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TECHNICAL BULLETIN 10

Difference in Repair Cost for DuraFuse Frames vs. Other Steel Moment Frame Systems

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Abstract: Buildings that are designed with current codes are expected to be damaged during severe earthquakes. FEMA-P58 was developed to quantify expected building losses, based on the characteristics of the building and the seismic hazard. This bulletin summarizes a FEMA-P58 study that was used to compare the difference in expected building repair costs for DuraFuse Frames vs. a traditional steel moment frame system (RBS). DuraFuse Frames reduce structural repair costs by a factor of four, and residual drift demolition losses by a factor of ten.

Introduction

Buildings that are designed with current codes are expected to experience inelastic deformation during severe earthquakes. Code-compliant buildings are designed to survive severe earthquakes, but may not be economical to repair. For example, after the 2011 Christchurch, New Zealand, earthquake, 70% of buildings in the Central Business District required demolition [Spencer (2011)].

DuraFuse Frames are steel special moment frames that have superior repairability as compared to other steel moment frames. DuraFuse Frames are designed such that all inelastic behavior is confined to a replaceable fuse plate, while other special moment frames are designed to form plastic hinges at the ends of the beam. DuraFuse Frames can be repaired by replacing the fuse plate, whereas other special moment frames require replacement of the beams.

In the past 20 years, there has been a coordinated effort in the research community towards quantifying expected losses for buildings from earthquake hazards. FEMA-P58 is a probabilistic performance prediction method that was developed for FEMA by the Applied Technology Council [(ATC (2019a), ATC (2019b)]. FEMA-P58 takes site hazard, structural response, and fragility curves, and uses Monte Carlo simulation to generate loss estimates (economic loss, repair time, and casualties).

FEMA-P58 has been used to quantify losses for steel special moment frame buildings that experience beam plastic hinging. For example, Fig. 1 shows loss estimates for a 9-story building with RBS connections. The figure is

indicating a total loss estimate of 38% of the replacement cost of the building, for a peak ground acceleration of 0.91g.

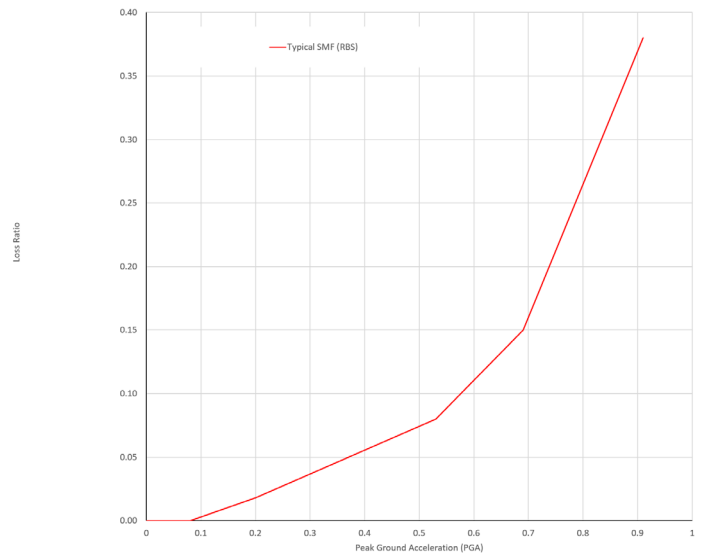


Fig. 1 Loss estimate for 9-story building with RBS moment frames [data from Haselton Baker Risk Group (2020b)]

This technical bulletin summarizes a FEMA-P58 analysis to quantify the difference in building repair cost for DuraFuse Frames and other moment frames.

Connection Repair Cost

In the FEMA-P58 methodology, connection repair costs are developed for distinct damage states. These

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damage states are generically called Damage State 1, Damage State 2, and so forth. Since “Damage State 1” and “Damage State 2” are different for each connection, it can be challenging to make an “apples-to-apples” comparison. Two factors must be considered when comparing systems: 1) the relative cost to repair particular damage states, and 2) the relative likelihood of particular damage states being reached.

First, the relative cost to repair particular damage states can be evaluated for different systems. For example, Table 1 shows costs to repair a DuraFuse Frames connection for the two defined damage states, next to costs to repair an RBS connection for its three defined damage states. The cost to repair DuraFuse Frames connections is about half that to repair conventional RBS connections [Haselton Baker Risk Group (2020a)]. Additional details on the damage state definitions and methods for determining repair costs are found in Haselton Baker Risk Group (2020a).

Table. 1 Repair cost comparison between DuraFuse Frames and conventional RBS detailing with costs in 2011 USD [Haselton Baker Risk Group (2020b)]

DS	DuraFuse (B1035.301)		RBS (B1035.001)	
	Description	Repair Cost	Description	Repair Cost
1	Damage to Fuse Plate	\$12,868	Local beam flange and web buckling	\$21,750
2	Beam/column deformation	\$15,000	DS1 plus lateral-torsional distortion of beam in hinge region	\$36,625
3	-	-	Low-cycle fatigue fracture in buckled region of RBS	\$36,625

The other factor that has to be considered when comparing systems is the likelihood that particular damage states will be reached. This information is communicated through fragility curves. Haselton Baker Risk Group (2020a) used experimental data for DuraFuse Frames [Reynolds and Uang (2019)] to develop fragility curves for the DuraFuse Frames connection following the same methodology that has been used to develop fragility curves for other SMF connections [ATC (2019a), ATC (2019b), Baker (2019)]. Fig. 2 compares fragility curves for the DuraFuse Frames damage states with those for an RBS connection. The DuraFuse Frames fragility curves are further to the right, indicating that DuraFuse Frames connections are less likely to require repair after a severe earthquake.

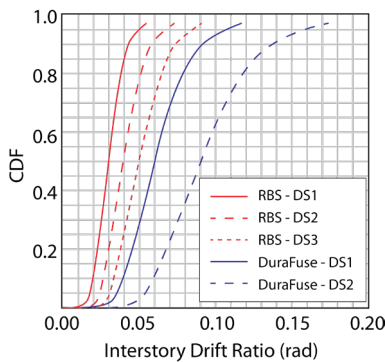


Fig. 2 Fragility curves for traditional (red) and DuraFuse Frames (blue) connections [data from Haselton Baker Risk Group (2020a)]

In order to appreciate the combined effects of less expensive repairs and the lower likelihood of needing repairs, building studies were performed to compare the probable repair costs (in terms of loss ratios) for DuraFuse Frames vs. typical special moment frames. These building comparison studies are discussed in the rest of the bulletin.

Building Comparison Study

Two buildings at a high seismic site in Los Angeles were used for a comparison study. The spectra for the site are shown in Fig. 3. Both buildings had a 10,000 SF footprint, but one building was 3-story, and the other 9-story. Both buildings were evaluated twice, once assuming RBS connections and once assuming DuraFuse Frames connections.

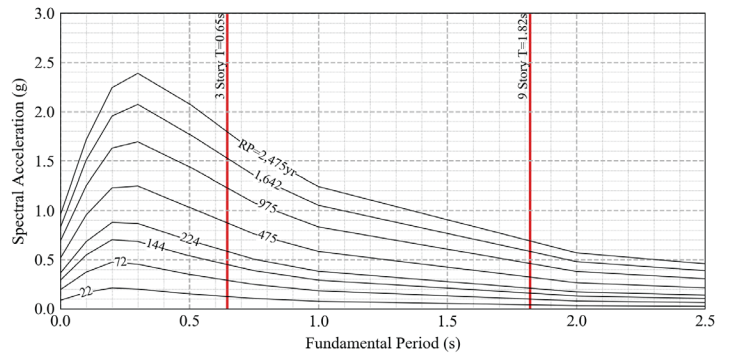


Fig. 3 Spectra used for FEMA-P58 [Haselton Baker Risk Group (2020b)]

At each intensity, structural responses were estimated using the SP3 Structural Response Prediction Engine. The DuraFuse Frames and RBS would have similar drifts since they would be designed for the same drift limits and the systems have similar connection strength relative to the beams. Figs. 4 and 5 shown the inter-story drift ratios that were estimated using the SP3 Structural Response Prediction Engine, which appear reasonable compared to typical design drift ratios.

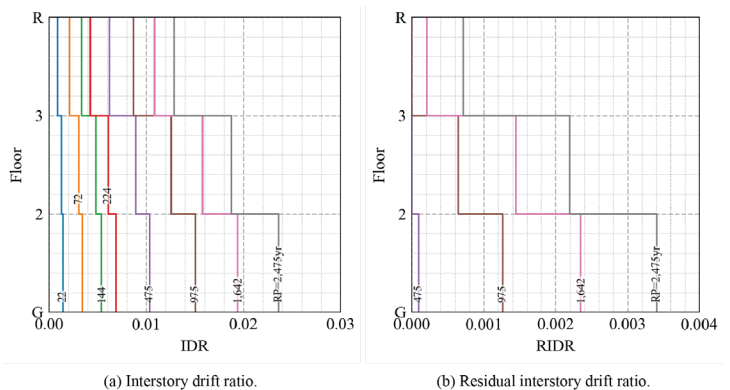


Fig. 4 Three-story drift-based response prediction [Haselton Baker Risk Group (2020b)]

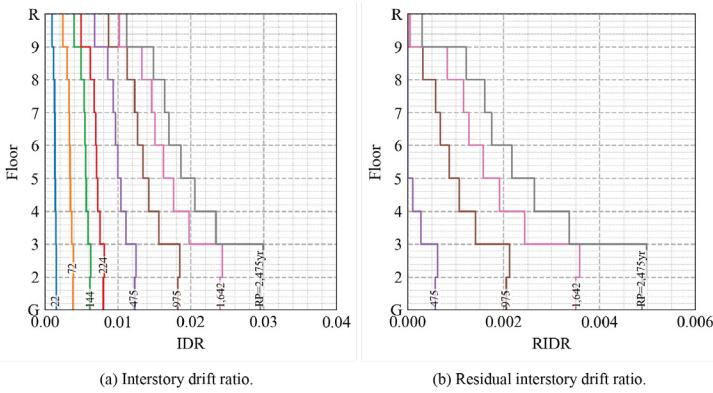


Fig. 5 Nine-story drift-based response prediction [Haselton Baker Risk Group (2020b)]

The first FEMA—P58 results to be presented are those when the costs associated with residual drift are ignored. Fig. 6 shows the structural loss ratio for the various cases. DuraFuse Frames reduce structural losses by a factor of four. This dramatic reduction in structural loss is the combination of less expensive repairs and lower likelihood of needing repairs.

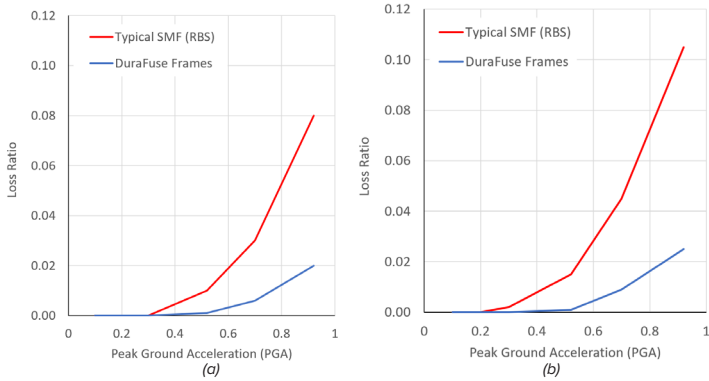


Fig. 6 Expected structural losses from FEMA-P58 Analysis, neglecting residual drift: (a) 3-story building, (b) 9-story building [data for plots from Haselton Baker Risk Group (2020b)].

The second results to be presented are those that include the impact of residual drift on building repair. For typical moment frames, a median residual drift demolition threshold is assumed to be 1%. This is consistent with observations from the Christchurch Central Business District, where 70% of buildings required demolition after the 2011 earthquake. With DuraFuse Frames, replumbing is more feasible because the beams and columns remain elastic, and residual drift can be unlocked by removing the fuse plates. DuraFuse Frames are deemed to be repairable for residual drifts up to at least 2.5% [Haselton Baker Risk Group (2020a)]. In the FEMA-P58 study, thousands of cases were considered in the Monte Carlo simulation and some showed excessive residual drifts (demolition required, 100% loss). Data was aggregated from all the cases, and an expected median loss associated with residual drift demolition was determined.

Fig. 7 compares residual drift demolition losses for the DuraFuse Frames vs. RBS frames. “The repair cost associated with residual drift demolition is greatly mitigated by the DuraFuse Frame’s ability to be re-plumbed post-earthquake instead of demolishing the building” [Haselton Baker Risk Group (2020b)]. DuraFuse Frames reduce losses by a factor of ten or more, when residual drift considerations are included.

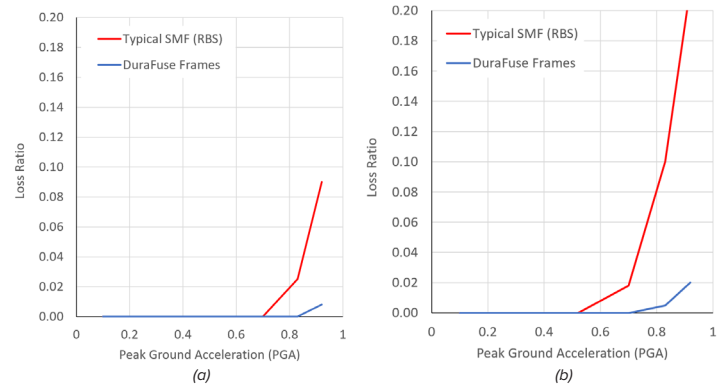


Fig. 7 Residual Drift losses from FEMA-P58 Analysis, neglecting residual drift: (a) 3-story building, (b) 9-story building [data for plots from Haselton Baker Risk Group (2020b)].

Conclusions

Buildings that are designed with current codes are expected to be damaged during severe earthquakes. FEMA-P58 can be used to quantify the cost of expected building damage, based on the characteristics of the building and the seismic hazard. FEMA-P58 was used to compare the difference in expected building repair costs for DuraFuse Frames vs. a traditional steel moment frame system (RBS).

This note has discussed the following points, that are fully developed in the source reports:

- DuraFuse Frames are less likely to require repair after a severe earthquake, as indicated by fragility curves that are located to the right of traditional systems.
- If damaged, DuraFuse Frames connection are less expensive to repair because damage is limited to a fuse plate that can be unbolted and replaced.
- Neglecting residual drift consequences, DuraFuse Frames reduce expected structural repair costs by a factor of four.
- Including demolition consequences due to excessive residual drift, DuraFuse Frames reduce expected losses by a factor of ten or more.

References

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