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# Settlement of Building due to Pile Downdrag

## Tassement par le Tirage Négatif pour le Bâtiment

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**SYNOPSIS** This paper presents a general description of the ground condition, reinforced concrete building supported on pile foundation, which due to very large differential settlement, had to be demolished only 4 years after completion, circumstances of differential settlement and extent of damages to the building. The paper clarifies the cause of differential settlement to be negative friction working on piles resulting from the ground subsidence (typical of Tokyo), and endeavors to study the relation between differential settlement and negative friction loads.

### INTRODUCTION

It was quite an unusual occurrence for a building, properly designed and constructed, founded on steel tubular piles, to have had to be demolished only 4 years after completion, due to exceptionally large differential settlement caused by negative friction on piles which was induced by ground subsidence. Although this may be said to be an unusual example, however, close observation of this case have revealed many instructive points relative to differential settlement caused by negative friction loads.

### CONDITIONS OF THE SITE AND SOIL

The site is located in southwest corner of Edogawa delta facing the Tokyo Bay. The site preparation was started about 3 months prior to start of building construction work (Sept. 1966), which involved placing pit run sand at an average depth of about 2.5 meters for an area 2.3 hectares. Foundation pile driving work was completed in 2 weeks immediately following completion of this fill work. It is believed that weight of this fill and drawing of subterranean water in this general area had caused soft alluvium above diluvial dense sand (called Tokyo sand stratum) to settle for several years at a rate of about 10 cm per year.

Soil boring tests were conducted at the points and dates given in Fig. 1(a). Assumed representative soil profile, based upon the results of Boring B and C, is given in Fig. 1(b). Mechanical properties and physical properties of strata are given in Table I. Depth of stratum Ds, as given in Fig. 1(b), varies violently within the range of 2 to 4 meters depth, therefore its undulation is quite pronounced, moreover, in this stratum there is a 10 meters deep buried valley. There is in

this buried valley alternating layers of sand and sandy silt layers (Stratum I).

In Fig. 2 are given precompression loads of various strata and their pore pressure reading, taken 3 years and 5 months (Oct. 1970) after completion of the building. Pore pressure of strata under Stratum As-2 is very much lower than hydrostatic pressure by subsurface water level  $AP \pm 0$ . Drop in pore pressure of this nature is caused mainly by excessive drawing of underground water below Stratum Ds, giving rise to Am-2 stratum's consolidation settlement. No appreciable change in pore pressure was observed from start of field measurement recording to 1976, but pore pressure of Stratum Ds has shown tendency toward gradual increase since Apr. 1974. Although strata below Stratum Ds is settling, however, there are ample proofs that its effect is negligibly small to a building with overall length of 100 meters.

### GENERAL DESCRIPTION OF BUILDING AND FOUNDATION

The building was a 3 storied reinforced concrete school building resting on pile founded footings. Building's plan is given in Fig. 1(a), whereas, section showing foundation is given in Fig. 3. There were number of transversal reinforced partitions, and the north side were 2 stair wells of bearing wall construction connected to cantilever corridor. The building was 102 meters long in longitudinal direction, however, there were no structurally reliable reinforced concrete walls in this direction, but was of simple rigid frame construction without any structurally isolated joints.

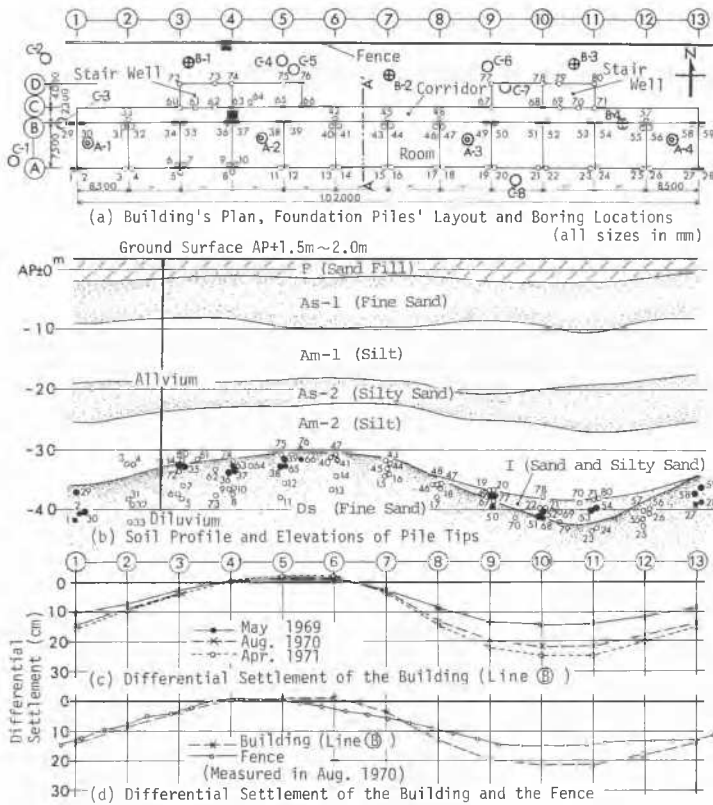


Fig. 1 Soil Profile and Differential Settlement

Legend of Fig. 1

Soil Boring Tests

- ⊙ : Boring A ; Mar. 1966  
(5 months prior to start of construction)
- ⊕ : Boring B ; Oct. 1970  
(3 years and 5 months after completion)
- : Boring C ; Jul. 1971  
(2 months after demolition)

Steel Tubular Piles

- : 508.0 mm
- : 457.2 mm
- : 355.6 mm  
(in outer diameter)

Reference Points

- : Measurements of Differential Settlement of the Building and the Fence

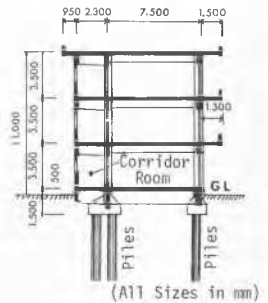


Fig. 3 Cross Section A-A' of the Building

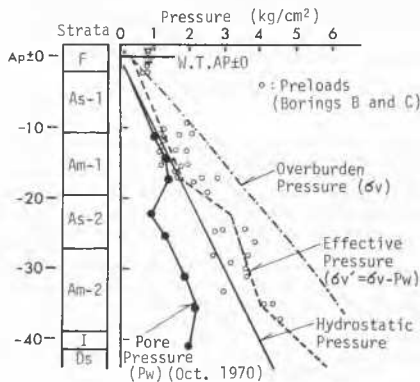


Fig. 2 In-Situ Pore Pressure

Table I Properties of Soils

Strata	Bulk Density $\gamma$ (t/m <sup>3</sup> )	Water Content Liquid Limit Plastic Limit	w LL PL (%)	Unconfined Compressive Strength $q_u$ (t/m <sup>2</sup> )	N-Value (SPT)
F	1.60*	—	—	—	1~3 1 <sup>A</sup>
As-1	1.85*	—	—	—	1~23 10 <sup>A</sup>
Am-1	1.50~1.80 1.55 <sup>A</sup>	w = 45~85 LL = 40~80 PL = 25~45	5.0~13.0 8.0 <sup>A</sup>	—	0~3 <1 <sup>A</sup>
As-2	1.80*	—	—	—	4~17 10
Am-2	1.50~1.85 1.60 <sup>A</sup>	w = 40~80 LL = 45~85 PL = 20~45	11.5~21.0 16.0 <sup>A</sup>	—	1~8 2 <sup>A</sup>
I	1.85*	—	—	—	5~17
Ds	1.95*	—	—	—	>30

\* Estimated Value    <sup>A</sup> Mean Value

Piling layout is given in Fig. 1(a). With the exception of stair case section, number of piles per footing is 2 to 3 piles, with piles being spaced about 2.8 times their diameter. Steel tubular piles are all of 9 mm thick wall, but in 3 outside diameters: 355.6 mm, 457.2 mm and 508 mm, with allowable design bearing values of 70 t, 90 t, and 100 t, respectively.

These steel tubular piles were open tip driven using Model 22 Diesel pile hammer (energy of hammer per blow:8 t·m) and each pile was driven to satisfy allowable design bearing value using pile driving test records and pile driving formula to obtain specified allowable bearing capacity for each pile. Relation between pile tip depth and soil profile of all piles based upon driving records are given in Fig. 1(b). According to this figure there are some piles which tips do not reach Stratum Ds. This is because, inspite of undulation at upper part of Stratum Ds representative cross section was taken, however, from pile driving test results and pile driving records, it can be determined that tips of all piles have penetrated into Stratum Ds with N-value over 50.

#### DIFFERENTIAL SETTLEMENT OF BUILDING AND DAMAGES

Building was completed in May 1967, about 8 months after first pile was driven, however, about 6 months thereafter ground surface had settled greatly, thereby causing damages to appurtenants resting on grounds adjacent to the building, and small cracks started to appear on the building itself. About 1 year after completion, some doors and windows started to become inoperative. Two years after completion, cracks started developing in columns and beams, unevenness in floor became noticeable even to naked eyes.

At this juncture it was decided that actual condition of the building should be grasped and cause determined. It was in May 1969 that serious effort was directed for the first time toward measuring differential settlement and for assessment of damage. Differential settlement measurement was continued, periodically, until the building was demolished in May 1971.

Simultaneous with completion of the building a precast concrete panel fence, rested on ground surface, as shown in Fig. 1(a), was constructed on north side of the building. Differential settlement of the fence was also measured in order to learn differential settlement of ground level.

Above mentioned differential settlement measurement results are given in Fig. 1(c), (d). Settlement along Line (A) on south side and Line (B) on north side of the building exhibited approximate same amount of settlement, therefore, differential settlements made the building to take a shape of bow with 2 ends low and center high. When the building was first measured maximum difference in levels

was 15 cm, however, it had increased to 25 cm just prior to start of demolition work. Shape of differential settlement did not change appreciably with time, only that bow shape became more pronounced. Shape of this unusual differential settlement, as shown in Fig. 1(c), is very similar to top contour line of stratum Ds, which is believed to be clear indication that depth change in Ds stratum to be the influencing factor. Another interesting phenomenon was that differential settlement of building was greater than that of the fence as given in Fig. 1(d).

Extent of damages to building at the start of survey, such as ratio of obstruction to doors and windows operation, cracks in rigid frames, angle deflection of spans and differential settlement on Line (B) are given in Fig. 4.

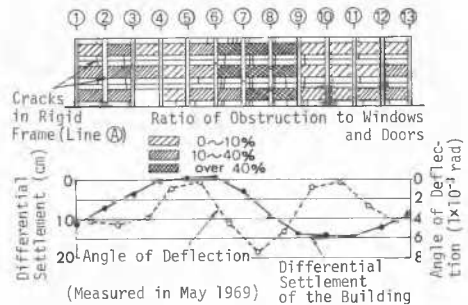


Fig. 4 Ratio of Obstruction and Angle of Deflection

By "Ratio of Obstruction" it is meant the ratio relative to number of obstructed doors and windows as against total number of doors and windows of the span. "Angle of deflection" is obtained by dividing settlement between 2 columns by span length of those 2 columns. Where angle of deflection was  $3/1000$  or larger, ratio of obstruction was great and numerous cracks in columns and beams were observed.

#### CAUSE OF DIFFERENTIAL SETTLEMENT AND NEGATIVE FRICTION WORKING ON PILES

Foregoing explanation leaves little doubt that differential settlement of the building was caused by negative friction on piles. Causes in this case may be attributable to inconsistency of pile shaft strength, bearing capacity of pile tip, magnitude of negative friction on piles.

Bearing capacities of pile tip as determined by driving formula indicated rather wide range of variations, however, when bearing capacity is considered in combination with pile shaft strength, the relation between unevenness of pile bearings and differential settlement of the building cannot be found.

Although it is very difficult to assume correctly negative friction on piles, here, by using measurement results of negative friction on piles of reconstructed building on the exact site, negative friction which worked on piles will be assumed.

The relations between pile length  $L_c$  in alluvium and 2 types of axial forces on piles,  $P_n + P$  and  $P_p + P$ , are given in Fig. 5.  $P_n$  and  $P_p$  are assumed by taking 85% of  $L_c$  as neutral point depth  $L_n$  and in due consideration that piles are open ended and group piles based upon Endo's proposal (1967). Difference between 31m and 39m for  $L_c$  results in 50 tons difference in  $P_n + P$ , whereas it is 30 tons for  $P_p + P$ . The relation between  $R_n$  and differential settlement of the building increases in proportion to  $R_n$  in Fig. 6. As indicated in Fig. 7, when alluvium is 34 meters thick differential settlement of the building is greater than ground surface (the fence) and in shallower points above 34 meters, differential settlement may be about same or that of the building may be smaller. By observing these points, it may be said that differential settlement of the building was caused because bearing capacity of piles in diluvial deposit were unable to properly

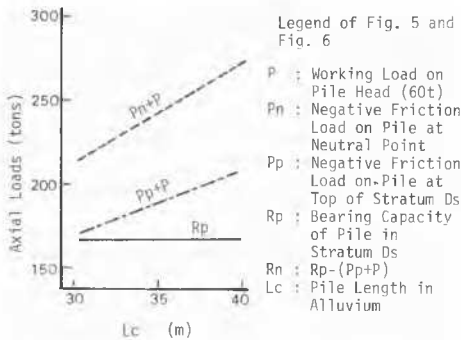


Fig. 5 Assumed Axial Loads on Piles 457.2mm in outer diameter

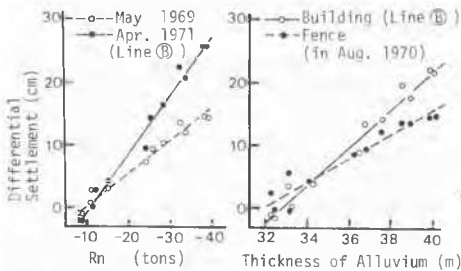


Fig. 6 Differential Settlement of the Building vs.  $R_n$

Fig. 7 Differential Settlement vs. Thickness of Alluvium

response to uneven negative friction loads caused by uneven alluvial deposit thickness. Now, when pile point bearing capacity is insufficient to respond to negative friction loads, then piles will be pulled down in proportion to subsidence of alluvium, giving rise of possibility for pile foundations to cause differential settlement, further, where thickness of stratum settling is uneven, then pile foundation may exhibit larger differential settlement than that of the stratum, therefore it becomes important to correctly assume negative friction on pile and pile tip bearing capacity.

CONCLUSIONS

From above study it may be summarised that indications for design of foundation piles where negative friction loads may work to be as given below:

- 1) Where pile tip bearing capacity is insufficient to respond to negative friction loads, settlement will take place in direct relation to such deficiency.
- 2) Even when piles should settle greatly, negative friction will not decrease appreciably, and pile will continue to settle in proportion to soil settlement.
- 3) Where thickness of stratum settling is markedly uneven, differential settlement of pile foundation may be more pronounced than differential settlement of that stratum.
- 4) Where soil settlement is great, differential settlement of pile foundation due to negative friction will appear within 1 or 2 years after piles are driven.

ACKNOWLEDGMENTS

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REFERENCE

Endo, M. (1967), "Negative Friction; Steel Pile," Library of Geotechnical Engineering. J.S.S.M.F.E., Series 6, pp. 257-315. (in Japanese).