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Static loading experiment of RC beams focusing on buckling of longitudinal bars
Part 1 Experimental program

Full scale test Performance based design
Reinforced concrete Safety limit Seismic assessment
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1. Introduction

The safety limit of RC beam members applied to the seismic performance evaluation of RC buildings[1] is defined as the smallest of drift ratios at which (1) the flexural resistance decreases to 80% of its maximum strength, (2) shear failure occurs after flexural yielding and (3) tensile rupture of beam longitudinal reinforcement bar occurs.

However, in a series of static loading experiment of weak beam-strong column type RC frames[2], damage conditions defined as above (from (1) to (3)) was not observed even under large drifts, but the buckling phenomena of the beam longitudinal bars were visually observed after the cover concrete was peeled off at the beam ends. This experiment showed that the reduction in strength due to the buckling was related to the safety limit of weak beam-strong column type RC moment-resisting buildings.

There are many previous studies on the buckling of longitudinal bars in columns under high axial forces. However, limited studies focused on that in beams. Hence, in this research, the buckling of the beam longitudinal bars observed as above was experimentally re-examined using full scale beam specimens considering different diameters of longitudinal rebar and spacing of shear reinforcement because the past research tested small scaled frame specimens with common beam structural details.

2. Experimental Program

2.1 Details of test specimens

The 1/2.5 scale, single-story and single-span specimen in the previous study[2] is shown in **Fig.1**. Three full scale specimens were designed based on the beams in the scaled specimen. They had different diameters of longitudinal bars and spacing of shear reinforcement which were likely to affect bucking of longitudinal bars. **Table 1** shows the specifications of specimens.

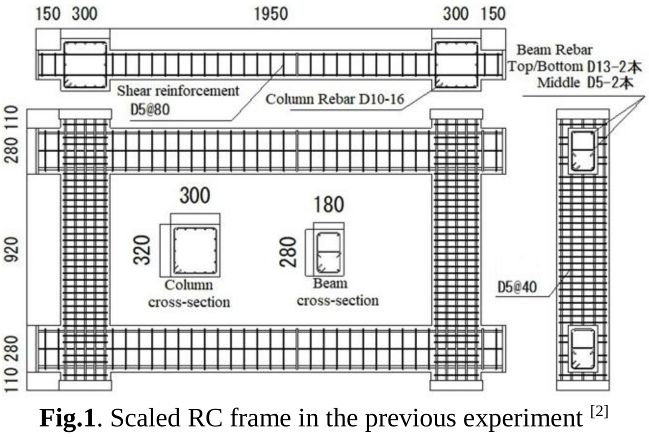


Fig.1. Scaled RC frame in the previous experiment [2]

Table 1 Specifications of the specimens

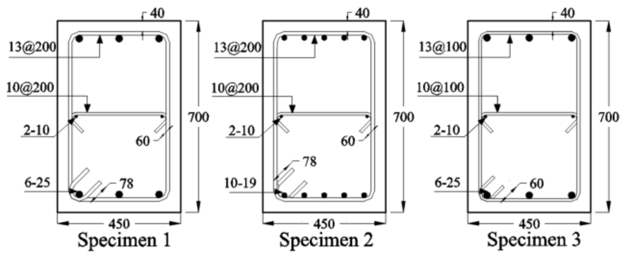
Descriptions	Specimen1	Specimen 2	Specimen 3
BXD	450X700		
Longitudinal bar (p_t)	3-D25 (0.48)	5-D19 (0.46)	3-D25 (0.48)
Shear reinforcement (p_w)	2-D13 D13@200 (0.28)	2-D13 D13@200 (0.28)	2-D10 D10@100 (0.31)

p_t: Tensile reinforcement ratio
p_w: Shear reinforcement ratio

The dimensions of each specimen were 450 X 700 mm with height of 1540 mm. The cross-sectional details of each specimen are shown in **Fig. 2**. The cylindrical compressive strength of the concrete and the material properties of the reinforcing bars are shown in **Tables 2** and **3**, respectively. The values on **Table 2** were obtained from standard cylinder tests according to the Japan Industrial Standards [3], [4].

2.2. Experimental methods

The specimens were tested using the static loading system at Osaka University. A test setup in the loading system is shown in **Fig. 3**. The specimens were mounted onto fixed supports in the loading system by using steel PC bars. The loading system



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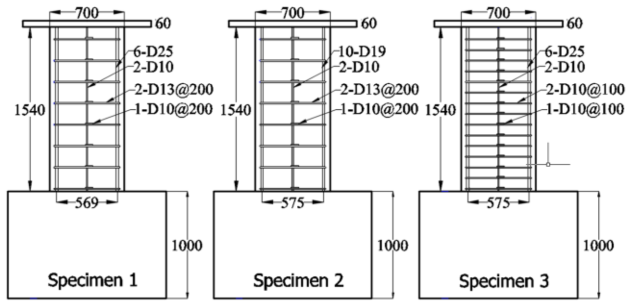
(a) Cross-sections of the specimens



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(b) Sectional elevation of the specimens

Fig.2 Detail of the specimen

Table 2 Material properties of concrete

	Compressive strength (N/mm^2)	Elastic modulus* (N/mm^2)	Strain at strength (μ)
Specimen 1	30.5	28736	1751
Specimen 2	35.7	29556	2064
Specimen 3	34.2	28717	1781

Table 3 Material properties of reinforcement

Rebar diameter	Specimen number	Yield stress (N/mm^2)	Tensile strength (N/mm^2)	Elastic modulus (N/mm^2)
D10	1	364	506	191090
D10	2,3	382	523	176928
D13	1	364	536	174698
D13	2	370	517	188872
D19	2	382	571	182882
D25	1	378	558	187641
D25	2,3	375	558	193293

consisted of one horizontal (1000kN) and two vertical hydraulic jacks (2000kN), as shown in **Fig. 3**.

Every specimen was subjected to a constant axial load of N/N_0 = 0.07 (where N is the axial load, and N_0 is the compressive strength of the specimen). The axial load was applied to the beam specimens, as the previous experiment of weak beam-strong column type RC frames [2] reported that the axial load of 7% to the beam compressive strength was induced due to the restriction to beam elongation by the columns. **Eq. (1)** gives the axial forces for the south (Ns) and north (N_N) vertical jacks during the experiment to maintain a bending moment diagram representing that in the previous specimen (**Fig. 1**), as shown in **Fig. 4**.

$$N_S = N/2 + Q \cdot a/l$$
$$N_N = N/2 - Q \cdot a/l \quad (1)$$

where N is the total axial load on the specimen (kN); Q is lateral force (kN); l is the center-to-center distance between the south and north vertical jacks (= 4000 mm) and a is height of the target inflection point from the center of loading beam (= 650 mm), as shown in **Fig.4**.

In this experiment, a drift ratio was defined by dividing the horizontal drift δ by its measured height H (= 1490 mm) i.e. $R_b = \delta/H$. Static cyclic lateral loads were applied according to the loading history, as shown in **Fig 5**. The loading drift ratio (R_b) represented the beam drift ratios applied to the beams in the previous specimen (**Fig. 1**) which was calculated according to the collapse mechanism model [2], as shown in **Fig 6**, by **Eqs. (2)** and **(3)**.

$$\delta = L \cdot sinR \quad (2)$$
$$R_b = R + sin^{-1}(2l_r sinR/l_b) \quad (3)$$

where L is the overall height of the frame specimen; R is a horizontal drift ratio of the specimen; l_r is length of rigid zones at the beam ends; l_b is beam length between assumed plastic hinges.

3. Conclusion.

A series of static loading experiment of full scale RC beam specimens was planned focusing on buckling of longitudinal bars. The test results are described in Part 2.

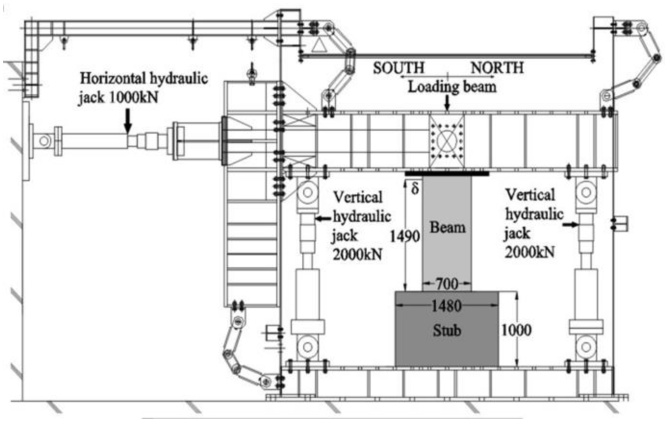
[References]

[1] Architectural Institute of Japan: Guidelines for Performance Evaluation of Earthquake Resistant Reinforced Concrete Buildings (draft), 2004.01 (in Japanese)

[2] Yoon, R., Sanada, Y., Akahori, T., Suzuki, S., Kuramoto, H.: Effects of Secondary Walls on Lateral Strengths of One-Story One-Bay R/C Moment Resisting Frames, Journal of Structural and Construction Engineering (Transactions of AIJ), Vol.79, No.706, pp.1869-1878, 2014.12 (in Japanese)

[3] Japanese Standards Association: Method of test for compressive strength of concrete (JIS A 1108), 2006 (in Japanese).

[4] Japanese Standards Association: Method of test for static modulus of elasticity of concrete (JIS A 1149), 2010 (in Japanese).



Unit = mm

Fig. 3 Test setup and loading system

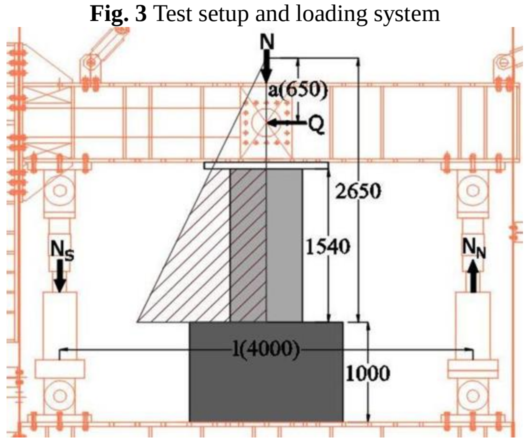


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Fig. 4 Target bending moment diagram

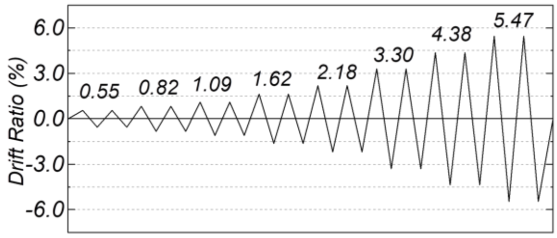

Fig.5 Lateral loading history for the experiments

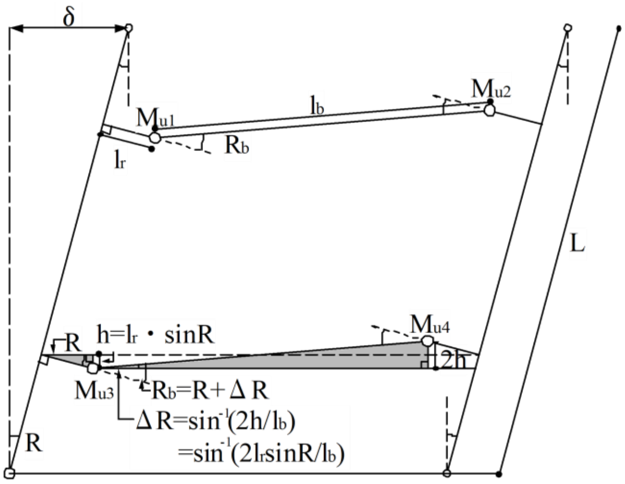

Fig. 6 Collapse mechanism model.

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