LIQUEFACTION: EJECTA SAMPLES FROM THE 1993 HOKKAIDO-NANSEI-OKI EARTHQUAKE

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INTRODUCTION

In studies of liquefaction case histories, particle size distributions of ejected sand have been useful in identifying layers which have liquefied. The aim of this note is to describe samples of ejecta that were retrieved by the New Zealand reconnaissance team to the M7.8 Hokkaido-Nansei-Oki, Japan earthquake in the hope that these might be useful in subsequent investigations.

Three samples of ejected sand were brought back to New Zealand for analysis: two from Hakodate, where many port facilities were damaged by liquefaction, and one from the Nakanosawa Primary School at Oshamanbe, where piles failed in shear due to liquefaction and lateral spreading of the surrounding soil. The Hakodate samples were both retrieved from the Hokodate Port area, sample HAKD1 from near the 2500 tonne Nittetsu Cement Company silo which had tilted by about 3° and whose base had displaced about 200 mm horizontally, and sample HAKD2 from the clearly reclaimed land of the wharf area some 300 m to the south.

Hakodate is 172 km from the epicentre and Oshamanbe 107 km. The two sites are shown on a magnitude-distance plot in Figure 1, and it is seen that the Hakodate sites lie just inside the criterion of Kuribayashi and Tatsuoka (1974) for distance to furthest site of liquefaction.

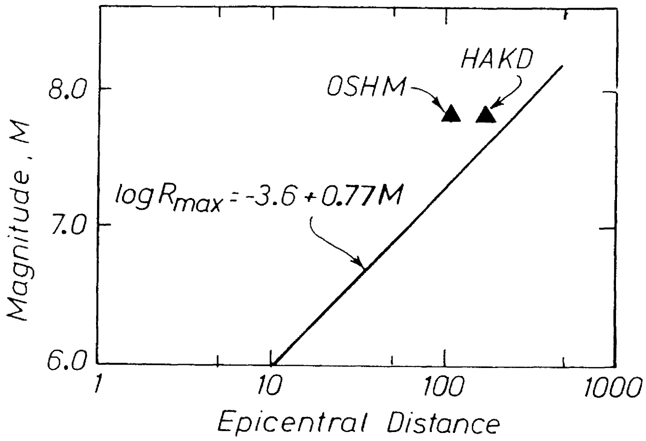

Figure 1 ***The Hakodate and Oshamanbe sites plotted with the criterion of Kuribayashi and Tatsuoka (1975) for distance to farthest site of liquefaction.***

EJECTA PROPERTIES

Particle size distributions of the three samples are shown in Figure 2. Two of the samples, HAKD2 and OSHM from the Hakodate and Oshamanbe sites respectively, are fine to medium sands (SP), and their gradings fall clearly within Tsuchida's *very easily liquefied* category (Figure 3). The second Hakodate sample, HAKD1, has a mean grain size of 0.073 mm which places it on the coarse silt-fine sand boundary in the Unified Classification System and just outside Tsuchida's most sensitive category, but clearly within his *easily liquefied* category. Mean grain sizes and uniformity and curvature coefficients are summarized in Table 1.

The Oshamanbe ejecta has a distinctive dark grey colour with no quartz or glass present, and was subjected to a more detailed geological inspection. Opaques comprised about 30 percent of the sample with magnetite forming the dominant component, but with ilmenite and rutile also present. Orthopyroxenes comprised the dominant translucent component, with hornblende and clinopyroxenes present as well as a small (< 5 percent) amount of plagioclase feldspar. The grains are generally not strongly abraided.

DESCRIPTION OF SITES

A briefing given by a Ports representative of the Hokkaido Development Bureau explained that the Hakodate Port area is underlain by some 70 m of sandy clays having SPT N values of 4 to 5. Piers for a new overhead motorway bridge

Table 1 **Grading coefficients for ejecta retrieved from Hakodate and Oshamanbe sites of liquefaction.**

Site	D_{50}	C_u	C_c	Colour
Hakodate 1 (HAKD1)	0.073	1.60	1.09	light grey
Hakodate 2 (HAKD2)	0.362	2.35	1.05	light grey
Oshamanbe (OSHM)	0.193	1.84	1.11	dark grey

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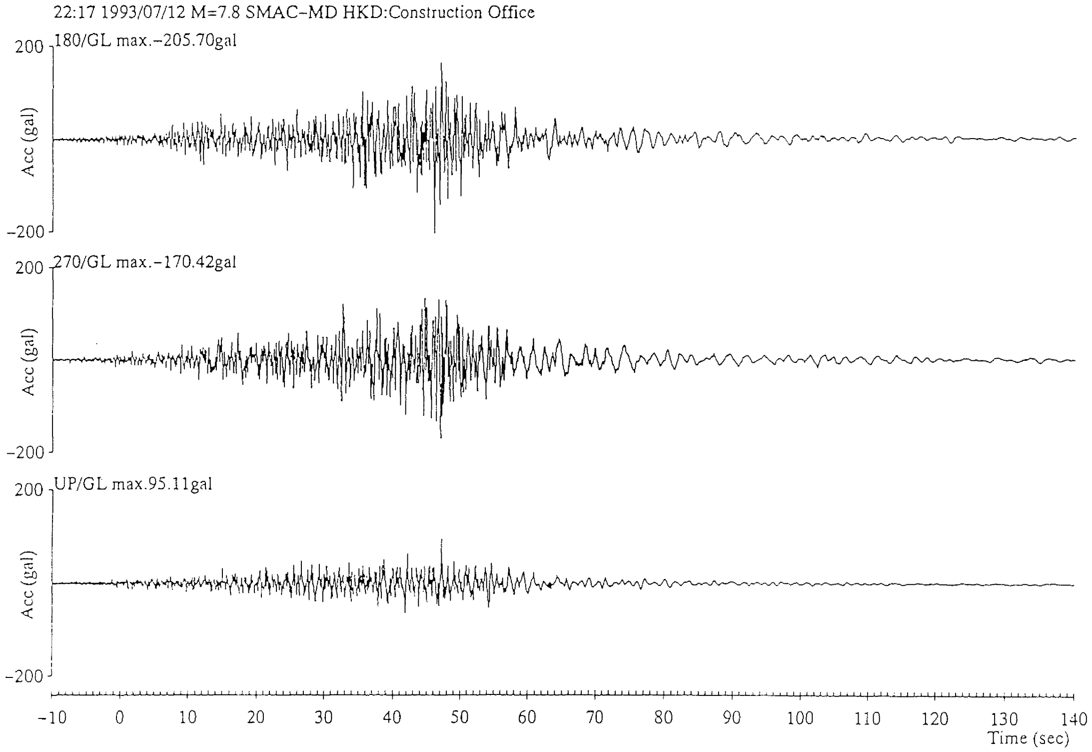

加速度記録(北海道開発局函館開発建設部地表)

Figure 2 ***Particle size distribution of ejected sand samples from the Nittetsu Cement Silo site at Hakodate and the Nakanosawa Primary School of Oshamanbe. The straight lines denote Tsuchida's grading criteria for liquefiable soils.***

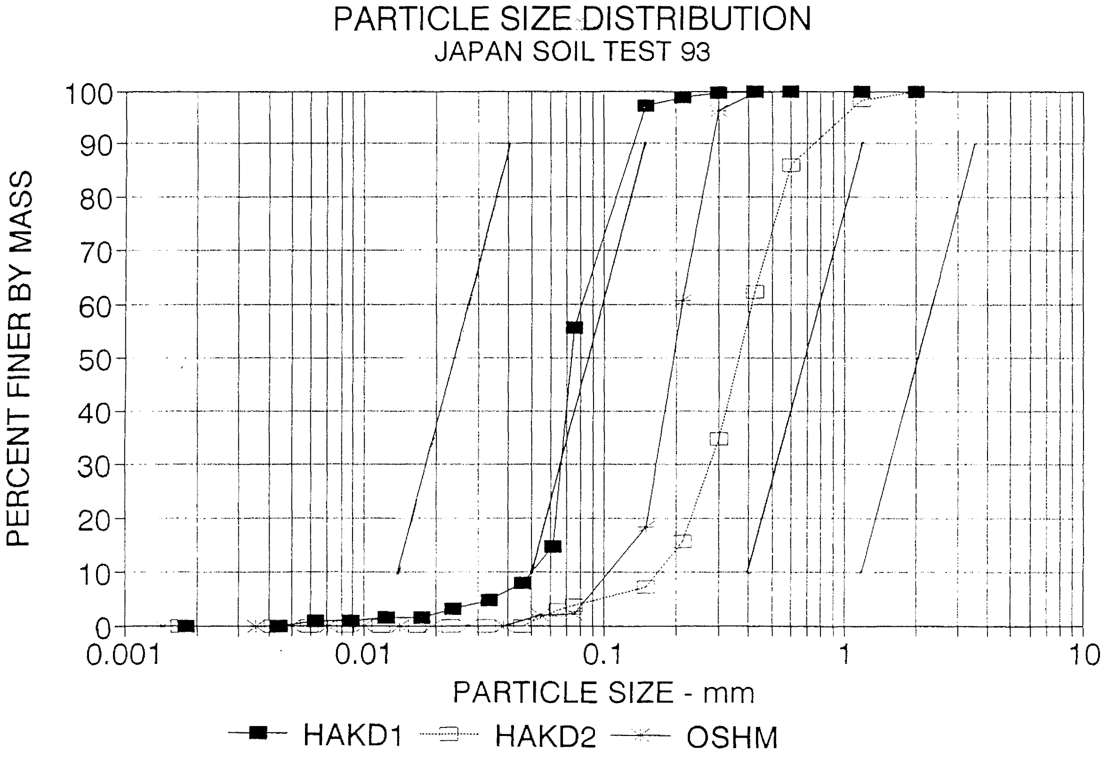

Figure 3 ***Ranges of particle size distribution for liquefiable soils, proposed by Tsuchida (from Iwasaki, 1986).***

being constructed along the port waterfront are piled through these soils to the bedrock beneath. A strong motion recorder located at ground level in the port office at the waterfront, recorded the earthquake (Figure 4). Of note is the peak horizontal ground acceleration of about 0.2 g, which corresponds with the other peak acceleration components at about 47 seconds, the duration of strong shaking of more than 60 seconds, and the site effect of the deep soil column which appears to have a natural period of about 3 seconds.

In the port area where the two samples were collected there was abundant evidence of liquefaction, with large quantities of uniform fine sands forming deposits up to 150 mm thick over the ground surface. Also there was, in many places, differential ground settlement; movement of the ground relative to more fixed facilities, such as concrete curbs and drains, footings and slabs; opening up of joints between 150 mm thick concrete paving slabs; flotation of buried structures such as concrete service ducts and tanks; bowing and tilting of (sheet pile) quay walls which had clearly been back-filled, possibly with harbour sediments, to reclaim the wharf land.

In the Oshamanbe area there was also ample evidence of liquefaction, with sand boils, lateral spreading, differential settlements, and ground fissuring causing damage to sparse buildings and facilities located there. Geographically this liquefaction had occurred in a back-dune area of low lying swampy ground, located several hundred metres from the present sea shore. Building plans at the Nakanosawa Primary School gave the SPT results shown in Table 2.

Table 2 **Standard penetration N values at the Nakanosawa Primary School and corresponding critical values for liquefaction.**

Depth (m)	SPT N value	Critical N value (Davis & Berrill, 1982)
2	5	6
4	1	5½
8	15	4½
10	50	4½

From the N values shown in Table 2 it is clear that the school is underlain by some 8 m of loose or soft sediments. The former swampy rice fields at the site had been filled with approximately 1.5 m of sand prior to construction of the school buildings, which were supported on piles through the soft ground into dense beach sands at 10 m depth. The ground beneath and surrounding the school buildings had subsided by 0.5 to 1 m, and had spread laterally, exposing the foundation beams and piles, and shearing off service pipes. Some of the 0.3 m diameter reinforced concrete piles showed signs of distress near their contact with the concrete foundation beams, with cracking and spalling of concrete exposing the pile reinforcing rods in the worst cases.

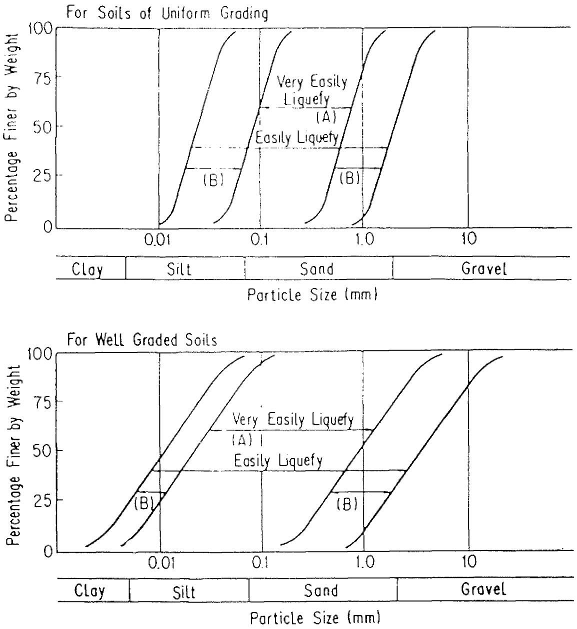

Figure 4 *Accelerogram recording a peak acceleration of a_{max} = 0.2 g at ground level at the Hokodate Port office, about 1 km from the Nittetsu Cement Company silos from where the ejecta samples were retrieved. (Courtesy of the Hokkaido Development Bureau.)*

CALCULATED LIQUEFACTION POTENTIAL

Rough calculations of liquefaction potential were made for both sites assuming bulk densities of 17 and 19 kN/m^3 above and below the water respectively. At Hakodate, with a uniform N-value of 4.5, the model of Davis and Berrill (1982) just predicts liquefaction in the upper few metres provided the water table is near the ground surface. If the water table were much below 1.5 m, then the prediction becomes marginal. On the other hand, with a_{max} = 0.2 g and N = 4.5, the procedure of Seed *et al.* (1985) predicts liquefaction to a considerable depth in both clean and silty sands.

At Oshamanbe, the Davis and Berrill model clearly predicts liquefaction in the very loose N = 1 layer at 4 m, but not in the denser soil tested at 8 and 10 m. At 2 m, liquefaction is just predicted provided the water table is above this level. Critical raw N values assuming a water table at 1.5 m (the former ground surface) are shown in Table 2.

CONCLUSION

Both sites appear to warrant further investigation. The Hakodate site is close to the boundary between liquefying and not, which should make it an important case for calibrating empirical models. At the Oshamanbe site the shear failure of the piles provides an interesting case for back analysis of pile loads induced by liquefied soil, with an eye to verifying the results of Tokida *et al.* (1993), for example. Although piling through the liquefaction-susceptible soil protected the buildings from damage, repairs to the piles and grounds are likely to be costly. It would be interesting to compare the overall cost of piling plus repairs with the cost of ground improvement in the first place.

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