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Seismic performance of recycled aggregate concrete–filled steel tube columns

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ABSTRACT

In this study, low cyclic loading tests were performed on nine seamless steel tube columns filled with recycled aggregate concrete (RAC) and two steel tube columns filled with normal concrete to analyse their seismic performance and damage mechanism. The hysteresis behaviour, skeleton curve, ductility coefficient, stiffness degradation, and energy dissipation capacity of the steel tube columns were studied. The influence of the axial compressive ratio, steel strength, and steel thickness on the seismic performance of the steel tube columns was discussed. In addition, the failure mode and damage mechanism of the specimens were investigated; a skeleton curve–fitting formulation based on the Boltzmann mathematical model was proposed. A damage degree–based model was built for representing the damage degree quantitatively. The results indicate that the RAC-filled steel tube columns exhibit a full hysteresis loop, the equivalent coefficient of viscosity ranges from 0.402 to 0.572, and the coefficient of energy dissipation ranges from 2.617 to 3.595. The comparisons between the two types of steel tube columns indicate that the seismic performances of the RAC-filled steel tube columns are similar to those of the corresponding normal concrete–filled steel tube columns and that the RAC-filled steel tube columns even have appreciably better lateral bearing capacity, better ductility, and slightly lower energy dissipation ability at the same displacement level. These results consistently indicate that desirable seismic performance is achieved, and they serve as a potential reference for the structural design and application of RAC components in seismic areas.

1. Introduction

To achieve energy savings and emission reduction, many solutions have been proposed, including the minimisation of environmental pollution from waste concrete and the reutilisation of waste concrete resources [1–3]. Recycled aggregate concrete (RAC) has been used to develop different types of columns; one of the newest types is the RAC-filled seamless steel tube column. In such a structure, the steel tube column confines the recycled concrete in the hoop direction, thereby enhancing the load capacity of the RAC; the core RAC prevents the early buckling of the steel column. This new composite structure combines the advantages of RAC and steel columns in an attempt to provide excellent mechanical and seismic performance, thereby offering great economic and social benefits in an energy efficient and environmentally benign manner. Hence, this structure holds great promise for commercial exploitation as well [4–6].

Studies conducted on RAC so far have mainly focused on the static loading of RAC components [7–10]. Studies on seismic performance and damage evaluation are generally undertaken by performing low cyclic loading tests using parameters such as the steel strength, thickness, and axial compressive ratio. The hysteresis behaviour, skeleton curve,

Table 1
Basic properties of coarse aggregate.

Aggregate	Size (mm)	Stacking density (kg/m^3)	Apparent density (kg/m^3)	Water absorption (%)
Ordinary	0– 10	1548	2894	0.67
Recycled	0– 10	1347	2543	4.71

Table 2
Material properties of steel tube.

Strength (MPa)	Diameter (mm)	Thickness (mm)	Ultimate strength (MPa)	Yield strength (MPa)
Q235	200	6	394	321
Q235	200	8	401	328
Q345	200	6	532	382
Q345	200	8	501	372

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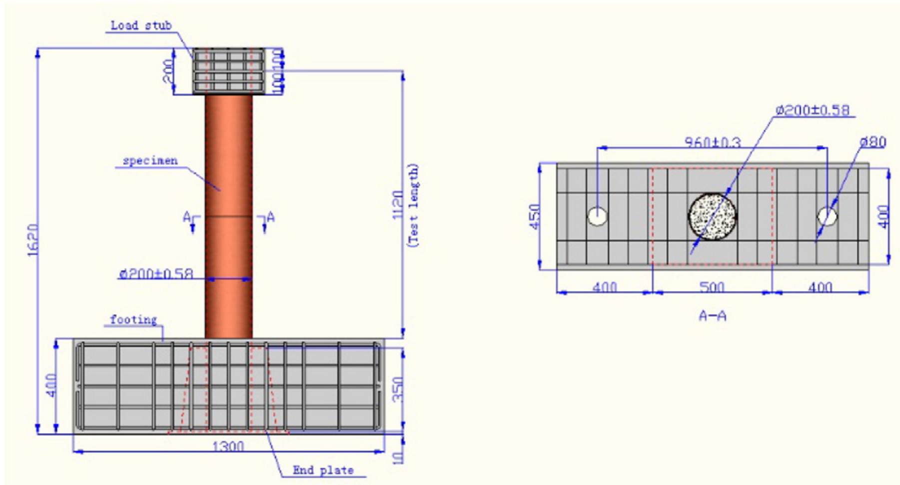
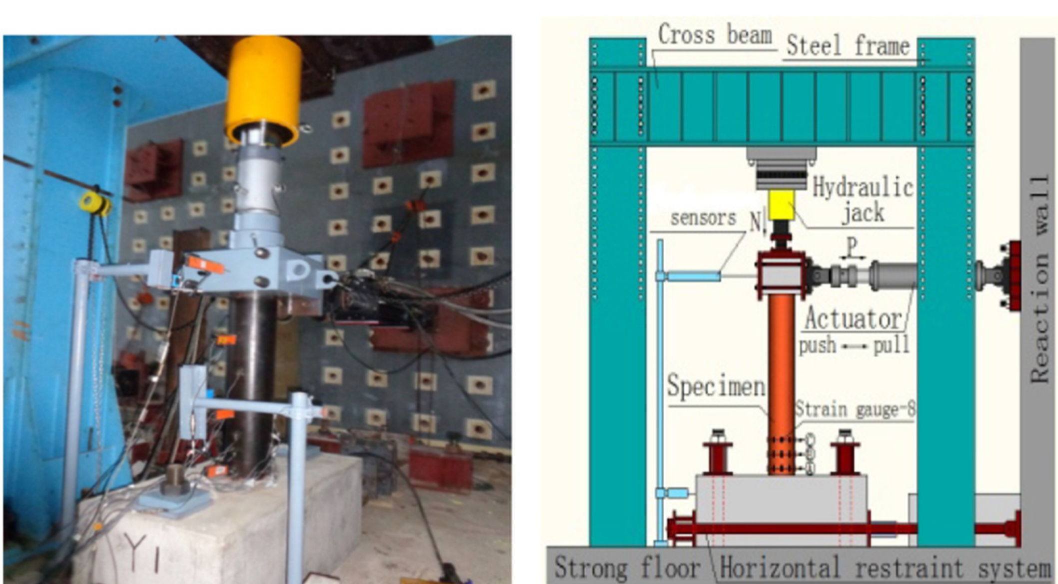


Fig. 1. Design of specimens (unit: mm).

ductility coefficient, stiffness degradation, and energy dissipation capacity of RAC columns have been investigated [11,12]. The new composite structure (RAC-filled steel tube column), which has desirable energy dissipation and deformation abilities [13–15], is suitable for application in areas requiring earthquake-resistant design [16]. The mechanical properties of a seamless column are superior to those of a welded column; for example, a welded column has lower ultimate loading capacity because of stress concentration. Therefore, it is worthwhile to conduct further studies on the mechanical properties of RAC-filled seamless steel tube column components. Quasi-static tests have been performed using RAC replacement percentages and RAC strength to construct a mathematical model for damage evaluation [17]. In contrast to the case of recycled concrete components, some investigations have been conducted on the damage evaluation of normal concrete components [18,19]; in addition, low cyclic loading tests have been performed based on the number of loading cycles and the confinement index, and a damage model of the concrete-filled steel tube column based on stiffness degradation and hysteretic energy dissipation has been developed. A skeleton curve–fitting model can predict changes in the strength and displacement of a column and reflect the influence of the

Table 3
Parameters of specimens.

Specimen	f_a (MPa)	$f_{cu,k}$ (MPa)	f_c (MPa)	θ	N_u (kN)	n	N (kN)
SL1	309	44.8	29.9	1.36	1893.1	0.2	378.6
SL2	309	44.8	29.9	1.36	1893.1	0.4	757.2
SL3	309	44.8	29.9	1.36	1893.1	0.6	1135.9
SH1	367	44.8	29.9	1.62	2086.5	0.2	417.3
SH2	367	44.8	29.9	1.62	2086.5	0.4	834.6
SH3	367	44.8	29.9	1.62	2086.5	0.6	1251.9
EL1	309	44.8	29.9	1.88	2181.8	0.2	436.4
EL2	309	44.8	29.9	1.88	2181.8	0.4	872.7
EL3	309	44.8	29.9	1.88	2181.8	0.6	1309.1
X	328	45.8	30.6	1.94	2281.4	0.4	912.5
Y	328	59.7	39.9	1.49	2542.5	0.4	1017.0



(a) Loading mechanism (b) Layout of displacement sensors

Fig. 2. Loading device.