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Deformation of Retaining Walls Caused by Construction of Soil-Cement Column

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ABSTRACT

With the increasing demand for housing, homes built on cut earth or embankments have also been increasing. In order to effectively use the land for housing, houses in the vicinity of retaining walls are often built during reclamation. A problem sometimes occurs in the vicinity of the existing retaining wall due to displacement. However, because the mechanism is not clear, it is difficult to carry out the suitable countermeasure for the displacement of the retaining wall.
In this paper, based on the observed displacement of the retaining walls in the vicinity of the ground reinforcement work, some considerations are described. In addition, the actual troubles of the retaining walls are also described in the paper.

KEY WORDS: Retaining wall, Soil-cement column, Deformation

Results of Deformation of Retaining Walls

Columnar improvement method is often used in residential ground, because it is an inexpensive method. Construction of the soil-cement column method is performing the mixing and stirring of the soil of the original ground and cement slurry. Cement slurry is made by mixing the water and cement stabilizers. The purpose of the soil-cement column is to improve the bearing capacity of the ground and decrease the differential settlement of the foundation of the house. In the land with a retaining wall, there are some cases where spread foundation cannot be adopted as ground is weak, and the compaction of the backfilling of the retaining wall is insufficient. In these cases, the soil-cement column or steel pile of small diameter are frequently used in the construction site. When the soil-cement column is constructed in the vicinity of the existing retaining wall, it has been reported that the displacement and cracks of the existing retaining wall are observed in many cases.
However, it is difficult to carry out the suitable countermeasure to the displacement of the retaining wall because the mechanism and cause are not clear (see Fig.1). In this chapter, we show the results of a survey on deformation cases.

Fig.1 Deformations of retaining wall

The authors investigated 18 construction companies which experienced the deformation and cracks of retaining wall by columnar improvement method. The authors summarized 58 cases in 2007-2009. Research items are deformations of retaining wall, positional relationship of the soil-cement column and the height of retaining wall and construction machine. Total result with regard to the types of deformation of retaining walls is shown in Fig.2.
The concrete block (CB) is largely used as simple earth retaining wall, and the result of 35 cases except for the CB is shown in Fig.3. Deformation caused by sliding of the retaining wall is the largest percentage, as shown in Fig.2. This result shows that retaining wall is displaced by lateral earth pressure when the soil-cement column is constructed. It is in the order of crack, followed by the incline of the retaining wall. In past experiments, lateral earth pressure acting on bottom slab of the retaining wall is about 100kN/m^2 when the soil-cement column is constructed, and it is considered that the cause of the deformation is the lateral earth pressure acting on the retaining wall.

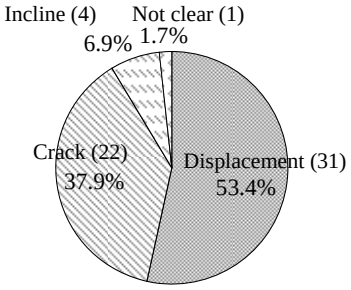

Fig.2 Ratio of deformation types (including concrete blocks)

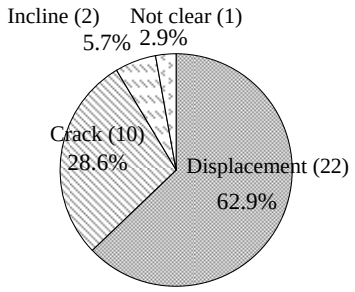

Fig.3 Ratio of deformations types (except concrete blocks)

Total result with regard to types of retaining wall deformations is shown in Fig.4. 23 of 58 cases is CB. According to the research result of the survey of the existing retaining wall, 7.1% of 212 cases surveyed by Susuda in 2008 and 4.1% of 127 cases surveyed by Kurosaki in 2009 was CB, but it is the largest proportion in the deformation case. CB is easily deformed by lateral earth pressure because it is the simplest earth retaining wall with small resistivity.
L-type retaining wall (precast) is 16 of 58 cases, and (cast in place) is 9 of 58cases. According to the research result, L-type retaining wall has been used 20.8% of 212 cases, and 22% of 127 cases. Kenchi blocks retaining wall was used 29.7% of 212 cases, and 23% of 127 cases. However, deformation case was less, and an example of Kenchi blocks retaining wall is shown in Fig.5.

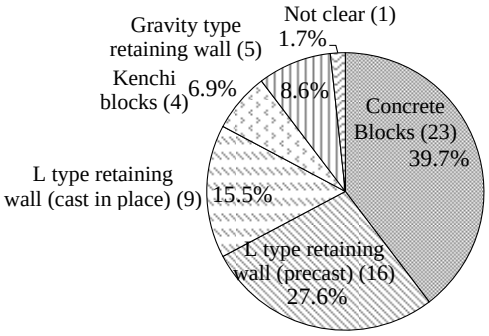

Fig.4 Ratio of retaining wall types

Fig.5 Example of Kenchi blocks retaining wall

In Fig.6, a graph of the relationship between X (the distance of the soil-cement column position from the front retaining wall) and H (retaining wall height) is shown. As shown in Fig.6, deformations occur within the first 2 meters from the ground.
It may be due to the fact that retaining walls of less than 2m in visible height is not subjected to the regulation of the Building Standards Law and the Law on the Regulation of Housing Land Development in Japan, and the retaining wall structure is not enough to satisfy the adequate specification. The retaining wall of less than 2m in visible height is easily deformed by lateral earth pressure because weight of backfilling and its own weight are relatively small. In those cases, it is necessary to examine soil-cement column position and construction sequence in the design phase.

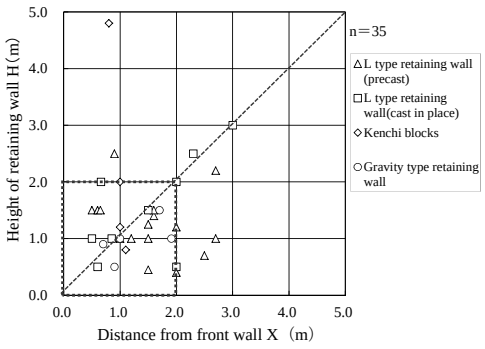

Fig.6 Relation between height and distance

Total result with regard to types of construction equipment is shown in Fig7. Within 58cases we studied from 2007-2009, crawler type construction machine was used for soil-cement column more than 80%. Ground pressure of 8t class crawler is about 50kN/m^2 calculated from the ground area of caterpillar and construction machine weight. However, loaded weight of the retaining wall is usually 10kN/m^2 when designing the structure. This value is a ground pressure by the traffic load. The center of gravity is moved when setting up the leader of the construction machine, and ground pressure of the machine front is calculated about 110kN/m^2. It is possible that the retaining wall is deformed just by construction machine movement.
In order to reduce the influence of the ground pressure of the construction machine, it is preferable to select construction machine as light weight as possible in some cases. Total result by type of crawler is shown in Table 1. It is only four cases in case of machine weight less than 6 tons.

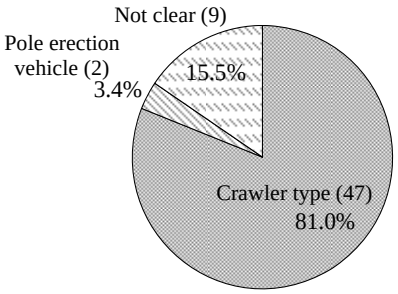

Fig.7 Ratio of construction equipment types

Table 1 Weight of construction equipment

Weight of construction equipment	Numbers
~6t	4
8t	29
8~10t	10
10t~	2
25t	1
Not clear	1
Total	47

Fig.8 shows the change in the ground pressure at the time of the extraction and excavation of the stirring blade of construction machine. Ground pressure at the rear of the construction machine is increased at the time of stirring blade extraction. On the other hand, ground pressure at front of the construction machine is about 150kN/m^2 at the time of the excavation.

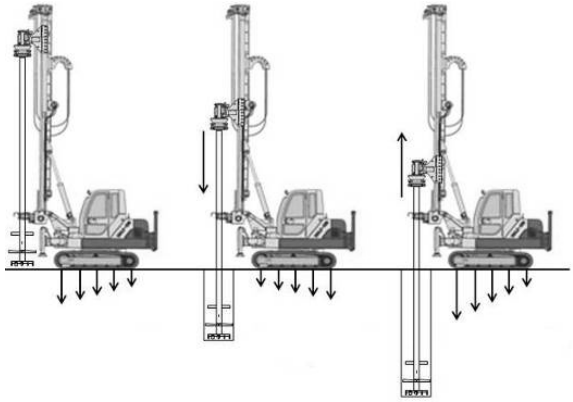

Fig.8 Vertical pressure of crawler type machine

Ground pressure due to the construction machine would cause deformation of retaining wall. During the construction of the soil-cement column, deformation of existing retaining walls is influenced by a variety of overlapping factors. Causes considered are the ground pressure due to the construction machine, speed of the extraction and excavation, lateral earth pressure, and amount (volume) of the slurry. When planning stage of construction, it is important to predict the deformation of retaining wall and examine the countermeasures.

Cases of Deformation of Retaining Walls

In this chapter, the authors describe 10 deformation cases of retaining wall when the soil-cement column is constructed in the vicinity of the existing retaining wall.

Case1 (Masonry retaining wall)
Joints of retaining wall were cracked after the soil-cement column had been constructed in the land where old masonry retaining walls existed. Soil-cement column was constructed by 11t class machine. Fig.9 shows the retaining wall joints. If there is old masonry retaining wall on site, it is necessary to consider the possibility of deformation occurring when applying ground improvement work.

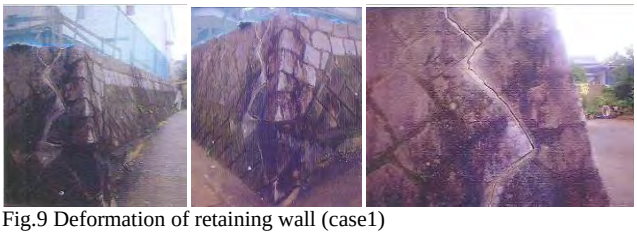

Fig.9 Deformation of retaining wall (case1)

Case2 (Oya tuff stone retaining wall and concrete blocks)
The CB was cracked when the soil-cement column was constructed in the housing site where the CB was constructed on top of Oya tuff stone retaining wall. Example of the Oya tuff stone retaining wall is shown in Fig.10. This site is estimated to be cohesive soft clay ground from the location. Soil-cement column was constructed by 6t class machine. Column's diameter was 500mm and length was 3.5m. Fig.10 shows crack of the CB. Crack was found in the the CB when leveling the ground, and was 3cm width at most. The cause is considered to be related to speed of the extraction, excavation and the cement slurry injection. It is inferred from the crack condition of the CB that the soil pressure had affected the lower part of the retaining wall.

Fig.10 Example of Oya tuff stone retaining wall

Fig.11 Deformation of retaining wall (case2)

Case3 (Masonry retaining wall and concrete blocks)
The masonry retaining wall and concrete blocks were deformed by the lateral earth pressure when the soil-cement column was constructed. This site is estimated to be cohesive soft clay ground. The Soil-cement column was constructed by 6t class machine. Column's diameter was 500mm and length was 7.0m. Fig.12 shows deformations of the masonry retaining wall and the CB. The Soil-cement column was constructed away from the retaining wall because the retaining wall and column position was close. However, deformation and cracks in the block joints occurred in the masonry retaining wall.

Fig.12 Deformation of retaining wall (case3)

Case4 (Concrete blocks)
5 block high retaining wall was displaced when the soil-cement column was constructed in the housing site. The Soil-cement column was constructed by 8t class machine. Column's diameter was 500mm and length was 5.0m. Fig.13 shows displacement of the CB. Preceding excavation was carried out at soil-cement column position for the soil pressure reduction because the retaining wall and column position was close. However, the displacement of about 15mm occurred in the CB. The cause is presumed that the counterfort 800mm protruding from CB was affected by the lateral earth pressure.

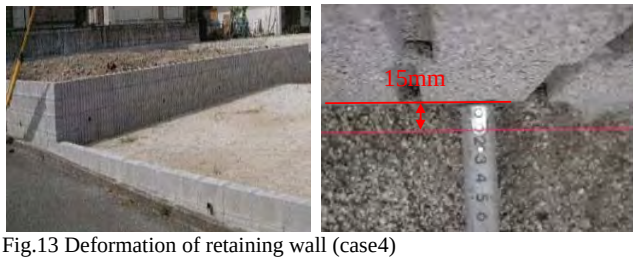

Fig.13 Deformation of retaining wall (case4)

Case5 (Gravity type retaining wall and concrete blocks)
2 block high retaining wall added on top of the existing gravity type retaining wall was damaged. The soil-cement column was constructed by 8t class machine. Column's diameter was 500mm and length was 4.5m. Fig.14 shows crack of the CB. Workers had to check the condition of the retaining walls during construction. However, the CB and gravity retaining wall was cracked after the completion of construction. Cracks did not occur when soil-cement column was constructed near the retaining wall. The cause is considered to be the inflation pressure due to solidification of the soil-cement column.

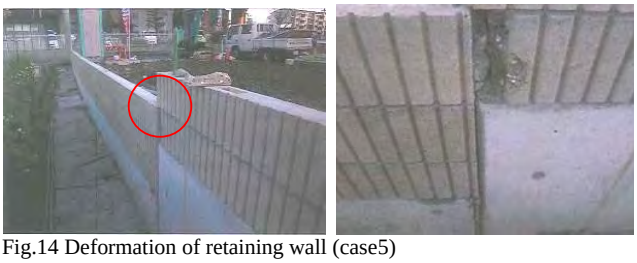
Fig.14 Deformation of retaining wall (case5)

Case6 (Gravity type retaining wall)
The gravity type retaining wall was cracked about 5mm at the center of wall when the soil-cement column was constructed. Soil-cement column was constructed by Pole erection vehicle. Column's diameter was 600mm and length was 3.5m. Fig.15 shows crack of the gravity retaining wall. Largest amount of confirmed displacement damage is 20mm. The length of the retaining wall was 10m or more, but there were no drainage holes and expansion joints. Cause is presumed to be structural defects of the retaining wall.

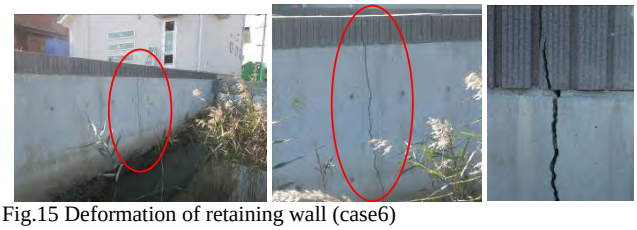
Fig.15 Deformation of retaining wall (case6)

Case7 (L-type retaining wall <precast>)
The L-type retaining wall (precast) was displaced when the soil-cement column was constructed. Height of the wall was 1200mm and length of deck slab was 800mm. The Soil-cement column was constructed by 8t class machine. Column's diameter was 600mm and length was 5.0m. Fig.16 shows displacement of the L-type retaining wall (precast). Deck slab of retaining wall and the column position had been checked before soil-cement column was constructed. However, the L-type retaining wall moved horizontally about 30mm because workers had not paid much attention to the retaining wall.

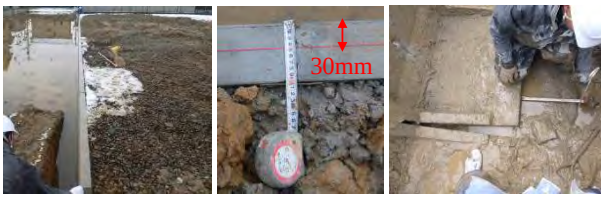

Fig.16 Deformation of retaining wall (case7)

Case8 (L-type retaining wall <cast in place>)
The L-type retaining wall (cast in place) was displaced and cracked when the soil-cement was constructed. Height of the wall was 1800mm and length of deck slab was 1300mm. The Soil-cement column was constructed by 8t class machine. Column's diameter was 600mm and length was 8.5m. Fig.17 shows crack and displacement of the L-type retaining wall (cast in place). Deck slab of the retaining wall had been checked before soil-cement column was constructed. In addition, in spite that the construction sequence and column position were examined, the deformation occurred by the soil-cement column construction.


Fig.17 Deformation of retaining wall (case8)

Case9 (L-type retaining wall <precast>)
The L-type retaining wall (precast) was deformed when the soil-cement column was constructed. Height of the wall was 1500mm. The Soil-cement column was constructed by 8t class machine. Column's diameter was 500mm and length was 2.5m. Fig.18 shows deformation of the L-type retaining wall (precast). Preceding excavation at soil-cement column position was carried out, but the deformation occurred. The change of construction method should be examined in residential land when there is a retaining wall.

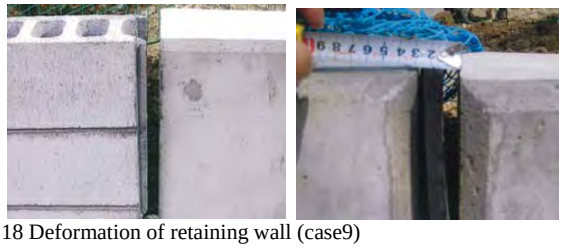
Fig.18 Deformation of retaining wall (case9)

Case10

Hair line crack of the retaining wall worsened when the soil-cement column was constructed in the vicinity of the existing retaining wall. The Soil-cement column was constructed by 8t class machine. Column's diameter was 600mm and length was 7.0m. Fig.19 shows crack of the retaining wall of unreinforced concrete.

Before construction of the column

After construction of the column

Fig.19 Deformation of retaining wall (case10)

As there were pores near the cracking point, it is considered to be a defect at the stage of construction of the retaining walls. In addition, the corners are not reinforced and there are no expansion joints. The cause of deformation is considered to be the defect structure of the retaining wall. It should be noted that corner of retaining wall is easily deformed by tensile force (Fig.20).

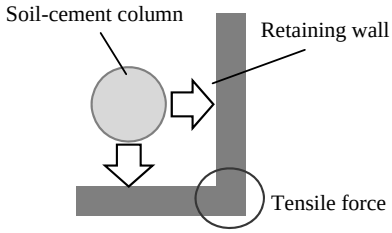

Fig.20 Soil-cement column and corner of retaining wall

SUMMARY

In this paper, we reported on a survey on deformation cases and the contents of 10 deformation cases. Cause of deformation cases observed are as follows.

1. The displacement is mostly caused by horizontal sliding of the existing retaining wall.
2. It was also inferred that the lateral earth pressure to the existing retaining wall is exerted significantly when the stirring blade of the construction machine passes through the side of bottom slab of the retaining wall, and influence of the weight of the construction machine to the displacement is not negligible.
3. Damages caused by the displacement of the existing retaining walls are mostly observed within 2m height of the ground. It may be because the retaining wall of less than 2m in visible height is not subject to the regulation of the Building Standards Law and the Law on the Regulation of Housing Land Development in Japan, and does not satisfy adequate specification.
4. Finally, it was found that the damage and displacement of the existing retaining wall are observed in many cases especially when the prior prediction of displacement was insufficient.

It is a future task to investigate the simple method of estimating the possibility of displacement and damage prior to and during construction of retaining walls. Further, prediction for preventing accidental deformation of existing compromised retaining wall is also necessary because retaining walls are an important structure to protect the life and property of people living in the houses and also guarantee the peripheral equipment safety.

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