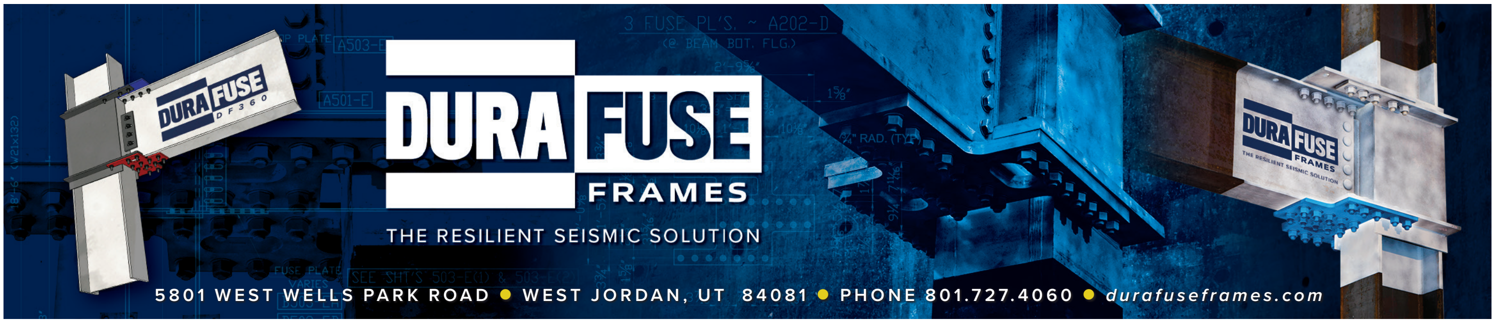

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TECHNICAL BULLETIN 12

Subassembly Stiffness Comparison for R=3 Steel Moment Frames

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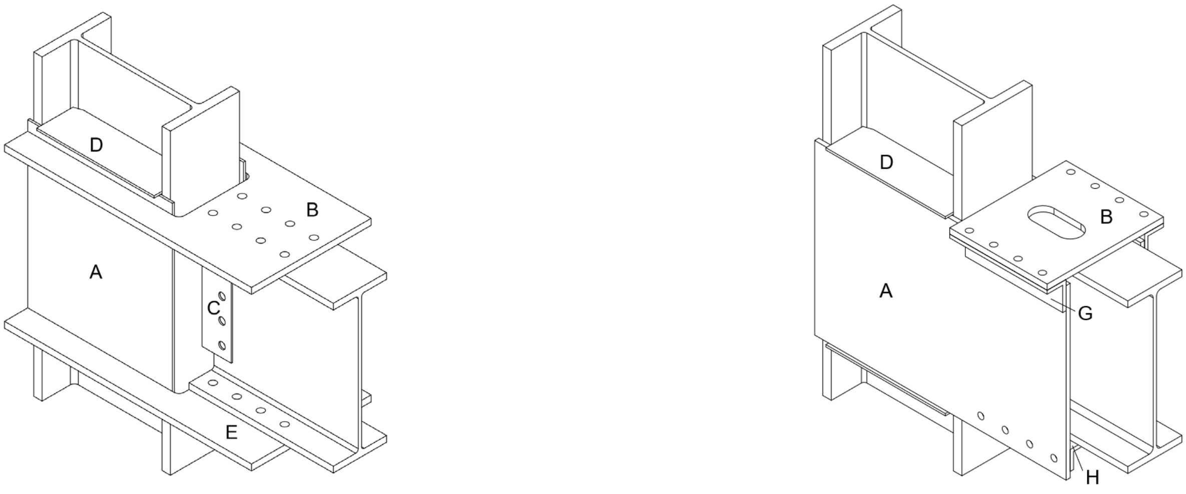
Abstract: In low-seismic regions, proprietary moment frame connections may be used for R=3 steel moment frames to reduce beam and column sizes. A study was performed to compare the weight and stiffness of moment frames with R=3 DuraFuse Frames (DFF) and R=3 SidePlate (SP) connections. Finite element modeling of four subassemblies with each type of connection was performed with ANSYS. The analyses showed that the DFF subassemblies had greater stiffness and less connection weight than comparable SP subassemblies. For R=3 moment frames, DFF connections can be used in place of SP connections without changing beam and column sizes.

Background

Steel moment frames are inherently flexible compared to other lateral force resisting systems, so member sizes in steel moment frames are often governed by drift requirements. Moment frame connections that can enhance connection stiffness result in lower beam and column sizes. Two proprietary connections, DuraFuse Frames® (DFF) and SidePlate® (SP), have features to enhance stiffness and reduce overall frame weights.

DFF and SP connections are optimized depending on the R factor used in design. In regions with lower seismic hazard, steel moment frames may be designed with a low response modification coefficient (R=3), and the connections may be designed per AISC 360 (2016a). Fig. 1 illustrates DFF and SP connections for R=3 moment frames. DFF and SP are both bolted connections that eliminate field welding.



(a) (b)

Fig. 1 *Proprietary connections for R=3 moment frames: (a) DFF; and (b) SP*

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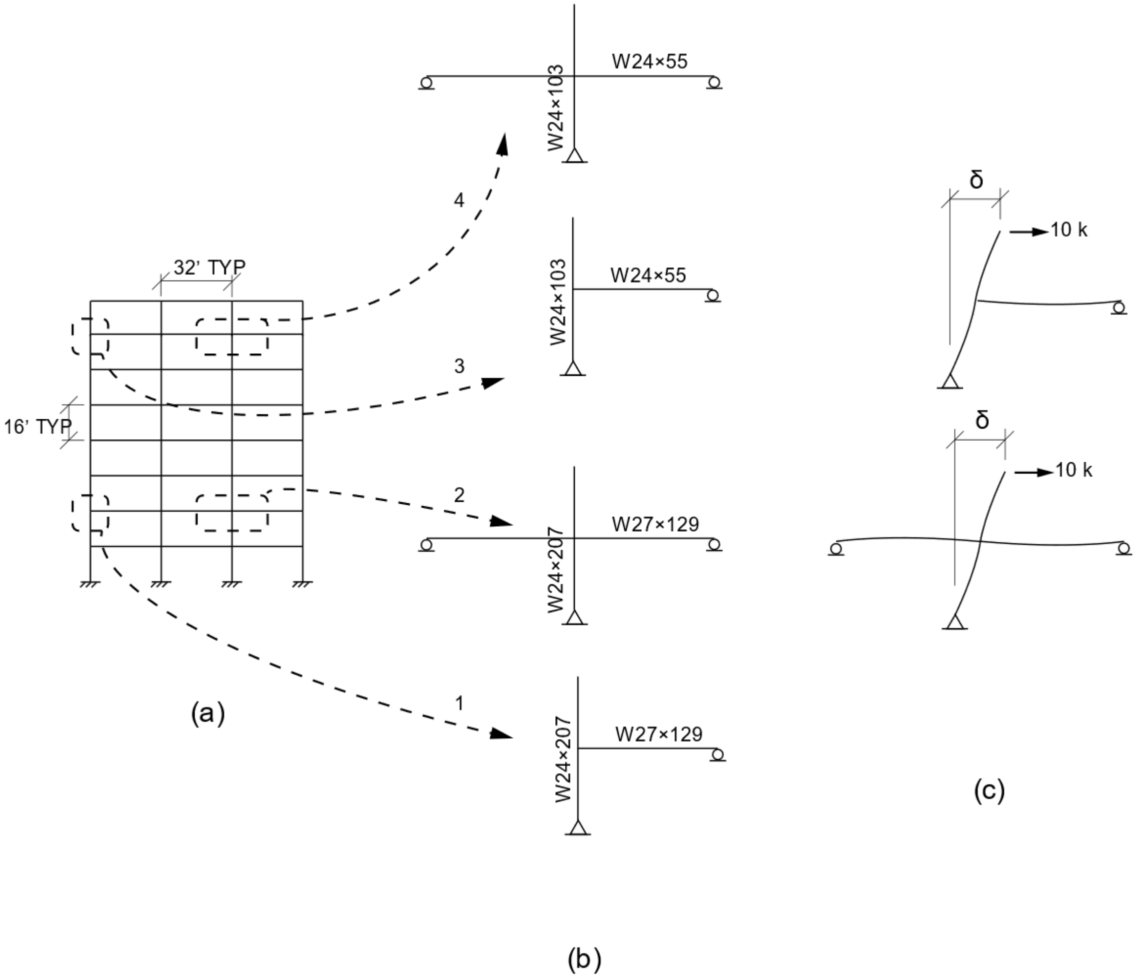
In R=3 moment frame design, engineers typically select member sizes and connection types to provide the best economy. It is necessary to know the relative weight and stiffness of R=3 DFF and SP connections to evaluate the relative economies.

This bulletin summarizes a study to compare the weight and stiffness of moment frames that use R=3 DFF and SP connections.

Sub-assemblies for the Study

Sub-assemblies are commonly used for moment frame experiments and finite element analyses (AISC, 2016b), and were used for the present study. The sub-assemblies came from an eight-story moment frame building with frame sizes governed by wind. A typical moment frame from the building had W24×207 columns and W27×129 beams at the lower levels, and W24×104 columns and W24×55 beams at the top [Fig. 2(a)]. Typical story heights and bay widths were 16 ft and 32 ft, respectively. Fig. 2(b) shows four sub-assemblies from the typical frame that were used for the study. Table 1 summarizes the beam demands at the connections for each sub-assembly.

The four sub-assembly geometries were considered in combination with the two connection types (DFF and SP) resulting in eight unique designs. The same size and number of "flange" bolts were used for the DFF and SP designs for each sub-assembly type. Fig. 3 shows the connection details that were used for the study.



(a)

(b)

(c)

Fig. 2 *Moment frame sub-assemblies that were used for the study*

Table 1 *Beam demands at the connections analysis*

Sub-Assembly	M_u (k-ft)	V_u (kips)
1	1100	78
2	1200	85
3	700	45
4	700	45

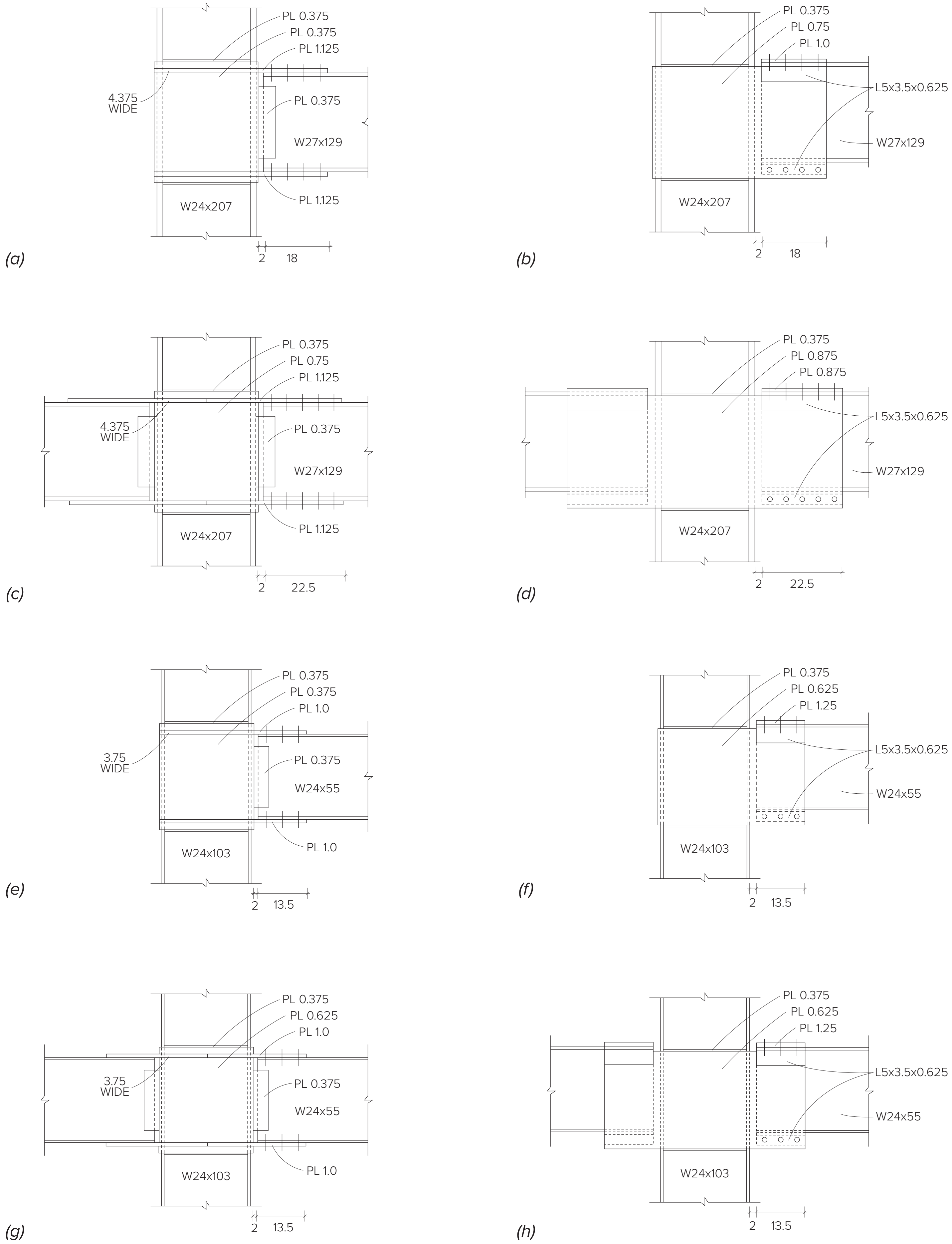


Fig. 3 *Connection designs that were investigated:*
(a) DFF-1; (b) SP-1; (c) DFF-2; (d) SP-2; (e) DFF-3; (f) SP-3; (g) DFF-4; and (h) SP-4

Weight Comparison

The weights of the various connection materials are summarized in Table 2. The part labels for each connection type are shown in Fig. 1. DFF connections had much lower weights for the "A" plates and overall lower connection material weights. Table 3 provides a total connection weight comparison for the different sub-assemblies. DFF connection weights were 15 to 22 percent less than the comparable SP connections.

Modeling Procedures for Stiffness Comparison

The software ANSYS Mechanical (2020) was used to develop rigorous FE models to determine the lateral stiffness of the various sub-assemblies. Modeling techniques suited the purpose of evaluating upper-bound elastic stiffness. The models were not used to predict bolt-slip, yielding, post-yield response, or stress concentrations. For all models, the steel material had a modulus of elasticity of 29,000 ksi and poisons ratio of 0.3. Inelastic material properties were not defined. Since the purpose of the models was to evaluate upper-bound elastic stiffness, bolted surfaces were tied to each other, representing conditions prior to bolt slip. Individual bolts and bolt holes were not modeled explicitly. Solid elements with 20 nodes (SOLID186 in ANSYS) were used for all the models with a maximum element size of 1 in. Weld geometry was not represented explicitly in the models. Plates were assumed fused to each other where they made contact.

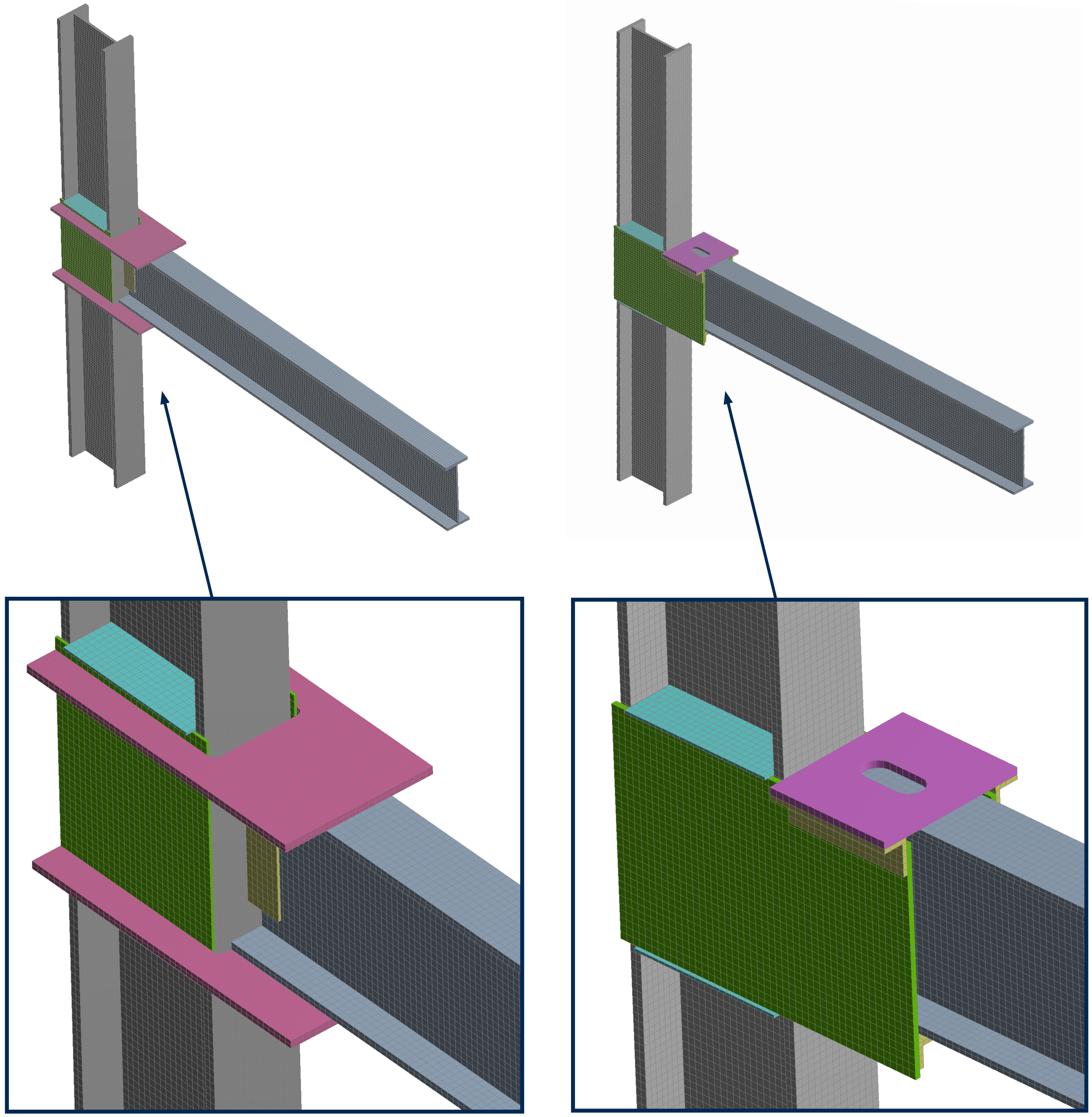
Fig. 4 illustrates the finite element model mesh for DFF-1 and SP-1. Other models were similar. The boundary conditions at the beam and column ends matched those shown in Fig. 2(c). Nodes at the end cross-sections of the beams and column were constrained so that pinned boundary conditions could be applied at the center-points of the cross-section without causing stress concentrations. An arbitrary lateral load of 10 kips was applied to all the models [Fig. 2(c)] to evaluate the lateral stiffness.

Table 2 *Weight of connection parts in lbs. See Fig.1 for part labels*

Sub-Assembly	As	Bs	Cs	Ds	Es	Gs	Hs	Total
DFF-1	194	209	12	69	209	0	0	692
SP-1	615	101	0	69	0	50	50	885
DFF-2	389	441	23	69	417	0	0	1338
SP-2	1154	224	0	69	0	126	126	1697
DFF-3	161	134	9	68	134	0	0	506
SP-3	407	101	0	68	0	38	38	651
DFF-4	269	225	18	68	225	0	0	805
SP-4	530	201	0	68	0	75	75	950

Table 3 *Overall connection weight comparison*

Sub-Assembly	DFF Connection Weight (lbs)	SP Connection Weight (lbs)	DFF/SP
1	692	885	0.78
2	1338	1697	0.79
3	506	651	0.78
4	805	950	0.85

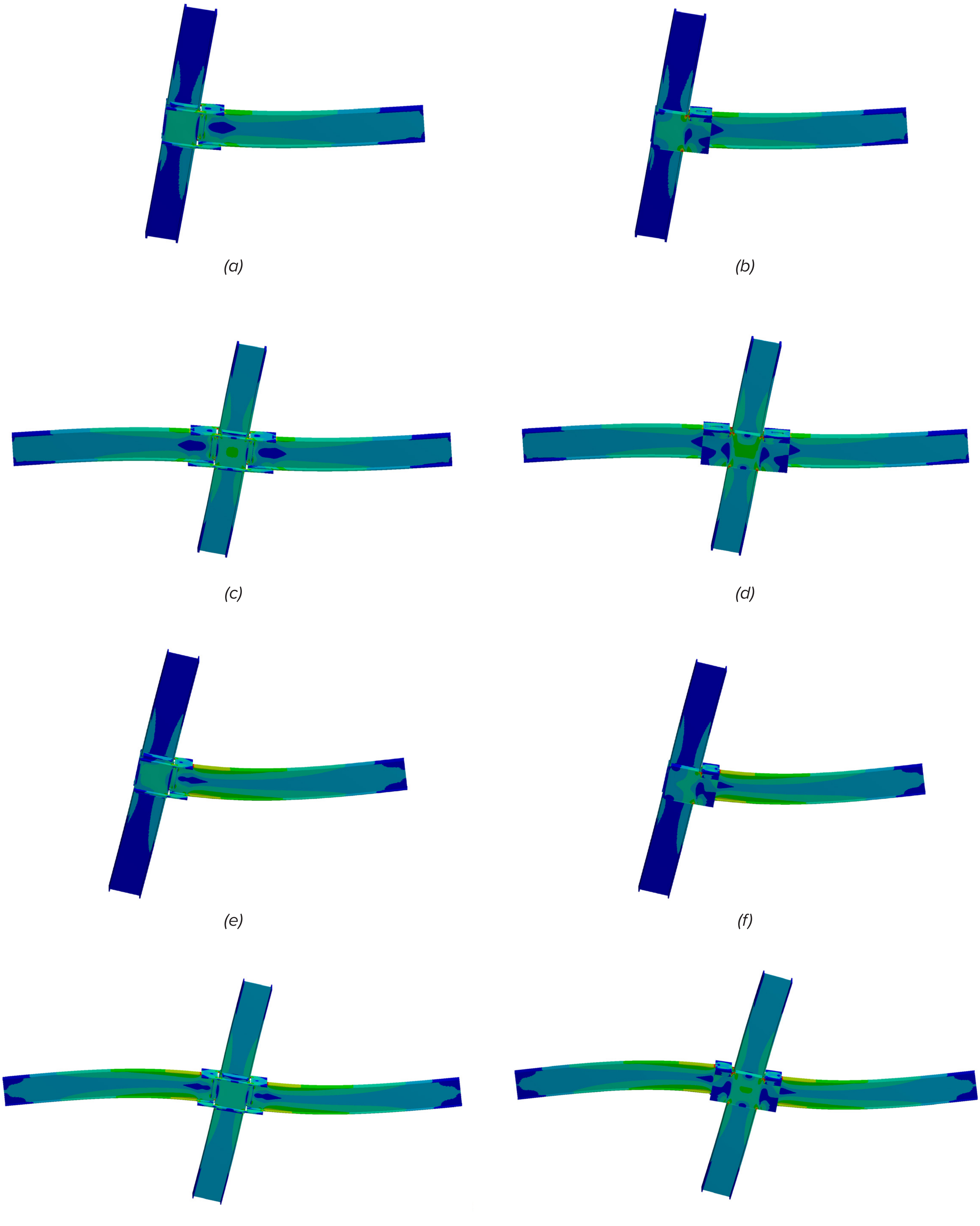


(a) *(b)*

Fig. 4 *Finite element models for evaluating sub-assembly stiffness: (a) DFF-1; (b) SP-1. Other models similar*

Results and Discussion

The finite element models were used to determine sub-assembly stiffness. Fig. 5 shows the models under lateral loading with deformations exaggerated and Mises stresses shown. The models for each sub-assembly (e.g., DFF-1 and SP-1) are shown with the same scales.



(a) *(b)*

(c) *(d)*

(e) *(f)*

(g) *(h)*

Fig. 5 *ANSYS models subjected to lateral loading:*
(a) DFF-1; (b) SP-1; (c) DFF-2; (d) SP-2; (e) DFF-3; (f) SP-3; (g) DFF-4; and (h) SP-4

Table 4 summarizes the stiffness results from the study. For each model, the stiffness was calculated as the applied lateral force (10 kips) divided by the lateral displacement, δ [see Fig. 2(c)]. The last column of Table 4 compares the stiffness of the DFF and SP models for each sub-assembly. DFF stiffnesses were all greater (2.1 to 3.6 percent) than the comparable SP connections, despite using less connection material (Table 3).

Table 4 *Sub-assembly stiffness results from the finite element analyses*

Sub-Assembly	DFF Stiffness (k/in)	SP Stiffness (k/in)	DFF/SP
1	48.1	46.8	1.027
2	87.0	85.2	1.021
3	16.7	16.3	1.024
4	30.0	29.0	1.036

The source of the higher efficiency for DFF is suggested in Fig 5. The Mises stress contours show that for SP connections [Fig. 5(b), (d), (f), (h)], very little force is resisted in the regions of plate A (Fig. 1) that extend past the face of the column. Also, the lack of a shear tab in the SP connection is detrimental to the SP overall connection stiffness.

Since R=3 DFF connections have greater stiffness than SP connections, they may be used in place of SP connections.

Conclusions

In low-seismic regions, proprietary moment frame connections may be used for R=3 steel moment frames to reduce beam and column sizes. The purpose of this study was to compare the weight and stiffness of DuraFuse Frames® (DFF) and SidePlate® (SP) connections for R=3 design.

Finite element modeling was performed with ANSYS to compare the stiffness of moment frame sub-assemblies with R=3 DuraFuse Frames (DFF) and SidePlate (SP) connections. Four sub-assembly geometries were considered in combination with the two connection types.

The study supports the following conclusions:

- DFF connections required less material than comparable SP connections. DFF connections used 15 to 22 percent less steel.
- Despite using less connection material, DFF sub-assemblies had greater stiffness than comparable SP sub-assemblies. DFF sub-assemblies had 2.1 to 3.6 percent greater lateral stiffness.
- R=3 DFF connections can be used in place of R=3 SP connections without changing beam and column sizes.

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