BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 66 (70), Numărul 3, 2020
Secţia
CONSTRUCŢII. ARHITECTURĂ

EVALUATION OF BEHAVIOUR TO SEISMIC ACTIONS FOR MULTI-STOREY STEEL STRUCTURES BRACED WITH OR WITHOUT BRBS

BY

SILVIU-CRISTIAN IONESCU-LUPEANU*, **EMANUEL-ŞTEFAN DIMA and ŞERBAN-ADRIAN DIMA**

Technical University of Civil Engineering of Bucharest,
Faculty of Civil, Industrial and Agricultural Engineering

Received: July 6, 2020
Accepted for publication: July 21, 2020

Abstract. This study aims to highlight the advantages and disadvantages of the main types of concentric braces used for steel structures. The structures analyzed in this paper were equipped with concentrically buckling restrained braces or regular concentric braces. The concentrically braced structures are tall office buildings, located in Bucharest. Concentrically braced frames have been designed in 6 different cases: 3 cases with concentrically two story X braced frames and inverted chevron braced frames and 3 cases with buckling restrained braces disposed like in the above mentioned cases. In this study advantages and disadvantages of structures equipped with buckling restrained braces were identified using geometric and element nonlinear analysis, conclusions and observations resulting from the study being presented.

Keywords: BRB; concentrically braced structure; hysteretic dampers; tall buildings.

*Corresponding author: *e-mail*: ionescu.lupeanu.silviu@gmail.com

1. Introduction

This paper aims to highlight the advantages and disadvantages of the main types of concentric braces used for steel structures (Ionescu-Lupeanu and Dima, 2017). The studied structures were equipped with concentrically buckling restrained braces and regular concentric braces. The concentrically braced structures are tall office buildings, located in Bucharest.

Frames equipped with buckling restrained braces (BRB, Fig. 1) have a high seismic absorption capacity, the hysteretic behaviour of these frames being symmetrical and stable in the plastic domain (Fig. 2).

Buckling restrained bars are composed of a ductile steel core inside an external buckle preventing tube (Fig. 1). The core and the casing are decoupled using an unbonding material to prevent the interference between them.

The layer of unbonding material disconnects the steel tube from the steel core. Therefore, the axial bending stress is transmitted only through the steel core, while the steel tube (due to its bending stiffness) provides the appropriate lateral support against the bending buckle of the core.

The outer casing is usually composed of steel tubes filled with concrete or other unbonding materials. The steel tube must be designed so as to prevent lateral buckling of the steel core.

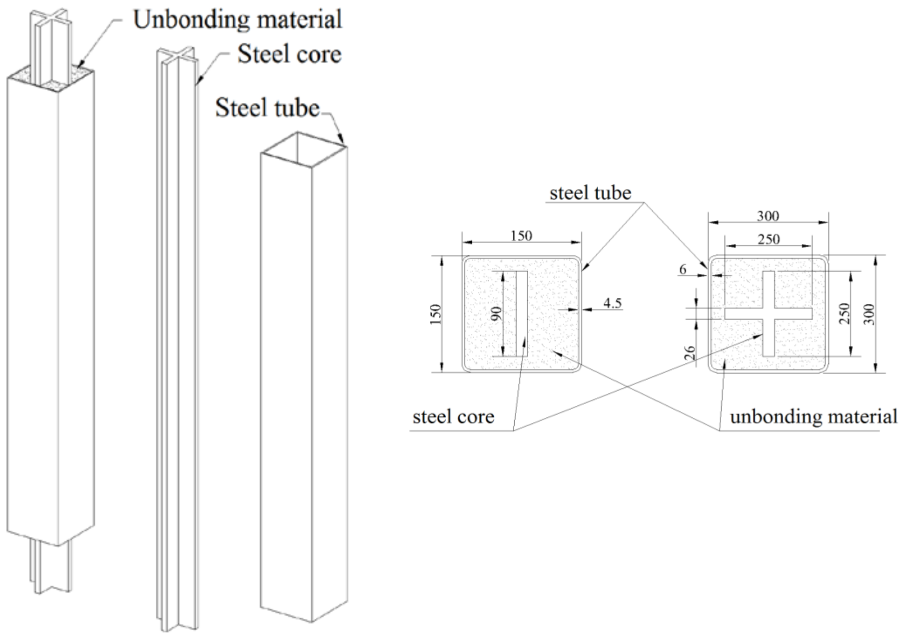

Fig. 1 − BRB types used in structural analysis (Black *et al*., 2002).

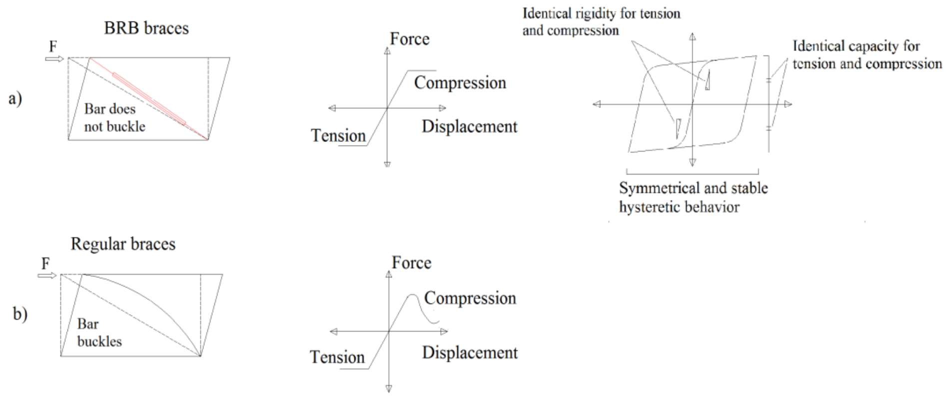

Fig. 2 – *a*) behaviour of BRB; *b*) behaviour of regular braces.

2. Description of the Analyzed Structures

In this paper 6 structural models were analysed, aiming to highlight some favourable or unfavourable characteristics of the main types of bracings used in the multi-storeys steel structures. The considered structures are configured with both regular concentric braces and with dissipative buckling restrained braces. The basic building is a 15-level office building (Fig. 3), located in Bucharest. The structural system is a dual one composed of frames and central braced core (Dalban *et al*., 1997).

The analysed structure consists of 6 bays of 8.10 m and 5 spans of 8.10 m. The story height is 4.0 m, the structure having 15 stories (G + 14F). The steel used is S355. The first 3 structural models, 1a, 1b and 1c, have been designed with two-story X braced frames, the model 1a being equipped with regular braces and the models 1b and 1c (Fig. 3) being equipped with ductile buckling restrained bars designed with medium ductility for model 1b and with high ductility for model 1c. The same basic building was used for models 2a, 2b and 2c (Fig. 4) but instead of X braces, inverted chevron braces were provided (Dalban *et al*., 1997).

The structure configuration (layout and elevations) is presented in Figures 3 and 4.

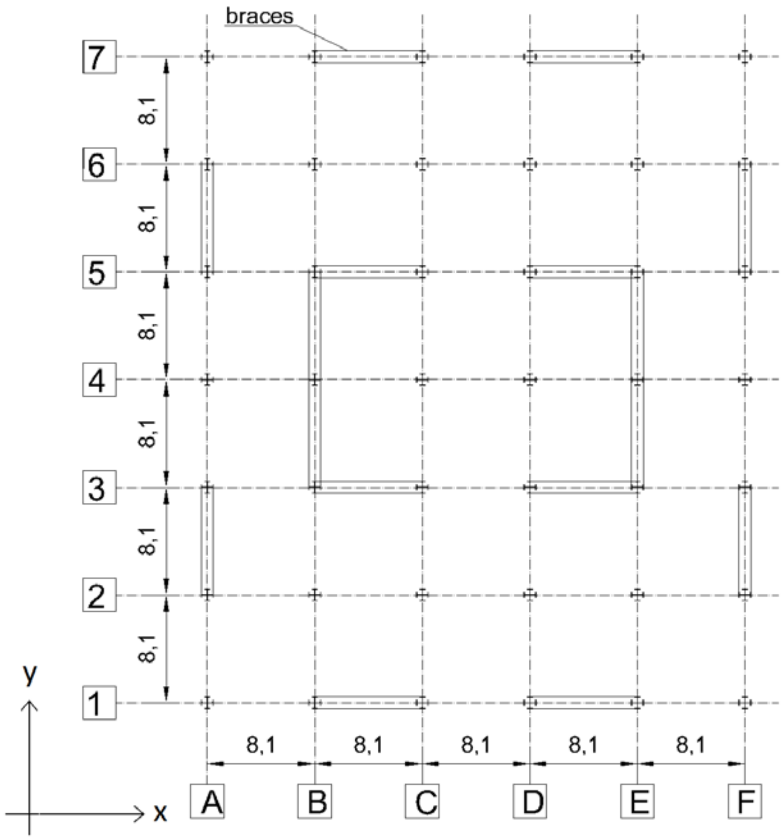

Fig. 3 – Structure layout (Ionescu-Lupeanu and Dima, 2017).

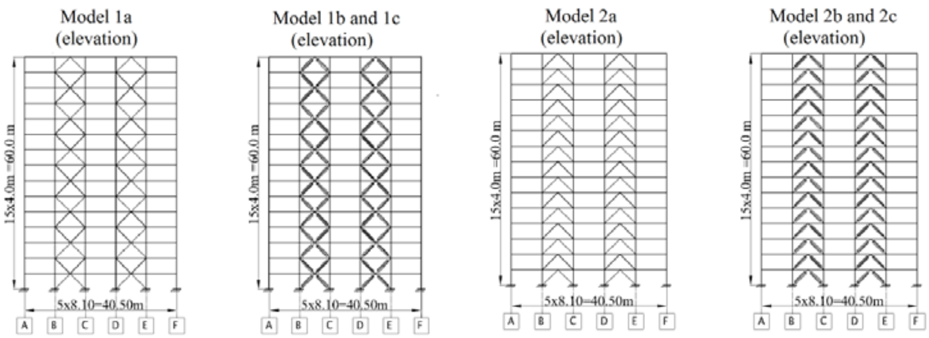

Fig. 4 – Models elevations (Ionescu-Lupeanu and Dima, 2017).

3. Calculation Phases for the Considered Models

The design process for buckling restrained braces used in high ductility systems is (ASRO, 2006):

- calculating the shear force for the structure, taking into account a medium ductility factor q = 4 (DCM - model 1b, 2b) or higher q = 7 (DCH - Model 1c, 2c).

– structural analysis: determining the strength and stiffness for the structural elements.

– design of non-dissipative elements: beams, columns.

– static nonlinear analysis (pushover analysis) is performed and verifications are carried out according to the design based on the capacity spectrum: verification of the capability of the elements for the target displacement level and the maximum bending distortions.

– Obtaining the required strength and rigidity of buckling restrained braces.

– equipping the structure with buckling restrained braces (FEMA 273, 1997; EN 15129, 2009).

– redesigning the non-dissipative elements of the structures.

– resumption of the pushover analysis for the final verification of the structure based on capacity spectrum.

Beams, columns and buckling restrained braces have been designed to the maximum load level that may occur during a seismic action (Dalban *et al*., 1997; Dunai 2011; P100-1, 2013).

4. Comparison of Analyses and Comments

Comparison between structures with braces in X – system on 2 levels with and without buckling-restrained braces:

BRB type structures are more ductile than structures with a classical bracing system that consists of CHS section braces, this is shown in the push-over curves resulted from the nonlinear analyses (Fig. 5). The energy dissipated by the BRB type structures is greater than the classical bracing systems (FEMA 273, 1997; ASRO 2004; EN 15129, 2009).

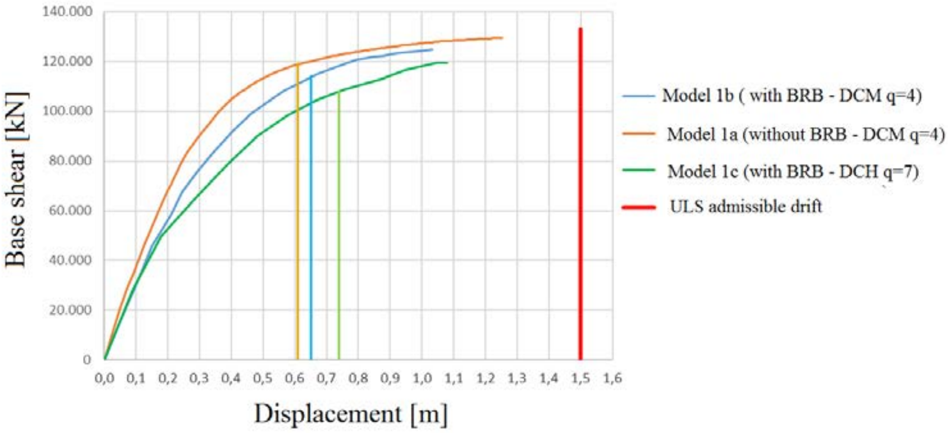

Fig. 5 – Push-over curves for 1a,1b and 1c models on X direction.

Table 1
Steel Consumption for 1a,1b si 1c Models

	Model 1a Classic: q=4	Model 1b BRB: q=4	Model 1c BRB: q=7
Total weight, [t]	4146	3895	3750
Consumption comparison	100%	94%	90%

The lowest material consumption was obtained in the case of model 1c (BRB DCH q=7), the high ductility BRB type structure proving a 10% economy in terms of material consumption compared to the structure without buckling-restrained brace (Table 1).

Comparison between structures with chevron type bracing with and without buckling-restrained braces:

BRB type structures are more ductile than structures with a classical bracing system that consists of CHS section braces, this is shown in the push-over curves resulted from the nonlinear analyses (Fig. 6). The energy dissipated by the BRB type structures is greater than the classical bracing systems.

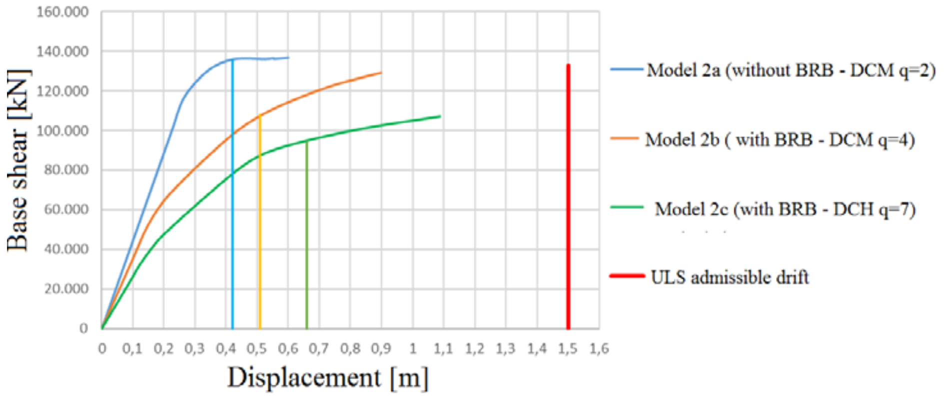

Fig. 6 – Push-over curves for 2a,2b and 2c models on X direction.

Table 2
Steel Consumption for 2a,2b si 2c Models

	Model 2a Classic: q=4	Model 2b BRB: q=4	Model 2c BRB: q=7
Total weight, [t]	4644	3998	3803
Consumption comparison	100%	86%	82%

The lowest material consumption was obtained in the case of the high ductility BRB type structure (2c). This type of chevron bracing system shows an 18% economy in terms of material consumption compared to the structure without dissipative elements and a 14% economy compared to medium ductility BRB type structure (Table 2).

5. General Conclusions

After conducting analyses on all 6 structural models having both concentric BRB as well as classical type concentric bracings the following conclusions resulted:

– the static non-linear analyses conducted to similar results as the ones obtained from the dynamic non-linear analysis, only 10 to 12 elements out of 3075 needed replacement at the end of the analyses meaning that the structure had a positive behaviour during the push-over analyses.

– for developing the same amount of dissipated energy, the BRB type structures had 10% greater displacements.

– in the case of BRB type structures after simulating the maximum earthquake the only elements which needed replacement were the BRBs, other structural elements having minimum plastic deformations. The BRBs can be simply and fast replaced with minimum costs.

– in the case of the classical bracings (without BRB) in X – system on 2 levels and also chevron bracings, because of high plastic deformations and rotations in the beams and bracings these elements should be replaced. This is a difficult, time consuming and expensive procedure.

– the structures without BRB are stiffer than the ones having BRB as long as the compressed elements which are designed based on resistance and rigidity criteria, do not buckle.

– the steel consumption decreases with 10 to 15% in the case of high ductility BRB type structures but it should be taken into consideration the higher costs of the BRB system.

– the high ductility BRB structure designed in X system is with 3-4% more expensive than the structure without BRB.

– in order to reduce the costs, the BRB from the upper third part of the building can be replaced with classical bracings due to the fact that they do not develop plastic deformations or rotation.

REFERENCES

Black C., Makris N., Aiken I., *Component Testing*, Stability Analysis and Characteerization of Buckling-Restrsained Unbonded Braces – Pacific Earthquake Engineering Research Center, 2002.

Dalban C., Chesaru E., Dima S., Serbescu C., *Construcţii cu structură metalică*, Editura Didactică şi Pedagogică, 1997.

Dunai L. (D.Sc. Professor Head of Department), *Type Testing of Buckling Restrained Braces According to EN 15129* Budapest University of Technology and Economics – Department of Structural Engineering, 2011.

Ionescu-Lupeanu S.-C., Dima Ș.-A., *Assessment of Multi-Storey Steel Structures Behaviour Concentrically Braced with or without BRBs*, 6th National Conference on Earthquake Engineering and 2nd National Conference on Earthquake Engineering and Seismology, 2017.

*** *Cod de proiectare seismică, Partea I – Prevederi de proiectare pentru clădiri*, P100-1, 2013.

*** *Nehrp Guidelines for the Seismic Rehabilitation of Buildings*, BSSC, FEMA 273, 1997.

*** *Normativ european pentru dispozitive antiseismice*, EN15129, CEN, 2009.

*** *Proiectarea structurilor de oțel, Partea 1-1: Reguli generale si reguli pentru cladiri*, SR EN 1993-1-1, Eurocod 3, ASRO, 2006.

*** *Proiectarea structurilor pentru rezistenta la cutremur, Partea 1: Reguli generale, actiuni seismice si reguli pentru clădiri*, SR EN 1998-1, Eurocod 8, ASRO, 2004.

*** Star Seismic® | Buckling Restrained Braces, http://www.starseismic.eu/.

STUDIUL COMPORTĂRII LA ACŢIUNI SEISMICE A STRUCTURILOR METALICE PREVĂZUTE CU CONTRAVÂNTUIRI CENTRICE CU FLAMBAJ ÎMPIEDICAT

(Rezumat)

Lucrarea își propune să pună în evidență avantajele și dezavantajele principalelor sisteme de contravântuiri centrice utilizate la structurile metalice multietajate. Studiul a fost desfăşurat pe o gamă de clădiri multietajate cu structură metalică, în diferite variante de alcătuire constructivă. Sistemul structural ales este unul dual, alcătuit din cadre contravântuite centric şi cadre necontravântuite. Cadrele contravântuite centric au fost analizate în 6 situații distincte de alcătuire și anume: 2 situații în care se utilizează contravântuiri clasice centrate la noduri cu diagonale încrucișate în „X pe două niveluri", respectiv cu diagonale în „V inversat" şi 4 situații în care se utilizează contravântuiri din bare cu flambaj împiedicat (BRB) dispuse în „X pe două niveluri", respectiv în „V inversat". Au fost identificate, utilizând analiza neliniară la nivel geometric şi de element, avantajele şi dezavantajele utilizării BRB pentru structurile metalice multietajate şi au fost prezentate concluziile şi observaţiile rezultate în urma studiului realizat.