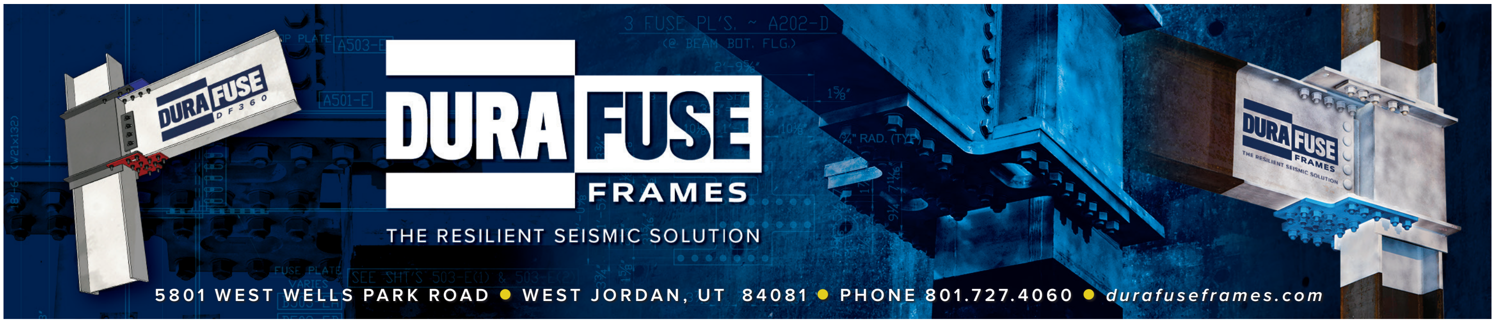

04/23

TECHNICAL BULLETIN 26

Criteria for Replacing Fuse Plates after a Severe Earthquake

Paul Richards, PhD, PE[1]

Abstract: DuraFuse Frames (DFF) have replaceable fuse plates that prevent beam and column damage during severe earthquakes. This technical bulletin reviews criteria for determining if fuse plates need to be replaced after an earthquake. Fuse plates should be replaced if residual drifts are causing serviceability problems or if there is evidence that maximum story drifts have exceeded 4%. Otherwise, experimental testing indicates that fuse plates will work for another design event.

Introduction

DuraFuse Frames (DFF) have replaceable fuse plates that prevent beam and column damage during severe earthquakes. This technical bulletin reviews criteria for determining if fuse plates need to be replaced after a severe earthquake. The recommendations are based on experimental testing.

There are two criterion that dictate the need to replace the fuse plates. First, fuse plates need to be replaced if residual drifts are problematic. Second, fuse plates need to be replaced if the remaining energy dissipation capacity is insufficient for another design-level event.

The flowchart in Figure 1 can be used to determine if fuse plates need to be replaced in a particular story of a building. The first question is: “Are residual drift story drifts impacting building service?” Since this is a serviceability question it can be answered by a non-engineer. If residual story drifts are impacting building service, fuse plates in the effected stories should be unbolted, the stories re-plumbed, and new fuse plates installed.

If residual drifts are not impacting building service, fuse plates should still be inspected after a design-level earthquake and checked for evidence that the story experienced drifts in excess of 4%. Figure 2 shows typical fuse plate yielding at different levels of story drift (Richards 2022). Flaking of the mill-scale on the fuse plate is evidence of the extent of fuse yielding and the amount of strain hardening in the primary yielding regions. Comparing the mill scale flaking with Fig. 2 can provide an estimate of the drift that the story experienced. If flaking suggests that the drifts exceeded 4%, then the fuse plates in that story should be replaced.

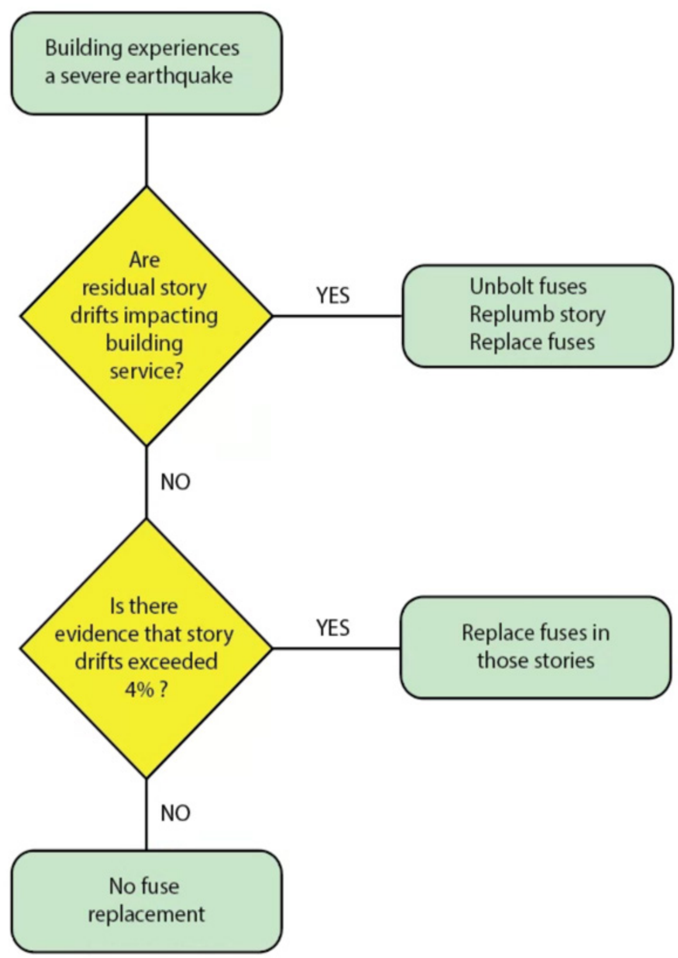

Fig. 1 *Flowchart for post-earthquake assessment of fuse plates.*

1 Vice President, DuraFuse Frames, 5801 West Wells Park Road, West Jordan, UT 84081. Email: *paul.richards@durafuseframes.com*

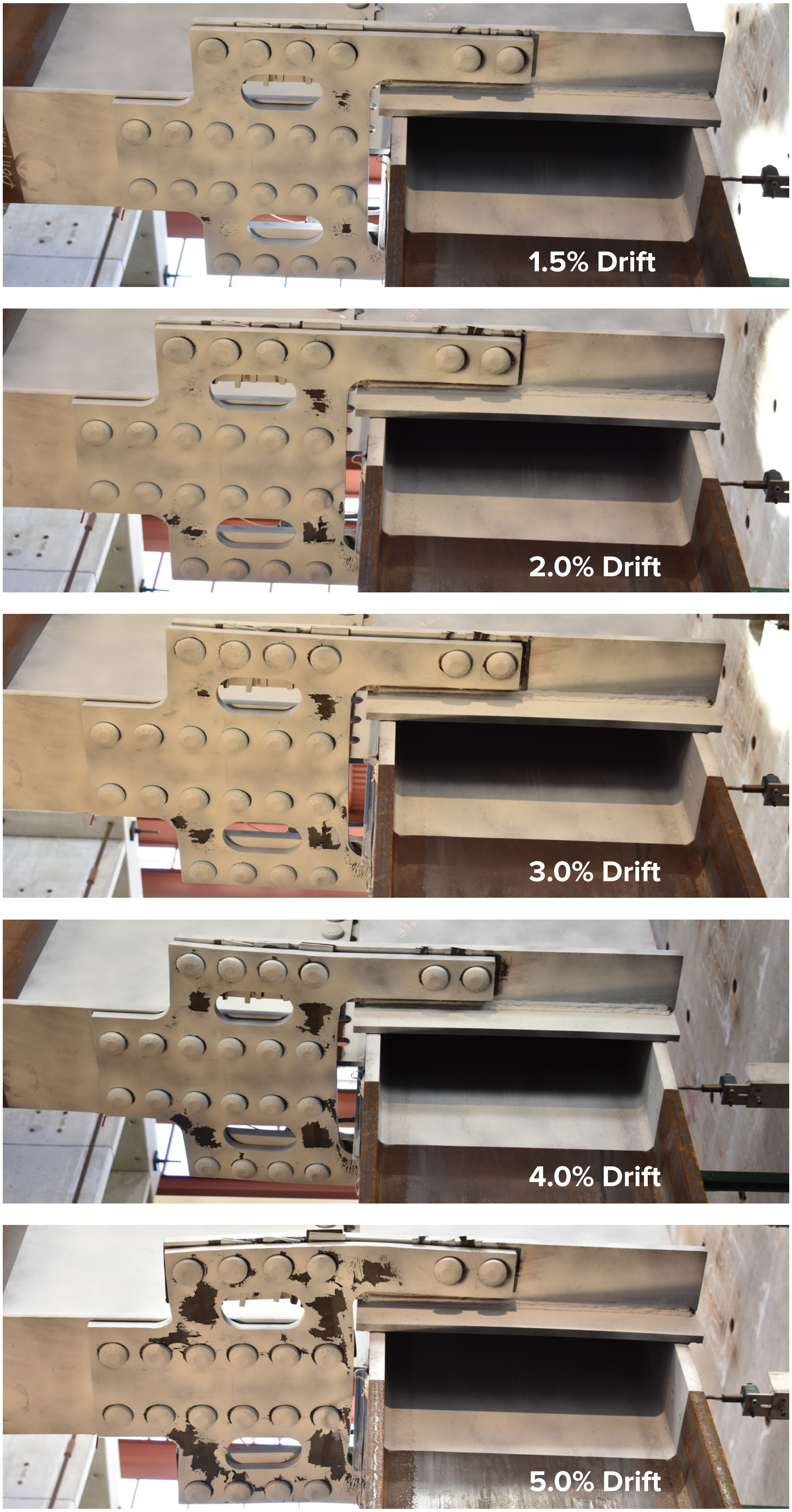

Fig. 2 *Mill scale flaking corresponding to different levels of story drift (Richards 2022).*

Example 1 – UCSD MTB2 Building

In 2022, a three-story building with DFF connections was tested on the outdoor shake table at the University of California San Diego (UCSD). The frame was subjected to more than 10 strong ground motions, including the full-scale near-source recording from the Rinaldi Station during the 1994 Northridge Earthquake.

Inspection of the building after the completion of testing did not indicate residual drifts that would impact building service. The fuse plates in the bottom stories showed evidence of yielding (Fig. 3), but not evidence that the story drift exceeded 4%. Mill flaking suggested a maximum story drift of about 2% (compare Fig 3. with Fig. 2), which is similar to what was measured by the instruments during testing. Fuse plate replacement would not be required under these circumstances.

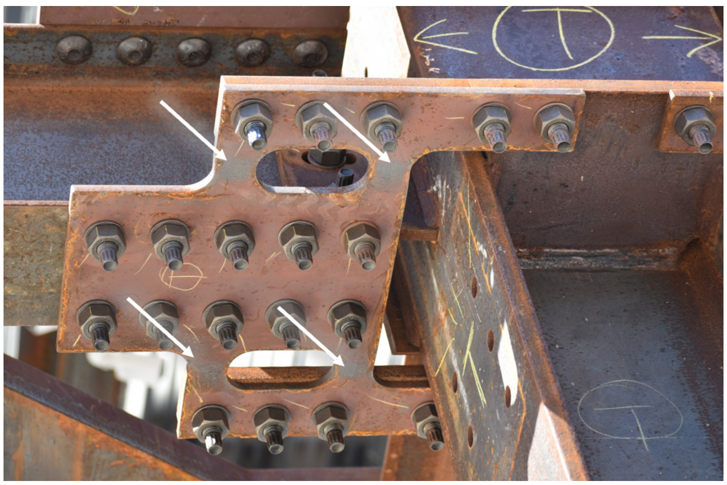

Fig. 3 *Mill scale flaking consistent with about 2%story drift.*

Example 2 – Specimen H2

In 2019, a sub-assembly test was performed with a loading protocol that represented three MCE earthquakes (Northridge scaled up, Loma Prieta scaled up, and Kobe scaled up) applied to a building in succession, without any repairs in between. Figure 4 shows the fuse plate after the three earthquakes.

If the fuse plate had been inspected after the Northridge loading, the estimated maximum drift based on mill scale flaking would have been about 2%, which is consistent with what was measured during testing. The flowchart (Fig. 1) would indicate that the fuse plate would be fine without replacement. If the fuse plate had been inspected after the Loma Prieta loading, the estimated maximum drift based on mill scale flaking would have been about 2.5% which would have suggested the fuse plate was good for at least another design earthquake without replacement. The successful subsequent testing with the Kobe loading proved that correct.

Looking at the fuse plate after the Kobe loading, the mill scale flaking suggests story drifts around 4% were reached, which is consistent with what was measured by the instruments. This level of fuse plate yielding and hardening makes the fuse plate questionable for future events, and it should be replaced (Fig. 1).

(a) *after Northridge*

(b) *after Loma Prieta*

(c) *after Kobe*

Fig. 4 *Mill scale flaking for MCE tests in sequence. (Lee and Uang, 2021).*

Additional Discussion

While the method for evaluating fuse plates described above is somewhat crude, it is justified by prequalification testing and material theory. Low-cycle-fatigue material failure occurs as a result of cumulative inelastic demands, with inelastic strains from large cycles being more damaging than those from smaller cycles with the same cumulative strain.

Figure 5 shows the cumulative inelastic rotation that is experienced by a connection tested under the standard AISC moment frame loading protocol (assuming 1% elastic rotation). By the qualification limit (one cycle at 0.04 rad), the cumulative inelastic rotation demand is 0.4 rad. DuraFuse Frames specimens have completed two cycles at 0.05 rad or one or two cycles at 0.06 rad prior to fuse plate fatigue (Richards 2022). Figure 5 illustrates how this represents more than double the cumulative inelastic rotation capacity that is required to resist the event represented by the standard loading protocol up to 0.04 rad. Therefore, it is reasonable to judge that a fuse plate has sufficient capacity to resist another design-level earthquake, as long as there is no evidence that a previous earthquake has caused story drift greater than 4%.

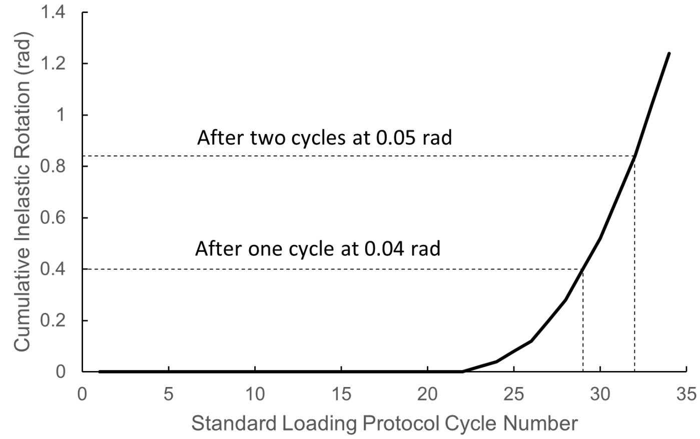

Fig. 5 *Cumulative inelastic rotations from the standard special moment frame loading protocol (assuming elastic rotation of 0.01 rad).*

Conclusions

A flowchart is presented to assist engineers in determining if DuraFuse Frames fuses need to be replaced after a severe earthquake. If residual drifts are causing serviceability problems, the fuse plates can be removed, the building replumbed, and new fuse plates installed. If there are no residual drift issues, fuse plates only need to be replaced if there is evidence that story drifts have exceeded 4%. Otherwise, experimental testing indicates that fuse plates will work for another design event.

References

Lee, H., and Uang, C.-M. (2021). “TR-21/05, Cyclic Testing of DuraFuse Frames Moment Connections for SMF and IMF Applications: Series K Specimens.” La Jolla, CA.

Richards, P.W. (2022). “Cyclic behavior of DuraFuse Frames moment connections.” Engineering Journal, 2022(Q2), 135-148.