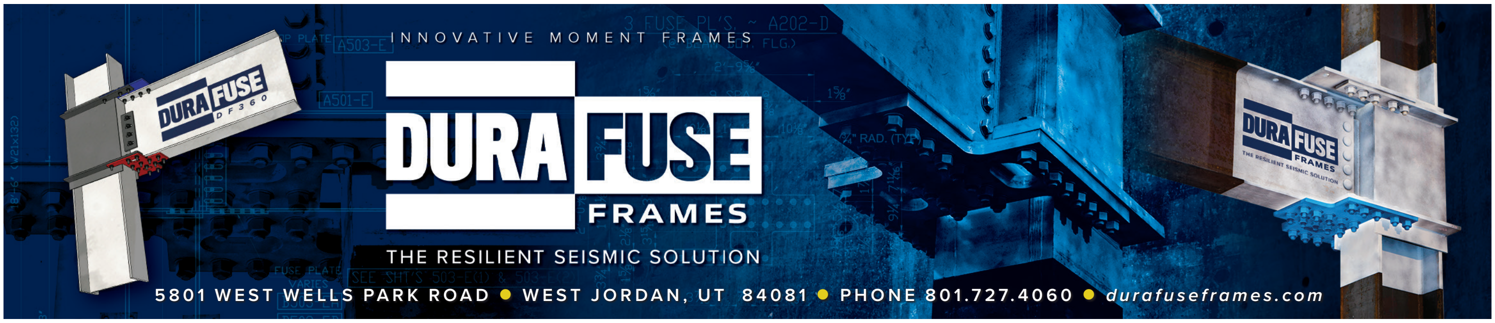

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TECHNICAL BULLETIN 7

How DuraFuse Frames are Represented in RAM

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Abstract: The software RAM Frame has the option to model moment frame connections as DuraFuse Frames connections. When this option is selected, the joints have stiffness parameters assigned to reflect the stiffness of DuraFuse Frames connections, as determined from analytical methods and experimental testing. The beam-to-column connection is considered to be fully restrained (FR) and the panel zone stiffness is modeled using the scissor method, following procedures recommended in the literature.

Introduction

Connection modeling procedures for moment frames are governed by ASCE/SEI 7-16 § 12.7.3b (ASCE, 2016), ANSI/AISC 360-16 § B3.4 (AISC, 2016a), and precedents in ANSI/AISC 358-16 (AISC, 2016b). Basic requirements are that the panel zone deformations be explicitly considered in all models that are used for drift calculations (ASCE, 2016) and that the connection stiffness be explicitly considered unless the connection is fully restrained (FR) (AISC 360, 2016a).

With regards to the panel zone, the most common mathematical models for representing panel zone deformations explicitly are the Krawinkler model and the scissor model. Charney and Marshall (2006) provide a thorough description of both models and derive the spring constants for both models. Fig. 1 illustrates the scissor model. Charney and Marshall demonstrate that the scissor model gives equivalent results as the Krawinkler model if the spring stiffness is defined correctly.

With regards to the beam-column connection itself, when connections are fully restrained (FR), it is not necessary to introduce a spring between the beam and column elements in the model. The DuraFuse Frames connection has been shown through experimental testing to be a fully-restrained (FR) connection (Richards, 2020). In some DuraFuse Frames configurations, connection plate material increases the flexural stiffness at the end of the beam.

The software RAM Frame has built-in features to model the DuraFuse Frame connection, correctly representing the panel zone stiffness and the connection stiffness. Technical Bulletin No. 3 (McCall and Richards, 2020) explains the steps of assigning DuraFuse Frame connections in RAM.

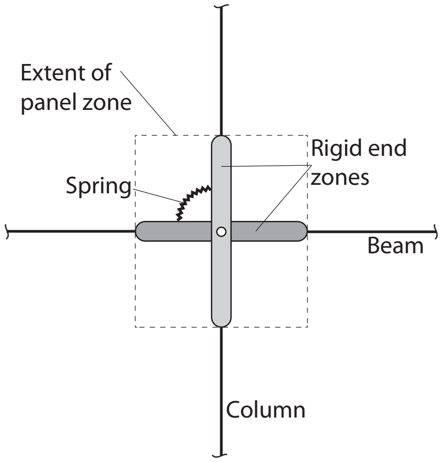

Fig. 1 *Scissor model for representing panel zone deformations in drift models*

The purpose of this bulletin is to explain the finite element formulation within RAM that is used to represent the DuraFuse Frames connection and panel zone.

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RAM Frame - Finite Element Model

Fig. 2 shows the general finite element representation of the DuraFuse Frames connection as built into RAM Frame. Each of the regions will be discussed in turn.

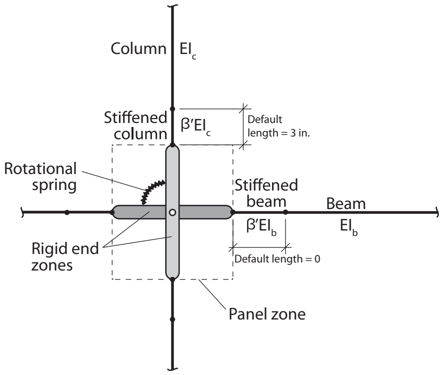

Fig. 2 *Finite element representation of DuraFuse Frames connection region in RAM Frame*

Column. The elements in this region have the un-modified cross-sectional properties of the column that frames into the connection. The flexural stiffness in the region is calculated using EI_c, where E is the modulus of elasticity of steel and I_c is the moment of inertia of the column.

Stiffened column. The default length of the stiffened region is 3 in., which is the standard distance that the cover plates extend beyond the panel zone. In this region, the column flexural stiffness is increased by a factor α'x, where α' is determined from the cover plate geometry (see Appendix A).

Beam. The elements in this region have the un-modified cross-sectional properties of the beam that frames into the connection. The flexural stiffness in the region is calculated using EI_b, where E is the modulus of elasticity of steel and I_b is the moment of inertia of the beam.

Stiffened beam. The default length of the stiffened end region is 0, such that the default is for beam properties to be constant all the way to the face of the column. In some DuraFuse Frames configurations, additional flexural stiffness is provided at the end of the beam. If the stiffened end region is assigned a non-zero length, the strong-axis moment of inertia of the beam elements in that region is increased by a factor β'x, where β' is determined from the connection plate geometry.

Rigid end zones. The regions of the beam and column within the panel zone are represented with rigid elements as part of the scissor model for the panel zone. For joints with two beams framing in, the rigid end zones at the end of each beam are united as part of the scissor model (Fig. 1). Similarly, for joints with two columns framing in, the rigid end zones at the end of each column are united as part of the scissor model.

Rotational spring. A rotational spring element connects the beam and column rigid elements as part of the scissor model.

Panel Zone Spring Stiffness

For a DuraFuse Frames connection, the stiffness of the panel zone spring in the scissor model is calculated using formulas developed and validated by Charney and Marshall (2006). The total spring stiffness (Eq. 1) is computed as the sum of two parts, one corresponding to the web stiffness in the panel zone (Eq. 2), and the second corresponding to the flange stiffness in the panel zone (Eq. 3).

$$K = \widetilde{K}_{ps} + \widetilde{K}_{fs} \tag{Eq. 1}$$

$$\widetilde{K}_{ps} = \frac{G\nabla_p}{(1+\alpha+\beta)^2} \tag{Eq. 2}$$

$$\widetilde{K}_{fs} = \frac{0.78G(b_{fC})(t_{fC})^2}{(1+\alpha+\beta)^2} \tag{Eq. 3}$$

where:

α	Ratio of effective depth of column to span length (L)
β	Ratio of effective depth of beam to column height (H)
b_{fC}	Width of column flange
t_{fC}	Thickness of column flange
G	Shear modulus of steel
∇_p	Volume of panel zone, including cover plates

Conclusions

This note has described the way that RAM Frame models the DuraFuse Frames connection. The beam-to-column connection is considered to be fully restrained (FR) and the panel zone stiffness is modeled using the scissor method, with spring parameters determined using procedures recommended in the literature. The model can also account for increased flexural stiffness in the columns and beams in the connection region, where appropriate.

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Appendix A

– Derivation of Column Stiffness Adjustment Factor

This appendix derives the factor α’ which adjusts the flexural stiffness of the column in the regions where the cover plates extend past the panel zone.

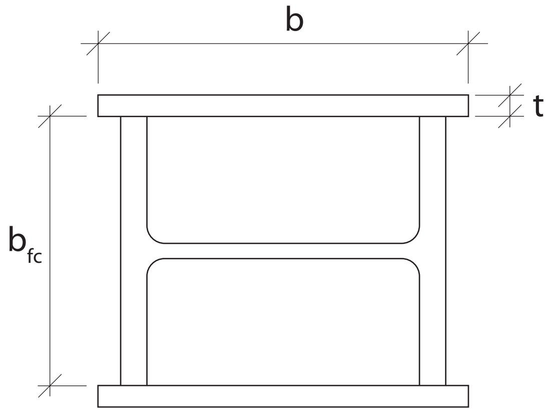

Fig. A1 *Cross-section of the column in the regions where the cover plates extend past panel zone*

Strong Axis

$$I_x = I_{cx} + 2\left(\frac{tb^3}{12} + 0^2\right)$$

where, I_{cx} = moment of inertia of the un-reinforced column about the strong axis.

$$I_x = I_{cx} + \frac{t}{6}b^3$$

$$I_x = I_{xc}\left(1 + \frac{t}{6I_{xc}}b^3\right)$$

$$\alpha'_x = \frac{I_x}{I_{xc}}$$

$$\alpha'_x = 1 + \frac{tb^3}{6I_{cx}}$$

Weak Axis

$$I_y = I_{cy} + 2\left(\frac{t^3b}{12} + tb\left(\frac{b_{fc}}{2} + \frac{t}{2}\right)^2\right)$$

where, I_{cy} = moment of inertia of the un-reinforced column about the weak axis

$$I_y = I_{cy} + 2tb\left[\frac{t^2}{12} + \left(\frac{b_{fc}}{2} + \frac{t}{2}\right)^2\right]$$

$$I_y = I_{cy}\left(1 + \frac{2tb}{I_{yc}}\left[\frac{t^2}{12} + \left(\frac{b_{fc}}{2} + \frac{t}{2}\right)^2\right]\right)$$

$$\alpha'_y = \frac{I_y}{I_{cy}}$$

$$\alpha'_y = 1 + \frac{2tb}{I_{yc}}\left[\frac{t^2}{12} + \left(\frac{b_{fc}}{2} + \frac{t}{2}\right)^2\right]$$

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