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SETTLEMENT OF BUILDINGS DUE TO LIQUEFACTION DURING THE CHI-CHI AND OTHER EARTHQUAKES

Susumu YASUDA
Tokyo Denki University, Saitama, Japan *yasuda@g.dendai.ac.jp*

Nozomu YOSHIDA
Sato Kogyo Co., Ltd., Tokyo, Japan *Nozumu.Yoshida@satokogyo.co.jp*

Masayuki SATO and Hitoshi AZUMA
Tokyo Electric Power Services Co., Ltd., Tokyo, Japan *sato@tepsco.co.jp*
wang@tepsco.co.jp

Masaaki KAMEI
Kiso-jiban Consultants Co., Ltd., Tokyo, Japan *kamei.masaaki@kiso.co.jp*

Abstract

Many builedings settled and tilted in Yuanlin City during the 1999 Chi-Chi earthquake in Taiwan. The settlement of buildings was compared with the settlement of buildings in Niigata, Dagupan and Adapazarı cities during the 1964 Niigata, the 1990 Luzon and the 1999 Kocaeli earthquakes, respectively. The settlement in Yuanlin City was smaller than the settlements in Niigata and Dagupan cities. It seemed that the difference of grain size of the liqueied soil caused the difference of the settlements of buildings in these cities.

Introduction

During the 1999 Chi-Chi earthquake, liquefaction occurred in several cities; Yuanlin, Wufeng, Shetou etc. in Taiwan. The authors visited Yuanlin City about one month after the earthquake. Buildings settled and buried pipes were damaged in the liquefied zone. However, settlement of the damaged buildings was not large as about 10 cm to 20 cm. On the contrary, the settlement of buildings in liquefied grounds during the 1964 Niigata and the 1990 Luzon earthquakes was large as more than 2 m in maximum. The settlement of buildings in Adapazarı City during the 1999 Kocaeli earthquake was the middle. The authors reviewd the settlements of buildings during the past three earthquake and compared with the settlement in

Yuanlin City. Then the reason why the settlement in Yuanlin was not so large, was discussed.

Settlement of buildings during the 1964 Niigata earthquake

The 1964 Niigata earthquake brought severe damage due to liquefaction in Niigata City, which has been developed on an alluvial plane formed by two big rives, Shinano River and Agano River. Some zones in the city are artificially reclaimed lands. Therefore, clean and loose sand layers are deposited from the ground surface to the depth of about 5 to15m.

In Niigata City, 1530 buildings had been constructed before the earthquake. Among them 340 reinforced concrete buildings were damaged due to liquefaction during the earthquake. About a half of the damaged buildings settled and tilted without cracks on the walls. Building Research Institute of Ministry of Construction (1965) conducted detailed survey including the measurement of settlement for the 340 buildings. Figure 1 shows the frequency distribution of the settlement of the buildings.

Many buildings in Niigata City had pile foundations.

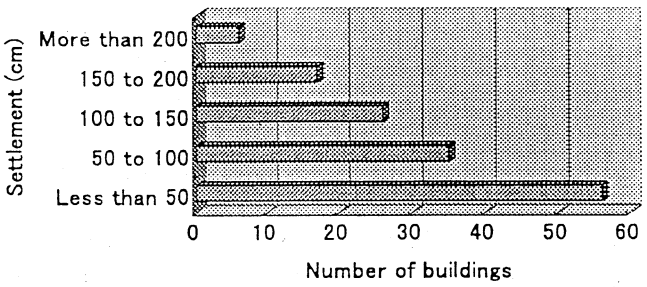

Fig.1 Frequency distribution of the settlement of damaged buildings in Niigata City (Building Research Institute, 1965)

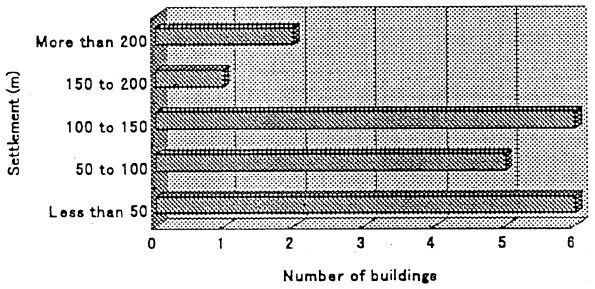

Fig.2 Frequency distribution of the settlement of selected buildings with spread foundations in Niigata City (Yasuda, 2000)

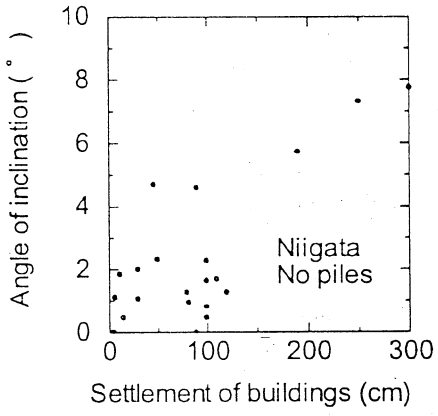

Fig.3 Relationship between angle of inclination and settlement of the selected buildings with spread foundations in Niigata City (Yasuda, 2000)

Then the author selected the buildings, which have no pile and the amount of settlements were measured. Main types of spread foundations were continuous footing and independent footing. Number of stories of the buildings was 1 to 4. Figure 2 shows frequency distribution of the selected buildings (Yasuda). The depth of liquefied layer was around 10 m. Figure 3 shows relationship between angle of inclination and settlement of the selected buildings. About a half of the selected buildings settled more than 1 m. The maximum settlement and angle of inclination were 3m and 8 degrees, respectively.

Settlement of buildings during the 1990 Luzon earthquake

The 1990 Luzon, Philippines earthquake also brought severe damage due to liquefaction. Dagupan City was the most severely damaged city in the liquefied area. The city is situated on the delta formed by Agno River. Alluvial loose sand layer is deposited from the ground surface to the depth of about 10 m. Ground water level is high as GL.-1 m to -2 m.

A lot of buildings were severely damaged due to liquefaction. In the center of the city, reinforced concrete buildings of 2 to 5 stories settled and tilted. Type of foundation of those buildings was spread foundation. Measurement of settlement and angle of inclination was carried out by Architectural Institute of Japan (1988). Liquefied layer was estimated by Wakamatsu et al. (1993) based on boring data conducted after the Luzon earthquake. Then the author selected the data, which contain both settlement and depth of liquefied layer by comparing the above two studies (Yasuda, 2000). Based on the data frequency distribution of the settlement of the buildings was drawn as shown in Fig.4. Though the number is not so large, ten buildings settled more than

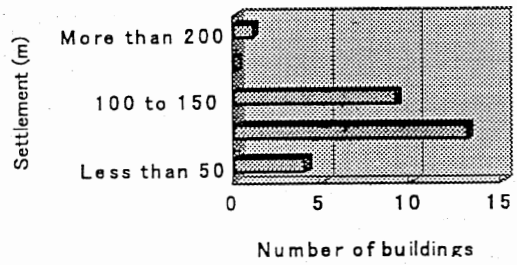

Fig.4 Frequency distribution of the settlement of selected buildings with spread foundations in Dagupan City (Yasuda, 2000)

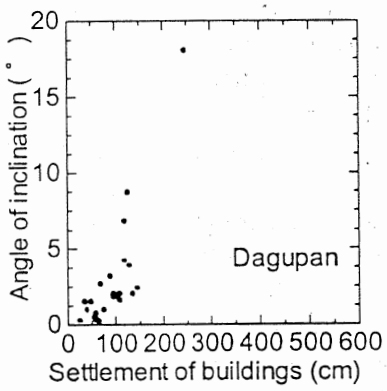

Fig.5 Relationship between angle of inclination and settlement of the selected buildings with spread foundations in Dagupan City (Yasuda, 2000)

100 cm. The maximum settlement was 2.5 m. Figure 5 shows the relationship between angle of inclination and settlement of the damaged buildings. Angle of inclination increased with settlement also.

Settlement of buildings during the 1999 Kocaeli earthquake

Many buildings settled and tilted due to liquefaction in Adapazarı during the 1999 Kocaeki earthquake in Turkey. Adapazarı City is located on the low land formed by two rivers, Sakarya River and Cark River which flow east and west sides of the city, respectively. City area is almost flat with the level of about 30 m. The central zone is slightly higher than surrounding zones. "Ada" and "pazarı" mean island and bazaar, respectively. About 150 years ago, the bazaar was located on an island. Then the surrounding zones were filled by soils transported by the two rivers. Ground water level is shallow as GL.-1 to 3 m. The reconneissance team of the Japanese Geotechnical Society tried to measure the settlement and angle of inclination for about 200 buildings (JGS, 2000). Among them the data for settled buildings only were selected and the relationship between settlement and angle of inclination was drawn as shown in Fig. 6. The maximum settlement was about 0.6 m. Though detailed investigation was not conducted, type of foundation for the buildings shown in Fig.6 must be spread foundation.

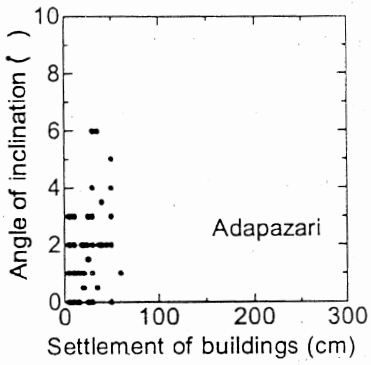

Fig.6 Relationship between angle of inclination and settlement of the investigated buildings in Adapazarı (Yasuda, 2000)

Settlement of buildings during the 1999 Chi-Chi earthquake

During the 1999 Chi-Chi earthquake, liquefaction occurred in several cities, Yuanlin, Wufeng, Shetou etc. However liquefied sites were limited to only several zones though a vast alluvial plain is formed in west side area from the epicenter. Damage to structures due to liquefaction was not so severe compare with the past three earthquakes.

The authors visited Yuanlin City about one month after the Chi-Chi earthquake (Association for the Development of Earthquake Prediction, 2000). Liquefaction occurred in south to south-east districts in Yuanlin City. Buildings settled and buried pipes were damaged in the liquefied zone. In Huilai Alley, a nine-story building settled slightly and titled about 0.5 degree. This building was built 8 years ago at the paddy field, which had been reclaimed on a river channel. According to the soil investigation conducted at this site, silty sand or silty clay layer with 3 to 8 in SPT N-value is deposited from the ground surface to the depth of about 12 meters.

In Minsheng Alley, many houses settled slightly. The authors tried to measure settlement and inclination of a four-story building, which was seemed as the most settled building in this district. The measured settlement and angle of inclination were about 30 cm and 1.5 degrees, respectively. In Lunya Alley, many buildings settled and tilted. According to the authors' measurement for three buildings, angles of inclination of these buildings were 1 to 2 degrees.

Discussion on the difference of the settlements of buildings in four cities

Several factors affect the settlement of buildings in liquefied ground. Yoshimi and Tokimatsu (1977) summarized the settlement of buildings in Niigata City and found the relationship between width ratio and settlement ratio. Kawasaki et al. (1998) conducted many dynamic centrifuge tests to demonstrate parameters, which influence the settlement of an isolated footing for a power transmission. They found that nine factors shown in Table 1 affect the settlement of the footing.

Table 1 Factors influence the settlement of footing

Factor	Influence
Thickness of liquefied layer	Settlement increases with thickness of liquefied layer.
Thickness of unliquefied layer	Settlement decreases with thickness of unliquefied layer.
Density of ground	Settlement decreases with density.
Grain size	Settlement decreases with fines content.
Amplitude of acceleration	Settlement increases with acceleration.
Number of cyclic loadings	Settlement increases with number of cycles.
Width of footing	Settlement decreases with width of footing.
Load intensity	Settlement increases with load intensity.
Penetration depth	Settlement decreases with depth.

Among these, factors for thickness of liquefied layer, thickness of unliquefied layer, density of ground cannot be compared for four cases, because the authors do not have detailed soil data in liquefied area in Yuanlin City. Factors for amplitude of acceleration, number of cyclic loadings, load intensity and penetration depth may be not so different among the four cases. For width of buildings, not only the width of individual building but also the density of buildings in a block must be considered (Yasuda, 2000). However, densities of buildings in Yuanlin and Dagupan cities are similar. Then, the effect of the remaining factor, grain size, was discussed below.

As mentioned above, the authors don't have detailed soil data in Yuanlin and Adapazarı cities. Then, grain sizes of boiled sands in Yuanlin and Adapazarı cities were assumed as the grain sizes of liquefied soils. Two boiled sands were taken at Minsheng Alley and Lunya Alley in

Yuanlin City. Figure 7 compares the grain size distribution curves of the liquefied soils in four cities. As shown in the figure, grain size of the soil at Minsheng Alley in Yuanlin was the minimum and the grain size in Niigata was the maximum. Figure 8 compared the relationship between mean diameter of the liquefied soils and the maximum settlement of buildings in four cities. The maximum settlement of buildings in Yuanlin City was assumed as 0.3 m based on the measured settlement at Minsheng Alley mentioned before. The settlement of buildings decreased with the mean diameter of the liquefied soil as shown in Fig.8. Therefore, it seemed that the grain size of liquefied soil influences the settlement of buildings. However, more study is necessary because the soils taken in Yuanlin and Adapazarı cities were not actual liquefied soils but boiled soils.

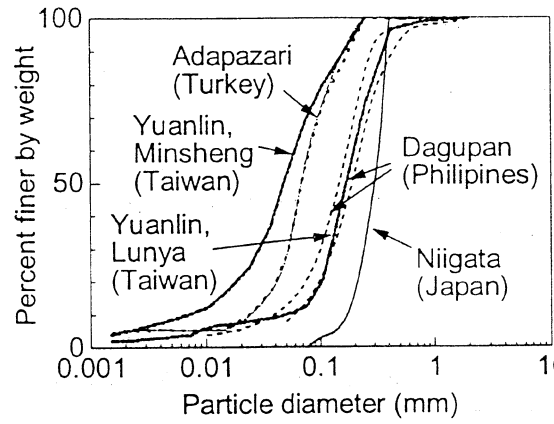

Fig.7 Grain size distribution curves of liquefied soils in four cities

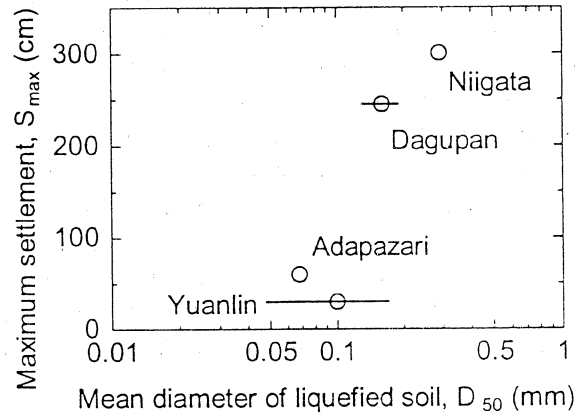

Fig.8 Relationship between mean diameter of liquefied soil and maximum settlement of buildings

Conclusions

Liquefaction-induced settlement of buildings in Yuanlin City was compared with the settlement of buildings in Niigata, Dagupan and Adapazarı, cities, and the following conclusions were derived:

1. Liquefaction-induced settlement of buildings in Yuanlin City was smaller than those in

Niigata and Dagupan cities.
2. Settlement of buildings decreases with the decrease of grain size of liquefied soil.

Acknowledgements

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