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STRENGTHENING EFFECTS OF RC COLUMNS USING THIN STEEL SPIRAL TUBE

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SUMMARY

This paper describes a mechanical behavior of a proposed new system reinforced concrete column which has core concrete strengthened by a thin steel spiral tube. The aim of the new system RC column is to improve axial strength and to prevent crushing of columns from high axial load.

The thin steel spiral tube used here is spirally wound-up thin steel band plate and it has no strength and stiffness in the axial direction. But it has a certain confining effect of increasing strength of concrete in the tube and some separation effect to prevent cracks occurred in the outside concrete of tube from penetrating to core concrete.

From experimental results of both an uniaxial compressive test of the core concrete and a biaxial loading test of new system RC column, we obtained the following characteristics:

Strength of the core concrete increases by confining effect of the thin steel tube, and axial strain is over 1.5% when strength declined to non-confined concrete strength.

As for the specimens of RC column, the effect of the core concrete clearly increased strength and displacement capacity. And the accumulated compressive strain of column by the cyclic lateral load under the constant axial force became very small in comparison with the ordinary RC column.

Moreover, when the encased concrete collapsed, the core concrete does not decrease in strength, and remaining axial strength is almost equal to the calculated axial strength of ordinary RC column. This shows the supporting ability enough to prevent the column from axial crushing.

INTRODUCTION

The remarkably damaged RC buildings due to the 1995 Hyogoken-nanbu earthquake are characterized by the story collapses of the middle floor, and as the other characteristics, there are seen many crushed columns of the 1st story of the pilotis type RC buildings [3].
It is thought that the cause of the crushing of these first story columns is due to the combined high axial force and the high shear force subjected at the same time under the earthquake motion.
To prevent such crushing, it is important to secure the axial and lateral strength of column and thr deformation ability of the column to subject high shear and axial force.

Moreover, the RC column is failed by shear force, the axial strength is rapidly lost, and brittle failure occurs by shear cracks expanding to the whole section obliquely.

Since 1983, we have researched the trial to prevent the decline of the axial strength caused by the shear failure, and to improve the strength and ductility. And finally to prevent axial crushing of RC columns to subject high shear and axial force, we proposed that very thin steel spiral tube should be inserted as confining concrete of the center in the column section.

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And some research results have already been reported. [5]

There is an actual example based on those research results; the thin steel spiral tube was installed in the 1st story columns of the 5th story RC residence, which was built in 1994 in Ashiya City, Hyogo Prefecture.

This building was hardly damaged in the 1995 Hyogoken-nanbu earthquake, though it was built in one of the most severe earthquake areas and many RC buildings in the neighborhood suffered great damages.
By this fact, the validity of the strengthened effect by thin steel spiral tube was confirmed, and therefore we may conclude that this research will lead to establishment of the design method of proposed new system of RC columns.

PROPOSED NEW CONSTRUCTION SYSTEM OF RC COLUMN WITH CORE CONCRETE

Strengthening the concrete portion in the center of RC column is named "core concrete". In this paper, the core concrete is strengthened by the thin steel spiral tube（of the following TSS tube）, which is made up of the spirally wound-up steel band plate which is 150mm in width and t=0.4～0.6mm in thickness.

Photo 1:actually constructed thin steel tube

Moreover, the joints of plate edges of TSS tube is mechanically bent-up as the seam to set each other and is comparatively flexible in axial direction, and therefore the compressive strength of TSS tube can be hardly expected.
And, as shown in Figure 1, TSS tube is designed to be inserted only in the clear span of the columns, and it can't resist tensile force, either.
Therefore, the mechanical property of TSS tube is expected only about confining effect to concrete inside the tube, and separation effect to prevent cracks from penetrating to core concrete.
Execution process of new system RC column shows that after TSS tube is set at the time of the arrangement of reinforcing bars, concrete is placed in the whole section of column.
If core concrete strength is designed higher than that of the outside concrete of tube, after setting TSS tube, the different strength concrete is placed divided by two times in the inside and outside of the tube. Or, as another method, after core concrete precasted beforehand is set, the outside concrete of TSS tube would be placed.
The problem about the latter construction method will need to be considered in future.

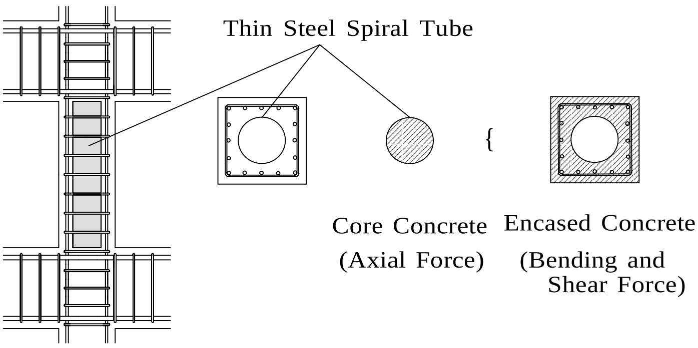


Figure 1: Proposed New System of RC Column

THE CHARACTERISTICS OF NEW SYSTEM OF RC COLUMN

1）New system RC column is a hybrid structure with core concrete strengthened by TSS tube and encased RC column with hollow core as shown in Figure 1.
Encased concrete can resist bending moment and shear force and a part of the axial force, but core concrete is thought to resist only axial force.
2）TSS tube used here is very thin and light in weight, so it has features which need little labor for conveyance

and construction.
3)As mentioned before, TSS tube itself is flexible in axial direction, and the stiffness and strength of TSS tube are not taken into consideration. This is a quite different characteristc from the SRC steel pipe structure.
4)TSS tube contributes increasing the strength of core concrete by confining effect, and at the same time, it is assumed to have certain separation effects which prevent the cracks occurred in the encased concrete from penetrating to core concrete.
Therefore, even if the damage of encased concrete expands, it can be expected that the axial strength of core concrete does not decline.
5）The strength of new system RC column can be evaluated by superposing strength of encased concrete and core concrete.

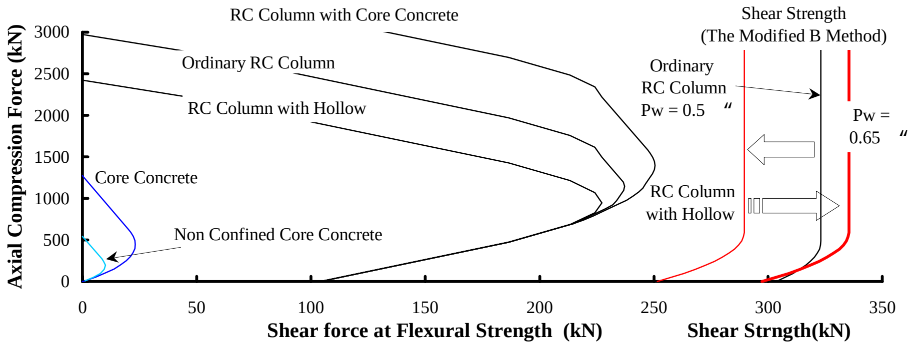


Figure 2: Mechanical characteristics of RC column with core concrete

As shown in Figure 2, on the interaction curve between axial force and bending strength of the ordinary RC column, the maximum bending strength point of the column which usually appears at axial force is about N=0.43bDFc. This N-M interaction curve approximately corresponds to the superposing strength of the RC column with hollow core and non-confined concrete in the center of column.
It follows that, due to confining effect of TSS tube, N-M interaction curve of RC column becomes large and the axial force at maximum bending strength point increases to the direction of axial force.
Similarly, by superposing N-M interaction curve of high strength core concrete and the one with hollow core, both maximum bending strength and axial force at maximum bending strength would increase together.
From this, the relaxation of the axial force limitation of the FA member, defined in AIJ design code [2] which is considered to have large ductility, can be possible, or sectional area of column can be cut down in the case of the same axial force.
And, by separation effect of TSS tube to prevent cracks from penetrating to core concrete, even when the great damage of encased concrete occurs due to the lateral force, core concrete can be thought to be within elastic limit and with no damage. Therefore the column can secure axial load supporting capacity under the ultimate condition, and axial crushing of the column can be prevented.
However, the elevation of core concrete is very slender and the shear strength due to arch mechanism is very small. Therefore, as shown in Figure 2, shear strength of RC column with core concrete decreases to that of encased concrete. But it can be reinforced by adding appropriate amount of shear reinforcement to clear the shear strength of ordinary RC column, (so it must be designed so that the shear strength of the column has to be evaluated only by encased concrete from which core concrete is deducted.)
As mentioned later, the shear strength of encased concrete can be evaluated with the modified B method in AIJ design code [1] to apply effective section of encased concrete.

VENIFICATIONS BY EXPERIMENTAL TESTS

The Uniaxial Compressive Strength test of Core concrete Strengthened by TSS Tube:

Test specimens and outline of uniaxial compressive test:

To confirm the confining effect of TSS tube, uniaxial compressive tests were performed as below.
Parameters of these test specimens are concrete strength filled in TSS tube and diameters of TSS tube.
Design strength of filled-in concrete has two kinds of 30 and 60N/mm^2, but actual compressive strength at the time of testing are 31.9 and 52.4N/mm^2 respectively. Diameters of TSS tube were seven kinds of φ=100,125,150,175, 200,225,250mm, and each kind of test specimen has two specimens respectively.
Yield strength of the thin steel plate of TSS tube is 279N/mm^2, and thickness of the plate is t=0.6mm.
Length of the test specimens was planned so that displacement measuring length is 2.5 times of the diameter, and

the top and bottom nearby loading point of specimens are reinforced by the steal ring as shown in Figure 3. Specimens were loaded with 500ton universal test machine of Fukuyama university to the maximum strength in the loading range of 0.02□0.05N/mm^2/sec, and after that, the load-displacement relation was recorded until the strength declined to 60% of the maximum strength.

Uniaxial compressive Test Result:

Table 1 shows the average compressive strength of the same 2 specimens strengthened by TSS tube, and the strength increasing ratio to filled-in concrete strength. As shown in Figure 4, from the stress-strain relations in the specimens of low concrete strength, the decrease of strength after maximum strength is very small and ductile behavior can be seen. In the case of the specimens of high concrete strength, the decrease of strength after maximum strength is rather rapid, but it can hold the strength of concrete till it reaches over 2 times of the ultimate deformation of ordinary concrete.

Figure 5 shows the experimental compressive strength ratio and calculared value by the Richart's equation [6] .

As for the confining effect of TSS tube, it was confirmed that almost good correspondence with the Richart's equation is shown.

Table 1: Results of uniaxial compressive strength test

Diameter	2t/φ (%)	Maximum strength			
		$\sigma_{\square}$=52.4 N/mm^2		$\sigma_{\square}$=31.9 N/mm^2	
		σ_{max} (N/mm^2)	σ_{max} / $\sigma_{\square}$	σ_{max} (N/mm^2)	σ_{max} / $\sigma_{\square}$
φ100	1.20	64.2	1.23	46.5	1.46
φ125	0.96	62.9	1.20	43.7	1.37
φ150	0.80	60.5	1.16	40.9	1.28
φ175	0.69	57.8	1.10	38.7	1.21
φ200	0.60	57.2	1.09	37.0	1.16
φ225	0.53	57.2	1.09	37.7	1.18
φ250	0.48	56.1	1.07	37.6	1.18

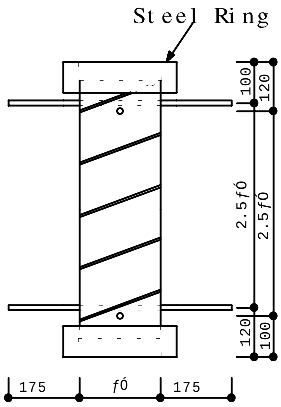


Figure 3: uniaxial specimen

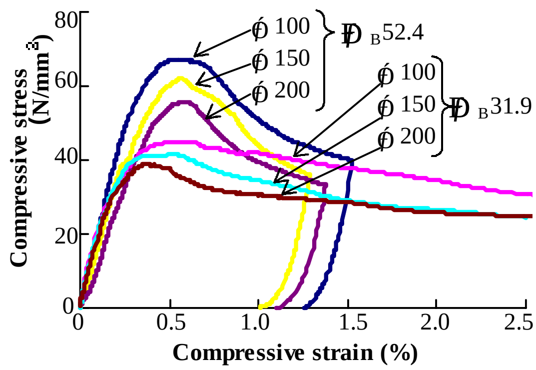


Figure 4: Stress –Strain Relations

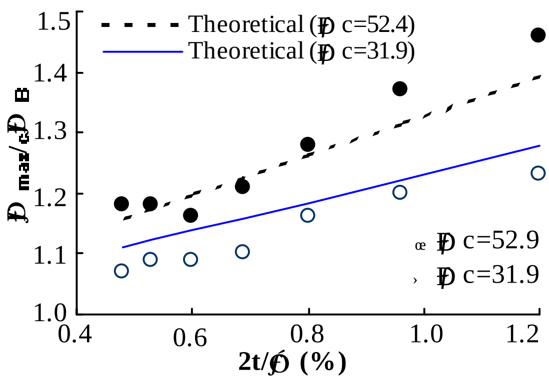


Figure 5: Confining effect of TSS tube

From uniaxial experiment, even thickness of TSS tube is very thin compared with the diameter of concrete, but the increase of concrete strength by the confined effect of TSS tube was clearly recognized.

Compressive displacement capacity of core concrete was remarkably improved. Axial strain at maximum compressive strength is over 0.4%, which is about 2 times of non confined concrete. Axial strain, when its strength declines to non-confined concrete strength, is over 1.5%.

By this result, it is actually proved that the mechanical property of the RC column with core concrete is used even when the steel spiral tube is very thin.

Biaxial experiments of new system RC column:

Test specimens and loading sequence of biaxial experiment:

To confirm the mechanical behavior of proposed new system RC columns, biaxial experiments using over 20 specimens are already performed. All the column sections is 30×30cm, number of main reinforcements are 16, width-length ratio of column H/D are 3.0 and 3.5 with various parameters of axial force ratio, strength of concrete ,TSS tube diameter and so on, and some experimental results are presented in the previous reports[4,7]. In this paper, experimental characteristics of new 14 specimens of which H/D is 4.0 are presented.

The experimental parameters here are diameter of core concreteφ, axial force ratio n (=N/bDFc), encased concrete strength Fce, filled-in concrete strength in TSS tube Fcc, total cross-sectional area of main reinforcement A_g and shear reinforcement ratio pw, as shown in Table 2.

The loading program of biaxial experiment is shown in the following, after loading certain decided axial force, 2 cycles alternative lateral force under displacement control is loaded on every deflection angle R=0.5% until the strength declines to 60% of maximum strength.

After lateral loading test was finished, deflection angle of specimen was returned to R=0, and axial compressive force was loaded until the depression of axial strength occurred. The aim of this test is to ascertain the remaining axial strength after the collapse of columns by lateral load.

Biaxial experimental results of RC columns:

Table 2 also shows some experimental results: ${}_{ex}Q_{max}$ is maximum strength, R_{max} the deflection slope angle at maximum strength under lateral force, and N_u remaining axial strength of column after collapse by lateral load.

The failure types of these specimens are varied by the existence of TSS tube, shear reinforcement ratio and loaded axial force ratio, but the maximum lateral strength of specimens almost coincides with the minimum theoretical calculated value of bending or shear strength ${}_{cal}Q_{min}$, when the shear strength of all the specimens are calculated by modified B method in AIJ design code [3].

Figure 6 shows the relation between ${}_{ex}Q_{max}$ and ${}_{cal}Q_{min}$ calculated by AIJ code [6]. The experimental value of all the specimens is higher than that of the calculated value. And this tendency is quite similar to the previous experimental results of which H/D is 3.0 and 3.5.

Table 2: Parameters of Specimens and Experimental Results

Specimen	Experimental Parameters					Experimental Results				
	$\frac{N}{bDF_{ce}}$	$A_g\sigma_y$ (kN)	$p_w\sigma_y$ (N/□²)	F_{ce} □ F_{cc} (N/□²)		${}_{ex}Q_{max}$ (kN)	R_{max} (%)	N_u (kN)	$\frac{{}_cN_u □ A_g\sigma_y}{\Sigma A_cF_c}$	${}_{cal}Q_{min}$ (kN)
CN-2	0.2	725.3	2.29	28.7		251.4	1.99	1110.9	0.149	203.8
CN-3	0.3	725.3	2.29	28.2		273.1	2.74	1305.0	0.229	247.6
CN-5	0.5	725.3	2.29	29.6		322.9	1.99	-------	------	282.5
CN-2φ150	0.2	725.3	2.29	28.7		202.0	2.41	1704.0	0.379	181.5
CN-3φ150	0.3	725.3	2.29	28.2		263.8	1.25	1918.8	0.471	218.1
CN-5φ150	0.5	725.3	2.29	29.6		262.1	1.10	2146.2	0.534	250.4
CN-2φ175	0.2	725.3	2.29	28.7		224.1	2.29	1809.0	0.419	173.5
CN-3φ175	0.3	725.3	2.29	28.2		251.5	1.91	2002.2	0.504	207.4
CN-5φ175	0.5	725.3	2.29	29.6		267.8	1.15	2069.4	0.505	238.8
CF-2φ150	0.2	831.4	4.64	31.1	65.0	211.6	3.00	2833.8	0.581	194.1
CF-4φ150	0.4	831.4	4.64	30.6	65.0	250.8	2.99	3000.0	0.636	241.9
CF-6φ150	0.6	831.4	4.64	30.6	65.0	259.8	3.00	2888.4	0.603	246.8
CT-3φ150	0.3	686.2	2.51	42.6	0	253.3	1.24	1545.0	0.279	228.9
CT-3φ175	0.3	686.2	2.34	42.5	0	223.1	0.98	963.0	0.099	222.6

Figure 7 shows the comparison of envelope curves of specimens with high strength core concrete and with hollow core. In the case of high strength core concrete, the decline of strength after maximum strength is very small and it has enough ductility. In the case of the one with hollow core, maximum strength itself almost coincides with that of high strength core concrete, but after it reaches the maximum strength, the decline of strength is quite rapid, and remaining axial strength after lateral loading test is small.

This means the core concrete does not contribute to the increase of shear strength but is very effective to prevent the axial crushing of RC column

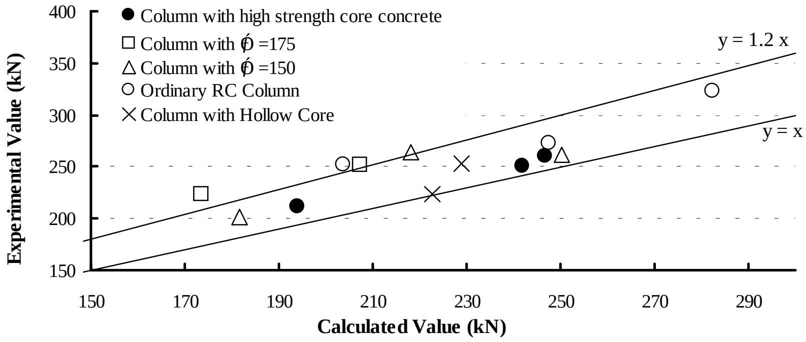


Figure 6: Experimental Verification of Lateral Strength

Figure 8 shows the accumulative axial deformation during alternative lateral loading under constant axial load. Accumulative axial deformation of proposed RC column is approximately proportional to slope deflection. And by the observation of specimens after the lateral loading, very few damages of core concrete can be guessed in spite of great damages of encased concrete. On the other hand, the accumulative axial deformation of ordinary column rapidly increases after maximum strength occurrs, and this means that the ordinary column can not prevent axial collapse due to the great damages of all the sections of concrete.

Axial property of RC column with core concrete:

Figure 9 shows the axial deformation of columns from the starting to the end of the experiment.
First, during the loading of axial force to set axial-force ratio, axial deformation increases linearly to axial load. Next, by the alternative lateral loading under constant axial load to the collapse of specimen, axial deformation of column is accumulated, and after returning deflection angle to 0, by the increase of axial force, further axial deformation is accumulated. Finally the axial crushing of columns with buckling of main reinforcement occur.

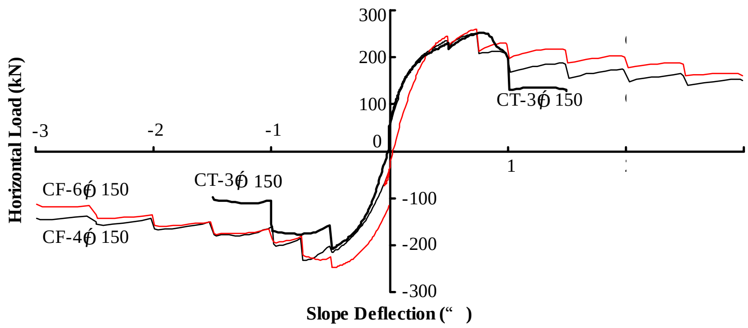


Figure 7: Envelope Curves of Specimens with high strength core and with hollow core

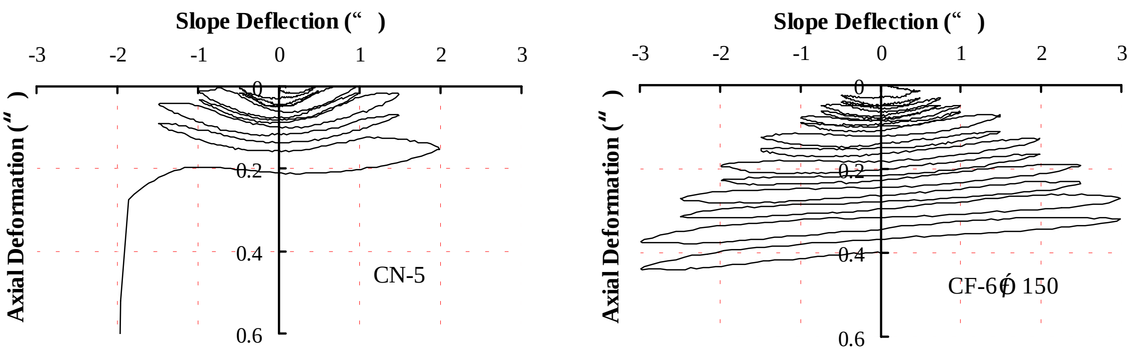
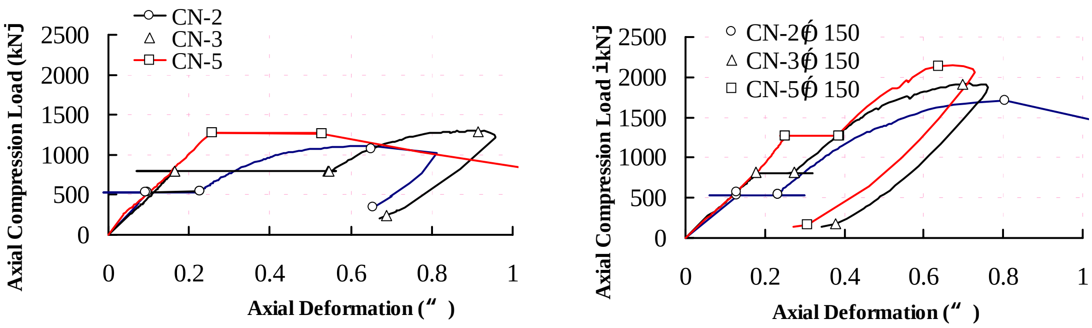


Figure 8: Accumulated Axial Deformation by the Lateral Loading

Accumulated deformation of ordinary columns during alternative lateral load is larger than that of columns with core concrete, and in the case of high axial-force ratio n=0.5, at halfway of alternative lateral loading, the column crushes by setting constant compressive force. This means at this time axial strength of ordinary column decreases under designed axial force. In the case of low axial-force ratio, remaining axial force is under the half of the calculated axial ultimate strength of RC column.

On the other hand, accumulated axial deformation under alternative force of columns with core concrete is considerably small compared with ordinary columns, and remaining axial strength after shear failure of encased concrete is remarkably large. It means that the column with core concrete has enough axial strength to prevent axial crushing after large lateral deformation.



Ordinary Constructed Columns **Columns with Core Concrete**

Figure 9: Behavior of Axial deformation of specimens during every step of experiment

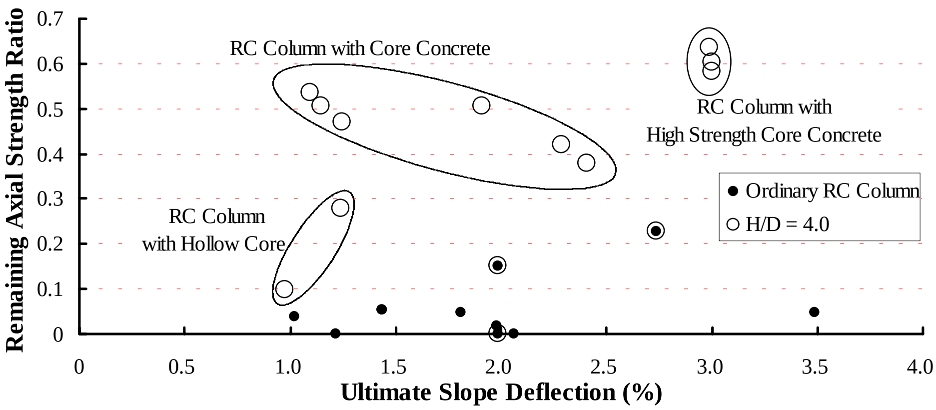


Figure 10: Remaining Axial strength of structure of columns

Figure 10 shows the ratio of remaining compressive strength of concrete of the column of which lateral strength decreased under 60% of maximum strength, which is obtained by $(N_u - A_g \cdot \sigma_y)/\Sigma A_c F_c$; N_u is the remaining axial strength of collapsed specimen, A_g and σ_y is the total cross-sectional area and yield strength of the main reinforcement respectively, and $\Sigma A_c F_c$ is the sum of calculated maximum compressive strength of encased and core concrete of column. The previous experimental result of ordinary column is presented in this figure,.Remaining axial strength of concrete of column with core concrete is over o.4 times of $\Sigma A_c F_c$, but it proportionally decreases to ultimate deformation. In the case of high strength core concrete, remaining axial strength of concrete is over o.6 times of $\Sigma A_c F_c$, and its ultimate deformation increases to about 3.0%. But, for the column with hollow core, both deformation capacity and remaining axial strength are clearly small, and especially in the case of hollow column of φ=175,the property is quite different from the columns with core concrete. Also, in the case of ordinary columns, in spite of various structural designing, remaining axial strength is very small, and it can not support design axial force at the ultimate condition of lateral deformation.

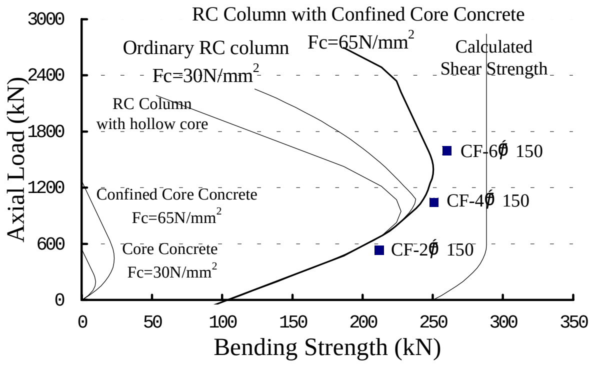
THE DESIGN CRITERIA OF THE PROPOSED NEW RC COLUMN SYSTEM

1. The diameter of core concrete and the thickness of TSS tube are decided that compressive stress of core concrete against axial design load may become under the strength of core concrete, when confining effect of TSS tube can be used by the Richart's equation [5].

2. The main reinforcement is decided by the same method as usual RC column by calculating the bending moment coefficient and axial force ratio in consideration of the whole sections.
3. The shear reinforcement toward the design shear load is decided by usual design equation, when the effective concrete section which core concrete is deducted should be used, and the ultimate shear strength is evaluated by the modified B method of AIJ design code [6].

Figure 11 shows the calculated and experimental values of columns designed by the above method. High strength concrete in the TSS tube is used to support the whole axial load of axial load ratio is o.6, and high strength shear reinforcement is also used to improve shear strength of the encased concrete.

The experimental values are well correspondent, and the higher axial ratio becomes, the higher bending strength appears. Especially in the case of axial load ratio of 0.6, the bending strength is higher than that of axial ratio of 0.4, and is very improved compared with the property of ordinary RC column.



And the remaining axial strength of these columns is almost equal to the calculated ultimate axial strength

Figure 11: Design and experimental value

of ordinary RC column before loading.

CONCLUSIONS

1. Proposed RC column with core concrete is a superposed structure of encased concrete and core concrete and its strength can be evaluated as superposition of both strength.
2. Very thin steel spiral tube used in this paper can be respected to have practical confining effect and separation effect to prevent damage of encased concrete from penetrating core concrete.
3. Higher axial force ratio, bending strength and displacement capacity of column with core concrete increases together compared with the ordinary RC column, and is more effective to prevent crushing of RC column.
4. The accumulated compressive displacement during the alternative lateral load under the constant axial force became very small in comparison with the ordinary RC column.
5. The guideline of design method of the column with core concrete is showed, and the utility of design method is evaluated by the experiments.
6. Proposed RC column with core concrete has the certain property to prevent crushing of RC column.

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