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Seismic behavior of recycled aggregate concrete beams under cyclic torsion

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HIGHLIGHTS

- Seismic behavior of recycled aggregate concrete (RAC) beam under cyclic torsion was presented.
- Cyclic torsion performance of RAC beam and natural aggregate concrete (NAC) beam were compared.
- Research on seismic performance of RAC members under cyclic torsion is still very limited now.

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ABSTRACT

Although the material property and structural behavior of recycled aggregate concrete (RAC) have been widely investigated, the research on seismic performance of RAC members under cyclic torsion is still very limited. In this paper, the failure mode, hysteresis loop, strain of steel reinforcement, principal strain of concrete, energy dissipation capacity, skeleton curve, deterioration of stiffness and ductility factor of RAC beams and natural aggregate concrete (NAC) beams under cyclic torsion were compared and investigated. The results indicate that although both the RAC and NAC torsional beams present a torsional failure mode with spiral cracks, the cracks of RAC beams are larger than that of NAC beams. The hysteresis loop shape and corresponding inflection points of NAC and RAC torsional beams are very similar, but the energy dissipation capacity and ductility factor of RAC torsional beams are about 20% and 7% higher than those of NAC beams, respectively. The use of RAC in cyclic torsional beams does not bring apparent influence on the deterioration of stiffness, but the bearing capacity of RAC torsional beams is lower than that of NAC beams.

1. Introduction

With the rapid development of economy and urbanization all over the world, many existing concrete structures need to be removed and rebuilt, thus generating a huge amount of waste concrete. In order to relieve the pressure of environmental protection, it is urgent to process these waste concrete in a reasonable way. After recycling, crushing, screening and blending, recycled aggregate can be obtained, thus producing the so-called Recycled Aggregate Concrete (RAC) [1–4]. It can not only solve the problem of environmental protection, but also meet the demand of sustainable society.

Existing research of RAC mainly focuses on two points: properties of RAC materials and performances of RAC members. Compressive strength [5–7], tensile strength [8], elastic modulus [9], constitutive relationship [10–13], durability [14–17] of RAC materials and modified RAC materials [18–21] have been widely investigated. Flexural and shear performance of RAC beams [22–26], compressive performance of RAC column [27–30], seismic performance of RAC beam-column joint [31,32], RAC shear wall [33] and RAC frame structure [34] have also been reported in previous papers. Within many theoretical and experimental studies available in literature on the use of RAC for the structural members, the case of torsional loads does not seem to have been exhaustively investigated, although it frequently occurs in civil engineering. Not too much attention has previously been given to the behaviors of such members subjected to torsion moment because of the fact that, except for exceptional cases, the structural strength is not compromised by the torsional capacity. A torsional moment in building structures always arises when the resultant force acts eccentrically relative to the longitudinal axis of an element. Examples of reinforced concrete elements often loaded with a torsional moment are: lateral beams of

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Fig. 1. Morphology of recycled aggregate.

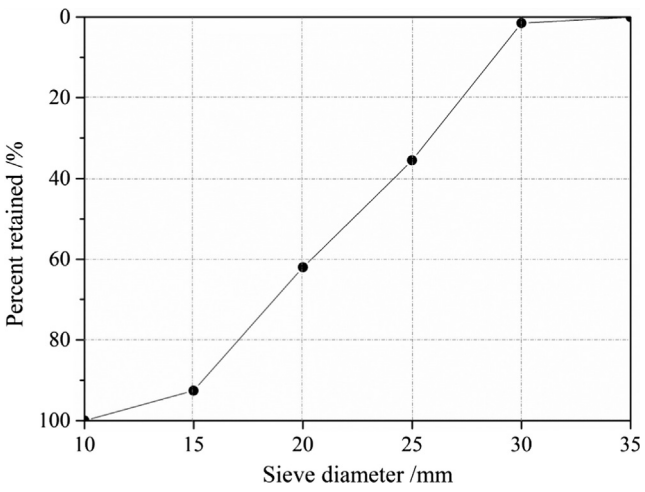

Fig. 2. Grading curve for the recycled aggregate used in this study.

stairways, edge floor joists, spatial frames, spiral stairs, bridge decks subject to highly eccentric loads and reinforced concrete arches loaded perpendicularly to their plane. It is very important that the cracked torsional stiffness of a reinforced concrete beam may be much smaller than its uncracked stiffness. In some cases torsion becomes a primary effect and torsional response of beams may also control the overall structural behavior [35]. For this reason, the torsional behavior of RAC members should be studied and comprehended as well as their flexural or shear behavior. In this paper, experiments were carried out to better understand the seismic performance of RAC members under torsion loading.

2. Material and methods

2.1. Materials

Two types of concrete mixtures have been prepared, one of which with natural aggregates (crushed limestone) only and the other one by replacing 100% coarse natural aggregate with coarse recycled concrete aggregate. Morphology and grading curve of recycled aggregate are shown in Figs. 1 and 2, respectively. Basic properties of recycled aggregate and natural aggregate are given in Table 1. Cement (P·S 32.5), river sand (0–5 mm) and water are also used in this study. Mix design of concrete with or without recycled aggregate is illustrated in Table 2. The 28d compressive strength of the natural aggregate concrete (NAC) and RAC is 22.2 MPa and 28.2 MPa, respectively. Mechanical properties of steel reinforcement bars are shown in Table 3.

2.2. Design and construction of specimen

Two types of concrete beams have been manufactured, two NAC beams (NAC-1 and NAC-2) and two RAC beams (RAC-1 and RAC-2),

Table 1
Basic properties of coarse aggregate used in this study.

Coarse aggregate type	Size/mm	Crush index/%	Water absorption/%	Apparent density /(kg/m^3)	Fine powder content/%
Natural	10–25	3.5	0.6	2810	0.9
Recycled	10–25	16	4.21	2700	3.2

Table 2
Mix proportion of concrete/(kg/m^3).

Concrete type	Cement	Water	Sand	Crushed aggregate	W/C ratio
Natural	484	218	519	1103	0.45
Recycled	433	195	538	1143	0.45

Table 3
Mechanical properties of steel reinforcement bars.

Diameter/mm	Yield strength/MPa	Ultimate strength/MPa	Elongation/%	Elastic modulus/GPa
8 (stirrup)	298.1	385.2	30	210.9
10 (longitudinal)	455.3	541.8	8.5	200