Influence of Dissipative Joints on the Behaviour of Steel MRFs: FREEDAM vs Equal-Strength Bolted Joints

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Abstract. Modern practice and codes provide design rules of moment resisting frames (MRFs) based on the assumption that the dissipative zone is the end of the beams, which implies assuming full-strength joints. The recent EQUALJOINTS Research Project demonstrated the advantages of using equal-strength joints in MRFs in seismic areas. Further beneficial aspects can be attained when replacing the plastic deformation mechanism with a friction-based energy dissipation mechanism, as highlighted within FREEDAM Research Project, where friction connection have been developed and qualified. The current paper presents the comparison between the response of MRFs alternatively equipped with equal-strength joints and friction connections.

1. Introduction

The modern seismic design of steel structures [1-18] focuses on the capacity-based principle, which fundamentally allows the plastic deformation of specially designed areas of the frame members, preserving the integrity of the remaining elements. Following the recommended guidelines, the safety requirements under design seismic events are met; however, in the earthquake aftermath, the repair costs can be large.

In the case of steel moment resisting frames (MRFs) it is expected to have plastic deformations in the beams while the joints are generally designed to be full strength, which imply costly solutions. The recent RFCS EQUALJOINTS project showed that equal-strength joints can be effective in seismic areas. The test results showed that, when the component design is properly addressed, and sufficient ductility is guaranteed, equal strength joints exhibit good behavior, being also cheaper than full strength joints [19-21].

Friction connections can be viable alternative to traditional steel joints. Friction connections dissipate the seismic input by means of relative displacement of surfaces held in contact by preloaded bolts [22-30]. The connection typology presented by [25, 26] is characterized by very stable cyclic behavior and ductility while localizing the damage in easily replaceable elements of the connection.

The fundamental difference between the traditional MRFs and the MRFs equipped with friction devices (FD-MRFs) is the dissipative element i.e. the beam or joint for the former, while the friction connection (or damper) for the latter. The initial steps are naturally identical with the design of traditional moment resisting frames, as the friction devices do not bring substantial alterations to the MRFs. However, the seismic design requirements differ consistently, especially due to the special application of the capacity design rules. Within the framework of the FREEDAM Research project, a modified design methodology of the MRFs equipped with friction devices has been proposed based on the EC8 recommendations [3].
The current work presents the main characteristics, design and response of two frame models: (i) frames equipped with the more traditional equal-strength bolted extended stiffened end-plate connection and (ii) frames equipped with friction devices.

2. Features of the considered joints

Equal-strength joints are designed to guarantee simultaneous yielding of both connection and beam (see figure 1a). The design resistance of this joint typology is assumed equal to the plastic resistance of the beam. The adopted connection is a bolted extended stiffened end-plate. The design of equal-strength joints can be done according to the Component method implemented in EN1993 Part 1-8. However, a complete design methodology is reported in [11].

![Figure 1. Joint geometrical configuration and main components.](image)

The friction connections transfer the seismic energy input by means of relative sliding at the level of surfaces held together by means of preloaded bolts. Figure 1b presents the geometry and the components of the connection. The beam is connected to the column at the top by means of bolted T-stub and the bottom flange is connected to the rib. The rib is the mobile part hence, it is detailed with horizontal slotted holes while the friction pads and L-stubs have vertical slotted holes, in order to allow for the kinematics of the connection. The rib, friction pads and L-stubs are clamped together by means of high-strength bolts, and the whole assembly is connected to the column by the L-stubs’ flanges.

![Figure 2. Details of the case study frames.](image)

3. Case study

The geometry of the frames selected for the case study is depicted in figure 2a. The structures were designed assuming S355 steel members. The permanent and live loads considered for design were chosen within a practical range (4.5 kN/m² and 2 kN/m² respectively). A High seismic Hazard (HH) level was considered for the design with PGA equal to 0.35g, assuming a Type 1 response spectrum
and soil conditions Type C. The maximum behavior factor \( q = 6.5 \) was adopted for the design spectrum. The second order (P - \( \Delta \)) effects as well as the accidental torsional effects are accounted for in the design. The interstorey drift for serviceability conditions was limited to 0.01\( \text{storey} \). Global and local ductility requirements according to EN 1998-1 were checked. Both static and dynamic nonlinear analyses were performed in Seismostruct. Four structures were designed and analyzed, varying the number of MRF bays (3 and 5) and the span length (6 and 8m). The investigated structures are identified by a code: MRF-number of storeys-number of bays- and span length, therefore for instance the MRF-6-5-8 is a structure with 6 floors and 5 moment-resisting bays with a length of 8m.

Both Eurocode 8 compliant and the models of the FREEDAM frames were detailed with rotational springs at the column face (see figure 2b and c). These elements were used to model the bending capacity of the equal-strength joint and the friction device, respectively. The response of the traditional equal-strength joint was modelled based on the experimental tests performed within the EQUALJoints RFCS Research Project using a smooth model, while the bending resistance of the rotational spring for the FREEDAM joints was defined as given by equation (1).

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M_{j,Rd,FD} = m \cdot M_{pl,b}
\]

Where \( m \) is the utilization factor of the FREEDAM devices necessary for the obtained frame members and \( M_{pl,b} \) is the bending plastic capacity of the connected beam. From the stiffness point of view, the joints were assumed as full rigid.

4. Results

The seismic design of the two types of structural configurations led to similar member sizes, obvious from Figure 3a, which depicts the frame structural weight. The results show slightly lighter EC8-FD frames in some cases (due to the lower overstrength coefficient for the design of non-ductile elements) but the serviceability check (interstorey drift ratios) was generally governing the design, which resulted in similar solutions for the two design situations.

Figure 3b and c show that the frames equipped with equal-strength joints (EC8-EqStr) are severely overdesigned. In terms of redundancy (Figure 3d), both frame sets are in the same range, with better values for the EC8-FD, due to the sequential activation of the friction joints and the reduced degradation. Finally, as depicted in Figure 3e, it can be concluded that designing frames in which the resistance and the stiffness are uncoupled (like the frames equipped with friction joints) more reasonable results are obtained compared to traditional solutions even if optimized.

![Results obtained from static pushover analyses.](image-url)
5. Conclusions
The design methodology currently implemented in EC8 leads to largely overdesigned moment resisting frames, even when equal-strength joints are used, with the main culprits being the severe deformability and global stability checks. Structural solutions that have disconnected strength and stiffness, like the frames equipped with friction joints, lead to optimized structures that have sufficient redundancy, without being severely overdesigned. Moreover, the benefits in terms of repair costs are expected to be significantly lower given the low-damage solution.

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