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New Steel Pipe Pile Method, "Gantetsu Pile Method", with Low Surplus Soil, Noise and Vibration

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The "Gantetsu pile method" is a steel pipe pile method with few surplus construction soil and low noise and vibration. The development of this steel pipe pile method focused on "few surplus soil" as chief development concept by considering that the disposal of surplus soil from the construction of foundations would become a pressing issue in the near future. The present paper describes the background for the initiative taken in reducing the volume of surplus construction soil, the development concept involved, and the basic technology and ideas employed to achieve the objective.

1. Introduction

The "Gantetsu pile method" is a new steel pipe pile method with low surplus construction soil, noise, and vibration. The development of the Gantetsu pile method started about 11 years ago or 1988, when the "surplus construction soil issue" began to be addressed by the government authorities concerned. Foundation construction methods, such as the cast-in place pile method, that drill holes in the ground and discharge the excavated soil are one of sources of surplus construction soil, although this type of surplus soil does not account for a large portion of the entire construction-generated surplus. Considering that the surplus construction soil problem would have to be confronted in the near future, Nippon Steel started the development of the Gantetsu pile method as a foundation construction method of the low surplus soil type.

The Gantetsu pile method received a technical audit certificate as a general civil engineering method from the Japan Institute of Construction Engineering in 1995 and a special approval of Minister of Construction in the building sector in 1998. Recently, it has been recognized as a method for constructing foundations with low cost and excellent earthquake resistance, and has started to spread in infrastructure foundations, like bridge foundations, and building foundations.

The technical aspects of this method are already reported elsewhere[1]. The background for the initiatives taken to reduce the surplus construction soil, the development concepts of the Gantetsu pile method, and the basic techniques devised and combined to realize the Gantetsu pile method are described in the present paper.

2. Background for Initiatives Taken to Reduce Surplus Construction Soil

In the first half of the 1980s, the surplus construction soil was raised as one issue for construction administration, and the administrative agencies concerned started to take the initiatives to develop necessary techniques (refer to **Table 1**). To meet these social and technical movements, Nippon Steel searched for the measures to cope with the surplus construction soil in the foundation sector and started the development of the Gantetsu pile method about 1988.

The surplus construction soil is a reusable material by its nature. The volume of soil discharged out of construction sites, however, is by far greater than the volume of soil re-utilized in public works and private housing lot development works, among other projects. The surplus construction soil is chronically oversupplied, and it is increasingly difficult to find inland places to receive the excess soil. Some of the surplus construction soil is illegally dumped, causing an environmental problem. As shown in **Fig. 1**, the construction-gener-

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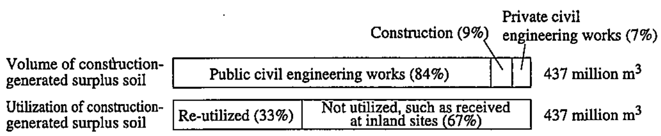
Table 1 Examples of initiatives taken at administrative level and taken in technology development (when the development of Gantetsu pile method started)

	Time	Example of initiative
Administrative level	1983	Establishment of Comprehensive Surplus Construction Soil Countermeasure Study Group (Ministry of Construction)
	1990	Establishment of Metropolitan Advanced Construction Resources Center, Inc. (Company founded by Tokyo Metropolitan Government and others to secure and manage sites to receive surplus construction soil)
Technology development (comprehensive project of Ministry of Construction)	Fiscal 1981-85	Development of technology for utilizing waste in construction industry
	Fiscal 1992-96	Development of technology for reducing generation of construction by-products and re-utilizing construction by-products

Source: Comprehensive Construction By-product Countermeasures, Fiscal 1996 Edition (Construction By-product Recycle PR Promotion Conference)



Source: Comprehensive Construction By-product Countermeasures, Fiscal 1996 Edition (Construction By-product Recycle PR Promotion Conference)

Fig. 1 Volume and utilization of construction-generated surplus soil (fiscal 1993)

ated surplus soil reached as much as 437 million m^3 in fiscal 1993. About two-thirds of the generated surplus soil is left unutilized and is carried to mountain sand and gravel quarry sites, valleys, and other inland locations. In recent years, transportation by truck of the surplus soil out of the construction sites has come to cause traffic congestion on roads around the construction sites.

3. Development Concepts and Basic Techniques for Realization of Gantetsu Pipe Method

3.1 Development concepts

Basic measures to deal with construction by-products are suppression of generation, promotion of reutilization, and execution of approximate treatment. Development of the Gantetsu pipe method positioned the first of these three key measures as the basic concept by considering that response to the surplus construction soil would become an essential challenge for foundation construction methods in the near future.

The cast-in-place pile method that generates a large volume of surplus soil was positioned as the foundation construction method to be improved by the Gantetsu pile method. The development concepts established for the Gantetsu pile method were low surplus soil, noise and vibration, high quality, and environmental friendliness, as shown in **Table 2**.

3.2 Basic techniques for realization of Gantetsu pile method

It was very difficult to meet all of the development concepts mentioned above. A keyword for realization of the Gantetsu pile method was utilization of soil cement as pile material.

3.2.1 Basic techniques for fulfilling low surplus soil, noise, and vibration requirements

Soil cement is a cement-based solid material produced at the pile construction site by injecting cement milk into the ground at the site, agitating the cement milk with the site soil, and using the site soil as aggregate. The soil cement remains soft during the construction and then sets hard. Turning the site soil into the soil cement can reduce

Table 2 Development concepts and basic techniques for realization of Gantetsu pile method

Development concept	Basic technique
Low surplus soil	· Solidification and soil cement conversion of site soil
Low noise and vibration	· Reduction in penetration resistance during construction by soil cement conversion of site soil
Low cost	· Utilization of site-formed soil cement column as pile material · Combination of site-formed soil cement soil and steel pipe pile with external projections (high strength and low surplus soil generation)
High quality	· Utilization of Teno-Column method and steel pipe with external projections (high quality) · Adoption of simultaneous burial method (high construction accuracy) · Construction control system (e.g., bearing stratum confirmation, construction data storage)

the generation of surplus soil in the construction stage and can reduce the soil resistance during the burial of steel pipe piles. The steel pipe piles can be thus installed into the ground with low noise and vibration by conventional low-noise and low-vibration pile driving machines (e.g., earth augers or jacks).

3.2.2 Basic techniques for fulfilling low cost and high quality requirements

To meet the low cost requirement, positive use was made of the soil cement column formed at the site during the construction as pile material after the construction. It was an unprecedented attempt that a soil cement column was combined at the site with a steel pipe pile to obtain a composite pile with high bearing capacity and a diameter (about 200 to 400 mm) greater than that of the steel pipe pile (refer to **Fig. 2**). The techniques required to accomplish such a composite pile were: (1) technique for improving the quality of the soil cement column; (2) technique for improving the bond strength of the outside surface of the steel pipe pile with the soil cement as required to form the composite pile; and (3) technique for preventing the misalignment of the steel pipe pile and the soil cement column.

The improvement in the quality of the soil cement column was achieved by incorporating into the basic technology of forming the soil cement column the Teno-Column method of Tenox Corporation, a soil improvement method credited with high quality. It is generally known that the desired quality of the soil cement can be assured better by forward-reverse two-axis agitation than by one-direction, one-axis agitation whereby lumps of soil are left in the soil cement. With the forward-reverse two-axis agitation method, on the other hand, the mechanism is complicated, as represented by an agitating rod of the double-wall pipe type, so that construction troubles are likely to occur. Addtionally, a long time is required to connect the agitating rods at the site.

As shown in **Fig. 3**, the Teno-Column method uses a drilling and mixing unit fitted with a co-rotation preventing blade. The co-rotation preventing blade is not fixed to the rotating rod, but is designed to eat into the surrounding soil and not to rotate during the construction. Although a one-axis rotation system, the Teno-Column method can accomplish the quality of a forward-reverse two-axis agitation system. The high quality of the soil cement column and the simplification of the construction process can be accomplished by the Teno-Column method at the same time.

The second technique for improving the outside surface bond strength of the steel pipe pile for the formation of a composite pile, was solved by using a steel pipe pile with outside surface projec-

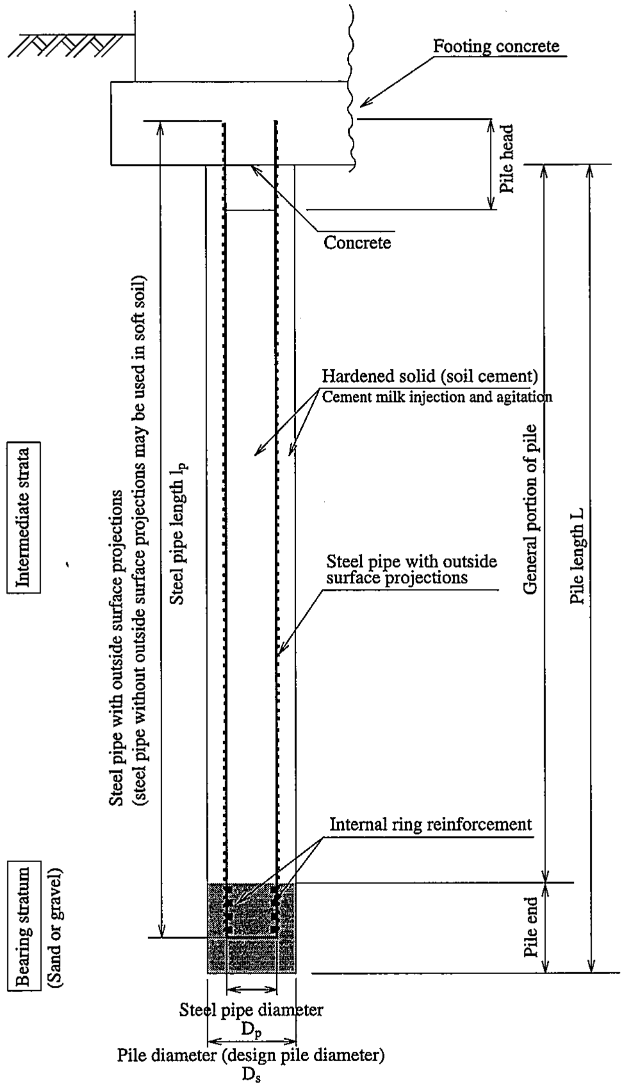


Fig. 2 Schematic diagram of Gantetsu pile

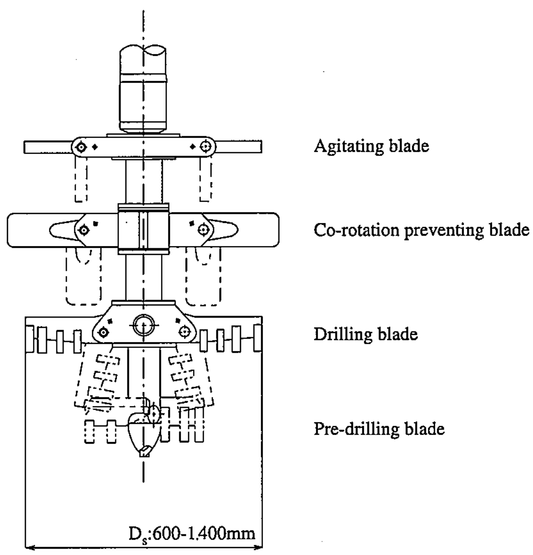


Fig. 3 Drilling and mixing unit

tions, which was made from steel strip with projections for conventional concrete-filled composite piles (refer to **Fig. 4**). The bond strength between the soil cement column and the steel pipe pile as required for the formation of the composite pile was assured by determining the cement milk concentration so that the uniaxial compressive strength of the soil cement column should exceed the target strength, because the bond strength is a function of the uniaxial compressive strength of the soil cement.

The last is the technique of preventing the misalignment between the steel pipe pile and the soil cement column. This problem was solved by the simultaneous burial method that performs the formation of the soil cement column and the burial of the steel pipe pile at the same time (refer to **Fig. 5**). The largest technical problem for the simultaneous burial method was the determination of the collapse/expand mechanism for the drilling and agitating blades. Since the outside diameter of the soil cement column is 200 to 400 mm larger than that of the steel pipe pile, the drilling and mixing blades are larger than the steel pipe pile. With the simultaneous burial method,

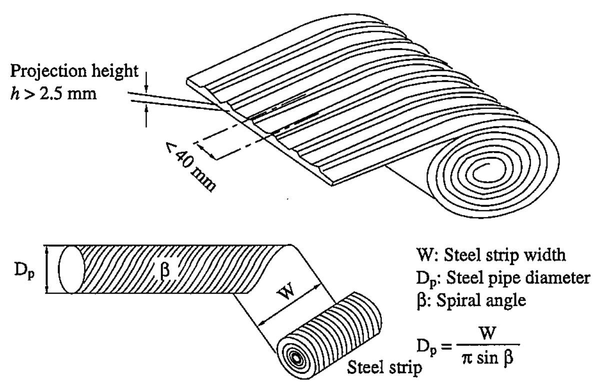


Fig. 4 Steel strip and process for manufacturing steel pipe with outside surface projections

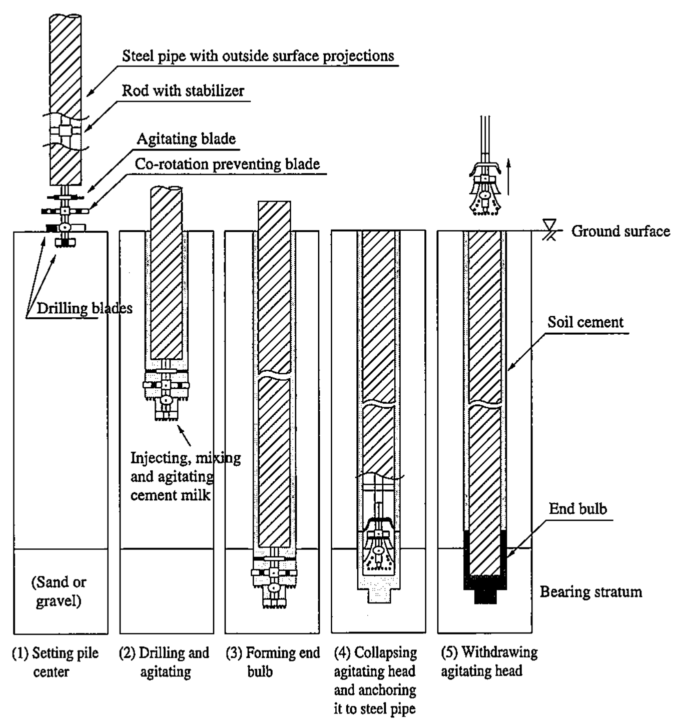


Fig. 5 Gantetsu pile construction procedure

the drilling and mixing blades must be folded and raised after the steel pipe is installed to the desired bearing stratum depth. A hydraulic collapse/expand mechanism or a mechanical collapse/expand mechanism with screws, for example, are complicated. A mechanism that expands and collapses the drilling and mixing blades in accordance with the forward and reverse directions of rotation cannot guarantee the desired diameter of the soil cement column.

In the Gantetsu pile method, each drilling and mixing blade is provided with two pins (a main structural pin and an auxiliary construction pin). The blade is expanded and fixed with the two pins during the construction. After the construction, the blade is collapsed by breaking the auxiliary pin with the end of the steel pipe as the fulcrum. Drilling and mixing blades of this simple mechanism were devised to provide a simple and reliable construction method (refer to Fig. 3). A construction control system that controls the installation depth of the pile with reference to the supporting stratum of the site and stores the construction data is developed and incorporated to fulfill the high quality requirement.

4. Realization Level of Development Concepts

4.1 Low surplus construction soil

The data that compare the Gantetsu pile method (measured values) and the cast-in-place pile method in terms of the discharged soil volume with respect to the pile volume are shown in **Fig. 6**. The pipe volume being equal, the discharged soil volume for the Gantetsu pile method is about one third to fourth of that for the cast-in-place concrete pile method. In actual design, the end area of the Gantetsu pile can be reduced to a half of that of the cast-in-place concrete pile due to the difference in the end bearing capacity. Under the same design conditions, the discharged soil volume can be reduced to about one-sixth to one-eighth to meet the low surplus construction soil requirement. The surplus soil cannot be completely eliminated because injection of the cement milk for formation of the soil cement column causes the discharge of soil in an amount equal to that of the cement milk injected.

4.2 Low noise and vibration

Fig.7 shows noise and vibration measurements at sites. The Gantetsu pile method produces noise and vibration lower than those of the earth drill method for cast-in-place concrete piles, let alone the regulatory values.

4.3 Low cost

Fig.8 shows the economics of the Gantetsu piles as compared with the cast-in-place piles (reverse-circulation drill method) and inner-excavation steel pipe piles when used to construct civil engineering foundations. The Gantetsu piles are about 8% more eco-

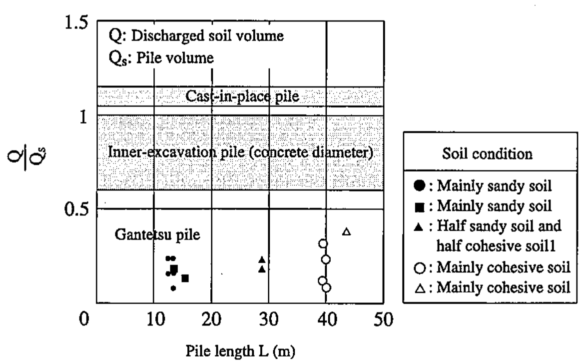


Fig. 6 Relationship between discharged soil volume/pile volume ratio and pile length

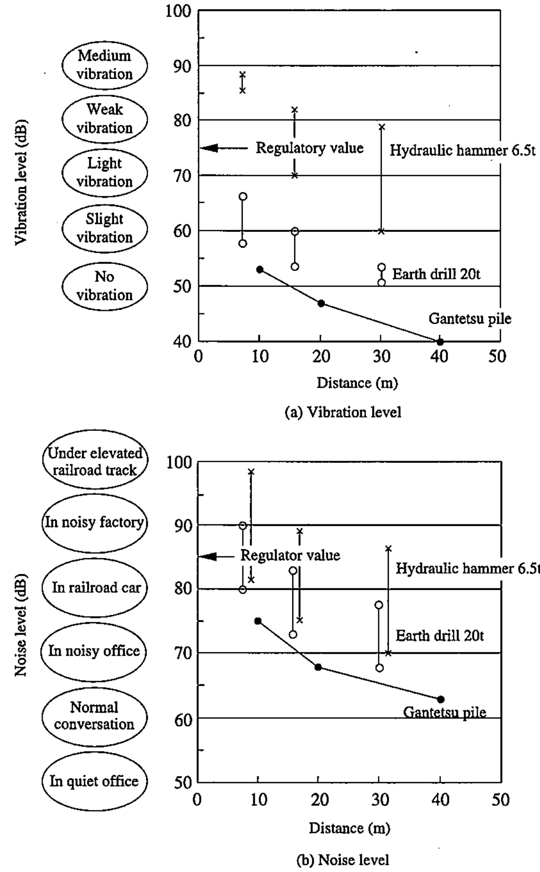


Fig. 7 Vibration and noise levels during Gantetsu pile construction

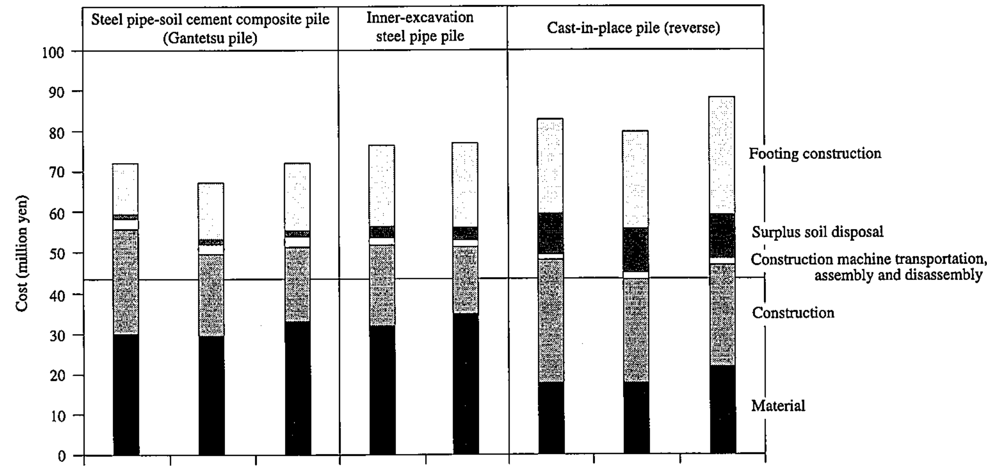
nomical than the cast-in-place concrete piles in the pile work cost (material and construction) and 17% more economical when including the footing work cost (material and construction). This is primarily because (1) the design end bearing capacity is a maximum of 7,500 kN/m^2 in sand (10,000 kN/m^2 in gravel) for the Gantetsu pile method against a maximum of 3,000 kN/m2 in sand for the cast-in-place concrete pile method, meaning that less Gantetsu piles are required to provide the same end bearing capacity, and (2) the concrete footing can be thus reduced in size for the Gantetsu pile method.

4.4 High quality

As one example of strength developed by the soil cement, **Table 3** shows the average core strength (uni-axial compressive strength) of the soil cement of the pile ends formed at 14 sites (sand or gravel). The average core strength of the pile end soil cement is 24.1 N/mm^2 in sand and 22.5 N/mm^2 in gravel. The uni-axial compressive strength of 15 to 16 N/mm^2 required for the pile end is fully satisfied. **Photo 1** shows the end of a Gantetsu pile formed in gravel, excavated, and sectioned. The soil cement is tightly bonded to the steel pipe with outside surface projections, and functions well as a composite pile.

5. Application Results and Reasons

The Gantetsu pile method was adopted in the construction of pier foundations for the New Meishin Expressway (see **photo 2**). As of June 1998, the Gantetsu piles have been in 9,000 tons for nine civil engineering projects and in 16,000 tons for 24 building projects. The main reasons why Gantetsu pile method has been adopted are its low noise, vibration, and cost in most of these projects. There are still only a few building projects where the Gantetsu piles have been



Pile diameter (mm)	800	1,000	1,200	800	1,000	1,000	1,200	1,500
Steel pipe diameter (mm)	600	800	1,000	800	1,000	–	–	–
Number of piles	42	30	25	63	42	49	36	28
Construction period (days)	25	19	17	34	26	47	48	48

(Soft ground, Pile length: 25 m, Force active at lower end of pier:
Vertical direction = 55,000 kN, Horizontal direction = 15,000 kN, Moment = 14,000 kN·m)

Fig. 8 Example of economic study for Gantetsu piles

Table 3 Average core strength of soil cement at pile end

Type of soil at pile end	Sand	Gravel
Number of data items	78	24
Average core strength (N/mm^2)	24.1	22.5

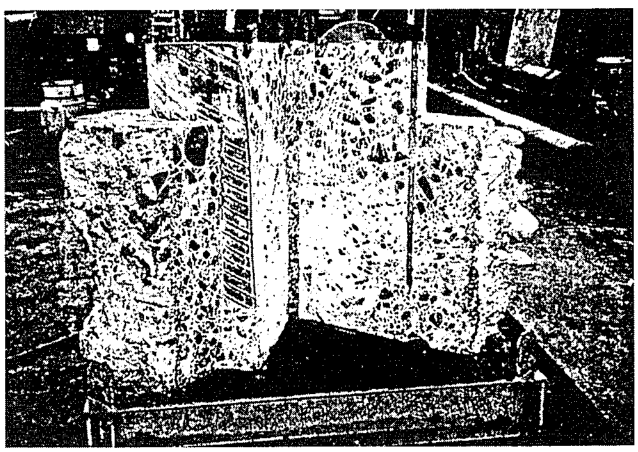


Photo 1 End of Gantetsu pile formed in gravel. Gantetsu pile constructed at site was excavated, sectioned, and photographed

adopted for the main reason of low surplus soil generation. However, the number of such projects is on the rise with skyrocketing surplus soil disposal costs, since it has become increasingly difficult to find inland disposal sites near urban areas in recent years. In line with this trend, the Gantetsu pile method has seen increasing inquiries as a low-surplus soil pile construction method. Since the soil cement discharged by the Gantetsu pile method is a high-quality improved soil, its can be used as fill material at the pile construction site or nearby work site. The Gantetsu pile method is being rated for this advantage as well.

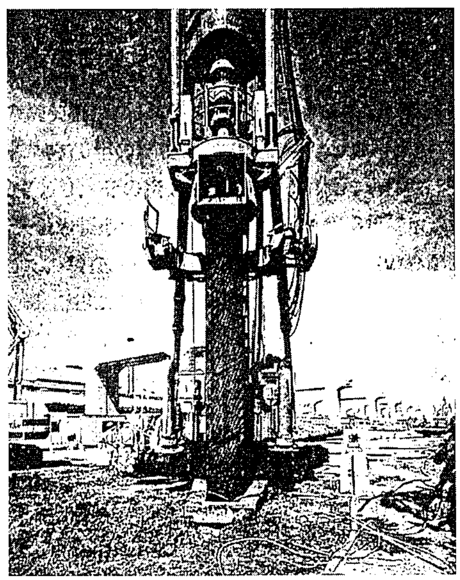


Photo 2 Gantetsu pile being installed at construction site of New Meishin Expressway

6. Conclusions

The Gantetsu pile method was developed as a pile foundation construction method with low surplus soil, noise and vibration, and environmental friendliness. We will continue to reduce the cost of the Gantetsu pile method, develop technology to expand its applications, and improve and refine it.

The authors greatly thank the Housing and Urban Development Corporation, Kubota Corporation, Tenox Corporation, Japan Highway Public Corporation, and many other organizations and people for guidance and cooperation in the development of the Gantetsu pile method.

Reference

1) Oka,T. et al.: Development and Commercialization of Composite Foundation Pile (Gantetsu-pile). Shinnittetsu Giho, (368), 11 (1998)