

Numerical Study of Dual-core Self-centering Sandwiched Buckling Restrained Brace

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ABSTRACT: Current earthquake resisting systems such as moment resisting frames, buckling restrained braces, concentrically braced frames causes large residual deformation to structures after large earthquakes. In order to reduce structural damage and to increase post-earthquake performance of structures a new type of brace which provides both energy dissipation and self centering property is developed. In this paper the new Dual-core Self-centering sandwiched buckling restrained brace (DC SC BRB) was validated by applying cyclic loading. Numerical study of Ordinary sandwiched buckling restrained brace (SBRB) and DC SC BRB was done by seismic analysis of braces with different core plate thicknesses and suitable thickness for the core plate was suggested. Finally, in order to improve the performance of brace, steel is replaced by aluminium in DC SC BRB and its deformation characteristics are studied by seismic analysis.

KEYWORDS: Dual-core Self-centering sandwiched buckling restrained brace (DC SC BRB), Ordinary buckling restrained brace (SBRB).

I. INTRODUCTION

The novel Dual-core Self-centering buckling restrained brace combines the effect of energy dissipation and self centering properties of dual-core self-centering brace (DC-SCB) and sandwiched buckling restrained brace (SBRB). The proposed DC SC BRB which uses conventional steel materials and post tensioned technique exhibit a flag shapes hysteric response without residual deformation in large earthquakes. It includes three sets of conventional steel bracing members, two friction devices and two sets of post tensioning elements.

The configuration of a DC SC-SBRB has a SBRB inside a DC-SCB that creates self-centering forces in either tension or compression. A SBRB that is positioned inside a DC-SCB is composed of an energy dissipative core plate and a pair of buckling-restraining members sandwiched together by high-strength. Energy dissipation of the proposed brace is provided by a core plate of the SBRB. Both ends of the SBRB core are connected to the first core and the outer box of the DC-SCB, respectively, so that some external loads can be directed to the SBRB when the dual-core SC-SBRB is in loading. The DC-SCB positions the first core, second core, outer box and two sets of tensioning elements in parallel to form its force transfer mechanism. Two ends of second core are provided with inner end plates and outer end plates on either sides of first core. The outer tendons are anchored to the left inner end plate and the right outer end plate; the inner tendons are anchored to the left outer end plate and the right inner end plate to double the elongation capacity of the self-centering brace under loading. These tendons are post-tensioned to hold the bracing members against end plates and are the self centering property was provided by the elongation of tendons when the brace deforms axially.

The basic concept of the dual-core SC-SBRB includes a relative movement between the first core and the outer box. The left end of an energy dissipative core plate of the SBRB that is welded to the first core of the DC-SCB moves freely with respect to the left outer end plate of the DC-SCB and the outer box. The right end of an energy dissipative core plate of the SBRB that is welded to the outer box of the DC-SCB moves freely with respect to the first core and

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 5, May 2017

the right outer end plate of the DC-SCB. Under earthquake loads the hysteric response of DC SC BRB is due to the bi-linear elastic behaviour of DC-SCB and a hysteric plastic behaviour of SBRB.

Mohamed Omar [2] conducted studies on three different systems of steel frames:(a)un-braced frame; (b)braced steel frame with concentric X-bracings using shape memory alloy SMA at beam-bracing connection .(c)braced frame with mega bracing. The use of the SMA in the bracing system can be more effective than MBS in order to limit the frame top displacement. Chung-Che Chou [3] conducted tests on four BRB sub assemblages to investigate the inelastic deformation capabilities and verify the stability predictions for the braces. Test results indicate that three BRBs develop (1) stable hysteretic responses (2) maximum compressive loads (3) a cumulative plastic ductility. Shadiya.K.P [4] studied the effect of different bracing configurations on the behaviour of Buckling Restrained Braced Frames (BRBFs).Bracing configurations selected for study are single diagonal bracing, X-bracing, inverted V bracing. The results extracted show that the model with double diagonal bracing (X-bracing) at adjacent bays experience less stress and deformation. Dr. P. Eswaramoorthi [5] conducted nonlinear analysis of Steel frame using ANSYS 14.5 under the horizontal loading has been carried out and it is validated experimentally. Due to the presence of Steel bracing in frames, the diagonal stiffness of the frame is increased which in turn increase the yield strength and reduce the deflection

The main objective of this project is to study the effect of varying the thickness of core plate of proposed DC SC-SBRB (Dual-Core Self-Centering Buckling Restrained brace) and ordinary SBRB and to suggest adoptable core thickness by using ANSYS 16.2 software. For this, seismic analysis of SBRB and DC SC SBRB is conducted with different core plate thicknesses. Finally, steel elements in DC SC SBRB are replaced by aluminium to improve its deformation characteristics. The geometry and material property implemented by authors in [1] was validated and the results were found satisfactory so that the same geometry and material property are applied for the project model.

II. GEOMETRY AND MATERIAL PROPERTY

The geometry of the brace was prepared using workbench platform of ANSYS 16.2 Finite element Analysis software. Geometry of Dual-core self-centering buckling restrained brace and Sandwiched buckling restrained brace are given below:

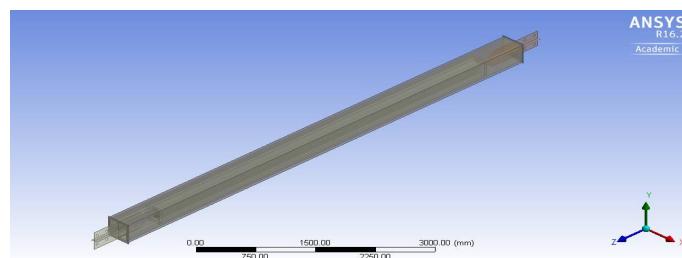


Fig1.Geometry of Dual-core self-centering sandwiched buckling restrained brace

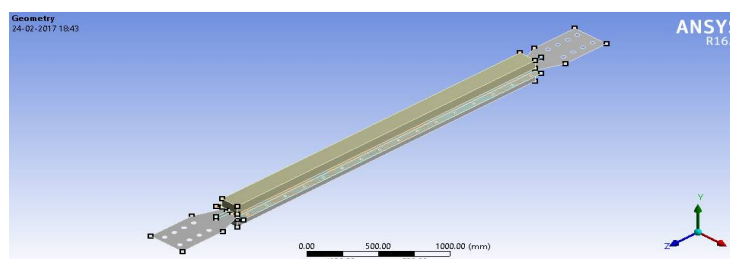


Fig2.Geometry of Sandwiched buckling restrained brace

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 5, May 2017

Table1. Material properties of DC SC SBRB

Dual-core SC-SBRB	Material	Member	Yield strength (MPa)	Elastic modulus (MPa)
DC-SCB	A572 Gr. 50	1st core	369	2.06 x10 ⁵
		2nd core	369	2.06 x10 ⁵
		Outer box	369	2.06 x10 ⁵
SBRB	A572 Gr. 50	Core plate	370	2.12 x10 ⁵
	A572 Gr. 50	Face plate	409	2.06 x10 ⁵
	A36	Channel	235	1.97 x10 ⁵
Tendons	Material	Member	Yield strength (MPa)	Elastic modulus (MPa)
Steel Tendons	A416 Gr. 270	Outer tendons	1358	1.98x10 ⁵
	A416 Gr. 270	Inner tendons	1358	1.98x10 ⁵

Table2. Material properties of SBRB specimen.

Brace Type	Material	Member	Yield strength (MPa)	Elastic modulus (MPa)
SBRB	ASTM Gr. 50	Core plate	367	2.12 x10 ⁵
	ASTM Gr. 50	Face plate	441	2.06 x10 ⁵
	A36	Channel	274	1.97 x10 ⁵

Various connections such as Bonded, Welded and Frictionless connections were provided between elements as per the requirements.

International Journal of Innovative Research in Science, Engineering and Technology

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Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

Table3. Contacts applied to DC SC SBRB elements

Types of Connections	Connections between elements		
Bonded connection	Core plate- Faceplate 1	Channel 1- Faceplate 1	Outerendplate1- Outerbox
	Core plate -Faceplate 2	Channel 2- Faceplate 2	Outerendplate2- Outer box
	Coreplate-Sideplate1	Innerendplate1 - Core plate	Outercoreplate1 to innerendplate1
	Core plate- Sideplate2	Innerendplate2 - Core plate	Outercoreplate2 - innerendplate2
	Sideplate1- Faceplate 1	Outerendplate1 - Core plate	Outercoreplate1 - Outerendplate1
	Sideplate2- Faceplate 1	Outerendplate2 - Core plate	Outercoreplate2 - Outerendplate2
	Sideplate1- Faceplate 2	Outerendplate1- First core	Outercoreplate1 - Core plate
	Sideplate2- Faceplate 2	Outerendplate2- First core	Outercoreplate2 - Core plate
	Outercoreplate1-Outerbox	Outercoreplate2 - First core	Outercoreplate1- First core
	Multiple-Outerendplate1	Multiple- Innerendplate2	Multiple- Innerendplate1
	Multiple-Outerendplate2	Channel1 - concrete	Channel2-Concrete
	Faceplate1-Concrete	Faceplate2- Concrete	-
Welded connection	Outercoreplate1 - Faceplate 1	Outercoreplate2 - Faceplate 2	-
	Outercoreplate1 - Core plate	Outercoreplate2 - Core plate	-
Frictionless connection	First Core-Outer box	-	-

Table4. Contacts applied to SBRB elements

Types of Contacts	Contact elements		
Bonded	Sideplate1-Coreplate	Faceplate1-Concrete	Faceplate2-concrete
	Side plate 2-Coreplate	Concrete-Channel1side	Concrete- Channel2side
	Faceplate1-Sideplate1	Channel2top-Concrete	Channel1top-concrete
	Faceplate1-Sideplate2	Faceplate2- Sideplate1	Faceplate2- Sideplate2

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

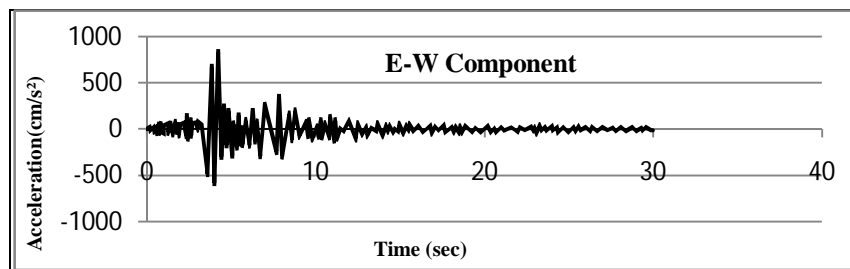
III. SEISMIC ANALYSIS

3-1 Seismic analysis of SBRB and DC SC SBRB

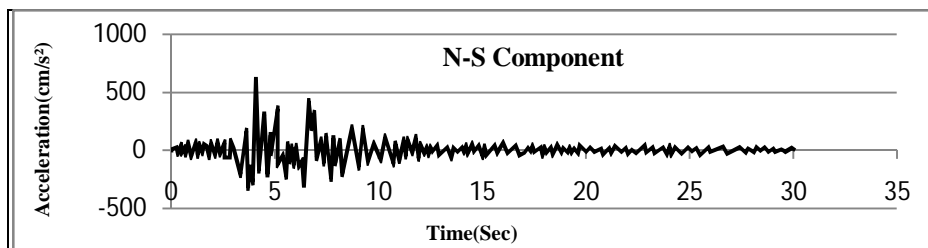
Seismic analysis of Buckling restrained Brace and Dual-Core Self-Centering Buckling Restrained Brace was done using ANSYS 16.2 software. It consists of three steps: (a) Static Structural Analysis, (b) Modal Analysis, (c) Transient Analysis.

Static Structural analysis is done by applying standard Earth gravity on the specimen. Both ends of the specimen are fixed. Standard Earth gravity of -9810mm/s^2 is applied to all elements of the specimen in z direction. Total deformation results are derived from the Static structural analysis. Modal analysis is the study of the dynamic properties of structures under vibration. Modal analysis uses the overall mass and stiffness of a structure to find the various periods at which it will naturally resonate and it is independent of the force acting on the system. From Modal analysis frequencies corresponding to 6 mode shapes are obtained in this study.

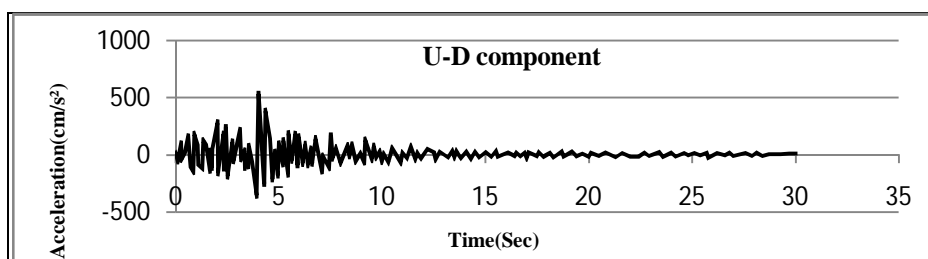
After static structural and modal analysis Transient analysis is done with fixed boundary condition. Three-components (x, y, z direction) of acceleration –time histories recorded at JR Takatori (1995 Hyogoken-Nanbu earthquake (M7.2)) is selected for Transient analysis. Total deformation and Equivalent (Von-Mises) stress of the specimen are obtained from the analysis.



(a) Along X direction



(b) Along Y direction



(c) Along Z direction

Fig 5. Strong ground motion measured at JR Takatori

International Journal of Innovative Research in Science, Engineering and Technology

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Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

3-2 Material replacement in DC SC BRB

Aluminium alloys have recently been employed to Dual-Core SC-SBRB to improve SBRB durability in corrosive environments. The core, which is the yielding element of the SBRB, was replaced by annealed and soft alloys of aluminium for its high ductility, low yield strength and high over strength. In addition to this, the bracing members of DC SCB such as first core, outer box and second core was also replaced by aluminium in order to reduce the overall weight of DC SC SBRB. Besides its excellent corrosion resistance, aluminium alloy offers a wide range of useful properties: It is light and has only one-third the density of steel, it is easily fabricated, and its recyclability provides both economic and environmental benefits.

Table5. Properties of Aluminium Alloy

Elements	Density (Kg/m ³)	Elastic Modulus (MPa)	Poisson's Ratio	Yield Stress (MPa)
Aluminium Alloy	2650	72000	0.33	145

Table6.Thickness of SBRB, DC SC SBRB and Aluminium DC SC SBRB

Type of brace	Thickness of core plate(mm)			
Ordinary SBRB	24mm	23mm	22mm	21mm
DC SC SBRB	8mm	7mm	6mm	5mm
Aluminium DC SC SBRB	8mm	7mm	6mm	5mm

IV. RESULTS FROM SEISMIC ANALYSIS

Table7.Results from seismic analysis of SBRB

Core plate thickness (mm)	Static analysis-Deformation (mm)	Modal Analysis-Frequency (Hz)	Transient Analysis-Deformation (mm)	Equivalent stress (Von-Mises) (MPa)
24	3.7×10^{-3}	125.29	1.412	66.31
23	3.82×10^{-3}	124.07	1.695	78.08
22	3.94×10^{-3}	122.79	1.916	86.507
21	4.06×10^{-3}	121.43	2.247	99.891

Table8.Results from seismic analysis of DC SC SBRB

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

Core plate thickness (mm)	Static analysis-Deformation (mm)	Modal Analysis-Frequency (Hz)	Transient Analysis-Deformation (mm)	Von-Mises stress (Mpa)
8	1.50×10^{-2}	17.52	2.52×10^{-2}	2.364
7	1.53×10^{-2}	15.34	1.36×10^{-2}	1.322
6	1.57×10^{-2}	13.64	1.16×10^{-2}	1.146
5	1.62×10^{-2}	13.69	9.54×10^{-3}	0.955

Table9.Results from seismic analysis of Aluminium DC SC SBRB

Core plate thickness (mm)	Static analysis-Deformation (mm)	Modal Analysis-Frequency (Hz)	Transient Analysis-Deformation (mm)	Von-Mises stress (Mpa)
8	2.08×10^{-2}	17.61	1.47×10^{-2}	0.488
7	2.79×10^{-2}	15.45	5.31×10^{-3}	0.439
6	2.87×10^{-2}	13.751	4.47×10^{-3}	0.375
5	2.96×10^{-2}	13.79	3.61×10^{-3}	0.308

IV. CONCLUSIONS

1. In case of ordinary SBRB,
 - As the core plate thickness decreases there was increase in deformation of the brace. Natural frequency of the brace also increases with decreasing core thickness. Von-Mises stresses obtained from 3 models are within the limit of yield stress.
 - Model 3 with 24mm core plate thickness exhibited minimum deformation of 3.7×10^{-3} mm under standard Earth gravity load and 1.412mm under transient analysis
2. In the case of DC SC SBRB,
 - As the core plate thickness decreases there was decrease in overall deformation of the brace. Natural frequency of the brace also decreases with the decrease in core plate thickness.
 - Model 4 with 5mm core plate thickness showed maximum deformation of 1.62×10^{-2} mm under standard Earth gravity load, but the overall deformation of the brace is 9.54×10^{-3} mm which is very less as compared to other braces.
 - As the clearance between core plate and restrainer increases, the core plate slightly buckles within the clearance provided and the restrainer restrains the buckling of core plate through friction.
 - The self-Centering property of Dual-core is also a factor that reduces deformation.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 5, May 2017

3. In case of Aluminium DC SC SBRB

- Replacement of steel in DC SC SBRB by Aluminium alloy was effective as the overall deformation under transient analysis of each model decreased. Von-Mises stress was also very much less as compared to Steel DC SC SBRB.
- Model 4 with 5mm core plate thickness showed minimum deformation of 3.61×10^{-3} mm and Von-Mises stress of 0.308 MPa under transient analysis.

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