CYCLIC TESTING OF REINFORCED CONCRETE COLUMNS WITH UNBONDED REINFORCEMENT

Keerthi RANASINGHE*1, Hiroshi MUTSUYOSHI*2 and Hiroki UCHIBORI*3

ABSTRACT: This paper describes the seismic behavior of RC columns having different bond conditions of longitudinal bars to concrete. Four RC columns were tested up to final failure under reversed cyclic load. Bond conditions were varied between perfect bond and no bond. It was observed that the ductility of an un-bonded specimen was improved significantly compared to the bonded specimen and the final failure was changed from shear to flexure.
KEYWORDS: reinforced concrete, flexural capacity, shear capacity, ductility, bond characteristics of reinforcement

1. INTRODUCTION

It has been confirmed that the use of deformed bars ensures good adhesion between the reinforcement and adjoining concrete that is essential for composite behavior of reinforced concrete (RC) structures. Many research have been conducted on bond, based on rib geometry, rib spacing and surface condition of bars, with a view to study and improve the bond characteristics of RC structures [1-3]. However, there has been only a few studies on the effects of bond on shear behavior of RC structures. Deformed bars with good bond can reduce shear carrying capacity of RC members due to formation of tensile cracks at the bar surface [4]. Such cracks may induce diagonal shear cracks depending on the stress states of RC member concerned [5], and then finally shear failure occurs.

It is well known that the ultimate failure mode and shear strength are influenced by the bond condition of reinforcing bars in RC members. It was reported by Kani [6] that RC beams with weaker bond showed higher shear strengths of more than 31% compared to beams with perfect bond. Ikeda and Uji [7] showed that the failure mode of RC beams could change depending on the bond condition of steel bars and this mechanism could be made clear by a finite element analysis. Ranasinghe et al. [8] reported that the shear strength of a RC beam with no bond is about 90% higher than that of the beam with perfect bond. Thus, it can be concluded that the shear behavior of RC beams must be governed by the bond condition of reinforcing bars. However, these studies were conducted on beams under monotonic loading and so far very little research has been done on the shear behavior of RC members with un-bonded bars under reversed cyclic loading. The objective of this study, therefore, is to clarify the effects of bond of reinforcement on shear behavior of RC columns under cyclic loading.

2. EXPERIMENTAL PROGRAM

Four RC columns having different bond conditions in the longitudinal bars were tested.

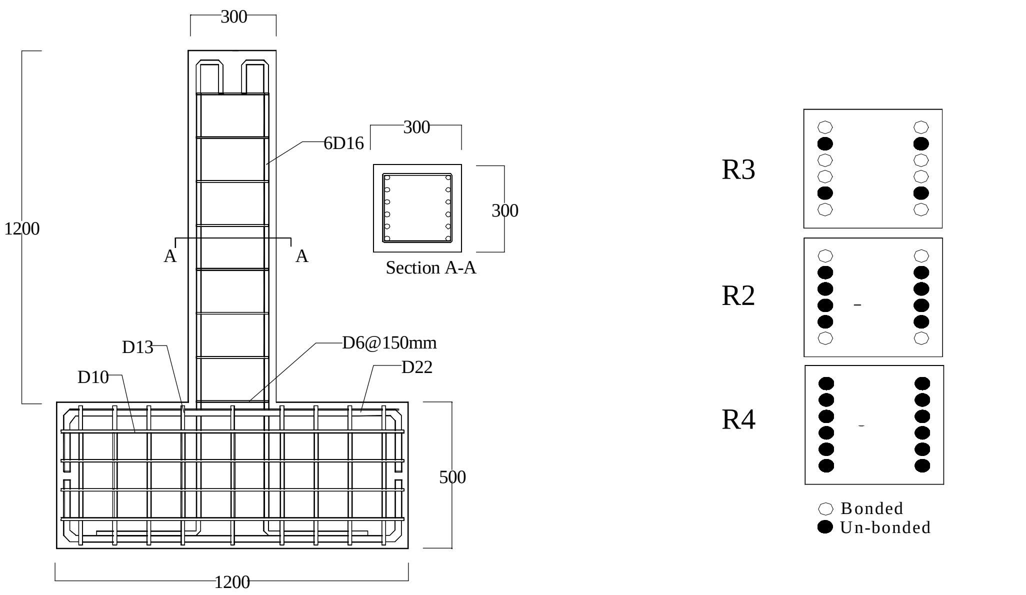
*1 Graduate School of Science and Engineering, Saitama University, Member of JCI
*2 Department of Civil and Env. Engineering, Saitama University, Member of JCI
*3 Graduate School of Science and Engineering, Saitama University

Deformed steel bars were used for main reinforcement as well as for the lateral ties. Table 1 shows the mechanical characteristics of reinforcements.

Table 1. Details of Reinforcements

Steel	Type	Yield Strength
Longitudinal Bars	D16 SD345	402 MPa
Lateral Ties	D6 SD 300	366 MPa

To make un-bond conditions of bars, sheaths in which deformed bars were placed, were installed before placing the concrete. Length of un-bonded area and pattern of un-bonded bars were varied among the specimens as shown in Table 2. Details of specimens are shown in Fig, 1.



(a) Reinforcement Details

(b) Arrangement of Bars

Fig. 1 Reinforcement Arrangement of Specimens (Dimensions in mm)

Table 2. Details of Specimens

No.	Main Reinforcement		Number of un-bonded bars
	Number X Dia.	Bond modification region	
R1	12 X D16	Reference specimen	----
R2	12 X D16	Up to 400 mm from interface	8
R3	12 X D16	Up to 800 mm from interface	4
R4	12 X D16	Up to 800 mm from interface	12

In specimen R1, all bars were bonded as a reference specimen. In specimen R4, all bars were un-bonded in the region of 800mm from the bottom of the column. In specimen R2, 8 bars were un-bonded in the region of 400mm from the bottom of the column and in specimen R3, 4 bars were un-bonded in the same region as for R4. Shear strength to flexural strength ratio of all specimens was kept around 1.1. Less lateral ties were provided to minimize the shear contribution of ties in order to ensure shear failure after yielding of longitudinal bars in all specimens. Concrete contribution to shear strength was calculated using the equation by Okamura and Higai [9]. Sheaths a little bigger than the bars were used to make un-bond condition for reinforcement. Strain gauges were attached to longitudinal bars as well as to lateral ties at different locations. Concrete strength was between 35 MPa and 43 MPa at the time of testing. Fig. 2 shows the loading setup.

Displacements were measured at each step of loading with three repetitions. Strains in the longitudinal bars and in the lateral ties were recorded at three different locations of specimens.

3. RESULTS AND DISCUSSION

Control specimen R1, and specimens R2 and R3 failed in shear. Specimen R4, however, failed in flexure. Table 3 shows the test results from the experiments. Fig. 3 shows the crack patterns observed during the first three loading steps in all specimens. Closely spaced flexural

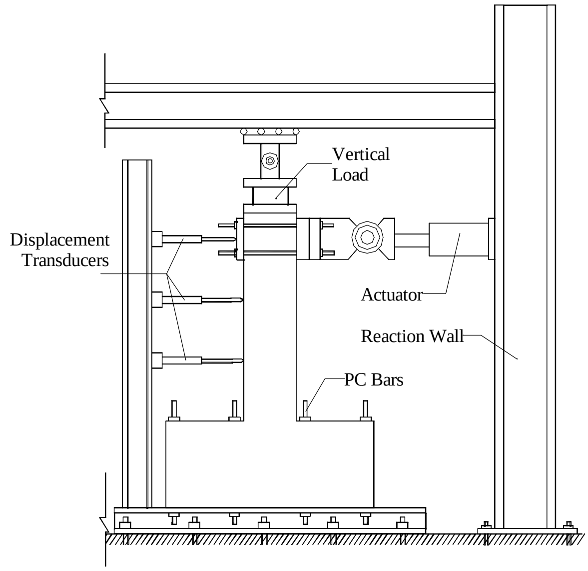
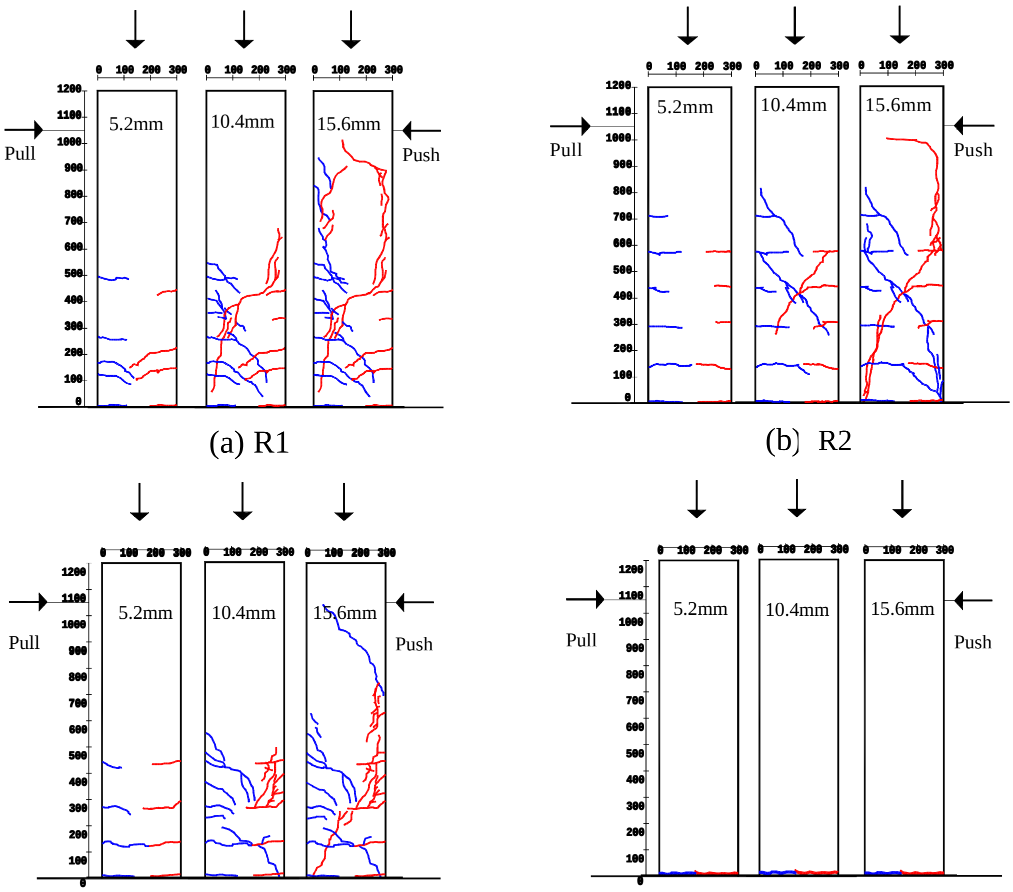


Fig. 2 Loading Setup

Table 3. Test Results

Specimen No.	Displacement (mm)		Load (kN)		δ_u/δ_y	Failure Mode
	δ_y	δ_u	P_y	P_{max}		
R1	9.66	15.74	117.02	118.21	1.63	Shear
R2	8.43	18.02	108.68	112.62	2.14	Shear
R3	9.20	18.64	112.97	123.88	2.03	Shear
R4	13.7	46.8	119.49	120.17	3.42	Flexure



(a) R1

(b) R2

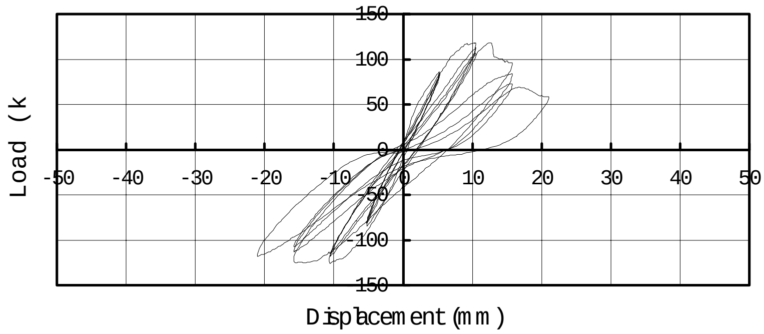
(c) R3

(d) R4

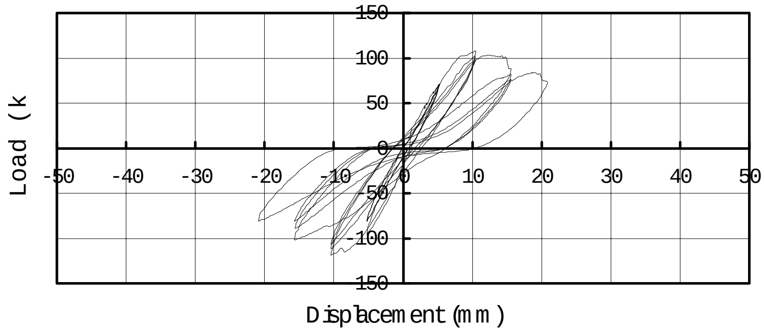
Fig.3 Crack Patterns

cracks were observed for specimens R1 and R3, whereas crack spacing increased markedly for specimen R2. The reason for this can be due to the fact that most of the bars of specimen R2 were un-bonded in the maximum moment region. The reduction in the crack spacing for R3 could be due to the fact that smaller number of bars were un-bonded for R3 compared to R2. During the initial loading, flexural cracks in R1 and R3 were concentrated in the 1/3 region of the column height from the bottom. However, for specimen R2, cracks appeared at relatively higher locations. Specimen R4 showed only one flexural crack at the column base. With further loading, the column rotated as a rigid body forming a plastic hinge at this crack location. Specimens R1, R2 and R3 showed prominent diagonal shear cracks at a displacement of 10.4 mm. In specimen R4 any diagonal cracks did not occur during the loading. No significant spalling was visible in any of the specimens.

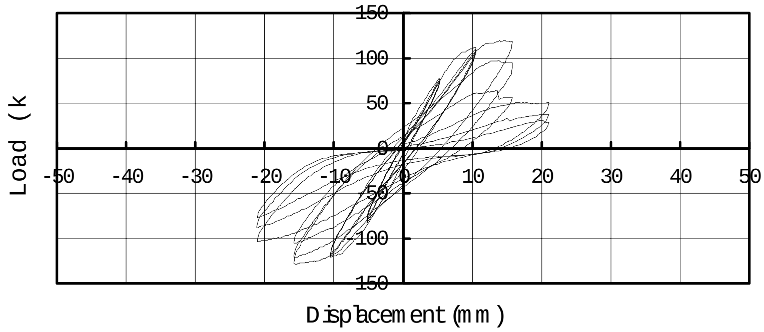
Fig.4 shows the hysteretic load displacement curves and Fig.5 shows the load-displacement skeleton curves and for all specimens. Specimens R1, R2 and R3 showed diagonal shear failures at a displacement of 15.6mm. Specimen R4 showed a reduction of load below 80% of the maximum load at a displacement of 46.8mm. This specimen also showed the largest ductility among all specimens. However, this was achieved at the expense of energy absorption characteristics, which was poor compared to the bonded specimen. Stiffness of specimens became reduced when the number of un-bonded bars increased, as can be seen from fig. 5.



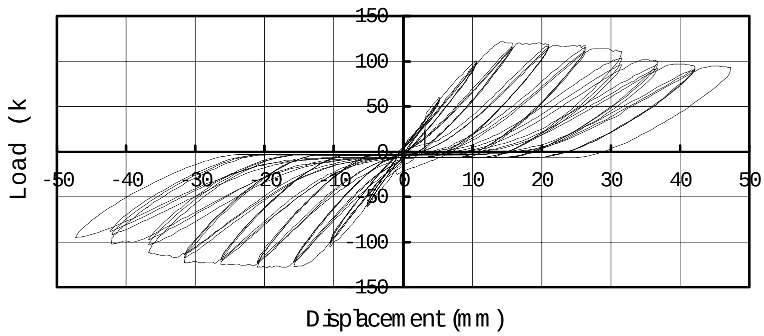
(a) R1



(b) R2



(c) R3



(d) R4

Fig. 4 Load Displacement Relationships

Yielding of longitudinal reinforcements occurred in all specimens. Strains in un-bonded bars were uniform throughout the un-bonded region. These strains were found to be much lower than those in the bonded regions of the same bars as well as the strains in the bonded bars. Due to un-bonded bars in the shear region, very high stresses were generated in the anchorage zone resulting in higher steel strains. In specimens R1 to R3, lateral ties 450mm from the column base were broken prior to failure of specimens.

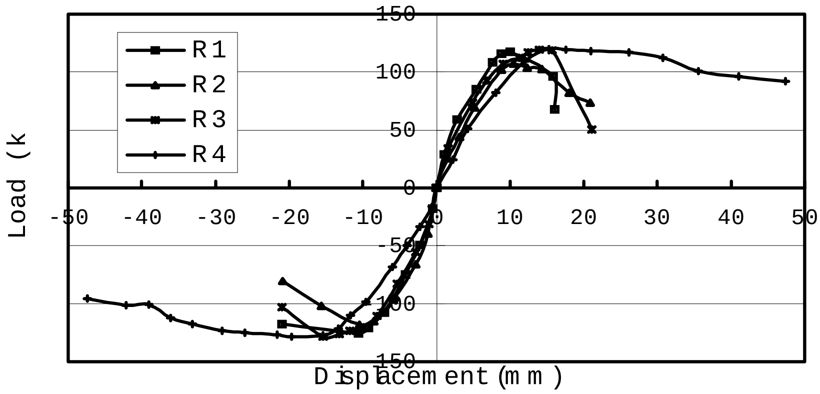


Fig.5 Load Displacement Skeleton Curves

Deformations of the specimens could be divided into two parts for the specimens R1, R2 and R3. During initial stages of loading, flexural deformations dominated. However, as the loading progressed, diagonal shear cracks occurred and started to widen. Thereafter shear deformations dominated. After this stage, on reversal of load, shear force was resisted by the interlocking action of cracked concrete along the main crack. This explains the difference in load capacities observed for loading and unloading. The hysteretic behavior of specimen R4 was similar to the hysteretic behavior of steel alone. In this specimen, there was no shear deformation and strains in the lateral ties were very low even at failure.

4. CONCLUSIONS

Four RC column specimens having different bond conditions of longitudinal bars were tested up to failure under reversed cyclic loading. From the results, th lowing conclusions can be drawn.

1. Ductility of RC columns can be improved greatly by un-bonding the longitudinal bars of columns.
2. Load capacity of columns does not reduce significantly due to un-bonding of longitudinal bars.
3. Cracking of concrete in the critical shear region can be reduced by using un-bonded bars. However, the presence of any bars with bond induces cracking, which may ultimately become a diagonal shear crack.
4. For fully un-bonded specimen, cracking concentrates at the maximum moment section and a plastic hinge forms, thereby increasing the displacement capacity.

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