
The Adequacy of Using Cumulative Inelastic Ductility to Predict BRB Fracture Capacity: Comparing CID to Fatigue Damage Index

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ABSTRACT

The durability of Buckling-Restrained Braces (BRB) has long been characterized through the cumulative inelastic ductility (CID) capacity of the steel yielding core. CID is a measure of the total amount of plastic deformation that a material undergoes in a given loading protocol. Since the incorporation of BRBs in the AISC Seismic Provisions in 2005, BRBs have been required to have a CID capacity of at least 200. However, CID capacity may not be a reliable predictor of BRB fatigue capacity as loading protocols can be developed which produce CID values that vary widely for BRBs of identical design and fabrication. In testing, for example, different loading protocols can produce a CID capacity of 3x the AISC requirement of 200, or more than 10x the AISC requirement, with the difference depending primarily on the loading protocol that was applied. This implies that CID may only be a reliable measure of fracture capacity within a common loading protocol. In contrast, recently developed fatigue modelling is available which can predict the fracture of the BRB yielding core with reasonable accuracy for each of the different loading protocols using a calculated damage index or D-Value. This paper will report on the varying protocols used to achieve the vastly different CID capacities and the testing done to establish the method for calculating the D-Value and establishing its accuracy and will aid in establishing reasonable limits for using CID values as a measure of BRB fracture capacity.

1 INTRODUCTION

Buckling-restrained braces (BRBs) are widely used as seismic structural fuses due to their stable hysteretic response and reliable inelastic deformation capacity. In current design practice, BRB ductility capacity is commonly characterized using cumulative inelastic ductility (CID), which represents the total inelastic deformation accumulated prior to fracture. Accordingly, the AISC *Seismic Provisions* (AISC 2022) require BRBs to demonstrate a minimum CID capacity of 200 during qualification testing.

Despite its simplicity, the reliability of CID as an index for predicting BRB fatigue fracture under general loading histories remains uncertain. Experimental results have shown that CID at fracture can vary

significantly with loading protocol, even for BRBs with similar geometry and material properties, suggesting that a single CID value may not adequately reflect fracture susceptibility under realistic seismic demands.

An alternative framework for assessing BRB fracture behavior is provided by strain–life–based low-cycle fatigue (LCF) models combined with rainflow cycle counting and cumulative damage concepts. This paper evaluates the suitability of CID by comparing it with strain–life–based low-cycle fatigue (LCF) damage indices, in which fracture is predicted when the accumulated fatigue damage reaches unity. The comparison is based on a comprehensive dataset of 18 full-scale BRB fatigue tests, and focuses on assessing the consistency and reliability of fracture prediction across different loading histories.

2 DETERMINATION OF CUMULATIVE INELASTIC DUCTILITY (CID)

Cumulative inelastic ductility (CID) is a nondimensional index, normalized by the brace yield displacement Δ_{by} , used to quantify the accumulation of inelastic deformation experienced by a buckling-restrained brace (BRB) over a given displacement history. As illustrated in Figure 1, the inelastic deformation is evaluated based on an idealized elastic–perfectly plastic (EPP) representation of the brace axial force–deformation (P – Δ_b) response for simplicity. Under this assumption, the elastic portion of a displacement excursion between two consecutive displacement reversals is taken as $2\Delta_{by}$, with any displacement excursion beyond this elastic component assumed to contribute to inelastic deformation.

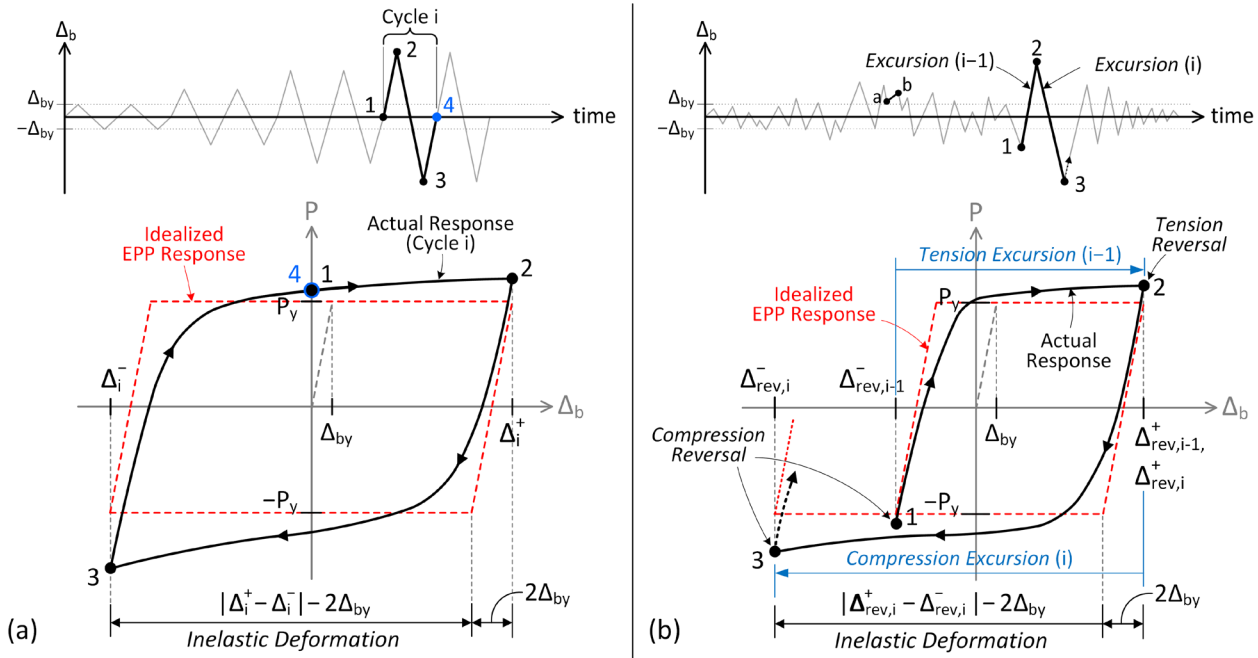


Figure 1: Determination of inelastic deformation for computing CID of BRBs for (a) regular cyclic loading history and (b) irregular loading history.

For regular cyclic loading histories [Figure 1(a)], the inelastic ductility demand produced by an individual full cycle i , denoted as $\mu_{i-cycle}$, is computed as

$$\mu_{i-cycle} = 2 \left(\frac{|\Delta_i^+ - \Delta_i^-| - 2\Delta_{by}}{\Delta_{by}} \right) = \frac{2|\Delta_i^+ - \Delta_i^-|}{\Delta_{by}} - 4 \quad (1)$$

where Δ_i^+ and Δ_i^- are the peak tensile and compressive displacements of the i -th cycle, respectively.

For irregular displacement histories, such as those resulting from earthquake ground motions, the cyclic response may not consist of clearly defined full cycles. In such cases, the displacement history is decomposed into individual tension and compression excursions between successive load reversals, as illustrated in Figure 1(b). Here, a tensile excursion refers to a displacement path that progresses toward tension between two successive load reversals, such as the excursion between points 1 and 2 where points 1 and 2 are the successive load reversals. Similarly, a compressive excursion is a path that progresses towards compression, such as the path from 2 to 3. A tension or compression reversal refers to the displacement reversal occurring at the end of a tensile or compressive excursion, respectively.

It is noted that only the displacement reversals that define the start and end of an excursion transitioning from a plastic state on one side (tension or compression) to a plastic state on the opposite side (compression or tension), and thus resulting in displacements beyond the elastic range, are treated as counted reversals for excursion identification; intermediate reversals and the associated excursions that do not produce additional inelastic deformation within an excursion counted toward CID are therefore disregarded. An example of a disregarded excursion is shown between points a and b in Figure 1(b). Cycles or excursions between counted reversals (those which produce inelastic deformation), will be referred to as counted cycles or counted excursions.

Under the same EPP assumption adopted for regular cyclic loading, the elastic portion of each counted displacement excursion is taken as $2\Delta_{by}$, except for the very first excursion from the virgin state to the first displacement reversal ($\Delta_{rev,1}$) reaching the plastic range, for which the elastic portion is taken as $1\Delta_{by}$. The corresponding inelastic ductility demand is therefore $\mu_1 = (|\Delta_{rev,1}| - \Delta_{by})/\Delta_{by}$. The inelastic ductility demand associated with the i -th excursion ($i > 1$) is then calculated as

$$\mu_{i-\text{excursion}} = \frac{|\Delta_{rev,i}^+ - \Delta_{rev,i}^-| - 2\Delta_{by}}{\Delta_{by}} = \frac{|\Delta_{rev,i}^+ - \Delta_{rev,i}^-|}{\Delta_{by}} - 2 \quad (2)$$

where $\Delta_{rev,i}^+$ and $\Delta_{rev,i}^-$ denote the peak displacements immediately before and after the i -th excursion.

The CID accumulated up to fracture, denoted by the subscript f , of a BRB is then obtained by summing the inelastic ductility contributions from all cycles or excursions:

$$CID_f = \sum \mu_i \quad (3)$$

where μ_i represents either $\mu_{i-\text{cycle}}$ or $\mu_{i-\text{excursion}}$, depending on the loading history type. CID_f is commonly used to represent the inelastic deformation capacity of a BRB.

3 LOW-CYCLE FATIGUE DAMAGE INDEX FOR FRACTURE ASSESSMENT

An assessment procedure combining experimentally developed low-cycle fatigue (LCF) models, the rainflow cycle-counting method, and Miner's damage index was developed by Li et al. (2022) to predict fatigue fracture of BRBs under random cyclic loading histories. The accuracy of the procedure was validated using a range of variable-amplitude test results, including simulated earthquake loading tests.

3.1 Low-Cycle Fatigue Model

A low-cycle fatigue (LCF) model expressed in terms of strain-life relationship was established based on a series of fatigue tests on 11 full-scale BRB subjected to symmetric, constant-amplitude cyclic loading up to fracture. Figure 2 shows a representative single-cycle stress-strain (σ - ϵ) response of a BRB. The core stress, σ , is obtained by dividing brace axial force by the yielding core area, A_{sc} , while the core strain, ϵ , is

calculated as $\varepsilon = \Delta_b / L_y$, where Δ_b is the brace axial displacement and L_y is the yielding core length, with the simplifying assumption that all brace deformation is concentrated within the yielding core region.

The hysteresis loop consists of a compression excursion (from points A to B) and a tension excursion (from points B to A). The strain range, also referred to as the total strain range and denoted as $\Delta\varepsilon_t$, is defined as the absolute strain excursion during either a tension or a compression excursion. Each strain range comprises elastic and plastic components. The elastic component, $\Delta\varepsilon_e$, is calculated as $\Delta\varepsilon_e = \Delta\sigma / E$, where $\Delta\sigma$ is absolute stress range of a strain excursion and E is the Young's modulus of steel. The plastic component $\Delta\varepsilon_p$ is determined as $\Delta\varepsilon_p = \Delta\varepsilon_t - \Delta\varepsilon_e$.

Using the conventional LCF model development approach used for metallic materials, a standard LCF model for BRBs was developed by regression analysis of the fatigue test data as shown in Figure 3. The model is derived by combining the independently established elastic and plastic strain-life relationships, with elastic and plastic components expressed in Basquin-type (Basquin 1910) and Coffin-Manson-type (Coffin 1954; Manson 1953) equations, respectively. The resulting model directly relates the total strain range, $\Delta\varepsilon_t$, to the number of cycles to fracture, N_f , as given in Eq. (1).

$$\Delta\varepsilon_t = \Delta\varepsilon_e + \Delta\varepsilon_p = 0.0066N_f^{-0.1279} + 0.1965N_f^{-0.5463} \quad (1)$$

This model is expressed in a form equivalent to the Coffin-Manson-Basquin equation (Morrow 1965). Owing to its nonlinear form, and due to the inclusion of separate elastic and plastic strain-life terms, determination of N_f for a given $\Delta\varepsilon_t$ requires an iterative solution, such as Newton-Raphson method. However, inclusion of the elastic strain-life term allows this standard LCF model to also account for high-cycle fatigue behavior at low strain ranges.

Because no closed-form solution can be obtained from the standard model, an alternative LCF model is developed for ease of practical application. As shown in Figure 3, using the same $\Delta\varepsilon_t$ - N_f data set, a linear regression in log-log space yields a direct power-law relationship between fatigue life and strain range,

$$N_f = 0.0151(\Delta\varepsilon_t)^{-2.2695} \quad (2)$$

with a coefficient of determination of $R^2 = 0.994$, indicating an excellent fit to the experimental data. This alternative model provides predictions similar to the standard model in the low-cycle fatigue domain but may underestimate fatigue life at low strain ranges where elastic-cycle contributions are significant; nevertheless, its applicability to earthquake-type loading histories, which are typically controlled by low-cycle fatigue, has been experimentally validated.

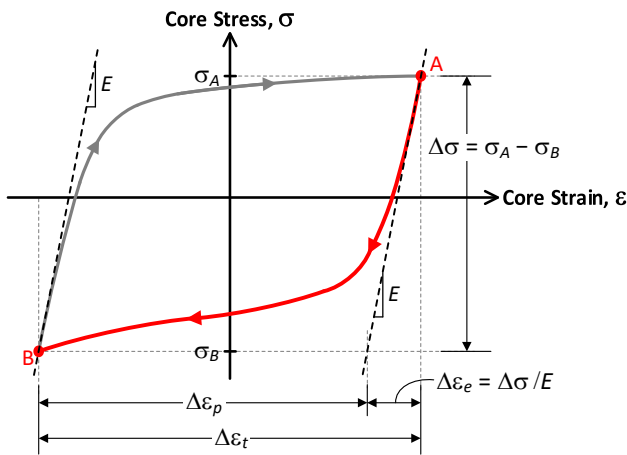


Figure 2: Definition of strain range, $\Delta\varepsilon$

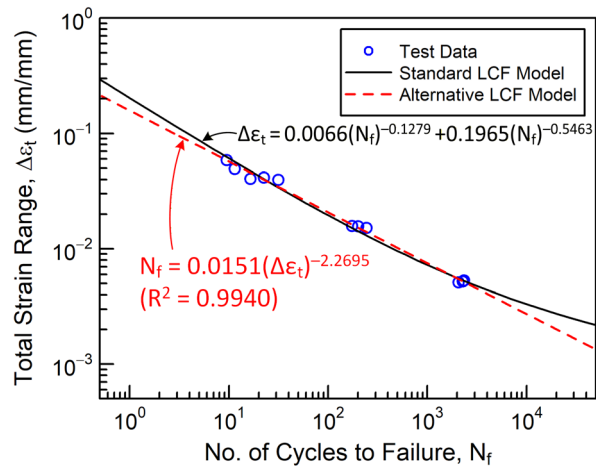


Figure 3: Low-cycle fatigue (LCF) models for BRBs

3.2 Damage Index for Fatigue Fracture Assessment

To assess the fatigue damage of BRBs subjected to variable-amplitude (random) loading histories, the strain-life LCF models developed by Li et al. (2022) (standard or alternative) are combined with the rainflow cycle-counting method (Matsuishi and Endo 1968; ASTM 2023) and Miner's damage index (Miner 1945). The rainflow cycle-counting method is first applied to a given BRB core strain time history to decompose the irregular loading history into a series of full cycles and half cycles of strain excursions, with each full or half cycle associated with a corresponding strain range.

For each identified strain cycle i , with a total strain range $\Delta\epsilon_{t,i}$, the corresponding fatigue life, $N_{f,i}$, is evaluated using either the standard or alternative LCF model, depending on the application. The fatigue damage contribution of each cycle is then quantified using Miner's linear damage accumulation rule. For a loading history consisting of N_{full} full cycles and N_{half} half cycles, the cumulative fatigue damage index, D , produced by the given core strain history is calculated as

$$D = \sum_{i=1}^{N_{full}} \frac{1}{N_{f,i}} + \frac{1}{2} \left[\sum_{j=1}^{N_{half}} \frac{1}{N_{f,j}} \right] \quad (3)$$

where $N_{f,i}$ and $N_{f,j}$ denote the fatigue lives associated with the strain ranges of the i -th full cycle and j -th half cycle, respectively. The value of damage index, D , reaching 1.0, corresponding to 100% consumption of fatigue life, is taken to indicate the predicted onset of fatigue fracture of the BRB core.

On the other hand, when this fatigue fracture assessment procedure is applied to a BRB core strain that is known up to the point of observed fracture, the resulting value of the damage index is denoted as D_f . The parameter D_f represents the cumulative fatigue damage predicted by the model at the actual fracture point and is therefore used as a validation metric to evaluate the accuracy of the fatigue assessment procedure. A value of $D_f > 1.0$ indicates that fatigue fracture occurs later than predicted by the model, implying an underestimation of the fatigue life, whereas a value of $D_f < 1.0$ indicates an overestimation of the fatigue life.

4 FATIGUE TEST PROGRAM AND RESULTS

4.1 BRB Fatigue Test Data Description

Table 1 summarizes the fatigue test data utilized in this study, which are drawn from a comprehensive series of 18 full-scale BRB tests previously reported by Li et al. (2022). These tests were conducted to characterize the low-cycle fatigue fracture behavior of BRB steel cores under a range of cyclic loading histories, as illustrated in Figure 4. The complete dataset is adopted herein to compare the effectiveness of CID and strain-life-based fatigue damage indices in predicting BRB fatigue fracture.

The specimens were grouped into three series, denoted as the A-, B-, and C-series, with increasing steel core cross-sectional areas of 3,652 mm², 7,232 mm², and 11,135 mm², respectively. All BRB steel cores were fabricated from A36 steel, with measured yield stresses of approximately 300 MPa across the three series, resulting in corresponding brace yield strengths (P_{ya}) of approximately 1,110 kN, 2,220 kN, and 3,330 kN for the A-, B-, and C-series, respectively. All BRB specimens had similar overall brace lengths, ranging from approximately 5,400 to 5,475 mm, with yielding core lengths (L_y) of 3,777 mm, 3,048 mm, and 2,883 mm for the A-, B-, and C-series, respectively.

All specimens were tested under displacement control using the Seismic Response Modification Device (SRMD) facility at the University of California, San Diego, with loading applied at a near-real-time velocity representative of earthquake response rates. The testing program included both constant-amplitude and variable-amplitude loading protocols. Constant-amplitude protocols included symmetric constant-amplitude (SCA) tests [Fig. 4(a,b)] with zero-mean strain cycles and strain amplitudes ranging from $\pm 0.25\%$ to $\pm 3.0\%$, as well as asymmetric constant-amplitude (ACA) tests [Fig. 4(c)] with constant applied strain ranges but non-zero mean strain to investigate mean strain effects. Variable-amplitude protocols included two-stage constant-amplitude (2SCA) loading [Fig. 4(d)] with sequential low- and high-amplitude blocks, symmetric increasing (SI) loading [Fig. 4(e)] consisting of repeated sequences of progressively increasing strain amplitudes adapted from the AISC-prescribed BRB qualification protocols (AISC 2022), and simulated earthquake loading (EQ1, EQ2, and EQ3) derived from nonlinear time-history analyses of a 4-story buckling-restrained brace frame (BRBF) structure (AISC 2018) subjected to 100%–120% of Maximum Considered Earthquake (MCE) level ground motions. A representative earthquake loading sequence (EQ3) is shown in Fig. 4(f).

Table 1 summarizes the key fatigue test results, including the number of cycles to fracture, N_f , the average total strain range, $\overline{\Delta\epsilon_t}$, the maximum strain amplitude attained during testing, the cumulative inelastic ductility at fracture, CID_f , and the fatigue damage index at fracture, D_f , computed using fatigue assessment procedure based on LCF models (standard and alternative). Collectively, these quantities provide a consistent basis for evaluating BRB fracture behavior across different loading protocols and for comparing the predictive capabilities of CID and fatigue-based damage indices.

4.2 Comparison of CID and Damage Index in Predicting Fracture

Figure 5 presents a comparison of the cumulative inelastic ductility at fracture, CID_f [Fig. 5(a)], and the fatigue damage index at fracture, D_f [Fig. 5(b)], for all 18 BRB specimens considered in this study. In both subfigures, the test results are plotted for individual specimens arranged along the horizontal axis according to loading characteristics. From left to right, the ordering reflects, at a first level, increasing variability (or irregularity) of the loading history, and, within similar loading types, at a second level, increasing strain amplitude.

As shown in Figure 5(a), the CID_f for all tested BRB specimens substantially exceed the minimum CID requirement of 200 specified in AISC *Seismic Provisions* (AISC 2022) for BRB qualification, indicating that the tested braces possess deformation capacities far greater than the code-prescribed minimum. However, despite this uniformly high capacity relative to the AISC requirement, the CID_f values at fracture exhibit pronounced scatter, ranging from 624 to 6,780, with an average value of 2,577 and a coefficient of variation (COV) of 83.1%. The large dispersion observed across different loading protocols and deformation histories suggests that a single, constant CID_f value is not suitable as a reliable index for assessing BRB fatigue fracture.

In contrast, as shown in Figure 5(b), the fatigue damage index at fracture, D_f , exhibits substantially reduced scatter and clusters closely around unity. The D_f values based on the standard LCF model range from approximately 0.69 to 1.41, with an average value of 1.02 and a COV of approximately 22%, which is significantly smaller than that associated with CID_f . This tighter clustering indicates that the fatigue damage index provides a more consistent and stable basis for predicting BRB fatigue fracture across different loading protocols and deformation histories. Results obtained using the alternative LCF model show similar ranges and levels of dispersion, confirming that both LCF models provide satisfactory and robust fracture predictions for the test cases considered.

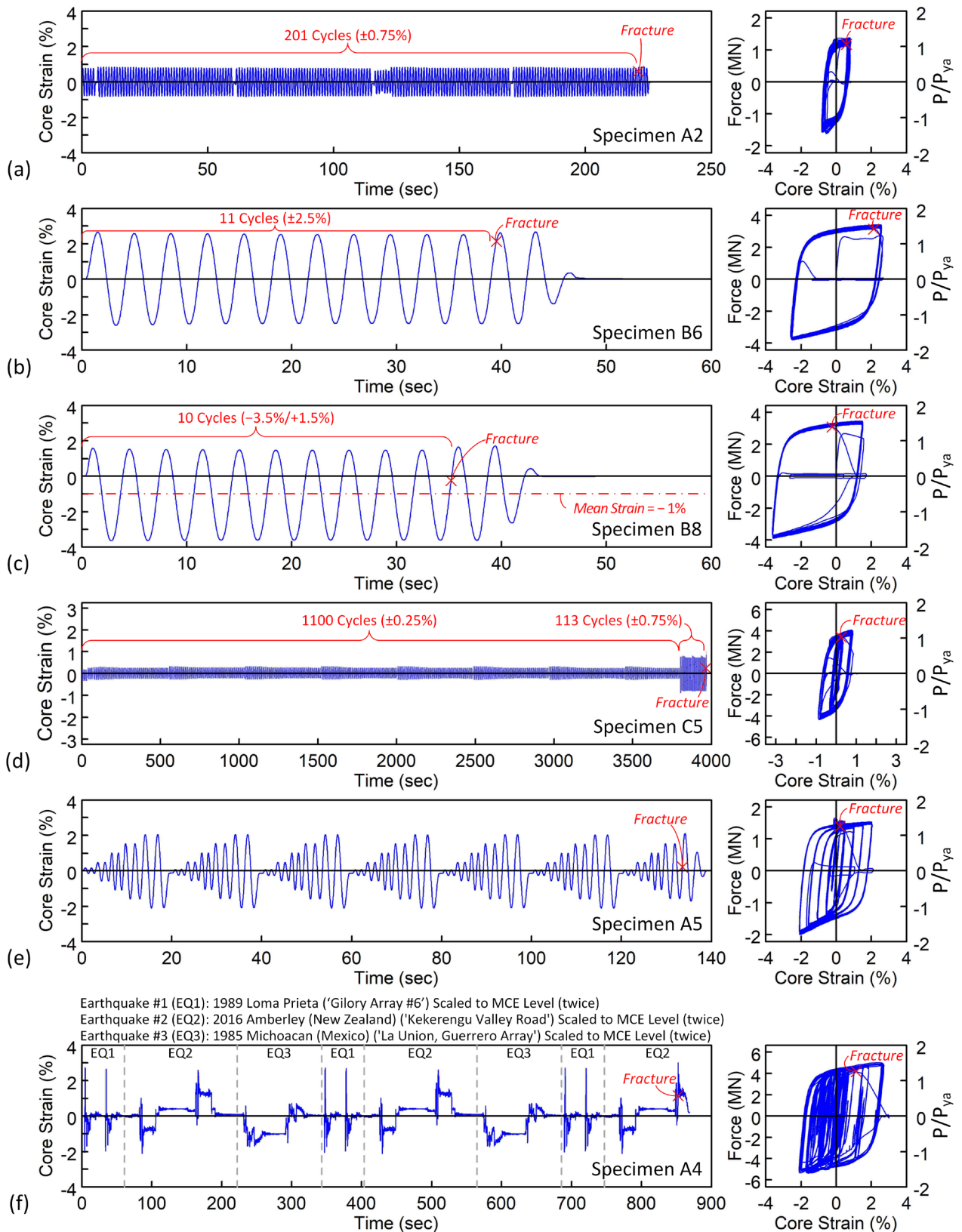


Figure 4: Fatigue testing results under various loading types: (a) constant-amplitude symmetric cycles at $\pm 0.75\%$ strain; (b) constant-amplitude symmetric cycles at $\pm 0.25\%$ strain; (c) constant-amplitude asymmetric cycles with a mean strain; (d) two-stage constant-amplitude symmetric cycles; (e) repeated sequences of symmetric increasing cycles; and (f) repeated simulated earthquake loading

Table 1: Summary of fatigue testing program and results.

Specimen	Loading Protocol	Rainflow Counting Results		Maxim Strain Amplitude (% mm/mm)		CID _f	D _f	
		N _f	$\overline{\Delta \varepsilon_t}$ (% mm/mm)	Tension	Compression		Std. LCF Model	Alt. LCF Model
A1	SCA ¹ (±0.25%)	2,072.5	0.509	0.28	−0.30	5,573	0.81	0.86
B1	SCA ¹ (±0.25%)	2,346.5	0.530	0.30	−0.31	6,780	1.02	1.07
C1	SCA ¹ (±0.25%)	2,278.5	0.519	0.37	−0.32	6,719	0.95	1.00
A2	SCA ¹ (±0.75%)	201.5	1.568	0.78	−0.88	3,346	1.25	1.07
B2	SCA ¹ (±0.75%)	174.5	1.570	0.91	−0.89	2,867	1.09	0.93
C2	SCA ¹ (±0.75%)	243.5	1.517	0.87	−0.80	3,957	1.41	1.20
A3	SCA ¹ (±2.00%)	16.5	4.027	2.15	−2.09	808	0.74	0.76
B3	SCA ¹ (±2.00%)	22.5	4.153	2.18	−2.13	1,126	1.07	1.10
C3	SCA ¹ (±2.00%)	31.5	3.956	2.06	−2.14	1,542	1.36	1.38
B6	SCA ¹ (±2.50%)	11.5	4.936	2.65	−2.60	694	0.77	0.84
B7	ACA ² (−1.5%/+3.5%)	14.5	4.934	3.66	−1.59	875	0.98	1.07
B8	ACA ² (−3.5%/+1.5%)	10.5	4.846	1.57	−3.64	624	0.69	0.75
B5	SCA ¹ (±3.00%)	9.5	5.855	3.22	−3.05	687	0.90	1.03
C5	2SCA ³	68.5	2.059	2.05	−2.10	1,580	1.11	1.09
A5	SI ⁴	1214.5	0.610	0.83	−0.89	5,033	1.13	1.06
A4	EQ1 ⁵	415.0	0.487	3.27	−2.98	1,584	1.26	1.34
B4	EQ2 ⁵	443.5	0.476	2.81	−1.85	1,592	1.03	1.03
C4	EQ3 ⁵	848.5	0.213	2.72	−2.11	998	0.75	0.77
Mean						2577	1.02	1.02
COV						83.1%	21.2%	17.8%

¹ SCA = symmetric constant-amplitude loading with zero mean strain;

² ACA = asymmetric constant-amplitude loading with nonzero mean strain;

³ 2SCA = two-stage constant-amplitude loading with sequential low- and high-amplitude blocks;

⁴ SI = symmetric increasing loading consisting of repeated sequences of progressively increasing strain amplitudes;

⁵ EQ1–EQ3 = simulated earthquake loading histories derived from nonlinear time-history analyses of BRBF structures.

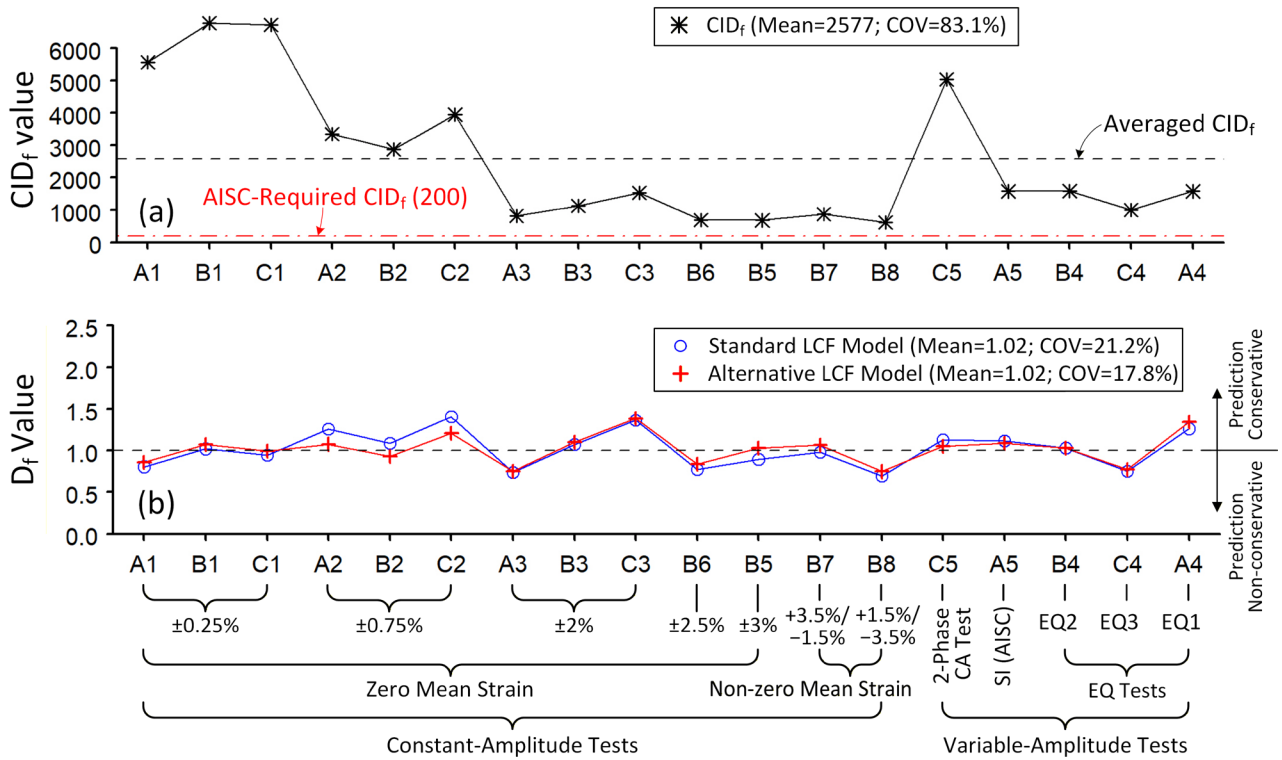


Figure 5: Comparison of (a) CID_f and (b) D_f values for the BRB fatigue test dataset.

Tables 2 and 3 summarize the statistical comparisons (mean and COV) of CID_f and D_f for the nine symmetric constant-amplitude fatigue tests, in which constant-amplitude cycles at each target $\Delta\epsilon_t$ were applied to all three braces within a series. These consist of the first nine tests from Table 1. Table 2 groups the results of these tests by applied total strain range ($\Delta\epsilon_t$) while Table 3 presents the same statistics grouped by brace size (braces of identical yield capacity and length grouped together). Because the statistical results for D_f obtained from the standard and alternative LCF models are similar, only the results from the standard model are reported in these two tables.

As shown in Table 2, the mean CID_f values within each strain-range group are similar but they vary significantly when considering different groups. Specifically, the larger the applied strain ranges, the lower the CID_f values, reflecting the accelerated fatigue damage accumulation associated with higher cyclic deformation demands. In contrast, the mean D_f values remain close to unity across all strain-range groups, indicating that the LCF model provides an overall unbiased prediction of fatigue life. The COVs within each strain-range group are of comparable magnitude, although they are generally slightly larger for CID_f than for D_f , suggesting somewhat greater dispersion in the CID-based metric than in the LCF model predictions.

For Table 3, the statistical results highlight the relatively high COV associated with CID_f , indicating that CID is not an accurate predictor of failure for different loading amplitudes even among identical braces and therefore cannot be used as a reliable fracture-prediction metric for irregular loading histories. In contrast, both the mean and COV of D_f remain generally consistent across brace-size groups and are comparable to those obtained when grouping by strain range, as summarized in Table 2, indicating that the LCF model provides stable and essentially unbiased fatigue-failure predictions independent of strain range and brace size.

Table 2: Statistical comparison of CID_f and D_f grouped by applied total strain range ($\Delta\epsilon_t$) for symmetric constat-amplitude tests

Specimen	Loading Protocol	Target $\Delta\epsilon_t$ (mm/mm)	L_b (mm)	L_{ysc} (mm)	P_y (kN)	CID_f		D_f (Std. LCF Model)	
						Value	Statistics	Value	Statistics
A1	SCA ($\pm 0.25\%$)	0.5%	5,475	3,777	1,110	5,573	Mean = 6,357 COV = 10.7%	0.81	Mean = 0.93 COV = 11.5%
B1	SCA ($\pm 0.25\%$)		5,461	3,048	2,220	6,780		1.02	
C1	SCA ($\pm 0.25\%$)		5,424	2,883	3,330	6,719		0.95	
A2	SCA ($\pm 0.75\%$)	1.5%	5,475	3,777	1,110	3,346	Mean = 3,390 COV=16.1%	1.25	Mean = 1.25 COV = 12.8%
B2	SCA ($\pm 0.75\%$)		5,461	3,048	2,220	2,867		1.09	
C2	SCA ($\pm 0.75\%$)		5,424	2,883	3,330	3,957		1.41	
A3	SCA ($\pm 2.00\%$)	4.0%	5,475	3,777	1,110	808	Mean = 1,159 COV=31.8%	0.74	Mean = 1.06 COV = 29.4%
B3	SCA ($\pm 2.00\%$)		5,461	3,048	2,220	1,126		1.07	
C3	SCA ($\pm 2.00\%$)		5,424	2,883	3,330	1,542		1.36	

Table 3: Statistical comparison of CID_f and D_f grouped by brace size for symmetric constat-amplitude tests

Specimen	Loading Protocol	Target $\Delta\epsilon_t$ (mm/mm)	L_b (mm)	L_{ysc} (mm)	P_y (kN)	CID_f		D_f (Std. LCF Model)	
						Value	Statistics	Value	Statistics
A1	SCA ($\pm 0.25\%$)	0.5%	5,475	3,777	1,110	5,573	Mean = 3,242 COV = 73.5%	0.81	Mean = 0.93 COV = 29.6%
A2	SCA ($\pm 0.75\%$)	1.5%				3,346		1.25	
A3	SCA ($\pm 2.00\%$)	4.0%				808		0.74	
B1	SCA ($\pm 0.25\%$)	0.5%	5,461	3,048	2,220	6,780	Mean = 3,951 COV = 80.6%	1.02	Mean = 1.06 COV = 3.40%
B2	SCA ($\pm 0.75\%$)	1.5%				2,867		1.09	
B3	SCA ($\pm 2.00\%$)	4.0%				1,126		1.07	
C1	SCA ($\pm 0.25\%$)	0.5%	5,424	2,883	3,330	6,719	Mean = 4,073 COV = 63.6%	0.95	Mean = 1.24 COV = 20.4%
C2	SCA ($\pm 0.75\%$)	1.5%				3,957		1.41	
C3	SCA ($\pm 2.00\%$)	4.0%				1,542		1.36	

5 CONCLUSIONS

This study evaluated the adequacy of using cumulative inelastic ductility (CID) as an index for predicting fatigue fracture of buckling-restrained braces (BRBs) by comparing CID-based metrics with strain–life–based fatigue damage indices using a comprehensive dataset of 18 full-scale BRB fatigue tests. The results show that although all tested BRBs substantially exceeded the AISC-required minimum CID of 200, the CID values at fracture exhibited pronounced scatter, with a coefficient of variation exceeding 80%. This large variability, which is strongly influenced by loading history, indicates that a single CID value is not suitable as a reliable indicator for assessing BRB fatigue fracture across different loading protocols. Furthermore, results showed clearly that CID values at fracture are highly influenced by, and correlate closely with, loading amplitude, strongly suggesting that different applied loading scenarios will produce different CID capacities.

In contrast, fatigue damage indices computed using strain–life–based low-cycle fatigue (LCF) models clustered closely around unity at fracture, with significantly smaller dispersion. The reduced scatter and consistent behavior of the damage index across constant-amplitude, variable-amplitude, and simulated earthquake loading histories demonstrate that fatigue-based damage indices provide a more stable and reliable framework for predicting BRB fracture than CID alone. While CID capacity remains useful as a qualification metric within standardized testing protocols with similar loading amplitudes, the results of this study highlight the limitations of using CID as a general fracture prediction index and support the adoption of fatigue-based assessment approaches for evaluating BRB durability under realistic seismic loading demands.

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