Reinforcement of foundations for small structures with micropiles
: L-shaped retaining wall and snowshed foundations

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1. Introduction

Micropiles are small-diameter (300 mm or less) cast-in-place or bored precast piles and are placed by lifting in reinforcements, such as steel reinforcing bars or steel pipes, into bored holes and grouting the holes with cement slurry or cement mortar. Primary characteristics of micropiles are that they can be installed under complex ground conditions because of their small diameters and borehole wall stabilization measures, and that grouting under pressure ensures bonding with the ground. Micropiling is a technique that has evolved, mainly in Europe, from the rehabilitation of historical structures such as brick or stone masonry temples and churches and the reinforcement of the foundations of those structures. Because of its flexible adaptability to complex ground conditions, micropiling is now used in a wide variety of applications including the rehabilitation of structures, underpinning of structural foundations and adjacent structures, stabilization of natural slopes, prevention of loosening of natural slopes, and auxiliary works for tunnel excavation.

In the United States, micropiling is being increasingly used for the seismic retrofit of viaduct foundations by taking advantage of the fact that micropiling can be carried out even within limited space available.This paper reports on projects in which steel pipe micropiles were used to reinforce the foundations of small structures. Figure 1 shows an example of a steel pipe mircopile.

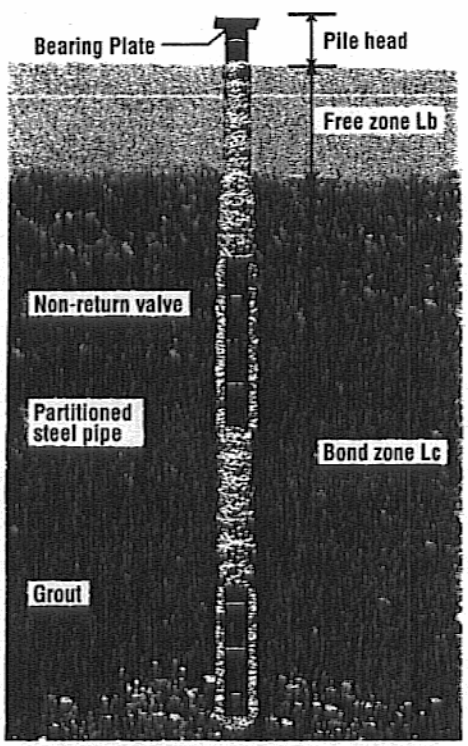


Figure .1 Steel Pipe micropile

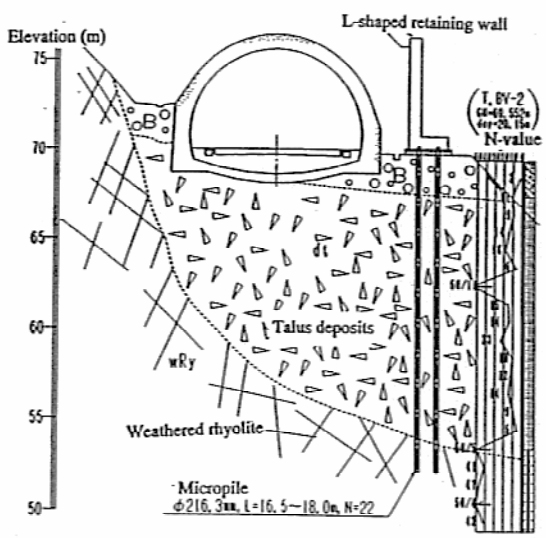


Figure .2 General view of the site

2. Construction of an L-shaped retaining wall

2.1 Outline of the work

This work was executed as part of an emergency disaster-prevention project for a portal zone of the Takanosu Tunnel on National Highway Route 113, and involved the construction of rockfall energy dissipation works and an L-shaped retaining wall to support them. The portal of the Takanosu Tunnel was constructed by cutting and shaping a slope. The tunnel has a 20-meter-long open construction section protruding from the portal. The rock slope behind the open construction section, which is composed of rhyolite, has a slope angle of 40 to 80 degrees. This steep slope, which is about 100 m higher than the national highway, has many loose rocks and is therefore a source of rockfalls. Talus deposits, which have fallen from the slope, are widely distributed near the portal. The weathered rhyolite, which serves as the bearing stratum, is at a depth of about 14 to 16 m. The construction work had to be carried out in a narrow area close to the national highway under severe geological conditions.

Figure 2 is a general view of the site. Photo 1 and Photo 2 show the portal before and after construction, respectively.

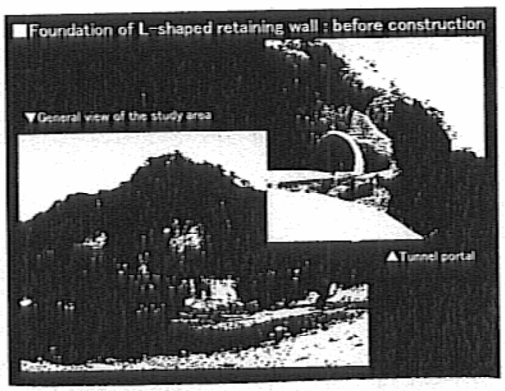


Photo .1 Work site before construction

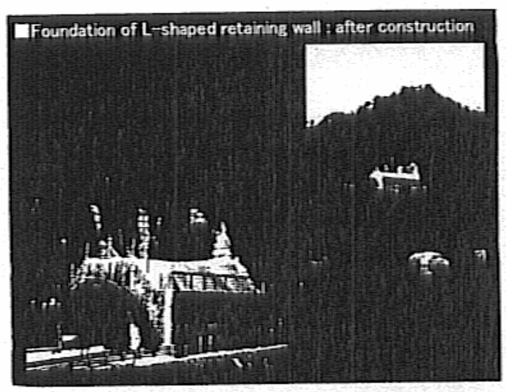


Photo .2 Completed retaining wall foundation

2.2 Selection of foundation type

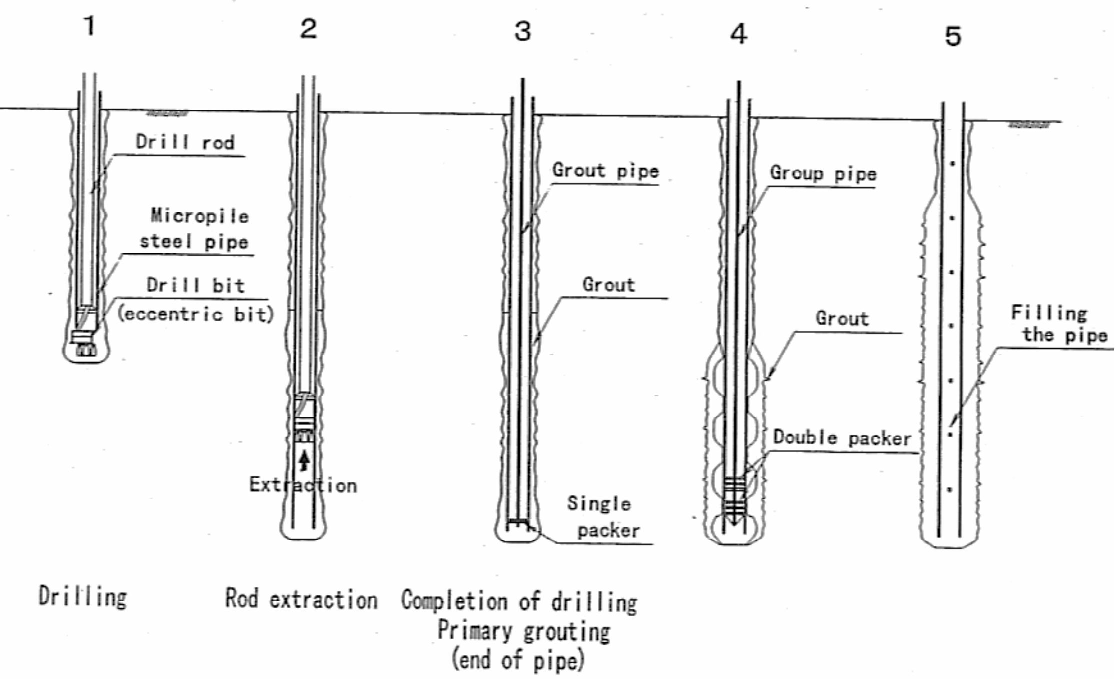
The type of foundation for the L-shaped retaining wall was selected according to the following criteria: The foundation (1) should be constructible even in a talus layer containing an intermediate layer of gravel and boulders about 10 to 50 cm in diameter; (2) should be easy to construct on a bedrock with a bearing stratum with a very rough surface; (3) should be constructible with small equipment and even in cases where the construction yard is limited; and (4) should make for a reduction of total cost including temporary works cost. The cast-in-place all-casing pile, the micropile, and the deep foundation pile were compared on the basis of a detailed study of work conditions and other factors, and steel pipe micropiling was adopted as a small-diameter cast-in-place pile foundation best suited to the project. Table 1 shows the foundation types considered.

Because micropiles are small in diameter (300 mm or less), the amount of excavation required and therefore the influence on existing structures are small. Since construction equipment used is compact and easy to maneuver and since the materials used are small and easy to handle, the micropile method is suitable for use at a space-limited site inaccessible to large equipment or a site in a mountain region. Micropile foundations can be applied to any kind of ground, including soft ground, sand and gravel, and rock, and is suitable for the construction of relatively small structures such as retaining walls. The micropiles used in the project reported here are composite piles made by injecting cement slurry under pressure into a steel pipe that has been designed to have high bond strength. The bearing capacity of the ground is provided by the cement grout at the base and along the skin, and pile stresses are carried mainly by the steel pipe.

Table .1 Comparison of fondation types

Critera \ Foundation type			Spread foundation	Driven pile foundation	Embedded pile foundation	Cast-in-place pile foundation: All casing	Cast-in-place pile foundation: Reverse circulation	Cast-in-place pile foundation: Earth drill	Cast-in-place pile foundation: Cast-place shaft with manual axcavation	Cast-in-place pile foundation: Micropile	Caisson foundation
Ground condition	Condition of strata above bearing stratum	There is a very weak intermediate layer	△	○	○	○	○	○	×	○	○
		There is a very hard intermediate layer	○	△	○	△	○	△	○	○	○
		An intermediate layer contains gravel: Gravel size : 5cm or less	○	○	○	○	○	○	○	○	○
		An intermediate layer contains gravel: Gravel size : 5cm to 10cm	○	△	△	○	○	△	○	○	○
		An intermediate layer contains gravel: Gravel size : 10cm to	○	×	×	△	×	×	○	○	○
	Condition of bearing stratum	Slope is steep (30 deg. or more)	○	○	○	○	△	△	○	○	○
		Surface is very rough	○	○	△	○	○	○	○	○	○
Characteristics	Type of bearing	End-bearing pipe		○	○	○	○	○	○	△	
		Friction pile		○		○	○	○		○	
Working conditions	Limited work space		○	△	△	△	△	△	○	○	△
	Construction of inclined shaft			○	△	△	×	×	×	○	
	Environment	Vibration and noise control	○	×	○	△	○	○	○	○	○
		Influence on adjacent structures	○	△	○	○	○	○	△	○	△

○: Highly applicable △: Applicable ×: Not applicable



Fugure .3 Micropiling procedure

2.3 Micropiling procedure

(1) Drilling

The micropiling procedure is illustrated in Figure 3. In this example, a double-pipe drilling system using a down-the-hole hammer and an eccentric hole-enlarging bit was used. In down-the-hole hammer drilling, impact is transmitted directly to the drill bit, instead of passing through the drill pipe. Consequently, energy transmission losses are small, and directionality of drilling is high. Because drilling is carried out by the dry drilling method, in which muck is removed by compressed air, strata where water for wet drilling might pose a problem such as talus or boulder strata can be drilled efficiently.The down-the-hole hammer method, which is usually applied to hard ground such as boulder strata or rock, adopts a double-pipe drilling system using an eccentric hole-enlarging bit. This makes it possible to perform drilling efficiently even in talus strata or sand and gravel strata in which the hole wall is usually unable to support itself.

While the drill is rotating in a clockwise direction during drilling, the reamer remains in an eccentric position to enlarge the hole diameter. When the drill rotation is reversed (that is, the drill is rotating in the counterclockwise direction), the reamer closes so that the bit can be extracted through the steel pipe.

This mechanism enables insertion of the steel pipe while drilling is being carried out. The hole diameter is 232 mm. Photo 3 shows micropiles being placed,and Photo 4 shows the drilling tool used..

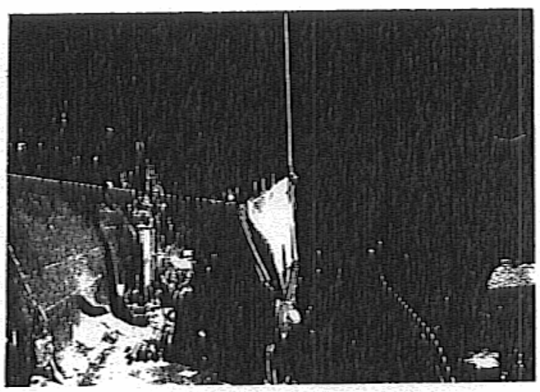


Photo .3 Placement of micropiles

Photo .4 Drill bit

(2) Grouting

An inflatable single packer is inserted into the steel pipe, and cement slurry is injected under pressure into the ground through non-return valves installed in the steel pipe. The grouting pressure is usually around 1 MPa and not greater than 2 MPa. The injection of cement slurry is performed by following the steps described below.

(i) Base grouting by which to place the packer at the lower end of the pile and exert pressure, mainly for the purpose of reducing pile end settlement and preliminary compaction

(ii) Skin grouting by which to apply pressure in the radial direction, mainly for the purpose of increasing the area of contact with ground and ensuring skin friction

(iii) Installation of the packer at the pile head followed by pile head grouting by which to achieve full-surface bonding between the ground and the steel pipe and fill the steel pipe with the grout

The water/cement ratio (W/C) of the cement slurry was 50%, and the target design strength was 30 N/mm2. In the grouting, full-surface bonding between the groundand the grout was ensured by confirming that cementslurry has flowed out to the ground surface during skin grouting. The steel pipe was equipped with non-return valves located at 1 m intervals over the length of the pipe so that full-surface bonding can be achieved. Photo 5 shows a packer in use.

Photo .5 Packer operation

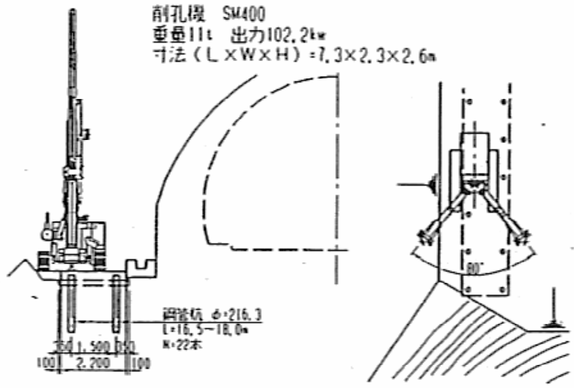


Figure .4 Arrangement of equipment

(3) Construction equipment

A diesel-powered, crawler-mounted hydraulic drilling machine equipped with a high-torque rotary head, which is easy to maneuver, was adopted. The reasons are that the space-limited site was inaccessible to large equipment, and that the above-mentioned drilling machine does not require a temporary platform and is suitable for deep drilling. Figure 4 shows the arrangement of the equipment used.

3. Reinforcement of snowshed foundation

3.1 Outline of the work

This work is the renovation and modification of a snowshed to be carried out as part of disaster-prevention work for National Highway Route 113. Micropiles were adopted, in view of the experience with the portal work at the Takanosu Tunnel, to reinforce the foundation for the renovation of the snowshed superstructure. The slope along the road section in which the snowshed is located has an average slope angle of 60 degrees. This slope is composed of slate, which forms the bedrock in the work area. The geology of the site consists of (from top down) a fill, talus deposits, tuffaceous sandstone, and slate. The depth to the bearing stratum is 9 to 16 m. A pile foundation was considered as a means of reinforcing the snowshed foundation. Figure 5 shows a geological profile of the site.

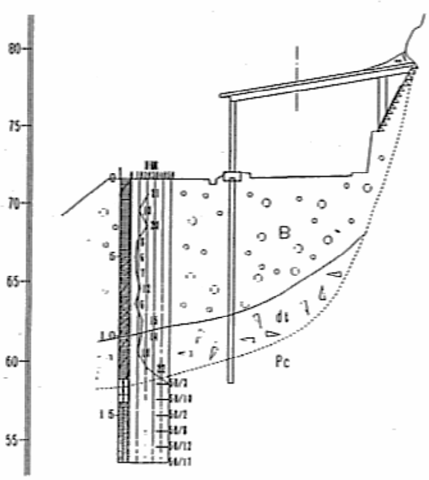


Figure .5 Geological section

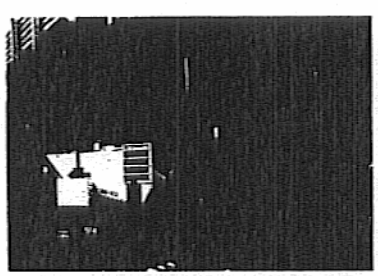


Photo .6 Micropileing work

3.2 Selection of foundation type

Foundation piles can be classified, according to how they are placed, into three types: driven piles, bored precast piles, and cast-in-place piles. The most suitable method is selected in view of such constraints as environmental conditions and ground conditions.

The site is located in an area where working space is severely limited. In view of this and the size of the structure involved, a micropile-type foundation was selected. Because of the interference with the existing snowshed, the height of the equipment used had to be 4 m or less. For this reason, screw-jointed steel pipe micropiles 165.2 mm in diameter and 1.5 m long were adopted. The length of the connected piles ranged from 10 to 16.5 m, and a total of 37 piles were placed. Photo 6 shows a micropilling operation .

4. Conclusions

In Japan, micropiles are used in applications such as soil and slope reinforcement and ground stabilization and bearing capacity improvement in connection with mountain tunnel construction. Steel pipe micropiles, however, have been used only in a limited number of projects. The projects reported in this paper have demonstrated that double-pipe drill type steel pipe micropiles are cast-in-place piles that can be flexibly and easily applied to space-limited sites and ground conditions that do not lend themselves to excavation.

In this connection, it is necessary to establish criteria for the selection of drilling methods, grouting methods, strength of reinforcements, and other details according to the working conditions. If skin friction is to be increased significantly, it is necessary to take creative measures such as increasing the interlocking effect between the ground and piles. Micropiles based on a new concept, namely, high-strength micropiles combined with soil improvement by jet grouting, have already been developed. Figure 6 illustrates this concept.

The rationale behind this new foundation construction method is that combined use of small-diameter steel pipe piles and soil-cement columns makes for greater ease of construction and versatility by eliminating the boundary between piling and soil improvement. . Figure 7 shows an example of high-strength micropiling.

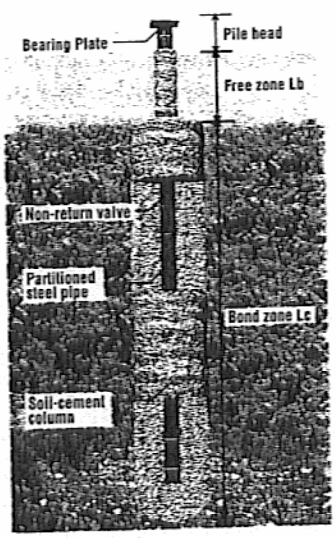


Figure .6 Micropilling combined with jet grouting

(Seismic retrofit of bridge pier foundation)

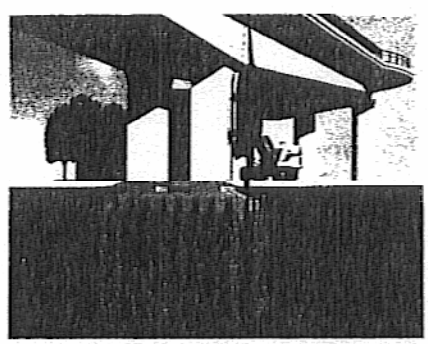


Figure .7 Micropile application

References

1) Watanabe, Nozawa and Toyama: "Micropiles applied to L-shaped retaining walls" (in Japanese), *The*