日本建築学会大会学術講演梗概集
（東北） 2018 年 9 月

Static loading experiment of RC beams focusing on buckling of longitudinal bars
Part 2 Experimental results and discussions

Full scale test　Performance based design　Member　○KAWAMURA Eriko *1　Member　PRADHAN Sujan *1
Reinforced concrete　Safety limit　Seismic assessment　Member　YOON Rokhyun *2　Member　SANADA Yasushi *3

1.Introduction

Three beam specimens with full scale focusing on buckling of longitudinal reinforcing bars were designed and the static loading experiment was conducted as explained in **Part 1**. This part describes the experimental results.

2.Experimental Results

Fig. 1 shows the comparison of the beam shear force vs. drift ratio relationships. Besides, flexural resistances calculated according to the Japanese design standards [1] are plotted by dotted lines. The symbols on **Fig. 1** represent drifts at flexural cracking (◇), formation of a yield mechanism with flexural hinging at the critical section (△), maximum strength (○) and ultimate state with buckling of the beam longitudinal reinforcing bars (×).

Fig. 2 compares the crack patterns among the three specimens at initiation of the bar buckling mentioned below.

From the experimental observation, the vertical cracks (along longitudinal reinforcing bars) shown in the red squares in **Photo 1(a)**, **(b)** and **(c)** were regarded as the initiation of the bar buckling, while **Photo 1(d)**, **(e)** and **(f)** clearly shows the bar buckling which was visually observed.

The behavior of each specimen throughout loading is summarized in the following section.

2.1 Common failure behavior

Flexural cracks occurred at each beam end during the first cycle to R = 0.55% rad, and every specimen formed a yield mechanism after flexural yielding at the critical section. Thus, the stiffness degraded in the following cycles. However, the shear resistance still increased with an increase of drift before the buckling of longitudinal reinforcing bars. The flexural yielding resistances of 206 kN, 225 kN and 233 kN for specimen 1, 2 and 3 were recorded, respectively, whereas the shear resistances of 204 kN, 212 kN and 213 kN were calculated for specimen 1, 2 and 3, respectively according to the Japanese design standards [1], where beam flexural strength with axial force was obtained with **Eq. (1)**.

$$M_u = 0.8 a_t \sigma_y D + 0.5ND\left(1 - \frac{N}{bDF_c}\right) \quad \textbf{(1)}$$

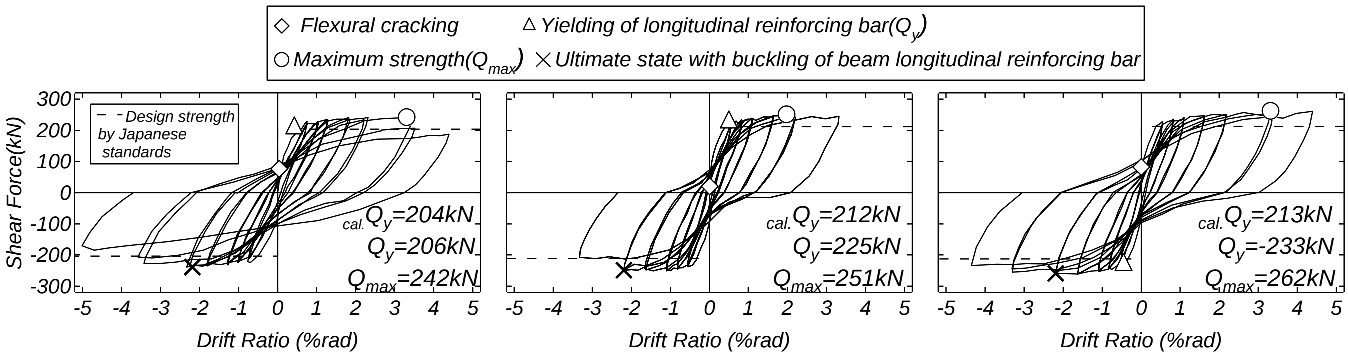
where, a_t is the cross-sectional area of the tensile reinforcing bars, D and b is the depth and width of the beam, σ_y is the yield stress of the tensile reinforcing bars, N is axial force on beam and F_c is the compressive strength of concrete.

After yielding of longitudinal reinforcing bars, spalling off of the cover concrete at the compression side started during the cycle to R = 2.18% rad. The maximum strength reached to 242 kN and 262 kN for specimen 1 and 3 respectively, at the first positive peak in the cycle of R = 3.3% rad, whereas that for specimen 2 reached to 251 kN during the first positive cycle to R = 2.18% rad. End cover concrete in tension was completely spalled off from every specimen and longitudinal reinforcing bars were exposed during the cycle to R = 3.3% rad.

2.2 Comparison of drifts at buckling of longitudinal reinforcing bar

The vertical compression cracks along the longitudinal reinforcing bars on each specimen appeared during the negative first cycle to R = 2.18% rad, as shown in **Photo 1(a)**, **(b)** and **(c)** for specimen 1, 2 and 3 respectively, which indicated that the buckling of longitudinal reinforcing bars in each specimen was initiated from this cycle.

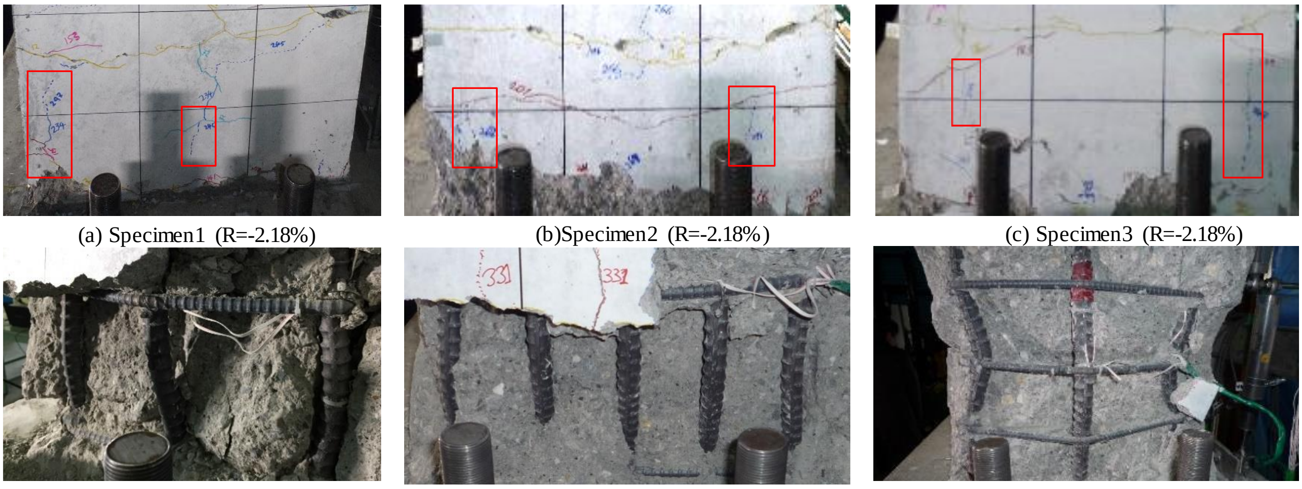
For specimen 1, the buckling of longitudinal reinforcing bars were visually observed after spalling off of the concrete cover during the second negative cycle to R = 3.3% rad. Then, the shear resistance dropped to less than 80% of the maximum strength in the positive cycle to R = 4.38% rad.



(a) Specimen1　(b) Specimen2　(c) Specimen3

Fig. 1 Beam shear force vs. drift ratio relationships

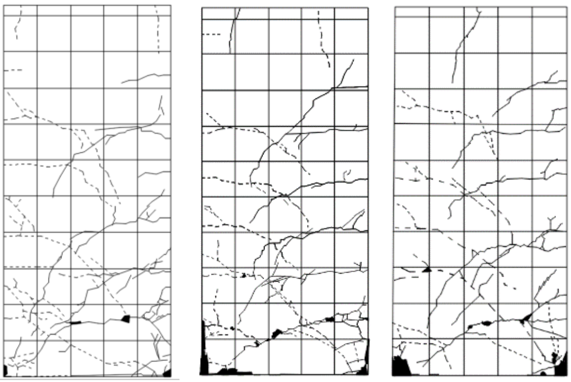
主筋座屈に着目した RC 造梁の静的載荷実験
(その 2)実験結果と考察
河村英里子，Pradhan Sujan，尹ロク現，真田靖士



(a) Specimen1 (R=-2.18%) (b)Specimen2 (R=-2.18%) (c) Specimen3 (R=-2.18%)

(d) Specimen1 (R=-3.30%) (e)Specimen2 (R=-3.30%) (f) Specimen3 (R=-4.38%)

Photo.1 Longitudinal reinforcement bar buckling



(a) Specimen 1 (b) Specimen 2 (c) Specimen 3

Fig.2 Crack patterns at the cycle of R = -2.18 %rad

For specimen 2, after the completely spalling off of the cover concrete, buckling of all longitudinal reinforcing bars were visually observed at the beam end during the negative cycle to R = 3.3% rad, as shown in **Photo 1(e)**. the strength was significantly decreased during the cycle to R = 3.3% rad.

For specimen 3, the buckling of mid longitudinal reinforcing bar in the loading direction was visually observed during the cycle to R = 3.3% rad, whereas that of the corner longitudinal reinforcing bar was observed in the transverse direction during the same cycle, which might be affected by smaller spacing of shear reinforcing bars. The buckling of longitudinal reinforcing bars during the negative cycle to R = 4.38% rad is shown in **Photo 1(f)**.

The diameter of longitudinal reinforcing bars and the shear reinforcing bar spacing were different among three specimens, however, the longitudinal reinforcing bars seemed to initiate buckling during the cycle to R = 2.18% rad, which were not visually observed but estimated by appearance of vertical cracks, as mentioned previously. For specimens 1 and 2 with the same spacing between shear reinforcing bars of 200 mm, the strength clearly decreased after the buckling of longitudinal reinforcing bars; hence, it is related to safety limit in the seismic performance evaluation of RC buildings [3]. On the other hand, for specimen 3 with smaller spacing of 100 mm, the strength drop was a little moderate compared to specimen 1 and 2; therefore, effects of the structural details on the ultimate performance at the bar buckling should be carefully investigated. Furthermore, no significant difference was observed between specimen 1 and 2 with different diameters of longitudinal bars within the present experiment, which should also be investigated based on future theoretical study.

3. Conclusions

This paper experimentally investigated the seismic performance RC beams focusing on the buckling of longitudinal bars. The major findings are summarized as follows:

1) It was experimentally verified that the buckling phenomena of beam longitudinal bars observed in the previous study [2] was also observed in the full scale beam specimens. Moreover, no phenomenon regarded as safety limit in the seismic performance evaluation of RC buildings [3] was observed in the present experiment.

2) In particular, it was found that the strength of all specimens decreased after the buckling of longitudinal reinforcing bars. Consequently, experimental results 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.

[References]

[1] Architectural Institute of Japan: AIJ Standard for Structural Calculation of Reinforced Concrete Structures, 2010.11 (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] Architectural Institute of Japan: Guidelines for Performance Evaluation of Earthquake Resistant Reinforced Concrete Buildings (draft), 2004.01 (in Japanese)

*1 Graduate Student, Graduate School of Eng., Osaka Univ.

*2 Graduate Student, Graduate School of Eng., Osaka Univ., Ms. Eng.

*3 Assoc. Prof., Graduate School of Eng., Osaka Univ., Dr. Eng.

*1 大阪大学大学院工学研究科 大学院生

*2 大阪大学大学院工学研究科 大学院生 修士(工学)

*3 大阪大学大学院工学研究科 准教授 博士(工学)