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Cyclic response of low yielding connections using different friction materials

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ABSTRACT

The experimental activity presented in this work intends to study in detail the cyclic behaviour of a set of three different friction shims preliminary selected in a previous experimental work regarding the behaviour of friction dampers of Sliding Hinge Joints (SHJs). These connections are able to dissipate seismic energy by means of friction through a proper application of capacity design principles. Their bending resistance is proportional to the slip resistance of a friction device which is usually installed at the bottom beam flange and can be governed controlling only two parameters: the friction coefficient and the clamping force of the high strength bolts.

The main goal of the experimental campaign presented is to investigate the dependence of the friction coefficient on some of possible significant parameters. In particular, the 51 tests presented are devoted to evaluate the response of the interfaces taking into account the effect of the bolts preloading, the effect of the type of washers and the influence of the random material variability. In detail, the tests have been carried out with four different configurations of washers (with flat washers and disk springs), considering a possible range of values of the clamping forces (between 40% and 100% of the standard proof preload). The results of the experimental activity are reported in the paper proposing a possible definition of the values of the friction coefficients to be used in design and regression analyses of the experimental data of the slip tests to be used in simplified rigid-plastic modelling for seismic analyses.

1. Introduction

The introduction of performance levels in seismic zone is nowadays a common principle shared by national and international codes. Following this approach structures are designed to remain elastic in case of ordinary load combinations (Serviceability Limit States-SLS), while in case of rare load combinations, such as those deriving from the occurrence of destructive seismic events, the damage of the structure is permitted (Ultimate Limit States-ULS). Specifically, concerning the design of steel Moment Resisting Frames (MRFs), the codified rules usually require an adequate lateral stiffness to minimize damage of the non-structural elements and suggest to dissipate the seismic energy (in case of rare events) in specific zones that must be able to sustain cyclic inelastic demands [1,2]. In particular, for the ULS design EC8 [1] proposes two alternative possibilities: *i)* the plastic zones can be located at the beam ends adopting full-strength joints and over-strength columns *(continuous frames)*; *ii)* the damage can be concentrated in the joints which have to be detailed to have a sufficient rotational capacity to satisfy a minimum local ductility demand of 35 mrad *(semi-continuous frames)* [3–8].

Although these strategies are successful in providing frames with a proper behaviour [9–18,49] they present, anyway, noteworthy shortcomings. In fact, although the damage is essential to dissipate the seismic input energy, at same time, this damage is a significant source of economic loss. In order to solve this issue in past years several strategies have been proposed. One of the solutions suggested during the 90s is represented by the application of supplemental energy dissipation systems. With this approach the demand on the structural elements is reduced, increasing the viscous or hysteretic damping by means of dissipaters [19,20]. Nevertheless, also in this case, even though the inelastic demand on the framing is reduced through the introduction of the dampers, this is not completely avoided because displacements of the structure are still required to activate the dissipaters.

Starting from this background, aiming to overcome the shortcomings of these design strategies, recently, low damage philosophies have been introduced [21–23,40–47]. In this recent approach, in order to minimize the structural damage, friction dampers are installed in

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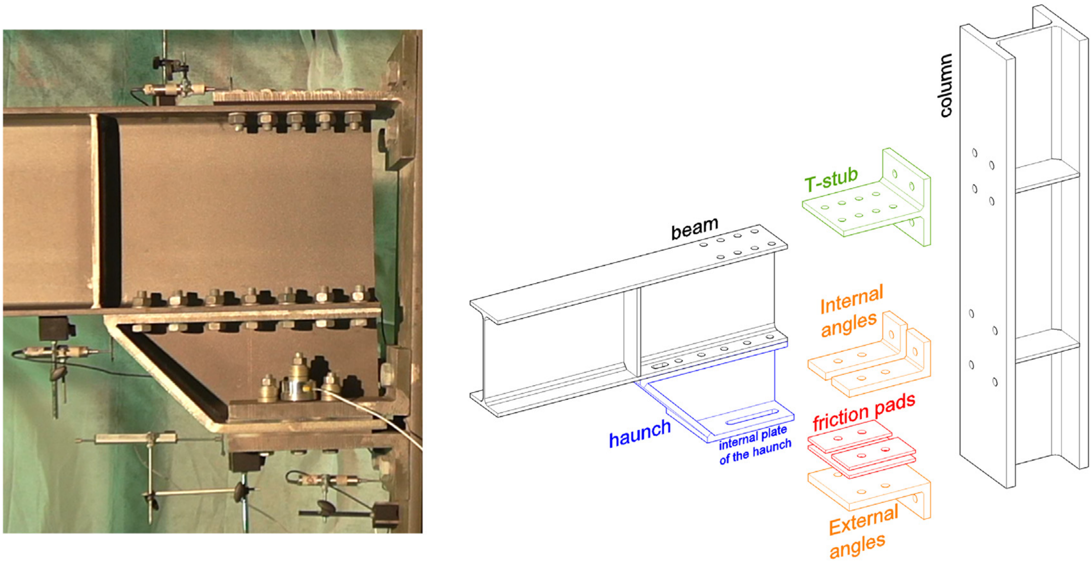

Fig. 1. Typical layout of a bolted connection with friction dampers.

beam-to-column connections substituting completely the traditional dissipative zones. From a technological point of view, the idea is to equip beam-to-column connections with friction dampers (realized with steel plates and friction pads pre-stressed with high strength bolts) located at the beam bottom flange. The typical layout of a low yielding friction joint (originally called Sliding Hinge Joint-SHJ [23]) is constituted by an upper Tee which acts as a pin concentrating the energy dissipation in the lower part of the connection where it is installed an Asymmetric or Symmetric Friction Connection (AFC or SFC) [24–27]. The damper is typically realized with steel plates, friction pads and high strength bolts. In particular, the typical layout which is under study in a recent proposal of the same authors is realized with a slotted haunch slipping on friction shims pre-stressed with high strength bolts (Fig. 1) [28–30].

In these joints, the bending moment transferred to the column is simply controlled by calibrating the slippage force of the friction damper, which is the result of the friction coefficient arising between friction pads and steel composing the internal plate of the haunch [22,31] or the bottom flange plate [23], and the clamping force of the bolts. Therefore, in order to predict the slip resistance of the connection an accurate knowledge of the clamping force and of the friction coefficient are normally required.

In general, the clamping force can be easily controlled applying one of the tightening procedures proposed by EN1090-2 [32] (i.e. combined, torque, DTI washers) achieving a 95% reliability [33,34]. Conversely, the friction coefficient of the interface is a parameter much more difficult to predict because of its dependence on several microscopic and macroscopic factors. In the past, many researchers have already investigated the behaviour of several interfaces examining the influence of influential parameters, such as the shims micro and macro hardness, the velocity of application of the loadings, the influence of the superficial finishing, the shear resistance of the materials and their roughness [31,35]. Nevertheless, the optimization of the friction interface is still an open issue which deserves further investigations. In principle, the optimal friction interface should be characterized by a high value of the friction coefficient, low cyclic degradation, repeatability and low randomness. To this scope, recently a research program has been undertaken at the University of Salerno investigating the behaviour of a large set of friction materials in order to individuate those more promising for application in friction joints. These analyses have allowed to individuate three possible materials on which further experimental tests have been carried out.

In this paper, the results of this second set of analyses are reported, while the first results regarding the larger set of materials are given in [35]. The main aim of this further experimental work is to characterize the friction coefficient investigating the influence of some of the most significant parameters. In particular, the influence of the bolt preloading level, the influence of the washers typology and the random variability of the friction coefficient are analysed. The experimental programme has regarded fifty-one specimens, tested at the STRENGTH laboratory (STRuctural ENGineering Testing Hall) of the University of Salerno, following the guidelines provided by EN 1090-2 [32] and EN 15129 (anti-seismic devices) [36]. The tests have been carried out considering variable values of the pre-loading (between 40% and 100% of the proof pre-loading value) and different typologies of washers (standard and disk spring washers). In particular, the influence of different configurations of disk springs has been examined in order to understand their effect over the loss of clamping force.

The main results of the experimental activity are given, reporting the friction coefficient values and evaluating the degradation of the bolt forces. Thirty of the fifty-one tests were realized to determine the random variability of the friction coefficient of the analysed interfaces providing a proposal for the values of the friction coefficient to be used in design for ULS and SLS.

2. Test layout

The test layout is composed by simple lap shear connections reproducing elementary friction dampers. These specimens are used to test the uni-axial behaviour of friction interfaces resulting from the coupling of a stainless-steel plate with friction shims coated with three different materials, whose main properties have already been described in [36], and are herein referred conventionally with the labels M1, M4 and M6. In total, fifty-one tests were carried out, as already said, to analyse the influence of the bolt preloading level, of the washers typology and of the random variation of the friction coefficient. In particular, four tests for each material were devoted to assess the influence of the bolt preloading, varying the tightening torque of the assembly from 40% to 100% of the proof preload suggested by EN 1090-2 [32] (Table 1).

Other four tests for each material were carried out to analyse the influence of the disk springs configuration, considering in one case the standardised pre-loadable bolt assembly and in other three cases the possibility to install in the assembly various arrangements of springs with the same resistance but different deformability. Disk springs are washers that can be arranged in different ways in order to achieve a