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Case-history
Development of Sheet Pile Foundation

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1. Introduction

Since the Great Hanshin earthquake in 1995, the seismic performance of newly designed buildings in the railway industry has been improved by the seismic design reviewed after the earthquakes. In addition, various aseismic reinforcement methods have been developed and utilized into existing buildings, improving their safety. After the massive seismic ground motion that occurred in the Great East Japan Earthquake, 2011, railway structures built after the Great Hanshin earthquake and reinforced by the aseismic reinforcement methods were found to be relatively less damaged, which clearly proved the effectiveness of the improved design and construction methods in the field of railway engineering. The social needs for foundations of railway structures are considered to be (1) Low cost, (2) Narrow space constructions, and (3) Harmony with the environment. This paper introduces "Sheet Pile Foundation" as one method meeting these three requirements.

2. Advantages of "Sheet Pile Foundation"

The "Sheet Pile Foundation" is a method to improve aseismic performance and secure high bearing capacity of shallow foundation by combining a footing and a series of sheet piles installed along the periphery of the shallow foundation. Both of which are firmly connected at the top. The vertical resistance can be obtained from the base of the footing and the installed sheet piles whilst the horizontal resistance can be gained from the group of sheet piles. This time of foundation has so far been applied for over 50 piers of both railway and road bridges as an anti-seismic reinforcement in Japan.

2-1. Temporarily installed sheet piles for a retaining structure can also be utilized for newly constructed foundations as a part of permanent structures.

In practice, excavation works to construct a footing are necessary for the cases of cast-in-situ concrete pile foundations. For this process, sheet piles are temporarily required as a retaining structure. After the footing is built, the installed sheet piles should be extracted and removed, which increases the cost and time of construction. Whereas, in the case of the Sheet Pile Foundation, the construction cost and time can be significantly reduced due to the use of the retaining structure as a part of the foundation (Figure 1).

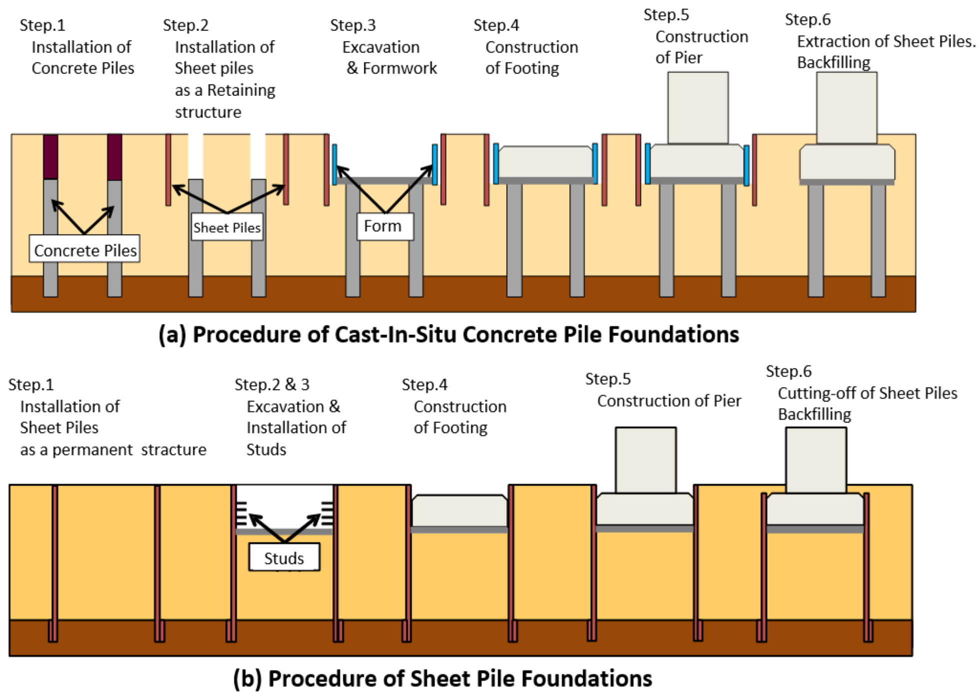


Figure 1 Procedures of cast-in-Situ concrete pile foundations & Sheet Pile Foundation

2-2. Large and heavy construction machines are not required to reinforce existing foundations and the installation can be conducted in a narrow working space.

The construction machines to install sheet piles are relatively compact, particularly press-in machines which can be applicable for constructions in a narrow space by the self-walking mechanism on previously installed sheet piles. Since piling works under low headroom often occur in reinforcement constructions for existing bridges. "Sheet Pile Foundation" in combined with the "Press-in Method" should be, therefore, useful for such a situation.

2-3. Physical interference on existing structures can be reduced and the construction can be conducted during the service period.

Due to the relatively small space required for installation, the reinforcement work can be conducted so as not to prevent both existing bridges and neighboring traffic from being affected.

2-4. Reduction of environmental impact

Comparing the installation of sheet piles with cast-in-situ piles, the volume of sludge is much less (almost zero is in its standard operation), which contributes a reduction of environmental impact.

2-5. More economical than conventional method

The piling plant of sheet piles is smaller than that of cast-in-situ concrete piles to install additional piles along the periphery of an existing footing. Also, the footing size reinforced by the installed sheet piles could be smaller than by conventional techniques like "Additional pile method".

3. Full-scale field test and its result

To examine the performance of "Sheet Pile Foundation", some laboratory model tests and full scale model tests were conducted. The results of the full-scale field test of the performance of Sheet Pile Foundation are presented as below;

3-1. Outline of full-scale models

Full-scale field tests were conducted in Kawagoe City, Japan for verifying the effectiveness of the method in practical use. The soil profile at the experiment site (outlined in Figure 2) showed a layer of volcanic origin clayer soil (Kanto loam) with a thickness of 5 m overlying on a gravel layer. The models for shallow foundation and sheet pile foundation shown in Figs.2 and 3 were constructed with square footings of 3.6 m in width and piers of 6 m in height. At 3.6 m, the sheet pile length (which was the same as the width of the footing) did not extend as deep as the gravel layer.

Figure 3 A view of full-scale models

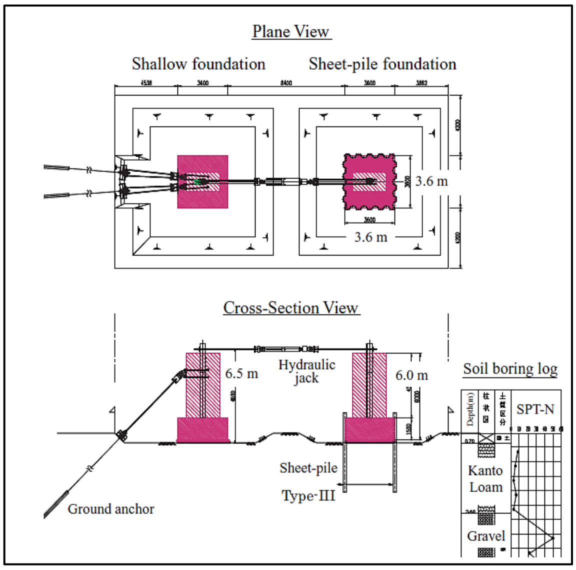


Figure 2 Outline of full-scale model

3-2. Construction experiment

In the practice of sheet pile foundation, it is important to have a method for rigidly connecting the sheet piles to the footing. One simple method involves welding reinforced bars to the sheet piles to unify them with the footing. However, with this method it can be very difficult to arrange the reinforced bars for the footing if the working space is limited. A construction experiment using this method was therefore adopted to confirm the feasibility of arranging the footing bars. Figure 4 shows a photo of the work of welding reinforced bars to the sheet pile, and a photo of the finished state of arrangement. The experiment confirmed the feasibility of this method.

a) Work to weld reinforced bars to sheet pile b) Work to arrange footing bars c) Finished state of footing bars

Figure 4 Photos of the construction experiment

3-3. Horizontal static loading test

The horizontal static loading test was conducted by pulling the tops of the two model foundations toward each other using a hydraulic jack. At first, the shallow foundation was pulled by the sheet pile foundation, and the sheet pile foundation was then pulled by the shallow foundation, reinforced by a ground anchor as shown in Figure 2. The horizontal load P and horizontal displacement δ relationship for each case is shown in Figure 5, which also includes a photo of the final deformation of each model. The figure shows that the ratio of the horizontal resistance of the sheet pile foundation to that of the shallow foundation was about four (Actually, this ratio was larger than that obtained in laboratory testing).

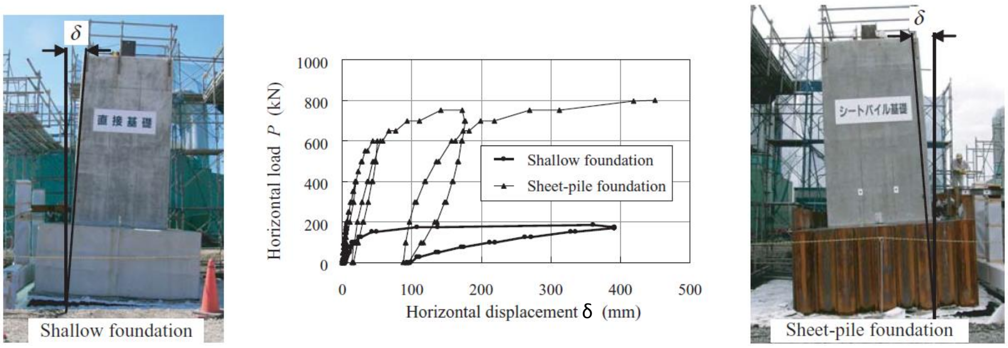


Figure 5 P-δ relationship and pictures of the models after loading

The results of measurements using a soil pressure gauge buried under the footing are shown in Figure 6. The figure indicates that the stress concentration occurs at the right edge of the footing without sheet piles and the contact stress at the edge sharply increases as increasing the jacking load, whereas the contact stresses of the sheet pile foundation are rather evenly distributed.

Figure 7 shows the charge in the axial force distribution of the sheet piles at the back and front sides. Axial compression force increases gradually in the front-side sheet piles, while axial tension acts on those at the back.

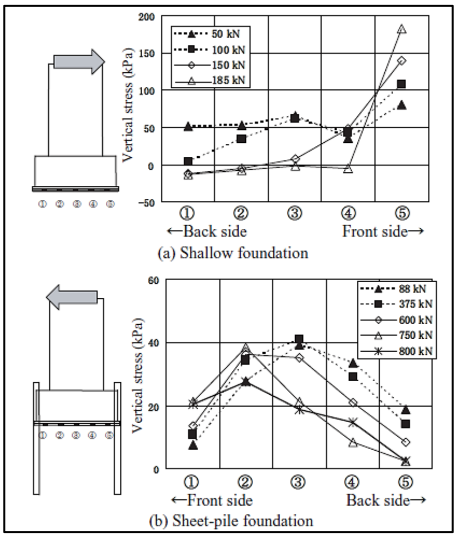


Figure 6 Distribution of vertical contact stress at the bottom of the footing

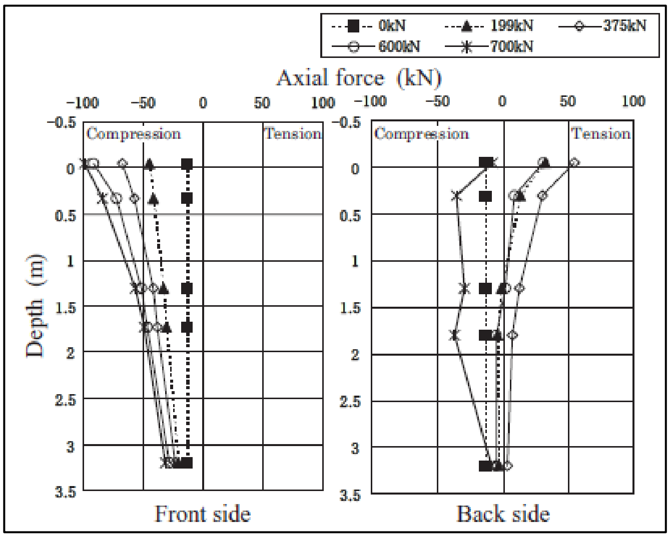


Figure 7 Distribution of axial force of sheet piles

Figure 8 shows the change in the bending moment distribution of the sheet piles at the back and front. The bending moment was the largest at a position of about 1.5 m in depth, but was sufficiently smaller than the yield bending moment.

Figure 9 shows the relationship between the jack load and the shear force at the head of the sheet piles. From this figure, it is clear that the shear resistance of the front-side sheet piles bears a large part of the shear resistance of the sheet pile foundation.

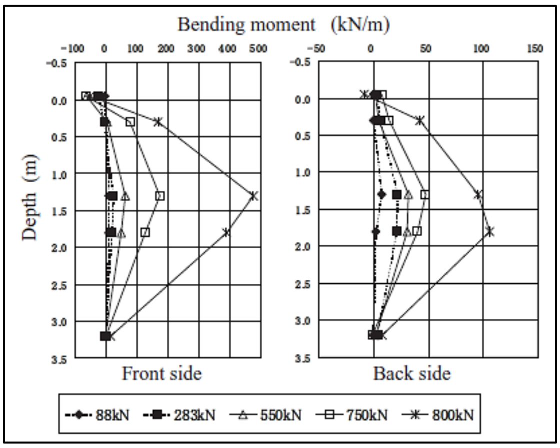


Figure 8 Distribution of the bending moment of sheet piles

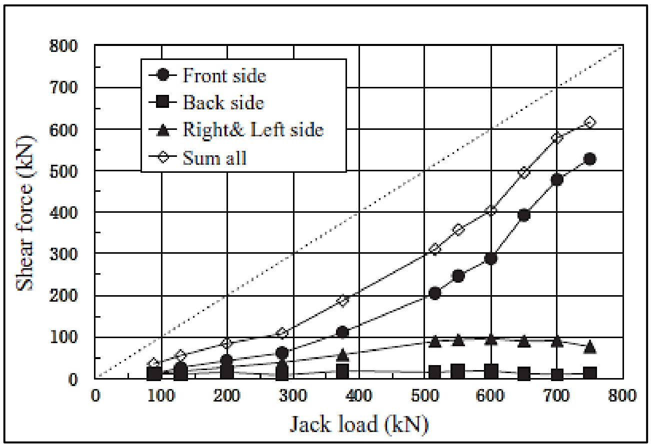
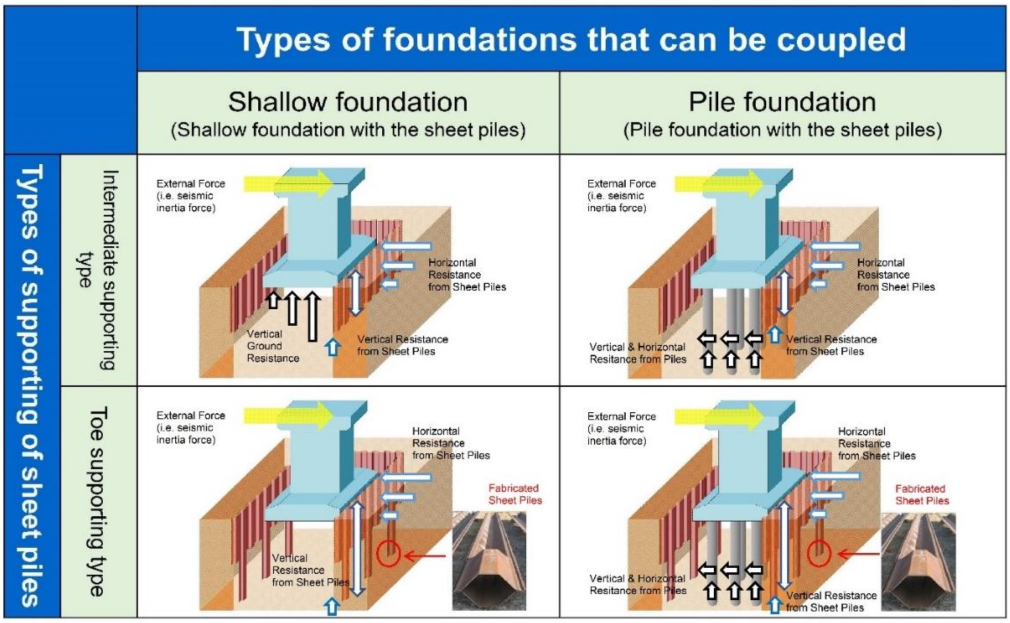


Figure 9 Relationship between the jack load and the share force of sheet piles

4. Future development of "Sheet Pile Foundation"

For soft ground conditions, the "toe supporting type" (Figure 9) of the sheet pile foundation has been developed. By utilizing the fabricated sheet piles whose toe is welded with a piece of sheet pile to create the plugged section like tubular piles, the sheet pile foundation can secure higher bearing capacity even when the intermediate layer is a soft layer.



Currently, Railway Technical Research Institute is developing the sheet pile foundation in collaboration with Obayashi Corporation and Nippon steel & Sumitomo Metal Corporation. To expand the applicability of this structure, the research applying the sheet pile foundation to water-saturated ground is being conducted. In addition, the design manual of the sheet pile foundation including the research results of the effect of liquefaction on the sheet pile foundation is available.

Reference:

Nishioka, H., Koda, M., Hirano, J., Higuchi, S., 2008, Development of Sheet-Pile Foundation that Combines Footing with Sheet Piles, Quarterly Report of Railway Technical Research Institute (RTRI), vol.49, Issue 2, pp.73-78 https://www.jstage.jst.go.jp/article/rtriqr/49/2/49_2_73/_article