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SEISMIC PERFORMANCE OF FULL-SCALE RECYCLED AGGREGATE CONCRETE COLUMNS

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Abstract. *This paper presents the results of reversed cyclic loading tests on reinforced recycled concrete columns. Recycled concrete aggregates were obtained from the waste of structural elements cast with low quality concrete. For investigating whether the structural concrete incorporating recycled aggregates can be reliably utilized in new reinforced concrete column construction, two full-scale reinforced concrete columns were constructed and subjected to constant axial and reversed cyclic lateral loads. The test results of the experimental study were evaluated in terms of seismic hysteresis loops, skeleton curves, energy dissipation capacities, crack patterns and failure modes. The test results showed that the RC columns made of either natural aggregate concrete and recycled aggregate concrete show similar seismic behaviour.*

1 INTRODUCTION

The disposal of the construction and demolition waste has become a severe social, economic and environmental problem. For sustainable solution for both the concern of increasing demand for natural aggregates (NA) and reducing the need to deposit the construction and demolition waste in landfills, recycling the waste concrete for reuse as an aggregate in new concrete production for building new structures becomes compulsory.

A lot of experimental studies have been performed since 1940s worldwide for the utilization of recycled concrete aggregate (RCA). While most of these studies concentrated on mixture design, chemical, physical, biological properties of RCA and mechanical and durability properties of recycled aggregate concrete (RAC) (Nixon 1978, Hansen 1986, Hansen 1992, ACI-555 2002, Li 2008, Casuccio 2008, Tabsh and Abdelfatah 2009, Xiao et al. 2012, Thomas et al. 2013, Kim and Yun 2013, Yang et al. 2008, Corinaldesi 2010, M. Malesev 2010), only a few experimental studies were carried out to investigate the seismic behavior of RC

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columns incorporating large volumes of RCA as coarse aggregate (Xio et al. 2012, Ma et al. 2013, 2015 and Soleimani et al. 2016). According to these studies, while the columns incorporating RCA showed similar structural behavior with the columns incorporating NA, their lateral loads and deformation capacities were found to be diminished as the replacement ratio of RCA increased. While there are some differences between these studies in literature and the study carried out by the authors in terms of type of the tested columns (the tested columns in the study of Xio et al. 2012 was semi-precast, the tested columns in the studies of Ma et al. 2013, 2015 were composite, the tested columns in the study of authors are RC), the main difference is the property of RCA, which was sourced from structural elements cast with low strength concrete in the present study. The main objective of this study was to investigate the seismic behavior of full-scale reinforced recycled concrete (RRC) columns incorporating large percentage of RCA sourced from low strength concrete. For this purpose, two full-scale, code-complying (TSDC, 2007) RC columns, one out of two columns incorporating RAC and the other one incorporating NA, were produced and tested under constant axial and reversed cyclic lateral loadings. The test results showed that the replacement of NA with RCA sourced from low strength concrete did not have adverse effect on load bearing and deformation capacities of the columns.

2 OUTLINE OF EXPERIMENTAL INVESTIGATION

For investigating the effect of replacement of RCA with NA, an experimental study was carried out at Structural and Earthquake Engineering Laboratory, Istanbul Technical University. In this experimental campaign, two flexure-critical full scale reinforced concrete columns (column RAC and column NAC) were constructed and then subjected to constant axial and reversed cyclic lateral loads (Fig. 1a). The geometric ratio of longitudinal reinforcements and volumetric ratio of transverse reinforcements were 1.13% and 0.52%, respectively. The thickness of the concrete cover to the outside surface of the transverse reinforcements was 21 mm. While one out of two columns was constructed incorporating RAC, the other column was constructed incorporating natural aggregate concrete (NAC). Both columns were constructed so as to be representative of the columns of ordinary code complying columns of RC structures. The concrete mix–proportions of NAC and RAC are presented in Table 1. As seen from Table 1, approximately 50% of medium size coarse NA was replaced by RCA for the column incorporating RAC.

Table 1. Concrete mix-proportions

Material quantity (kg/m^3)	NAC	RAC
NA-No 2 aggregate (12-22 mm)	489	493
NA-No 1 aggregate (5-12 mm)	501	-
RCA (5-12 mm)	-	522
Crushed sand (washed) (0-4 mm)	407	410
Mountain Sand (0-2 mm)	513	518
Cement (CEM 42.5 R)	300	300
Water	128	110
Superplasticizer (Glenium ACE 450)	1.95	2.10
Water/cement	0.43	0.37

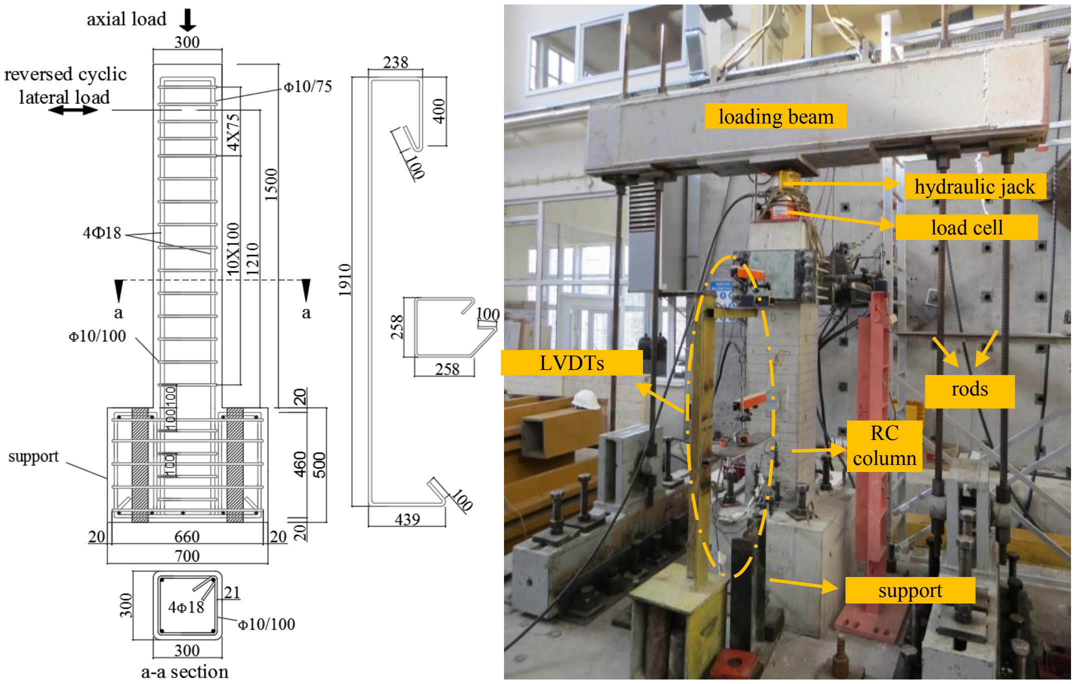

Fig. 1 (a) Reinforcement cage of the columns, (b) Test set-up.

The average compressive standard cylinder strengths of the columns NAC and RAC were obtained to be 35 MPa and 29 MPa, respectively. It should be noted that these results were based on the tests of drilled core specimens (100 mm diameter × 100 mm height), which were taken from the undamaged sections of these columns after the seismic test on the test day (at the age of 200 days). Ensuing, these core strengths were converted to standard cylinder compressive strength based on the recommendations of The Concrete Society (1976). The slump value of RAC and NAC was obtained to be around 18-22 mm. The mechanical properties of the deformed longitudinal (18 mm) and transverse (10 mm) reinforcing bars are illustrated in Fig. 2.

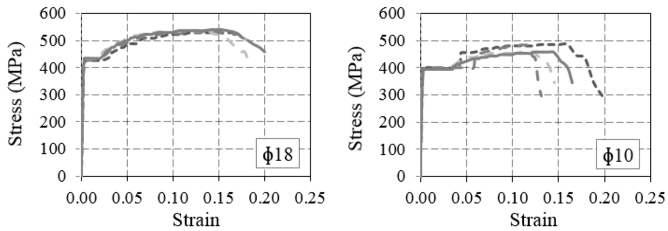

Fig. 2 Stress-strain relationships of longitudinal deformed (18 mm) and transverse (10 mm) reinforcing bars.

The axial loads of 222 kN and 184 kN were applied for the columns NAC and RAC, respectively, which corresponded to 7% of the axial load capacity ($n = P/P_0$, where n is axial load ratio, P is applied axial load, P_0 axial load capacity of the column ($P_0 = f_c'.A_g$), f_c' is the compressive strength of standard cylinder and A_g is the gross area of column cross-section) of each column without consideration of the capacity of the internal steel reinforcement.

3 INSTRUMENTATION, TEST SETUP, AND TESTING PROCEDURE

Both columns were subjected to constant axial and reversed cyclic lateral loading. The appearance of the test setup and the instrumentation details of the columns are presented in Fig. 1b and Fig 3, respectively. The reversed cyclic lateral load was executed under displacement control through a MTS hydraulic piston with a capacity of 250 kN. The instrumentation of the columns consisted of four horizontal and eight vertical linear variable differential transducers (LVDTs) and various strain gages installed on the longitudinal and transverse reinforcements. A displacement-based loading protocol was applied for the columns (Fig. 4). Drift ratios are calculated as the ratio of the lateral displacement (Δ_L) to the column height (H), where the actuator was connected.

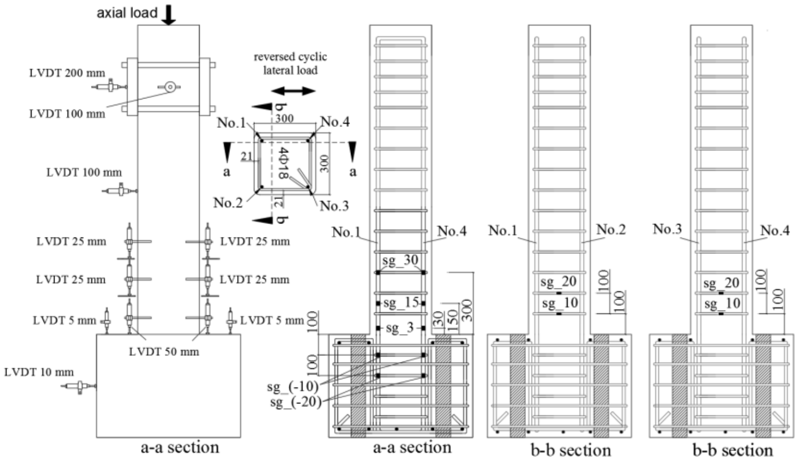

Fig. 3. Instrumentation details, LVDTs and strain gages (sg).

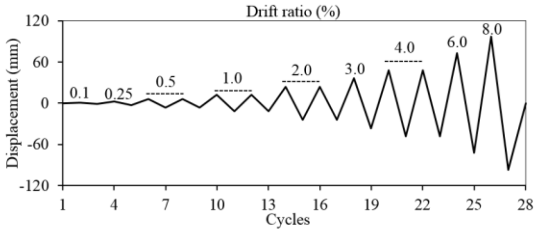

Fig. 4. Loading protocol.

4 EXPERIMENTAL RESULTS

The test results are summarized through lateral load-displacement relationships of the columns and envelopes of these relationships (Fig. 5 and 6a). As seen in Figs. 5 and 6a, both columns exhibited similar behaviors in terms of lateral load capacity. Furthermore, both columns sustained their load resistance capacities up to 8% drift ratio. The theoretical lateral load capacities of the columns, which were calculated through a section analysis program based on fiber analysis approach using the stress–strain relationships of materials, were obtained to be consistent with the experimental lateral load capacities of the columns without considering a further modification for the column RAC. The failure modes of these columns were governed by pure flexural failure. No cracking was observed up to 0.5% drift ratio. As the drift ratios increased, fine bending cracks increased gradually along the plastic hinge region of the columns. After yielding of the longitudinal reinforcing bars at around 2% drift ratio, the bending cracks developed and extended rapidly. When the drift ratios increased up to 3% and 4%, the flexural bending cracks of the columns widened and lengthened gradually. Buckling of longitudinal bars was not observed.

Energy dissipation capacities of the columns are presented in Fig. 6b. The energy dissipation capacities of the tested specimens are calculated as the areas enclosed by the lateral load-displacement hysteresis loops. As seen from Fig. 6b, it is clear that the energy dissipation capacities of the columns are similar. It can be concluded from Figures 5 and 6 that RCA did not seem to have an adverse effect on the seismic behaviour of the columns. This observation is valuable for demonstrating that RCA can be safely utilized in structural concrete.

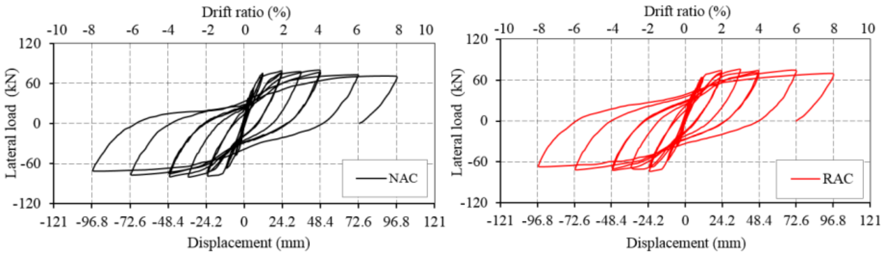

Fig. 5. Lateral load-displacement relationships of the columns

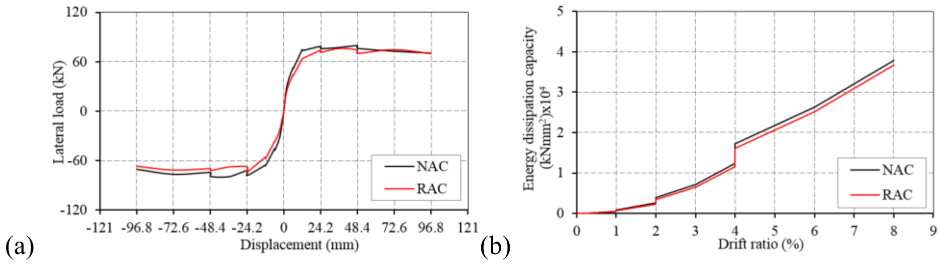

Fig. 6. (a) Envelopes of the lateral load-displacement relationships, (b) Energy dissipation capacities of the columns.

5 CONCLUSIONS

This paper presents the results of an experimental study carried on RC columns for investigating the effect of RCA on seismic behavior. The study differentiates from the available studies in the literature due to use of low strength waste concrete as a source for RCA. Two code-complying RC columns were constructed and tested under constant axial and reversed cyclic lateral loadings. While one of the column was incorporating NA, the other column was incorporating RCA as well as NA, cast by replacing approximately 50% of medium size coarse NA with RCA. The test results revealed that the RC columns made of either NA and RA showed similar seismic behaviour in terms of lateral load-displacement behavior, ductility and energy dissipation capacities.

While the findings reached in this study are valuable for demonstrating the viability of using RCA sourced from low strength concrete in structural concrete, further researches are necessary for validation of these test results in a more general sense.

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