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Shear capacity of steel fibre reinforced concrete coupling beams using conventional reinforcements

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ABSTRACT

The seismic performance of coupled shear wall systems is governed by the shear resistance of their coupling beams. Steel fibre reinforced concrete (SFRC) is widely applied in coupling beams for its positive contribution to their ductility. This study deals with the seismic behaviour of SFRC coupling beams using conventional reinforcements and develops a simplified model that applies the Mohr-coulomb failure criterion to predict the seismic shear strength of SFRC coupling beams. Variables studied include concrete compressive strength, fibre volume fraction and span-to-depth ratio. Results show that steel fibres improve the shear strength, deformation and energy dissipation capacity of the SFRC coupling beams. When fibre volume fraction is greater than 2.5% or span-to-depth ratio excesses 2.5, SFRC coupling beams present an excellent seismic performance and avoid effectively brittle shear failure. Using the Mohr-Coulomb failure criterion, a simplified shear model was proposed for SFRC coupling beams and presents a good accuracy and reliability. Furthermore, taking into account the negative effect of span-to-depth ratio, the proposed shear model was modified further. The comparative results demonstrated that the new shear model presents a more reasonable assessment accuracy and higher reliability.

1. Introduction

Reinforced concrete (RC) walls are widely applied in medium-rise RC building systems in order to resist effectively seismic effects due to their good stiffness properties and lateral resisting capacity. The presence of openings or other function requirements (*e.g.* windows and doors) in shear wall systems, however, results in the emergences of some special walls or connection elements such as slender wall and coupling beam (CB). They require structural designers to concern carefully for guarantying the seismic resistance of whole coupled RC (shear) wall system. Fig. 1 shows some simple schematics of the system including a RC wall, a coupled RC wall, CBs as well as their seismic response and design. During an earthquake, the primary purpose of CBs is to realize effectively shear transferring between two single RC shear walls. A well-designed coupled RC shear wall system generally presents a higher overall strength, better stiffness properties and energy dissipation capacity than the simple superposition of the individual walls [1]. In addition, coupling beams in coupled RC wall system are usually subjected to a higher cyclic shear reversal and a larger inelastic excursion [2] than the RC walls during an earthquake. Therefore, brittle shear failure, shear strength and deformation capacity are considered as the most critical concerns of RC coupling beams.

On the other hand, according to previous experimental investigations of coupling beams in 1970s (*e.g.* Luisoni et al. [3], Paulay et al. [4,5]) and an investigation report from American Iron and Steel Institute [6] focused on RC coupling beams with conventional horizontal distributed reinforcements, diagonally distributed reinforcement has been developed and used firstly for RC coupling beams (see Fig. 2). Subsequent experimental study [7] has verified further that this kind of RC coupling beams was able to resist higher shear loads and larger deformation as well as to dissipate more earthquake energy comparing with the ones using conventional reinforcements. As shown in Fig. 2, the utilization of diagonally reinforcements, however, brings a new problem of construction inconvenience due to the congestion of reinforcements in RC coupling beams. This disadvantage will be aggravated when coupling beams have a relative high depth-width ratio. In order to solve the problem, Chaallal et al. [8] experimentally investigated some high performance concrete coupling beams using steel fibres to replace partially the reinforcements of RC coupling beams. Their results illustrated that these fibre concrete coupling beams presented an equally distributed force situation and a higher energy dissipation capacity when compared with

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Nomenclature

f_c'	compression strength of concrete
l_n/d	span/depth ratio
V	shear strength of coupling beam
V_{cf}	shear provided by fibre reinforce concrete
V_{sd}	shear provided by diagonal reinforcements
V_s	shear provided by transverse reinforcements
b_w	the width of the coupling beam
d	the height of the coupling beam
A_{vd}	the cross-sectional area of one diagonal bar
f_y	yield strength of diagonal bars
f_{yt}	yield strength of transverse reinforcements
A_v	the cross-sectional area of shear rebars
S	spacing of transverse reinforcements
f_t	tensile strength of original concrete
λ_f	factors of steel fibre, calculated as $\rho_f l_f/d_f$
ρ_f	volume fraction of steel fibre
l_f/d_f	aspect ratio of steel fibre
h_0	effective height of coupling beam
τ	shear stress of cracked section of coupling beam
σ	normal stress of cracked section of coupling beam
c	the cohesion of materials
θ	the angle of internal friction
f'_{cfrc}	compression strength of SFRC
V_u	ultimate shear of coupling member in Fig. 4
V_c	concrete shear in compression zone in Fig. 4
V_s	shear force due to transverse steel in Fig. 4
d	overall depth of section in Fig. 4
τ_{cf}	shear stress along the diagonal plane in Fig. 4
σ_{cf}	normal stress perpendicular direction in Fig. 4
T	tension of longitudinal steel in Fig. 4
Fc	concrete force in compression zone
A, B	calculation factors
γ	compression-to-tension strengths ratio
V_{CB}	shear strength of SFRC coupling beam
η	affecting factor due to l_n/d
V_{SFCB}	modified shear strength of SFRC coupling beam

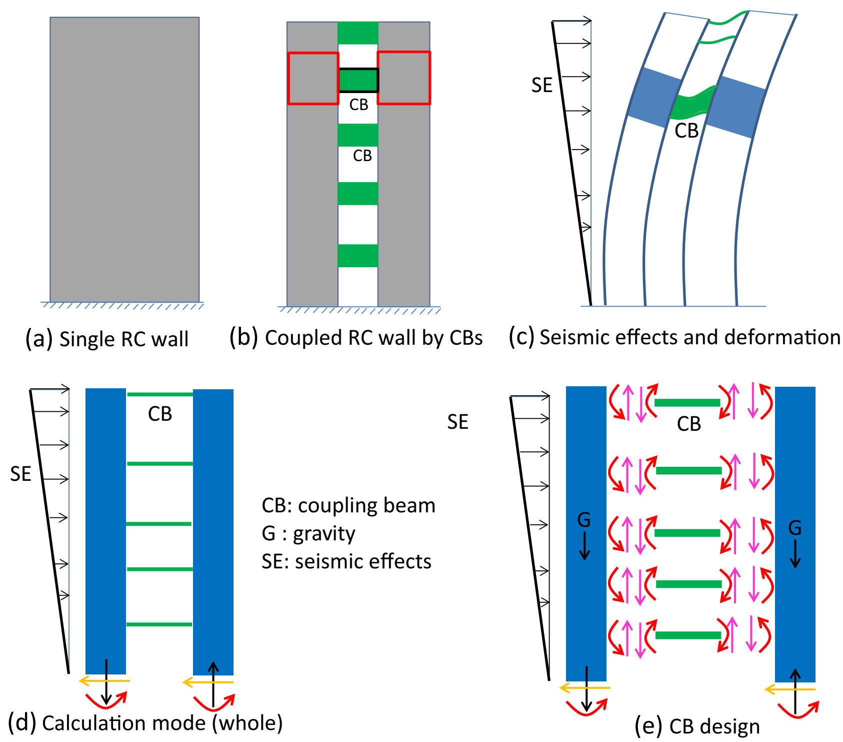

Fig. 1. RC wall, coupling beam and their seismic design.

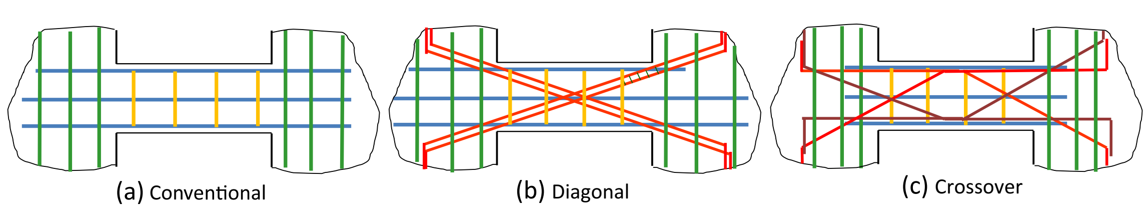

Fig. 2. Several arrangement examples of reinforcements in RC coupling beams.

conventional RC coupling beams. This was attributed to the fact that SFRC beam can resist a higher shear deformation and provide a better cracking resistance capacity than normal RC ones, which is same as the one reported by previous studies [*e.g.* 9]. Lequesne et al. [10] also reported that high performance fibre reinforced concrete (FRC) can reduce the required area of diagonal