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An enhanced component based model for steel connection in a hybrid coupled shear wall structure: Development, calibration and experimental validation

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ABSTRACT

In the present paper the development, calibration and experimental validation of two component-based models of dissipative steel links connecting a reinforced concrete wall to a steel gravity frame is presented.

The dissipative capacity of such structures is greatly influenced by the effective hysteretic behavior of the wall-to-column coupling system. Within the present work, experimental tests results on two different configurations of wall-to-column coupling system are presented. The development and calibration of two non-linear cyclic component-based models, one for each configuration, are described, allowing a better understanding of the force transmission mechanisms and their influence on the global structural behavior.

1. Introduction

During the last decades, numerous researches were carried out aiming at developing structural solutions capable to withstand the seismic lateral loads, assuring the life safety in case of strong intensity earthquakes and minimizing the damages to structural and non structural elements in case of low-to-mid earthquakes. The scientific community, in fact, understood that, besides the need to assure the safety of the building and of its occupants, related mostly to the structural behavior under strong earthquakes, the seismic risk, and so the economic loss, is deeply related to the behavior of the building under moderate earthquake. A recent proof was given from the Emilia (Italy) May 2012 earthquakes that, further to all the damages and losses of human life caused by the collapse of buildings located close to the epicenters, were characterized by huge economic indirect losses. The damages on the industrial buildings located on one of the most industrialized Italian region and the need of speed up their recovery pushed the Italian Government to issue special laws [1,2] and the scientific community to develop suitable tools [3,4] for the applications of these new-generation laws.

On the basis of previous considerations, several structural typologies, materials and innovative devices were studied, with particular attention to the ones capable to guarantee good ductile behavior allowing the design of lighter and more competitive structures [5–9].

Among all the possible solutions, concrete shear wall structure are characterized by high horizontal strength and stiffness allowing the control of horizontal displacements and storey drifts. The ductility of such structures is strongly dependent on rotational capacity of plastic hinges usually located at the base of the shear walls. In order to assure a ductile behavior, brittle mechanisms (for example concrete crushing caused by shear in boundary elements or in diagonal strut and tie elements, instability of thin walled sections or buckling of reinforcing bars under compression) should be avoided. Moreover, due to the predominant stiffness of the concrete wall compared to the one of the other structural elements (usually concrete frames), a very high ratio of the seismic force is absorbed by the shear wall itself so transmitting high localized force to the foundation.

In order to overcome aforementioned problems Coupled Shear Walls systems (CSW) were deeply studied by several authors in the past [10–12]. The functioning principle of CSW is schematized in Fig. 1: the presence of the coupling beams allows the formation of vertical forces, acting at foundation level, lowering the intensity of the bending moments on the walls' base.

The entity of vertical forces and, by consequence, of the bending moment acting at foundation level of each wall depends on the

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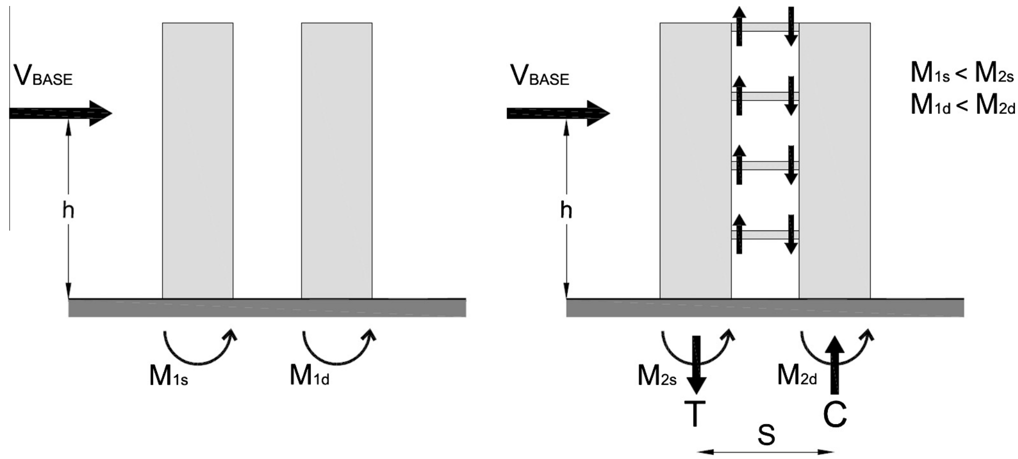

Fig. 1. Comparison between two isolated walls (left) and coupled walls (right).

walls coupling ratio, CR, function of the stiffness of the beams with respect to the one of the walls and generally evaluated as:

$$CR = \frac{T \cdot S}{M_{2s} + M_{2d} + (T \cdot S)} \quad (1)$$

with reference to symbols introduced in Fig. 1.

The major drawbacks in using reinforced concrete beams for the coupling of shear walls stem from the brittle behavior of the concrete. In fact, high level of detailing is needed in order to assure a stable hysteretic behavior of the concrete beams under cyclic reverse loading, including confinement of the concrete and sufficient anchorage of steel reinforcement in the connected walls [13]. In order to solve such problems, steel connecting beams can be used and the resulting structure can be addressed as a Hybrid Coupled Shear Wall (HCSW) system. In HCSW, the steel coupling beams can dissipate energy by yielding under either bending or shear forces, similarly to the eccentrically braced systems. Providing a sufficiently long embedment length to steel connecting beams, if enough vertical reinforcing steel is assured in the wall boundary element to prevent excessive cracking, special reinforcing details, such as bars welded to the beam flanges or passing through them, are not more required [14]. Embedment length can be reduced and the strength and stiffness of the connection can be increased if the embedded element is provided with shear studs and some additional reinforcing details [15,16]. HCSW solution, however, requires necessarily the presence of at least two concrete walls, reducing greatly its field of application due to possible architectural limitations or requirements.

A recent research, carried out in the framework of the European project INNO-HYCO (INNOvative HYbrid and Composite steel-concrete structural solutions for building in seismic area) [17], funded by the Research Fund for Coal and Steel (RFCS), proposed an innovative typology of HCSW extending basic principles of CSW and HCSW. The new solution was obtained by coupling a r.c. shear wall with two steel side column by means of steel links where the energy dissipation can take place, while the gravity loads are carried by a steel pendular structure, see Fig. 2. Several advantages can be so obtained, such as the possibility of foreseeing the presence of just one r.c. shear wall and an easier repair in case of damages to the dissipative elements.

It is straightforward that, in the case of design of a dissipative structure, the dissipative capacity of the steel coupling beams is a fundamental design parameter and, consequently, great attention should be given to the geometrical and mechanical characteristics of the embedded elements, of the dissipative ones and of their connection with the steel side columns.

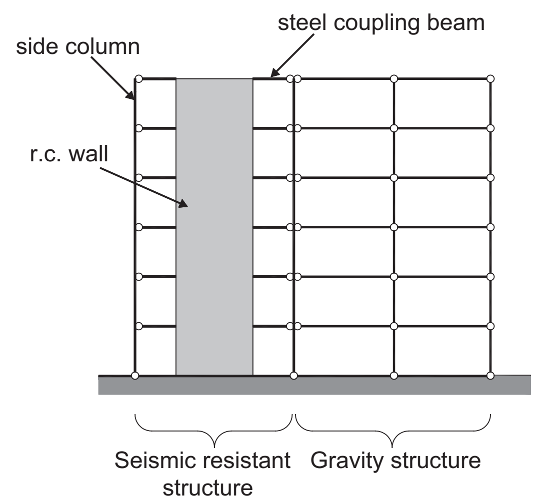

Fig. 2. Structural scheme of the innovative hybrid coupled shear wall system.

To these purposes, in the present study, the real hysteretic behavior of the elements connecting the r.c. wall to the side steel columns were investigated, developing an accurate mechanical model.

The general methodology schematically shown in Fig. 3 was followed. Referring to the HCSW case study designed within the INNO-HYCO project, an experimental campaign was carried out on sub-systems representing the wall-to-column dissipative connection and executing both monotonic and cyclic tests, with constant and increasing amplitude. To fully understand and represent the cyclic behavior of the coupling system, a component based model was then fully developed and calibrated on experimental results, as already successfully done in past researches such as [18–21] among others.

2. Innovative hybrid coupled shear wall systems

The innovative HCSW system, extensively described in [22,23] and shown in Fig. 2, is composed by an earthquake resistant structure realized by a reinforced concrete wall linked in correspondence of each side to steel columns by steel coupling beams. The HCSW system is connected to a steel hinged-frame in such a way that the HCSW system absorbs horizontal actions while gravity frame only withstands gravity loads. The overturning moment