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Optimizing the coupling ratio of seismic resistant HCW systems with shear links

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ABSTRACT

This paper investigates through nonlinear static and dynamic analyses the behaviour of a newly introduced steel and concrete hybrid coupled wall (HCW) system made by a single reinforced concrete (RC) wall coupled to steel columns by means of steel links, a structural solution of potential interest for seismic-resistant multi-storey buildings. The considered HCW is conceived as seismic resistant system where the RC wall and the steel columns remain undamaged while the seismic energy is dissipated by yielding concentrated in the steel links only. In order to achieve such a desired seismic behaviour, a proper design procedure must be adopted and validated. Accordingly, this study reviews a recently proposed design approach and presents some modifications to further improve the seismic behaviour of the considered HCW system. Case studies are designed using the proposed modified design method as well as its former version. Afterwards, the seismic behaviour of the considered case studies is analysed to identify the optimal degree of coupling between the RC wall and steel columns, also evaluating the influence of the building height and uniform or non-uniform distribution of shear links. The obtained results confirm the improvements of the modified design method proposed in this study and provide support for the selection of the design parameter that influences the most in the seismic behaviour of the innovative HCW system, i.e. the degree of coupling between RC wall and steel columns, controlled by the adopted steel links.

1. Introduction

Coupled walls are a very interesting solution for the design of seismic-resistant multi-storey buildings, starting from reinforced concrete (RC) walls coupled by RC beams [1–5] as shown in Fig. 1a to more recent steel and concrete hybrid coupled walls (HCWs) where coupling between RC walls is achieved through steel or steel-concrete composite beams [6–26], (Fig. 1b), which are often organized as structural fuses that can be substituted when damaged. To further improve the combination of the RC wall and steel elements, a new structural configuration for HCW systems (Fig. 1c) was recently proposed, developed and studied using numerical and experimental tools in the European research project INNO-HYCO (INNOvative HYbrid and COmposite steel-concrete structural solutions for building in seismic area [27]). This system consists of a RC shear wall coupled to steel side columns by means of steel links. The RC wall carries almost all the horizontal shear force while the overturning moments are partially resisted by an axial compression-tension couple developed by the two side steel columns rather than by the individual flexural action of the wall alone.

The HCW system performances are directly related to the strength and ductility of the links [28]. Well-designed links provide a suitable source of energy dissipation. The ability of a structure to deform inelastically without significant loss of strength generally improves the seismic response by limiting forces in the structural members, lengthening the effective period and providing hysteretic energy dissipation. According to previous researches [29–36], ductile yielding of members in shear prior to flexure represents an effective mechanism of energy dissipation in earthquake resistant structural systems, e.g. eccentrically braced frames. Shear links, i.e. links in which shear dominates the inelastic response, behave as a metallic hysteretic device (fuse) limiting the maximum lateral force that can be transmitted to the non-dissipative structural members and providing significant energy dissipation potential. Hjelmstad and Popov [30], as well as Kasai and Popov [31] demonstrated excellent efficiency regarding both strength and energy dissipation capacity of the shear links through both analytical and experimental studies of the hysteretic response. This particular idea of utilizing shear yielding members as energy dissipation devices gave inspiration to improved structural systems such as disposable knee braced frames by Balendra et al. [37], aluminium shear-links by Rai and Wallace [38], hybrid coupled walls

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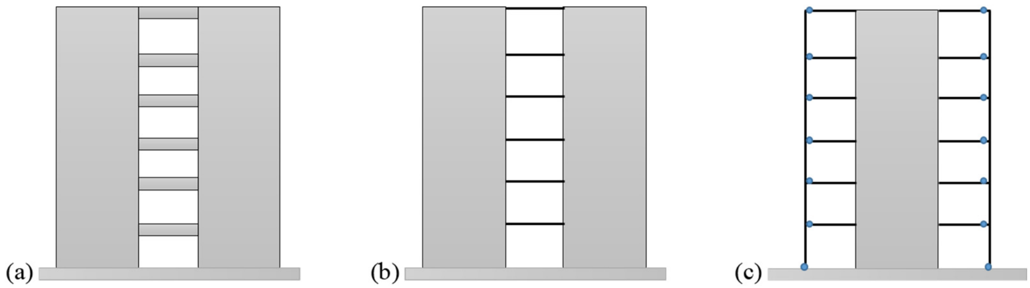

Fig. 1. Examples of: (a) conventional RC coupled shear wall system; (b) conventional hybrid coupled shear wall system; and (c) the proposed coupled wall system made by one wall coupled to two side columns.

by Harries et al. [39], and proposal for structural rehabilitation by Ghobarah and Elfath [40] as well as energy dissipation devices between the tower shafts by McDaniel et al. [41].

An important parameter characterizing the structural behaviour of coupled systems is the degree of coupling or coupling ratio (CR). For a conventional two-wall coupled system, CR is defined as the proportion of system overturning moment resisted by the coupling action [7],

$$CR = \frac{L\sum V_{\text{Beam}}}{L\sum V_{\text{Beam}} + \sum M_W} \tag{1}$$

where, $\sum V_{\text{Beam}}$ = accumulation of coupling beam shears acting on each wall pier; L = lever arm between the centroids of the wall piers; and $\sum M_w$ = total overturning moment resisted by the wall piers. Similarly, for INNO-HYCO HCW system considered in this study, the CR is defined as the ratio of the total overturning moment resisted by the two side columns (M_c) to the total overturning moment ($M_c + M_w$) as shown in Eq. (2).

$$CR = \frac{M_c}{M_c + M_W} \tag{2}$$

Table 1
Link category criteria based on link length as recommended by Eurocode 8.

Short (shear) links	Intermediate links	Long (flexural) links
$e < e_s = 0.8\frac{M_{p,link}}{V_{p,link}}$	$e_s < e < e_L$	$e > e_L = 1.5\frac{M_{p,link}}{V_{p,link}}$

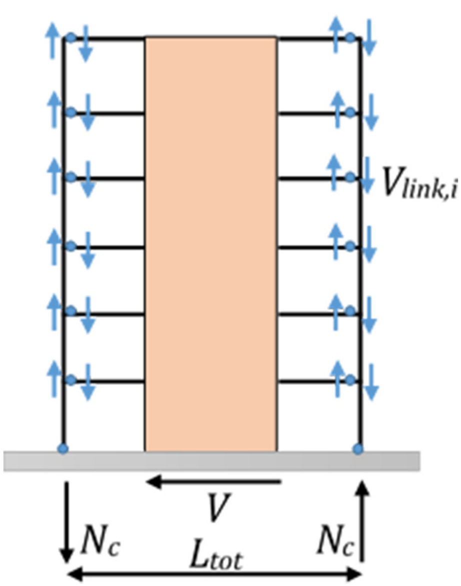

Fig. 2. Horizontal actions and relevant resisting forces (axial, and shear).

The coupling beams provide transfer of vertical forces between the RC wall and the side columns, which creates a coupling action that resists a portion of the total overturning moment induced by the seismic action. A significant number of investigations were carried out for understanding the influence and providing indications on the selection of CR in conventional RC and hybrid coupled systems, e.g. [42–48]. Coupling provided by the presence of a slab coupling two adjacent walls is very low and generally not considered in the design [42]. Harries [43] proposed a practical upper limit of 66% for the CR of HCWs, whereas El-Tawil and Kuenzli [8] recommended a CR range from 30 to 45% for an efficient design. Furthermore, Harries and McNeice [45], in a study on RC coupled walls, recommended "grouping" coupling beams and allowing for vertical redistribution of coupling beam forces (similar to the approach allowed in the Canadian A23.3 Concrete Design Standard) in order to minimize demands on the wall piers while continuing to provide coupling action consistent with the expected behaviour of the system. On the other hand, little information is available for the INNO-HYCO HCW system [28] and further research is indeed needed to provide more insight into the relation between adopted CR and attained seismic behaviour.

The objective of this research is to refine the currently available procedure for seismic design of INNO-HYCO HCW systems [28] by enforcing that the steel links are designed as shear critical links in order to improve the expected seismic behaviour. This goal is attained by integrating a mathematically derived relationship between flange thickness, web thickness, flange width, total depth of the link section and link length. The proposed design approach is verified by investigating through nonlinear static and dynamic analyses of the structural response of a number of case studies designed with varying CRs. Moreover, as very little information exists regarding an optimal range of CR for the INNO-HYCO HCWs, this present research also aims to search for an the most efficient CR with or without uniform link distribution, its lower and upper limit compatible with the adopted link distribution, as well as the influence of the building height.

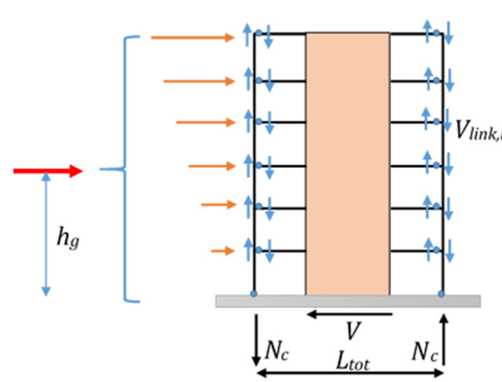

Fig. 3. Equilibrium of forces in the HCW system for the computation of the design base shear.