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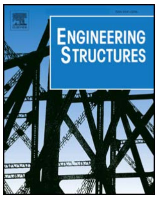

Hysteretic behaviour of steel fibre RC coupled shear walls under cyclic loads: Experimental study and modelling

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ABSTRACT

This paper presents the hysteretic behaviour of three 1/3-scale three-storey steel fibre reinforced concrete (SFRC) coupled shear walls (CSWs) under cyclic loads. The deformation, ductility, energy dissipation, stiffness and crack propagation of the specimens are also discussed and analysed. The results show steel fibre improves the ductility and energy dissipation capacity, and restrains the crack propagation of the CSWs, and delays the degradation of their lateral stiffness and force. Based on the experiments, a simple trilinear model is developed to simulate the skeleton curve of lateral force–displacement of the SFRC CSWs. Through analysing several typical cycles of the hysteretic of these CSWs, the feature points of the proposed hysteretic model are defined which subsequently is used to evaluate the complete hysteretic behaviour of the CSWs. Using existing experimental data and this study, several representative experimental hysteretic cycles are compared with the proposed model. The result indicates a good agreement is reached between the model and experimental results.

1. Introduction

Reinforced concrete (RC) coupled shear walls (CSWs) are widely applied in high-rise and multi-storey building systems to provide an effective resistance to horizontal loads such as wind or seismic effects. Fig. 1 shows the seismic effects and design method of RC coupled shear wall systems. With the demand of high-rise and multi-storey buildings, it is very significant and necessary to guarantee that this kind of support elements in building structures can effectively withstand earthquakes without collapses or unrepairable damages. In order to accomplish this goal, RC CSWs usually are designed to possess high lateral resistance strength, excellent deformation, high energy dissipation capacity and stable degradation of post-peak stiffness which all can provide a good control to the horizontal displacement or storey drift of the structures.

A number of experimental studies and numerical analyses have been conducted on RC CSWs in the past four decades [49,10,11,35,1,38]. Based on these studies, several basic design rules, calculation methods, and analytic models had been established. The studies also had mentioned one important fact that the behaviour of coupling systems (mainly coupling beam) greatly affects the structural behaviour of the RC CSWs subjected to seismic effects. These coupling elements usually connect two shear walls in series to transfer the vertical force to get better-distributed load and meet the deformation demands of the structures. This is different with the ones in cantilever shear wall, in which the stiffness, strength, ductility, and dissipating energy of the entire structural system are wholly contingent on the response of the plastic hinge region of the structures. Therefore, the behaviour of coupling beams is very important to the behaviour of CSW system for the elements can distribute effectively the external load effects, rather concentrate the effects on the plastic hinge region of shear walls. However, RC beams is expected to possess stable hysteretic response under reversed loads, a sufficient confinement of concrete in coupling beam and an anchorage of the reinforcements in shear walls should be provided. This often leads to the fact that the coupling beams are designed as a deep beam with heavy reinforcements increasing construction cost and cast inconvenience. In order to improve the resistance behaviour of coupling beams (CBs), many types of CBs have been proposed such as steel CBs [29,43,44,13], concrete-steel composite CBs [23,28], concrete filled tube CBs [30], partially post-tensioned CBs [4], fibre reinforced concrete CBs [12,45,9,58,8,3].

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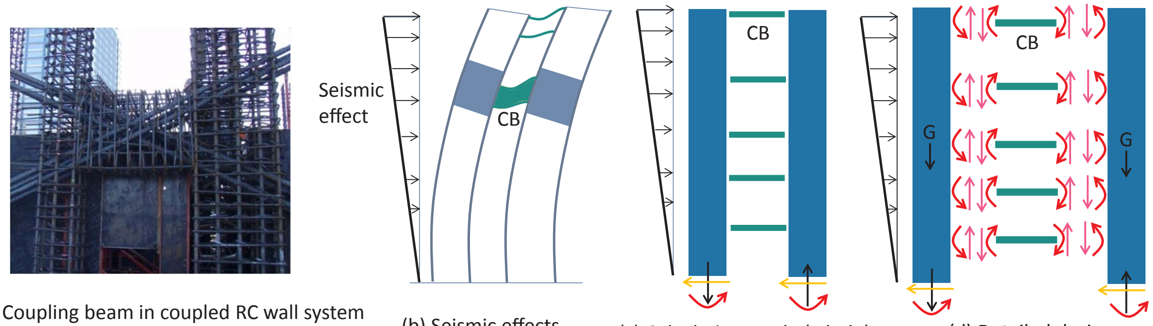
Nomenclature

Notations

E_cI_{eq}	equivalent stiffness, where E_c is elasticity modulus of concrete
I_w	moment of inertias of the entire cross-section of shear wall
A_w	area of cross section of wall without openings reported by CIS [17]
μ	calculation factor of the shape of cross-section taken as 1.2 for the rectangular section
A_{sw}, A_s	cross area of longitudinal steel rebars in the shear wall and edge columns
f_{yw}, f_y	yielding strength of longitudinal steel in the shear wall and edge columns
x, x_t	calculation height of compressive zone and tensile zone which is taken as $x_t = h_w$-1.25x
h_w, h_{wo}	height and effective height of cross section respectively
b_w, h_b, H	the width of the cross-section, and height of columns and a total height of shear walls
f_{ftb}	bending tensile strength of FRC, which can be calculated as $0.4f_{fts}$
f_{fc}, f_{fts}	compression strength, splitting tensile strength of FRC obtained from test or the model proposed by Han et al. [26]
Δ_y, Δ_u	yielding displacement ultimate displacement of the member when 85% V_{max}
δ_u, μ_{max}, μ_u	ultimate inter-storey drift ratio, the maximal and ultimate ductility of members
V_{max}, V_{imax}	the maximum strength of member and the one at ith cycle
Δ_{max}, Δ_{imax}, Δ_x	lateral displacement corresponding to V_{max} and V_{imax}, and the given x displacement
E_T, E_i, E_N	total, ith cycle and normalized dissipated energy of RC member
I_{wo}, I_E, ν_{eq}	total work and energy indexes, and equivalent viscous damping coefficient of the member
K_{int}, K_y, K_{max}, K_u	initial and yielding stiffnesses of the member; as well as lateral stiffness from yielding to maximum strength points, and the one after peak point
α_1, β_y	influencing factors for yielding strength and reduced stiffness
F_y, F_{max}, F_u, F_i	forces corresponding to yielding, maximum and ultimate displacements in envelop curve model; as well as the forces at i feature points of the skeleton curve model (i = 1–8)
M_u, M_{st}	maximum moment capacity of member, and the moment provided by transverse steel
M_{sl}, M_a, M_{FRC}	the moment provided by longitudinal steel, axial load action, and fibre reinforced concrete



(a) Coupling beam in coupled RC wall system (from https://theconstructor.org)

(b) Seismic effects

(c) Calculation mode (whole)

(d) Detailed design

Fig. 1. Coupled shear wall system: seismic effect and design.

To understand the basic behaviour of RC CSWs using conventional concrete under seismic loads, according to a short review of RC CSWs or RC CBs, several conclusions are drawn:

- The coupling beams in CSW systems have two main beneficial effects: (1) they can reduce the required moment of CSW system comparing with the one in two individual walls; (2) and they can effectively dissipate earthquake energy over the entire height of the walls [2].
- The three main types of the failure modes of ductile CSWs are: flexural failure of CB, shear failure of CB and rigid action of the CBs in the CSWs, depending on the degree of the interaction and resistance behaviour of the CBs in the system [53];
- The coupling beam at second floor of CSW structures usually yields first and stops resisting lateral deformation of the system;
- The use of diagonal reinforcements is an effective method to enhance the ductility and load resistance capacity of coupling beams. However, the addition of the reinforcement also brings new problems such as cast difficulty of concrete in beam-adjacent wall joint region;
- When CSW systems are subjected to large lateral deformation, most of the lateral force is resisted by the shear walls in the CSWs for the CBs have already undergone the effect of the inelastic deformation and usually failed at that moment;
- The applied axial load of CSWs has a significant influence on the lateral stiffness of the entire structure. Besides, in CSW system, the flexural deformation at the first floor is the highest and decreases along the height of CSW;
- The performance-based seismic designs have only begun to address in fibre reinforced concrete structural walls. Just limited experimental investigations focused on the seismic response and damage assessment of the CSW systems to support the development of numerical analysis method, especially large-scale experimental study;
- According to past experimental and survey studies, when RC CBs have a small shear span ratio, their shear failure usually results in that the entire CSW system works as two independent individual shear walls. This affects significantly the behaviour of the entire CSW system in subsequent seismic loads.

In addition, according to existing experimental studies [12,45,58,9,61], the use of steel fibre (SF) in RC CBs or RC shear walls improves the stiffness, ductility and energy dissipation capacity of these members and enhances their seismic and cracking resistance behaviours as well. However, these studies have just focused on the effect of steel fibre on individual RC coupling beams or cantilever shear walls such as the ones reported by our research group (e.g. [61,59]. Only a