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Research Paper

SEISMIC PERFORMANCE OF STEEL FRAMES EQUIPPED WITH BUCKLING RESTRAINED BRACE

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This paper Investigates the capabilities that BRB has and can help in facing seismic waves. Buckling-Restrained Braced Frames (BRBFs) are a steel seismic-load-resisting system used to dissipate energy. The focus of this paper is on the seismic response of braced frames utilizing buckling-restrained braces. It presents behavior of steel frames equipped with BRB and compare it with bare frames (not supported with BRB). ABAQUS is a package for structural analysis is used for modelling, calculating results for studied frames and getting a FEM model.

Keywords: BRB, Bare frame, BRBF, Cyclic load, Hysteresis loops

INTRODUCTION

The Buckling-Restrained Brace (BRB) was introduced in the United States in the late 1990s and since then has been used in more than 350 structures. Over the last 10 years, the technology has reached a significant level of maturity through research, codification and practice. The lateral-load resisting system in which it is an integral component, the Buckling-Restrained Braced Frame (BRBF), has been codified since 2005 and is covered by both the AISC Seismic Provisions and ASCE/SEI 7-10 (Robinson and Black, 2011).

The general level of awareness of BRBs and the BRBF in the engineering community has grown considerably in the last few years as

evidenced by the significant number of research manuscripts, trade magazine articles and conference presentations covering the system (Robinson and Black, 2011).

BRB devices are used to increase the resistance of frame structures by providing energy dissipation and introducing nonlinear behavior. Testing and evaluating are required for designing and ensuring quality control. Although the real experiments provide the accurate behavior of these anti-seismic devices, these tests require significant financial resources and may lengthen actual project schedules as well (Budaházy, 2011).

Leelataviwat *et al.* (2002) proposed a seismic design method based on the energy balance

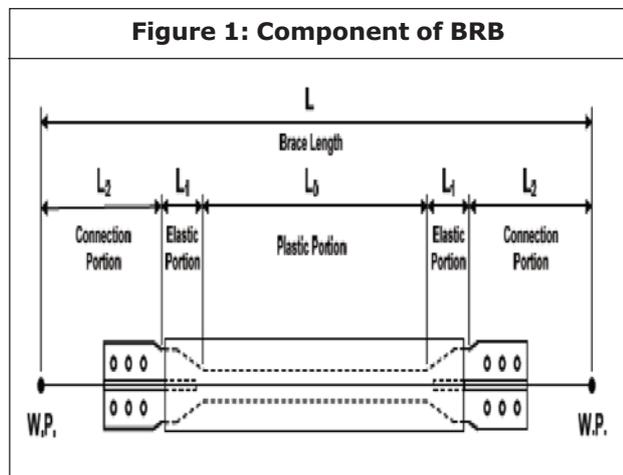
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concept. Chou and Uang (2002) proposed a procedure to compute the total energy demand and to distribute it along the height of structures using inelastic energy spectra.

Lin and MacRae (2012) introduced several development of BRBs in Taiwan. The development included: (i) the investigation of unbending material, (ii) the proposed novel design of BRBs (e.g., double tube and double core, detachable, and welded end-slot), and (iii) full-scale components and frame tests.

Prompted by the observations and concerns, seismic design requirements for braced frames have changed considerably and the concept of BRB frames has been introduced in which buckling of braces is prevented (Deulkar, 2010).

This paper explains the methodology for how BRB works and understand its behavior under the influence of cyclic loading.



The BRB is composed of a ductile steel core, a buckling-restraint mechanism, and an unbending mechanism. Only the steel core is supposed to provide the axial stiffness to the BRB. The steel core consists of three portions: a plastic portion, the elastic portion, and the connection portion. The sleeve is the outer part of BRB which covers the core. The basic principle in the

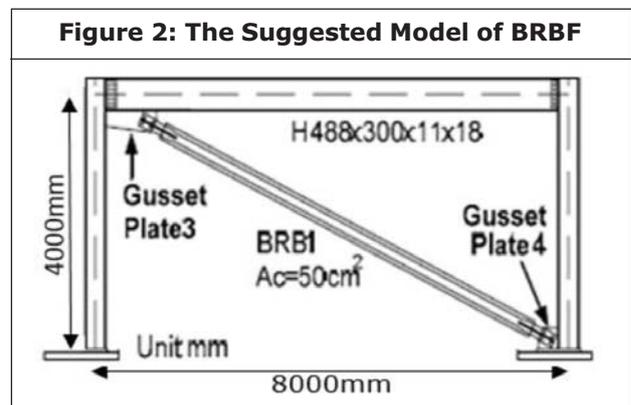
construction of BRB is to prevent buckling of a central steel core by encasing it over its length in a steel tube filled with or without concrete or mortar. BRB provides a slip surface between the steel core and the surrounding concrete, so that axial loads are taken only by the steel core (Tsai, 2010).

MATERIALS AND METHODS

The objective of this study is to study the improvement of seismic performance to steel frames equipped with BRB. Using ABAQUS 6.11 the research focuses on the following objectives:

- Study the behavior of BRBF under cyclic loading.
- Seismic behavior comparison between BRBF and Bare Frame .

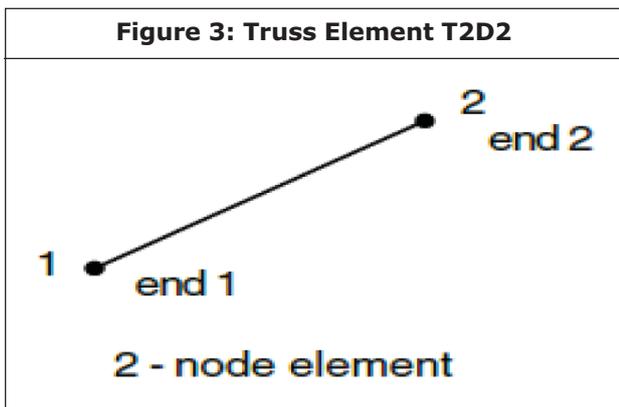
The suggested 2D steel frame for analysis is shown in Figure 2. The steel frame is equipped with buckling restrained brace with steel core area 500 mm² .



Experimental Data and Analysis

The element T2D2 is an element used in ABAQUS environment, BRB modelling in ABAQUS 6.11 has been done using this element.

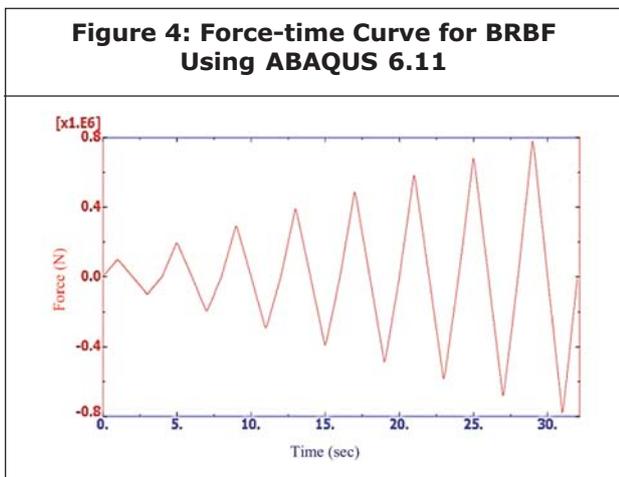
T2D2 is a truss element composed of two nodes and one element with two degrees of freedom for each node (Figure 3).



The element B21 is used for modelling beam and columns, this element is a linear element composed of two nodes in the same plane.

A cyclic load is used by applying a lateral force on the steel frame (force time history).

The loading protocol used is shown in Figure 4 with analysis time equals 32 s.



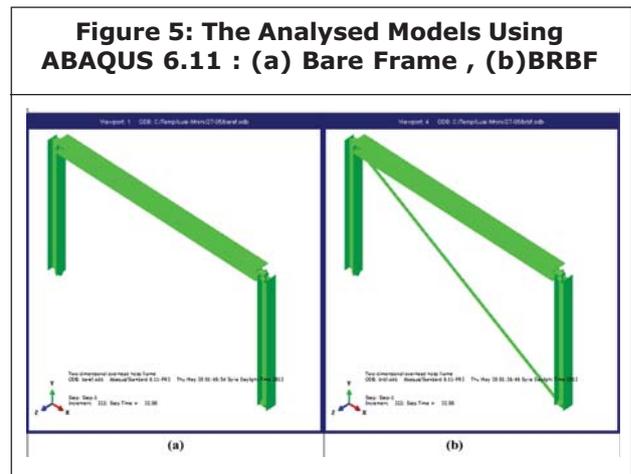
Using ABAQUS input file method, the two frames have been modelled . The same materials specifications and boundary conditions were approved with single difference that only one of the frames is equipped with BRB .

Elastic and plastic specifications for beam , columns and BRB are taken as follows:

Poisson ratio 0.3, Young modulus 225,000 Mpa, BRB yielding stress $F_{yB} = 234$ Mpa , beam

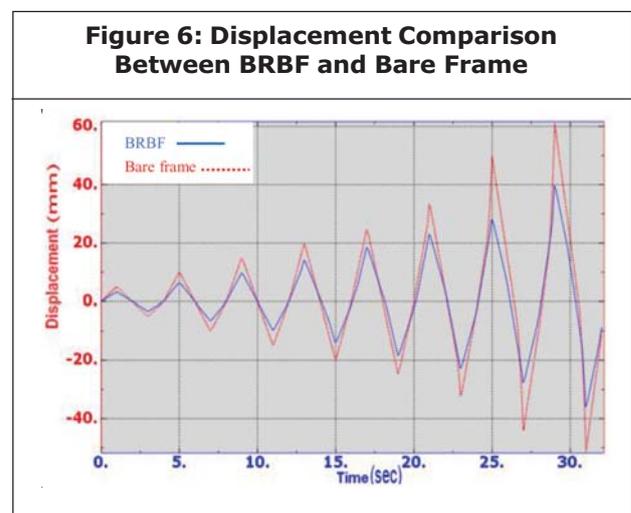
and columns yielding stress $F_{yf} = 250$ Mpa , Kinematic hardening 56,760 Mpa .

Figure 5 shows the analyzing model for the BRBF and Bare Frame depending on using the same conditions as discussed before, which can lead to study clearly the positive influence of BRB when its added to conventional frames, then to understand its role in energy dissipating and seismic load resisting .



RESULTS AND DISCUSSION

The comparison between BRBF and Bare frame in terms of displacement shows that lateral displacements in the top of frame have greater values in Bare frame than the values in case of BRBF through out whole analysis time (32 s).



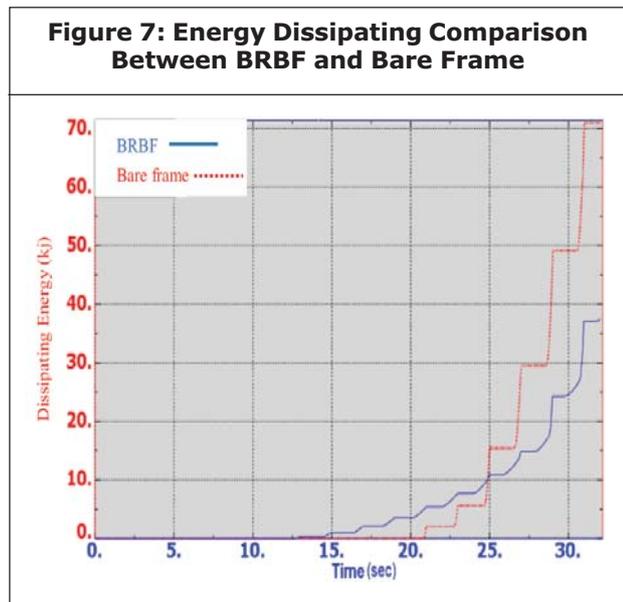
Maximum value of lateral displacement in case of BRBF equals:

$$(\text{Max Disp}) \text{ BRBF} = 61.081 \text{ mm}$$

Maximum value of lateral displacement in case of Bare frame has taken the next value:

$$(\text{Max Disp}) \text{ B-Frame} = 39.678 \text{ mm}$$

Figure 7 shows that during the first seconds of analysis (elasticity stage), the energy damping is virtually non-existent. But when the plasticity stage begins, dissipating energy in BRBF gets greater values than values in Bare frame then, gradually BRBF dissipating energy decreases.



By the end of analysis, dissipating energy in Bare frame becomes greater than dissipating energy in BRBF, which makes sense because in Bare frame case, energy dissipating takes place by forming plastic hinges in columns and beam.

Stresses reach greater values in Bare frame than values in BRBF, these maximum stresses in Bare frame happens in the bottom of the columns as shown in Figure 8.

$$(\sigma \text{ max}) \text{ Bare Frame} = 331 \text{ Mpa} > F_{yf} = 250 \text{ Mpa}$$

This means that frame steel in this case has exceeded yielding edge and has reached plasticity.

Maximum stresses in case of BRBF have exceeded yielding stress, so steel in this case is in the stage of plasticity.

$$(\sigma \text{ max}) \text{ BRBF} = 270.4 \text{ Mpa} > F_{yf} = 234 \text{ Mpa}$$

Figures 8 and 9 shows clearly the difference in stresses between Bare frame and BRBF which represent BRB importance in reducing stresses and energy damping.

Using ABAQUS 6.11, the next figures show stresses contours and associated strains in both studied frames.

Arrows in these figures refer to maximum stresses happened in both ends of the beam and maximum stresses happened in top, bottom of the right and left column.

Figure 9 shows that maximum stresses happen in BRB because it absorbs most of energy and prevent plastic hinges to be formed in frame elements .

This means that the analyzing test has accomplished the goal of preventing damages of frame elements when applying cyclic loads.

When stresses in steel frame exceed yielding stress, strains starts to show up and gradually increase until forming plastic hinges. These strains reach greater values in bare frame.

$$(\epsilon \text{ max}) \text{ Bare Frame} = 0.00443$$

$$(\epsilon \text{ max}) \text{ BRBF} = 0.002971$$

Figure 8: Stresses Contours and Associated Strains in Bare Frame

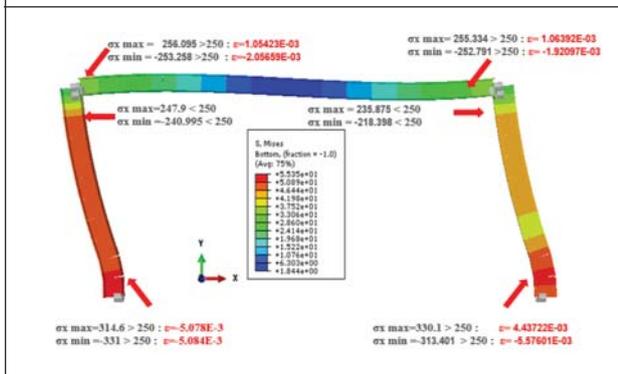


Figure 9: Stresses Contours and Associated Strains in BRBF

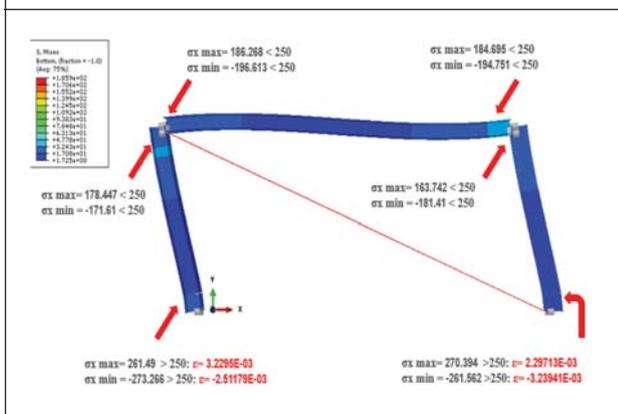
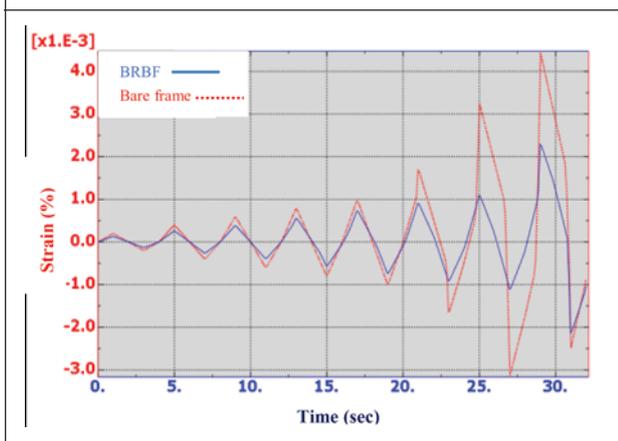


Figure 10: Strain Comparison Between BRBF and Bare Frame



One of the most important standards used to evaluate the seismic behavior in seismic structural engineering is hysteresis loops curve.

In this research hysteresis loops in BRBF are more symmetric than loops in the case of Bare frame, which means that by applying the same force on both frames, the frame equipped with BRB has less lateral displacement than the other frame.

So, It is found from the analytical results that by applying the same force BRBF has better hysteric behavior.

Figure 11: Hysteresis Loops Comparison Between BRBF and Bare Frame

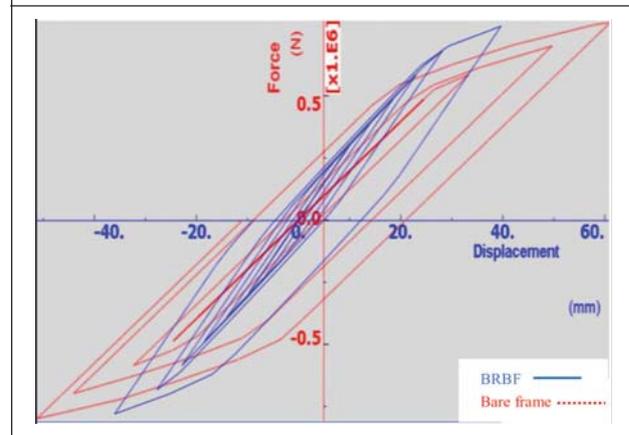


Table 1 shows that in Bare frame case, beam and columns has exceeded yielding edge. But in BRBF case only columns who exceeded yielding stress and beam remains elastic.

Table 1: Stress-Strain Comparison Between Bare Frame and BRBF

Element	Bare frame			BRBF		
	$\epsilon_{max}/\epsilon_y$	ϵ_{max} (%)	σ_{max} (Mpa)	$\epsilon_{max}/\epsilon_y$	ϵ_{max} (%)	σ_{max} (Mpa)
Beam	0.8	8×10^{-4}	186.3	0.9	1×10^{-3}	256
Column	2.7	2×10^{-3}	270.4	4.0	4×10^{-3}	333

CONCLUSION

Using BRB in conventional steel frames can improve seismic behavior of these frames by damping most of energy, reducing lateral displacement.

BRBF have more symmetric hysteresis loops comparing with Bare frames. Thus, using this kind of steel frames has a significant solution in seismic structure engineering which leads to better seismic behavior under cyclic and earthquake loads.

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