ULTIMATE STRENGTH AND RESTORING FORCE CHARACTERISTICS OF UNEMBEDDED TYPE COLUMN BASES IN STEEL-CONCRETE COMPOSITE STRUCTURES

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SUMMARY
Several studies have been made on the steel concrete composite column of new systems as a structure to have the earthquake-resistant, the workability and the economy. It is necessary to examine the connection and the column base to establish the design method of steel concrete structures. In this paper, it is discussed about the mechanical behavior of steel concrete composite column and column bases through the structural tests under the axial load and the cyclic horizontal load. The experimental parameters were as follows, axial load level and method of connecting the column to the footing beam. The structural tests make it clear that ultimate flexural strength can be evaluated to super posed strength method. Moreover, proposed evaluation method of restoring force characteristics matches the test result well under low axial compressive force.

Keywords: Composite Structure, Column Base, Flexural Strength, Hysteresis Curve

1. INTRODUCTION

Steel reinforced concrete structure possesses the properties of both concrete and steel, and by appropriate design it is possible to provide good earthquake resistance in such structures. High-rise buildings of steel reinforced concrete construction showed good earthquake-resistant capacity under the Kanto earthquake (1923) as compared with ordinary reinforced concrete structures. Since then the encased structural system, a form of composite construction has been employed in Japan for most building frames higher than seven stories.

However, from the situation of a recent construction cost, the demand for ordinarily steel reinforced concrete structures decreases. The reason for this is that the excellent mechanical property of steel reinforced concrete structure has not been demonstrated. Because extra steel is used, the material and construction costs are higher than those of reinforced concrete structures. It is thus necessary to perform research to assesst he earthquake resistance, constructability and cost of new composite structural systems. Figure 1.1. shows that new type steel concrete column. This new type steel-concrete column with advantage of reinforced concrete structure is the best use of the characteristic of steel reinforced concrete column and concrete filled steel tubular column. It is necessary to examine the connection and the column base to establish the design method of the new type steel concrete structures. Figure 1.2. shows that the column with unembedded type column base. In the case of bare type column base of which steel portion is set on the surface of the reinforced concrete foundation beam. Accordingly bare type column base is the connection in which the structure changes from steel concrete to reinforced concrete, the stresses at the base are transferred to the foundation through the steel column base consisting of base plate, anchor bolts or reinforcing bars.

This paper presents the results of the experiment carried out in order to study mechanical behavior of unembedded type column base in steel concrete structures under the axial compressive force and the cyclic bending moment. Main discussion is concentrated on the flexural strength, and hysteretic characteristics. In addition, we propose the analytical model of restoring force characteristics.

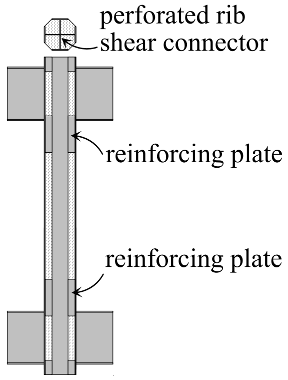


Figure 1.1. Column without column base

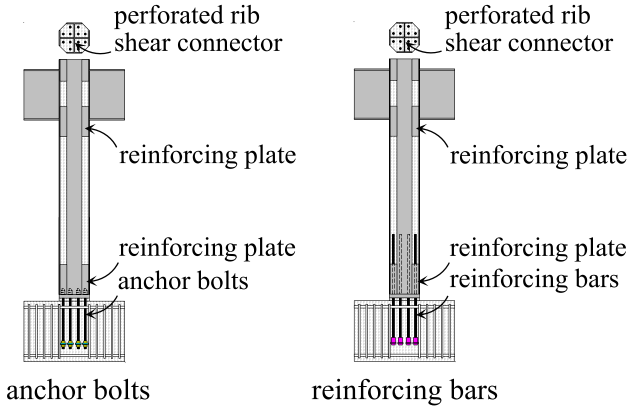


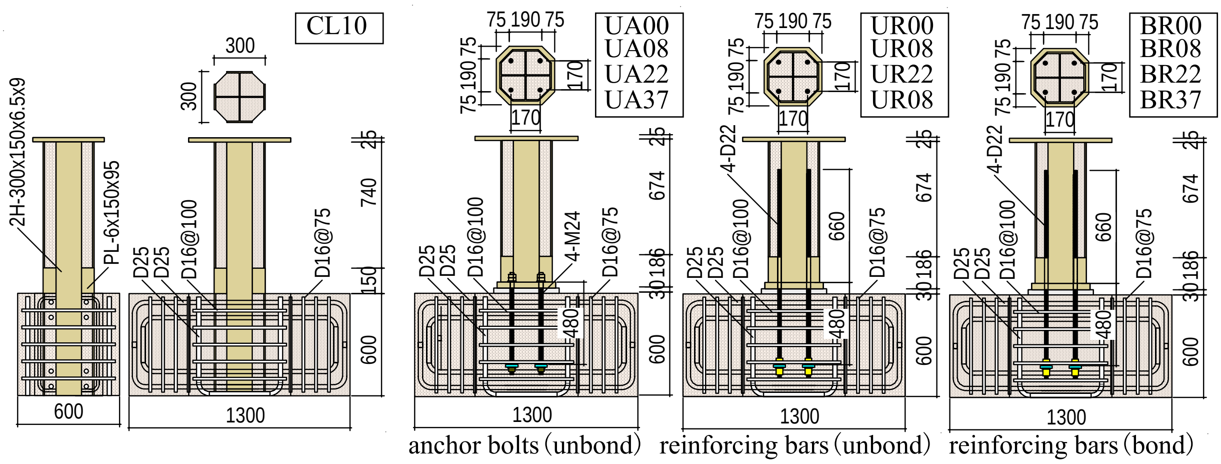
Figure 1.2. Column with column base

2. EXPERIMENTAL WORK

2.1. Test specimens and loading system

The specimen is a cantilever that assumes the behavior below an inflection point of the column of first floor in steel concrete structures. A total of 13 specimens were tested to investigate the elasto-plastic flexural behavior of column without column base and column with column base. All specimens were designed so that the failing in a flexural mode happened earlier than the failing in a shear mode.

Table 2.1. shows test program, and the bar arrangements and dimensions are shown in figure 2.1.. The specimens had a column section of 300mm×300mm, and a column steel was using 2H-300×150×6.5×9 (Grade SN400B). The following experimental parameters were selected:
(1) Axial load level: N=0kN, 724kN, 1887kN, 774～3000kN
(2) Method of connecting the column to the footing beam: Anchor bolts, Reinforcing bars
(3) Bond characteristic of connecting bars: Unbond, Bond
In the nomenclature for identifying specimen types, the first character (U, B) represents the bond characteristic of connecting bars, the second character (A, R) represents the method of connecting the column to the footing beam, the number (00, 08, 22, 37) means the axial force ratio. Anchor bolts M24(ABR 490B) or reinforcing bars D22(SD345) were inserted through the steel concrete column to the foundation concrete. The anchorage length of the built-in anchor bolts and reinforcing bars inside the steel concrete was 480mm.



(a) Column without column base **(b)** Column with column base

Figure 2.1. Test specimen (unit:mm)

The mechanical properties of concrete cylinder and grout mortar cylinder are shown in Table 2.2.. The mechanical properties of steel, reinforcing bar and anchor bolt are shown in Table 2.3..

Table 2.1. Test program

Specimen	Axial Load N (kN)	Strength of Section				Steel of Column	Connecting Bar of Column Base			Test Series
		${}_{cl}N_{cu}$ (kN)	${}_{cl}N_{tu}$ (kN)	${}_{cb}N_{cu}$ (kN)	${}_{cb}N_{tu}$ (kN)		Reinforcement	Anchor Bolts	Bond or Unbond	
CL01C	724	6812		—	—			—	—	Ⅰ
UA00C	0	5942		3280	-501		—	4-M24 (ABR490B)		Ⅲ
UA02C	724	6812		3329	-508					Ⅰ
UA05C	1887									
UA06V	774～3000	6140		4059	-519				Unbond	Ⅱ
UR00C	0	5942		3890	-609					Ⅲ
UR02C	724	6812	-3798	3918	-589	2H-300×150×6.5×9 (SN400B)				Ⅰ
UR05C	1887									
UR06V	774～3000	6140		4660	-600		4-D22 (D22SD345)	—		Ⅱ
BR00C	0	5942		3890	-609					Ⅲ
BR02C	724	6812		3918	-589				Bond	Ⅰ
BR05C	1887									
BR06V	774～3000	6140		4660	-600					Ⅱ

注）${}_{cl}N_{cu}$, ${}_{cl}N_{tu}$: Compressive strength and tensile strength of column section
${}_{cb}N_{cu}$, ${}_{cb}N_{tu}$: Compressive strength and tensile strength of column base section

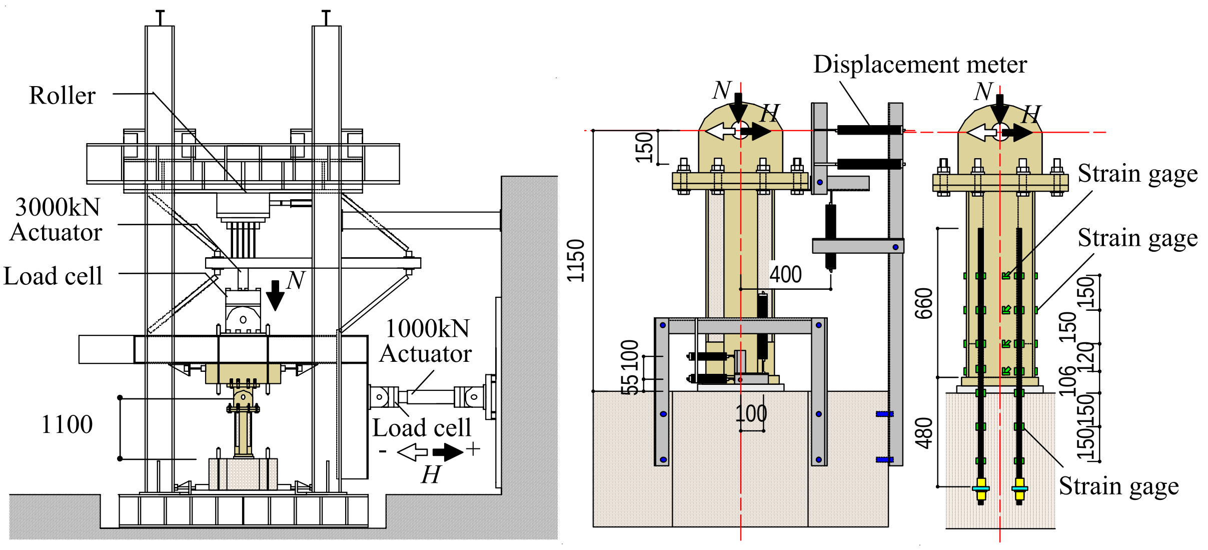
Table 2.2. Mechanical properties of concrete and grout mortar

		Test Series Ⅰ	Test Series Ⅱ	Test Series Ⅲ
Column	Compressive strength (N/mm^2)	42.6	33.1	30.3
	Cleavage strength (N/mm^2)	3.02	3.17	2.76
	Young's modulus (N/mm^2)	30612	29259	29681
Footing beam	Compressive strength (N/mm^2)	31.9	38.9	31.4
	Cleavage strength (N/mm^2)	1.89	3.28	2.64
	Young's modulus (N/mm^2)	28819	30057	30071
Grout mortar	Compressive strength (N/mm^2)	76.6	72.4	73.8
	Cleavage strength (N/mm^2)	5.21	4.90	4.97
	Young's modulus (N/mm^2)	30722	30529	28448

Table 2.3. Mechanical properties of steel, reinforcing bar and anchor bolt

		Test Series Ⅰ	Test Series Ⅱ	Test Series Ⅲ
PL-9 (SN400B) Steel flange	Yield stress (N/mm^2)		292	
	Tensile stress (N/mm^2)		426	
	Elongation (%)		26.9	
PL-6.5 (SN400B) Steel web	Yield stress (N/mm^2)		315	
	Tensile stress (N/mm^2)		426	
	Elongation (%)		26.9	
PL-6 (SS400) Reinforcing plate	Yield stress (N/mm^2)		334	
	Tensile stress (N/mm^2)		455	
	Elongation (%)		29.0	
PL-36 (SN490B) Base plate	Yield stress (N/mm^2)		342	
	Tensile stress (N/mm^2)		536	
	Elongation (%)		26.0	
M24 (ABR490B) Anchor Bolt	Yield stress (N/mm^2)	339	346	334
	Tensile stress (N/mm^2)	519	528	523
	Elongation (%)	28.6	24.7	29.1
D22 (SD345) Reinforcing bar	Yield stress (N/mm^2)	380	388	394
	Tensile stress (N/mm^2)	556	564	570
	Elongation (%)	24.0	22.4	23.5

All of the specimens have been tested using the test setup system as shown in figure 2.2.. The footing beam was fixed to the loading bed. Between the loading machine and the top of specimen, there was a rotational pin to ensure the corresponding relative displacement of the top and the bottom of column. The axial force *N* and lateral force *H* was applied by actuator connected to the loading frame at the top of the specimen. All specimens were subjected to cyclic lateral force and axial compressive load. The axial compressive load level is four stages (*N*=0kN, 724kN, 1887kN, 774～3000kN). Cyclic lateral loading is applied on every deflection angle *R*=0.5%rad. under displacement control. Where *R*= lateral displacement of top of column δ / shear span *l*.



(a) Loading system **(b)** Displacement measurement system

Figure 2.2. Test setup system (unit:mm)

2.2. Destruction state

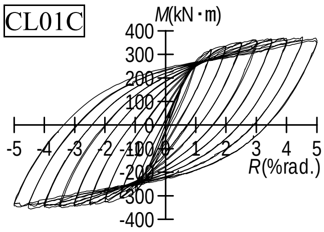
Photograph 2.1. shows the ultimate failure state. At the ultimate failure state of column without column base, the plastic zone develops near the fixed end, and flexural failure is concentrated in this zone. Moreover, local buckling of steel flange and crushing of compression concrete were caused. At the ultimate failure state of column with column base under the low axial compressive force (*N*=0, *N*=724kN) and middle axial compressive force (*N*=1887kN), failure of column steel and concrete above the base-plate were not caused. On the other hand, the plastic zone develops below the base-plate, and flexural failure is concentrated in this zone. At the ultimate failure state of column with column base under the high axial compressive force (*N*=774～3000kN), yield of column steel and failure of concrete above the base-plate were caused. Moreover, the plastic zone develops above and below the base-plate, and flexural failure was caused.

CL10C BR00C BR22C BR37V

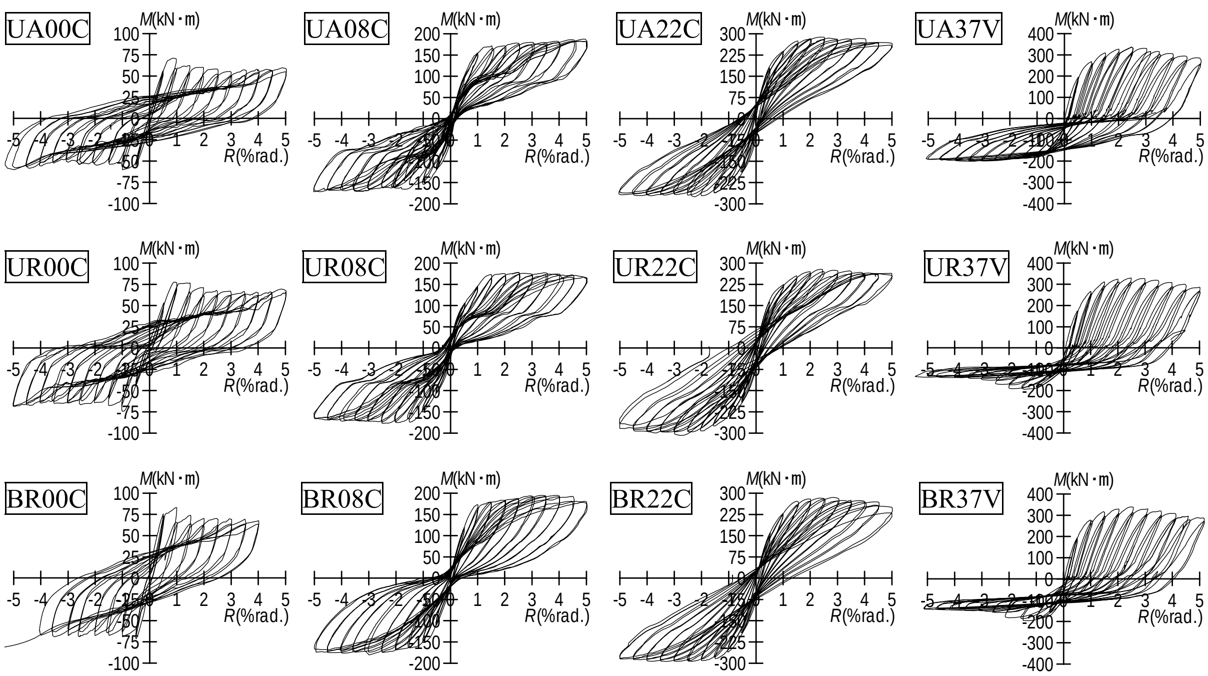
Photograph 2.1. Ultimate failure state

2.3. Hysteresis characteristics

The experimental relations of bending moment *M* and deflection angle *R* are shown in figure 2.3. At the hysteresis characteristics of column without column base, it is observed in the relationships that the hysteresis loop indicate spindle-shape. Moreover, ductility is large, and degradation of strength due to repetition of loading is small. At the hysteresis characteristics of column with column base under the low axial compressive force (*N*=0, *N*=724kN) and middle axial compressive force (N=1887kN), it is observed that ultimate strength increases with increasing value of axial compressive force, ductility is large, and degradation of strength due to repetition of loading is small. Moreover, hysteresis loops of pinched shape observed unembedded type column base in steel structures were not observed. The reason why these hysteresis characteristics are that due to the effect of mechanism for resisting compression force by connecting bars (anchor bolts or reinforcing bars). In the case of specimens where reinforcing bars were used, at the hysteresis characteristics of column with column base under the high axial compressive force (*N*=774～3000kN), it is observed that strength deterioration after maximum carrying capacity is drastic.



(a) Column without column base



(b) Column with column base

Figure 2.3. Relationships of *M* and *R*

3. ULTIMATE FLEXURAL STRENGTH

Relationships of axial force *N* and ultimate bending moment *M* are shown in figure 3.1.. The compressive axial force is assumed to be positive. Dotted points mean the experimental values. The calculation value is calculated to the method of the superposed strength. The following assumptions were used to generate the *N*-*M* curve:

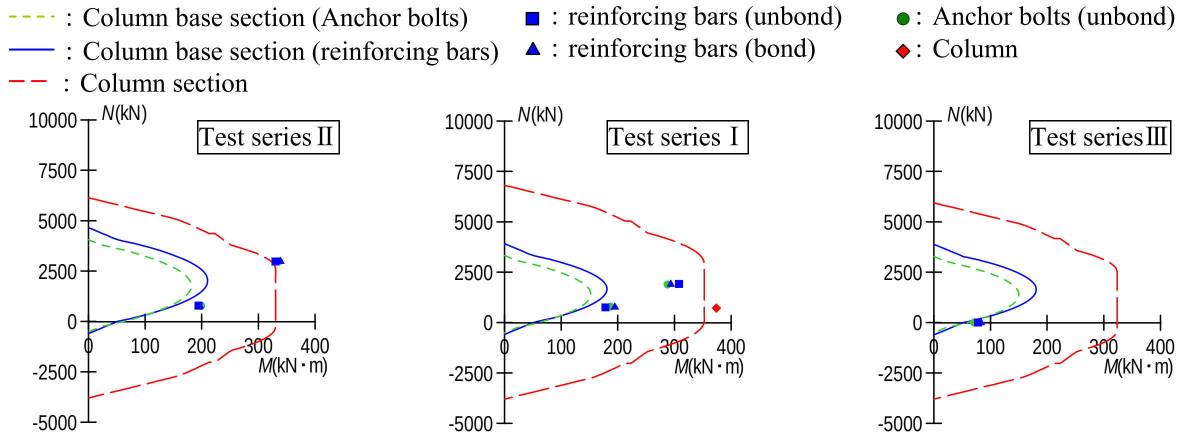
(a) Simulation Ⅰ:

- the concrete confinement provided by column steel was not considered,
- concrete strength of column base adopts compressive strength of footing beam,
- anchor bolts were not able to resist the compression power.

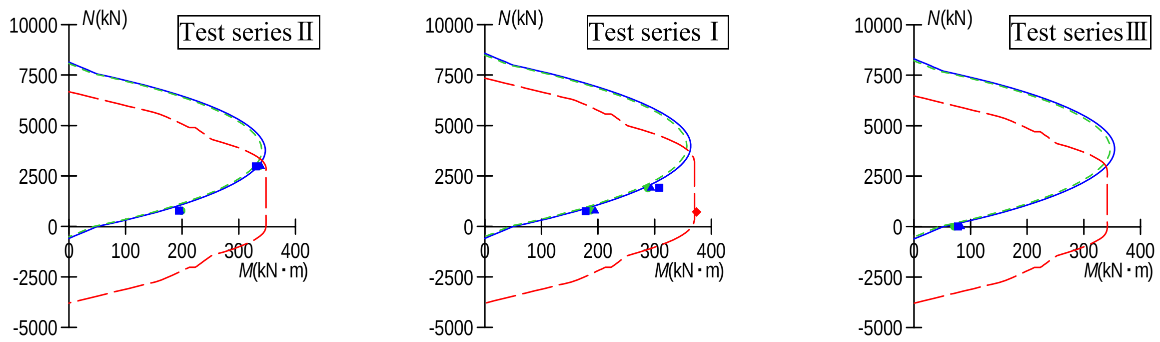
(b) Simulation Ⅱ:

- the concrete confinement provided by column steel was considered,
- concrete strength of column base adopts compressive strength of grout mortar,
- anchor bolts were able to resist the compression power.

In the case of simulation Ⅱ, it is clear that the calculation values evaluate ultimate strength to a safety side.



(a) Simulation Ⅰ



(b) Simulation Ⅱ

Figure 3.1. Relationships of N and M

4. EVALUATION OF RESTORING FORCE CHARACTERISTICS

4.1. Analytical Model

Figure 4.1. shows the resisting mechanism of column bases and the strain distributions of connecting bar for elastic rotational stiffness. Additional bending resistance, yield bending strength, elastic rotational stiffness and model of restoring force characteristics of the column base are obtained from these mechanisms. The model shown in figure 4.2.(a) is proposed for the column bases in steel structures. On the other hand, the model of restoring force characteristics for the column bases in steel concrete structures is shown in figure 4.2.(c). The following assumptions were used to generate the M–θ_B curve:

1) the connecting bars are the only yielding elements in the column base.

2) For the base plate in contact with the footing beam, the position of compressive reaction of the footing beam is at the edge of the base plate and the connecting bars on the tension side resist bending moment.

3) A coefficient of reduction R in elastic rotational stiffness is employed for elastic deformation of base plate and footing beam.
4) The perfectly elastic-plastic model is used to define the material properties of the connecting bars. Additional bending resistance M_n, yield bending strength M_y and elastic rotational stiffness K_B, K_C are given by the following equation.

$$M_n = N \cdot d_c \tag{4.1}$$

$$M_y = T_y \cdot d_t + N \cdot d_c \tag{4.2}$$

$$K_A = \frac{E \cdot A_t}{R \cdot l_e} d_t^2 \tag{4.3}$$

$$K_B = \frac{1}{R-1} \frac{d_t - \frac{N}{T_y} d_c}{d_t} K_A \tag{4.4}$$

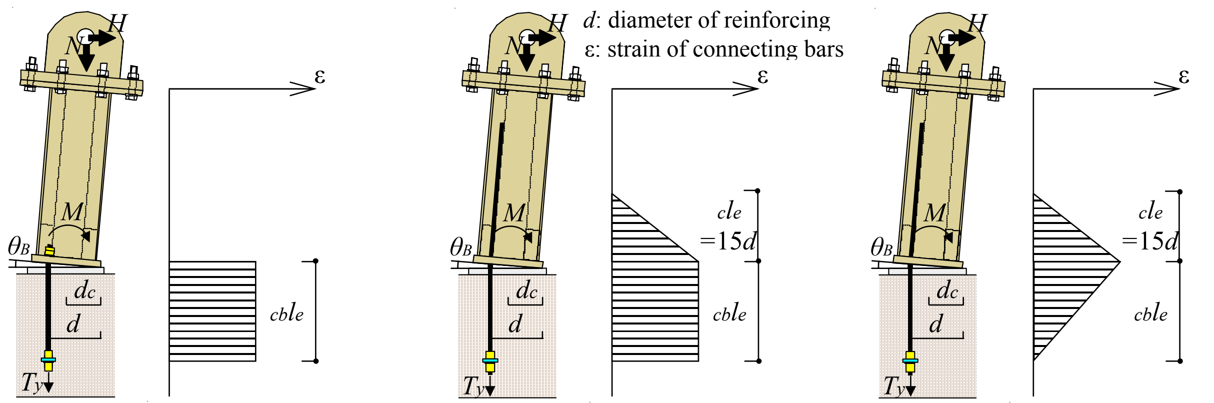
$$K_C = \frac{K_A \cdot K_B}{K_A + K_B} \tag{4.5}$$

$$l_e = c_{ble} \quad \text{[Anchor bolts (unbond)]} \tag{4.6}$$

$$l_e = c_{ble} + \frac{1}{2} c_{le} \quad \text{[Reinforcing bars (unbond)]} \tag{4.7}$$

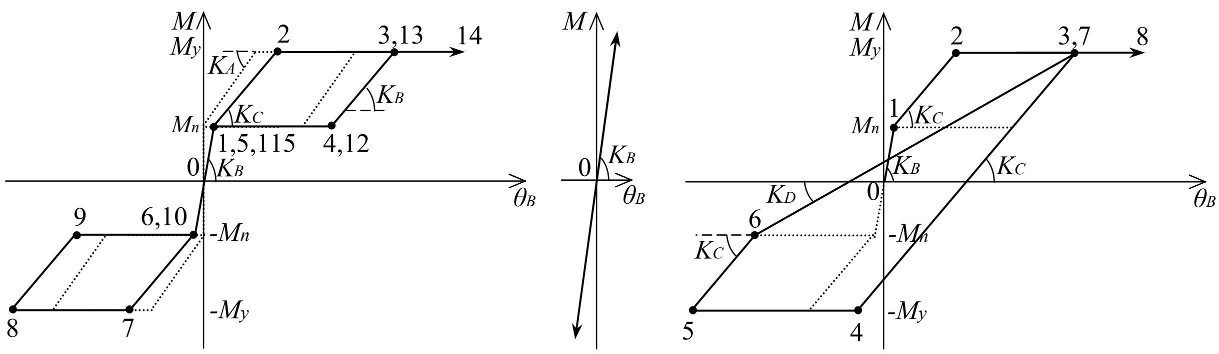
$$l_e = \frac{1}{2} c_{ble} + \frac{1}{2} c_{le} \quad \text{[Reinforcing bars (bond)]} \tag{4.8}$$

where T_y is tensile strength of the connecting bars, E is Young's modulus of the connecting bars, A_t is the gross area of the connecting bars, R is a coefficient of reduction in elastic rotational stiffness (R=2.0).



(a) Anchor bolts (unbond) **(b)** Reinforcing bars (unbond) **(c)** Reinforcing bars (bond)

Figure 4.1. Resisting mechanism and strain distribution of connecting bars for elastic rotational stiffness



(a) Rotation angle of Column Base (Model A) **(b)** Additional deformation **(c)** Rotation angle of Column Base (Model B)

Figure 4.2. Analytical model

4.2. Discussion on the Analytical Results

Fig. 4.3. shows the relationships of bending moment *M* and rotation angle of column base θ_B. In these figures solid lines indicate the analytical value and dotted line indicate the experimental value. The analytical values well predicts the experimental results under the low axial compressive force. However, for the analytical values under the high axial compressive force, analytical value of bending moment differs from experimental results. The reason for this is that distance from centroid of column to rotation center d_c is made a definite value regardless of axial force level in the analytical model.

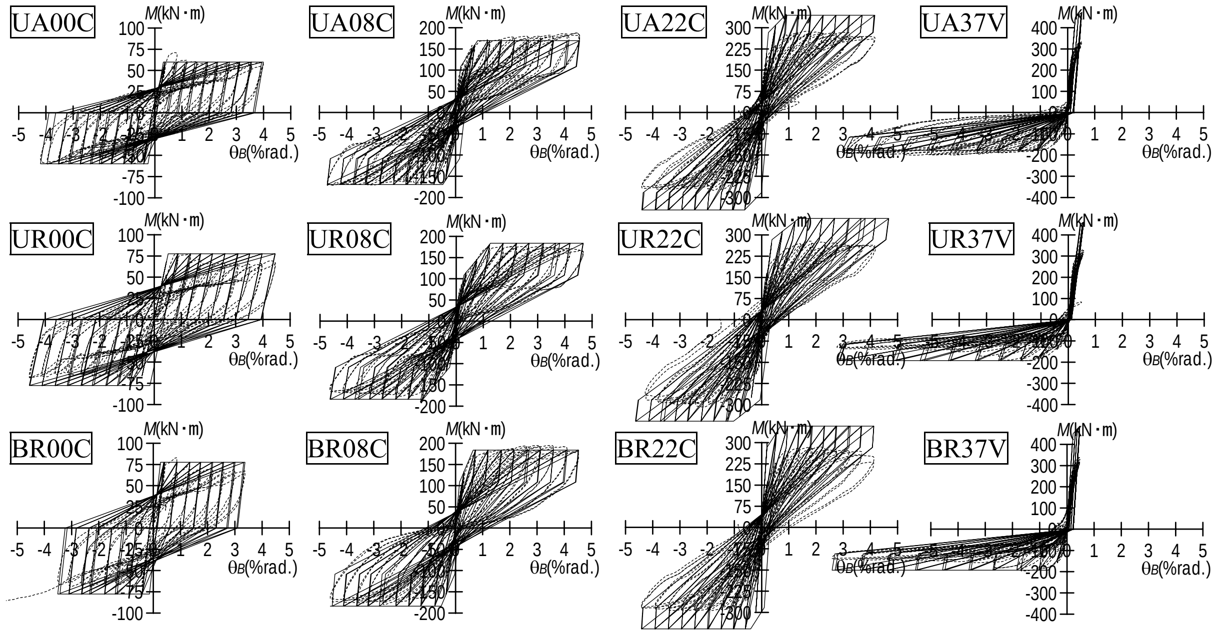


Figure 4.3. Relationships of *M* and θ_B

5. CONCLUSIONS

The structural test carried out in order to study ultimate flexural strength and restoring force property of column and column bases in steel concrete composite structures subjected to repeated bending moment under the axial compressive force. It has become clear from the test results that:

1. Ultimate flexural strength according to the method of the superposed strength of considering the confined effect of concrete and the compressive strength of grout mortar below the base plate can be evaluated to a safety side.
2. In the case of under the low axial compressive force, proposed analytical model of restoring force property matches the test result well.

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