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Experimental analysis of beam-to-column joints equipped with sprayed aluminium friction dampers

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ABSTRACT

In this paper, the results of an experimental analysis regarding beam-to-column joints equipped with friction dampers are presented. Even though the overall concept is not new, the connection structural detail and the friction pad material are different from previous proposals. In particular, the beam is connected to the column with a classical fixed T-stub fastening the upper flange and a friction damper located at the beam lower flange. The friction damper is composed of a stack of steel plates conceived to assure symmetrical friction. The friction pads are made of steel plates coated with thermally sprayed aluminium. The friction damper is designed in order to slide for a force level equal to or lower than the ratio between the nominal flexural resistance of the connected beam and the lever arm, i.e. the distance between the top T-stub and the friction damper. In this way, it is possible to obtain connections able to dissipate the seismic input energy almost without any damage to the steel elements, provided that all the joint components are designed with sufficient over-strength with respect to the actions corresponding to the friction damper sliding force. In this paper, such approach is validated reporting the results of an experimental campaign.

1. Introduction

The design of modern seismic resistant structures is based on a preliminary selection of the zones which have to be designed to assure the dissipation of the earthquake input energy. Dealing with Moment Resisting Frames (MRFs), the location of such dissipative zones at the beam ends is commonly preferred by adopting full-strength beam-to-column joints [1,2] which have to be designed with sufficient over-strength with respect to the connected beams. The required over-strength is aimed to assure the beam end yielding despite of the influence of random material variability [3,4] and the amount of strain-hardening occurring before the complete development of the ultimate flexural resistance of plastic hinges [5,6].

To date, the classical design philosophy based on weak beam-strong column-strong joint hierarchy has been widely applied in practical seismic design and surely provides some advantages, such as the development of stable hysteresis loops [7–10] and the prevention of soft-storey mechanisms which have to be avoided because of their poor energy dissipation capacity [11]. However, some drawbacks occur within the framework of the traditional design approach. On one hand, the use of full-strength beam-to-column joints with the code required over-strength can lead to the detailing of expensive structural connections which require the use of continuity plates, supplementary column web plates, reinforcing ribs or cover plates or, even, the use of haunched beams. On the other hand, also the overall frame design is costly, because of the column over-strength required to fulfil the strength hierarchy criteria, particularly in the case of long span beams, whose size is governed by gravity loads [12–15].

In order to overcome the drawbacks related to the use of full-strength beam-to-column joints, the use of partial-strength connections has been suggested and Eurocode 8 [1] has opened the door to their use provided that their plastic rotation capacity is properly demonstrated. Such design approach can be faced within the framework of the component approach [15–18]. The fastening elements of the beam-to-column joints have to be properly designed by selecting the weakest joint component, acting as dissipative component, and providing all the other joint components with sufficient over-strength. Moreover, the weakest joint component has to be designed to assure a ductile behaviour and the required plastic deformation capacity [19].

In last decades the application of partial strength joints to MRFs has been proposed and supported by a high number of research programs, both theoretical and experimental, devoted to characterise the behaviour of connections under monotonic [20–22] and cyclic loading conditions [23–27]. Nevertheless, even though the effort provided by the scientific community has been significant, there are still some issues which deserve further investigation, such as the codification of design criteria for dissipative joints or the development of new types of

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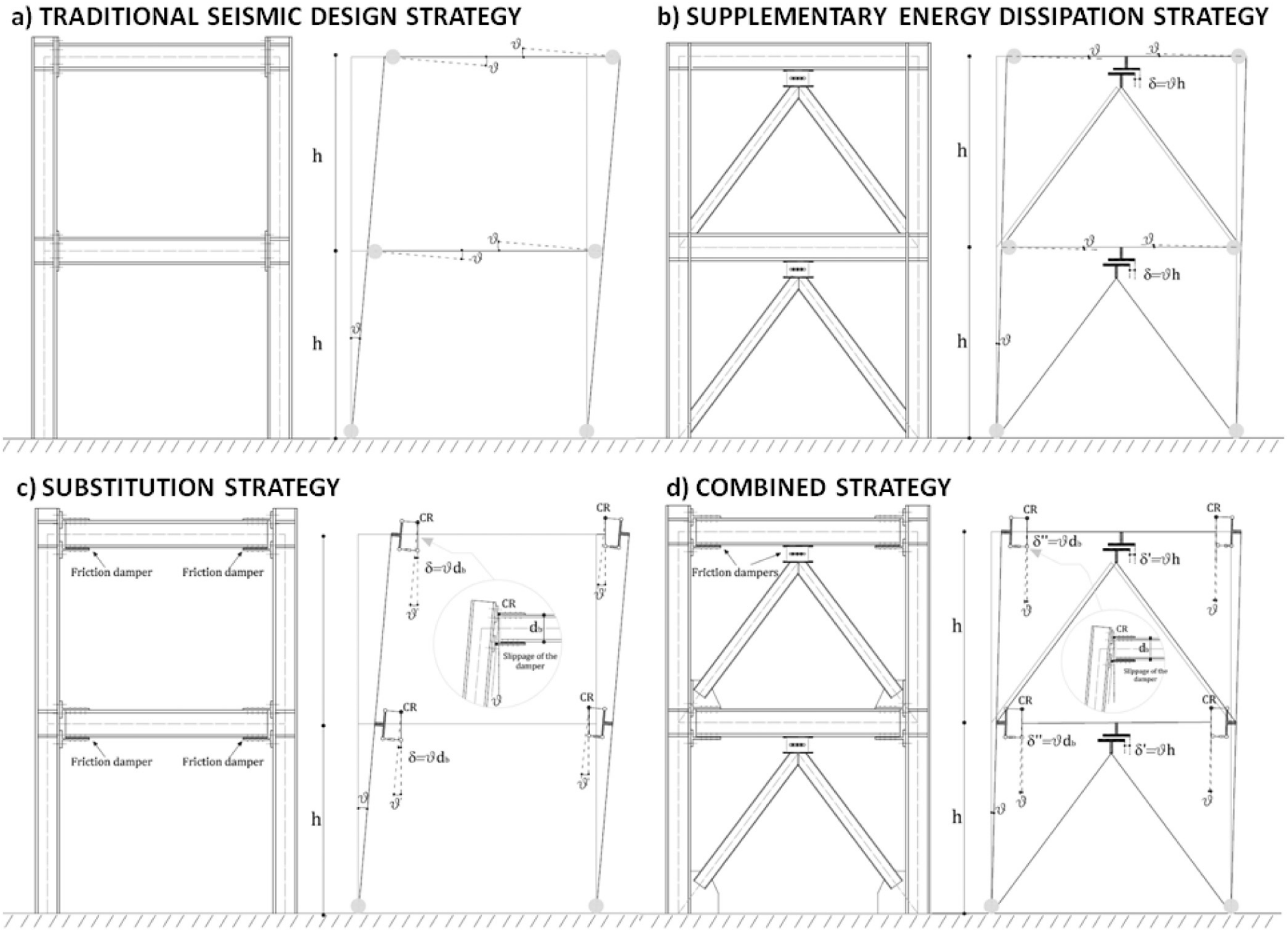
dissipative connections easy to replace or not requiring replacement after a severe seismic event [28–32].

However, independently of the use of either full-strength or partial-strength beam-to-column joints, the main drawback of the traditional seismic resistant design strategy is intrinsic in the strategy itself. In fact, on one hand the structural damage is essential to dissipate the earthquake input energy but, on the other hand, it is the main source of direct and indirect losses. For this reason, many researchers have focused their attention on the strategy of supplementary energy dissipation with the aim to reduce the structural damage under destructive seismic events and, as a consequence, the direct and indirect losses. This strategy is based on the use of energy dissipation devices which have to be inserted between couples of points of the structural scheme where high relative displacements or velocities occur under the action of severe ground motions [33–36]. Such displacements or velocities are expected to activate specifically designed passive energy dissipation systems based on simple mechanisms such as hysteresis, friction or viscosity of fluids.

Starting from the background briefly summarized above, in order to overcome the drawback of the traditional design approaches, research efforts have been recently devoted to the practical development of a new design strategy whose goal is the design of connections able to withstand almost without any damage not only frequent and occasional seismic events, but also destructive earthquakes such as those corresponding to rare and very rare events.

The concept behind this research is inspired to the strategy of supplementary energy dissipation, but it is based on the use of damping devices under a new perspective. In fact, while passive control strategies have been commonly based on the integration of the energy dissipation capacity of the primary structure by means of a supplementary dissipation coming from damping devices; conversely, the new design strategy is based on the use of friction dampers conceived in such a way to substitute the traditional dissipative zones of MRFs, i.e. the beam ends. To this scope, beam-to-column connections can be equipped with friction dampers which can be located either at the level of the two flanges [37–39] or at the bottom flange level only [40–42]. Also the beam web to column flange connection can be equipped with friction dampers. Moreover, symmetrical [39,43] or asymmetrical friction devices can be exploited [35,38].

In order to well clarify the aim of the work, its framework and the differences with either traditional seismic design or supplementary energy dissipation strategy, the different schemes are analysed in Fig. 1. In particular, Fig. 1a points out that dissipative zones of traditional MRFs are located at the beam ends where plastic hinges have to be developed. The seismic demand is usually expressed in terms of maximum interstorey drift (ϑ in the figure) which governs the plastic rotation expected in dissipative zones. The supplementary energy dissipation strategy (Fig. 1b) is aimed to the reduction of the seismic demand by introducing seismic dampers which have to be located, for their effectiveness, between couple of points subjected to high relative displacements. The supplementary energy dissipation provided by such devices allows the reduction of the drift ϑ and, as a consequence, the reduction of the structural damage occurring at the beam ends. Conversely, the substitution strategy (Fig. 1c) allows the prevention of the structural


a) TRADITIONAL SEISMIC DESIGN STRATEGY

b) SUPPLEMENTARY ENERGY DISSIPATION STRATEGY

c) SUBSTITUTION STRATEGY

d) COMBINED STRATEGY

Fig. 1. Comparison between different design strategies.