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Settlement of soft ground and damage of wooden houses by braced excavation

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ABSTRACT: During excavation, settlement of the ground behind earth retaining walls sometimes happens and produces undesirable effect such as harmful settlement and inclination to the neighboring wooden houses. In this report, damage of the wooden houses caused by the settlement of ground following excavation is analyzed and damage of the houses is clarified from aspect of the relation between distance from the earth retaining walls, settlement and inclined angle of the wooden houses. Furthermore, the settlement distribution pattern of the ground behind the earth retaining walls following the excavation is studied based on the relationship between braced excavation method and construction duration.

1. INTRODUCTION

When long stretches of sub-way, water supply canals, sewerage canals etc. are constructed by tunnel or shield method or open cut with earth retaining wall method, there are so many examples that many structures standing along the construction route suffer from damage caused by settlement of the neighboring ground. Therefore, counter-measures to avoid the settlement are quite important. The studies reported previously regarding ground settlement and damage of wooden houses are composed of mainly differential settlement of the ground caused by weight of building itself and damage of building caused by the differential settlement (for example, Matsmura, et al. 1974,1977).

Almost no systematic research and study regarding the relation between ground settlement caused by excavation using open cut method and damage of houses is reported except a study reported by Makata,et al.(1980). Moreover, these studies are not regarding wooden houses, but steel reinforced concrete or steel structures. Considering that there are so many wooden houses in Japan, it is quite essential to study the damage to wooden houses.

The purpose of this paper is to clarify the influence on the structures caused by settlement of the neighboring ground excavation, and to find its counter-measures. In order to achieve the purpose, the authors give due consideration to minimize the influences of harmful settlement and inclination on the neighboring structures caused by excavation when underground drainage pipeline which was installed using concrete placed in the site after carrying out open excavation. During this construction, the horizontal deformation of the earth retaining walls and settlement ground backward were measured and data of the deformation were already reported (Horiuchi, et al.1993,1994). In this report, using collected data and damage of wooden houses standing near the construction site, the following items are studied.

(1) The relationship between distance from the earth retaining walls and settlement amount, inclined angle of the wooden houses.
(2) The relationship between distance from the earth retaining walls and damage, damage degree of the wooden houses.
(3) The relationship between settlement distribution pattern of the ground behind the earth retaining

walls and breasting work and duration of excavation.

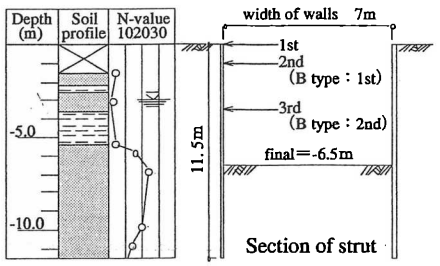
Thus, it is clarified the relationship between the distribution pattern of ground settlement and damage and its degree of wooden houses caused by the settlement of the earth retaining walls affected by the excavation adjacent to the wooden houses. Furthermore, the appropriate bracing work and construction duration to mitigate the damage of the wooden houses caused by the excavation adjacent to the wooden houses are proposed.

2.CIRCUMSTANCES SURROUNDING EXCAVATION JOB SITE AND BRACING WORK

Construction studied in this report is that an underground drainage pipeline with concrete placed in site, 4.7 m diameter and 300 meters in length, constructed by open cut excavation. Along about 200 meters out of the total length, wooden houses are standing. Location of the wooden houses near excavation job site, type of the earth retaining walls and positions of settlement measuring instruments are in Fig.1. Accordingly, in this excavation, in order not to give harmful influence to the neighboring wooden houses such as settlement and inclination, the following counter-measures are taken.

(1) In construction section which is the nearest to wooden houses, PW column wall (Φ=500mm, B-Type) of high stiffness which is so-called low level of pollution construction method was chosen in order to keep the allowable settlement of the neighboring ground less than 1.5 cm. Also attention was given to economical aspect and the strut setting position. In construction section which is remote from wooden houses, sheet pile(type Ⅲ, type Ⅳ)walls were used.

(2) In order to minimize the influence to the neighboring wooden houses and take necessary action easily when damage to wooden houses, total length of pipeline construction were divided into section of about 30 m long, then construction was carried out one by one sections, and construction duration was shortened.Outline of ground condition of the job site, standard cross-section of excavation, breasting work and construction duration are shown in Fig. 2.



Bresting type		Kind of walls	Duration of final stage	Duration of 1st cutting stage	Depth of cut (m) 1st	2nd	3rd
B		PW column	53 day	18 day	-1.7	-3.8	—
C	1,3,4,5	PW column	53・54	9	-1.0	-1.8	-4.0
	2	PW column	38	3			
	6,7	PW column	30	6			
D	1	Sheet pile	37	3	-1.0	-2.2	-4.5
	2,5	PW column	37	3			
	3	Sheet pile	30	6			
	4	PW column	30	6			

Fig. 2 Soil profile and earth retaining structure types

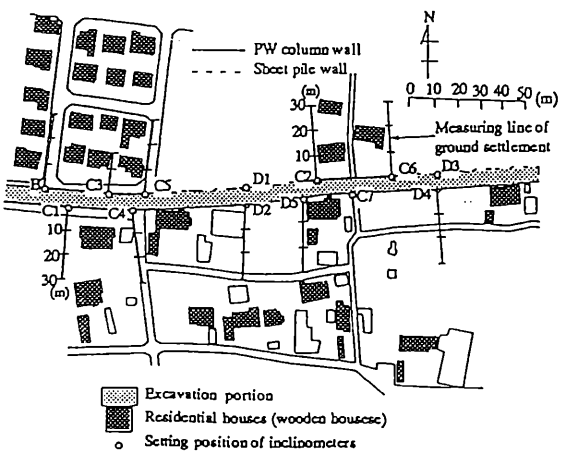


Fig. 1 Location map of job site

3.GROUND SETTLEMENT BEHIND THE RETAINING WALLS, SETTLEMENT AMOUNT AND INCLINED ANGLE OF THE WOODEN HOUSES

Fig. 3 is showing the relationship between distance from the retaining walls and settlement of ground behind the earth retaining walls classified by each type of breasting work as parameter. In this Figure, ground settlement behind the earth retaining walls is taken from settlement value which was measured at the date of strut setting after completion of excavation (refer to Fig. 2). From this figure, it is noted that settlement of ground behind the earth retaining walls caused by excavation in this construction is quite small with some fluctuation in each type of breasting work and ground settlement of the section where wooden houses are

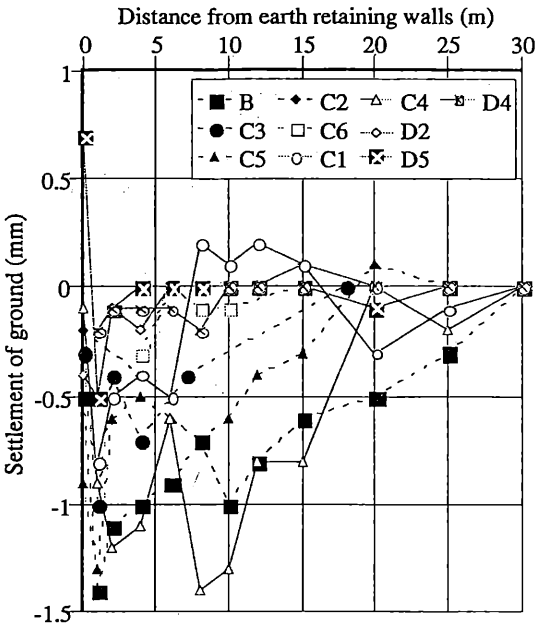


Fig. 3 Distance from earth retaining walls and settlement of ground

standing nearby is within allowable settlement when designed. Therefore, it is understood that use of PW column wall was effective.

Fig.4 and Fig.5 are showing the relationship between distance of the earth retaining walls and the maximum settlement and the maximum inclined angle of wooden houses which are located in northern part and southern part of the earth retaining walls, respectively. The maximum settlement was measured at corner pillars of the wooden houses when excavation was finished based on the bench mark which was installed in the houses before commencement of the construction. The maximum inclined angle of wooden houses are calculated by dividing the settlement of the corner pillars by distance between the pillars. The inclined angle is equivalent to the differential settlement

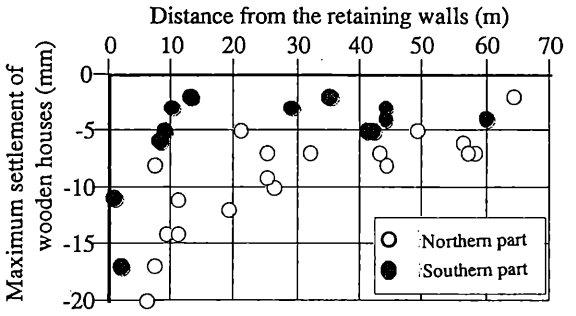


Fig. 4 Distance from earth retaining walls and maximum settlement

(Architecture Institution of Japan, 1988).

From these Figures, it is noted that the maximum settlement and the maximum inclined angle of the wooden houses has a tendency to decrease exponentialy according to the distance from the earth retaining walls. The settlement and inclined angle of the wooden houses are not so big difference between the houses located in northern part and that in southern part. However, attention should be paid to the fact that both the maximum settlement and the maximum inclined angle of the wooden houses which are located within 5 m from the earth retaining walls are considerably big.

4.STUDY OF DAMAGE, SETTLEMENT AND INCLINATION OF WOODEN HOUSES

4.1 *Classification of wooden houses' damage*

Damage investigation of residential wooden houses which are located in the area shown in Fig.1 was carried out. The damage and its degree are classified by comparing and assuring the progress of deformation of wooden houses and newly developed damage after completion of construction based on the state of the wooden houses before commencement of the construction.

Investigation items are settlement and crack of foundation, crack of inside and outside of the walls, function of the sliding doors and crack of concrete of the ground floor and step etc. as pre-investigation. They are measured and photographed. Then, the

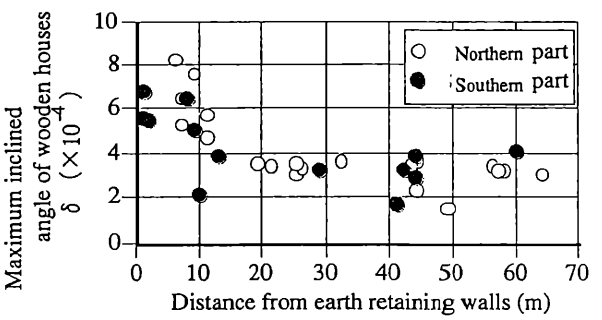


Fig. 5 Distance from earth retaining walls and maximum inclined angle of wooden houses

Table. 1 Damage ranking and definition

Rank	Damage definition
I	Crack of tile, Disorder of sliding door, Crack of concrete in earthen floor and steps
II	Crack of walls, Expanding of slit of walls, Drop of lower portion of walls, Rain water leaking
III	Settlement of foundation, Crack of foundation, Differential settlement of floor and ceiling

floor area, number of floors and construction years, etc..

Table 1 shows damage rank and damage details of wooden houses caused by excavation. In this table, damage rank I means damage degree that function of the damaged wooden houses can be recovered by simple repairs as replacement of some parts, damage rank III means degree that foundation of wooden houses is injured and large scale repairs are needed. Damage rank II means middle degree between rank I and III.

4.2 *Numbers of damages in houses and distance from earth retaining walls*

Fig.6 shows numbers of damages occurred in the wooden houses which are located 10 m in both side from the earth retaining walls. These numbers of damages are summed up by damage ranking. From this figure, it is clearly recognized that there is a correlation between damage of wooden houses caused by excavation and distance from the earth retaining walls.

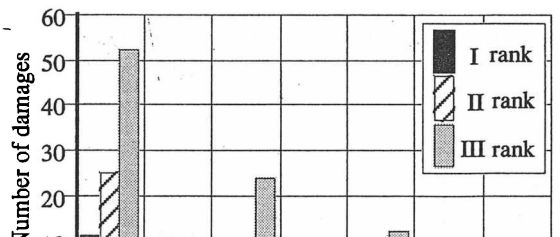


Fig. 6 Distance from earth retaining walls and number of damages classified damage ranking of wooden houses

In other words, the damages of wooden houses which are located within 20 m from the earth retaining walls are that of ranking III such as settlement of foundation, crack, settlement of floor, deformation of ceiling, namely, damage of main structure of the houses. The damages of wooden houses which are located within 40 m, are that of ranking II such as expand of slit between walls and pillars and crack of inside and outside walls. Comparatively slight damages such as disorder of slide doors, crack of tile and concrete of floor and steps occur up to as far as 60 m, from the earth retaining walls.In view of the foregoing, it is clear that numbers of the house damages decrease from damage ranking III to I according to the distance from the earth retaining walls. Moreover, there is no essential difference in damage between flat house and two stories house though not illustrated in the figure.

4.3 *Relationship between house damage and maximum settlement and maximum inclined angle*

Fig.7 shows the relationship between house damage and the maximum settlement and the maximum inclined angle. It also shows the extent of the maximum settlement and the maximum inclined angle corresponding to damage ranking of the wooden houses. From

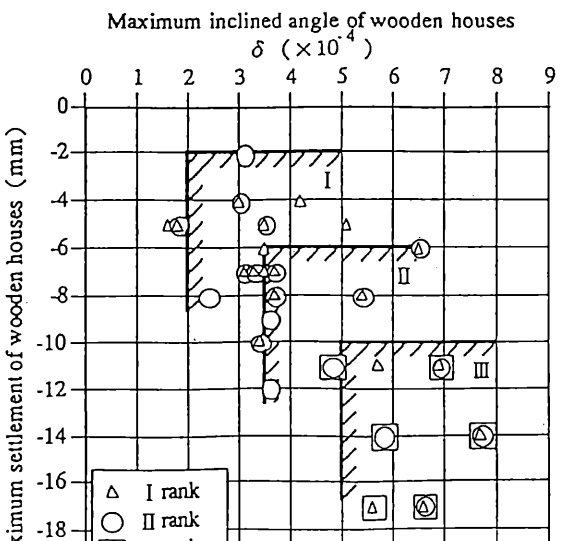


Fig. 7 The relation between damage ranking of wooden houses and maximum inclined angle, maximum settlement of woodden houses

this Figure, it is clearly noticed that the damages of the wooden houses are progressed from Ⅰ damage ranking of slight damage to Ⅲ damage ranking of main structure damage such as destruction of foundation, floor and walls corresponding to increment of the maximum settlement and the maximum inclined angle. Attention should be given to the fact that the maximum allowable settlement and the maximum allowable inclined angle corresponding to the damage ranking of wooden houses caused by ground settlement behind the earth retaining walls following excavation are 1.4/1000 and 1.0/1000 respectively, which are equivalent to the allowable inclined angle and allowable displacement angle proposed by Makata, et.al.(1980).

The Architectural Institute of Japan (1988) proposed in its criteria that limit of inclined angle corresponding to the first stage of damage such as crack of outside mortar walls and concrete step caused by differential settlement should be within 1.0/1000. It is noticed that the damage of wooden houses is considerably severe, though the maximum inclined angle measured in this study is smaller than the above-mentioned 1.0/1000.

5.SETTLEMENT DISTRIBUTION PATTERN IN GROUND BEHIND EARTH RETAINING WALLS AND DAMAGE OF WOODEN HOUSES

It is necessary to understand the distribution pattern of ground settlement behind earth retaining walls following excavation in order to study the influence that is given to the neighboring structures by the settlement. From such point of view, based on the theory which was proposed by Peck (1969), normal distribution of the ground settlement behind the earth retaining walls and distance from the earth retaining walls against the maximum excavation depth were estimated. Considering the normal distribution, the distribution pattern of the ground settlement behind the earth retaining walls is shown in Fig.8. In this case, ground settlement behind the earth retaining walls was measured at the date when the lowest strut was set after completion of the final excavation. In order to compare the distribution pattern of the ground settlement behind the retaining walls (line of demarcation shows -) with damage of wooden houses, location of the wooden houses standing along the measuring line is shown by marking ▼ in upper part of the same figure.

The following items are clarified after giving attention to the ground settlement behind the earth retaining walls and the settlement area in this figure.

(1) The ground settlement behind the earth retaining walls is small and the settlement area is not far from the earth retaining walls in case that duration of the excavation since its commencement up to completion is short.

(2) In this case, durations of the excavation are that first stage of excavation took 3 days and 6 days, then durations up to completion of excavation were 30, 37 and 38 days. Another case is that first stage of excavation took 9 and 18 days, then durations up to completion of excavation was 53 and 54 days.

(3) Particularly, in case of B type with 2 steps of strut, the influence extends so far. Regarding ratio of the ground settlement amount against the maximum excavation depth and the average ratio of breasting type with long excavation duration is about 3.1 and 3.3 times respectively, of ratio of short duration excavation.

Furthermore, compared Fig.8 and

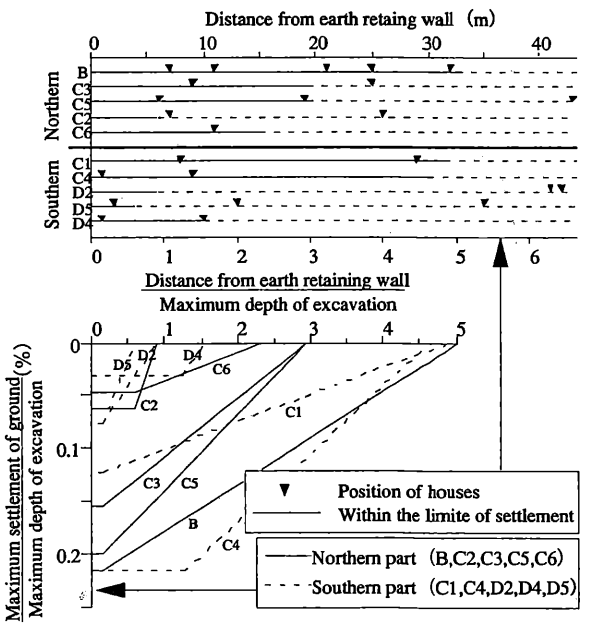


Fig.8 Damage of wooden houses and settlement distribution pattern of neighboring ground

Fig.6, it is understood that distribution pattern of the ground settlement behind the earth retaining walls caused by excavation and damage of wooden houses and its degree can be estimated from relationship of distance from the retaining walls. In other words, in case of construction adjacent to residential houses, it is clear that damage of neighboring wooden houses caused by the ground settlement behind the earth retaining walls can be mitigated by making excavation shallow and excavation duration short, specially by making duration of first step excavation short. Of course, stiffness of the earth retaining walls should be increased.

6.CONCLUSIONS

In this report, regarding the relationship between the ground settlement behind the earth retaining walls and the damages of the neighboring wooden houses during excavation with open cut in soft ground, distance from the earth retaining walls and the maximum settlement and the maximum inclined angle, moreover influence of settlement distribution pattern in ground behind the earth retaining walls are studied in aspect of the retaining walls and duration of excavation. It is concluded;

(1) The maximum settlement and maximum inclined angle of the wooden houses and number of the damages are decreased exponentially as increasing the distance from the earth retaining walls. Particularly, damage of the main structure happened within 20 m, and comparatively slight damages happened in area far up to 60 m.

(2) Magnitude classification of the maximum settlement and the maximum inclined angle corresponding to the damage ranking of the wooden houses are clarified.

(3) The settlement distribution pattern of the ground behind the earth retaining walls is substantially affected by the duration from first stage excavation to completion of excavation. It is clarified that the ground settlement behind the earth retaining walls and the settlement distribution pattern can make small by finishing the excavation within short duration.

(4) In order to minimize damage of the wooden houses caused by ground settlement behind the retaining walls, it is essential that excavation depth in each excavation stage should be shallow and excavation duration particularly excavation of first stage should be short.

In view of the foregoing, results of this will be useful to establish countermeasure corresponding to the foundation and neighboring resident condition in case to carry out excavation in the residential area under the strict restriction of the foundation condition and ecological circumstance. Results of this study will also be useful for reasonable set of the earth retaining walls, excavation method and construction management, measuring system management and furthermore for pre and post investigation of structure deformation and obtain the settlement distribution pattern of the neighboring area in order to restrain the deformation of the earth retaining walls and protect structures from harmful damages.

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