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

Yoshimichi TSUKAMOTO[1], Shouhei KAWABE[2], Takaji KOKUSHO[3]
and Kazuhiro ARAKI[4]
[1] Associate professor, Department of Civil Engineering, Tokyo University of Science,
Chiba, Japan, s-kawabe@rs.tus.ac.jp
[2] Assistant professor, Department of Civil Engineering, Tokyo University of Science,
Chiba, Japan, ytsoil@rs.noda.tus.ac.jp
[3] Professor, Department of Civil Engineering, Chuo University,
Tokyo, Japan, kokusho@civil.chuo-u.ac.jp
[4] Chemical Grouting, Co., Ltd., Japan, k-araki@tamacc.chuo-u.ac.jp

ABSTRACT: The earthquake reconnaissance investigations were conducted at some areas 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 Hinode of Itako City and Fukashiba of Kamisu City, where widely spread soil liquefaction was observed. The soil profiles responsible for damages inflicted by soil liquefaction were demonstrated along with a help of SPT data, and 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, soil liquefaction related damages to life lines, infrastructures and residential houses were widely spread over various regions on Kanto plain, and “soil liquefaction” again has become one of the important issues for natural disaster mitigations and reductions, since 1964 Niigata Earthquake.

It is most noteworthy that tens of thousands of residential houses were subject 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 located along the lower stream of Tonegawa River were also found to be subject to extensive soil liquefaction, including some areas in Katori City of Chiba Prefecture and Itako City,

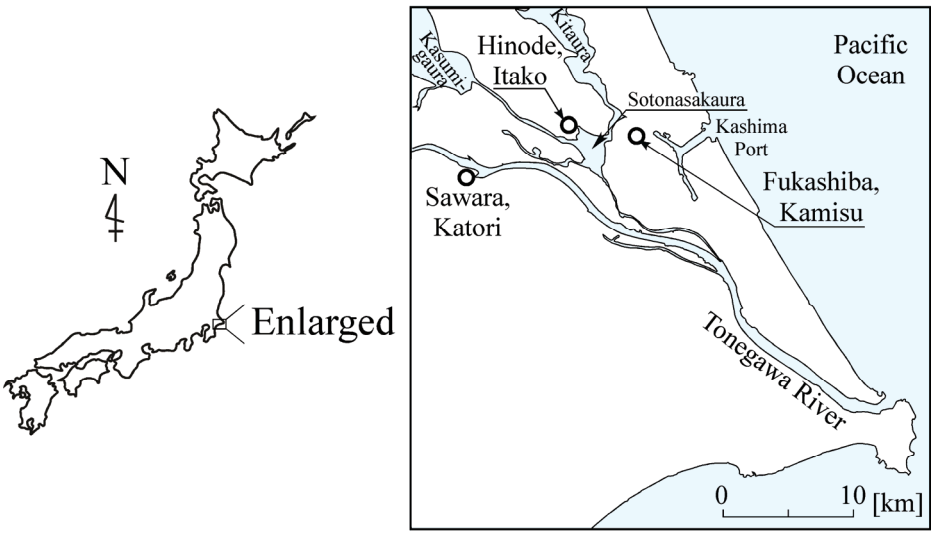

Fig. 1 Location of Hinode of Itako City and Fukashiba of Kamisu City

Kamisu City and Kashima City of Ibaraki Prefecture.

The authors had some opportunities to conduct multiple series of field Swedish weight sounding tests at 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 Sawara of Katori City are described in the accompanying paper by Kawabe et al. (2012). In the present study, the results of the earthquake reconnaissance investigations conducted at Hinode of Itako City and Fukashiba of Kamisu City are described in what follows.

BACKGROUND

To understand the wide-spread occurrence of soil liquefaction at the lower stream of Tonegawa River during 2011 Great East Japan Earthquake, it would be helpful to recognize the importance of geological history around this area.

In ancient history that just dates back to about one thousand years ago, there existed a large inner sea, which was as large as current Tokyo Bay, around the areas including the current lower stream of Tonegawa River, 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 Edo, the old capital of Tokyo, caused by the old abraded Tonegawa River, the extensive civil engineering works were carried out, and the course of the river was purposely deviated to run eastwards to flow directly into Pacific Ocean. The current stream of Tonegawa River was laid down at that time. The completion of these extensive civil engineering works needed to wait for about 60 years spanning from 1594 to 1654. 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” have been formed. However, the abraded Tonegawa River relentlessly caused floods along its stream. 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, (Fig. 1). The river improvement works conducted during the second and third periods covered the areas from Sawara to the upper reach of the river.

From a close look at the old map of 1880’s (TRLSO 2011) shown in Fig. 2, it is found that the current district of Hinode of Itako City exactly coincides with the area forming an inner lake connected with “Sotonasakaura”, as shown in Fig. 2. It is also found that current Wanigawa district,

Fig. 2 Old map of 1880's locating the current Hinode district of Itako City and Fukashima district of Kamisu City, (after TRLSO 2011), (Red lines indicate current waterside lines.)

corresponding to the triangle region immersed in the old Wanigawa River, was developed over old swamp areas, and part of Fukashiba district was developed over possibly easily inundated paddy fields, with a help of reclamation by means of draining.

OVERVIEW

The authors had some opportunities to conduct earthquake reconnaissance investigations at Hinode of Itako City and Fukashiba of Kamisu City.

The acceleration records of the main shock at 14 : 47 were observed at nearby Kashima station of K-Net, which is 308 km away from the epicenter, as shown in Fig. 3. The seismic shaking measuring over 50 Gal continued for about 90 seconds, with the maximum acceleration of 658 Gal. The large aftershock of M = 7.7, then struck the region at 15 : 13. The epicenter was off the coast of Ibaraki Prefecture, which was 59 km away from Kashima station of K-Net, and the focal depth was 43 km. The seismic shaking measuring over 50 Gal lasted again for about 100 seconds, with the maximum acceleration of 408 Gal.

At Hinode district of Itako City, the wide-spread soil liquefaction caused settlement and tilt of residential houses, uplifted manholes and drifted sheet pile walls for water channels, tilt of many electric holes, and fractured surfaces of many roads covered by quite a huge amount of erupted sand boils, as apparently seen in Figs. 4, 5 and 6.

It was shown above that from a close look at the old map of 1880's (TRLSO 2011), the current district of Hinode of Itako City exactly coincides with the area forming an inner lake connected with "Sotonasakaura", (Fig. 2). From the aerial photograph of this area taken in 1947, this area had been reclaimed by draining and had already been used as agricultural paddy fields, to cope with the shortage of foods experienced during that time. The reclamation by draining in Hinode district was completed in 1950, (Itako City HP). Since the development of nearby Kashima Coastal Industrial Region was resumed in 1960's, Hinode district of Itako City has become one of the areas chosen for residential district development. The reclamation by means of seafloor sludge over the once paddy fields was carried out during the period from 1970 to 1971. A series of construction works for water drainage, water supply and sewage, roads and bridges were then subsequently completed.

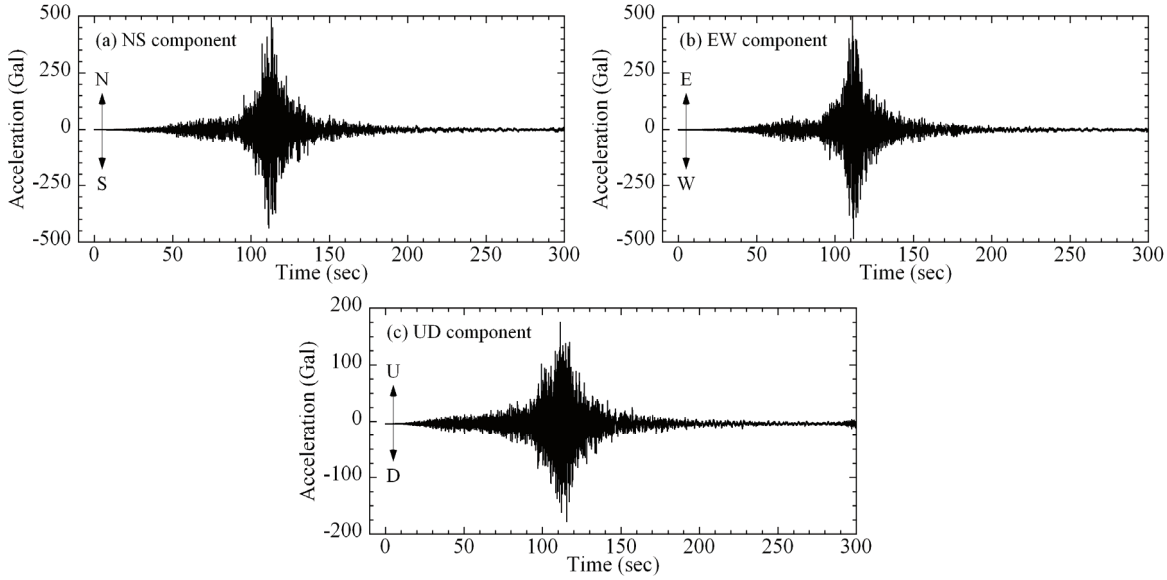

Fig. 3 Acceleration records of the main shock observed at Kashima station of K-Net

Fig. 4 Fractured and winding surface of roads, (Hinode of Itako City)

Fig. 5 Post-liquefaction ground settlement and tilt, (Hinode of Itako City)

Fig. 6 Uplifted and drifted sheet pile wall for water channel, (Hinode of Itako City)

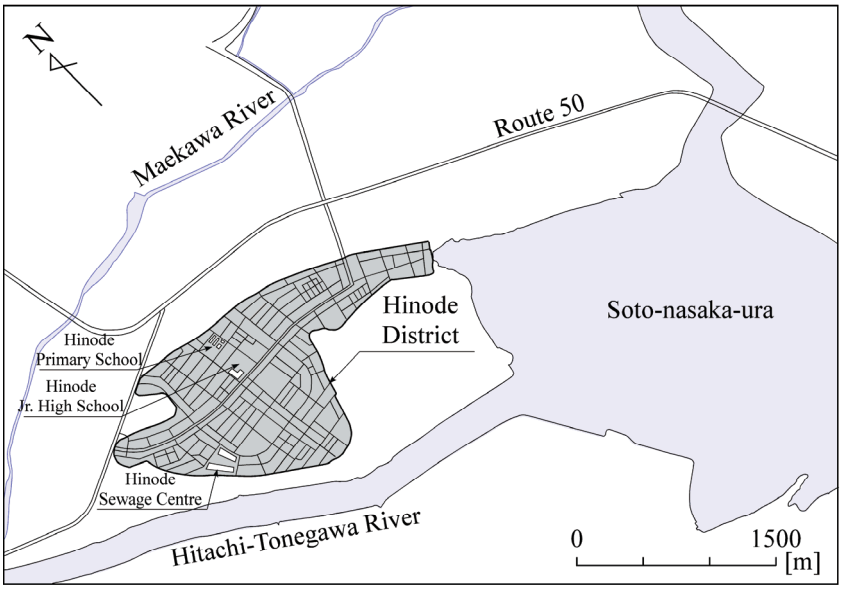

Fig. 7 Location of Hinode district of Itako City

It was also shown above that current Wanigawa and Fukashiba districts were developed over old swamp areas and possibly easily inundated paddy fields, with a help of reclamation by means of draining. The triangle region immersed in the old Wanigawa River shown in Fig. 2 was reclaimed by draining during the period from 1928 to 1933, and became called “Wanigawa” district, (Kamisu City HP). It is also noteworthy here that there had existed quite a large number of gravel pits in Fukashiba district. Since the groundwater level was high in this region, the underwater excavations for good gravels and pebbles to some depths had been supposedly implemented primarily during the period from 1960’s to 1980’s. Those gravel pits were then reclaimed by landfills originated from nearby regions such as Omigawa of Katori City.

SITE INVESTIGATION AT HINODE OF ITAKO CITY

The current district of Hinode of Itako City is shown in Fig. 7. With a help of staff members of Itako City, the authors have gained a good opportunity to conduct a series of Swedish weight sounding tests at Hinode district on September 8 and 9, 2011. The locations of Swedish weight sounding tests are shown in Fig. 8. The details of Swedish weight sounding tests are described by Tsukamoto et al. (2004) and Tsukamoto (2009).

Figure 9 shows the results of the field penetration tests, and the soil profile estimated along the cross section indicated in Fig. 8. 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. 9, it is seen that in the areas where the extensive soil liquefaction was observed, there existed a soil layer of what is estimated to be “old reclaimed sand deposits” overlain by relatively new fills. It is also noteworthy that these areas are underlain by a thicker layer of natural silt deposits. It is not clear if this thick natural silt deposit might have affected the occurrence of soil liquefaction in this area.

SITE INVESTIGATION AT FUKASHIBA OF KAMISU CITY

Another series of Swedish weight sounding tests were carried out at Fukashiba district of Kamisu City

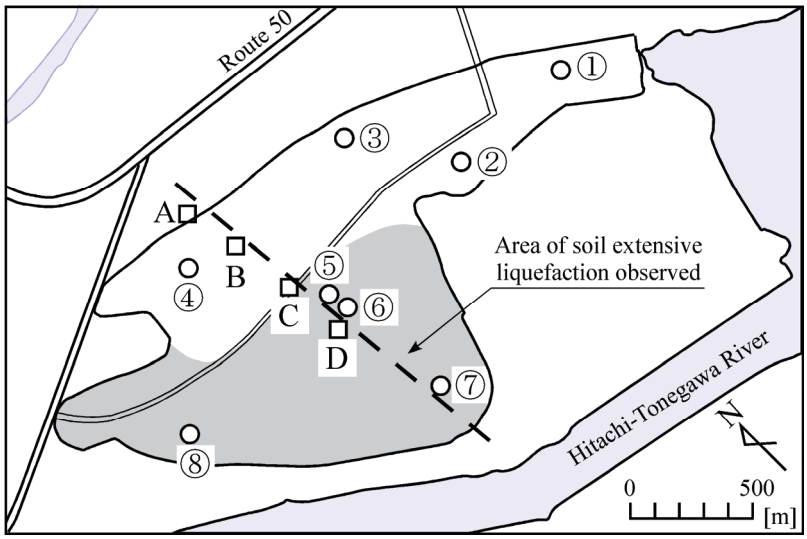

Fig. 8 Locations of Swedish weight sounding tests at Hinode district of Itako City

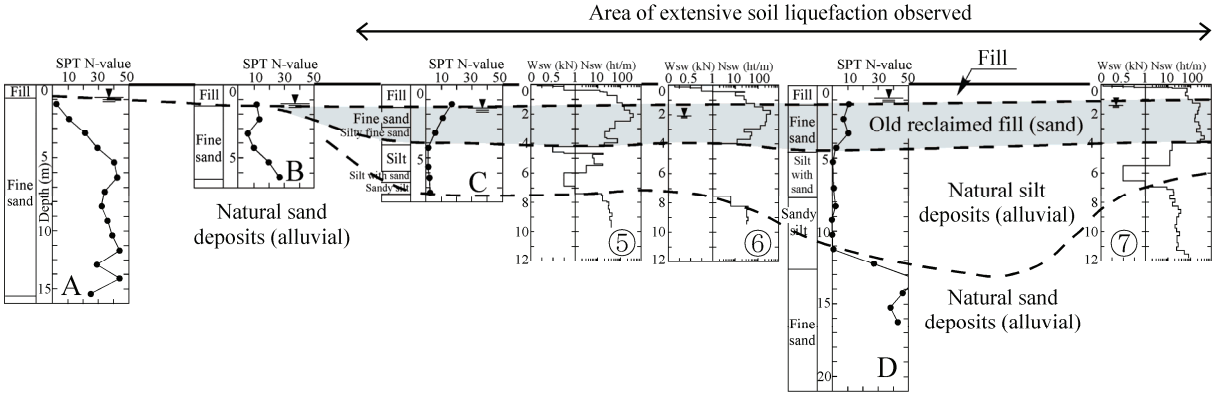

Fig. 9 Results of Swedish weight sounding tests at Hinode district of Itako City (The ratios of distance to depth/height are not to scale.)

with a help of staff members of Kamisu City on October 14 to 16, 2011. The shadow zones in Fig. 10 indicate the areas where the extensive soil liquefaction was observed. The circular zone that covers the current Gohno-ike pond corresponds well to the area where the “old Gohno-ike pond” was located. It is also seen that another shadow zone includes the area of reclamation on old swamp as well as paddy fields, However it also extends towards inland. Figure 11 shows the locations of Swedish weight sounding tests conducted in the present study, denoted as ① to ⑩, whereas the SPT data available are indicated in alphabetic symbols. In the areas containing the locations “G” and “B”, the thick layer of natural sand deposits can be identified, on which the reclaimed fills overlie. The locations of ② to ④ were positively identified as what had once been gravel pits and reclaimed with landfills, at which the extensive soil liquefaction was also observed. In the areas further inland, there seemed to have existed quite a large number of gravel pits unidentified yet and reclaimed again with landfills.

CONCLUSIONS

The earthquake reconnaissance investigations were conducted at Hinode district of Itako City and Fukashiba district of Kamisu City, where wide-spread extensive soil liquefaction was observed.

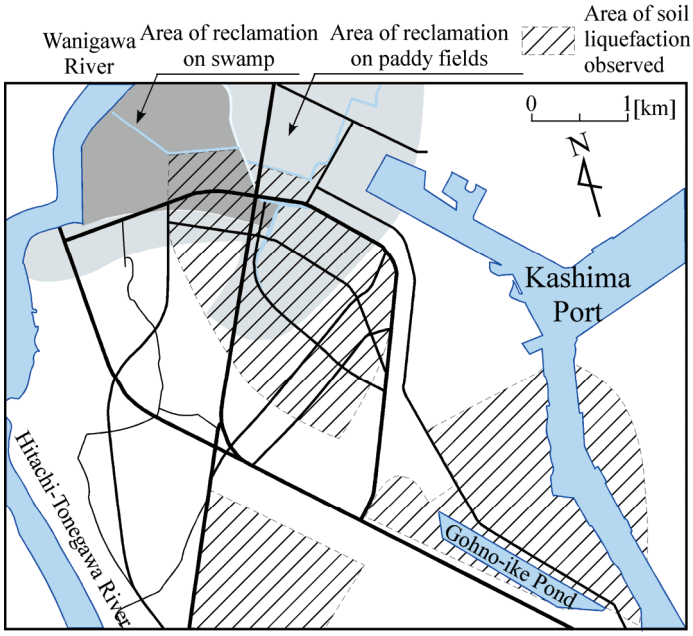

Fig. 10 Location of Fukashiba district of Kamisu City

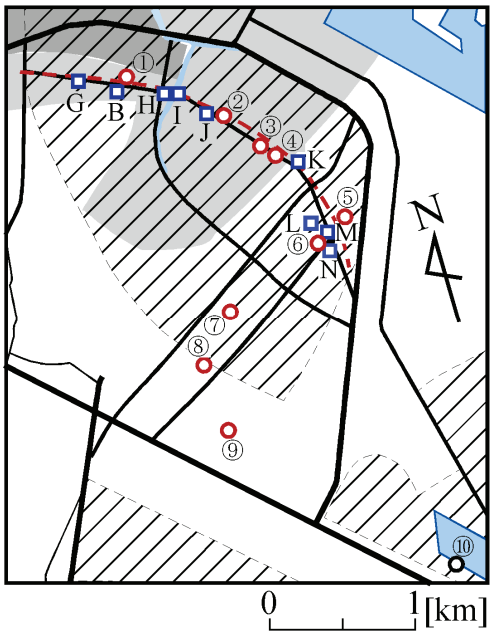

Fig. 11 Locations of Swedish weight sounding tests

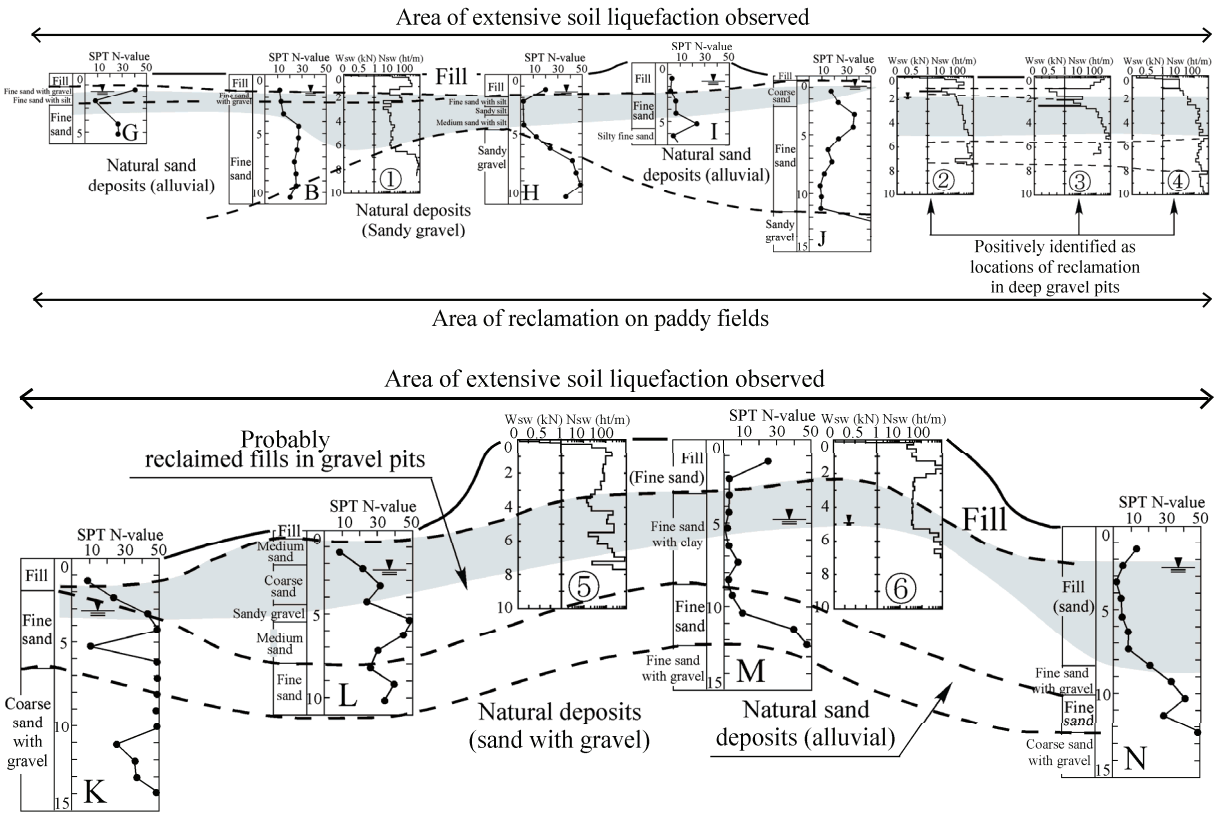

Fig. 12 Results of Swedish weight sounding tests at Fukashiba district of Kamisu City (The ratios of distance to depth/height are not to scale.)

Multiple series of Swedish weight sounding tests were carried out at these areas. From the results of Swedish weight sounding tests, the subsurface soil profiles were estimated, and the soil layers responsible for surface exposed damages inflicted by soil liquefaction were identified and discussed in detail.

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