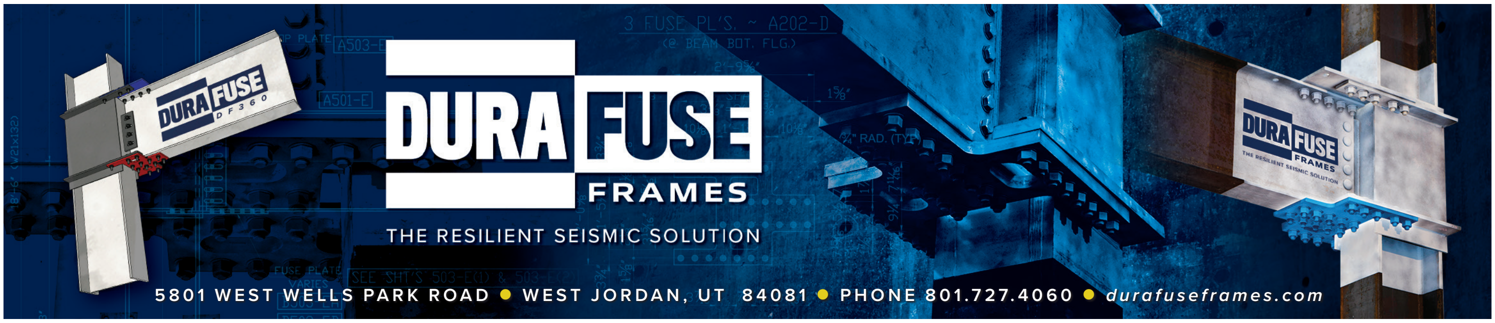

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TECHNICAL BULLETIN 24

DFF Arrow vs. Welded Haunch for SMF Retrofit Projects

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Abstract: Most pre-Northridge buildings with steel special moment frames (SMF) do not meet current seismic performance standards. One method to retrofit such buildings is to modify the beam-to-column connections. This bulletin compares the welded bottom haunch retrofit with the DuraFuse Frames (DFF) Arrow retrofit. The DFF Arrow retrofit has greater rotation capacity and prevents beam yielding, making functional recovery much more likely. The installation costs for the two retrofits are comparable.

Introduction

The 1994 Northridge earthquake revealed unacceptable performance of steel special moment frames (SMF). Fractures of SMF beam-to-column welds that were observed in buildings after Northridge (Youssef et al. 1995), were replicated in laboratories (Sabol et al. 1996; Uang et al. 1998; Yang and Popov 1995) and found to be related to inherent problems with the prescriptive pre-Northridge connection detail. Designs requirements for new construction address these issues, but many pre-Northridge buildings have SMF connections with limited/no ductility. Most pre-Northridge buildings will not meet life safety (LS) performance for the design earthquake unless they have been retrofitted.

One SMF retrofit strategy that has been documented in the literature is the welded bottom haunch (Civjan et al. 2000; Uang et al. 1998; Uang et al. 2000). This retrofit consists of adding a welded bottom haunch to an existing moment connection. Fig. 1 shows a welded bottom haunch detail.

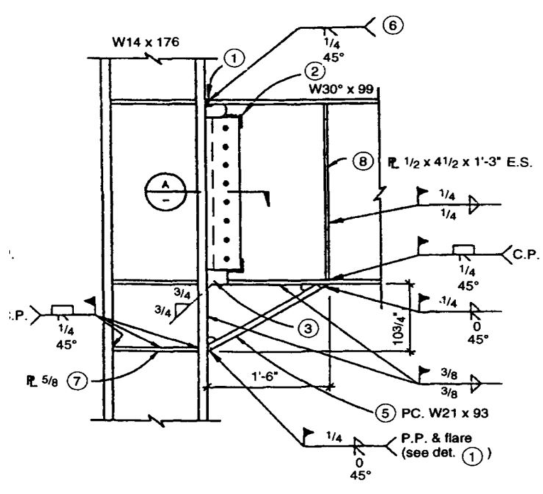

Fig. 1. *A welded bottom haunch retrofit (Uang et al. 1998)*

Full-scale experimental results for welded bottom haunch specimens, that were not damaged prior to retrofit, are summarized in Civjan et al. (2000) and Uang et al. (2000). In these studies, four specimens with W30×99 beams and two specimens with W36×150 beams were subjected to cyclic loading. The specimens with a top slab demonstrated rotation capacity around 0.035 rad. This rotation capacity is much better than an un-retrofitted pre-Northridge connection, but not quite as good as a new SMF connection (AISC 2016). For connections with slabs, the existing pre-Northridge weld at the top flange did not fracture during testing, and rotation capacity was limited by excessive local buckling in the beam plastic hinge (Fig. 2).

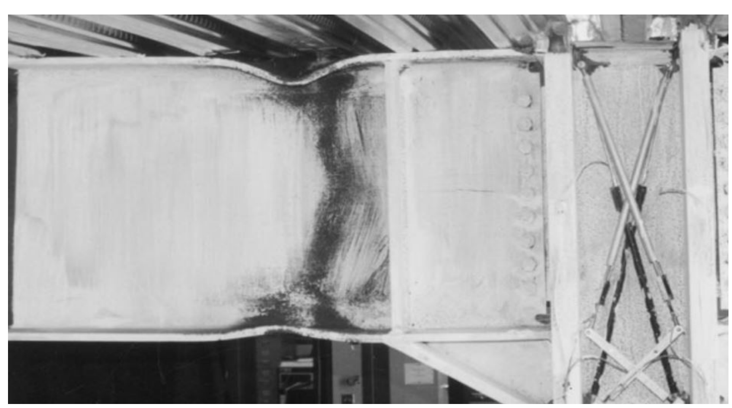

Fig. 2. *Experimental testing of welded bottom haunch retrofit (Uang et al. 2000)*

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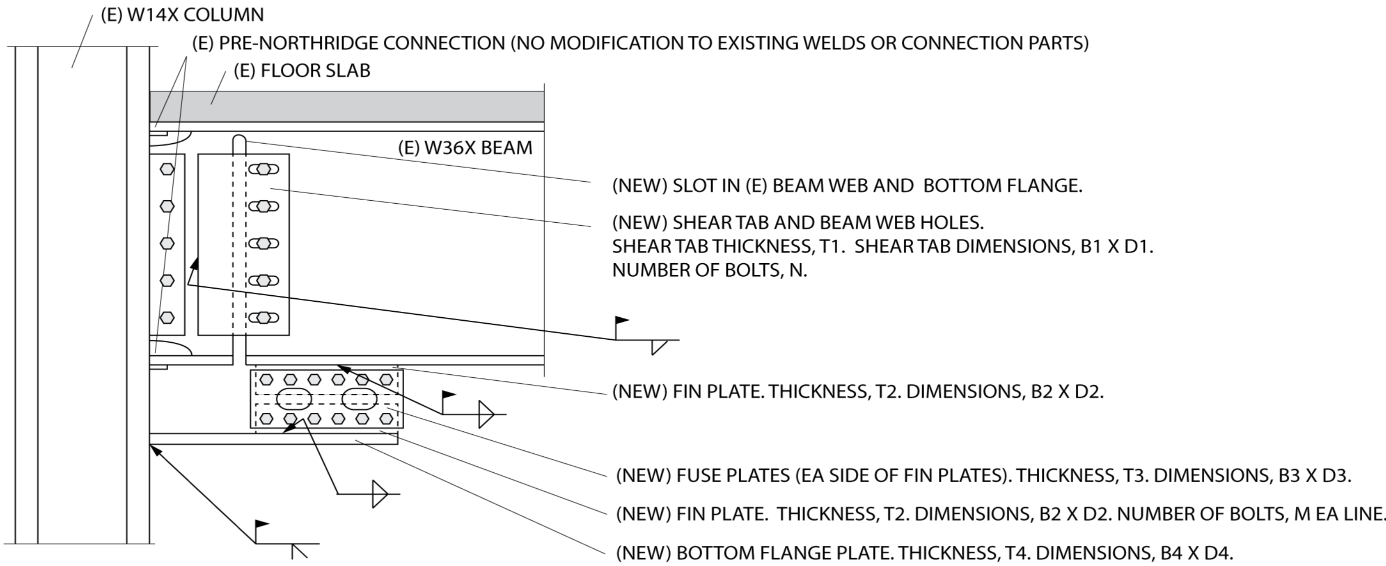


Fig. 3. *Detail for the DFF Arrow retrofit connection*

The welded bottom haunch retrofit is recognized in AISC 341 (2017), based on the testing previously cited. Since the welded haunch retrofit still relies on beam plastic hinging to provide ductility, the beams will be sacrificed during severe earthquake shaking. Widespread beam damage of the kind illustrated in Fig. 2 is impractical to repair. As a result, the welded haunch retrofit is capable of providing life safety (LS) performance, but is not expected to result in functional recovery (buildings may be a total loss after the earthquake).

DFF Arrow Retrofit

DuraFuse Frames (DFF) were developed to improve the repairability of moment frames so they will not have to demolished after a severe earthquake. The DFF Arrow configuration can be used to retrofit pre-Northridge connections, providing much better resiliency at competitive cost relative to a welded haunch retrofit.

The DFF Arrow retrofit is illustrated in Fig. 3. A DFF haunch assembly is added to the existing connection to by-pass the questionable existing bottom flange weld. The haunch includes two fuse plates that are proportioned to prevent beam yielding. The fuse plates sandwich two “fin” plates, one connected to the beam bottom flange, and the other connected to the new bottom plate that is the base of the haunch assembly.

After the haunch is installed, a vertical slot and a modified shear tab are added to the existing beam to accommodate the fuse-yielding kinematics. No modifications are made to the existing beam-to-column welds or the existing shear tab. The previously discussed bottom haunch experiments justify the use of as-is top flange welds for DFF Arrow retrofit, since the fuse plates reduce the maximum force that will be seen by the welds (making the DFF case less critical than the welded bottom haunch retrofit case).

Experimental Testing

Test results for the DFF Arrow connection are presented in TR 21/04 (Lee and Uang 2021). Three specimens were tested with W36×397 beams. Two of the specimens were subjected to cyclic testing. The other specimen was subjected to monotonic testing. The beam size for the DFF tests was more-than-sufficient to prequalify for any wide-flange shape in existing moment frames, based on the criteria for new buildings (AISC 2016).

The experiments demonstrated good ductility in the DFF Arrow connection. Fig. 4 shows the monotonic specimen at 6% drift. The cyclic specimens met the AISC criteria for SMF, as well as the more stringent HCAI criteria for California hospital projects (Lee and Uang 2021).

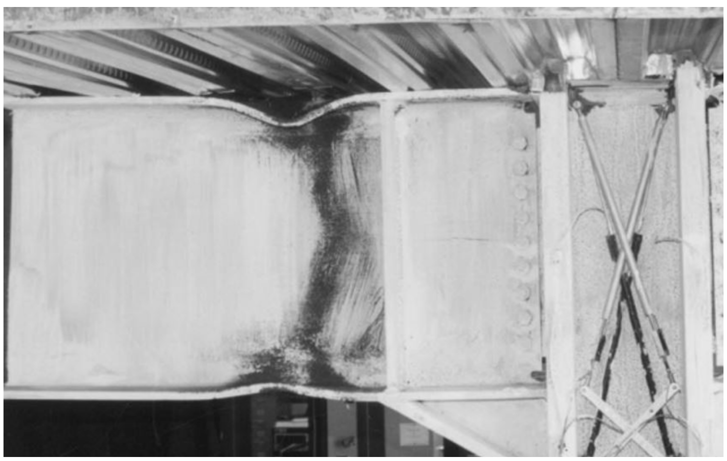
Fig. 4. *DFF Arrow connection at 6% drift (Lee and Uang 2021)*

The DFF Arrow retrofit detail shown in Fig. 3 differs slightly from the DFF Arrow for new-construction that was tested (Fig. 4) in that the experiments had a top flange plate, rather than an existing beam-flange-to-column-flange weld. However, the yielding mechanism in Fig. 3 is identical to what was tested (Fig. 4).

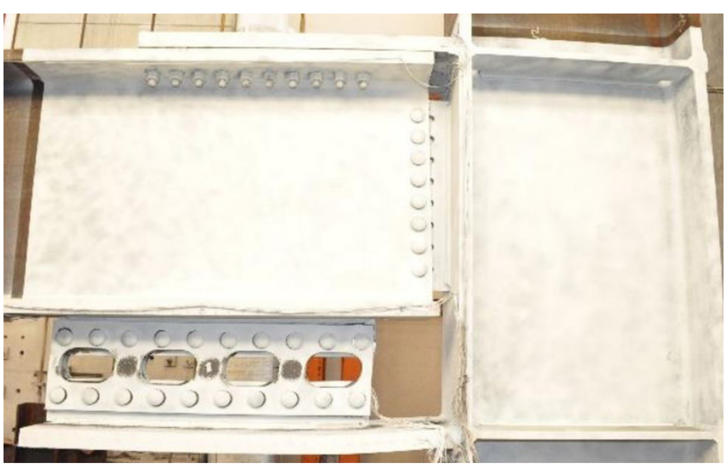
DFF Arrow vs. Welded Haunch: Expected Performance

The DFF Arrow retrofit offers performance advantages relative to the welded bottom haunch retrofit. Figure 5 shows pictures from two specimens at 3% drift during testing. Welded bottom haunch connections [Fig. 5(a)] are expected to accommodate large drifts, but with severe beam yielding and local buckling. In contrast, DFF Arrow connections [Fig. 5(b)] are expected to accommodate drifts of at least 4% without any beam damage (Lee and Uang 2021). Experimental testing has demonstrated that fuse plates in the DFF Arrow can be replaced, and the connection has repeatable performance.

This improved performance means that the DFF Arrow can be used to achieve functional recovery, in addition to meeting life-safety performance objectives.



(a) Welded Bottom Haunch



(b) DFF Arrow Connection

Fig. 5. *Damage to different connections at 3% drift*

DFF Arrow vs. Welded Bottom Haunch: Cost to Implement

In addition to better performance, the DFF Arrow has competitive installation cost relative to a welded bottom haunch. The welded bottom haunch detail that was tested (Uang et al. 2000) is shown in Fig. 6. The detail requires (2) CJP welds for the bottom plate of the haunch, one of which must be made in an overhead position. In addition, two more CJP welds for column continuity plates may be required. The web of the haunch is fillet welded, and beam stiffener plates are fillet welded on each side. In addition to the components shown in Fig. 6, beam bracing should be provided to prevent lateral torsional buckling after the formation of the plastic hinge.

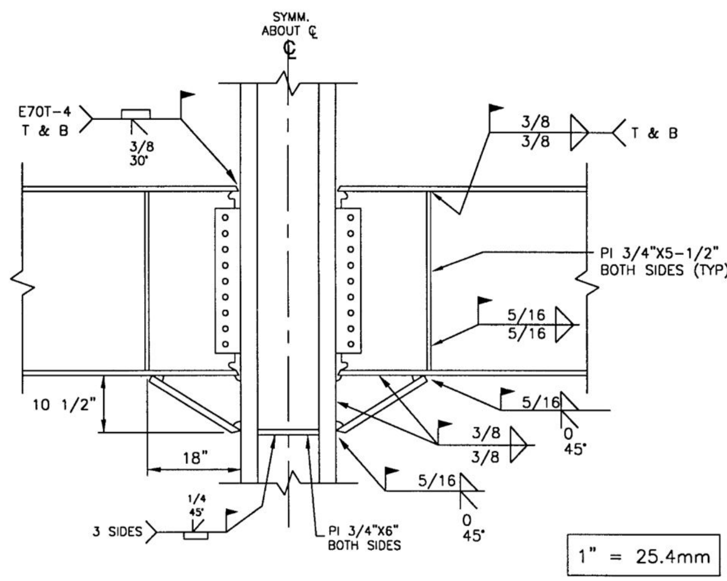


Fig. 6. *Detail from experimental validation of welded haunch retrofit (Uang et al. 2000)*

For the DFF Arrow retrofit (Fig. 3) there is only one CJP weld (between the new bottom flange plate and the face of the column). The DFF Arrow retrofit does require cutting the beam and installing a new shear tab (Fig. 1). However, there is no additional lateral bracing for the beam (since beam yielding is prevented), so the cost for the cut and shear tab are offset by the elimination of several lateral bracing points. The DFF Arrow connection is proprietary and there is a modest license fee for using it. This fee is included in the fabrication bid and paid by the fabricator. DuraFuse Frames, LLC provides free engineering support for design of the connections.

Conclusion

This bulletin compared the welded bottom haunch retrofit with the DuraFuse Frames (DFF) Arrow retrofit. The DFF Arrow retrofit has greater rotation capacity and prevents beam yielding, making functional recovery much more likely. The installation costs for the two retrofits are comparable.

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