Journal of Civil Engineering and Architecture 12 (2018) 213-224
doi: 10.17265/1934-7359/2018.03.004

New Rectangular-like Columns: Advanced Swing Jet Grouting Test and Quality Confirmation

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Abstract: Ordinary columns of jet grouting are circular or fan-shaped. But in recent years, such shapes as candy-shaped columns were put to practical use. They are constructed by switching the rotational speed of the stem in one rotation. We applied this method to swing jet grouting. That is, we changed the rotational speeds in the swing jet grouting to make elongated columns near rectangle. The test construction was succeeded and the columns' shapes conformed to those designed. In addition, the quality was confirmed to be as good as ordinary columns. Radii (distances from center to outer ends) were 1.03 to 1.21 times as large as those designed. Improvement ratios were 95% or more in any position. Strengths were varied by location, but they satisfied design strength 1.5 kN/m^2 at any position. We concluded that this new column can be applied to practice in the same way as ordinary columns.

Key words: Swing jet grouting, rectangular-like column, flexible shape, efficiency.

1. Introduction

1.1 Prior arts

In recent years a new jet grout column called "Rectangular Column" is developed [1, 2]. This column is an advanced type of jet grout columns called "candy jet" or "Bow tie jet". The candy jet partially changes the diameter of the columns by changing the rotational speed of the stems, and thereby creating such shapes as candies [3]. Rectangular-like columns are constructed by increasing of the points that alters the rotational speeds, and by adequate adjusting of the rotational speeds and the angles to switch speeds (Fig. 1). This is the rectangular column method. Rectangular columns can reduce both total number and unnecessary volume of columns (Fig. 2). It leads to cost reduction and shorter construction period.

1.2 Background of the Research

We had one construction program to apply rectangular columns in Japan. The purpose of the construction is to build up column walls for prevention of liquefaction of residential areas (Fig. 3). Ordinary column walls are built up by circular columns. Construction speed is increased by changing the shapes of columns from circle to the rectangle.

However, there was a problem on planning the project. The column walls are basically planned to be on site boundaries, but some adjacent land don't allow columns to cross boundaries. Therefore, in such locations, it is necessary to use one-way swing jet grouting (Fig. 4). And so we came up with the idea to apply rectangular method to swing jet grouting. That is, we proposed constructing rectangular-like columns by appropriate switching of rotational speeds of jet grouting stems (Fig. 5). We named these new columns "S-rectangular columns" (Table 1). Although the S-rectangular columns can be applied theoretically, there have been no construction examples so far, and the quality was also unknown. For this reason, the improved columns were actually created and were confirmed whether they could obtain the designed shapes and whether the required quality were satisfied.

2. Experimental Method

2.1 Experimental Conditions

Experimental site is in Tokyo Bay region, northwest

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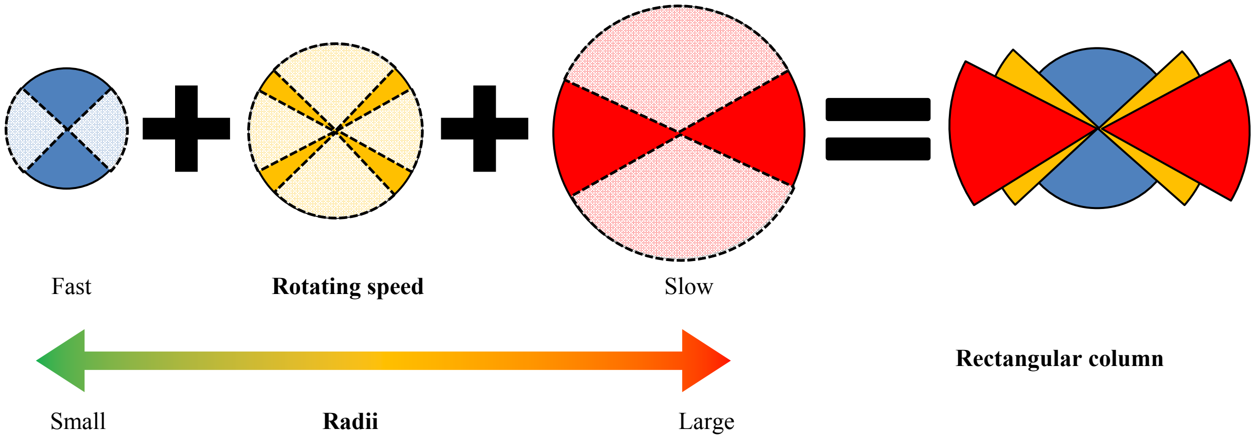

Fig. 1 Model diagram of rectangular columns.

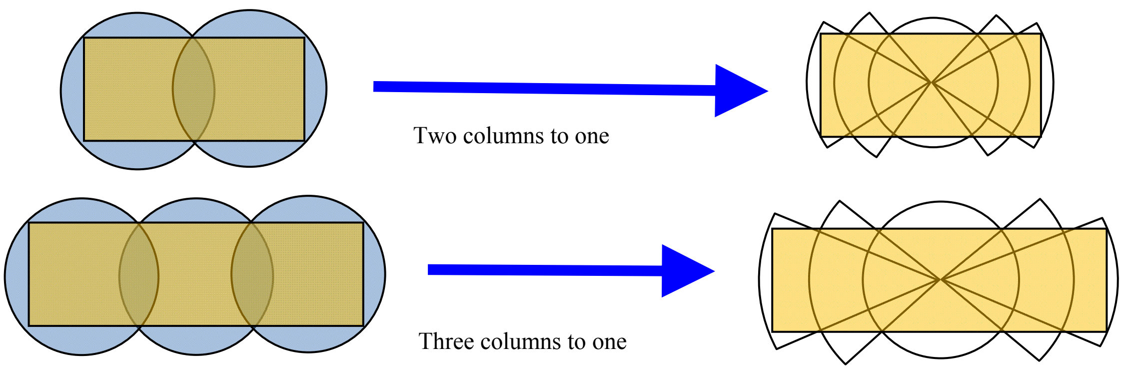

Fig. 2 Advantage of rectangular columns: reduction of number and unnecessary volume of columns.

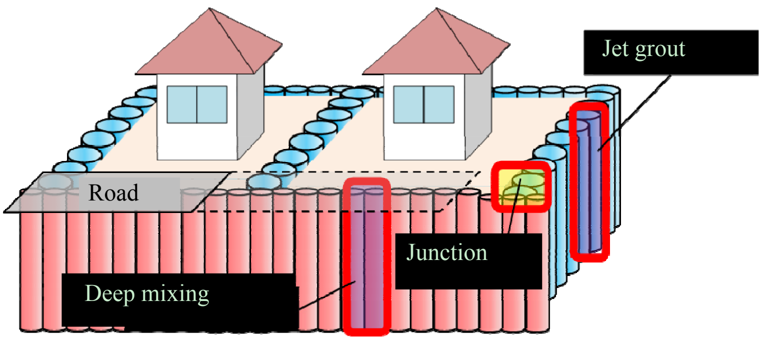

Fig. 3 Column walls against soil liquefaction.

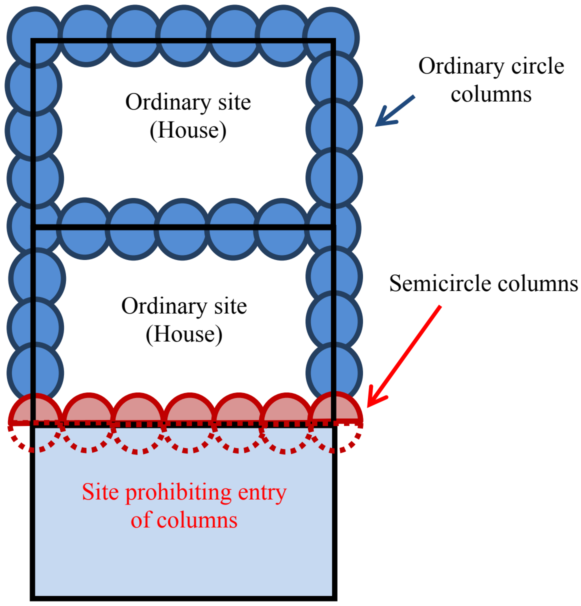

Fig. 4 Where to use semicircle columns.

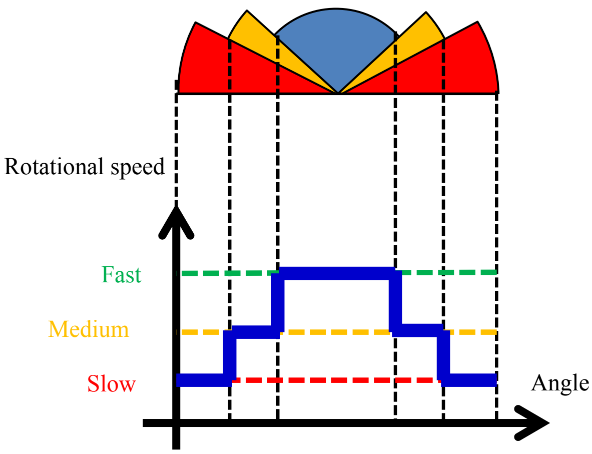

Fig. 5 Model diagram of S-rectangular column.

Table 1 "S" of S-rectangular column stands for.

1. Swing jet grouting
2. Single way injection
3. Semicircle or semi-rectangular (half of rectangular column)

part of Chiba prefecture, Japan (Fig. 6). The land is mainly reclamation landfill. Major specifications are shown in Table 2. Column depth is from GL -2.0 to -4.0 m. It is silty fine sand from surface to GL -3.7 m, and it is sand mixed silt at or deeper than GL -3.7 m. The designed shapes of the columns are shown in Fig. 7. Two columns (No. 1 and No. 2) were constructed to confirm reproducibility and variation of quality. Their shapes are designed so that their column walls have the same effective width 850 mm as those of original semicircular column with a diameter of 1,000 mm (Fig. 8).

2.2 Quality Validation

(1) Shapes

Columns are excavated after the construction. And

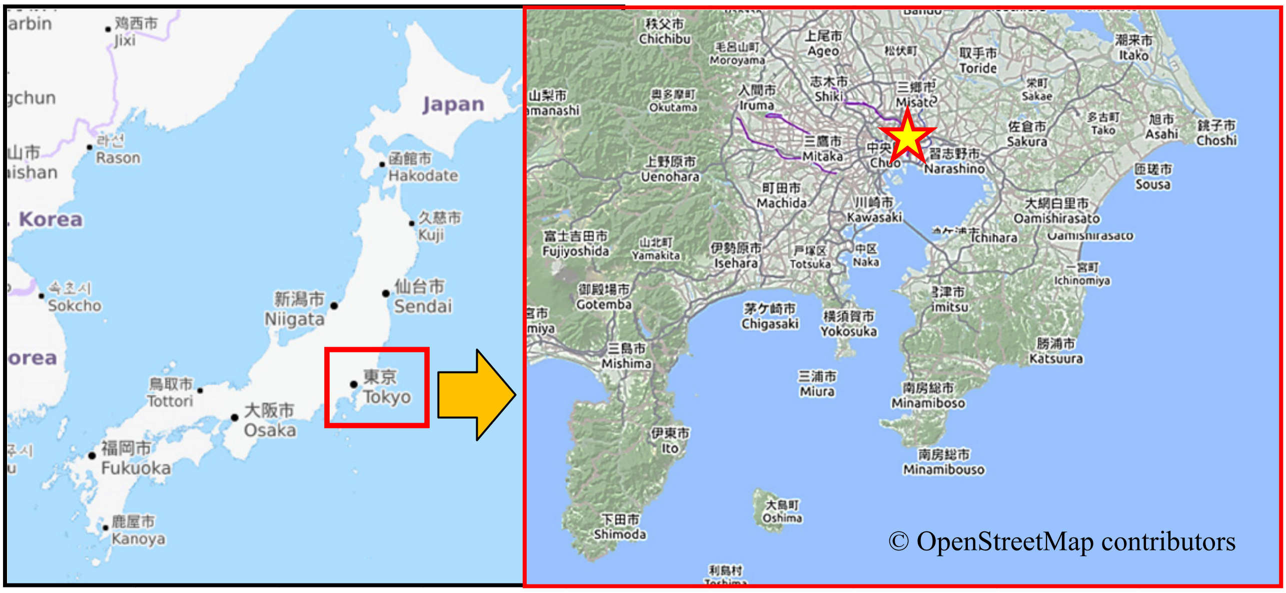

Fig. 6 Experimental site.

Table 2 Major specifications of the columns.

Radius	Max	1800 mm
	Minimum	1000 mm
Effective width		850 mm
Height		2000 mm
Depth		GL -2 to -4 m
Required average strength		1500 kN/m^2
Soil	GL -2.0 to -3.7	Silty fine sand
	GL -3.7 to -4.0	Sand mixed silt
flow rate		165 L/min

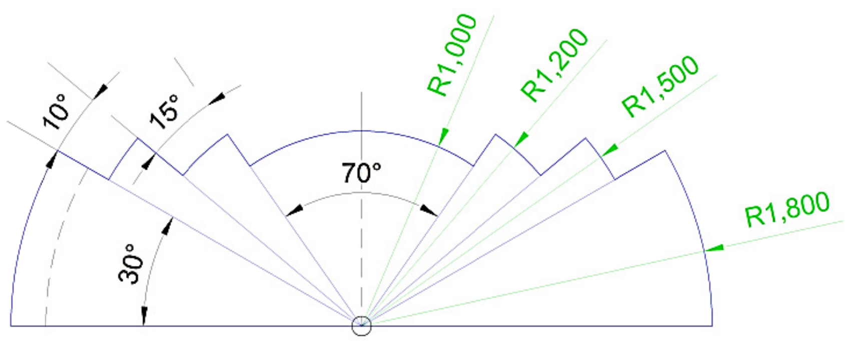

Fig. 7 Designed shape of the columns.

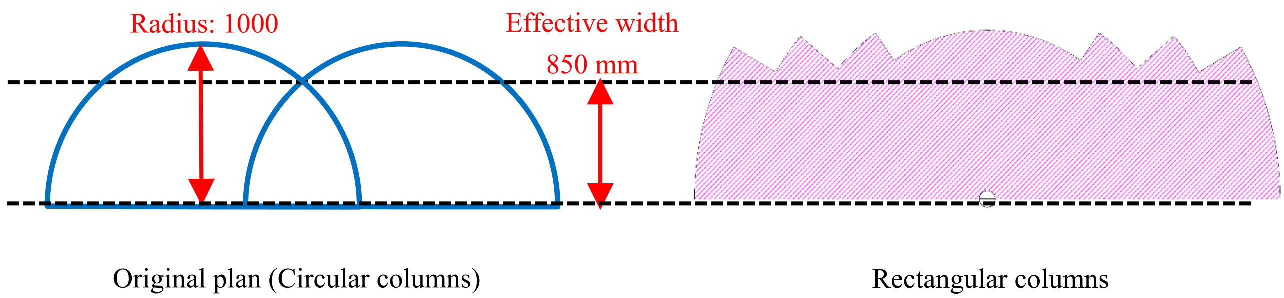

Fig. 8 The rectangular columns have the same effective width as walls of 1.0 m semicircle columns.

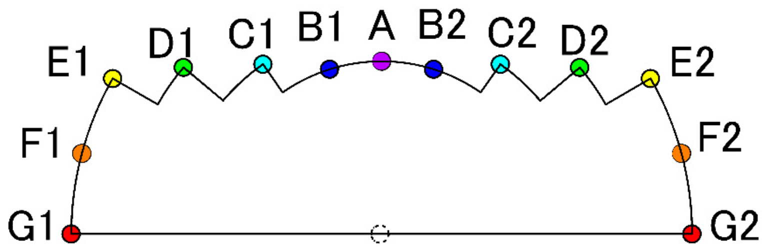

Fig. 9 Directions of radii measuring.

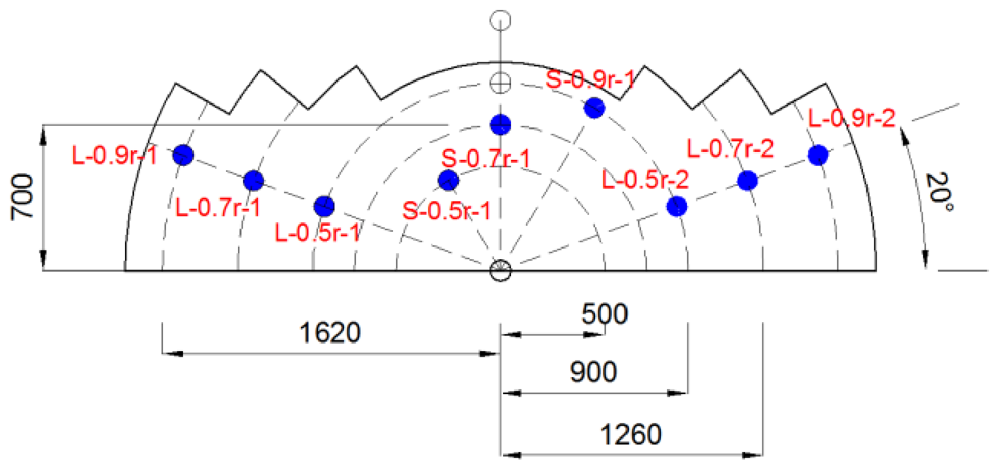

Fig. 10 Positions of core drilling.

radii (distances from the column center) were measured in 13 directions each column as shown in Fig. 9. In all the directions, radii were vertically measured every 10 cm from crown (GL -2.0 m) to the middle (GL -3.0 m).

(2) SCR (solid core recovery)

Nine cores were drilled in both columns as shown in Fig. 10. Core length matches whole column length (2.0 m). And then, we calculated SCR (percentage of cemented length in whole length).

(3) Strength

Test pieces were made from the core samples, and unconfined compressive strength tests were carried out for the test pieces. On the basis of the test results, the average strength and variation due to the position of the columns were obtained. The required average strength of the columns is 1,500 kN/m^2.

3. Results and Discussion

(1) Shapes

The photos of excavated columns are shown in Figs. 11 and 12. The results of measuring radii are shown in Figs. 13 and 14. Dashed lines are designed radii. Also, the average radii and the magnification ratio (measured radius / designed radius) are shown in Table 4. The radii are larger than those designed at any position. And the average magnification ratios are in the range 1.04 to 1.21. They don't deviate significantly from the design value. Therefore, we consider that S-rectangular columns can be constructed in the shapes as we design.

(2) SCR

Figs. 15 and 16 are photos of boring cores. SCR (1 m averages and whole core averages) are shown in Table 5.

Any core has improvement ratios more than 95%. It proves that S-rectangular columns are enough cemented at any position.

(3) Strength

The results of the unconfined compression test are shown in Figs. 17-20. Figs. 17 and 18 show variation of depth direction. Figs. 19 and 20 show that of plane direction. Both columns have the average strength more than the required value (1,500 kN/m^2). There is

Table 3 Number of samples.

Column	Drilling position	Number of samples	
		Individual	Total
No. 1	S-0.5r-1	9	64
	S-0.7r-1	2	
	S-0.9r-1	5	
	L-0.5r-1	7	
	L-0.5r-2	8	
	L-0.7r-1	11	
	L-0.7r-2	9	
	L-0.9r-1	10	
	L-0.9r-2	3	
No. 2	S-0.5r-1	3	29
	S-0.7r-1	4	
	S-0.9r-1	1	
	L-0.5r-1	4	
	L-0.5r-2	5	
	L-0.7r-1	3	
	L-0.7r-2	5	
	L-0.9r-1	1	
	L-0.9r-2	3	

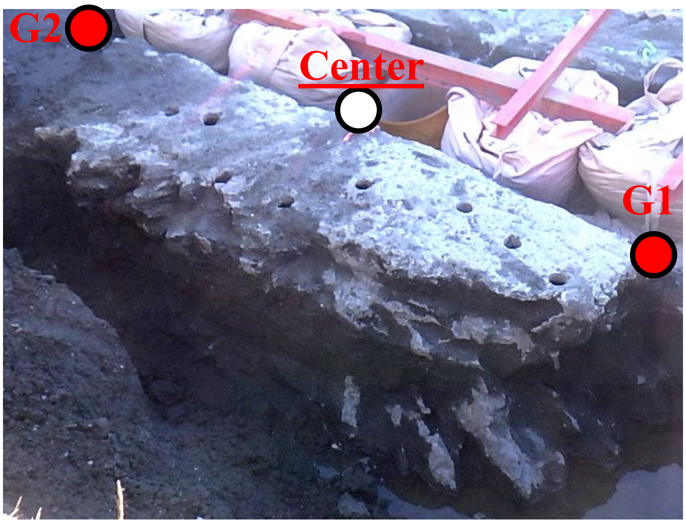

Fig. 11 Excavated column No. 1.

Fig. 12 Excavated column No. 2.

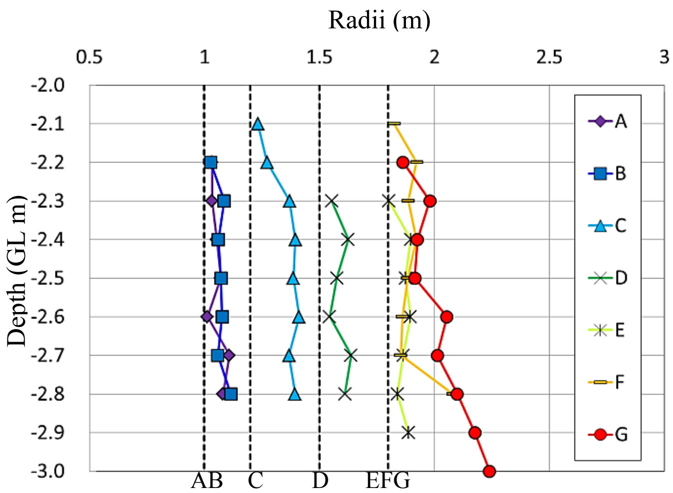

Fig. 13 Measured radii of No. 1.

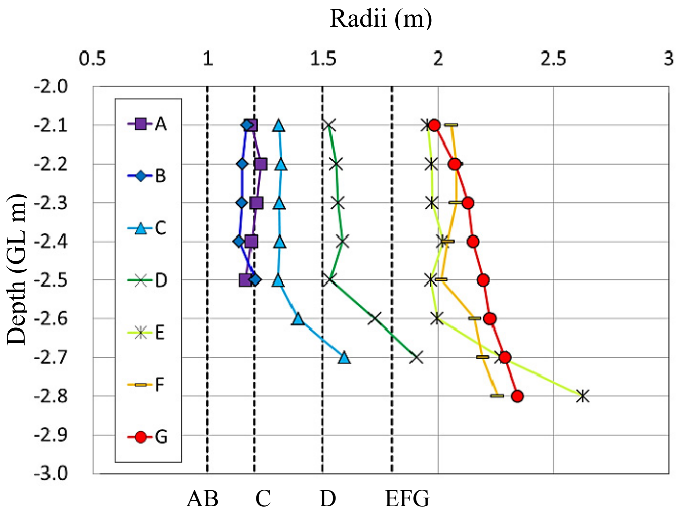

Fig. 14 Measured radii of No. 2.

Table 4 Magnification ratio of radii.

Measuring Position		A	B	C	D	E	F	G
A: Designed radii (m)		1,000	1,030	1,130	1,350	1,640	1,760	1,800
B: Measured radii (m)	No.1	1,009	1,185	1,355	1,561	1,843	1,905	2,006
	No.2	1,197	1,164	1,364	1,628	2,098	2,110	2,174
Magnification ratio (B/A)	No.1	1.01	1.15	1.20	1.16	1.12	1.08	1.11
	No.2	1.20	1.13	1.21	1.21	1.28	1.20	1.21

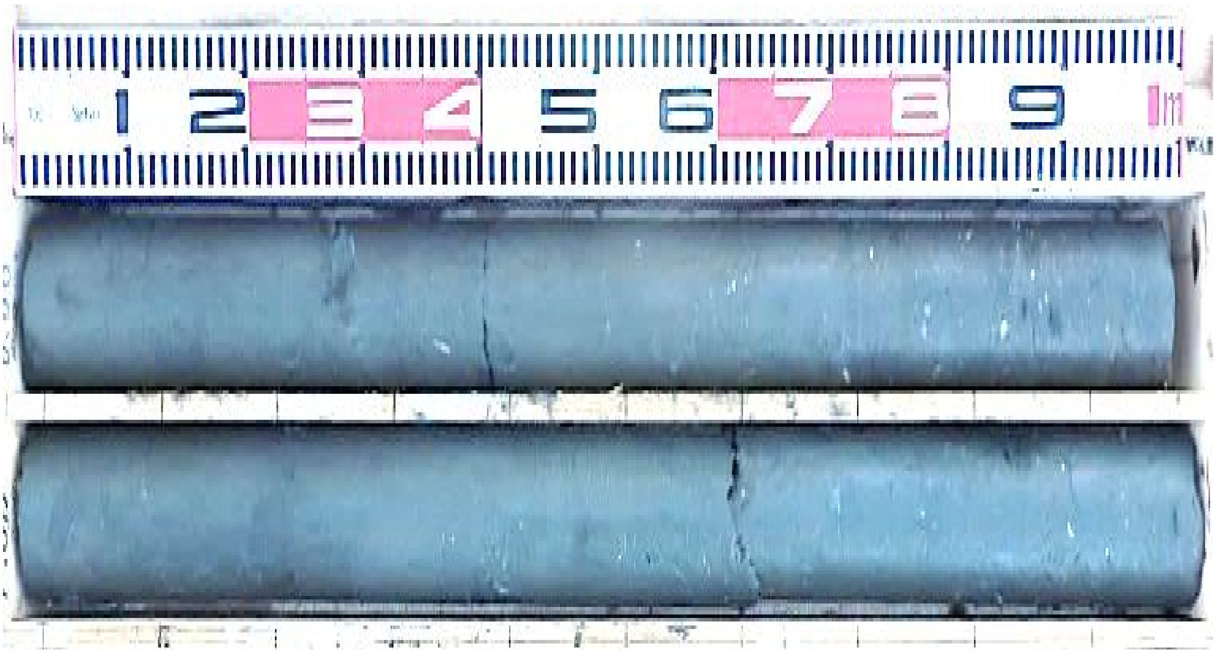

Fig. 15 Boring core (No. 1, S-0.5r-1).

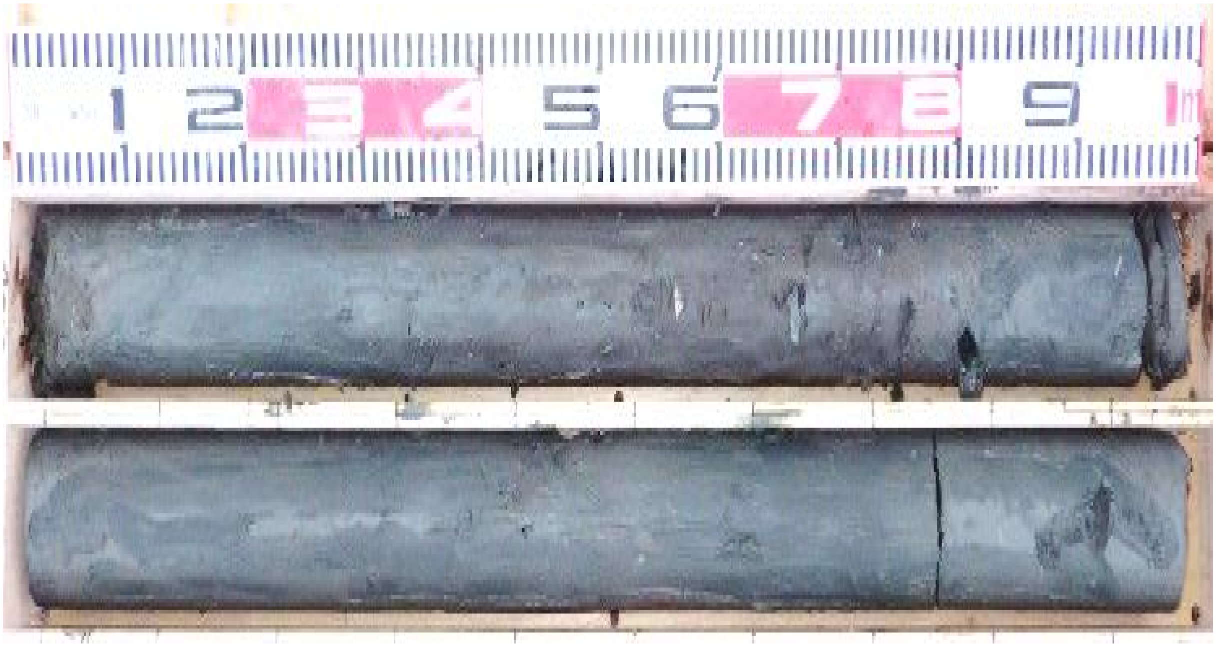

Fig. 16 Boring core (No. 1, L-0.9r-1).

Table 5 Solid core recovery.

Column	Drilling position	Solid core recovery (%)		
		GL-2.0 to -3.0	GL-3.0 to -4.0	Average
No.1	L-0.5r-1	100	100	100
	L-0.5r-2	100	100	100
	L-0.7r-1	100	100	100
	L-0.7r-2	100	100	100
	L-0.9r-1	99	100	99.5
	L-0.9r-2	100	100	100
	S-0.5r-1	100	100	100
	S-0.7r-1	100	100	100
	S-0.9r-1	100	100	100
No.2	L-0.5r-1	100	100	100
	L-0.5r-2	98	98	98
	L-0.7r-1	100	100	100
	L-0.7r-2	100	99	99.5
	L-0.9r-1	97	100	98.5
	L-0.9r-2	97	97	97
	S-0.5r-1	100	99	99.5
	S-0.7r-1	100	100	100
	S-0.9r-1	100	100	100

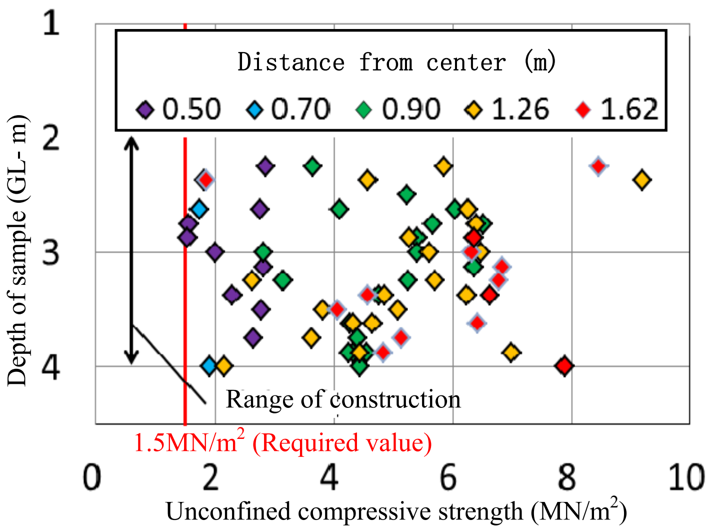

Fig. 17 Depth and strength (No. 1).

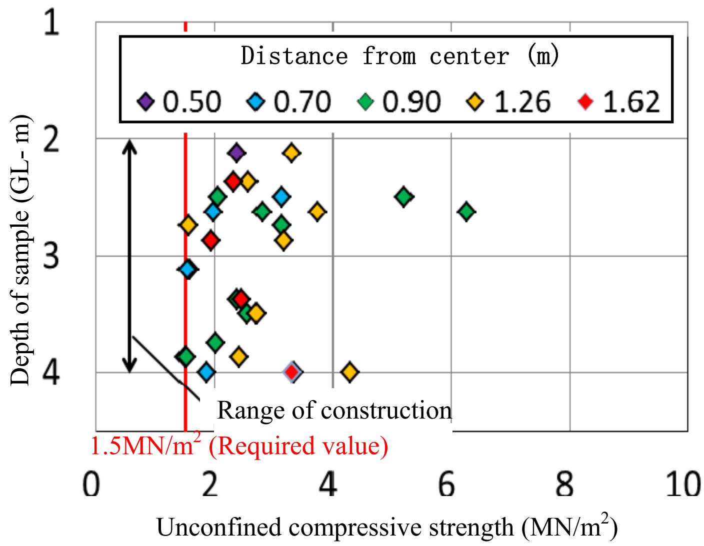

Fig. 18 Depth and strength (No. 2).

no dispersion of strength in the depth direction. However, there is dispersion of strength in the plane direction. The strengths far from the center are higher than those near the center.

We considered that this is due to the rotational speeds. Cores near to the center are drilled in the areas where designed radii are small. In these areas rotational speeds are high. On the other hand, cores far from the center are drilled in the areas where designed radii are large. In these areas rotational speeds are low. It is considered that difference in the rotation speed makes the differences in the cement concentration, which results in the strength differential.

In addition, there is also strength differential between No. 1 and No. 2. Average strength of No. 2 is higher than that of No. 1. We consider that this differential comes from the difference in radii. Fig. 21 shows the relations between cement concentration and core strength (average unconfined compressive strength). Before the on-site test, the interior proportioning test was held. Straight lines in the graph represent the assumed relationship as a result. This graph

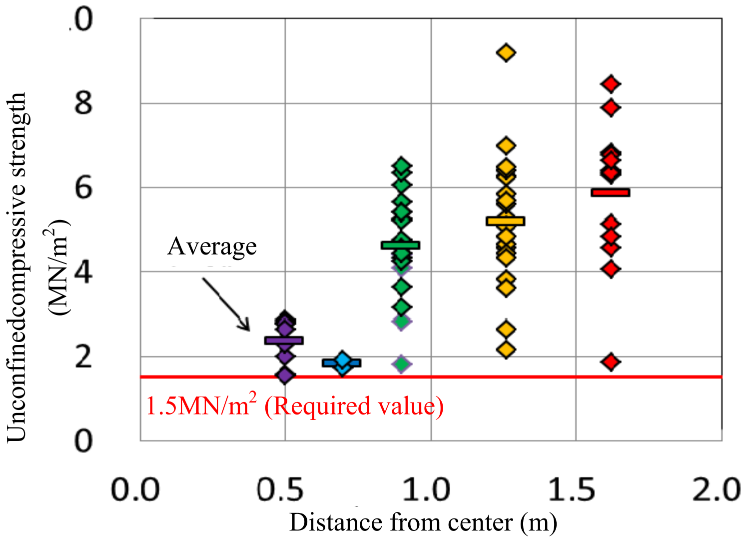

Fig. 19 Planar location and strength (No. 1).

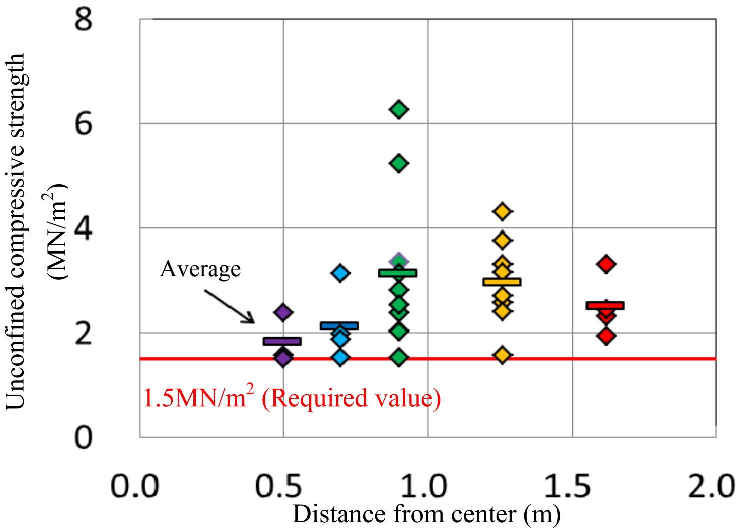

Fig. 20 Planar location and strength (No. 2).

shows that the actual strengths agree well with those assumed from the interior proportioning test. From this, we concluded that strength differential between No. 1 and No. 2 originates from the difference in cement concentration. Since both columns are constructed with almost the same amount of injection, the difference in cement concentration derives from the difference in radii. It is possible that the soil around No. 2 was weaker than the preliminary surveyed, which resulted in the expansion of radii.

4. Final Remarks

We succeeded in constructing rectangle-like columns as the advanced method of swing jet grouting. These columns are made by switching the rotational speeds of the stems. All the radii were larger than those designed, and the averages were 1.1 ± 0.1 times as large as those designed. All improvement ratios were 95% or more. Although there is strength differential in the plane direction, the required values were satisfied in any position.

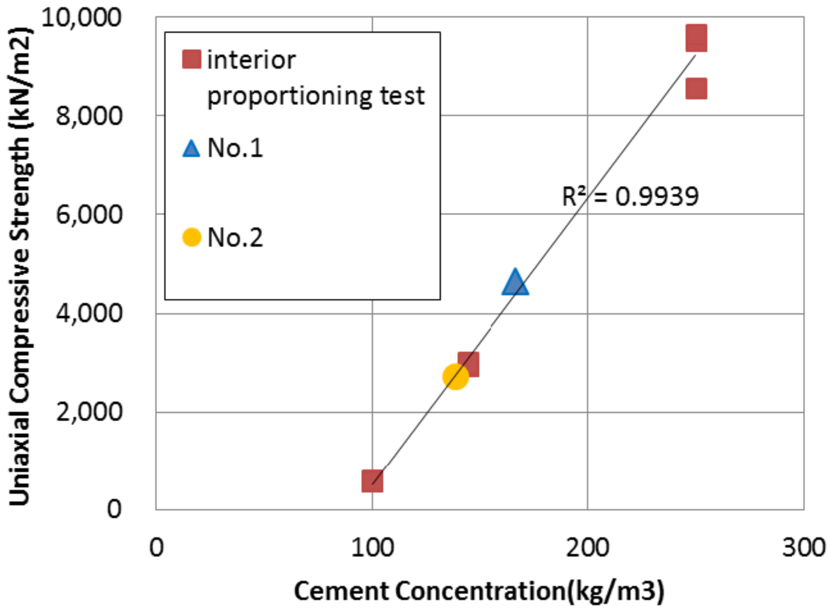

Fig. 21 Cement concentration and strength.

S-rectangular columns would be effective in some construction projects. But it is still not clear which combination of rotational speeds is the most effective in each site condition. It is necessary to calculate and test how the specification is effective as the same as ordinary columns.

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