Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Settlement and inclination of reinforced concrete buildings in Dagupan City due to liquefaction during the 1990 Philippine earthquake

T.Adachi & S.Iwai
Nihon University, Tokyo, Japan

M.Yasui
Toda Corporation, Tokyo, Japan

Y.Sato
Nishimatsu Construction Co., Ltd, Tokyo, Japan

ABSTRACT: Many reinforced concrete buildings in Dagupan City were damaged due to an extensive liquefaction of the sandy ground during the Philippine earthquake of July 16, 1990. The objective of the present paper is to investigate the effects of the dimensions of buildings on settlement and on inclination of buildings. The thirty reinforced concrete buildings along Perez Blvd. in Dagupan City, which were remarkably damaged due to the liquefaction, were investigated. According to the analysis, (1) depth of liquefied sand is estimated to be about 6 to 10 meters by FL-value and cross-section of sediments (2) the settlement and inclination angle decrease with increasing area and width of the building, and (3) the relationship between normalized average settlement and normalized width of the building is similar to the results in the 1964 Niigata earthquake in Japan.

1 INTRODUCTION

The earthquake of magnitude 7.8 (USGS: United States Geological Survey) occurred in the north-central region of Luzon Island, Philippines on July 16, 1990. The epicenter was at latitude 15.658 degrees N, longitude 121.227 degrees, E and the epicentral depth was 25 km. During the earthquake, extensive soil liquefaction in the alluvial plain along the southern coast of the Lingayen Gulf was widespread. The numerous damages due to liquefaction, such as settlements and/or inclinations of the buildings, falling down of bridges, lateral spreading along the river and so on, occurred specially in the central district of Dagupan City. The most number of building damages were concentrated along Perez Blvd..

The authors conducted site investigations of liquefaction-induced building damages in Dagupan City from September 20 to 30, 1990. This investigation was carried out as a part of the 2nd Damage Investigation Team organized by the Architectural Institute of Japan (AIJ).

In this paper, the liquefied layer along Perez Blvd. was estimated from the liquefaction resistance factors, FL-values, which were computed on the basis of N-values from standard penetration tests (SPT) conducted after the earthquake. The effects of building dimensions on settlement and/or inclination of the building were discussed. In addition, the results of the investigation of the reinforced concrete building damages were compared with that of the Niigata earthquake of 1964 in Japan.

2 GROUND CONDITION

Dagupan City with a population of about 130,000 is located about 200 km north-northwest of Manila, capital of the Philippines, and along the Lingayen Gulf. The city is approximately 100 km away from the epicenter (see Figure 1).

Dagupan City has a lot of fishponds developed on swampy lowlands, and some rivers. The ground surface is about one meter above mean sea level and the ground water table is very high. It is said that the central district of Dagupan City had been developed from fishpond, rice field and old river. According to aerial photographs and geomorphological condition, Perez Blvd. in the

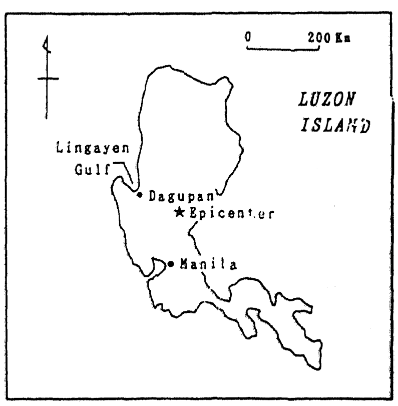

Figure 1. Location of Dagupan City.

central district of Dagupan City, where was heavily damaged due to liquefaction, was supposed to be on old riverbed (ADEP, 1990).

Ground failure such as sand boils, lateral spreading and cracks were observed at many places in and around Dagupan City.

Figure 2 shows the grain size distribution of samples taken from the traces of sand boil in and around the city. The mean grain size, D_{50}, is about 0.20 mm. These sands are uniformly graded and highly susceptible to liquefaction.

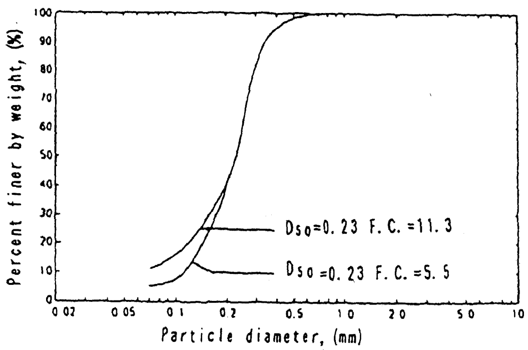

Figure 2. Grain size distributions of liquefied sands.

3 ESTIMATION OF LIQUEFIED SAND LAYER

Reinforced concrete building damages due to liquefaction were concentrated along Perez Blvd. in the central district of Dagupan City. Figure 3 shows soil profiles along Perez Blvd., the N-values were obtained from SPT executed after the earthquake. The locations of the boreholes are shown as black dots in Figure 4.

On the basis of these soil profiles and N-values, the liquefaction resistance factors, FL-values, were computed by the procedure of Recommendations for Design of Building Foundation (AIJ, 1988), labeled A in Figure 3, and by the procedure of Specifications for Highway Bridges, Part IV (JRA, 1980), labeled B in Figure 3.

The assumptions in computing the FL-values are as follows,

1. The N-values indicated in Figure 3 were corrected by multiplying them by 0.5 (Kiso-jiban Consultants, 1990).

2. The maximum acceleration on the ground surface is 200 gals which was estimated by Sato (Sato, 1990).

3. Fine contents, F.C., and mean grain size, D_{50}, were estimated based on the grain size distribution indicated in Figure 2, and the results of the other investigator (Kiso-jiban Consultants, 1990).

On the basis of the computed FL-values shown in Figure 3, the depth of liquefied sand was estimated to be about 6 to 10 meters.

4 INVESTIGATION OF BUILDING DAMAGE

4.1 Investigated buildings

Thirty reinforced concrete buildings along Perez Blvd. were investigated for settlements, inclination angles, number of stories, widths and lengths. Figure 4 shows the location of the buildings. The number of buildings against the number of stories are as follows:

2-stories : 2 buildings
3-stories : 13 buildings
4-stories : 9 buildings
5-stories : 6 buildings

Most buildings do not have basement floor and the type of foundation is spread foundation with shallow depth.

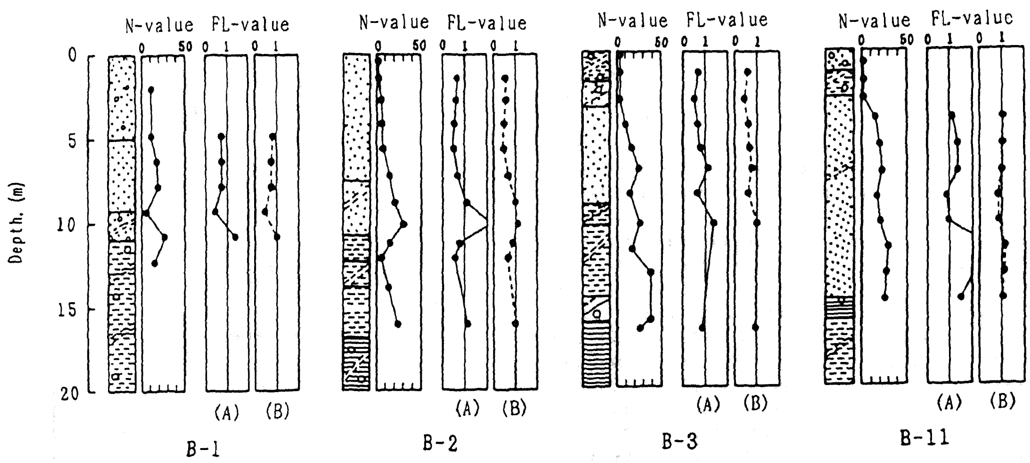

Figure 3. Soil profiles and FL-values along Perez Blvd.

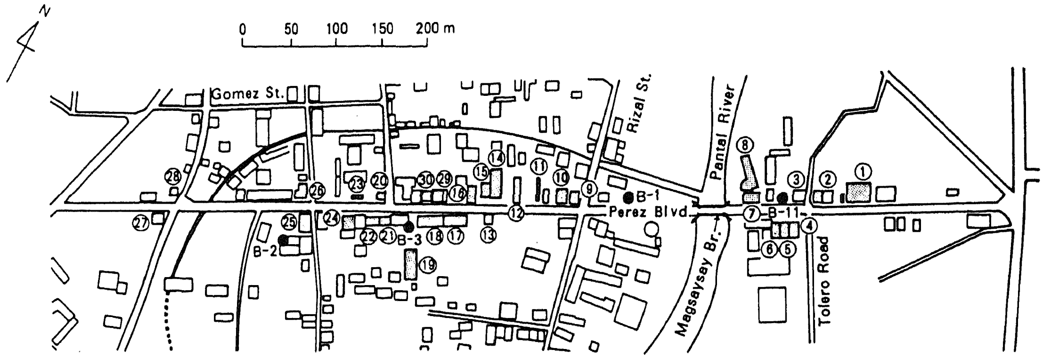

Figure 4. Locations of boreholes and investigated buildings.

4.2 Investigation procedures

1. Widths and lengths of building were measured with tape.
2. Settlements of corner points of building relative to the road surface were measured with range pole and hand level.
3. Inclination angles of columns or walls were measured for two cross directions with a clinometer.
4. Differences between two point settlements of beam or floor of building, which were assumed level before the earthquake, were measured with range pole and hand level. The inclination angles of floor were determined from the difference in settlements and the distance between two points.

5 INVESTIGATION RESULTS AND DISCUSSIONS

5.1 Investigation results

Figure 4 shows the locations of investigated buildings which were numbered individually. These numbers correspond to the building number in Table 1.

The maximum settlement of building is about 2.5 meters and the maximum angle of inclination is about 18 degrees. Figures 5 and 6 show the histograms of settlements and of inclination angles, respectively. It can be seen from Figures 5 and 6 that the settlement between 50 and 75 cm has the highest frequency, and the inclination angle between 1 and 2.5 degrees has the highest frequency.

Table 1. Investigation results of thirty reinforced concrete buildings along Perez Blvd.

Building No.	No. of stories	Width of building B (m)	Length of building L (m)	Maximum Settlement S (cm)	Maximum Inclination θ(°)	Building No.	No. of stories	Width of building B (m)	Length of building L (m)	Maximum Settlement S (cm)	Maximum Inclination θ(°)
1	3	10.8	23.1	25	0.3	16	4	11.8	20.8	95	1.8
2	4	10.32	13.30	75	1.0	17	4	12.5	38.5	60	0.3
3	3	10.55	16.80	130	3.9	18	5	12.5	50	40	1.0
4	5	8.1	23.5	60	0.8	19	4	20	35.9	-	1.0
5	3	7.1	23.5	35	1.5	20	3	8.25	8.4	120	6.8
6	4	10.1	23.5	80	2.0	21	3	12.16	16.4	60	0.5
7	4	13.15	21.45	110	2.0	22	3	7.77	8.56	120	4.2
8	5	15.5	19.0	-	3.3	23	3	7.5	8.6	125	8.7
9	3	15.35	16.85	55	0.5	24	2	13.52	19.10	135	2.0
10	3	18.9	19.1	65	0.2	25	3	9.1	15.6	145	2.4
11	4	5.15	29.05	245	18	26	3	5.15	12.2	100	1.9
12	5	7.95	38.4	110	1.6	27	3	15.3	10.5	60	0.7
13	3	11.16	13.5	95	1.8	28	2	10.9	12.2	35	1.5
14	4	12.05	25.0	95	2.0	29	5	14.35	15.1	50	1.5
15	4	12.05	32.0	70	2.7	30	5	9.75	14.8	90	3.2

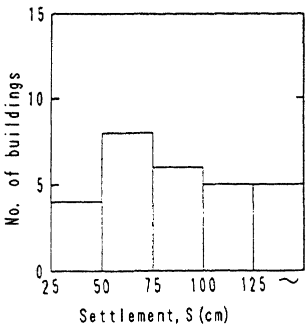

Figure 5. Histogram of settlements.

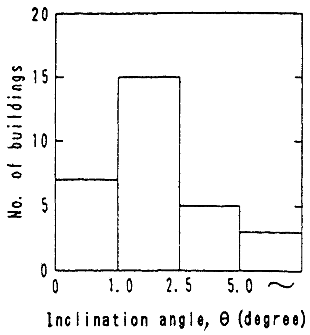

Figure 6. Histogram of inclination angles.

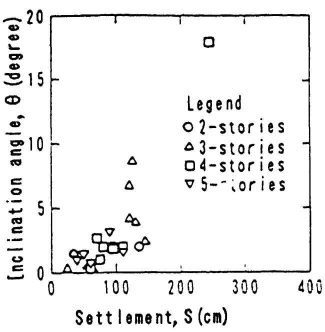

Figure 7. Relationship between settlement and inclination angle.

Figure 7 shows the relationship between settlement and inclination angle. It can be seen that the inclination angle increases with increasing settlement.

The settlements of individual buildings are shown in Figure 8 with cross-section of sediments along Perez Blvd.. The cross-section of sediments was estimated based on soil profiles in Figure 3 and Swedish sounding tests (ADEP, 1991).

According to computed FL-values and soil sounding results, layers As and B in Figure 8 are estimated liquefied. It can be seen from Figure 8 that the differences of settlements between individual buildings are large. It is considered that these differences are due to the effects of dimensions of individual buildings on settlement.

The effects of dimensions of building such as number of stories, area and width on settlement and inclination angle of building are discussed hereafter.

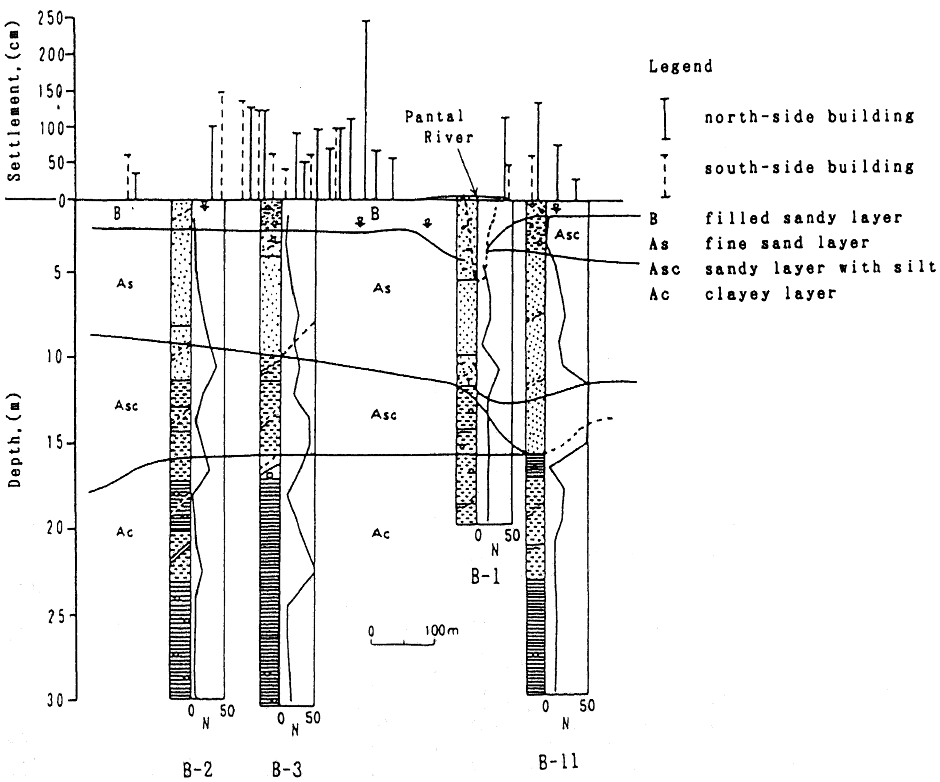

Figure 8. Cross-section of sediments along Perez Blvd. and settlement of buildings.

5.2 The effect of dimensions of building on settlement

The settlements of buildings are plotted against the number of stories in Figure 9. No clear trend is found.

The relationship between settlement and base area of buildings is shown in Figure 10. Plotted data disperses considerably, however, the envelope of dispersion shows that the settlement decreases with increasing area of building.

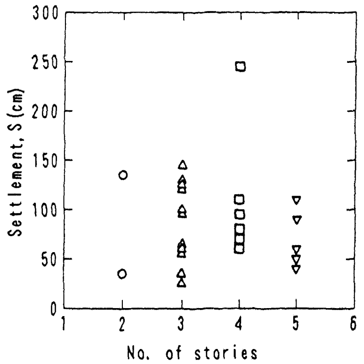

Figure 9. Relationship between settlement and number of stories.

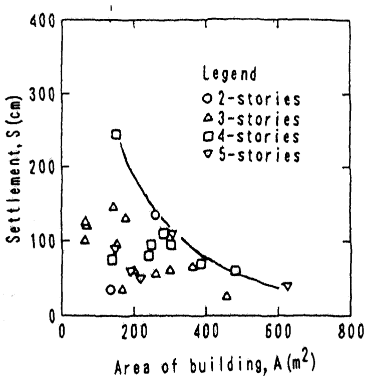

Figure 10. Relationship between settlement and area of building.

5.3 The effect of dimensions of building on inclination angle

The inclination angles are plotted against the number of stories in Figure 11. Figure 12 shows the relationship between inclination angle and width of buildings. It can be seen in Figure 12 that, despite the scatter, the envelope of dispersion shows that the inclination angle decreases with increasing width of building.

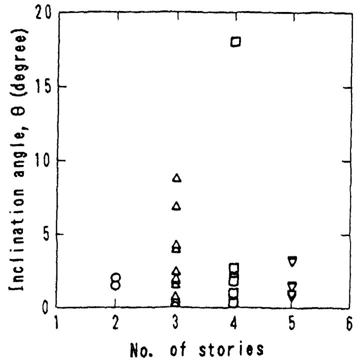

Figure 11. Relationship between inclination angle and number of stories.

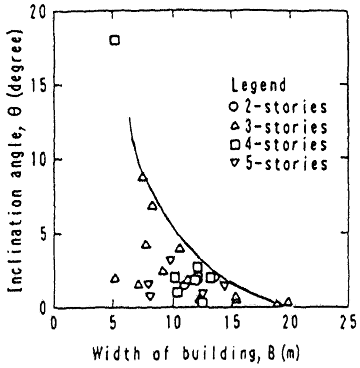

Figure 12. Relationship between inclination angle and width of building.

5.4 Relationship between average settlement and width of building

In order to compare the results of this investigation with the reinforced concrete building damages of Niigata earthquake of 1964 in Japan, the average settlement was determined from maximum settlement, inclination angle of floor, width and length of building by assuming rigid floor of base of building.

Figure 13 shows relationship between average settlement and width of building. The line shows envelope of dispersion of the data of Niigata earthquake, which were obtained from the thirty-five reinforced concrete buildings in Niigata city (Yoshimi, 1980). It can be seen that the average settlements of this investigation are smaller than those in Niigata earthquake.

As one of the factors of this difference in results, it is considered that the depth of liquefied sand along Perez Blvd. is relatively smaller than that of Niigata city during the Niigata earthquake.

According to the FL-value and cross-section of sediments along Perez Blvd., average depth of liquefied sand, D, is estimated to be about 8 meters. Normalized average settlement, Sa/D, is determined by dividing the average settlements by the average depth of liquefied sand, and the normalized width of building, B/D, is determined by dividing the width by the average depth of liquefied sand.

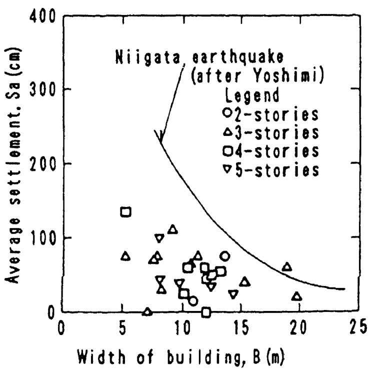

Figure 13. Relationship between average settlement and width of building.

Figure 14 shows the relationship between normalized average settlement, Sa/D, and normalized width, B/D. The range between the two curves shows the range of dispersion of the data of Niigata earthquake (Yoshimi, 1980). It can be seen that the normalized settlement decreases with increasing normalized width, and the relationship between the normalized settlement and normalized width of this investigation is similar to that of Niigata earthquake.

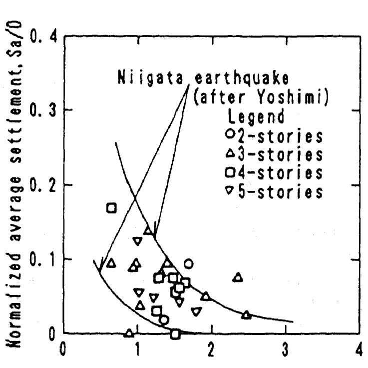

Figure 14. Relationship between normalized settlement and normalized width.

6 CONCLUSION

Based on these investigation results and discussions, it can be concluded that,

1. On the basis of computed liquefaction resistance factors, FL-values, and cross-section of sediments along Perez Blvd., the depth of liquefied sand is estimated to be about 6 to 10 meters.
2. The dimensions of the building strongly influence the amount of settlement and inclination angle of the reinforced concrete building. The settlement and inclination angle decrease with increasing area and width of building.
3. The relationship between the normalized average settlement and the normalized width of the building is similar to that of the 1964 Niigata earthquake.

ACKNOWLEDGMENT

Investigation works in the disaster area were carried out on September 20-30, 1990 with the 2nd Damage Investigation Team from the Architectural Institute of Japan. The authors wish to thank Dr. Takao Nishikawa, Professor of Tokyo Metropolitan University and team leader, the members of the investigating team and Assist. Prof. Victor Macam, Jr., Bernardo Lejano, and Loreto Apilado of the Technological University of the Philippines for their kind cooperation to carry out the investigation.

REFERENCES

Association for the Development of Earthquake Prediction (ADEP) 1991. Report of damage *investigation during the 1990 Philippine* Earthquake (in Japanese).

Architectural Institute of Japan (AIJ) 1988. Recommendations for Design of Building Foundation (in Japanese).

Japan Road Association (JRA) 1980. Specifications for Highway Bridges, Part IV (in Japanese).

Kiso-jiban Consultants 1990. Report of investigation during Luzon earthquake on July 16, 1990 (in Japanese).

Sato, T. 1990. Damage of Cabanatuan, estimation of maximum acceleration. preliminary report of the 1990 Philippines earthquake, Japan Society of Civil Engineers (in Japanese).

Yoshimi, Y. 1980. Liquefaction of Sands. Tokyo: Gihodo (in Japanese).