawara station of K-Net, and the focal depth was 43 km. It lasted again for over 2 minutes, and the maximum acceleration was 220 Gal.

The damages on infrastructures are widely spread. The surface of the athletic ground of Sawara Junior High School was covered by erupted sand boils, and the post-liquefaction settlement was observed, causing the gap between the pile-supported school building and the surrounding ground surface, as shown in Figs. 4 and 5. The subsurface liquefiable soils were erupted from the river bed of local Jukken-gawa River and the floor of the river bed became full of such erupted sand boils, as shown in Fig. 6. The extensive soil liquefaction was observed even at the dry river bed of Tonegawa River, covering the entire surface of the ball park, as shown in Figs. 7 and 8.

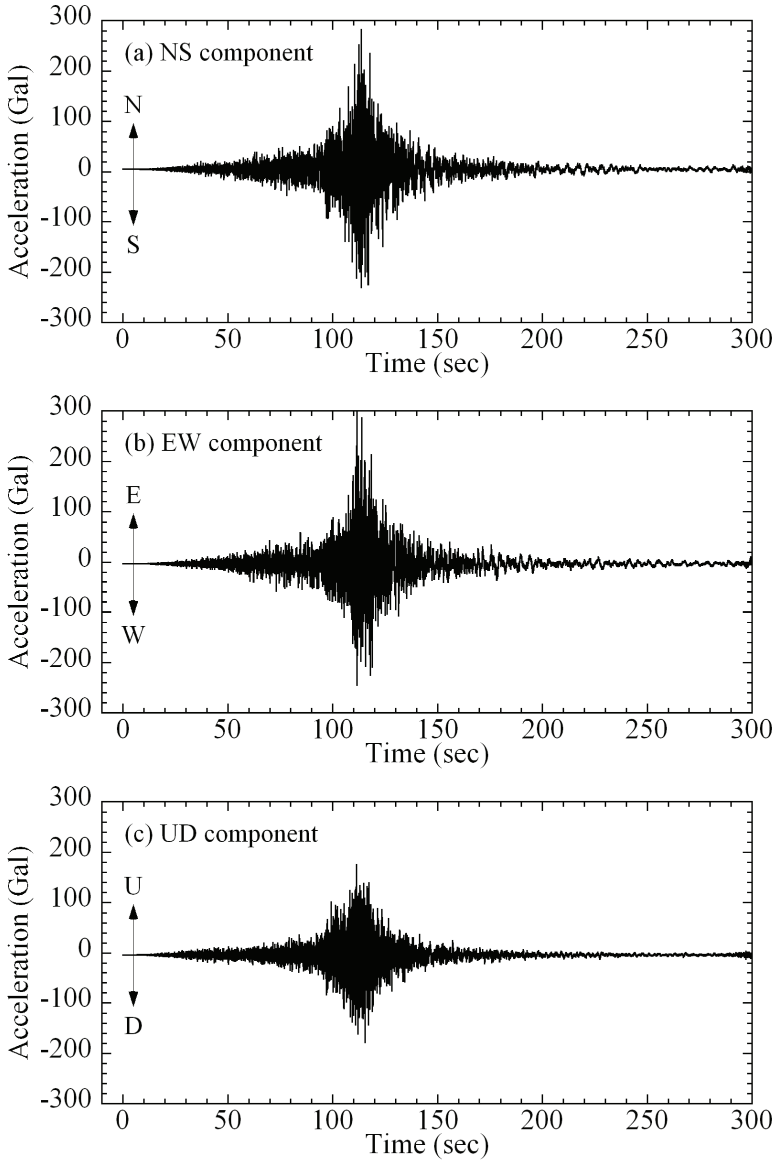

Fig. 3 Acceleration records of the main shock observed at Sawara station of K-Net

SITE INVESTIGATION AT JUKKEN-GAWA RIVER

At one of the sites along local Jukken-gawa River, where the river bed was full of sand boils, the ground surface was laterally spread, causing erroneous bends of the road behind and possibly subsidence and tilt of the hut further behind, as shown in Figs. 9 and 10. A series of Swedish weight sounding tests were carried out at this site on August 4, 2011, as shown in Fig. 11. The details of Swedish weight sounding tests are described by Tsukamoto et al. (2004) and Tsukamoto (2009). Figure 12 shows the results of the field penetration tests, and the soil profile estimated. One of the advantages in using static penetration tests such as Swedish weight sounding tests, compared with dynamic penetration tests such as SPT, lies in the fact that they can easily detect weak thin strata, though they would not accompany sampling of soils with depth and accurate monitoring of a ground water depth. In Fig. 12, down from a depth of 4 metres to 8 metres, there exists an extremely weak stratum of natural sand deposits, overlain by what is estimated to be a relatively weak stratum of a possibly old reclaimed fill. It is most likely that this old reclaimed fill has been erupted as sand boils

Fig. 4 Sand boils over the school ground of Sawara Junior High School

Fig. 5 Post-liquefaction ground settlement at Sawara Junior High School

Fig. 6 Erupted sand boils at Jukken-gawa River

Fig. 7 Sand boils at the dry river bed of Tonegawa River (view towards river embankment)

Fig. 8 Sand boils at the dry river bed of Tonegawa River (view towards river)

Fig. 9 Lateral spreading along Jukken-gawa River (view towards southeast)

Fig. 10 Lateral spreading along Jukken-gawa River (view towards northwest)

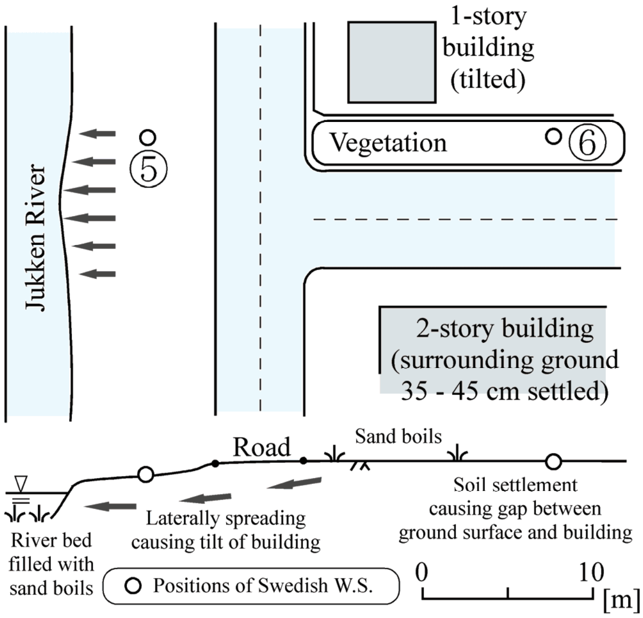

Fig. 11 Locations of Swedish weight sounding tests at Jukken-gawa River (cross section a-a')

and thus was responsible for surface-exposed lateral spreading.

SITE INVESTIGATION AT TONEGAWA RIVER AND BEYOND

Another series of Swedish weight sounding tests were carried out at the site of a ball park corresponding to a dry river bed of Tonegawa River, where extensive soil liquefaction was observed and the entire ground surface was covered by erupted sand boils. From the results of Swedish weight sounding tests along with SPT data, the soil profile spanning over the river embankment was estimated along the cross section b-b'-b'' indicated in Fig. 2, as shown in Figs. 13 and 14. It is easily seen that there exists a weak liquefiable soil layer at a depth of 2 to 4 metres down from the ground surface, extending from the area close to the route 356 to the right bank of Tonegawa River, which corresponded to the area of possible reclamation during the river improvement works, and therefore denoted as "old reclaimed fill" herein.

CONCLUSIONS

The earthquake reconnaissance investigations were conducted at Sawara district of Katori City, Chiba, where extensive soil liquefaction and associated phenomena were observed. Multiple series of Swedish weight sounding tests were carried out at several sites. From the results of Swedish weight sounding tests, the subsurface soil profiles were estimated, and the weak liquefiable soil layers responsible for surface exposed damages inflicted by soil liquefaction and lateral spreading were identified.

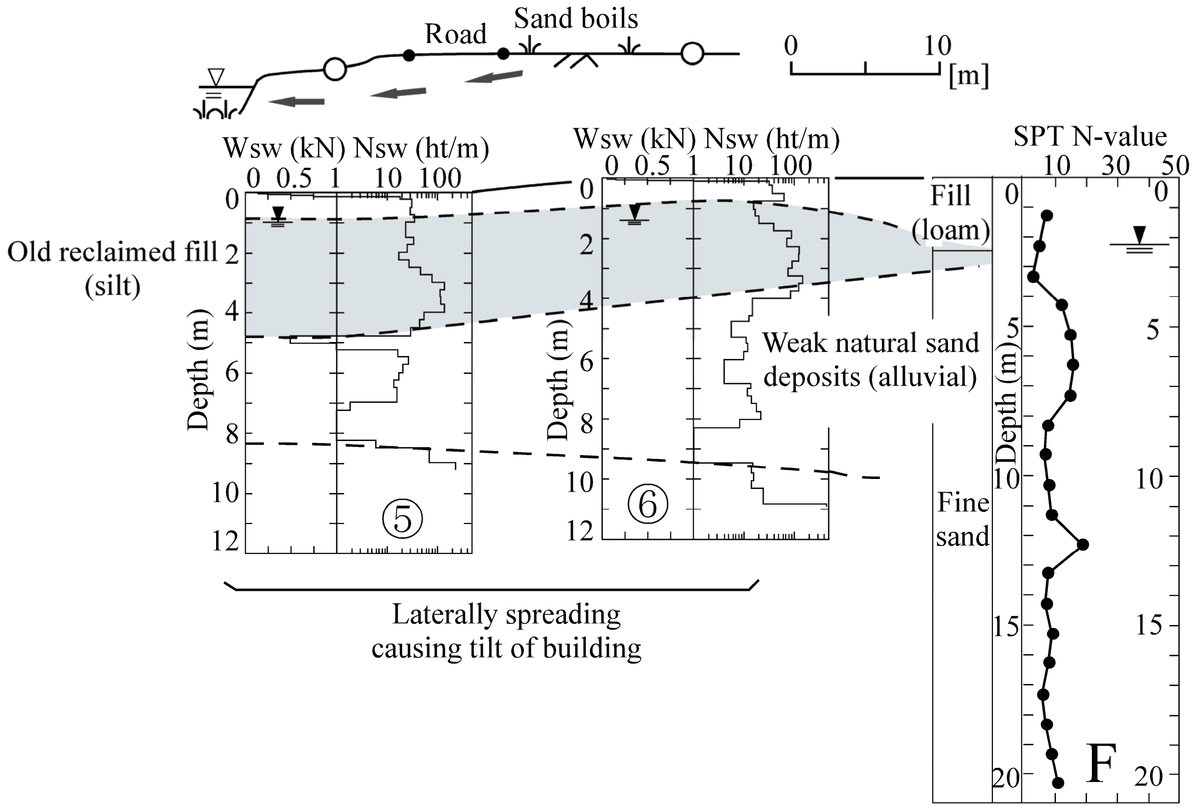

Fig. 12 Results of Swedish weight sounding tests at Jukken-gawa River (cross section a-a’) (The ratios of distance to depth/height are not to scale.)

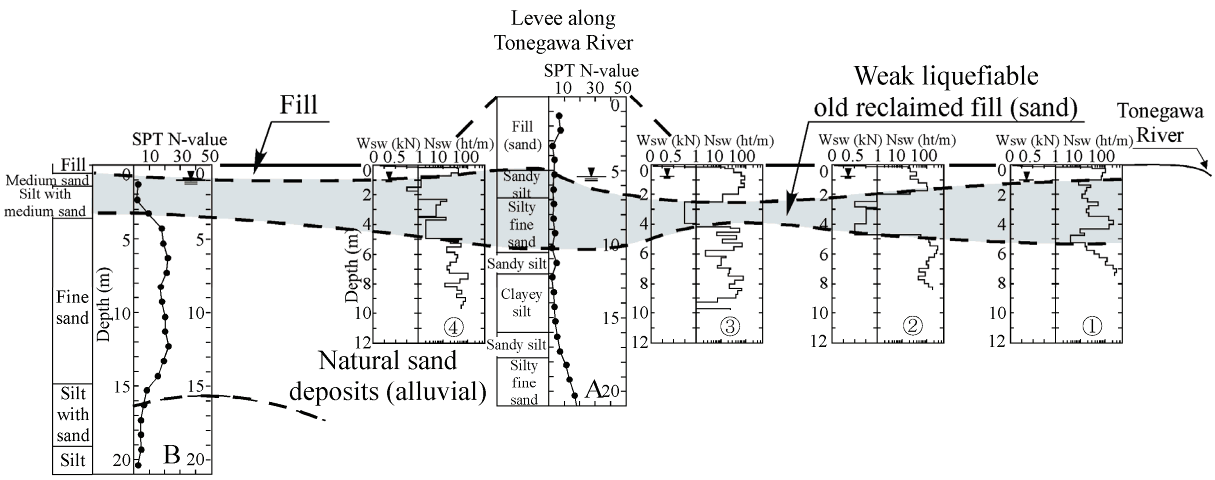

Fig. 13 Soil profile along cross section b-b’ (The ratios of distance to depth/height are not to scale.)

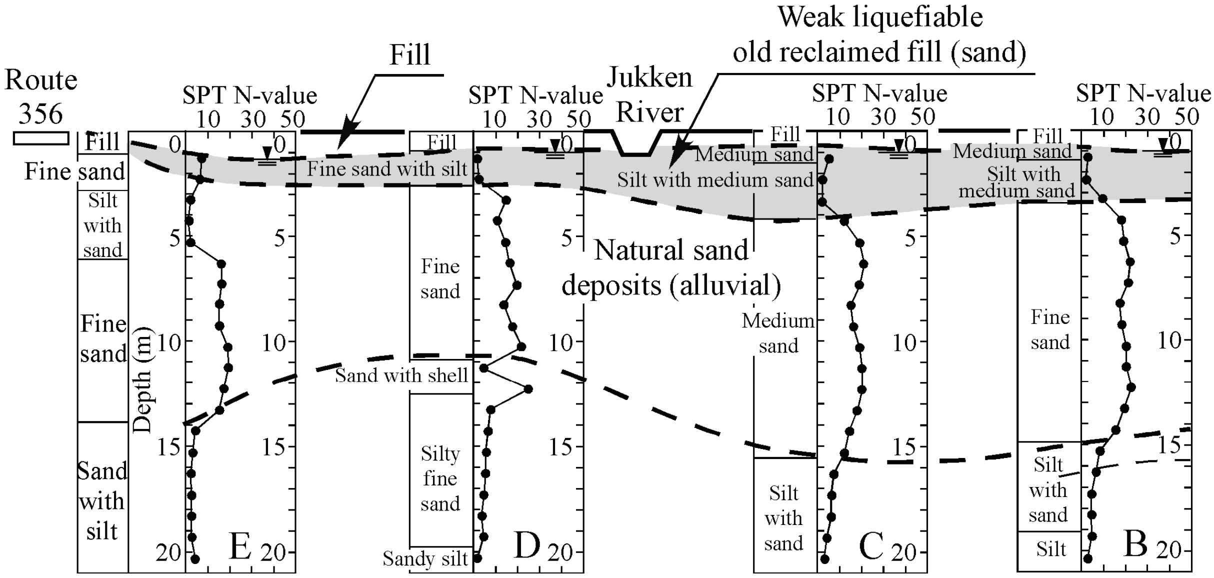

Fig. 14 Soil profile along cross section b’-b’’ (The ratios of distance to depth/height are not to scale.)

ACKNOWLEDGMENTS

The authors would like to acknowledge Professor K. Ishihara for his continued support. Thanks are also extended to the kind assistance from the staff members of Katori City and the local office of Ministry of Land, Infrastructure and Transport for Tonegawa River. The boring data of SPT were obtained from Chiba information bank of local geology and environments. The acceleration records shown in the present study are obtained from K-Net database. The financial assistances provided by J-Rapid of Japan Science and Technology Agency and Graduate School of Tokyo University of Science are also acknowledged. The Swedish weight sounding tests described in the present study were conducted with a help of R. Saito, R. Kobayashi and K. Sakai.

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