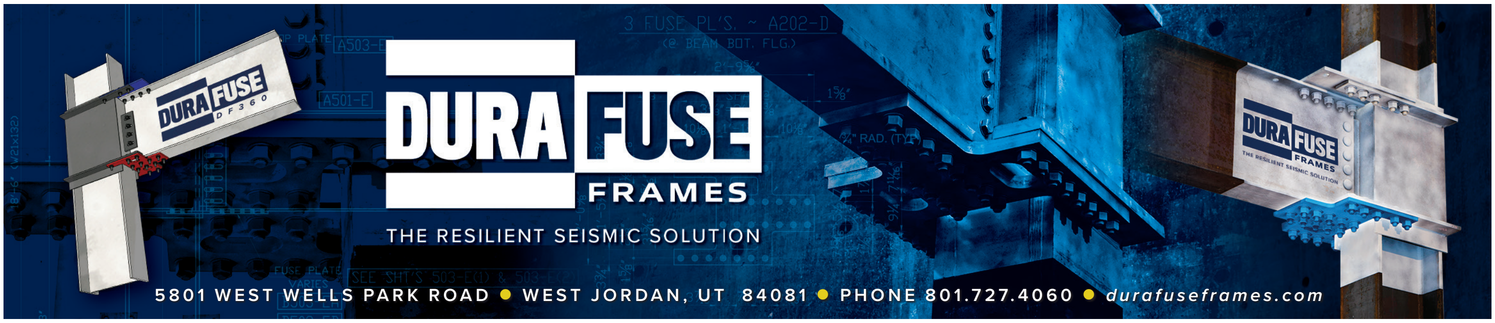

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TECHNICAL BULLETIN 14

Using DuraFuse Frames in Seismic Retrofit Applications

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Abstract: Most existing special moment frames do not meet current code requirements. The DuraFuse Frames (DFF) Arrow retrofit introduces a fuse plate that mitigates common deficiencies including welds that are susceptible to brittle fracture, weak column panel zones, insufficient column flexural strength, insufficient frame stiffness, and insufficient beam width-thickness ratio. A case study is presented that illustrates the DFF Arrow joint retrofit. The retrofit is discussed in the context of ASCE 41 and AISC 342.

Background

Design requirements for special moment frames (SMFs) have changed over time. A dramatic shift in requirements occurred in the years immediately following the 1994 Northridge Earthquake, and adjustments have been made with each subsequent edition of AISC 341. As a result, most existing SMFs do not meet current code requirements.

The primary areas where existing SMFs do not satisfy current code requirements are:

- Welds that are susceptible to brittle fracture
- Weak column panel zones
- Insufficient column flexural strength relative to the beams
- Insufficient overall frame stiffness (under-sized beams and columns)
- Insufficient beam width-thickness ratios to accommodate large inelastic strains

Projects are regularly undertaken to retrofit existing SMFs to address such deficiencies. While a variety of retrofit techniques can address some of the problems, it is challenging to find a solution that addresses them all. For example, adding haunches or replacing welds may reduce the possibility of brittle weld fracture, but may increase the inelastic demands in the column (shear in the panel zone and/or flexure outside the panel zone). As another example, adding RBS cuts at the bottom flange may reduce demands on the column and connection, but may exacerbate insufficient overall frame stiffness.

This bulletin describes a DuraFuse Frames (DFF) retrofit solution that addresses all the common SMF deficiencies. The connection configuration will be described and the steps to implement the DFF connection retrofit will be summarized. The inelastic response of the connection will be discussed in the context of the problems above and a case study will be presented to quantify the benefits. Finally, the retrofit will be discussed in the context of ASCE 41-17 and AISC 342 (2019).

DuraFuse Frames – Arrow Configuration

The DFF Arrow configuration is well-suited for seismic retrofit applications. A retrofitted connection is shown in Fig. 1 where the existing top flange weld between the beam and column is utilized (alternative embodiments can be employed if the existing top flange weld is inadequate). The connection has a slotted shear tab and a haunch assembly that incorporates fuse plates [Fig. 1(a)]. Under severe earthquake loading, the fuse plates are designed to yield in shear, limiting the forces that are imposed on the column [Fig. 1(b)]. The strength of the fuse can be selected based on the capacities of the existing components to ensure that the fuse-yielding mechanism governs the response. Table 1 summarizes how the DFF Arrow connection addresses the common SMF problems.

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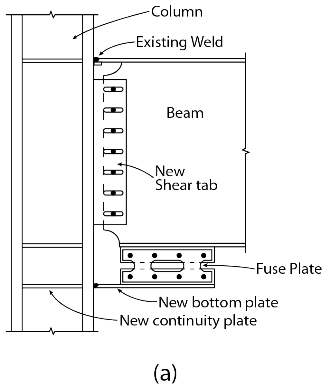

Fig. 1 *Connection with the DFF Arrow retrofit*

Table 1 *How the DFF Arrow retrofit solves common SMF problems*

Common SMF Problem	DFF Arrow Retrofit Solution
Welds that are susceptible to brittle fracture	Replace susceptible bottom flange weld with a fuse-haunch connection
Weak column panel zones	Proportion fuse plate to limit the force imparted to column panel zone
Insufficient column flexural strength (weak column-strong beam)	Proportion fuse plate to limit the moment that can develop in the column
Insufficient overall frame stiffness	Improve frame stiffness by the addition of the haunch at the connection; improve building stiffness by converting some gravity frames to moment frames
Insufficient beam width-thickness ratios to accommodate large inelastic strains	Replace beam yielding with fuse plate yielding, existing width-thickness ratios are okay

Steps for DFF Arrow Retrofit

The steps to retrofit a connection where the top flange weld is deemed acceptable are:

1. Remove finishes to gain access
2. Shore the beam
3. Remove existing shear tab and existing beam bottom flange-to-column weld
4. Remove 1 in. of the beam near the connection (except the top flange)
5. Drill new bolt holes in beam web
6. Weld new shear tab, bottom plate, fuse attachment plates, and continuity plates
7. Install fuse plates and shear tab bolts

Adjustments to steps 3 and 4 can be made if the top flange connection needs to be repaired, or if a top flange plate needs to be introduced to upgrade the connection.

Case Study

As a case study, a DFF Arrow retrofit was developed for a particular joint in a frame. The joint came from the three-story pre-Northridge moment frame building documented in *FEMA-355F* (Foutch, 2000). The joint had a W14×311 column with two W33×118 beams (Fig. 2). The joint had all of the problems listed in Table 1.

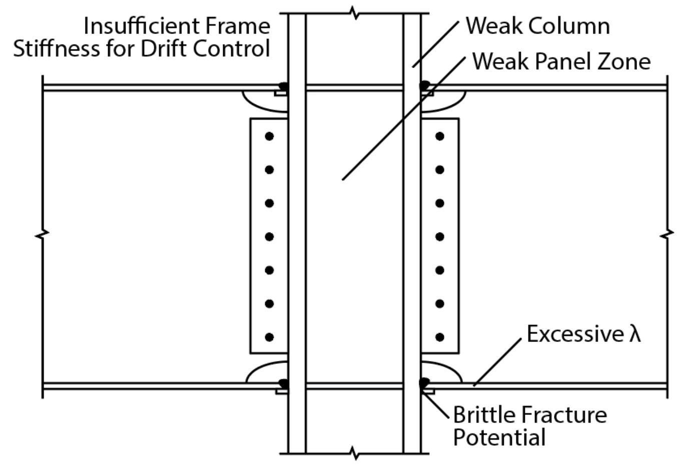

Fig. 2 *Case study joint from SAC pre-Northridge study building (FEMA-355F)*

Brittle weld detail – The weld detail had the typical pre-Northridge connection. The weld tab for the bottom flange was left in place and the bottom flange was susceptible to brittle fracture.

Weak panel zone – The panel zone shear demand corresponding to beam plastic hinging was 1740 kips. The panel zone shear capacity, calculated per AISC 360 J10.6 (2016a) was only 948 kips. The incredibly weak panel zone would experience severe inelastic deformation that would preclude beam plastic hinging.

Weak-column strong-beam – The flexural demand on the column corresponding to beam plastic hinging was $\Sigma M_{pb}^* = 5218$ k-ft. The column flexural capacity was $\Sigma M_{pc}^* = 4201$ k-ft. The ratio of column strength to beam strength was 0.8, indicating that the column would form plastic hinges before the beams, and that the joint would not satisfy the beam-to-column relationship.

Insufficient Stiffness – More stiffness was desirable for controlling drifts.

Beam flange width-thickness ratio – The width-thickness ratio for the beam flange was 7.86 which was above the λ_{hd} limit of 7.34.

Fig. 3 shows results from finite element analysis of a sub-assembly with the connection at 4% drift, assuming that brittle fracture did not occur. As expected from the calculations above, only limited yielding occurs in the beams while severe inelastic deformation is imposed on the column. These results represent a best-case scenario; a more likely scenario is that the bottom beam-to-column welds would fracture.

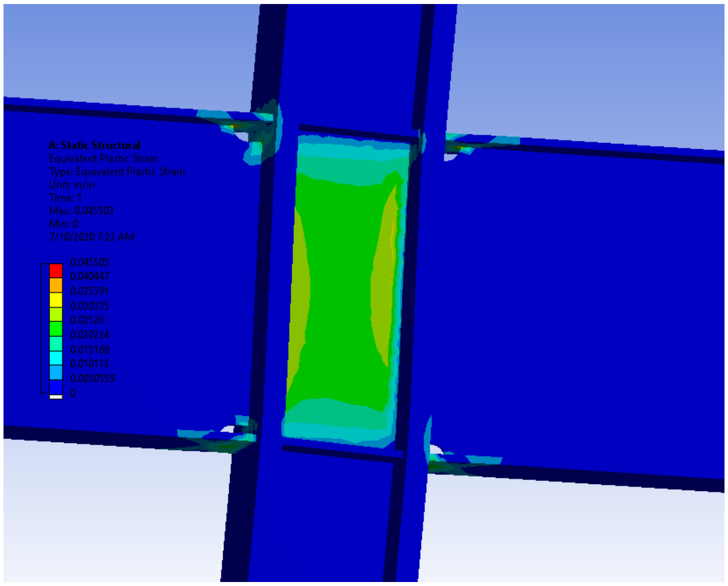

Fig. 3 *Plastic strains from finite element analysis of case study joint prior to retrofit (4% drift)*

The DuraFuse Frames Arrow Retrofit Solution

The DFF Arrow retrofit for this case is shown in Fig. 4. The bottom flange weld was removed, and the bottom flange reconnected to the column with fuse plates on the path. The fuse plates were proportioned so that fuse yielding would be the governing limit state.

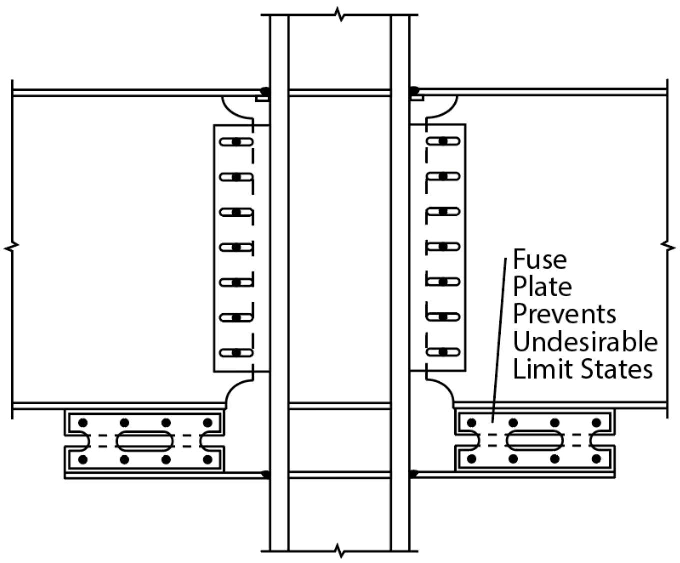

Fig. 4 *DFF retrofit for the case study joint*

The problems with the original connection were resolved as follows:

Brittle weld fracture was addressed by removing the problematic bottom flange weld.

Weak panel zone was addressed by reducing panel zone demands by introducing fuse plates that deliver less than 900 kips total shear to the column.

Weak-column strong-beam was addressed by reducing column demands by introducing the fuse plates that limit ΣM_{pb}^* to 4200 k-ft.

Insufficient stiffness was addressed by stiffening the connection with the fuse-haunch.

Beam flange width-thickness ratio was addressed by preventing beam flange yielding through introducing the fuse.

Figure 5 shows results from finite element analysis of a sub-assembly with the retrofitted connection at 4% drift. Inelastic deformations are limited to the fuse plates. The connection is able to achieve 4% drift without any yielding in the column or in proximity to the welds.

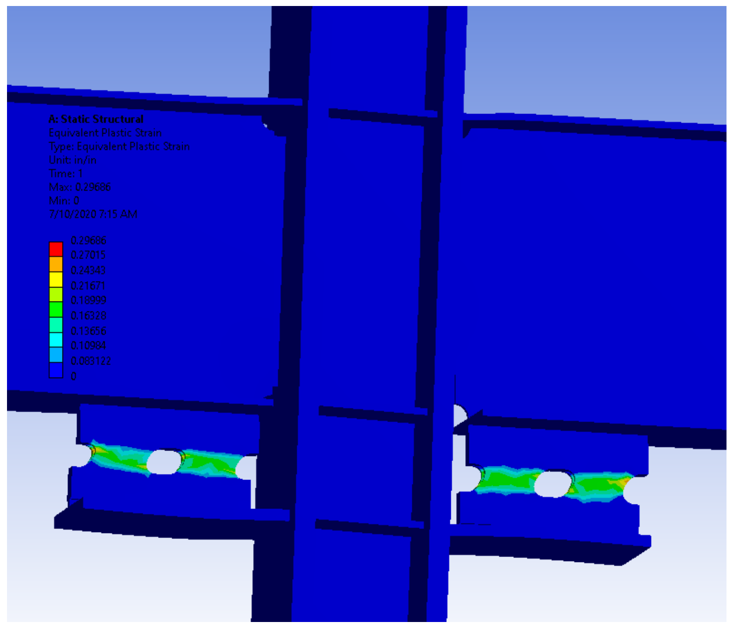

Fig. 5 *Plastic strains from finite element analysis of case study joint after retrofit (4% drift)*

Other Retrofit Concepts

In buildings with insufficient stiffness, it may be possible to convert existing gravity frames into moment frames using a detail similar to Fig. 1.

Another possibility is to introduce additional frames with new beams and columns that use DuraFuse Frames connections.

Discussion of DFF Arrow Retrofit in the Context of Retrofit Standards

Standards for seismic evaluation of buildings and retrofits have continued to evolve. ASCE 41 (2017) provides a framework for seismic evaluation and retrofit and guidance for modeling existing and retrofitted steel moment connections. AISC 342: *Seismic Provisions for Evaluation and Retrofit of Existing Structural Steel Buildings* is in development and will be the source for steel-specific evaluation and retrofit content in the future. Currently, ASCE 41-17 and AISC 342 (2019 draft) have tables that provide m-factors and backbone curve parameters for steel moment frame connections.

ASCE 41 recognizes that "new methods and materials, not currently in use, will be developed that may have direct application to building retrofit." Section 7.6 of the standard describes alternative modeling parameters and acceptance criteria that apply to steel moment frame connections. The required experiments and guidelines for developing m-factors and backbone curves are explained. DuraFuse Frames have been thoroughly tested in the process of qualification per AISC 341 Chapter K (AISC 2016b). DuraFuse Frames, LLC, can work with engineers to determine if additional testing is necessary for their particular retrofit application, and to provide them with m-factors and backbone parameters.

Conclusions

Most existing SMFs do not meet current code requirements. Connection deficiencies include brittle welds, weak panel zones, inadequate column flexural strength, inadequate frame stiffness, and inadequate beam width-thickness ratios. The DuraFuse Frames Arrow retrofit incorporates a fuse plate at the bottom flange level that can address all of these deficiencies.

A case study was presented where the peak moment at the face of the column was reduced, while the overall stiffness and inelastic rotation capacity of the sub-assembly was increased.

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