DISCUSSION OF

Fragility Curves for Wide-Flange Steel Columns and Implications for Building-Specific Earthquake-Induced Loss Assessment

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INTRODUCTION

We congratulate the authors for their extensive use of laboratory test data in developing fragility curves (Elkady et al. 2018). In particular, we appreciate how they derived fragility curves from two sets of laboratory test data that used different component-loading protocols. There are huge differences in the fragility curves depending on the data set used in their formulation (figure 10 in Elkady et al. 2018). The purpose of this discussion is threefold:

1. To underscore the importance of using laboratory test protocols that reflect actual earthquake-response patterns.
2. To emphasize that data from laboratory tests using "standard" protocols have shortcomings, making them of dubious value in fragility curve development as well as in performance-based engineering methods such as *ASCE/SEI 41-17* [American Society of Civil Engineers (ASCE) 2017].
3. To encourage future tests to use protocols reflecting actual earthquake-response patterns so that the results are suited for performance-based engineering applications, such as in backbone curve formulation.

The authors make an important observation that laboratory test results using "standard" symmetric loading protocols can be very different from those using "collapse-consistent" protocols. Figure 1 shows how the collapse-consistent protocol can lead to median damage state drifts being a factor-of-two larger than those from standard protocols. Which set of damage state drifts is best suited for use in performance-based engineering? The answer is the drift set that reflects actual expected earthquake component response, as explained below.

LOADING PROTOCOLS

Figure 2 shows typical standard loading protocols. They are characterized by fully reversed cyclic loading with progressively increasing levels of displacement. It is readily apparent that such displacement patterns do not mimic the responses one would expect from actual earthquakes.

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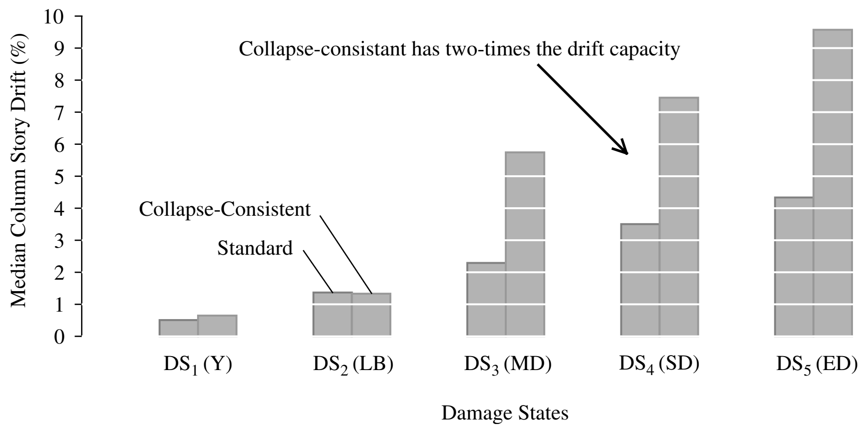

Figure 1. Drifts defining column damage states from laboratory tests using different loading protocols (standard and collapse-consistent). Data taken from tables 3 and 8 of Elkady et al. (2018). Y, onset of yielding; LB, onset of local buckling; MD, onset of moderate damage; SD, onset of severe damage; and ED, onset of excessive damage.

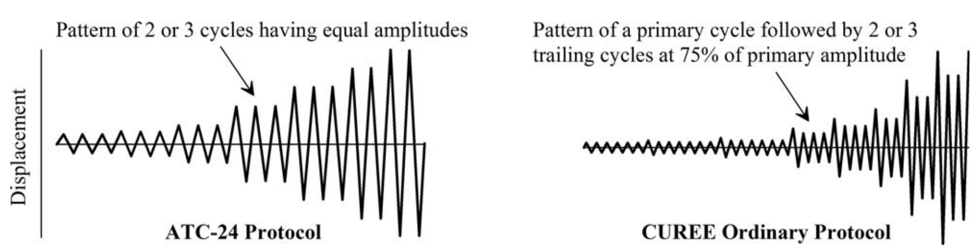

Figure 2. Representative standard loading protocols: *ATC-24* (Applied Technology Council 1992) and CUREE ordinary (Krawinkler et al. 2001).

Figure 3 shows loading protocols derived from numerous earthquake-response simulations of four-story buildings. Figure 3a shows a collapse-consistent protocol representing a near-collapse condition. In essence, it has numerous undulations centered on one major excursion in the positive direction. Figure 3b shows a maximum considered earthquake (MCE)-level protocol based on the median results at MCE shaking intensities. The MCE-level protocol has smaller peak drift than the collapse-consistent protocol, as expected, because the latter is an incipient collapse condition. Both protocols are similar in that they have relatively few major excursions with a one-direction bias. A design earthquake (DE)-level protocol corresponding to a DE is similar to the MCE-level protocol except with several more major excursions at smaller peak drift.

Note how protocols reflecting actual earthquake response vastly differ from standard protocols (Figures 2 and 3). It can be expected that component laboratory tests using the standard

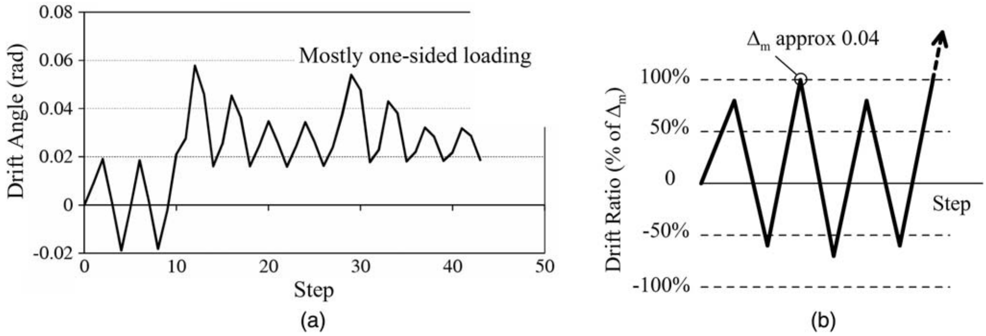

Figure 3. Loading protocols based on simulated building response. (a) Collapse-consistent protocol (adapted from figure 8a in Yusuke and Lignos 2014), and (b) maximum considered earthquake protocol based on median building response (adapted from figure 18a in Maison and Speicher 2016).

protocol will lead to results that are not representative of those from actual earthquakes, and such data must be treated with caution in performance-based engineering application.

FRAGILITY CURVES

The authors perform an impressive rigorous development of multivariate fragility curves, but, unfortunately, they use data only from laboratory tests that used the standard protocol (table 1 of Elkady et al. 2018). The fragility curves therefore require further development to better reflect actual earthquake response. Accordingly, the authors correctly note that the fragility curves based on table 1 (Elkady et al. 2018) data are valid only up to the onset of local buckling (DS_2 in Figure 1). More credence should be placed on their univariate fragility curves based on the table 7 (Elkady et al. 2018) data using collapse-consistent protocols.

The authors' example building study shows that monetary losses because of column damage constitute only a small portion of the total monetary loss when using the different fragility curves (figure 12 of Elkady et al. 2018). This can give the impression that the fragility curves are somewhat equivalent because they lead to same conclusion. While this may be the case for the example building, it is important to recognize the significant influence loading protocols can have on other aspects of performance-based engineering.

BACKBONE CURVES

ASCE/SEI 41-17 component force-deformation (backbone) curves are commonly based on envelopes of component hysteresis loops derived via experimental testing (ASCE 2017). Figure 4 illustrates how standard fully reversed cyclic protocols generally have envelopes of component response (backbones) with the smallest displacement capacities, consistent with the authors' observations (Figure 1). Recognizing the problem with standard loading protocols, *ASCE/SEI 41-17* (section 7.6) now emphasizes the importance of protocols in the formulation of backbone curves. The rationale for the change can be found in Maison and Speicher (2016).

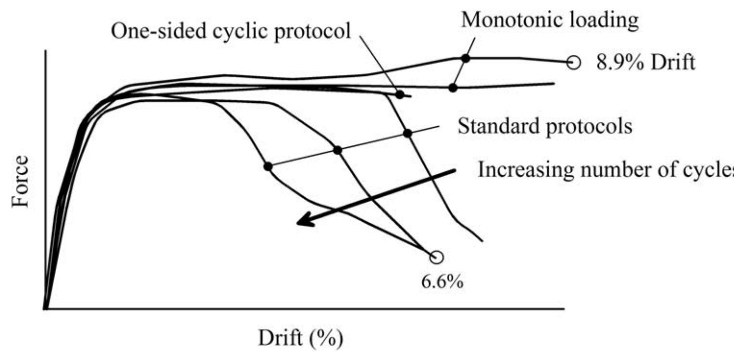

Figure 4. Envelopes of cyclic test results (backbones) from six identical reinforced-concrete bridge piers subjected to various loading protocols. Figure adapted from figure 2-20 in *FEMA P-440A* report (*ATC-62* project), *The Effects of Strength and Stiffness Degradation on Seismic Response* (Federal Emergency Management Agency 2009).

CONCLUSIONS

We acknowledge the authors' impressive rigorous formulation of fragility curves but would appreciate special emphasis on laboratory tests that use loading protocols reflecting actual earthquake response. Future laboratory tests using realistic earthquake loading patterns are encouraged so that the results are best suited for performance-based engineering.

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