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Experimental investigation of slitted web steel moment resisting frame

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ABSTRACT

This paper presents the results of three tests to evaluate cyclic behavior of Special Moment Resisting Frames (SMRF) with Slitted web section (SW-MRF). Typically, in SMRFs energy is dissipated by formation of plastic hinges at the beam ends. Nevertheless, based on the recent seismic codes, the span-to-depth ratio of beams in SMRFs should be larger than a minimum value to assure the development of plastic hinges with sufficient length at beam ends, reducing application of short span beams. In this paper, a new approach is proposed for short and medium span beams to transmit the flexural plastic hinges from the beam ends to the beam center by slitting a portion of the beam web at the mid-span and formation of a shear link. The idea can be applied for design of new buildings and for the purpose of rehabilitation in the damaged SMRFs. Two single-bay one-story SW-MRFs are constructed and tested under the quasi-static cyclic loading. One test was conducted on a new frame and the other test on an already flexurally damaged frame. This paper describes the specimen design, construction, experimental setup and results of the test. The test results are compared with the corresponding MRF specimen with a similar geometry and material properties. The results indicate that the proposed idea provides a stiff and ductile system via stable hysteretic loops, which makes it a suitable option for the design of new buildings and retrofit of damaged moment resisting frames.

1. Introduction

This paper presents the results of a set of tests on an innovative steel moment resisting frame with shear fuse, namely, slitted web moment resisting frame (SW-MRF). Based on the capacity design, energy dissipation is provided from development of plastic hinges at the beam ends [1]. One of the limitations of moment resisting frames, imposed by the seismic codes, is the minimum span-to-depth ratio to satisfy the formation of flexural hinges with sufficient length. Based on the seismic codes the minimum span-to-depth ratio for special and intermediate moment resisting frames is seven and five, respectively [2]. This paper aims at resolving this limitation for moment resisting frames by a shear fuse, replacing flexural hinges at the beam ends to nonlinear shear behavior at the mid-span of the beam.

Steel moment resisting frames are one of the most desirable load resisting systems for several reasons. Due to the high architectural flexibility, usually more architectural spacing is created using moment resisting frame in the building. Steel moment resisting frames are known as a highly ductile system and thus the largest force reduction factor is assigned to this type of system based on the codes [3,4]. Due to the inherent lateral flexibility of moment resisting frames, compared to other seismic resisting systems, moment frames usually require larger member sizes. This is mostly caused because of the control of the structural drift. In other words, stiffness and strength are interrelated and stronger members are generally stiffer [5]. Prior to the Northridge earthquake, steel moment resisting frames were among the first and safest choices for control of lateral loads in the buildings. The Northridge earthquake caused extensive damages to the moment resisting frames and this trust was broken [6]. Therefore, changes in the design of MRFs and reliable connections seemed to be necessary [7,8]. In this earthquake, brittle failure was the most observed damage at the welded beam-to-column connections of typical MRFs. This earthquake also highlighted the importance of connections in MRFs [9,10]. Several solutions to the connection of moment frames were suggested shortly after the Northridge Earthquake. Most of them can be summarized in two categories: first, weakening the beam at the beam-to-column face and second, strengthening the beam-to-column connections. The main purpose was to move the location of plastic hinges far from the face of the column. One efficient way for weakening the beam is to cut the beam flanges where the formation of plastic hinges is desirable [11,12]. Some recent studies improved the seismic performance of the reduced beam section (RBS) connection, such as the web weakening instead of flange trimming and implementation of the double reduced beam section [13–15]. For strengthening the connection, some strategies have been proposed such as using cover plates, flange

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ribs and haunches [16,17]. Using bolted end-plate connection is another method to enhance the connection strength and to move the plastic hinge location farther from the column face [18,19]. For the purpose of concentrating damage to a preselected region in moment resisting frames, many studies have been conducted [20–22]. Ricles et al. constructed posttensioned connections using high strength strands for application in beam-to-column connections [20]. Lin et al. showed that steel sliding-controlled coupled beam eliminates residual drift and resolves the incompatible deformation [22]. Other limitations of the moment resisting frames are hardly rehabilitation and costly repair. Some studies have developed replaceable structural fuse components to diminish the downtime of moment resisting frames [23–26], eccentrically braced frame [27], linked column frame [28], coupled concrete shear wall [29] after earthquakes.

All the above mentioned studies have tried to develop a stable cyclic behavior for moment resisting frames with a distributed plastification. On the other hand, as mentioned, to avoid the plastification on a limited portion of the beam, code specifies a minimum span-to-depth ratio of seven for special moment resisting frames. The criterion of the minimum span-to-depth ratio limits application of moment resisting frames and in particular, limits the application of tubular frames in high rise buildings where the outer frames are usually accompanied with beams with the span-to-depth ratio of 3–4 [30]. In this paper a shear link is proposed to transfer the plastic region from the beam ends to the middle of the beam especially for the application in the short-span frames. The paper presents the design procedure, test setup, test observations and the test results for three tested specimens.

2. Design concept

Fig. 1 shows two moment resisting frames with identical column height and beam depth. The beam cross section is also identical in these two frames. The span-to-depth (L/D) ratio in Fig. 1(a) and (b) is seven and four, respectively. As mentioned, the minimum L/D ratio in special moment resisting frames should be at least seven according to AISC341-10; thus, the frame in Fig. 1(b) violates the minimum L/D criterion of the code. The shear and moment diagram and the associated plastic hinge of two frames under the lateral loading (F) are presented in this figure. As shown, the slope of the moment diagram in the short span beam (Fig. 1(b)) is much sharper than that of the long span beam. Thus, plastic hinge length (colored area in Fig. 1) is shorter in the short span beam that triggers more cumulative plastic strain. This increases the fracture probability of the beam in short span frames.

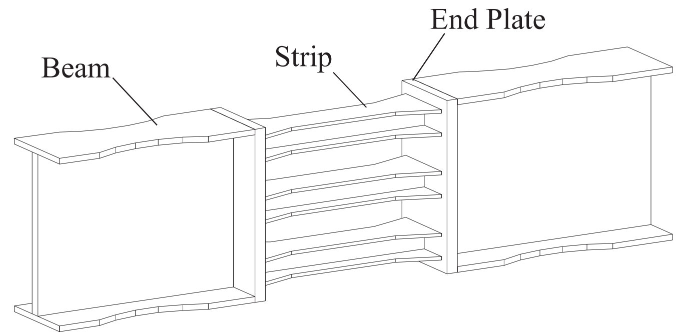

Fig. 2. Proposed shear link.

Another reason that the code specifies a minimum L/D ratio is lack of experimental data on cyclic behavior of short span beams. In many cases, to control the drift limit of the buildings it is inevitable to use deep beams leading to short L/D ratios. This paper proposes a shear link, shown in Fig. 2, to be used in moment resisting frames with short L/D ratio to overcome all the mentioned limitations. The link transfers the plastic hinges from the beam ends to the middle of the beam, where the shear link is placed. The link is composed of small beams (strips) that each strip follows the seismic criteria such as minimum L/D. According to Fig. 1 the moment at the mid-span is zero and placement of the link does not change the stiffness of the frame. Thus, the strength of the frame can be changed without altering the global stiffness of the system.

Another benefit of the proposed link is that it can be used as a rehabilitation method for already damaged moment frames. In cases that the residual drift of the building after the earthquake is negligible, the link can be replaced at the middle of the beam to protect the damaged flexural hinges from more plastic rotation in subsequent earthquake events. This will be more discussed in section "Specimen Construction".

In this paper the results of three cyclic tests are presented. The tests are composed of a MRF with L/D = 4, a SW-MRF with the same geometry as of the MRF. The last test, rehabilitated SW-MRF, was conducted on the damaged MRF specimen of the first test that was rehabilitated using the proposed link.

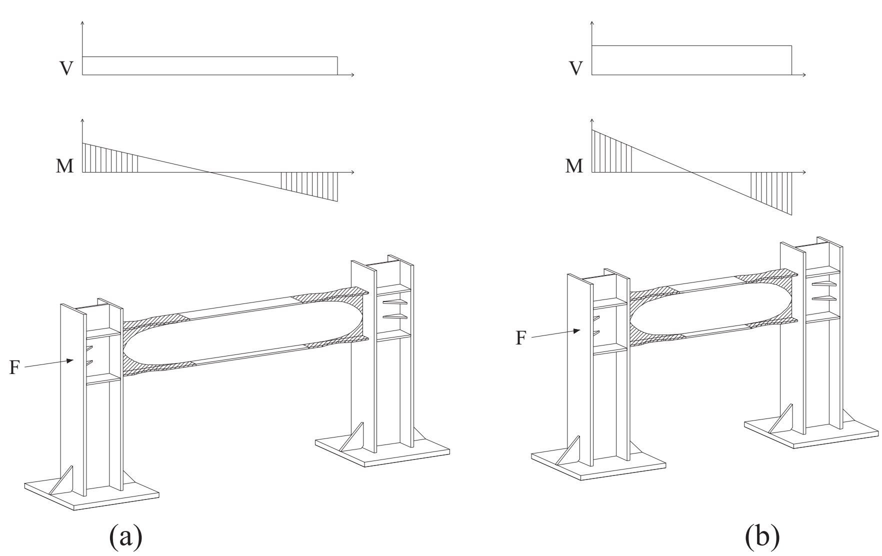

Fig. 1. Flexural hinging of MRFs with different beam span-to-depth ratios: (a) long span (b) short span.