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Reliability of Shear Strength of Recycled Aggregate Concrete Beams

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ABSTRACT

Since construction and demolition waste from concrete structures is leading to a significant environmental problem, a sustainable solution is required. As one of the solutions, recycled aggregate concrete (RAC) has been extensively studied in this area in recent years. The usage of RAC is, however, still limited due to a lack of proper structural regulations and provisions for RAC. This study investigates a safety margin of RAC beams that failed in shear which is comparable to natural aggregate concrete (NAC) beams. To this end, a database for RAC beams was used, which has been established from various works in the existing literature. The strength margin between RAC and NAC was identified by means of reliability analysis and it was found that the current design provision can be used for the shear design of RAC beams with a desirable safety level.

1. INTRODUCTION

Recycling concrete for use as coarse aggregate has been paid attention to as a sustainable solution to address environmental concerns in the construction industry. However, the presence of old mortar on the surface of the recycled aggregate has an

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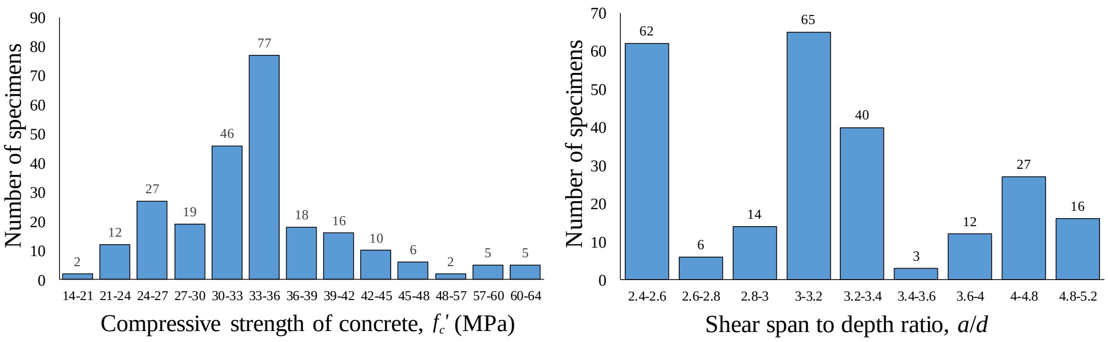
adverse effect on the mechanical properties of recycled aggregate concrete (RAC) (Kisku et al. 2017, Mistri et al. 2019, Mistri et al. 2020). It has low density, high porosity and water absorption compared to natural aggregate concrete (NAC) (Ryu 2002). Thus, it should be carefully used when it comes to structural members especially, shear dominant members which have quite brittle and abrupt failure nature.

This study is aimed to analyze a database established by collecting various experimental studies from the existing literature (Ju et al. 2021). The database comprises RAC beams with and without shear reinforcement that failed in shear. Current design codes do not have proper provisions for the use of RAC to determine the shear strength of the beams. In this study, the ACI 318–19 (ACI 2019) provision is used to evaluate the shear strengths of RAC concrete beams and reliability analysis is conducted to identify the safety margin of RAC compared to NAC.

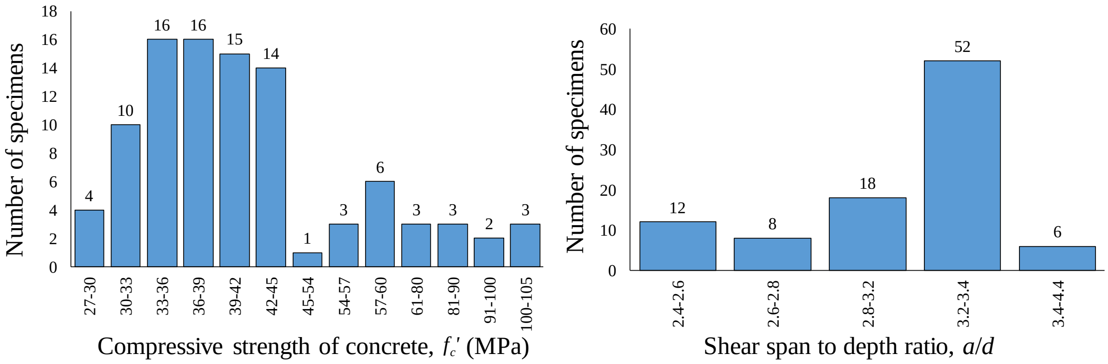
2. SHEAR DATABASE OF RAC

A database used in this study has been compiled from available existing studies on the shear strength of RAC beams. A total of 591 specimens from 41 studies were included in the database. The experimental data includes NAC beams as control specimens whose recycled aggregate replacement is 0%. RCA specimens have replacement ratios of RCA ranging from 0% to 100%.

Fig. 1 shows the distribution of key parameters of the RCA concrete specimens without shear reinforcement in the database for RCA specimens. The compressive strength of concrete (f_c') ranges from 14 MPa to 104 MPa, and most of the specimens are in the range of normal strength, from 24 to 36 MPa. The shear span-to-depth ratio (a/d) of specimens ranges from 2.4 to 5.1.



(a) Without shear reinforcement



(b) With shear reinforcement

Fig. 1 Distribution of key parameters in RAC

3. RELIABILITY ANALYSIS

The shear strength ratio between the RAC beams and its control specimen (V_{RAC}/V_{NAC}) is taken into consideration. To evaluate the shear capacity, the current ACI 318-19 provision is used, which suggests the square root of the compressive strength of concrete ($\sqrt{f_c'}$) to consider the material properties for calculating the shear capacity of reinforced concrete beams. Thus, to investigate the effect of recycled aggregate on the shear strength of the members, the shear strength was normalized, which is defined as normalized shear strength ratio, as follows:

$$\frac{V_{RAC}}{\sqrt{f'_{c(RAC)}}} / \frac{V_{NAC}}{\sqrt{f'_{c(NAC)}}} \tag{1}$$

The specimens in the database were categorized into several groups according to the replacement ratio to remove any uncertainties and misinterpretation caused by the limited number of tests at a specific replacement ratio. The specimens without shear reinforcement are grouped as replacement ratio of 1 ~ 30%, 31 ~ 50%, and 51 ~ 100%, while the groups for specimens with shear reinforcement as 1 ~ 50% and 51% ~ 100%.

A reliability analysis based on FORM (first-order reliability method) was carried out to investigate the safe margin of RAC beams that failed in shear and an appropriate strength reduction factor for the shear design of RAC beams was estimated. The chosen load combination was $1.2D+1.6L$, thus, the safety factor is defined as follows:

$$SF = \frac{(1.2D+1.6L)/\varphi}{D+L} \tag{2}$$

where D and L are dead and live loads, respectively, and φ is the strength reduction factor. Then, the limit state function (g) is expressed as follows:

$$g = SF \times V_n - V_{test} \tag{3}$$

where V_n is the nominal shear capacity calculated by ACI 318-19, and V_{test} is the shear strength obtained from the test data. As the shear equation specified in ACI 318-19 consists of random variables, the bias factors and coefficient of variances (COVs) were taken from Nowak and Szerszen's study (2003), as presented in Table 1. For the compressive strength of concrete, which has several bias factors depending on its nominal value, the closest upper value in Table 1 was taken.

As a result of estimating the reliability index (β) for the specimens in the database, the reliability indices for almost all specimens are above 3.5 which is the ACI 318 target value (Cho et al. 2017), except for only one specimen in the database without shear reinforcement regardless of the replacement ratio. Fig. 2 shows the reliability indices (β) for RCA and RC databases. RCA concrete beams follow the general trend given for the RC database. Thus, it can be concluded that and that the safety level of RAC beams in terms of the shear design by ACI 318-19 code provision is at an acceptable level for any replacement ratios and that the current shear design equation can be applied without any adverse effect on safety and conservativeness in the shear design of RCA concrete beams.

Table 1 Statistical parameters for variables (Cho et al. 2017)

Parameters	Nominal Value	Bias Factor	COV
f_c'	48	1.19	0.115
	55	1.09	0.090
	62	1.16	0.100
	69	1.13	0.115
	83	1.04	0.105
b_w	–	1.00	0.060
d	–	1.00	0.060
$dia_{long.rein.}$	–	1.00	0.060
f_{vy}	–	1.145	0.050
s	–	1.00	0.060
$dia_{trans.rein.}$	–	1.00	0.060
RC beam, shear	–	1.16	0.120

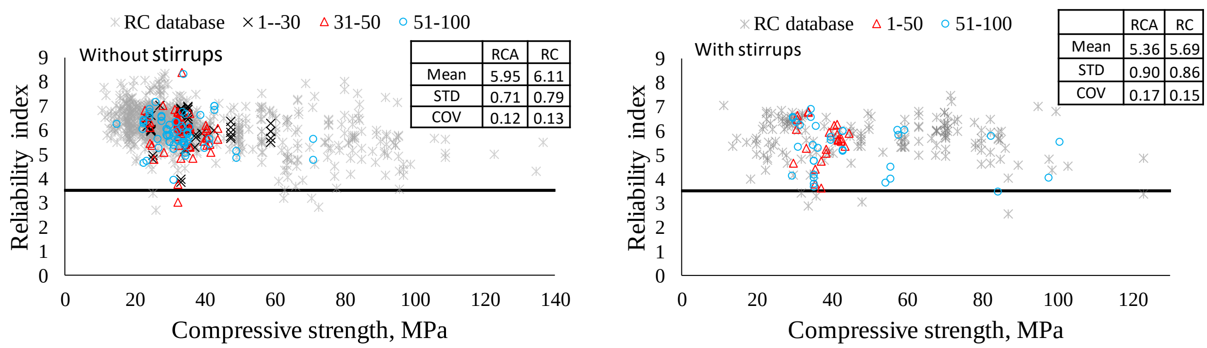


Fig. 2 Reliability indices for RAC beams compared with NAC beams

4. CONCLUSION

In this study, the performance of RCA concrete beams was assessed regarding its shear capacity, for which an extensive literature review was conducted and an up-to-date database for RCA concrete beams was established. A comparability study with well-established RC beams indicated that there is no difference in shear capacity between RCA and RC databases. Moreover, RCA concrete beams follow general trends and safety margins, which are set for conventional reinforced concrete members, regardless of key influencing factors or reliability index.

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