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Removable friction dampers for low-damage steel beam-to-column joints

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ABSTRACT

Beam-to-column joints equipped with friction dampers are promising solutions to improve the performance of steel moment resisting frames due to the possibility to guarantee large dissipation capacity limiting the structural damage under severe seismic conditions. In this paper, the experimental tests and the numerical simulations of two types of joints are shown and discussed with the aim of developing pre-qualified configurations. The friction dampers are designed to be easily removable from both the lower beam flange and the column face by means of bolted connections. The devices are composed of a stack of steel plates conceived to assure symmetrical friction. The friction surface is set in vertical direction in first case and in horizontal direction in the second type. The experimental tests confirmed the effectiveness of both examined joints and the finite element analyses allowed characterizing their local response, thus providing additional insights to improve the design requirements.

1. Introduction

The design criteria currently implemented by seismic codes are based on the philosophy of hierarchy of resistances, which aims to guarantee overall ductile and dissipative behavior by enforcing the plastic deformation, namely the damage, into specific ductile zones of the structure. However, economic and social reasons have recently pushed researchers and designers towards systems that can resist severe ground motions with low or without structural damage [1].

Traditional seismic resisting systems widely adopted for steel buildings (e.g. moment resisting frames, concentrically and eccentrically braced frames) entail a dissipation mechanism based on plastic deformations of several structural elements, which may correspond large repairing costs in the aftermath of a seismic event. Therefore, the idea of low or free from damage structures has become very appealing in the last decades [2–4].

The use of friction connections is a viable and promising strategy to achieve this objective for steel structures [5–24]. In the framework of Eurocodes, this type of connections can be classified as partial strength according to EN1993:1-8 [25] because their design resistance should be lower than the strength of the connected members to prevent any damage into the primary structural members. EN1998-1 [26] allows the use of partial strength connections provided that their rotation capacity is properly demonstrated. In the case of conventional partial strength joints the ductility can be designed by imposing local hierarchy rules among the components constituting the joints [27–31] and verified by means of pre-qualification tests [32–34].

Moment resisting friction connections are conceived to develop the dissipation mechanism by means of the relative slip into ad-hoc devices located between the lower beam flange and the outer cap plate connected to the column flange, while the upper flange of the beam is connected to a plate either bolted or welded to the column. The cover plate connecting the upper beam flange may be subjected to some moderate plastic bending deformations to accommodate the joint rotation following the sliding of the device, thus enforcing the formation of an ideal center of rotation that prevents the damage of the slab. To increase the moment capacity, friction devices can be also adopted for the beam web. In addition, the resistance of the joint can be modulated keeping the same assembly but varying the friction resistance that changes with the clamping force used for the bolts. Indeed, the friction device is composed of a stack of steel plates that are clamped together by means of tightened high strength bolts, which are inserted in the slotted holes of the plates to allow the relative sliding.

The non-linear response of these connections depends on the type of friction mechanism, which can be either asymmetric or symmetric. The asymmetric friction connection (AFC) has been thoroughly investigated [7–10] and even successfully implemented in recent practice [1]. However, the bolts that clamp the friction pad of AFCs can experience yielding due to large bending moment, shear and axial force interaction, which can induce clamping loss of the bolts and consequently

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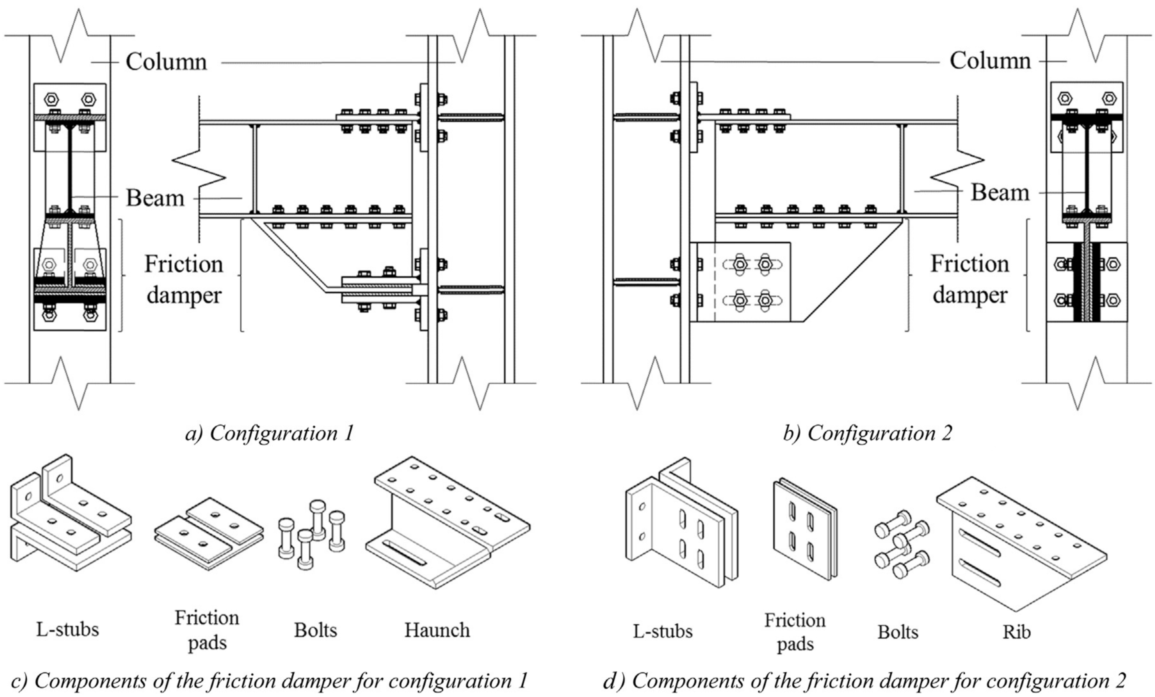

Fig. 1. Typologies and features of the investigated joint configurations.

pinching and loss of strength of the connections. On the contrary, these phenomena can be mitigated with the use of a symmetric friction connection (SFC) [16–22].

Latour et al. [23] recently carried out an experimental study on SFCs with the friction damper applied by means of an additional haunch welded to the lower flange of the beam. The friction pad was located at the interface between the haunch and L-stubs that are connected to the column flange. It was composed by an 8 mm S275JR steel plate (steel hardness 211HBW, sand blasted surface) coated with a thin layer of sprayed aluminum to improve the friction resistance with low cost of the raw material, as also shown by [35]. The tests showed that this solution is very effective, because the allowable flexural strength of the connection at column face is greater than the plastic resistance of the connected beam. Hence, full-strength connections can be also obtained without requiring any damage to the beam. In addition, the use of a haunch increases the stiffness of the connection, since its internal lever arm is larger than the beam cross section depth, thus obtaining rigid connections prior the sliding of the device. These features are very important from design point of view, because the structural models adopted for the seismic analysis do not need to account for the deformability of the joints.

It is also worth noting that the geometry of these connections is similar with a split tee connection with the particularity of the friction pads needed in order to ensure specific friction properties. The resistance of the connection is dictated by the friction damper but, once the design resistance is established, the design of such connection can be carried out entirely according to EC3 Part 1–8 [25]. In addition, the constructional costs for such connection are marginally different compared to traditional steel bolted connections. The economic advantages of the MRFs equipped with friction connections include also the limited extent of the damage that is localized at the level of the joint components, this further simplifying the rehabilitation work in the earthquake aftermath [15,16].

However, after severe seismic events the friction pad should be substituted, and the surface of the haunch should be treated to restore its initial roughness and to remove the residual portions of the friction layer scraped out the pad. These types of interventions can arise some operational difficulties especially concerning the tightening of the bolts that clamp the friction device. Indeed, as shown by [21,23] it is crucial to control and guarantee the level of bolt pre-loading to ensure the design value of friction resistance. Indeed, if the clamping force is excessively large, the corresponding strength of the connection can be larger than the resistance of the adjacent members. On the contrary, lower preloading may either anticipate the sliding of the connections under serviceability non-seismic loading or weaken the global structural capacity under the design earthquake that may induce disproportionate rotation demand of the connections.

A viable solution to solve these issues can be the use of removable friction dampers that can be easily detached from both the lower beam flange and the column face by means of bolted connections, thus simplifying the reparability of the friction device. Indeed, if the whole friction damper is conceived as a demountable kit containing both the friction pad and the relevant steel supports, this option allows tightening the bolts in the shop with the reliable control of the applied torque. In addition, the friction kit can be entirely substituted in the aftermath of severe earthquake without the need to perform superficial treatments of the beam flange on site.

These considerations motivated the research activity presented in this paper, which was devoted at developing two types of connections with detachable friction dampers. To achieve this objective both experimental cyclic tests and finite element simulations have been carried out. The paper is organized in three main parts as follows: i) the design criteria of the proposed joints are presented in the first part; ii) the experimental campaign is described in the second part; iii) the finite element simulations and the characterization of the local response of the joints are discussed in the third part.

2. Design criteria of joints

2.1. Features of the investigated joints with removable friction dampers

The examined joints are characterized by double split-T connections, where the bottom tee element is replaced by detachable friction dampers, as depicted in Fig. 1. The main mechanical difference of the two investigated types of devices is the direction of the friction plan that is horizontal in the case of bolted haunch (hereinafter also