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A case history of liquefaction from the Chibaken Toho-Oki earthquake of December 17, 1987

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ABSTRACT:During the 1987 Chibaken Toho-Oki earthquake, liquefaction-induced ground failures occurred at the Mukohya site along the lower reaches of the Tone River. A detailed investigation of the ground failures, their effects on structures, geomorphologic settings, and geotechnical conditions was performed at the site. This paper summarizes the ground failure patterns and related subsurface conditions at the time of the 1987 earthquake. In addition, liquefied layers are estimated based on liquefaction analysis, grain size analysis, micrographs of soils, and electrical conductivity of pore water.

1 INTRODUCTION

An earthquake of magnitude 6.7 on the Japan Meteorological Agency (JMA) scale hit Boso Peninsula near the Tokyo Metropolitan on December 17, 1987 at 11:08 local time. Tow human lives were lost and 161 persons were injured. Sand boils were observed at many places including the Tokyo Metropolitan area. This case history focuses on ground deformations and related-damage at a site where liquefaction effects were particularly pronounced. Descriptions are given of site conditions, subsurface soils and ground water, and ground deformations. Relationships are examined between ground deformations and site conditions.

2 GENERAL FEATURE OF LIQUEFACTION DURING THE 1987 EARTHQUAKE

JMA intensity V was assigned at Chiba, Katsuura, and Choshi, which corresponds to approximately Modified Mercalli Intensity VIII. During the earthquake many accelerographs were triggered and strong motions were recorded in the affected regions. The maximum ground accelerations are also plotted in Figure 1.

Many sand boils occurred extensively in low-lying areas which experienced a ground motion of excess of 100 gal as shown in Figure 1. The most distant liquefied site from the epicenter is located in Miura City, where 78 km west-southwest of the epicenter. Wooden houses, road embankments, dikes, and pipe lines were affected by liquefaction, but damage was not so severe as seen in Niigata City at the time of the 1964 Niigata earthquake.

3 LIQUEFACTION-INDUCED GROUND FAILURES AT MUKOHYA SITE

Mukohya site in Kohzaki Town is located on the right bank of the lower reaches of the Tone River and was about 62 km north of the epicenter as shown Figure 1. During the 1987 earthquake numerous very large sand boils occurred in the rice fields. Figure 2 shows distribution of sand boils based on our field survey and interpretation of aerial photographs taken after about one month after the earthquake. Sand boils densely concentrated within a approximate 1.5 km long zone along the river. Sand and water were issued from fissures in the western portion of the zone and from craters in the eastern portion. A eyewitness reported that water shot up to more than 1m in the air everywhere in the zone. A few small sand boils occurred in the rice field north of the zone,whereas no superficial liquefaction effects developed in the field south of the zone. No significant effects of lateral spreading were observed at the site in spite of large and violent sand boiling.

4 DAMAGE TO STRUCTURE

The site was sparsely populated agricultural area at the time of earthquake. No major structures were built in the zone where large sand boils were observed. Lanes and ridges between rice fields settled several tens centimeters at some places. Curved lines of rice plants suggested that a small amount of lateral movement was caused by liquefaction. Dike of the Tone river immediately north of the site was not affected by liquefaction, but dikes of the both banks located at 2 km downstream settled or cracked over a total distance of 450 m as consequence of liquefaction.

5 SITE CONDITIONS

5.1 Geomorphologic Settings

The site lies on the deltaic lowland formed by the Tone river. Figure 3 shows former river channels and ponds which were interpreted of aerial photographs. These channels were abandoned as consequence of the shortcut works of the channel conducted during the years 1900 through 1930. The channels and ponds were filled up with the dredged sand of the Tone river during 1957 through 1960. In some areas the fill materials were replaced by sands excavated from nearby hills during early 1970's. The extent of these fills are shown in Figure 4.

5.2 Soil Profiles

Soil borings and SPT tests were performed two months after the earthquake. Borehole locations are shown in Figure 4. B-1 is located in the convex bank of the abandoned channel, where a few small sand boils developed. B-2 is located in the abandoned channel filled with the river sand and then replaced by the hilly sand, where large quantities of sand were ejected from

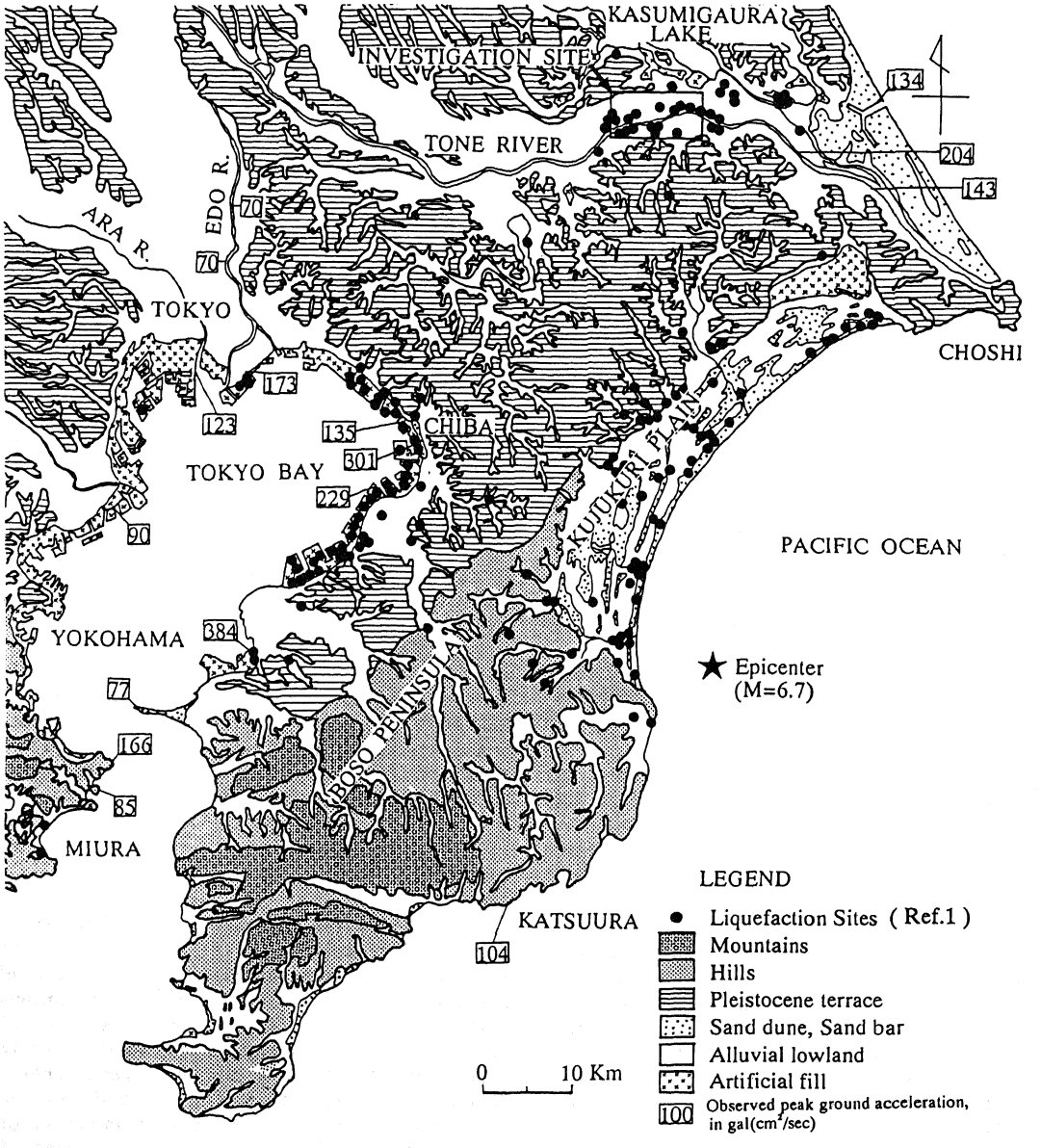

Figure 1. Map of Boso Peninsula Showing Principal Area Affected by the 1987 Chibaken Toho-Oki Earthquake

fissures. B-3 is located in the concave bank of the abandoned meander, where no evidences of liquefaction effects were observed. B-4 is also located in the abandoned meander, but filled with only dredged river sand, in which the most violent eruptions of sand occurred.

Figure 5 shows soil profiles and SPT N-value at B-1 through B-4. The borings disclosed that there were five types of loose sand deposits at the Mukohya site: clayey sand fill composed of hilly sand which covers the ground surface at B-2; fine sand fill composed of river bed sand, which lies beneath the hilly sand fill at B-2 and to a depth of two meters from the ground surface at B-4; loose fine sands of point-bar origin which lie to a depth of four meters from the surface at B-1; fine to coarse sands of river bed deposits with N-values of approximate 10, which are encountered at three holes except B-3; and very fine sand of deltaic deposits which underlie at all of holes. No distinct differences in water tables at the time of drilling(February,1988) were found among the four boreholes as shown in Figure 5.

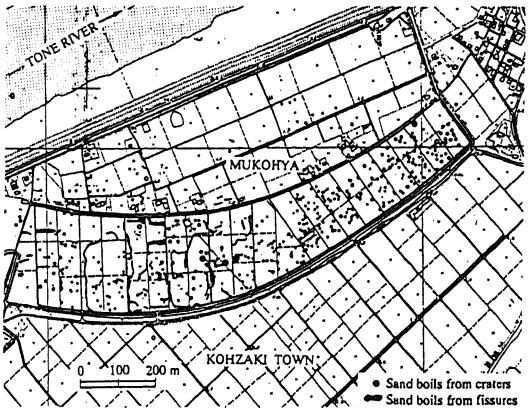

Figure 2. Map of Sand Boils in Mukohya, Kohzaki Town

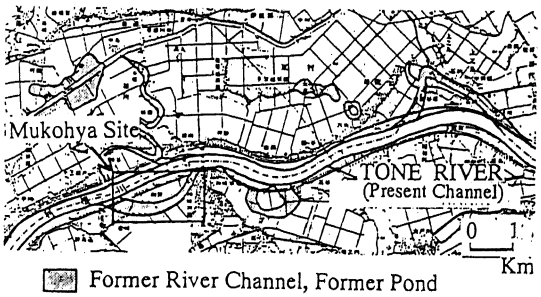

Figure 3. Former River Channel and Former Ponds Lying along the Banks of Tone River

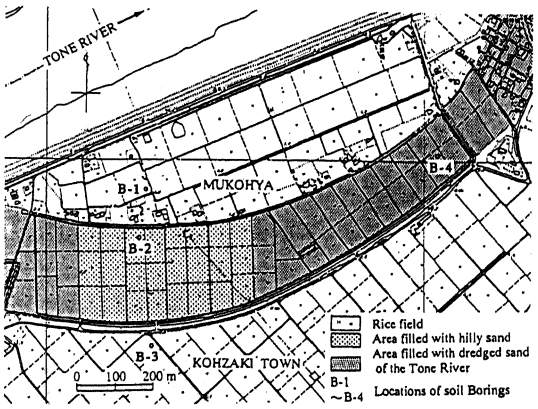

Figure 4. Map of Mukohya, Kohzaki Town showing Filled Area and Locations of Boring for the Soil profiles

6 ESTIMATION OF LIQUEFIED LAYERS

Four techniques were applied to identify liquefied layers of the site; liquefaction analysis, grain size analysis, micrographs of soils, and measurement of electrical conductivity of pore water.

6.1 Liquefaction analysis

Liquefaction resistance factor, FL values are shown in Figure 6. They were calculated using both procedures outlined in Japanese Highway Bridge Code (1991, Japan Road Association) and in Recommendations for Design of Building Foundations (1988, Architectural Institute of Japan),which are commonly used for evaluating liquefaction potential of soils in Japan. A peak horizontal acceleration of 150 through 200 gal was estimated to have occurred at the site based on 143 gal and 204 gal peak acceleration recorded at two sites along the Tone River, whose epicentral distances were approximately same as the Mukohya site. The results of the analysis show that all of five types of loose sand deposits were susceptible to liquefaction (FL<1) for 150 through 200 gal as shown in Figure 6.

6.2 Grain size analysis

Figures 7.1 through 7.4 are comparisons of the grain size distribution curves for sands taken from boreholes and sand boil deposits near the holes. Curves for boiled sands in Figure 7.1, 7.2 and 7.4 have similar grain size characteristics as the sands of river bed deposits. They are also similar to the curves for fine sand of point-bar deposits and fine sand of fill in Figures 7.1 and 7.4, respectively. On the contrary, curves for very fine sands of deltaic deposits and hilly sand of fill were quite different from those for boiled sands. The similarity in grain size distributions between boiled sands and soil samples taken from the boreholes implies that the source of liquefied materials was three types of fine sands of river bed deposits, point-bar deposits and fill.

Figure 8 shows soil classification chart developed by the Mississippi River Commission in which sands taken from boreholes and sand boil deposits are plotted. The plots indicate that fine contents of the boiled sands and the liquefied materials which were estimated based on the grain size distributions are less than 10%,whereas

those of very fine sands of deltaic deposits and a sand with clay of fill material are about 30%.

6.3 Micrographs of Soils

Figure 9 are comparisons of micrographs of the samples taken from sand layer in boreholes B-4 and sand boil deposit near B-4. Grain size, shape and color of the ejected sand are very similar to those of No.1 and No.3 sands. These characteristics of the soil particles imply that the source of liquefied materials at B-4 are fill materials of No.1 and river bed sands of No.2.

6.4 Electrical Conductivity of Pore Water

Comparison of grain size are not perfect method to identify liquefied materials, since ejected sands are likely to sort during upward migration of pore water. The authors had tried to identify liquefied soils by mean of measurement of electrical conductivity of pore water, because electrical conductivity of pore water represents concentration and kind of ions which reflects sedimentary environment of soils.

Figure 5 shows electrical conductivity for typical sand deposits in the boreholes and boiled sands near the holes. The conductivity for pore water of the river bed sands including the artificial fill of river bed origin is ranged from 170 to 460 $\mu\,\Omega$/cm, which implies that the deposits are continental sediments. Whereas that for the very fine sands of deltaic origin is ranged from 1600 to 8200 $\mu\,\Omega$/cm, which implies that the deposits are brackish-water sediments The conductivity for pore water of the ejected sands is ranged from 220 to 830 $\mu\,\Omega$/cm, which agree with degree of that of continental deposits.

7 CONCLUSIONS

The following conclusions can be summarized from our detailed investigation on liquefaction and related site conditions at the Mukohya site.

(1) Five types of loose sand deposits occurred in the upper 20 meters: a fill material composed of river bed

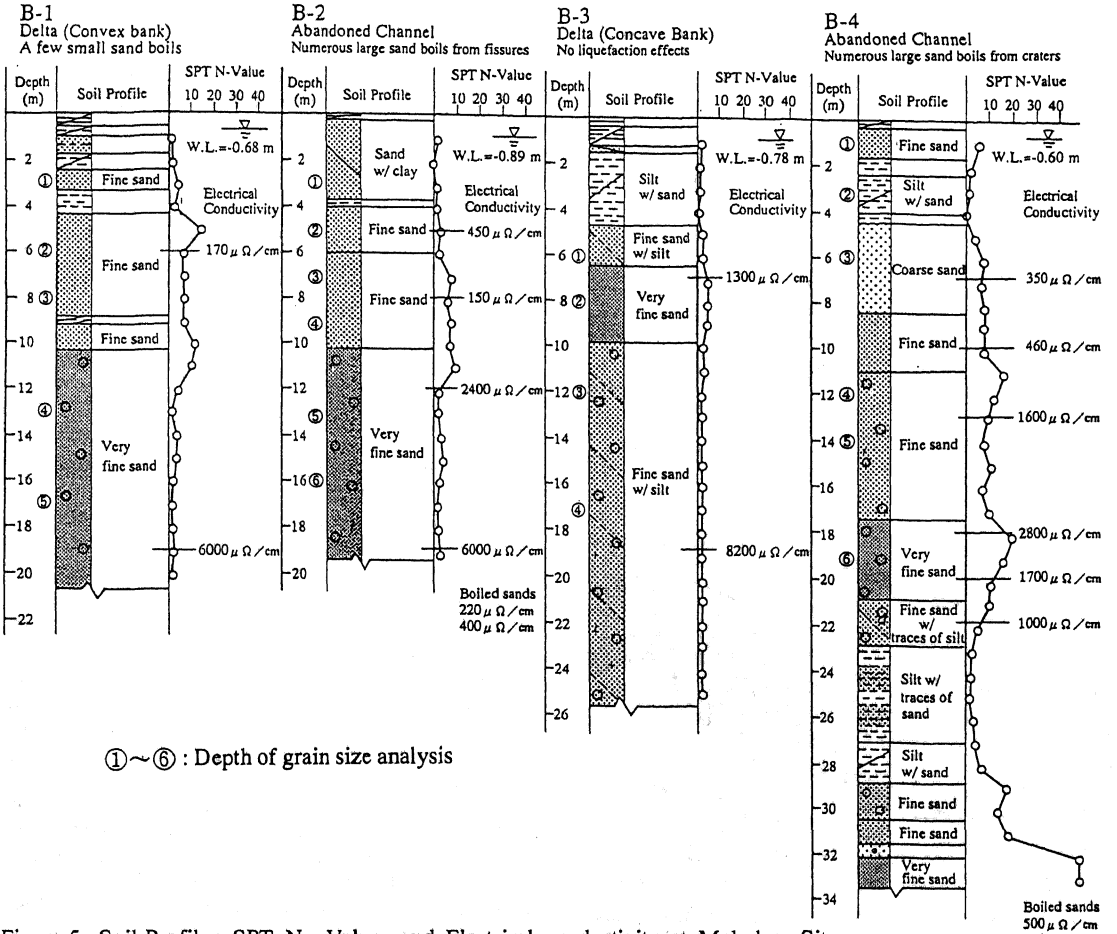

Figure 5. Soil Profiles, SPT N−Values and Electrical conductivity at Mukohya Site

sand; a fill material composed of hilly sand; fine to coarse sands of river bed deposits; a fine sand of point-bar deposits; and a very fine sand of deltaic deposits. The liquefaction analysis predicted that liquefaction would have occurred at all types of sand deposits, whereas results of other investigations for identifying liquefied materials imply that liquefaction occurred in three types of the sand deposits; the point bar deposits, the river bed deposits and the fill materials of river bed sand. Field behavior agreed with the latter prediction.

(2) According to the grain size analysis, the liquefied sands have the following characteristics: fine contents are less than 10 %; mean grain size was ranged from 0.15 to 0.27 mm; uniformity coefficient is less than 4; and coefficient of curvature is nearby 1.

(3) Measurement of electrical conductivity of pore water of ejected sand may be effective method for identifying the source of liquefied materials.

(4) Sedimentary environment of soil deposits reflects geotechnical properties of the soil controlling liquefaction susceptibility. In other words, liquefaction induced ground failures are confined to specific geomorphologic settings.

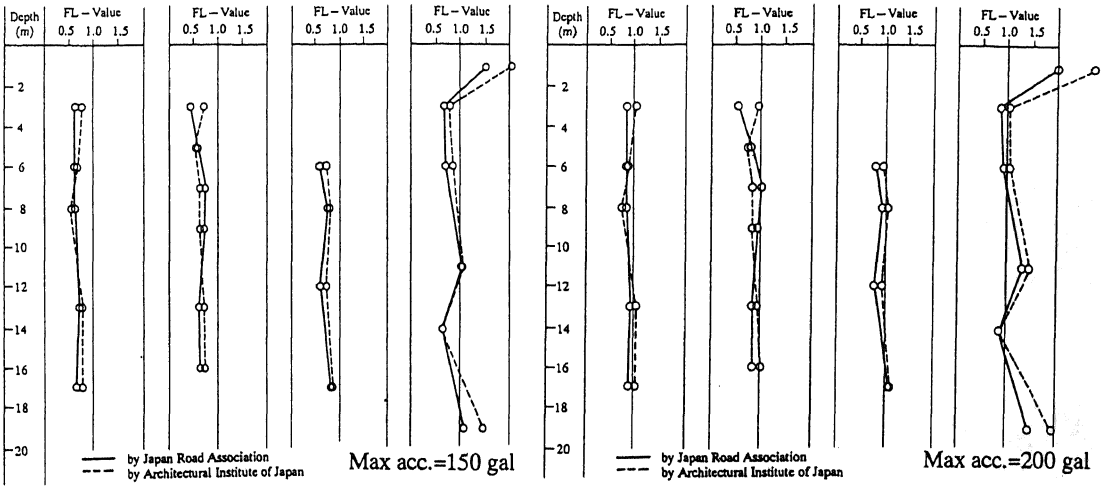

Figure 6. FL–Values of Liquefaction Analysis at Mukohya Site

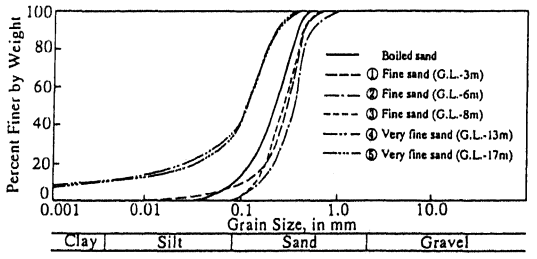

Figure 7.1. Grain Size Distribution Curves for Samples Taken from Sand Boil Deposit near B-1 and for Soils from Borehole at B-1

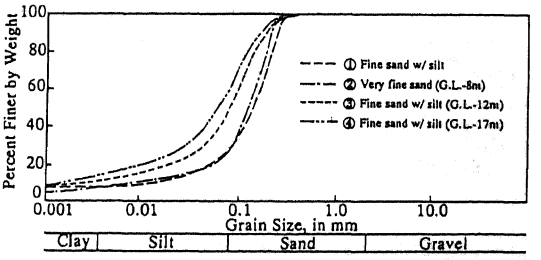

Figure 7.3 Grain Size Distribution Curves for Samples from Borehole at B-3

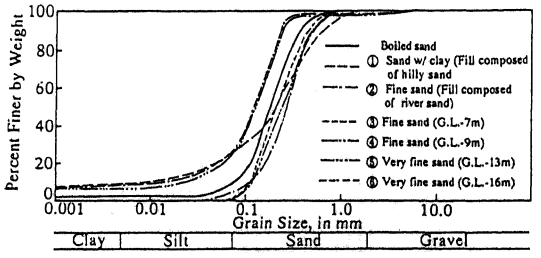

Figure 7.2 Grain Size Distribution Curves for Samples Taken from Sand Boil Deposit near B-2 and for Soils from Borehole at B-2

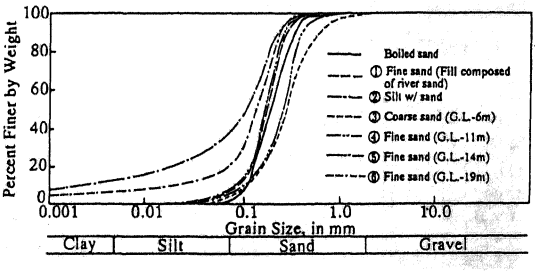

Figure 7.4 Grain Size Distribution Curves for Samples Taken from Sand Boil Deposit near B-4 and for Soils from Borehole at B-4

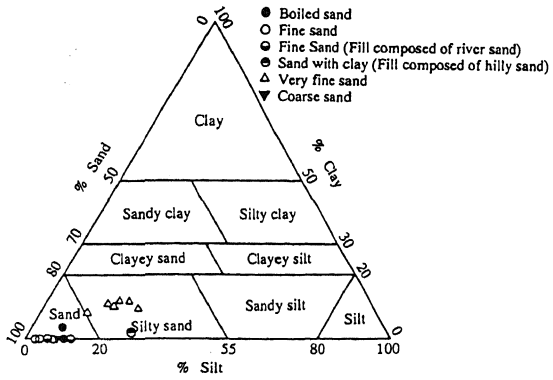

Figure 8. Soil Classification Chart Developed by the Mississippi River Commission

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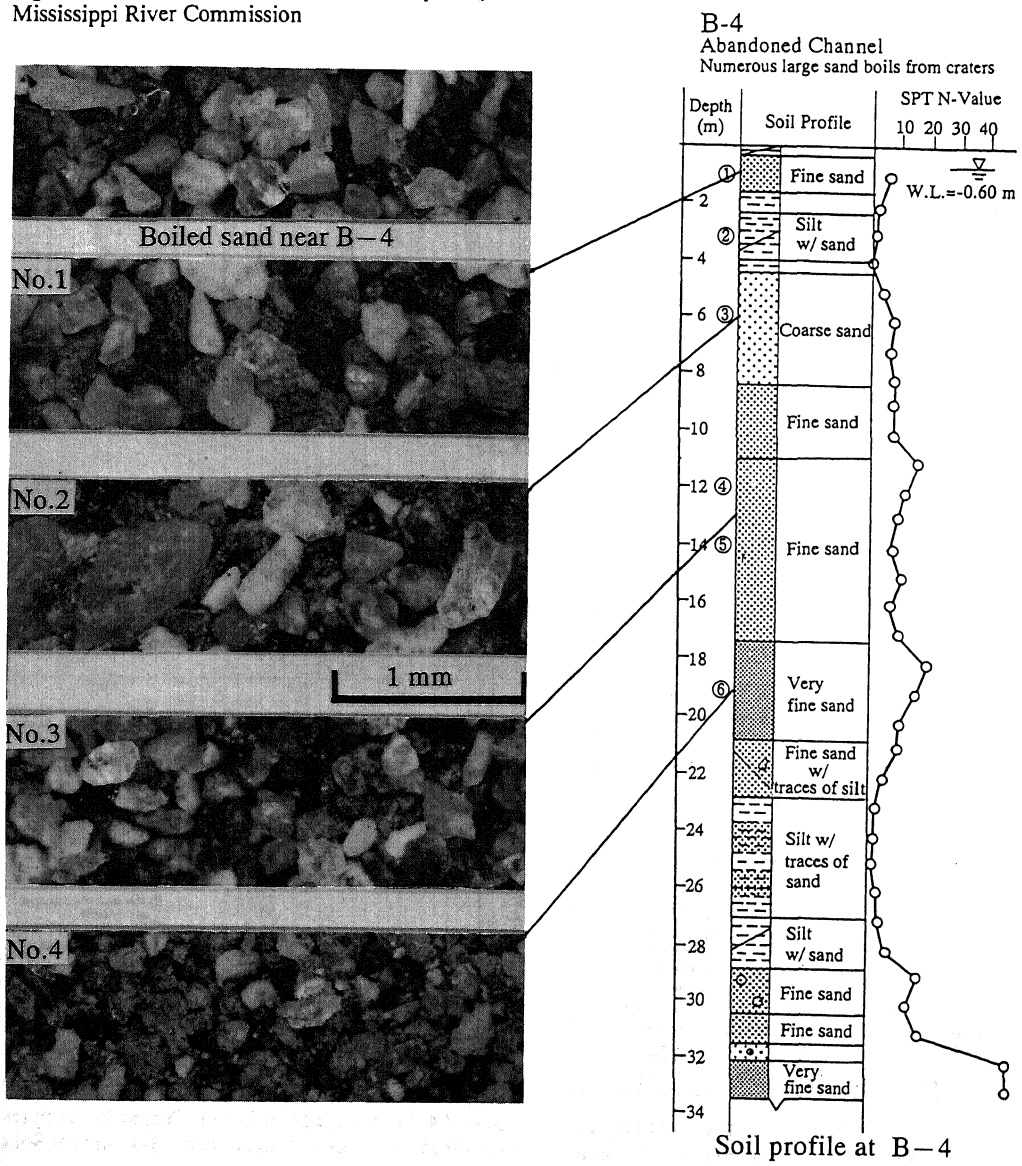

Figure 9 Micrographs of Sands Taken from Borehole at B-4 and Sand from Sand Boil Deposit near B-4