DUCTILE BRACE FUSES FOR COST-EFFECTIVE SEISMIC DESIGN OF LOW-RISE CONCENTRICALLY BRACED STEEL FRAMES

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Keywords: Steel braced frames, HSS member, bracing memebrs, lease provide a minimum of three and a maximum of five keywords here. Separate the keywords with a semicolon. They should be written in Times New Roman 10, and the line must begin with the word "Keywords:" boldfaced.

Objectives

Concentrically braced steel frames have been commonly used to resist lateral loads in building structures because of their simplicity and high efficiency. For seismic resistance, however, capacity design principles and special detailing requirements have been implemented in codes to achieve ductile response, which has had negative effects on the structure costs. One main consequence is the increase in design loads that must be considered for beams, columns, connections, diaphragms, and foundations along the structure lateral load path. One approach that has been proposed to mitigate this impact while maintaining proper inelastic response is to introduce ductile fuses in the bracing members.

This article presents a study that has been conducted to develop and validate a fuse detail for square HSS bracing members. The fuse detail is illustrated in Fig. 1. The braces are cut near one of their ends and the two segments are connected by means of four steel angles that are welded on the HSS corners. As shown, the angle legs are reduced over a portion of the fuse length to develop the minimum required brace axial strength in compression. For local buckling in compression, the angles are confined between the HSS members and a steel box section built-up around the fuse. The built-up section is attached to only one of the two brace segments. It also designed to provide sufficient global flexural strength and stiffness to maintain the brace overall compressive resistance. During a strong seismic event, braces with fuses are expected to buckle in compression, as is the case for conventional steel braces. However, yielding in tension is constrained to the fuses, which can considerably reduce the force demands imposed by the braces to surrounding components of the seismic force resisting system.

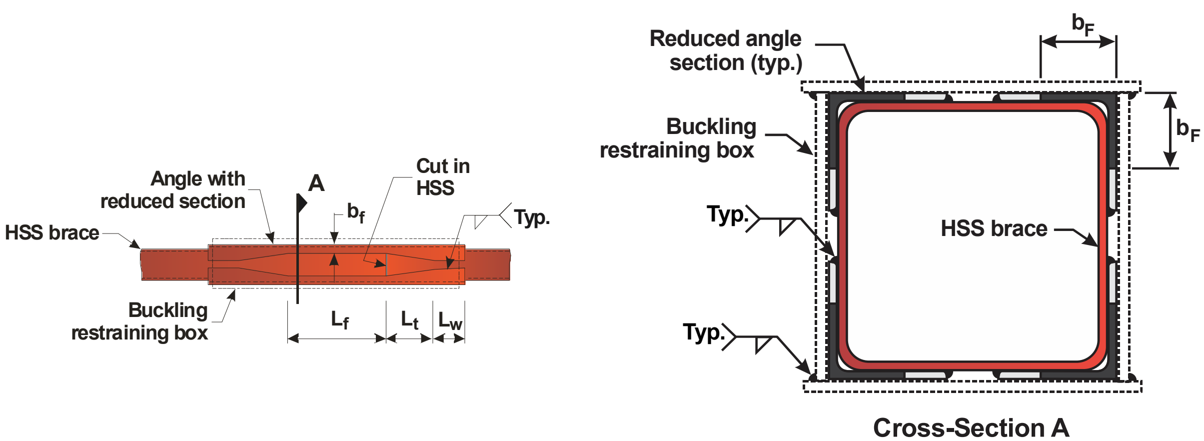

Fig. 1 HSS brace fuse detail studied.

Relevant results

Test programs have been performed to characterize the load-deformation response up to failure of steel angles with reduced cross-sections, and the results were used to establish minimum plastic deformation capacities in tension for the fuses. Quasi-static testing of individual brace-fuse assemblies and braced frames with brace fuses were also carried out to validate the hysteretic brace response and develop criteria for the design of the built-of-box sections. A braced frame test is illustrated in Fig. 2a. For direct comparison, tests were carried out on braces with and without the fuse details. As shown, the brace fuse can reduce the brace tensile strength without affecting the brace compressive strength upon inelastic cyclic loading but the fuse does not have detrimental effects on the brace inelastic deformation capacities in tension and compression. The figure also shows that brace fuses can develop strain hardening at large deformations, which can result in braced frames exhibiting a beneficial positive lateral stiffness when subjected to large storey drifts.

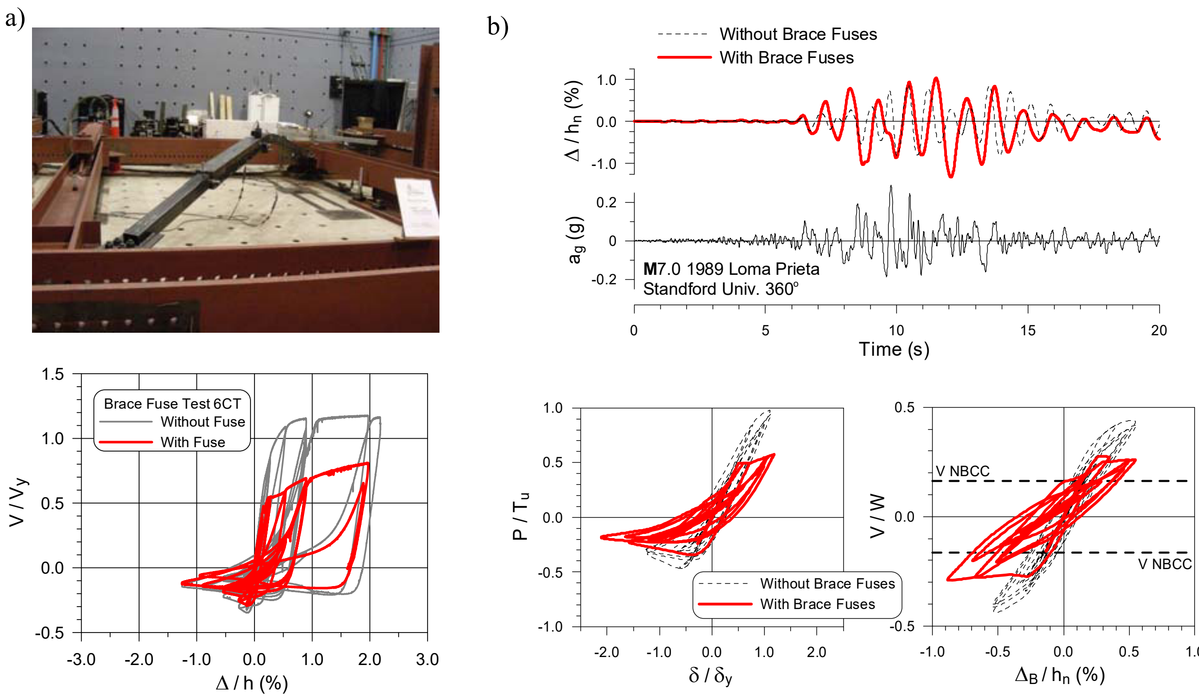

Fig. 2 a) Cyclic testing of braced frames with and without fuses;
b) Time history response of a single-storey building with braced frames with and without brace fuses.

Prototype structures were designed with and without the proposed brace fuse detail. The comparison showed that braced fuses can significantly reduce the force demands on braced frame components and result in lighter seismic force resisting systems. For single-storey buildings with large foot prints constructed with vertical bracing and steel roof deck diaphragms, the use of brace fuses can lead to considerable reductions in costs for the roof diaphragm, which represents a large portion of the total lateral system costs. The seismic response of these structures was investigated through nonlinear response history analyses using detailed models that could reproduce the hysteretic response of brace-fuse assemblies as well as the in-plane deformation response of steel deck diaphragms spanning between vertical bracing elements. Typical responses with and without brace fuses are compared in Fig. 2b. In general, structures with brace fuses experience larger total lateral displacements due to tension yielding occurring earlier in the braces and the greater flexibility of the roof diaphragm designed for reduced lateral loads. However, the displacements remain within acceptable limits (1.35% of the building height for the example show in Fig. 2b) and the cost benefits resulting from the reduced force demands imposed by the braces can be fully exploit in design.

Conclusions

A fuse detail for HSS bracing members has been developed to reduce brace induced forces while exhibiting ductile inelastic response under severe seismic loading. The response of the proposed detail was verified through full-scale testing of fuses, brace-fuse assemblies, and braced frames. The seismic response of prototype buildings incorporating the proposed brace fuse detail was validated through inelastic dynamic seismic analysis. It was found that the fuse system has potential for reducing the structure costs while achieving satisfactory seismic response.

SEISMIC PERFORMANCE OF ECCENTRICALLY BRACED FRAMES COMBINATION WITH HIGH STRENGTH STEEL

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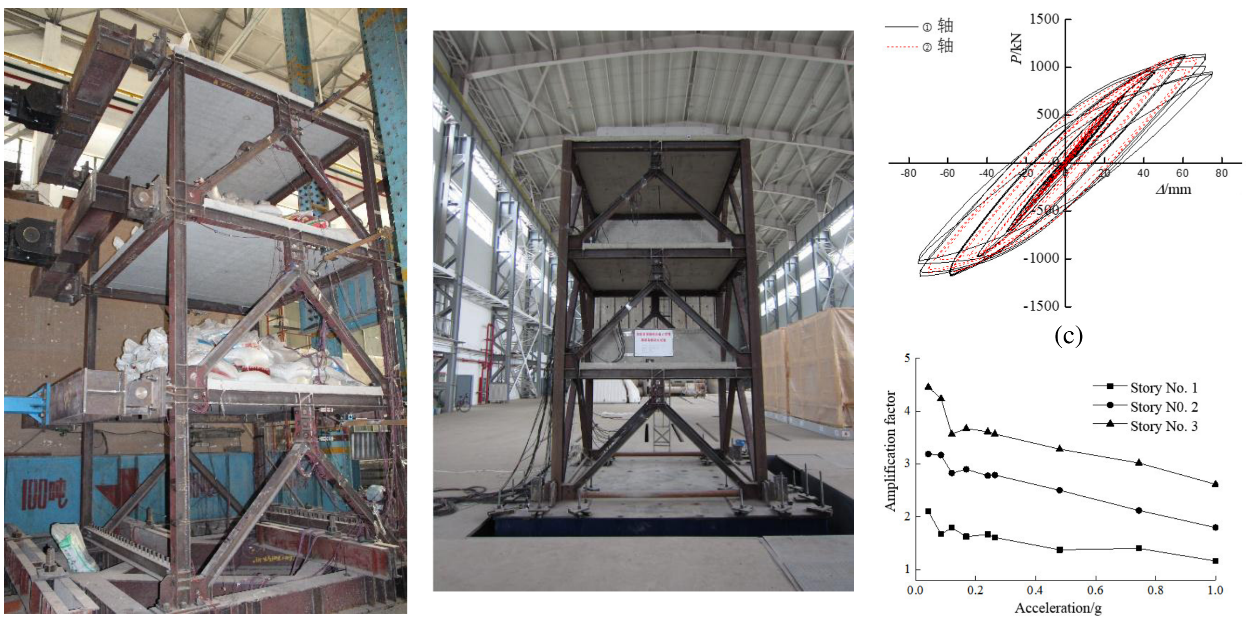
In eccentrically braced frames (EBFs), the energy induced by earthquake loads is dissipated through the inelastic deformation of links. The design procedures for EBFs are based on capacity design principles and aim to produce a structure whose links have a stable inelastic response while other structural members exhibit an elastic response during seismic action. Therefore, the cross-sections of non-dissipative members in EBFs, including beams, columns and braces, are often enlarged to ensure these structural members are in elastic during earthquakes, which leads to increase material costs. In eccentrically braced frames combination with high strength steel (HSS-EBFs), links use conventional steel (with a specified nominal yield stress $f_y \leq 345$ MPa), braces use conventional steel or high strength steel (HSS, with a specified nominal yield stress $f_y > 345$ MPa) while other structural members use HSS. Under earthquake loads, beams, columns and braces of HSS-EBFs are designed to remain in elastic or have slight plastification while links enter the plastic stage completely. This structure can satisfy seismic design requirements with no demands of plastic deformation for the steel used in columns and beams. Under the same design conditions, considering the properties of HSS, HSS-EBFs have smaller member sections relative to conventional EBFs. Therefore, HSS-EBFs offer seismic performance equivalent to that of EBFs and improved economy through reduced material costs. Experimental tests and numerical analyses were used to study the seismic performance of HSS-EBFs. The design methods for HSS-EBFs were also obtained based on the experimental and numerical analysis results.

Static monotonic loading and cyclic loading tests for eight half-scale one-bay and one-story K-shaped and Y-shaped HSSEBFs specimens with shear and flexure links were carried out to study their seismic behaviors, including the failure modes, lateral stiffness, load-bearing, ductility and energy dissipation capacities(Fig. 1). Two half-scale three-story HSSEBFs specimens with shear links, including one K-shaped specimen and one Y-shaped specimen, were made to study their hysteretic behaviors during the cyclic loads(Fig. 2a). The failure modes, lateral stiffness degradation, interstory drifts, the shear link deformation and energy dissipation capacities were considered. Moreover, shake table tests of two half-scale three-story K-shaped and Y-shaped HSS-EBFs specimens were carried out to study their seismic performance under ground motions with different peak ground accelerations(Fig. 2b). The dynamic properties, acceleration, displacement and strain responses of the specimens were obtained from the shake table tests. The test results indicated that the main damage of the specimens was the link failure, but the other structural members remained in elastic and the frame could continue resisting the lateral loads. During the tests, the HSS-EBFs specimens had reliable lateral stiffness and load-bearing capacities, and exhibiting good ductility and stable energy dissipation capacities. During the ground motions with different intensity, the specimens exhibited sufficient lateral stiffness and safety but suffered some localized damages of shear links. During the high seismic intensity earthquakes, there was no dangerous of collapse for the specimens. The links of the specimens dissipated the energy via the inelastic shear deformation, while other structural members remained in the elastic responses.

Based on the experimental study for the seismic performance of HSS-EBFs, the finite element models of the above test specimens were established by ABAQUS. The numerical analyses were considered to research the influence of different design details, e. g. link length, link web ratio of height to thickness and ratio of depth to span, to the seismic performance of HSS-EBFs. Moreover, several HSS-EBFs and conventional EBFs structures with different total heights were designed using the same design conditions. The finite element models of these structures were established by SAP2000 for determining seismic effects. Nonlinear pushover and dynamic analyses were conducted to compare their seismic performance and economy. The numerical analysis results indicated that different design details had different influence to the failure modes, lateral stiffness and load-bearing, ductility, energy dissipation capacities. Under the same design conditions, the seismic performance of HSSEBFs were slightly lower than that of conventional EBFs if the HSSEBFs were designed to match the member section strengths of conventional EBFs, but HSSEBFs used less steel than that of conventional EBFs, which could reduce the usage amount of steel in HSSEBFs and improve economy.

(a) (b) (c)

Fig. 1. Test of HSS-EBF: (a) Y-type link, (b) K-type link and (c) hysteretic curve of K-type EBF.



(a) (b) (d)

Fig. 2. Test of HSS-EBF structures: (a) Cyclic loading; (b) Shaking table test; (c) hysteretic curve and (d) Dynamic response.

Performance-based plastic design (PBPD) method is used to design HSSEBFs with shear links. Target drift and ideal global failure model are adopted as key parameters to estimate and control the plastic behavior of the structure, which makes all links dissipate energy under the severe earthquakes. Moreover, the story drifts are uniform along the structural height, and they avoid the presence of weak layer in the structure. The finite element models of structures by PBPD method were developed. Nonlinear pushover and dynamic analyses were adopted to study the seismic performance of these structures. The results indicate that the HSSEBF structures designed by PBPD method have good seismic performance, and the structures are damaged when the ideal failure model is followed. All links entered the plastic stage to dissipate the energy. The story drifts are distributed uniformly along the structural height.

Thus, based on the experimental and numerical studies for the performance of HSSEBFs, the HSSEBFs are reliable dual system with good seismic performance. Using HSS in EBF can reduce the usage amount of steel, which can achieve economy.