DISCUSSION

Observations from Cyclic Tests on Deep, Wide-Flange Beam-Columns

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Discussion by BRUCE F. MAISON

The writer congratulates the authors for a truly impressive number of lab tests on beam-columns (Ozkula et al., 2017). Such data are valuable for advancing our knowledge of actual component behaviors in step with the gaining popularity of performance-based seismic design. The purpose of this Discussion is to point out that component backbone curves are strongly influenced by the specimen loading history (protocol) used in lab tests, and realistic seismic loading protocols ought to be included when formulating backbone curves.

The loading protocols used in the authors' tests were mostly those from AISC 341 (AISC, 2010) consisting of fully reversed cyclic loading at progressively increasing peak displacement amplitudes. The AISC 341 loading protocol is for moment connection qualification in new construction. It provides evidence that a component satisfies certain ductility requirements and is a consistent way to compare the relative performance of different components. The protocol does not mimic actual earthquake loading histories and is *not* specifically intended for use in backbone curve formulation. As a result, backbone curves derived from the envelope of cyclic test data may not adequately describe component behavior at near-collapse inelastic displacement levels (FEMA, 2009). The component ductility can be significantly underestimated. Loading protocols used in tests to demonstrate connection qualification are not the same as those for backbone curve formulation.

Figure 1 illustrates the significant difference in component response resulting from the loading protocol used in the test. A backbone curve based on the cyclic envelope would be appropriate if the earthquake generates numerous fully reversed cycles of response, but the monotonic test would be a better backbone if the quake generates few cycles. Near-collapse seismic response is more like a monotonic as opposed to fully reversed cyclic loading (Krawinkler, 2009). Note how the strength deterioration in the authors' backbone curve is an artifact from the load reversal points in the loading protocol.

The authors' study included one test of strong-axis bending under monotonic loading. Backbone curves for the Group 2 tests (W24×131) are shown in Figure 2. Specimen 2L-P (monotonic loading) had no strength deterioration at a story-drift ratio (SDR) of 4%. However, specimen 2L (fully reversed cyclic loading) had notable strength deterioration. The authors' observation that most of the strong-axis bending specimens were not able to deliver a plastic rotation of 0.03 radian is relevant to AISC 341 component qualification requirements. However, in the context of actual earthquake performance, the observation is not as ominous as might be perceived by the casual reader. Albeit, more tests using realistic earthquake loading histories are needed for confirmation.

The new ASCE 41-17 (2017) recognizes the importance of loading protocols and provides additional freedom in protocol selection to better reflect actual seismic demand patterns. It does not prescribe a specific "one-size-fits-all" loading protocol due to the wide variation of factors involved with a particular component—for example, performance objective, type of structure, and seismic setting. To ensure reasonable protocols are selected for a particular component and project, concurrence is required by independent peer reviewers experienced with the use of test data in design and analysis of structures.

Figure 3 shows a loading protocol depicting a median building response from a maximum considered earthquake (MCE). It is based on statistics from analysis of a four-story building model subjected to numerous earthquake records (Maison and Speicher, 2016). Note how the protocol has a bias in the positive direction and relatively few response cycles. A monotonic push to component failure is added at the end of the cycling portion to capture response at large near-collapse displacement levels. Another protocol based on long duration earthquakes has a similar pattern but with more response cycles (Maison and Speicher, 2018).

Because most prior component tests were performed using fully reversed cyclic loadings, ASCE 41-17 allows

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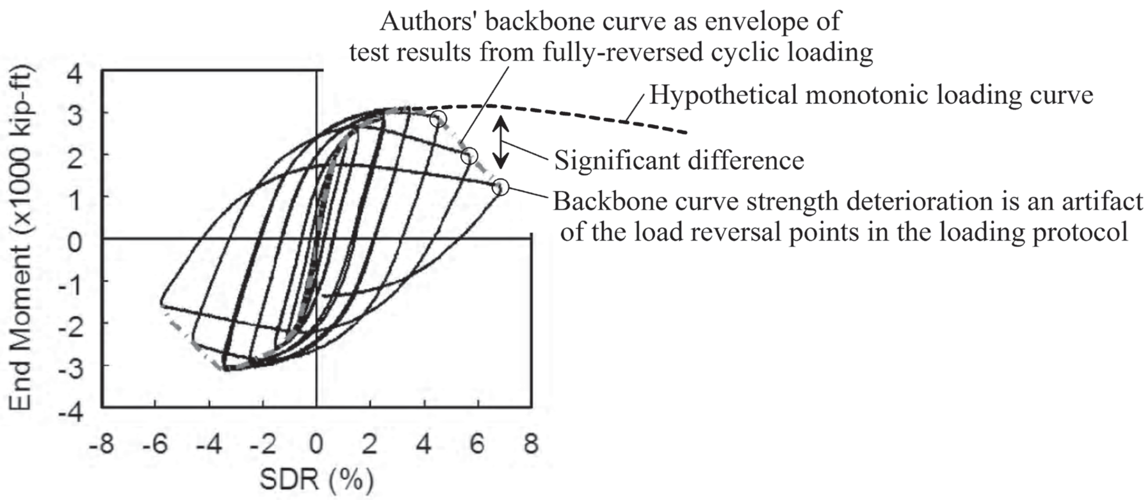

Fig. 1. Comparison of backbone curves derived from fully reversed and monotonic loading protocols (adapted from Fig. 11a of Ozkula et al., 2017).

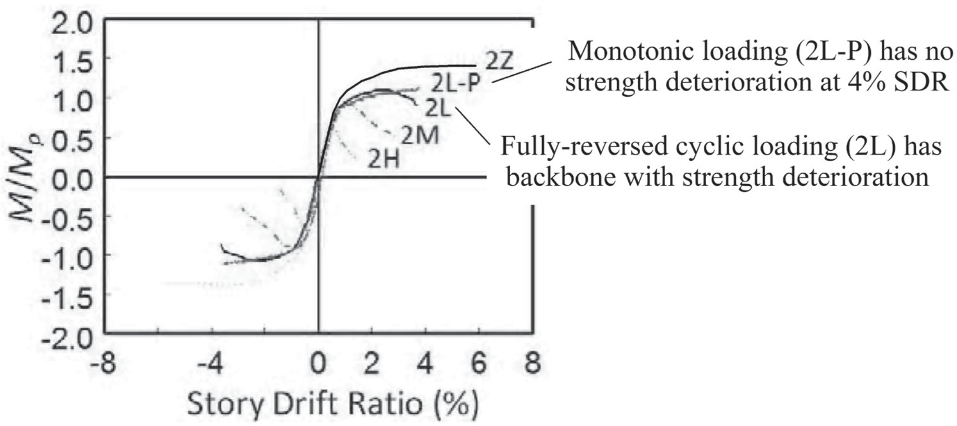

Fig. 2. Backbone curves derived from Group 2 (W24×131) lab tests (adapted from Fig. 12b of Ozkula et al., 2017)

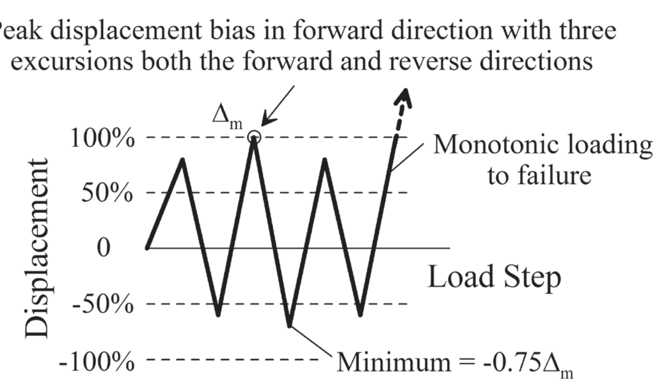

Fig. 3. MCE level median loading protocol (adapted from Fig. 18 of Maison and Speicher, 2016).

such test data to be supplemented to better define behavior at large near-collapse displacement levels. It is permitted to combine cyclic and monotonic test data in the formulation of backbone curves in cases where the cyclic tests show specimen strength degradation that is an artifact of the loading protocol as that shown in Figure 1. Figure 4 from ASCE 41-17 illustrates one way this can be done. As a precaution, a displacement limit is placed in the monotonic data leading to the abrupt decline in the backbone at point *E*.

In closing, the writer appreciates the value of the authors' research but encourages the inclusion of test data from realistic earthquake and/or monotonic load patterns in the future to supplement AISC 341 cyclic testing, thus providing more comprehensive results that are better suited for ASCE 41 backbone curve formulation.

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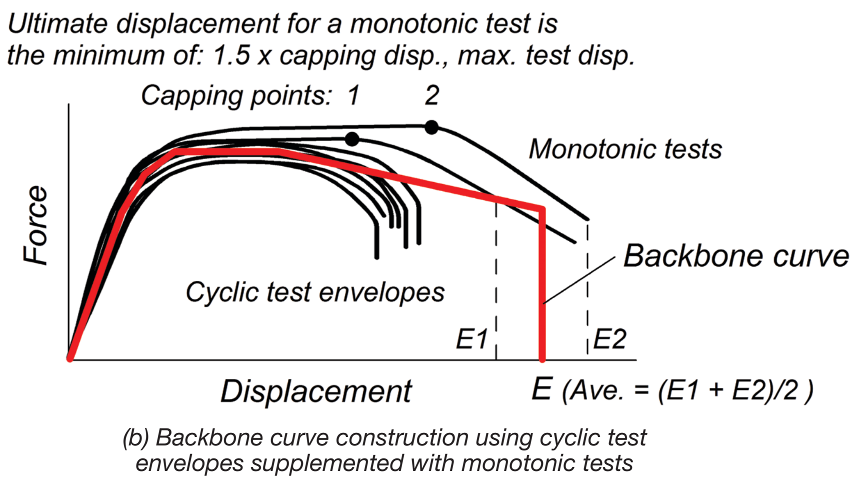

Fig. 4. Illustration of backbone curve derived from combination of cyclic and monotonic test data [adapted from Fig. 7-6 of ASCE 41-17 (2017)].