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NCREE

BRB Technical Sheet

Bolted end BRB   Pinned end BRB

Introduction

A Buckling Restrained Brace (BRB) is used in braced frame seismic resisting systems to dissipate seismic energy. BRB can be a good alternative for conventional bracing systems to overcome the problems related to the compression buckling of the bracing elements in conventional bracing systems.

The BRB system has been increasingly used in the erection of new buildings and in strengthening projects due to its balanced hysteretic behaviour, high ductility, and high resistance against fatigue loading to provide high seismic resistance and produce a structural system that is code compliant and satisfies the established performance criteria in active seismic zones.

Each BRB is designed and detailed to meet the design engineer's specified performance requirements and to meet all requirements of the relevant Building Codes. It is an excellent return on investment to ensure dependable, maintenance-free, and low damage structural performance.

The key characteristics that will be delivered by the BRB are as follows:

- **Innovative and Efficient**

BRBs combine design innovation, world-leading engineering technology and advanced testing methodologies - improving structural performance, as well as saving time and materials.

- **Strong**

The BRB is able to yield under both tension and compression, taking advantage of the full material strength from the core, and the full elastic buckling strength from the restrainer. As a result, the BRB is equally as stiff and strong in compression as it is in tension in both the elastic condition and the yielded condition.

- **Cost-effective**

By employing the BRB systems, design engineers are already achieving several benefits, including reduced foundation sizes with smaller connections, reduced structural weight through smaller columns, beams, and other elements, reduced materials with fewer braces and connections, and reduced construction time.
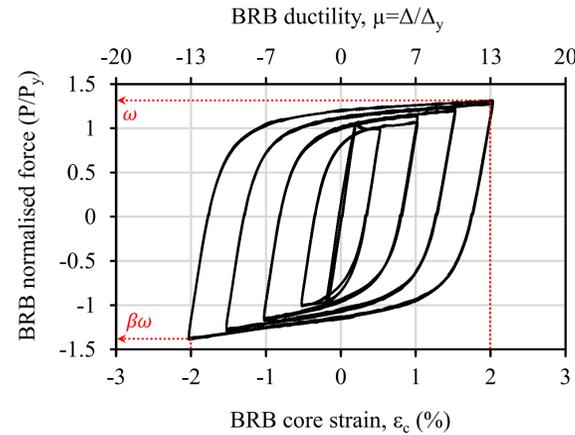
Cyclic Tests for Qualification

For cyclic testing, the AISC Seismic Provisions provides a step-wise standard testing protocol to ensure the BRB member meets the strength and inelastic requirements, and also for the calculation of the maximum adjusted BRB strengths to design the adjacent elements. The BRBs can also be tested under customised displacement protocol on a project specific basis, if required.

Full-scale cyclic test of BRB

General Seismic Performance and Characteristics

The hysteretic behaviour of a tested BRB is shown below.

Key results from previous BRB tests are summarised below:

Max BRB core strain: $\varepsilon_{c,max} = \pm 2\%$ to $\pm 3\%$

Compression overstrength factor: $\beta_{2\%} = 1.05$ to 1.15

Strain hardening overstrength factor: $\omega_{2\%} = 1.3$ to 1.4

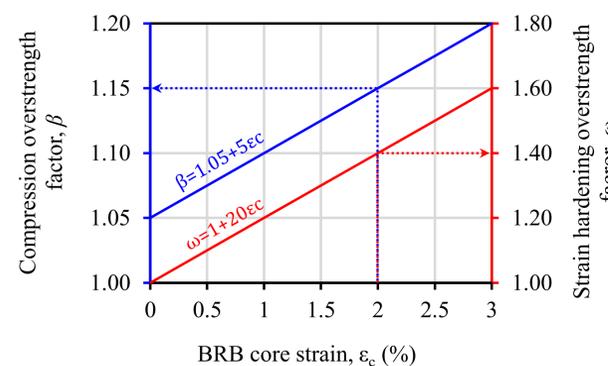Material overstrength factor: $R_y = 1.1$ to 1.3

Cumulative inelastic ductility: $CID = 700$ to $1400 > 200$ prescribed by AISC

Recommended BRB Overstrength Factors (β & ω)

The following equations provide upper-bound solutions for the maximum adjusted BRB strengths in tension and compression.

$$T_{max} = \omega R_y F_{y,min} A_c$$

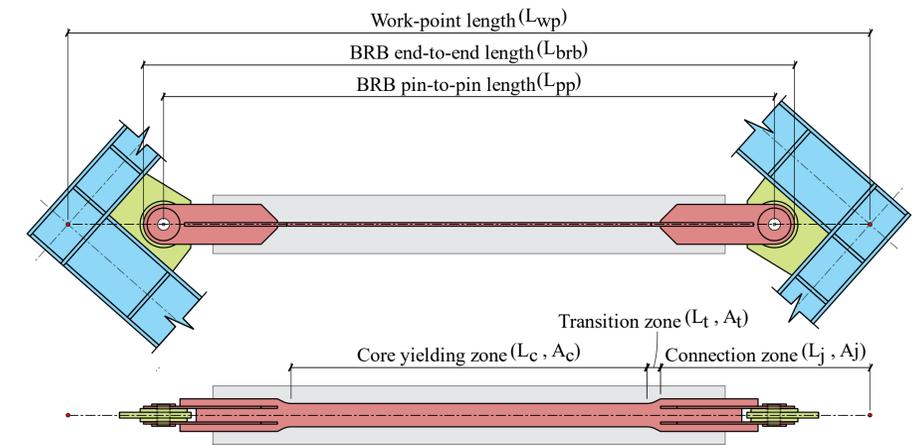$$C_{max} = \beta \omega R_y F_{y,min} A_c$$

$\beta=1.05+5\varepsilon_C$

$\omega=1+20\varepsilon_C$

Recommended Material Overstrength Factor (R_y)

To address material variability, the specified minimum yield stress of the steel core ($F_{y,min}$) is used when calculating the nominal design yield strength of BRB and determining the core area, while the upper-bound yield stress ($F_{y,max} = R_y F_{y,min}$) is used when calculating the maximum adjusted BRB strengths. The typical measured yield stress of the steel core material is shown below.

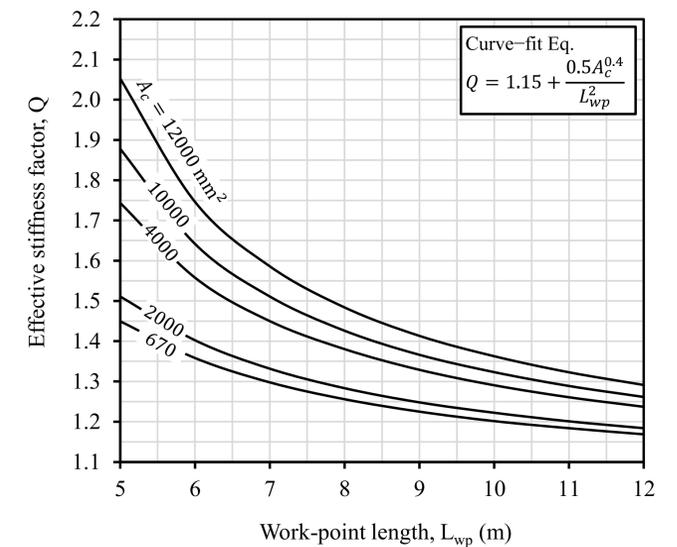| Core area (mm²)	Thickness (mm)	Steel grade	Yield stress (MPa)	R_y
$A_c \leq 2000$	$t \leq 20$	G300	$300 \leq F_y < 390$	1.3
$2000 < A_c \leq 12000$	$20 < t \leq 50$	G300	$300 \leq F_y < 360$	1.2
$A_c \geq 12000$	$t \geq 50$	G350	$350 \leq F_y < 420$	1.2

Axial Stiffness

The effective stiffness of the BRB when connected to the framing members can be expressed mathematically as the total stiffness of linear elastic springs that are assembled in series, and using the chosen notations shown below:

Work-point length (L_{wp})
BRB end-to-end length (L_{brb})
BRB pin-to-pin length (L_{pp})
Transition zone (L_t, A_t)
Core yielding zone (L_c, A_c)
Connection zone (L_j, A_j)

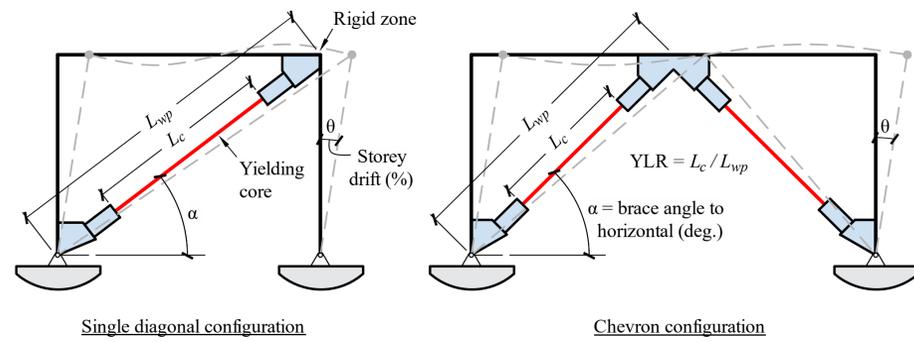The effective stiffness of the BRB can be established as:

$$K_{eff} = \cfrac{1}{\cfrac{L_c}{EA_c} + \cfrac{L_t}{EA_t} + \cfrac{L_j}{EA_j}} = Q\frac{EA_c}{L_{wp}}$$

The actual magnitude of the effective stiffness factor (Q) can be determined only after the detailed design of the BRB is completed. However, for preliminary analysis, the Q factor can be approximated as follows:

Curve–fit Eq.
$$Q = 1.15 + \frac{0.5A_c^{0.4}}{L_{wp}^2}$$

A_c = 12000 mm², 10000, 4000, 2000, 670

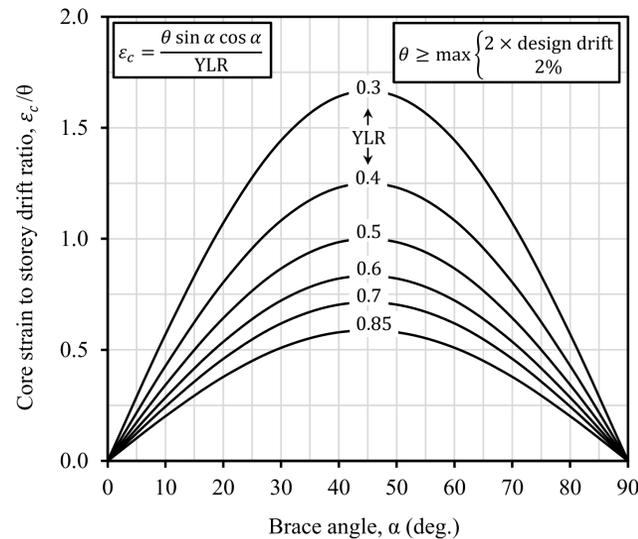Effective stiffness factor, Q

Work-point length, L_{wp} (m)

BRB Strain and Yield Length Ratio (YLR)

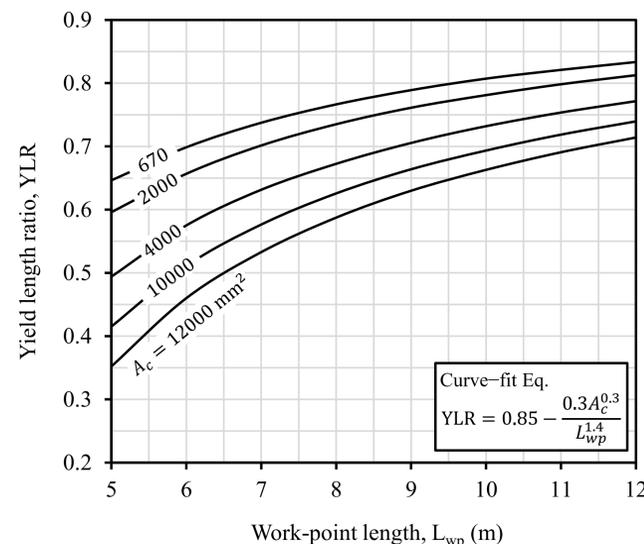The schematic deformed shape of the BRBFs with single diagonal and chevron configurations are shown below.

Single diagonal configuration   Chevron configuration

$$YLR = L_c / L_{wp}$$

α = brace angle to horizontal (deg.)

From the diagram, the core strain of the BRB can be obtained as:

$$\varepsilon_c = \frac{\theta \sin\alpha \cos\alpha}{YLR}$$

$$\theta \geq \max \begin{cases} 2 \times \text{design drift} \\ 2\% \end{cases}$$

It is seen that if YLR = 0.5 and α = 45°, the core strain is equal to storey drift.

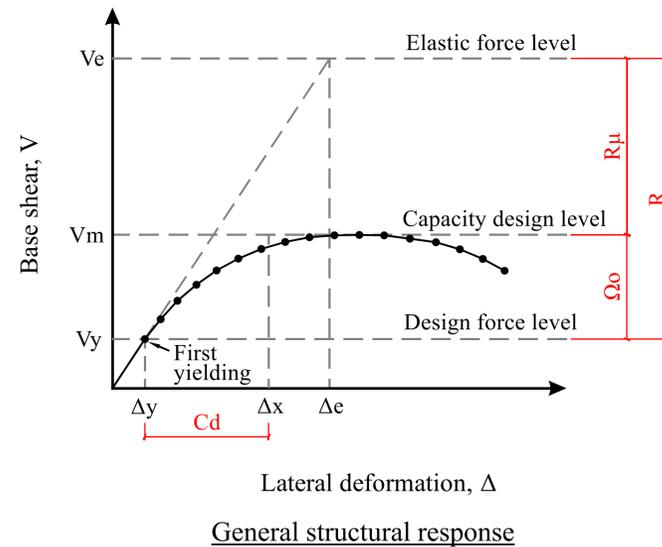In practice, it is recommended that the core strain does not exceed 2.5%.

The actual magnitude of YLR can be determined only after the detailed design of the BRB is completed. However, for preliminary analysis, it can be approximated as follows:

Curve–fit Eq.
$$YLR = 0.85 - \frac{0.3 A_c^{0.3}}{L_{wp}^{1.4}}$$

Structural Analysis

Generally, the structural analysis of BRBFs is similar to the conventional CBFs, with the key distinction being the prevention of brace buckling in compression.

In a capacity design perspective, the plastic links exist over the BRB members. Such deformation-controlled elements are chosen as primary elements where a large amount of plastic deformation can take place over the yielding segment without strength degradation to ensure that significant plastic energy can be absorbed in a stable manner. Then, the other surrounding secondary elements (force-controlled elements) can be designed without concern for inelastic deformations, provided their load-carrying capacities surpass the maximum adjusted strengths of the BRBs in tension and compression (T_{max} & C_{max}).

General structural response

Design Spectrum		
Code	Elastic response spectrum	Period parameters $T = C(h^x)$
ASCE7	DBE = MCE/1.5	$C = 0.0731$ $x = 0.75$
NZS1170.5	DBE = MCE/1.8	$C = 0.0750$ $x = 0.75$

Seismic Parameters of BRBF					
Code	Design force level	Response reduction factor	Overstrength factor	Ductility factor	Deflection factor
ASCE7	$V_y = V_e/R$	$R = 8$	$\Omega_o = 2.5$	$R_\mu = 3.2$	$C_d = 5$
NZS1170.5	$V_y = V_e/(k_\mu/S_p)$	$4.3 \leq k_\mu/S_p \leq 5.7$	$1/S_p = 1.43$	$3 \leq k_\mu = \mu \leq 4$	$3 \leq k_d . k_{dm} . \mu \leq 5$

Due to the smaller response reduction factor in NZS1170.5, the resulting BRBF is likely to be stiffer than one designed based on ASCE7. In fact, the ductility-related reduction factors are relatively similar; however, it seems that the current NZS value for the overstrength-related reduction factor underestimates the potential overstrength of a BRBF.
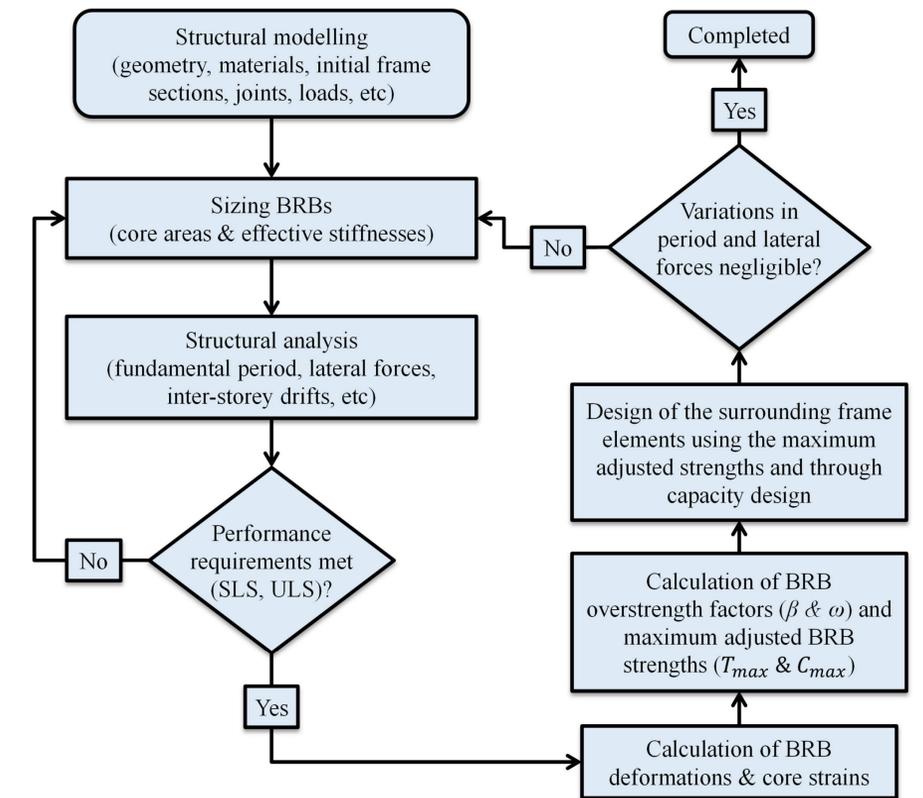
While the smaller response reduction factor can be translated into a more earthquake-resilient structure, there is concern that this can impact the structural cost.

It is worth noting that, in NZS, ductility factor μ = 4 is the upper limit where the ULS load for yield threshold dropping below the SLS load.

Where the self-centring property of the seismic lateral force resisting system is important, a dual BRBF-MRF system can be employed to attain the desired dynamic self-centring response even in cases the building is designed based on larger response reduction factor.

Basic Design Procedure for BRBF

Basically, the BRBs are sized using the overall building analysis to provide sufficient nominal design yield strength ($0.9 F_{y,min} A_c$), and with the other surrounding frame elements protected through capacity design using the maximum adjusted strengths of the BRBs. The basic design procedure for a BRBF is shown below.

In order to minimise the concentration of inelastic demand, it is recommended to maintain similar demand-to-capacity ratios (DCRs) for BRBs throughout the building's height and across its floor plan.

In cases where the linear elastic equivalent static method or the modal response spectrum method of analysis along with capacity design procedure result in forces that are deemed unrealistically high, appropriate nonlinear models can be used to extract more realistic demands on the framing members. Such nonlinear analysis may be static or dynamic.

It is important to use suitable overstrength adjustment factors that the BRBs would generate in the qualification testing in order to determine the design forces for the secondary elements. Coordination with the BRB manufacturer is key to obtain the best overstrength adjustment factors, and to ensure that the values obtained during testing do not necessitate redesign of any structural members.

For design assistance, please contact Grayson Engineering Ltd.

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