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Ductile design of innovative steel and concrete hybrid coupled walls

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ABSTRACT

An innovative hybrid coupled wall (HCW) system made of a single reinforced concrete (RC) wall coupled to two steel side columns by means of steel links is presented, its lateral load resisting mechanism illustrated, and a simple design procedure proposed. The design objective is to reduce or possibly avoid the damage in the RC wall while concentrating the seismic damage to the replaceable steel links intended to be the only dissipative components of the presented HCW system. In this way it is possible to obtain a seismic resistant system that can be easily repaired through the substitution of the yielded steel links. The proposed design procedure is applied to a case study considering various assumptions for the design parameters. The designed solutions are analysed through a nonlinear finite element model in order to evaluate the results of the design methodology and provide useful information on the ductility capacity under horizontal loads of the proposed innovative HCW system.

1. Introduction

Reinforced concrete (RC) walls are a classical solution for resisting seismic loads [1] even if they might suffer from degradation of their dissipative capacity and high replacement costs are faced when seismic damages are experienced. Coupled wall systems (Fig. 1a) were introduced to better exploit the stiffness and shear strength of RC walls. In coupled walls horizontal forces are resisted through a combination of flexural action of the walls and frame action between the coupling beams and the walls. The resulting stiffness and strength of the coupled system is greater than the summation of the contributions of the individual wall piers acting separately as uncoupled walls. Coupled shear wall systems made of RC walls connected by means of RC beams placed at the floor levels are the first examples of coupled wall systems studied in the past, e.g. [2–4]. The walls are subjected to bending, shear, and an alternation of tension and compression axial forces while the linking beams are subjected to bending and shear. Conventional RC coupled shear wall systems still suffer from being difficult to repair after seismic damages, even when damage is concentrated in the coupling beams. Steel coupling beams or steel–concrete composite coupling beams provide an attractive alternative, e.g. [5–9], thanks to their more stable hysteretic behaviour and easy repair if the connections between steel elements and RC wall facilitate link replacement. In order to farther improve the combination of the RC wall and steel elements, an innovative steel and concrete hybrid structural solution is presented here. The proposed hybrid coupled wall (HCW) system is made of a single RC wall coupled to two steel side columns by means of steel links (Fig. 1b). Pinned connections are used between the links and the side columns ensuring the transmission of shear force only while the connections of the links to the RC wall transfer both shear and bending moment. As a consequence, the side columns are subject to an alternation of compression and traction (with small bending moments due to the eccentricity of the link connections) while the RC wall is subjected to bending (with a small and constant amount of axial force deriving from permanent loads). The development of the presented HCW structural configuration was one of the outcomes of a larger study that involved innovative and improved hybrid steel and concrete systems investigated in the European research project INNO-HYCO (INNOvative HYbrid and COmposite steel–concrete structural solutions for building in a seismic area) [10].

When compared to conventional HCWs obtained from coupling two RC walls [9], the proposed innovative system brings the following benefits: the RC wall is subjected to bending only and this permits to more easily control and limit damage in the wall given that no additional alternate traction–compression forces are applied; a smaller horizontal dimension in the HCW plane can be achieved for the same coupling action thanks to the smaller size of the steel side columns with respect to the two RC walls of conventional systems; the mass is reduced due to the reduction of RC elements in favour of the increment of steel elements. On the other hand, possible critical issues in the proposed innovative HCW system are those related to the concentrated traction/compression forces induced in the foundations by the side columns as well as the attention required to stability verification when the side columns are compressed.

The proposed hybrid solution is effective as a seismic resistant component provided that the yielding of a large number of links is obtained while the RC wall is still undamaged. In this way such system permits

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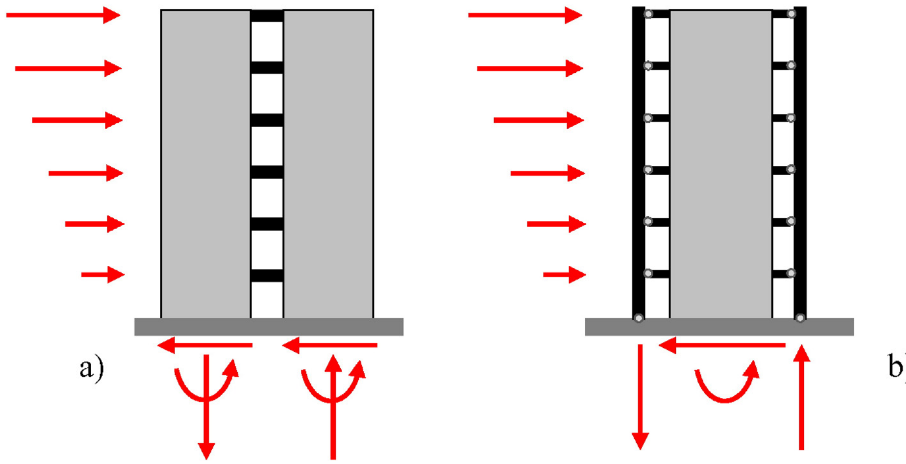

Fig. 1. Base reactions under horizontal loads in: (a) a conventional coupled wall system made by two coupled walls; and (b) the proposed coupled wall system made by one wall coupled to two side columns.

exploiting both the stiffness of the RC wall, necessary to limit building damage under low-intensity earthquakes, and the ductility of the steel elements, necessary to dissipate energy under medium- and high-intensity earthquakes. The damaged steel links can be replaced after a seismic event, provided that a suitable connection detailing is used, as those proposed and tested in the experimental campaign made during the INNO-HYCO research project [10,11] and illustrated in Fig. 2. Two solutions were considered for the link splice: a splice connection is placed at a distance from the RC wall sufficient to allow an easy bolting of the replaceable part (Fig. 2a); or, the splice connection is placed at the face of the RC wall with threaded bushings to allow replacement of the dissipative tract of the steel link (Fig. 2b). The design of the connection is made to enforce the creation of a plastic hinge in the replaceable part of the steel link acting as a fuse and give adequate over-strength (capacity design) to the fixed part of the link embedded in the shear wall, the link-to-wall connection and the bolted beam splice connection between the fixed and replaceable parts of the link. The connection between the steel link and the side steel column is made by a conventional web angle connection bolted to the column flange (Fig. 2). The structural details as well as the link replacement procedure were studied with the support of two construction companies (Shelter S.A., Greece, and OCAM s.r.l., Italy, partners of the INNO-HYCO research project) and further details can be found in the project final report [10]. It is remarked that the steel links do not contribute to sustain the vertical loads in the HCW system, thus, their replacement does not require temporary constraints and has no effect on the structure as long as there are no horizontal actions. For the same reason of ensuring link replaceability, floors should be connected to the RC walls only and any connections between the floors and the steel links must be excluded.

In this paper attention is focused on the resisting mechanism and relevant design procedure for the proposed innovative HCW system under horizontal loads. Specifically, the design indications developed for the attainment of the desired ductile behaviour, i.e. steel link yielding before damage in the RC wall, are discussed and applications illustrated in order to provide information on the structural behaviour of the proposed innovative HCW system and the influence of the most important design parameters.

2. Ductile design of the proposed HCW system

2.1. Resisting mechanism and coupling ratio

Horizontal loads in the proposed HCW system generate the forces and moments highlighted in Fig. 3. It is supposed that these horizontal loads are applied directly to the RC wall, i.e. floors of the gravity-resisting frame are connected to the RC wall only. In this situation the axial forces in the links are small and their effect can be neglected in the design. The summation of the shear forces $V_{link,i}$ ($i = 1, \ldots, n_{links}$) in the links gives the axial force N_c at the base of the side columns:

$$N_c = \sum_{i=1}^{n_{links}} V_{link,i} \tag{1}$$

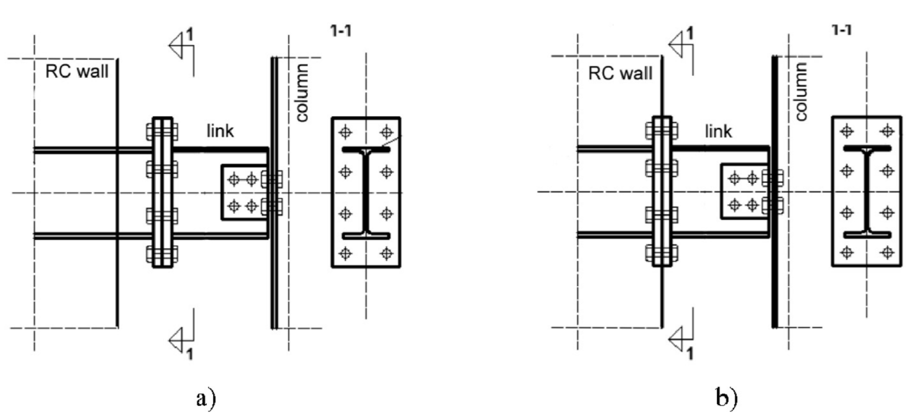

Fig. 2. Examples of connections to allow link replaceability: (a) splice connection with bolts; (b) splice connection with threaded bushings.