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Strength and drift capacity of squat recycled concrete shear walls under cyclic loading

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ABSTRACT

In order to provide an improved understanding of the behavior of squat reinforced concrete shear walls and promote the application of recycled concrete in structures, six rectangular squat recycled concrete wall specimens were tested under in-plane cyclic loading. The specimens were designed based on Chinese code for design of concrete structures GB 50010-2010, which specified minimum horizontal and vertical reinforcement ratios of 0.25% in web, and vertical reinforcement ratio of 1.0% in boundary element. The main parameters investigated are axial load level and the amount of vertical and horizontal web reinforcement. This research presents the experimental results which include test observation, lateral load versus drift response, and measured strain distribution of vertical and horizontal reinforcement, measured strength and drift capacity of wall specimens. It was found that increasing of axial load level resulted in a higher peak load but less ultimate drift capacity, and increasing of horizontal web reinforcement had small effect on peak load but could improve the drift capacity. In this study, a mixed flexure and diagonal compression mechanism was proposed to reflect the lateral load resisting behavior of squat walls. Particularly, a simplified analytical method was developed to predict the peak loads of squat walls failed in flexure or a mixed flexural–diagonal compression mode, which was proved to accurately predict the peak loads of specimens.

1. Introduction

Recycled concrete is prepared by partially replacing the natural aggregate in mix proportion by recycled aggregate which is the product of construction and demolition concrete waste. It provides a sustainable way of both preserving natural aggregate and solving the pollution problem. At present in China, with the rapid development of construction industry, shortage of resources is becoming an urgent matter. At the same time, billion tons of construction waste is generated each year. The traditional disposal method of landfill or dumping will have fatal impact on environment, recycling and reuse of the huge amount of the construction waste becomes an inevitable choice and is attracting more research activities in the area.

Studies on the structural performance of using recycled concrete have been carried out in the past decade [1–4]. Letelier et al. [1] investigated the seismic behavior of recycled concrete beam–column joints under cyclic loading. Xiao et al. investigated the seismic behavior of plane frame under cyclic loading and conducted a shaking table test of a 1/4-scale recycled concrete frame [2]. Their testing results indicated that it was feasible to use recycled concrete in reinforced concrete structures. More recently, the flexural behavior of reinforced concrete beams that use recycled concrete aggregates were studied by Arezoumandi et al. [3]. They found out that recycled concrete aggregates beams have comparable ultimate flexural strength and approximately 13% higher deflection corresponding to the ultimate flexural strength of the conventional concrete. Although a large amount of experimental research has been conducted, additional studies should be performed to further the knowledge and use of recycled concrete in reinforced concrete building structures, especially laboratory testing on large-scale recycled concrete specimens. Previous study [4] carried out by the authors on the seismic behavior of full-scale recycled concrete columns indicated that recycled concrete specimens exhibited more brittle characteristic than normal concrete specimen. In order to meet the requirements of seismic design, it is suggested that the seismic behavior of recycled concrete members must be carefully studied.

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Squat reinforced concrete shear walls with a height h_w to length l_w ratio of less than 2 are commonly used in low-rise buildings because they show good performance in lateral load resistance and drift control. Since the 1950s, many research projects have been carried out in order to understand the behavior of squat reinforced concrete walls under monotonic or simulated earthquake loading. Some of them are shown in Refs. [5–15]. When shear walls are used in the lateral force resisting system, it is highly desirable that they are designed to exhibit a ductile behavior which means supplying sufficient shear strength to favor a flexural yielding [7,8]. However, for a squat wall, the behavior is dominated by a shear response or mixed modes of flexure and shear. Although a relatively large number of wall tests are reported in the literature [7], there is a significant uncertainty to predict the squat wall behavior. This is due to the following factors: wall specimens experienced different failure modes (flexure, shear and sliding shear) and the interaction between each failure mode was not well defined; different parameters (e.g., material strength, geometry of wall cross section, amount and distribution of reinforcement) were used which resulted in different formulas; and small-scale specimens used may not reflect the real behavior of full-scale walls. Consequently, the deign equations derived from the experimental data probably give least predictable behavior of squat walls [15].

Currently, there is still a lack of studies on the behavior of large-scale squat recycled concrete walls. In this study, six large-scale rectangular squat recycled concrete wall specimens with a height to length ratio of 0.89 were designed and tested under quasi-static cyclic loading. This research aimed at providing an improved understanding of squat recycled concrete shear walls and giving design suggestions. The principal research objectives are: (1) the lateral load-transferring mechanism and failure modes of squat recycled concrete shear walls; (2) the peak load and its prediction method; (3) drift capacity; (4) the effect of vertical and horizontal web reinforcement; and (5) the adequacy of current detailing requirements for design of recycled concrete walls.

2. Research significance

This study presents the experimental results of six large-scale squat recycled concrete shear walls under cyclic loading. It can be used as reference for engineering practice and development of design guidelines. Especially, the proposed mixed flexure and diagonal compression mechanism is quite suitable for explaining the lateral load resisting behavior of squat walls with boundary elements, and the simple analytical method for predicting the peak loads will be useful for the rational design of squat walls.

3. Experimental program

3.1. Specimen design

Six rectangular squat wall specimens were designed based on Chinese code for design of concrete structures GB 50010-2010 [16], as shown in Table 1. The main variables are axial load level, the amount of vertical and horizontal web reinforcement. All specimens have a length of 1800 mm and a height of 1600 mm (h_w/l_w = 0.89), and a thickness b_w of 180 mm. The height from wall base to the action point of lateral loading (H) is 1800 mm. The length of boundary element l_c is 360 mm, which is two times the thickness or 20% of the overall length of wall specimen. The details of specimens are illustrated in Fig. 1.

The boundary element of all specimens was vertically reinforced with six hot rolled ribbed bars D14 (diameter = 14 mm), constituting a longitudinal reinforcement ratio ρ of 1.4%; and transversely reinforced with hot rolled plain bars D10 (diameter = 10 mm) hoops and ties spaced at 75 mm (D10@75). The details in boundary element meet the requirements of Chinese code. Hot rolled plain bars D8 (diameter = 8 mm) spaced at 180 mm (D8@180) were used as the vertical web reinforcement of specimens RCSW-1 through RCSW-4, and hot rolled plain bars D10 spaced at 135 mm (D10@135) were used as the vertical web reinforcement of specimens RCSW-5 and RCSW-6, constituting vertical web reinforcement ratios ρ_v of 0.310% (minimum requirement 0.25%) and 0.646%, respectively. The horizontal web reinforcement ratio ρ_h varies from 0.186% to 0.873%. Specimens RCSW-1 through RCSW-6 were horizontally reinforced in web region by D10@100, D10@150, D10@150, D10@300, D8@150 and D8@300, respectively. In order to prevent a premature sliding shear failure at wall base, four hot rolled ribbed bars D14 with a length of 700 mm were added as dowel reinforcement for all specimens. The length of the dowel bars extended into the foundation and into the wall section was 400 mm and 300 mm, respectively. The axial load ratio of specimens RCSW-1, RCSW-3 and RCSW-4

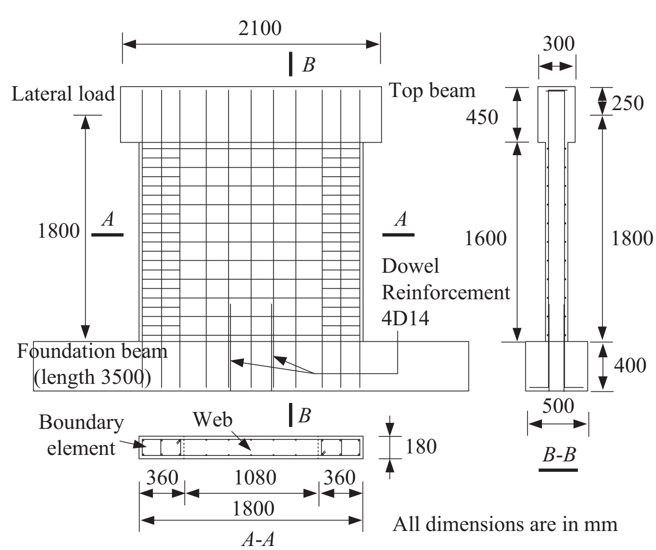

Fig. 1. Details of specimens.

Table 1
Parameters of specimens.

Specimen	h_w (mm)	l_w (mm)	l_c (mm)	b_w (mm)	f_{cu} (MPa)	f_c (MPa)	f_t (MPa)	ρ (%)	ρ_v (%)	ρ_h (%)	N (kN)	$N/(A_cf_c)$
RCSW-1	1600	1800	360	180	50.3	42.0	2.26	1.4	0.310	0.873	1792	0.13
RCSW-2	1600	1800	360	180	50.3	42.0	2.26	1.4	0.310	0.582	870	0.06
RCSW-3	1600	1800	360	180	51.9	43.2	2.16	1.4	0.310	0.582	1818	0.13
RCSW-4	1600	1800	360	180	51.0	42.5	2.16	1.4	0.310	0.291	1791	0.13
RCSW-5	1600	1800	360	180	53.4	44.0	2.16	1.4	0.646	0.372	–	–
RCSW-6	1600	1800	360	180	49.3	46.7	2.16	1.4	0.646	0.186	–	–

Note: f_{cu} = average compressive strength of three 150 mm cubs; f_c = average compressive strength of three 150 mm × 300 mm prisms; f_t = splitting tensile strength; N = axial load; $N/(A_cf_c)$ = axial load ratio; $A_c = l_wb_w$.