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Assessment of the quality of soil-cement columns of square and rectangular shapes formed by a Deep Mixing Method

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ABSTRACT: A new deep mixing method developed to form soil-cement columns of a square or a rectangular cross-section, rather than the circular one prevalent so far, is described. Such shapes are advantageous in that more uniform soil improvement over wide area can be achieved vertically as well as horizontally. A series of model and field tests were carried out in clayey and sandy soils to investigate the effectiveness of the method. The technique is referred to as RM (Rectangular Mixing) method and its mechanisms found to be very effective as indicated by good quality of improved soil.

1 INTRODUCTION

Unlike the conventionally circular cross-sectional shape of columns formed by the deep mixing method (DMM), a unique mixing technique, referred to as RM (Rectangular Mixing) method, that is capable of forming square and rectangular cross-sections, has been developed in Japan. The unique cross-sectional shapes are made possible by attaching a special box-type casing around the agitating blades. This feature in the installation machine makes it possible to increase the soil improvement ratio to up to 100 %, horizontally as well as vertically, through close spacing of consecutive columns.

The paper describes the mechanism of RM method and presents the results of field tests undertaken to assess the quality of improved soil. Quality assessment is based on the strength tests, uniformity of strength throughout the improved soil cross-section, coefficient of variation in compressive strength, and comparison with laboratory mixing tests. Cases of tests carried out on columns of square cross-section formed by RM method in clayey and sandy soils are presented. The agitating blades in RM method rotate to describe a circular cross-section, just like in conventional DMM, while the cross-section of the column formed is square or rectangular. As a result, quality of improved soil around corner portions may be thought to be inferior to that in the middle portion (see Fig.3-2). A comparison of the core drilled in the middle portion with that drilled around corners of the same column is presented to investigate this effect.

2 OUTLINE OF THE RM METHOD

As described above, RM method results in soil-cement columns of square or rectangular shape. The specially designed agitator is screwed into the ground together with a box-type casing in a manner similar to drilling operation. The slurry of cement-type stabilizer is injected as the penetration proceeds. The system has blades for cutting the soil into small pieces while at the same time agitating and mixing with the slurry. Installation steps and the details of the special agitator of RM method is shown in Fig.2-1 and Fig.2-2 respectively.

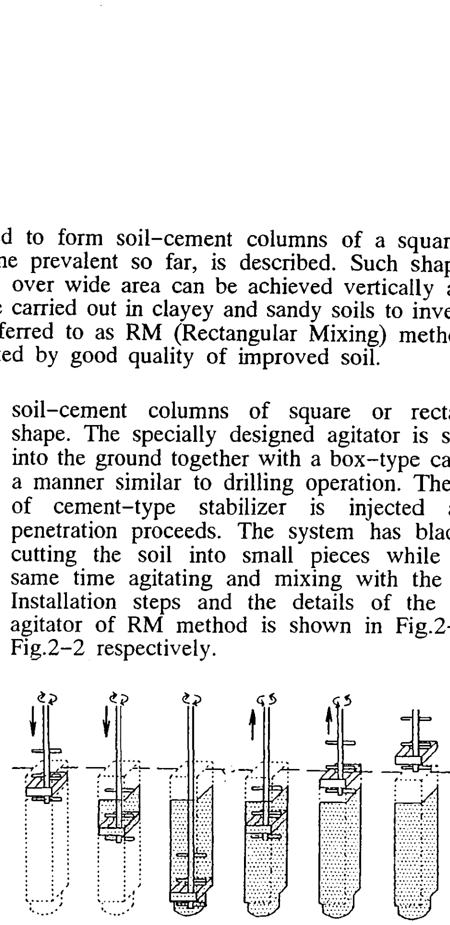


Fig.2-1. Installation steps

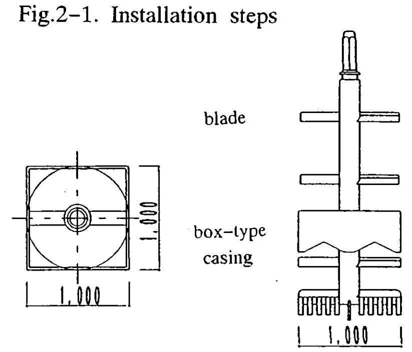


Fig.2-2. Details of the agitator

A series of model tests were carried out to study the basic mechanism involved in the formation of square column by RM method. Photo 2–1 shows the several phases of mixing process in the case of sand. It was observed that the colored area spread evenly to the edges inside the square box as the number of mixing times increased.

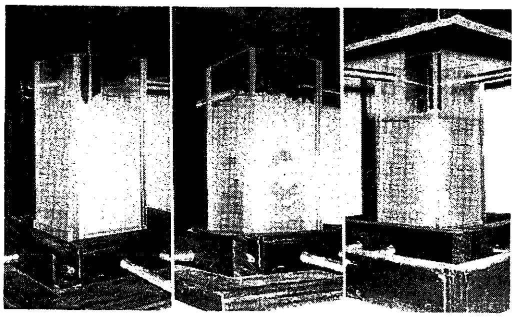


Photo 2–1. Mixing process

These test results bring the following hypothesis: the soil around the corner portions of the box–type casing starts to move along with the rotation of agitator as its force exceeds that of passive earth pressure. In addition, the grated and well mixed soil from mid part also moves into corner areas. As the process gets repeated with continued mixing, uniformly strong square column section results. Movement patterns of the soil inside the casing can be drawn as shown in Fig.2–3.

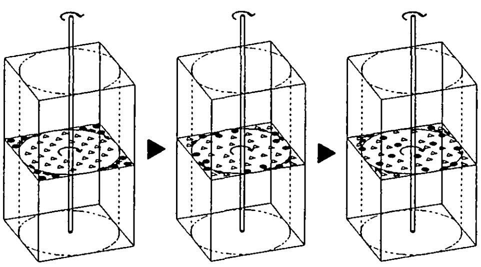


Fig.2–3. Movement pattern of soil

3 QUALITY OF THE COLUMN IN CLAYEY SOIL CONDITION

3.1 *Outline of the experiment*

The six columns were tested as follows to ensure the quality of columns formed by the RM method. The test site was at Sakai–machi, Ibaraki–prefecture. As is shown in Fig.3–1, the ground condition at the test site consists of Kanto loam, tuffaceous clay and medium dense, fine sand.

The test consists of the following :

1. Comparison of the unconfined compressive strength (q_u) of the core specimens recovered from the middle portion and the corner portions of column.
2. Evaluation of quality from core recovery rate.
3. A coefficient of variation in compressive strength q_u.
4. Comparison of the strengths of laboratory mixed sample and core specimen from the field.

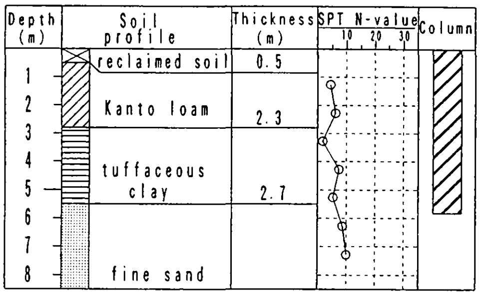


Fig.3–1. Soil profile (Clayey soil)

The test column has 1 m square and 5.8 m in length. Kanto loam and tuffaceous clay are the clayey soil types focused in this investigation. Table 3–1 gives the physical index properties of these soil types. Details of the installation record during installation and the chemical ingredients of cement–type stabilizer are shown in Tables 3–2 and 3–3 respectively.

Table 3–1. Physical index properties

soil type	w (%)	G_s	w_l (%)	w_p (%)	I_p	grain size(%) sand	silt	clay
loam	129.9	2.67	179.6	89.4	89.4	6	56	38
clay	54.2	2.67	90.8	47.2	49.6	14	56	30

NOTE: w : water content
G_s : specific gravity
w_l : liquid limit
w_p : plastic limit
I_p : plasticity index

Table 3–2. Installation records

execution rate (m/min) penet–ration	pull –out	r.p.m.	stabilizer amount (kg/m³)	type
0.5	1.0	30	100,200,300	cement–type

Table 3-3. Chemical ingredients

Cao	SiO_2	SO_3	Al_2O_3	Fe_2O_3	MgO	others	Total
62.6	19.5	7.5	4.2	2.7	1.3	2.2	100

NOTE: All units are in %.

3.2 *Test results*

3.2.1 Comparison of the q_u of core specimens recovered from the middle portion and the corner portions of column:

The core specimens recovered from the column were tested in unconfined compression. The test results are classified into two groups. One group consists of the results obtained from the core cut continuously along the vertical axis of the column. The other consists of results from core cut transversely along a direction perpendicular to the column axis. The cores in transverse direction were taken at a depths of 0.9 m and 1.6 m from the top of the column. Cores were recovered from the middle portion as well as from the corner portion of the column as shown in Fig.3-2. Cores from the middle portion consist of those collected from within r/2 and those from the area between r/2 and r, where r is the radius of the circle described by rotating blades as shown in Fig.3-3.

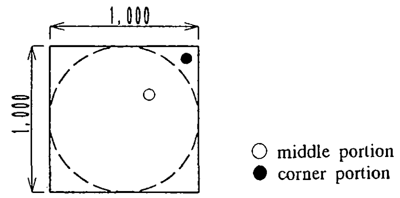


Fig.3-2. Core recovered location in depth

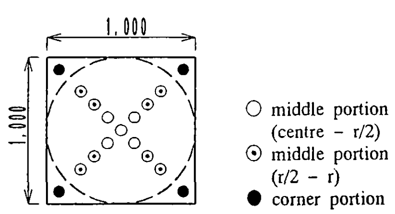


Fig.3-3. Core recovered location in section

Fig.3-4 compares q_u of core specimens from the middle portion with those from the corner portion of a square column formed by RM method. The comparison is shown for a number of samples along the length of the column. Fig.3-5 shows a comparison at the same depth. No significant difference between the strength of samples from the middle and corner portions can be seen from these comparisons.

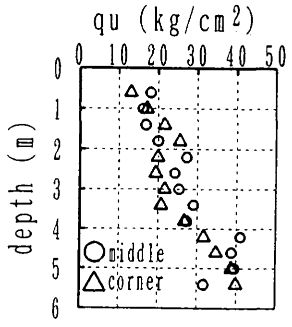


Fig.3-4. q_u distribution

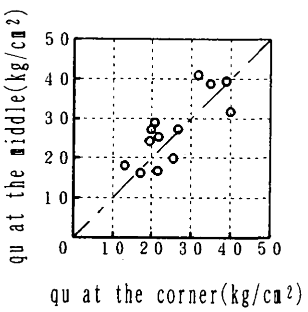
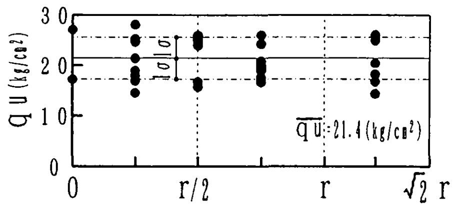
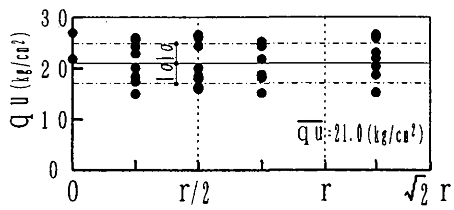


Fig.3-5. q_u comparison



(a) GL - 0.9 m



(b) GL - 1.6 m

Fig.3-6. q_u distribution in section

The q_u values from core samples taken from the same column in transverse direction are also seen to be quite close (Figs.3-6(a)(b)). In conclusion, it can be noted that the square column formed by RM method has uniform strength throughout its volume including the corner portions.

3.2.2 Quality assessment of core recovery rate:

The core recovery rate represents the percentage of the core length from which quality cores can be recovered. This index is usually utilized to assess the condition of base rock. Low core recovery rate indicates parts of weathering base rock where it may have many cracks. This concept is introduced here in order to assess the integrity of the column based on the recovery rate of the core along the vertical axis of column at both the middle portion and the corner portion. Table 3-4 shows the results from the assessment of six columns. The core recovery rate is more than 90 % in all the cases, and no noticeable difference can be seen between middle parts and corner parts. The consistent core recovery rates demonstrate that the quality of column formed by RM method is reliable.

Table 3-4. Core recovery rate

soil type	depth section (GL- m)	core recovery rate(%) middle	corner
loam	0.5 - 1.5	98 - 100	94 - 100
	1.5 - 2.5	96 - 100	94 - 100
clay	2.5 - 3.5	97 - 100	97 - 100
	3.5 - 4.5	98 - 100	95 - 100
	4.5 - 5.5	92 - 100	97 - 98
sand	5.5 - 5.8	100	100

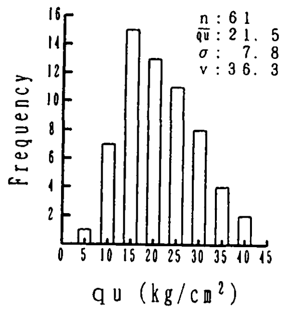
3.2.3 Coefficient of variation in q_u values of core samples:

Figs.3-7(a)(b) show histograms of q_u values of core samples taken along vertical axis at the middle portion and at the corner portion of six columns installed in Kanto loam. There is no significant difference in coefficients of variation between middle portion (36.3 %) and corner portion (38.3 %). Generally, the coefficient of variation in q_u value in case of DMM is known to be in the range 20 to 40%. Thus it can be seen that the variation in the value of q_u in the case of RM method is well within the range of other methods.

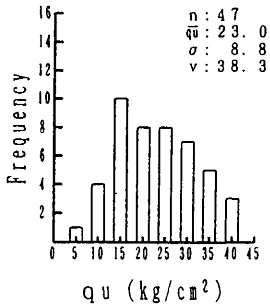
3.2.4 Comparison of the strength laboratory mixed sample with that of core from field test:

Fig.3-8 shows the strength q_u of the soil-cement samples mixed in the laboratory with the amount of cement 200 kg/m^3, 300 kg/m^3 and 400 kg/m^3. The amount of cement used in the field was 300 kg/cm^3. The strength q_u of the laboratory mixed sample when the amount of cement was 300 kg/m^3 was 26 kg/cm^2 in case of Kanto loam and 51 kg/cm^2 in case of tuffaceous clay.

Compared to the strength from laboratory test, the strength q_u of core samples from the field test is around 75 % in the case of Kanto loam and 60



(a) middle portion



(b) corner portion

Fig.3-7. q_u histogram of Kanto loam

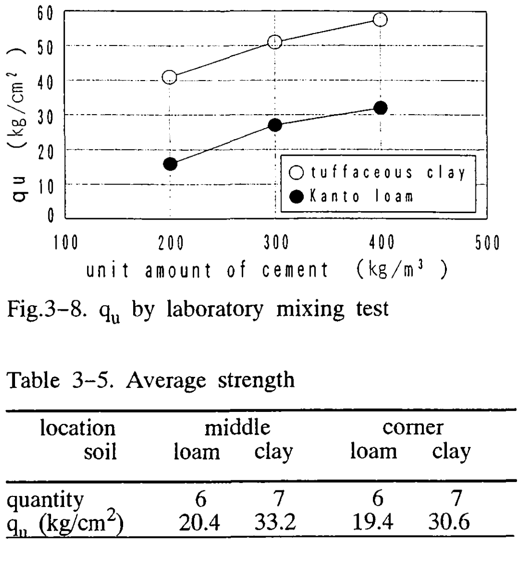


Fig.3-8. q_u by laboratory mixing test

Table 3-5. Average strength

location / soil	middle loam	middle clay	corner loam	corner clay
quantity	6	7	6	7
q_u (kg/cm^2)	20.4	33.2	19.4	30.6

% in the case of tuffaceous clay (Table 3-5). The strength of core specimen from the field is sometimes reported to be only about one third to one fifth of that of laboratory mixed samples. In comparison, 60 to 80 % of the laboratory mixed samples achieved in RM method in the field can be considered to be the result of fairly good quality control technique.

4 QUALITY OF THE COLUMN IN SANDY SOIL CONDITION

4.1 *Outline of the experiment*

About 20 columns (1 m square, 4 m in length) were constructed in loose alluvial sandy soil. Strength test on core specimens and dig-out test were carried out. The test site was Yatomi-cho, Aichi-prefecture in the south western part of Nagoya. Fig.4-1 shows ground condition of the site. Upper two-third part of the columns are in reclaimed soil and silty sand layers. Lower one-third parts consist of medium dense fine sand. The water table at the site was observed to be at a depth of GL-0.8-0.9 m.

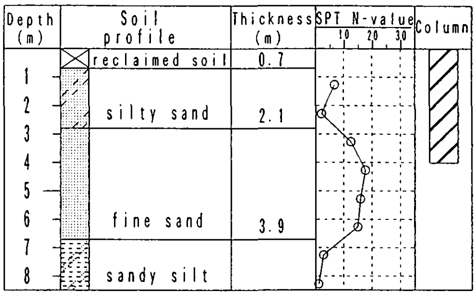


Fig.4-1. Soil profile (Sandy soil)

4.2 *Test results*

4.2.1 Strength test:

Similar to the tests at clayey soils described above, core specimens along axial and transverse directions were taken from the column. The q_u values were assessed by taking into account the following parameters:

1. amount of the cement-type stabilizer
2. soil type
3. core location
4. water-cement-type stabilizer ratio (W/C)

Values of q_u are tabulated in Table 4-1.

Following deductions can be made regarding the influence of the above parameters on q_u:

1. The amount of cement-type stabilizer influences both the mean strength and its dispersion. In particular, small amount of cement-type stabilizer results in very remarkable decrease of the strength.

2. Soft sandy soil that contains large silt fractions results in distinctly small strength and the dispersion is also high.

Table 4-1. Comparison in q_u value

		location		W/C	
		middle	corner	100(%)	120(%)
150	silty sand	8.0	---	7.6	8.3
(kg/cm^3)	sand	15.5	---	15.3	---
	average	8.9	---	9.5	8.3
200	silty sand	13.8	16.9	18.7	12.1
(kg/cm^3)	sand	30.7	32.2	35.5	29.2
	average	22.2	26.4	27.1	21.9
300	silty sand	19.1	33.8	28.3	15.4
(kg/cm^3)	sand	26.6	27.4	32.5	26.3
	average	23.6	29.5	29.1	24.3

NOTE: All units are in kg/cm^2

3. There is little differences between the middle and corner portions of the column with regard to q_u value and its dispersion.

4. Higher W/C ratio results in lower value of q_u.

From above observations, it is seen that the strength of the column formed by RM method in sandy soil condition shows little difference between the middle and corner portions of the square cross-section. Overall the strength depends on the amount of cement-type stabilizer, and type of soil W/C ratio.

4.2.2 Dig-out test:

Two columns were dug out for observation of the cross sectional shape column and its overall condition. The installation records of columns are shown in Table 4-2.

Table 4-2. Installation condition

No.	length L (m)	amount of stabilizer C (kg/m^3)	W/C (%)	slurry quantity Q (l)
1	4.0	190	100	1008.0
2	4.0	318	120	1936.9

Photos 4-1, 4-2 show the dug-out column No.1 and its cross-sectional cut. The cross-section is seen to be of square shape. In dug-out column No.2, some non-improved small clods 10-20 cm in size were observed around the end section. However, no difference was observed between the middle portion and the corner portions of the column with regard to the presence of non-improved clods.

Photo 4-1. Column No.1 (general view)

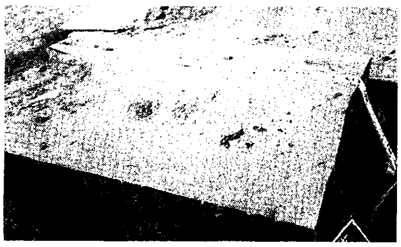


Photo 4-2. Column No.1 (cross section)

5 CONCLUSIONS

Based on the investigations carried out at part of this paper, the following features of the RM method can be considered remarkable:

1. The square or rectangular cross-sectional shape can be formed by the box-type casing fixed around the rotating blades.
2. The mechanism of the formation of square or rectangular shape can be noted to be as follows: the soil that gets into the corner portions of the box-type casing is drawn in by the rotating blades once the force exceeds that of passive earth pressure. Meanwhile, the well mixed soil from the middle portion moves out to take its place.
3. The strength at middle portion and at the corner portion is identical.
4. There is only a slight difference in quality between axial direction and transverse direction of the column
5. The overall strength of soil-cement columns formed by RM method compares well with those of conventional columns with circular cross section.

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