Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VI)

6-4-9

BEHAVIOR OF REINFORCED CONCRETE COLUMN UNDER HIGH AXIAL LOAD

Xiaozhen ZHOU[1], Toshio SATO[2], Weishan JIANG[1], Arata ONO[2] and Yasushi SHIMIZU[3]

1 Department of Architecture, Xi'an Institute of Metallurgy and Construction Engineering, Xi'an, China
2 Department of Architecture, College of Science and Technology, Nihon University, Tiyoda-ku, Tokyo, Japan
3 Department of Architecture, Faculty of Engineering, Tokyo Metropolitan University, Setagaya-ku, Tokyo, Japan

SUMMARY

In order to investigate the aseismic behavior of reinforced concrete columns under high compressive stress and cyclic horizontal loading. Reversed cyclic loading tests were performed on seventy specimens. The behavior of reinforced concrete columns subjected to combined high axial compression, flexural moment and shear forces is described in terms of type of cracking and mode of failure, strength and ductility. The main variables in this test are axial compression ratio, shear span ratio, amount of main bar and amount of hoop. Simple formulae which predict the strength and ductility of the reinforced concrete members under eccentric compression and shear loading are applied to these test specimens.

INTRODUCTION

In China, many reinforced concrete buildings have been planned in such a manner as to minimize the area of columns. The effects of high compressive stress in columns have to be considered especially under seismic loading. The purpose of this study is to confirm the effect of high compressive stress from the tests of seventy specimens where the main variables are the axial compression ratio. The careful consideration should be given to know the limit of useful region of the axial compression ratio.

TEST SPECIMEN

The shape of the specimens, dimensions, details and its reinforcement are shown in Figure 1 and Table 1. There are five series and seventy specimens. Mechanical properties of materials are listed in Table 2. The main variables in this test are axial compression ratio, shear span ratio, amount of hoop and main bar, and shape of hoop. Throughout this report an attempt is made to compare the ductility with the effect of web reinfocement in specimens under various axial compression stress. So, in the majority of cases, the specimens are designed to be failed in bending. Three types of shape of web reinforcement have been chosen. Most compression concrete strength Fc varied from 161 to 402 kg/cm^2. Careful consideration should be given to know the limit of useful region of the axial compression ratio. The authors reported the test results on these specimens subjected to the constant vertical load and cyclic horizontal load in the Transaction of The JAPAN CONCRETE INSTITUTE vol.7,8,9. in 1985,1986,1987.

Table 1 Test Specimens

(A) AZ,BZ,CZ,DZ series

Specimen No	Fc kg/cm^2	σ_0 kg/cm^2	ηo
1AZ0-0	402	0	0
2AZ1-01	365	36.5	0.1
3AZ2-02	390	78.0	0.2
4AZ3-03	350	105.0	0.3
5AZ4-04	263	105.2	0.4
6AZ5-04	293	117.2	0.4
7AZ6-05	396	184.5	0.5
8AZ7-055	331	185.4	0.55
9AZ8-06	329	197.4	0.6
10AZ9-06	335	201.0	0.6
11AZ10-07	347	242.9	0.7
12AZ11-07	325	227.5	0.7
13AZ12-08	313	250.4	0.8
14AZ13-09	334	300.6	0.9
15AZ14-09	284	255.6	0.9
16AZ15-11	343	343.2	1.1
17AZ16-12	270	324.0	1.2
18BZa1-02	310	62.0	0.2
19BZa2-04	240	96.0	0.4
20BZb3-04	304	122.0	0.4
21BZa4-05	310	155.0	0.5
22BZa5-06	310	186.0	0.6
23BZb6-06	240	134.0	0.56
24BZa7-07	304	213.0	0.7
25BZa8-08	240	192.0	0.8
26BZa9-095	240	228.0	0.95
27CZa1-02	310	62.0	0.2
28CZa2-04	310	124.0	0.4
29CZb3-04	310	124.0	0.4
30CZa4-05	310	155.0	0.5
31CZa5-06	310	186.0	0.6
32CZa6-08	240	192.0	0.8
33DZa1-04	260	104.0	0.4
34DZa2-06	260	156.0	0.6
35DZa3-08	260	208.0	0.8

(B) S series

No.	Fc kg/cm^2	σ o kg/cm^2	η o	p w %	M/QD	Type of hoop
102-02	294	58.8	0.2	0.61	1	A
122-02	161	32.2	0.2	1.05	1	C
103-04	272	108.8	0.4	0.61	1	A
113-04	272	108.8	0.4	0.61	1	B
123-04	272	108.8	0.4	1.05	1	C
124-04	272	108.8	0.4	1.05	1	C
121-06	161	96.6	0.6	0.61	1	A
111-06	161	96.6	0.6	0.61	1	B
121-06	161	96.6	0.6	1.05	1	C
104-08	202	161.6	0.8	0.61	1	A
114-08	202	161.6	0.8	0.61	1	B
124-08	202	161.6	0.8	1.05	1	C
106-10	161	161.0	1.0	0.61	1	A
116-10	161	161.0	1.0	0.61	1	B
126-10	161	161.0	1.0	1.05	1	C
213-02	215	43.0	0.2	0.61	2	B
212-04	215	86.0	0.4	0.61	2	B
222-04	215	86.6	0.4	1.05	2	C
201-06	211	131.0	0.62	0.61	2	A
211-06	211	126.6	0.6	0.61	2	B
221-06	211	126.6	0.6	1.05	2	C
204-08	215	172.0	0.8	0.61	2	A
214-08	215	172.0	0.8	0.61	2	B
224-08	215	172.0	0.8	0.61	2	C
223-09	215	193.5	0.9	1.05	2	C
303-04	268	107.2	0.4	1.05	2	A
313-04	268	107.2	0.4	0.61	3	B
323-04	268	107.2	0.4	0.61	3	C
301-06	294	176.4	0.6	1.05	3	A
311-06	294	176.4	0.6	0.61	3	B
321-06	294	176.4	0.6	0.61	3	C
302-07	294	205.8	0.7	1.05	3	A
312-07	294	205.8	0.7	0.61	3	B
322-07	294	205.8	0.7	1.05	3	C

(note)

B, D : width, depth of column

Fc : concrete cylinder compressive strength

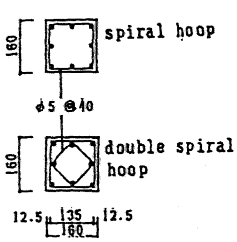
N : axial load

σ o : unit axial stress of column

η o : axial compression ratio

p w : reinforcement ratio of a group of hoops

$\sigma_0 = N/(B \cdot D)$ $\eta_0 = \sigma_0 / Fc$



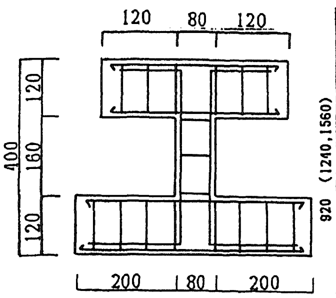
S series
Type of hoop
- A : hoop
- B : spiral
- C : double spiral

Table 2 Mechanical Characteristics of Materials

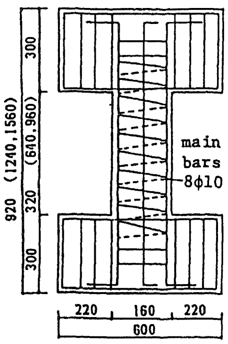
Steel	as cm^2	σ y kg/cm^2	σ m kg/cm^2
4φ	0.126	3480	4570
5φ	0.196	5700	6000
6φ	0.283	3400	4420
D 6	0.285	3430	3860
10φ	0.785	3480	4570
D10	0.97	3720	5760
D13	1.31	3710	5560
D14	1.53	3730	5810

as : area of steel

σ y, σ m : steel yielding, maximum strength



AZ series



BZ,CZ,DZ series
BxD=16x16 cm
M/QD=2.0
Main bars
BZ series 4-D10(pt=0.61%)
CZ series 4-D13(pt=1.04%)
DZ series 4-D14(pt=1.20%)
Hoop 6ϕ@100
pw=0.36%
*6ϕ@60(pw=0.59%)
20BZb3-04,23BZb6-06,29CZb3-04

S series
BxD=16x16 cm
M/QD=1,2,3
Main bars 8-10ϕ
pt=0.92%
Hoop
hoop 5ϕ@40
pw=0.61%
spiral
pw=0.61%
double spiral
pw=1.05%

Figure 1 Test Specimen BZ,CZ,DZ series S series

TEST PROCEDURE

Figure 2 shows the test set-up of BZ series with specimen under the load. To investigate the cyclic behavior of these specimens, each of them was subjected to similar sequences of static reversed cycle deflections. The axial load N was maintained at a constant level during each test. The cyclic horizontal forces were applied by a pulling and pushing hydraulic jack. The forces provided by the jack were monitored by the load cell mounted at the top of the jack. The horizontal force was controlled by the magnitude of the load before the specimen yielded. After yielding, it was controlled by the displacement at the top of the columns. The horizontal deflections at the top of specimens were measured using displacement transducers. Besides, the strains in the reinforcement were measured using electric resistance strain guages, respectively.

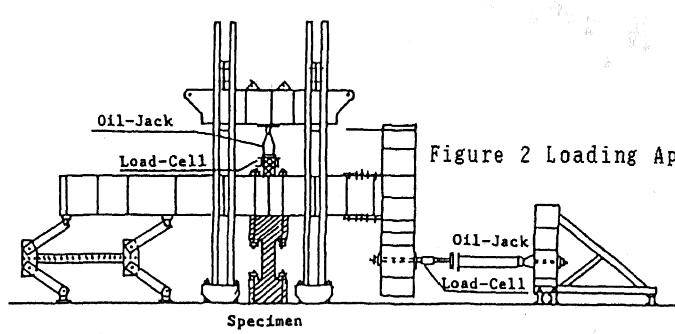


Figure 2 Loading Apparatus

COMPARISON OF TEST RESULTS WITH CALCULATED VALUES

Initial Clacking Load   Initial clacking loads are compared with calculated values by means of several formulae for predicting the initial cracking load of the column as follows. The relationship of the axial compression ratio and initial cracking load is shown in Figure 3.

(cQBC;bending crack)

$$cQBC=\left(\frac{2}{ho}\right)\left(1.8\sqrt{Fc}\cdot Ze+\frac{N\cdot D}{6}\right) \quad \text{Eq.(1) (Ref.1)}$$

(cQSC;shearing crack)

$$cQSC=0.971\sqrt{Fc}\cdot B\cdot D\left(1+\frac{\sigma o}{c\sigma t}\right)^{0.411}\left(\frac{M}{Q\,D}\right)^{-0.605} \quad \text{Eq.(2) (Ref.2)}$$

in which, Ze; equivalent section modulus, ho; inside height of column, σo; axial stress, N; axial force in column, B; width of column, D; over-all depth of column, $c\sigma t$; tensile strength of concrete, Fc; compressive strength of concrete, $\sigma o=N/(B\cdot D)$, $c\sigma t=1.8\sqrt{Fc}$

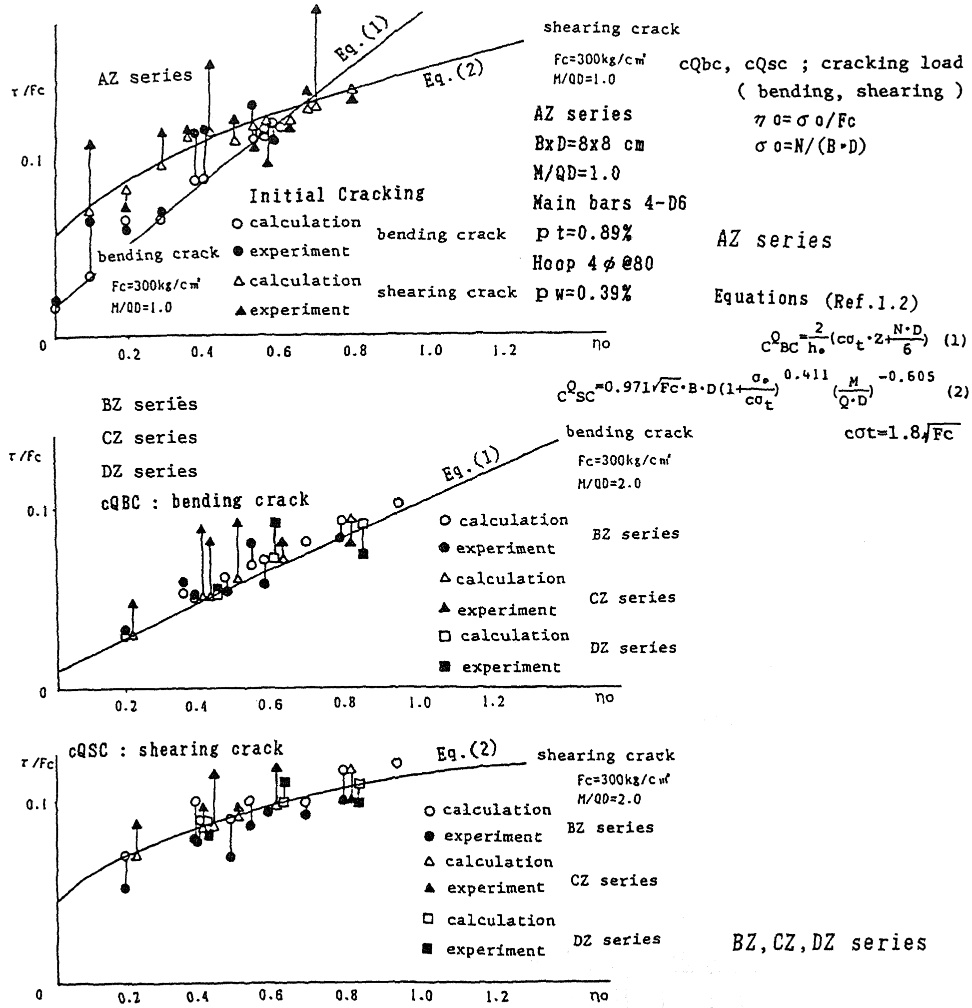


Figure 3 Discussion on Initial Cracking

In general, the calculated values shows a similar tendency of the experimental values in the initial cracking loads untill the compressive stress reaches to 0.8Fc.

Maximum Strength The maximum loads are compared with calculated values by means of several formulae for predicting the maximum load of the column. The relationship of the axial compression ratio and maximum load are shown in Figure 4. Shear force decided by the flexural strength and the capacity for shear failure for each specimens are calculated by the following equations.

$$cQmu=(\frac{2}{ho})\{0.8a_t\cdot{}_s\sigma_y\cdot D + 0.5N\cdot D(1-\frac{N}{B\cdot D\cdot Fc})\} \quad \text{Eq.(3) (Ref.3)}$$

in case N>0.4B·D·Fc

$$cQmu=(\frac{2}{ho})(0.8a_t\cdot{}_s\sigma_y\cdot D + 0.12B\cdot D^2\cdot Fc)(\frac{Nm-N}{Nm-0.4B\cdot D\cdot Fc})$$

$$cQmean=\{\frac{0.115ku\cdot kp(180+Fc)}{(M/Q\cdot D)+0.12} + 2.7\sqrt{p_w\cdot{}_s\sigma_{wy}} + 0.1\sigma o\}B\cdot j \quad \text{Eq.(4) (Ref.3)}$$

in which, ku=1.0, $kp=0.82pt^{0.23}$, j=0.875d, d; depth from compression surface to centroid of tension reinforcement, at; sectional area of tensile reinforcing bars, sσy,sσwy; yielding strength of main bar and hoop, Nm=B·D·Fc + 2at·sσy

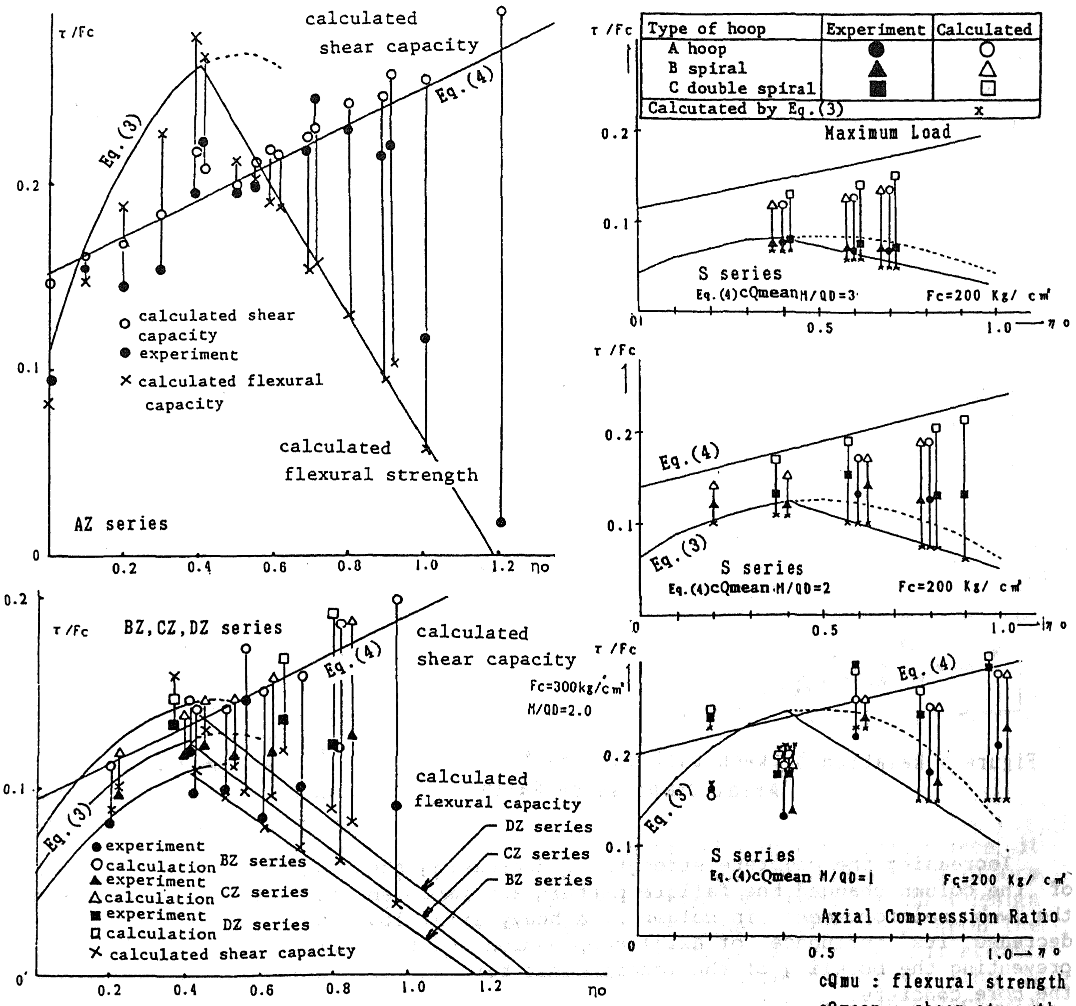
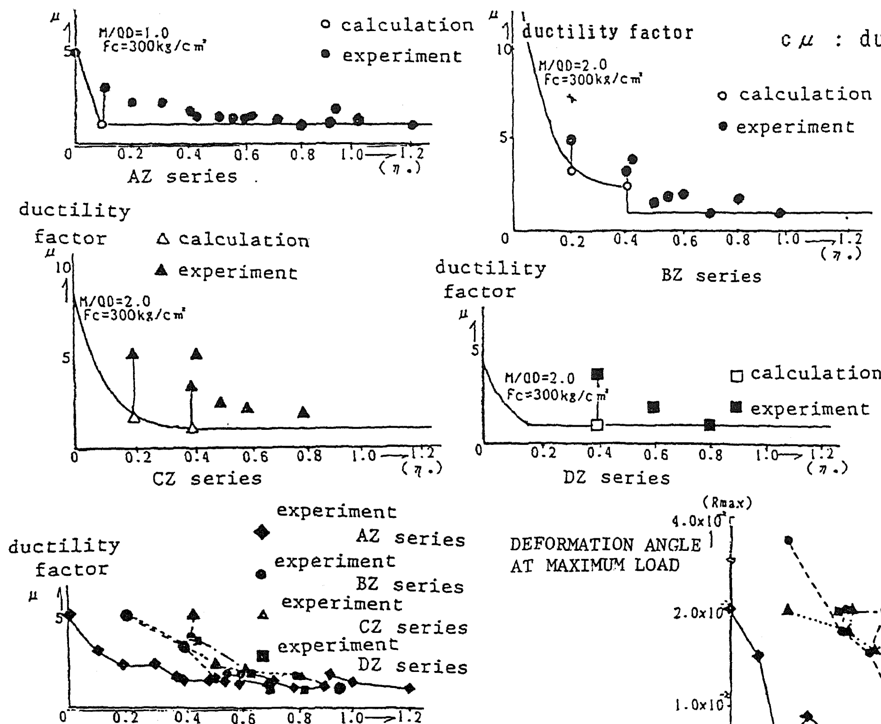


Figure 4 Discussion on Maximum Load

Shear strength increased with the increase in the axial compression and the test results fairly agreed with values calculated by equation (4) when the axial compression ratio is less than 0.8 on AZ series. On BZ, CZ, DZ series, the values calculated by equation (3) fairly agreed with the test results when the axial compression ratio is less than 0.4. The compressive area in the cross section of a specimen under loading and compressive stress increased with the increasing of the axial compression, and the compressive area of the specimen contributes to more shear strength. The ultimate strength would be controlled by the compressive stress of concrete till the compressive stress reached to 0.8Fc. The shear strength of the column can increase with the increasing of the concrete strength. In the case that axial compression ratio is more than 0.6, double spiral hoop is very useful to prevent the buckling of the longitudinal bars. And the calculated bending strength was less than the test results. Therefore, in such case, there are practically increased in strength and ductility.

Ductility The ductility of specimens are compared with calculated values by means of equation (5) for predicting the ductility of the column. The relationship of the axial compression ratio and ductility is shown in Figure 5. The ductility for each specimen is calculated by the following equation.

$$c\mu = 10\left(\frac{cQmean}{cQmu} - 1\right) \geq 1.0 \quad \text{in case } no > 0.4 \; c\mu = 1.0 \qquad \text{Eq.(5) (Ref.3)}$$



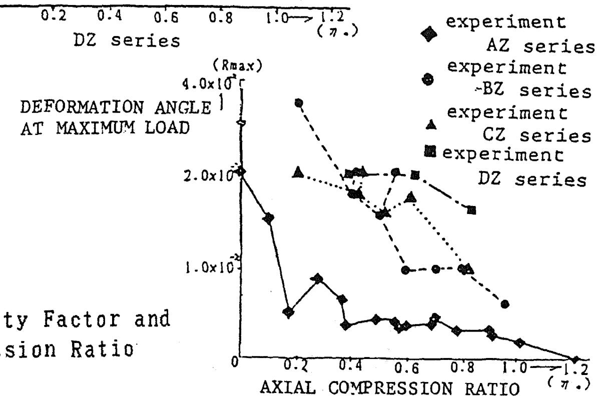


Figure 5 Relation between Ductility Factor and Axial Compression Ratio

Increasing the concrete strength or decreasing the longitudinal reinforcement of the column changed the failure pattern and improved its ductility. Increasing the web reinforcement in column of a heavy axial load building will lead to decrease its influence of axial compression and to improve its ductility by preventing the buckling of the longitudinal bars and increasing the confinement of the core concrete.

CONCRUSIONS

Axial compression ratio is the one of the main factor that effects the anti-seismic performance of the reinforced concrete columns. When the axial compression ratio is less than 0.6, the flexural strength of the reinforced concrete columns increases with the increasing of the axial compression ratio. When the axial compression ratio is more than about 0.6, the flexural strength and the shear strength decreases with the increasing of the axial compression. Double spiral hoop is very useful to prevent the buckling of the longitudinal bars and to increase the confinment of the core concrete.

REFERENCES

(1) Architectural Institute of Japan, "AIJ Standard for Structural Calculation of Reinforced Concrete Structures", 1982.
(2) Hirosawa, M., "Strength and Ductility of Reinforced Concrete Members", Report of the Building Research Institute No.76, March, 1977.
(3) Japan Building Disaster Prevention Association, "Criterion on the Evaluation of Seismic Safety of Existing Reinforced Concrete Buildings", March, 1977.
(4) China Architecture Industry Publishing Company, "Design Code of Reinforced Concrete Structure TJ 10-74"