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REUSE OF EXISTING PILES IN BUILDING RECONSTRUCTION AND ITS ENVIRONMENTAL EFFECTS

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Summary

This paper presents two case studies on reuse of existing cast-in-place concrete piles including existing underground structures in building reconstruction in Tokyo and Osaka, Japan. The main contents are how to deal with the existing piles in structural design and the evaluation of the supporting capability, namely integrity, durability and bearing capacity of the existing piles. It is expected that settlement stiffness of the existing pile is larger than that of the newly constructed pile due to loading hysteresis. In the two cases, the difference in settlement stiffness between the existing and newly constructed piles was obtained from pile loading tests. Using the different settlement stiffness, we made an overall settlement calculation of the building with foundation and piles. According to the stress distribution obtained from the settlement calculation, we designed the mat foundation and the reinforcement of existing foundation beams. Trial calculation was made for evaluating an amount of reduction in pile input-resources. The reduction is brought by the reuse of existing piles instead of a part of newly constructed piles. A new technique for checking out the pile-shaft integrity, namely borehole sonar, is also introduced. We confirmed its validity through site measurement tests.

1. Introduction

Existing piles are usually removed in the case that they are obstructive when a new foundation is designed by leaving such piles as they are. However, they are pulled out of the ground with difficulties and may loosen the ground when pulled out. It results in a lowering of the bearing capacity of adjacent piles installed newly in many cases. Besides, removed piles have to be disposed as construction wastes.

Reuse of existing piles, which is capable of the reduction in pile input-resources, yields not only the reduction in the construction cost and the shortening of the term of works but also the reduction in environmental impact. Therefore, reuse of existing piles in building reconstruction is very important for structural sustainability [1]. In view of the social situation for environmental problems, Building Contractors Society of Japan [2] published the guidance for utilization of existing piles.

This paper introduces the outlines of two case studies on reuse of existing cast-in-place concrete piles in Japan. The results of trial calculation of its environmental effects are also presented for reference. Besides, a new pile-shaft integrity technique for investigating the configuration of pile cross-section, namely borehole sonar, is introduced.

2. Characteristics of Case Studies on Pile Reuse

Table 1 shows the characteristics of the two case studies on reuse of existing cast-in-place concrete piles. The pile construction methods were caisson type pile method and overall casing method. For the two cases, the foundation was formed by the combination of existing piles and newly constructed piles. Rapid pile loading tests, those are relatively simple in operation, were adopted for the two cases to investigate the settlement stiffness of the piles. However, conventional static pile loading tests are more advantageous in some cases when checking the designed ultimate bearing capacity of a pile. The method of pile loading should be selected according to the situation on the occasion of investigation.

Table 1 Characteristics of Case Studies on Reuse of Existing Cast-in-Place Concrete Piles [3]

Case No.	Construction Method	Old Building	Survey of Existing Piles	Use Method of Existing Piles	Total Numbers	Nos. for Rapid Loading Test
1	Caisson Type Pile Method	Constructed in 1972	In 1994	Support Vertical Load	14 Existing, 8 New Piles	1 Existing, 1 New Piles
2	Overall Casing Method	Constructed in 1971	In 1996 (Pre. in 1994)	Support Vertical, Horizontal Loads	157 Existing, 90 New Piles	1 Existing Pile (Pre. 1 Exist.)

3. Case Study on Pile Reuse in Tokyo (Case 1)

3.1 Building and Ground Conditions [4,5]

Two reinforced concrete buildings constructed in 1972 were located at the construction site of a proposed new ten-storied building in Chiyoda-ku, central part of Tokyo. One building in the northern part of the site had four stories above ground and two stories underground, and was supported by large diameter cast-in-place concrete bell piles. The other building in the southern part of the site had six stories above ground and one story underground, and was supported by cast-in-place concrete piles.

The new ten-storied, 48 m high building has three stories underground, and its floor area is about 37 m by 50 m as shown in Figs. 1 and 2. The foundation in the southern part of the new building is a raft foundation. In the northern part of the new building, existing cast-in-place concrete bell piles were reused as a part of the foundation. The existing piles were designed to support only vertical loads since seismic lateral loads had not been fully taken into account in their past design. The entire seismic lateral loads were designed to be supported by newly constructed piles. Therefore, eight new cast-in-place concrete bell piles were added to 14 existing piles, as shown in Fig. 2. For both the exiting and new piles, the shaft diameter was 2.4 m to 3.9 m and the toe diameter was 2.6 m to 4.1 m. The existing and new piles were connected to a 1.4 m thick reinforced concrete mat slab to cope with eccentricity of the piles and columns.

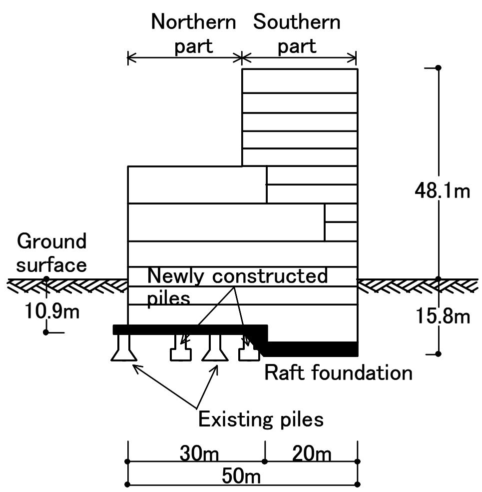


Figure 1 Schematic of new building [4] (Case 1)

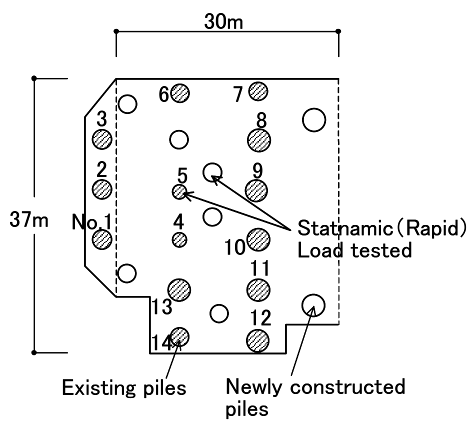


Figure 2 Layout of existing and newly constructed piles [4] (Case 1)

Soil profiles are shown in Fig. 3, together with the schematics of rapid loading test piles mentioned later. Those were obtained from the soil investigation at the bottom of the second basement floor of the old building which was about 10 m deep from the ground surface. The pile toes were embedded in the very dense sand layer.

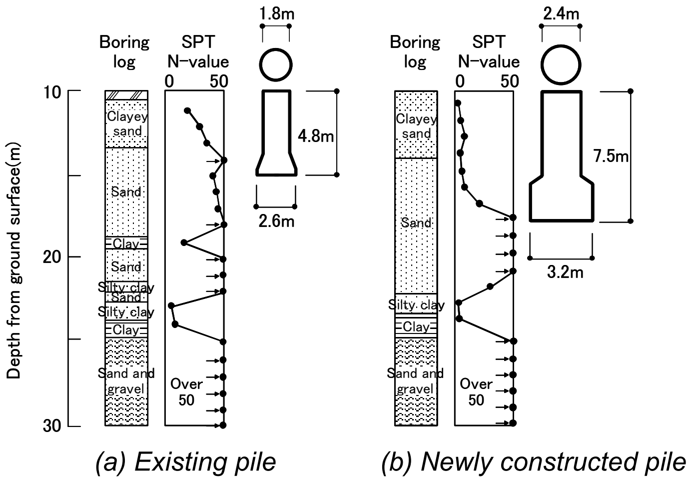


Figure 3 Soil conditions and schematics of load-tested piles [4] (Case 1)

3.2 Investigation of Existing Piles [4,5]

When reusing existing piles, it is necessary to guarantee the quality of the pile materials including their durability during the lifetime. To assure the quality of the pile materials, several kinds of tests were conducted.

Sonic integrity testing using a low-strain method was conducted for all 14 existing piles to investigate their soundness and lengths (see Photo. 1). In the tests, any severe defect was not detected in the pile bodies. The validity of the values of pile lengths estimated from the test results was assessed by selecting three existing piles whose lengths were known by means of core-borings of the pile concrete (see Photo. 2).

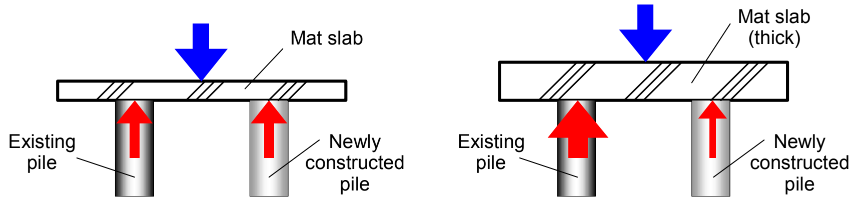
To investigate the durability of the pile materials, carbonation testing of concrete, compressive testing of concrete and tensile testing of reinforcing bars were conducted. In the carbonation testing, the degree of carbonation was evaluated by spraying a mixture of 1 % phenolphthalein and 99 % ethyl alcohol onto the pile-top surface of the selected six piles (see Photo. 3). Since those portions underwent a color change to red, it was judged that the pile concrete was not carbonated. 18 compressive tests were conducted on the concrete core specimens sampled from the three piles mentioned above (Photo. 2), and the compressive strength obtained from the tests was more than the design strength of 17.6 MPa. Six specimens of reinforcing bars were cut off from the top part of the selected two piles, and the tensile strength obtained from the tests was more than the design strength of 490 MPa.

Photograph 1 Sonic integrity testing (Case 1)

Photograph 2 Concrete cores of a pile (Case 1)

Photograph 3 Carbonation testing of pile concrete (Case 1)

It is expected that the vertical pile head stiffness, namely settlement stiffness, of the existing pile is larger than that of the newly constructed pile due to the effect of pre-loading from the old building. To investigate the difference in settlement stiffness between the existing and new piles, rapid pile loading tests were conducted for one existing pile and one new pile whose positions are indicated in Fig. 2. Rapid pile load testing is simpler and more cost-effective than conventional static pile load testing. As indicated in Fig. 4, the mat slab is thicker for larger difference in settlement stiffness between the existing and new piles.



(a) Equal settlement stiffness *(b) Different settlement stiffness*

Figure 4 Schematic diagram of design of mat slab according to difference in settlement stiffness between existing pile and newly constructed pile [3]

The rapid loading tests were conducted on the second basement floor of the old building after demolishing its superstructure. The dimensions of the two test piles are shown in Fig. 3. The planed maximum pile head loads were 4.9 MN and 7.8 MN for the existing and new piles, respectively. Fig. 5 shows the relationship as static behavior between unit toe resistance and ratio of pile head settlement to pile toe diameter, where the unit toe resistance was obtained by dividing the pile head load by the cross-sectional area at the pile toe. It was concluded that the settlement stiffness of the existing pile per unit cross-sectional area at the pile toe was almost equal to that of the new pile. Moreover, the difference between the settlement stiffness in design and that obtained from the rapid loading tests was within 25%, so that the validity of the design value was confirmed.

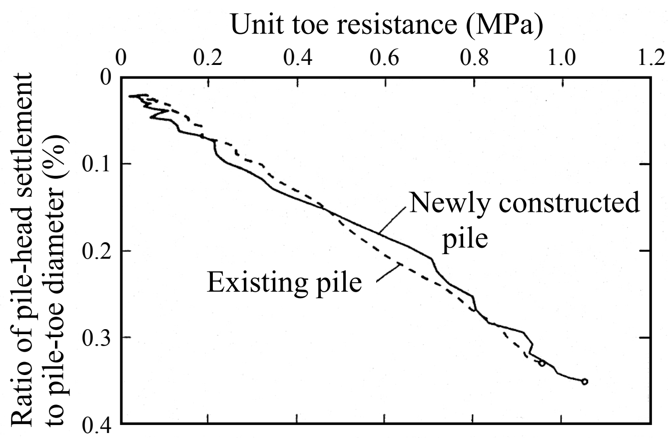


Figure 5 Relationship between unit toe resistance and ratio of pile-head settlement to toe diameter [4] (Case 1)

3.3 Trial Calculation of Environmental Effects

Simple trial calculation of the environmental effects yielded by reuse of existing piles was made on a certain assumption. The environmental effects considered were the reduction in the volume of newly constructed piles and the reduction in the amount of emission of carbon dioxide when demolishing existing piles and/or constructing new piles.

On the assumption that the weight of the new building is equal to that of the old building, 14 new piles are required when no existing pile is reused. It results in the reduction of six new piles because of eight new piles for reusing existing piles. Therefore, the rate of reduction in the volume of new piles is about 40 %.

When no existing pile is reused, it is assumed that 14 new piles are constructed and 6 existing piles are demolished due to the overlap with 6 new piles. According to the results of trial calculation where the amount of emission of carbon dioxide for demolishing an existing pile is about three times that for constructing a new pile [2], the rate of reduction in the amount of emission of carbon dioxide is about 70 %.

4. Case Study on Pile Reuse in Osaka (Case 2)

4.1 Building and Ground Conditions [6,7]

The old building constructed in 1971 had eight stories aboveground and three basement floors.

The new building in Umeda-district, central part of Osaka, is a commercial one of 48.8 m in height, ten stories aboveground and three basement floors. Each floor has a J-shaped plan of 114.6 m by 75.7 m. The total floor area is 44,335 m^2. In addition, a Ferris wheel of 75 m in diameter is mounted on the seventh floor. Fig. 6 shows a section of the new building. Fig. 7 shows an arrangement plan of piles.

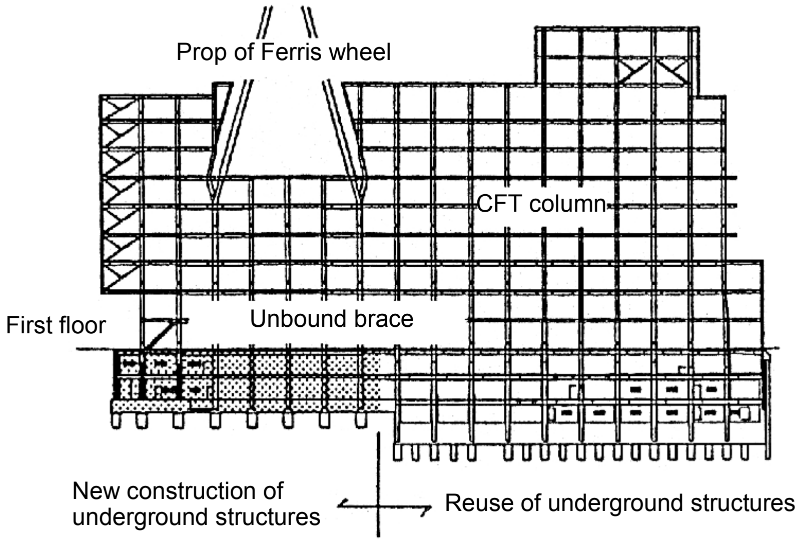


Figure 6 Schematic of new building [3] (Case 2)

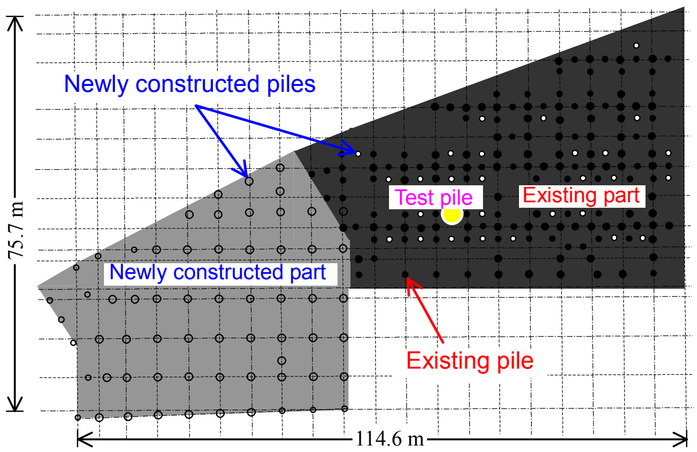


Figure 7 Layout of existing and newly constructed piles [6] (Case 2)

As indicated in Figs. 6 and 7, the left half is a totally newly constructed part, and the right half is an existing part where underground structures including existing piles were reused. The left and right parts have been designed structurally as one body. To reuse the underground structures according to the present technical standards, it was necessary to reinforce them against the increment of working loads due to redesign of aboveground structures and against earthquakes. To ensure the overall bearing capacity and earthquake resistance of pile foundation at the right existing part, new piles were constructed as shown in Fig. 7. Existing piles were designed to carry mostly part of working loads. Both the existing and newly constructed piles are cast-in-place concrete ones. The existing piles are straight ones by the overall casing method, whose diameter is 1.0 m or 1.2 m. The new piles have enlarged bases by the earth drill method, ranging 1.2 m to 1.6 m in shaft diameter. The numbers of the existing and new piles are 157 and 90, respectively.

Fig. 8 shows an existing pile and summary of soil investigation. The soil surrounding pile shaft is alluvial clay. The bearing stratum is gravel bed at a depth of about 30 m from ground surface. Pile toe is socked into it by 1.0 m. We confirmed that a diluvial clay layer under the bearing stratum was overconsolidated.

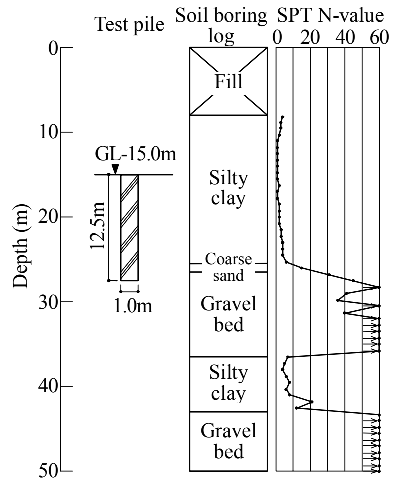


Figure 8 Test pile and summary of soil investigation [7] (Case 2; main investigation)

4.2 Investigation of Existing Piles [6,7]

To take into account the difference in settlement stiffness of the existing and new piles in design, we decided to investigate the settlement stiffness of the existing pile by a loading test. Since the old building had not been demolished at that time, rapid pile loading tests were planed at two stages. The first stage was previous investigation at a design step, where rapid load was applied to an existing cast-in-place concrete pile at the adjoining empty lot. The test pile had been constructed almost at the same time and by the same method as the existing piles of the old building. The second stage was main investigation at a construction step, where an existing pile to be reused was rapidly loaded to confirm its settlement stiffness after the demolition of the old building. The sequence of operation of the two rapid loading tests is illustrated in Fig. 9.

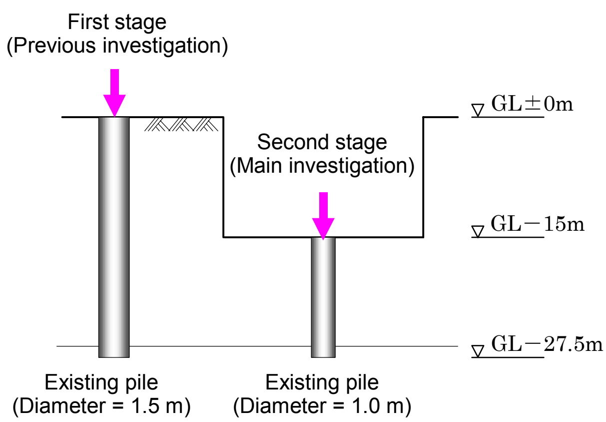
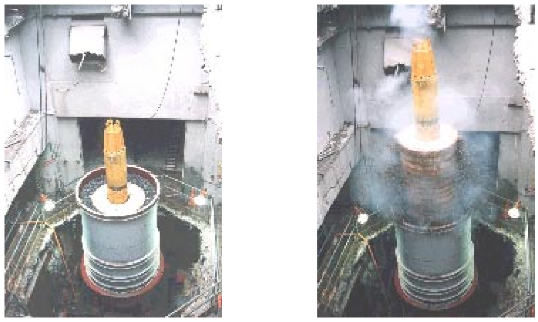


Figure 9 Sequence of operation of two rapid loading tests of existing piles [3] (Case 2)

In the first stage, the settlement stiffness of an existing pile of the old building was estimated by analyzing the results of the rapid loading test using the finite element method. On the other hand, the settlement stiffness of a new pile was obtained by the conventional pile settlement analysis. The settlement stiffness of 730 kN/mm for an existing pile was about 1.4 times that of 530 kN/mm for a new pile with the same diameter, and both were used in the design. For the test pile, the integrity and durability of the pile materials were also checked out.

In the second stage, the rapid loading test was conducted at a depth of 15 m from ground surface. Photo. 4 shows the test scenes. The test pile was 1.0 m in diameter and 12.5 m in length as shown in Fig. 8. Fig. 10 shows the estimated static load-settlement curve at pile head, together with the measured rapid curve and its simulation one. From the estimated static curve, the settlement stiffness of 710 kN/mm was obtained at a load level of the allowable bearing capacity of 2 MN, which was almost equal to that of 730 kN/mm in the first stage. In addition, the designed ultimate bearing capacity of 6 MN was confirmed from the static curve.



(a) Before loading *(b) During loading*

Photograph 4 Scenes of rapid pile loading test (Case 2; main investigation)

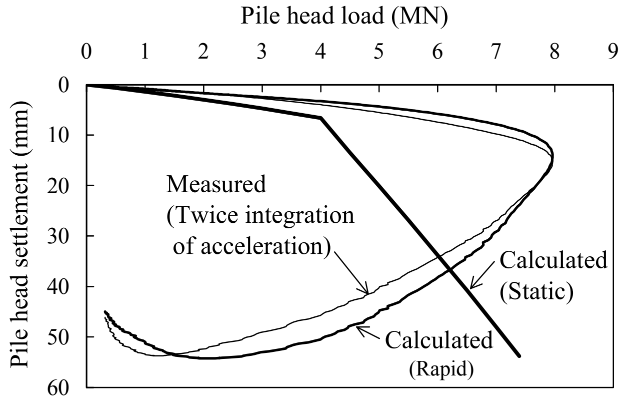


Figure 10 Estimated static load-settlement curve at pile head [3] (Case 2; main investigation)

4.3 Trial Calculation of Environmental Effects

For simplicity, the volume of a new pile is assumed to be uniformly 2.6 times that of an existing pile with the different diameter and the different length. Moreover, the resistance against earthquakes of an existing pile is assumed to be equal to that of a new pile, and the total volume of additional new piles required for no reuse of existing piles is set to be equal to that of existing piles. In this case, the rate of reduction in the volume of new piles is about 40 %.

When no existing pile is reused, the total volume of additional new piles is assumed to be equal to that of existing piles. In addition, it is assumed that all existing piles are demolished due to the overlap with new piles. In this case, the rate of reduction in the amount of emission of carbon dioxide is about 70 %.

5. Borehole Sonar

For an existing cast-in-place concrete pile, it is important that the cross-sectional area of the pile is guaranteed along the pile shaft. We introduce a new pile-shaft integrity technique for investigating the configuration of pile cross-section, namely borehole sonar.

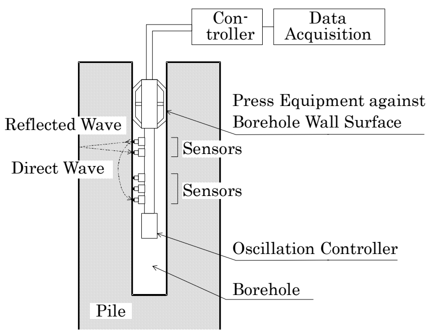
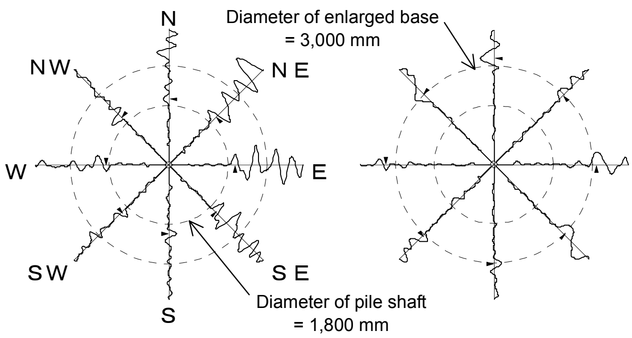


Figure 11 Schematic of borehole sonar



(a) Pile Shaft *(b) Enlarged base*

Figure 12 Example of borehole sonar measurements

Fig. 11 shows the schematic diagram of the borehole sonar measurement. At first, the sonar heads of generator and receiver is attached to the inside of the borehole vertically drilled in the pile concrete. Next, P wave is generated in the horizontal direction, and the reflected wave from the outer circumferential surface of the pile is received. Fig. 12 shows an example of the results of the borehole sonar measurement performed on a cast-in-place concrete pile with an enlarged base [8]. The performance of the borehole sonar has been confirmed through the site measurement tests.

6. Concluding Remarks

This paper presents two case studies on reuse of existing cast-in-place concrete piles and the results of simple trial calculation of its environmental effects. A new technique for checking out the pile-shaft integrity, namely borehole sonar, is also introduced.

The amount of occurrence of sludge from construction site is certainly reduced with the reduction in the volume of newly constructed piles when reusing exiting piles. However, it is desirable that we consider not only newly constructed piles but also the mat slab coped with eccentricity of the piles and columns when we evaluate the amount of reduction in the input-resources such as concrete and reinforcing bars.

It is noted that the results of trial calculation of the environmental effects yielded by reuse of existing piles are expected to easily vary according to the design condition.

The trial calculation on the amount of emission of carbon dioxide was made only for execution. However, in fact the unit load for material production is several times that for execution. Therefore, it is desirable that we evaluate the amount of emission of carbon dioxide including the amount for material production.

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