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Rapid construction of railway bridge by soil cement and steel pile method

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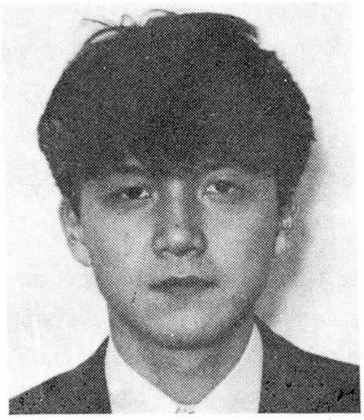


SUMMARY

In The Akita Sinkansen Line that started operation in March '97, the new construction of its elevated viaducts which connects to the elevated bridge of Tohoku Sinkansen Line had to be rushed in half a year in city area.
In the competent place, soft ground(N-value:under10) accumulates under the gravel bed that is supposed to be bearing stratum of spread foundation, and pile foundation was adopted.
The pile foundation could be constructed with little noise and shock, rapidly, and it was necessary to excavate the ground including boulder. So, it was impossible to adopt driving pile, pile installation by inner excavation, and cast-in-place pile. For that, a friction pile by soil cement and steel pile method with rock auger was adopted as a part of viaduct foundation for the first time as railway structure. This method differs from ordinary method in using rock auger method with steel pile casing to crush and excavate underground obstacle.
In real construction, the diameter of excavation was 1000 millimeters, the length of soil cement was 16.5 meters. Before real construction, vertical loading test was enforced to confirm bearing capacity by means of test pile. Through four-thirds the load of design that was loaded, settlement of pile top was 13 millimeters. In real construction, 42 piles were constructed for 20 days with two machines. This progress speed is about twice that of overall casing method.
This paper reports about the selection of foundation type in the competent viaduct area, the outline of this method, the result of the pile construction test and vertical loading test, and construction.

1 INTRODUCTION

In the Akita Shinkansen Line that started operation March '97, the new construction of its elevated viaducts which connects to the elevated bridge of the Tohoku Shinkansen Line had to be rushed in half a year in city area. The viaducts of the Morioka approach are in the north of Morioka St, are by through trains between Tokyo and Akita as they go from the Tohoku Sinkansen Line to the Tazawako local line.

For that, a friction pile by soil cement and steel pile method with rock auger was adopted as a part of viaduct foundation for the first time as railway structure.

This paper reports about the selection of foundation type in the competent viaduct area, the outline of this method, the result of the pile construction test and vertical loading test, and construction.

2 SELECTION OF FOUNDATION TYPE

2.1 The Morioka approach

The extension of the Morioka approach is 1.2km (Fig.1). The extension of the viaducts is 1.0km. The houses stand close together around that. In the area, we had to construct the Akita Shinkansen Line over the Tazawako Local Line. We devised to construct foundations and pillars on both sides of the railroad, connect that two pillars, and erect a beam. But in that method, the construction expenses was high. It was difficult to secure the road for construction, the construction period was long. So, we have suspended train service in the Tazawako Local line for an year, constructed the viaducts for six months.

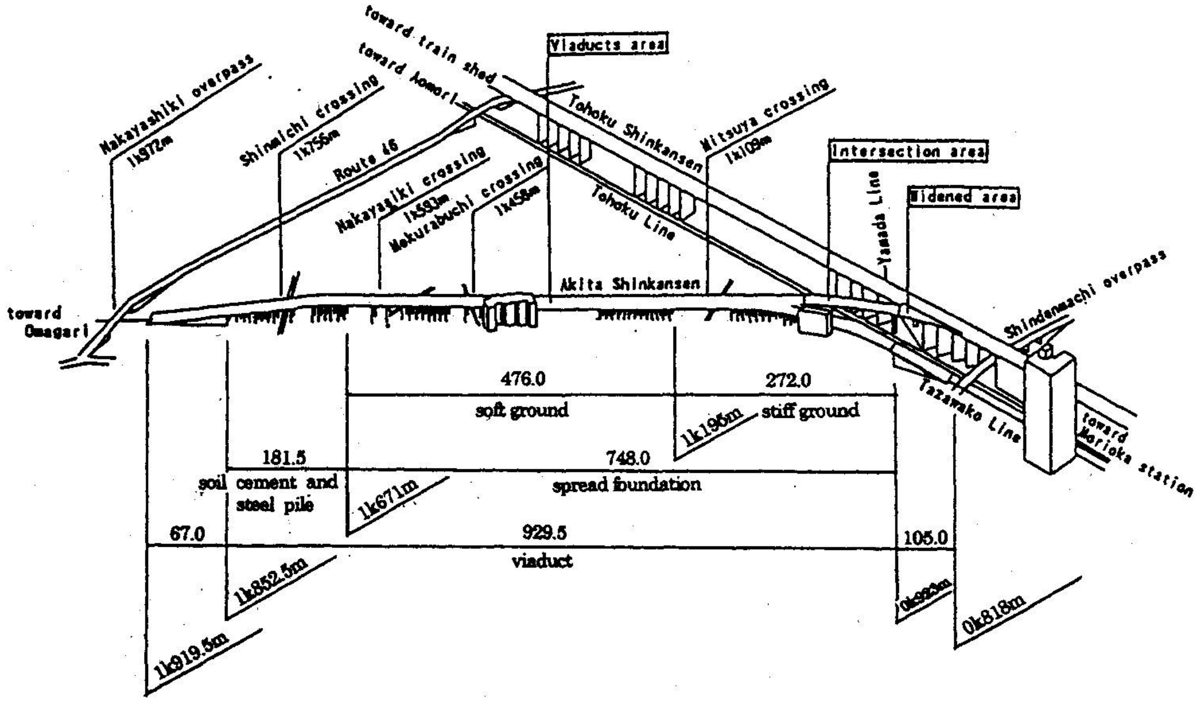


Fig.1 The Morioka approach near Morioka Sta.

2.2 Selection of foundation type

2.2.1 Topographic features and geological condition

In the viaducts area, geological survey and plate loading test were enforced. We planed to construct spread foundation from starting point to 1k671m. But except that area, sandy clay including gravel (N-value : under 10), the thickness was 3 or 6m, accumulated under the gravel bed (N-value : about 20) which we supposed as bearing stratum of spread foundation, so we adopted pile foundation in fear of consolidation settlement (Fig.2).

And, diluvial gravel bed that was bearing stratum was inclined, uneven. Medium alluvial gravel bed included boulder, the maximum size of that was 150mm.

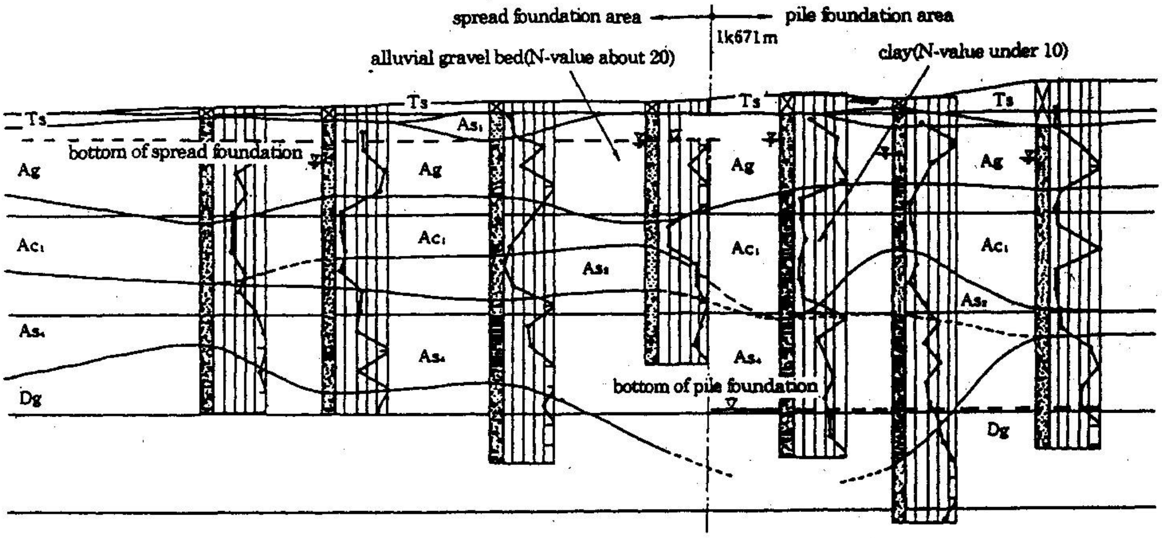


Fig.2 Geological longitudinal profile

2.2.2 Selection of pile method

The viaducts was rigid-framed structure of one pillar and one pile. Pile diameter was 1m, pile length was 15m. Medium stratum included big boulder and gravel. The houses stand close together around there, we had to construct rapidly two piles per a day by one pile driving machine. By those conditions, we selected pile the method.

We evaluated popular pile method as follows.

Driven pile method : Because this method has noise and vibration, we can not use it in city area.

Pile installation by inner excavation : Medium stratum includes big boulder, so it is impossible to construct by this metod. It depends on end bearing capacity of a pile, so it is unsuitable for rapid construction.

Cast-in-place pile method : Overall casing method has noise and shock. In reverse circulation drill method, and earth drill method, working efficiency declines when big boulder and gravel are.

So, we examined to adopt soil cement and steel pile method using steel casing pile and rock auger together, that could construct rapidly, excavate easily without removing boulder, gravel and obstacle in a ground.

3. SOIL CEMENT AND STEEL PILE METHOD WITH ROCK AUGER

3.1 The feature of this method

3.1.1 Construction order (Fig.3)

① Excavation to pile edge by rock auger with steel casing pipe. Grouting cement milk, and first agitating.

② Second agitating, taking down it to pile edge again after pulling up casing to ground surface with turning it. And pulling auger with grouting cement milk.

③ Positioning of steel pile with rib.

④ Completion.

3.1.2 Feature

This method differs from ordinary method in the following.

Excavation machine : Rock auger method with steel pile casing to crush and excavate underground obstacle (cobblestone, a cloud of concrete) is used.

Mouth pipe : For rapid construct, this method excavates, grouts and agitates from surface directly without using mouth pipe.

Foot protection : For rapid construct, foot protection of end of pile isn't performed. This pile is skin bearing pile.

Fig.4 shows the general drawing of this soil cement and steel pile.

Because this method was adopted for the first time for railway structure, construction test and vertical loading test were done. That purpose was as follows.

Construction test : This test confirmed the result of the pile in that ground and the construction condition, and progress speed.

Vertical loading test : This test confirmed the bearing capacity, skin friction in particular, of the pile constructed by this method.

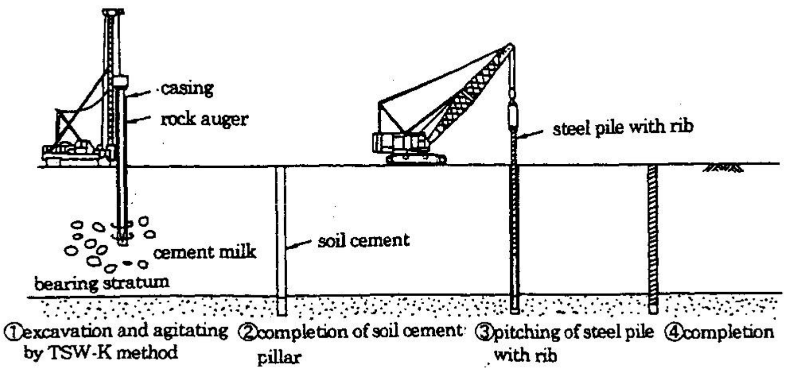


Fig.3 Construction order

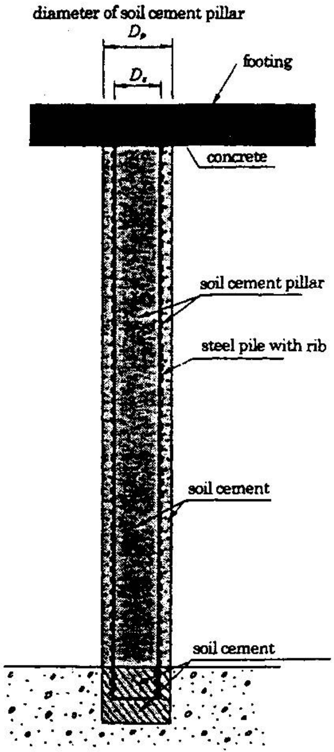


Fig.4 The general drawing

3.2 Construction test

The diameter of the test pile was 1000mm, the length of soil cement was16.5m. We adopted the steel pile, the diameter was 800mm, the thickness was 9mm, without foot protection. That had rib inside in the section of 2m from pile edge. We set up strain gauges in turning point of geology to measure linear stress when vertical loading test was done.

After vertical loading test, we dug out the pile, and surveyed shape of the pile. We confirmed the fixed pile. Table.1 shows the result of progress speed. It took 180 minutes from excavation to positioning of pile. In real construction, it takes time to move machine and quality control etc, so it is need to take some measures for progress speed, two piles per a day. This progress speed is about two times as fast as popular overall casing method.

Table.1 The result of progress speed

Kinds of working		Time(minutes)	
Excavation	Excavation/grouting	72	115
	Agitating	43	
Pitching of pile	Setting out/set staging	45	65
	Pitching of steel pile	20	
Total		180	

3.3 Vertical loading test

This test was done by multi-cycle form, based on the rule of Japanese Society of Soil Mechanics and Foundation Engineering. Planning ultimate load was 930t, four-thirds the ultimate bearing capacity of cast-in-place pile that was based on the design rule of railway structure. Table.2 shows the calculation result of ultimate vertical loading capacity.

Table.2 The calculation result of ultimate vertical loading capacity

Soil	Depth	Thickness of soil L_i(m)	N-value		Cohesion (tf/m²)	Diameter of soil cement ϕ Circumference U Sectional area A_p	f_i (tf/m²)	L_if_i (tf/m)	q_dA_p (tf)
Ts	0.30	0.3	—		—	ϕ=1.0m U=3.14m A_p=0.5026m² 16.5m	—	—	—
Ag	7.30	7.0	26				13	91	
Ac_1	12.30	5.0	8		7.0		7	35	
As_2 Dg	15.20	2.9	30		—		15	43.5	
Dg	16.00	0.8	12				6	4.8	
Dg	17.40	1.4	37	30				ΣL_if_i=174.3	150.8
Dc	19.20	1.8	23						
Dg	Under24.00		40				Subtotal	$U\Sigma L_if_i$=547.3	
							total	698.1tf	

Table.3 shows mix proportion of cement milk. When loading test was done, the unconfined compressive strength of the set cement (age : 43 days) was 30.7kgf/cm^2, the modulus of elasticity E_{50} was 10,000 kgf/cm^2 on an average. Fig.5 shows *P-s-t* curve. Fig.6 shows log*P*-log*s* curve. We judged ultimate load from log*P*-log*s* curve. Ultimate load was larger than planning ultimate load, 930t. When we loaded planning ultimate load, settlement of pile top was a little 13mm. This showed that constructed pile had sufficient bearing capacity.

Table.3 Mix proportion of cement milk

Unconfined compressive strength q_u(kgf/cm^2)	Cement C(kg)	Bentonite B(kg)	Water W(kg)	W/(C+B) (%)	Retarder (%)	Quantity of grouting
over10	400	20	749	178	0.6	0.884

Fig.7 shows the distribution of linear stress. When we loaded ultimate load, 10 percent of that, about 90t, was transmitted to the end of pile. We grasped that skin friction worked well, and that skin friction corresponded to the ground strength of stratum. The skin friction calculated from this distribution of linear stress was larger than assumed that in all stratum. In clay stratum that we feared the decline of skin friction by excavation and agitating stir with casing, the skin friction satisfied expectation value.

As mentioned, we realized that we could design the pile constructed by this method as skin friction pile, could apply the estimation formula of cast-in-place pile of the design rule of railway structure to estimate this ultimate fearing capacity.

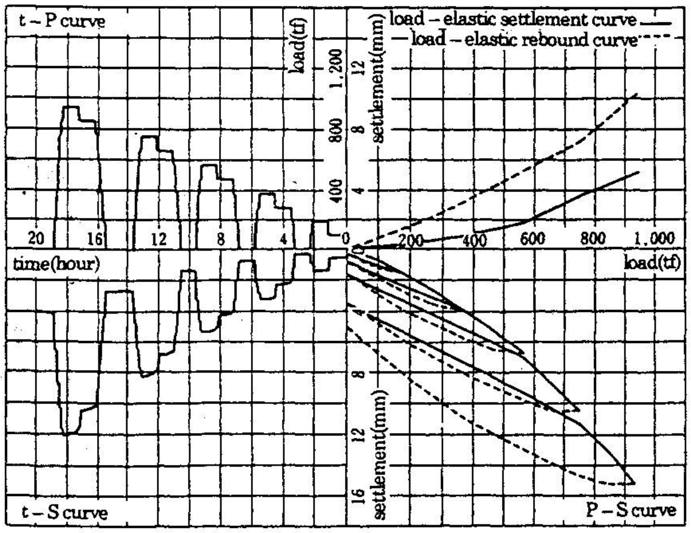


Fig.5 *P-s-t* curve

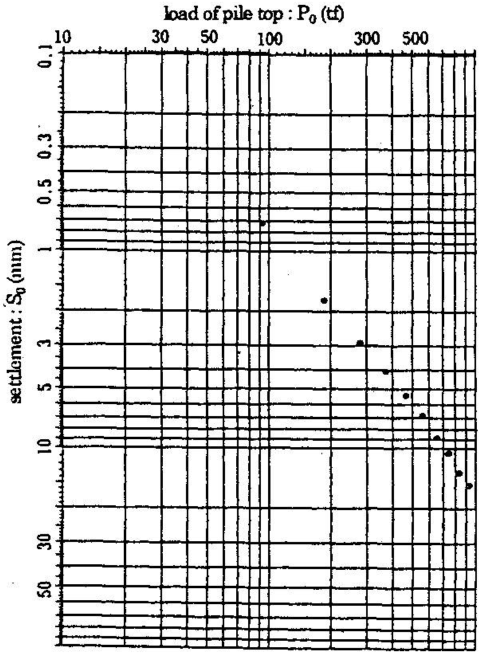


Fig.6 log*P*-log*s* curve

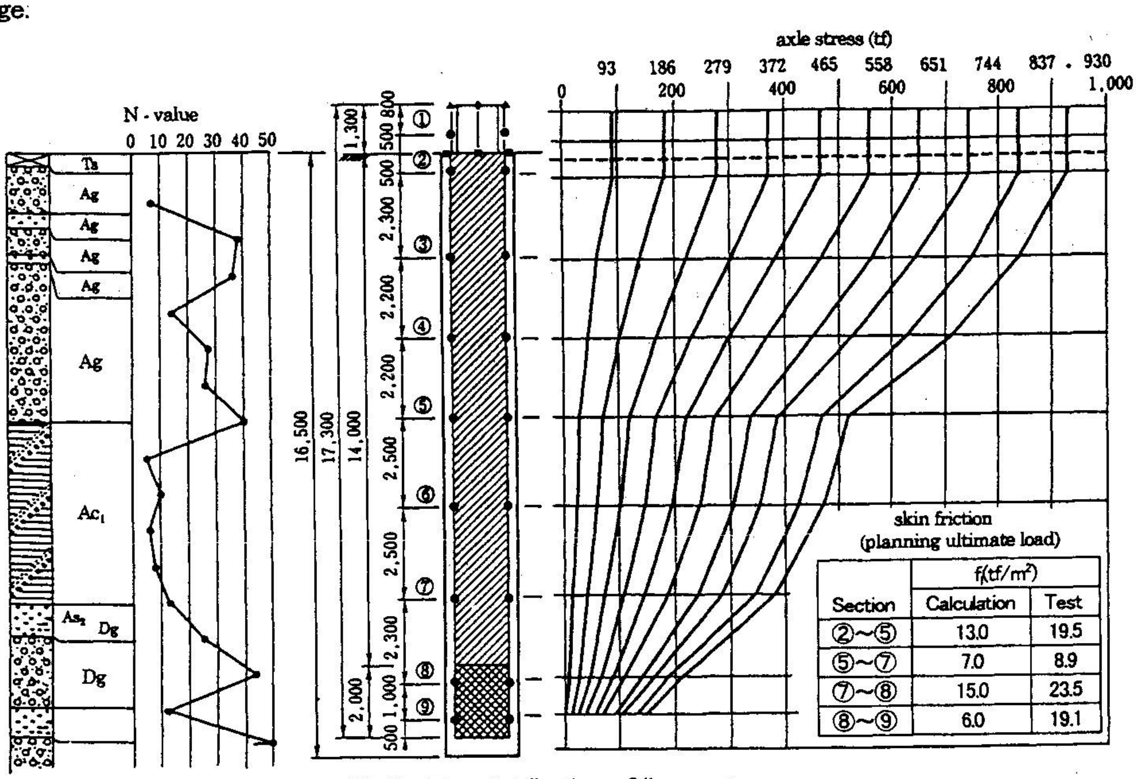
4 REAL CONSTRUCTION

4.1 Cycle time

In real construction, we could construct 42 piles for the total 20 days by 2 machines. We could construct 2.1 piles per a day on the average, exceeded the original plan, 2 piles per a day. Fig.8 shows the planning cycle time based on construction test, and that of real construction(average).

4.2 Execution error

We decided that the allowable of execution error was one two-hundredth, based on execution guide of cast-in-place pile of Japanese Association of foundation Construction. When we excavated, we confirmed the accuracy of vertical direction by using together the inclinometer in excavation machine and the measurement by two transits from right-angled directions. When setting out was done for pitching of steel pile, we set the exclusive device for that with guide roller, with checking by transit. When pitching of steel pile was done, we checked the vertical by plumb bob, too. We secured the accuracy more than the stated that. While the strength of the set soil cement was solid more than the stated strength, 10 kgf/cm^2(design). The 4 week strength of core specimen from the pile head was 20 kgf/cm^2 on average.



Section	f(tf/m^2) Calculation	Test
②~⑤	13.0	19.5
⑤~⑦	7.0	8.9
⑦~⑧	15.0	23.5
⑧~⑨	6.0	19.1

Fig.7 The distribution of linear stress

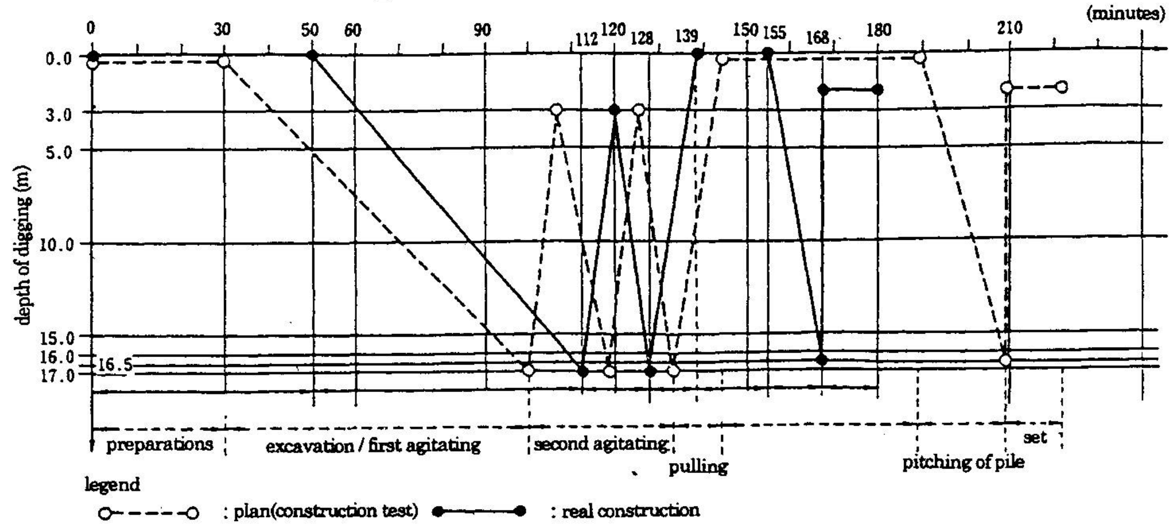


Fig.8 Cycle time

5 CONCLUSION

Soil cement and steel pile method is agitating and mixing ground and cement milk, needs little earth removal work, don't give industrial waste(slurry, etc). The method that this report showed, uses that method and rock auger method together. The cost is 20 or 30 percent higher than that of overall casing method. In this method, the material cost of steel pile with rib is high. This is one of matter for examination.

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