



Determination of the Parameters Influencing Behavior Factor of Buckling Restrained Braced Reinforced Concrete Frames

F. Dehghan¹, A. A. Tasnimi^{2*}

1- M.Sc., Faculty of Civil and Environmental Engineering, Tarbiat Modares University

2- Professor, Faculty of Civil and Environmental Engineering, Tarbiat Modares University

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ABSTRACT

The advantages of buckling restrained braces (BRB) attract the researches and engineers attention to use this bracing system. High ductility, high-energy dissipation capacity and symmetric hysteresis behavior are the main advantages of this system that is the most effective system to resist the earthquake induced lateral forces. Disadvantages of conventional bracing system such as low ductility, low energy dissipating capacity and local as well as global buckling with unsymmetrical hysteresis performance in tension and compression are the main reason to rehabilitate and or replace this system with the new generation of braces. Buckling restrained brace (BRB) is an energy-dissipating member that enhances the structural stiffness, energy dissipation and ductility. There are few worldwide code of practices provide some recommendations about the buckling-restrained braced frames whereas most of them do not deal with such system. This paper illustrates the good performance of buckling restrained braces used for RC frames. This article determines the behavior factor for RC frames braced with buckling restrained braces. For this purpose RC frames with four, eight, twelve and sixteen stories (each having three and five bays) were considered in this study. All frames designed in accordance with Iranian standard 2800 and P9-INBC for concrete structures. Analyses for all 24 structural models were carried out utilizing nonlinear static push-over method. The results indicate that the average value of behavior factor for all models corresponding to the allowable stress design is around eight.

KEYWORDS:

Buckling Restrained Brace, Ductility, Energy Dissipation, Nonlinear Analysis, Behavior Factor

* Corresponding Author, Email: tasnimi@modares.ac.ir

1- Introduction

Seismic design of structures is based on absorbing and dissipating seismic energy by the inelastic behavior of effective structural members in a severe earthquake. One of the structural systems in seismic design is reinforced concrete frames with steel bracing. However, concentrically bracings are the appropriate lateral load resisting system against the earthquake-induced forces. Past sever earthquakes have shown this type of braces may not have the desired behavior because the compression capacity of such brace system is considerably less than that in tension.

There are some modified brace system that their hysteresis response are quite symmetric and stable, and then have very good strength in both compression and tension. This kind of brace called buckling restrained brace (BRB) [1-17].

Buckling restrained braces consist of a ductile steel core with ability to yield under both tensile and compressive forces. The core placed in a steel casing, which filled by mortar or concrete in such a manner that the steel core is surrounded by nonbonding material or air gap to minimize, the transfer of axial force from steel core to mortar and the casing. This arrangement prevents global buckling in compression.

This research focuses on response modification factor of buckling restrained braced reinforced concrete frames. This factor is called behavior factor and in some codes is called force reduction factor [18]. It is generally consist of three components R_μ , Ω , Y where R_μ is the ductility reduction factor, Ω is the over strength factor and Y is the factor of allowable stress design method (ASD). In a diagram of the actual force–displacement, response curve of a structure that idealized by a bilinear elastic–perfectly plastic response curve, the behavior factor parameters may be defined as:

$$R_\mu = \frac{V_e}{V_y} \quad (1)$$

$$\Omega = \frac{V_y}{V_s} \quad (2)$$

$$Y = \frac{V_s}{V_w} \quad (3)$$

where V_e , V_y , V_s and V_w correspond to the structure's elastic response strength, the idealized yield strength, the first significant yield strength and the allowable stress design strength, respectively for structures designed using an ultimate strength method, the

allowable stress factor, Y , becomes unity and the behavior factor is reduced to:

$$R = R_\mu \cdot \Omega = \frac{V_e}{V_s} \quad (4)$$

2- Methodology, discussion and results

In this research, moderate ductile reinforced concrete moment resisting frames (RCMRF) contain four, eight, twelve and sixteen stories with three and five bays in each direction of building plan is selected. Storey height of 3.2 m with 5 m spans was considered. The frames have designed, in accordance with Iranian national building code-part 9. The initial behavior factor of eight for buckling restrained braced frames, ordinary braced frames and frames without bracing was considered respectively. These frames have been loaded laterally according to Iranian seismic code (Standard No. 2800) [18] and designed, in accordance with Iranian National building code part-9 and part-10 [19-20].

Some initials are used as reference codes to address the structures. They are given in the form of “NOB” for moment resisting frame with no braces, “ORB” for ordinary moment frames with concentric braces and “BRB” for restrained braced frames. General view of twelve storey frames are shown in Fig. 1.

Concrete with compressive strength of 30 MPa, rebar with tensile strength of 240 MPa and steel, with a yield stress of 240 MPa (steel ST-37) have been used to design steel braces.

All of incremental static (push-over) analyses are conducted using program OPENSEES-2009 [21]. The program establishes the damageability of RC structures and their components under horizontal and vertical earthquake excitations. Some of the modeling schemes used in the program are:

1) Rectangular or cruciform cross section was assumed for the mild steel restrained yielding segment, which is designed to yield under cyclic

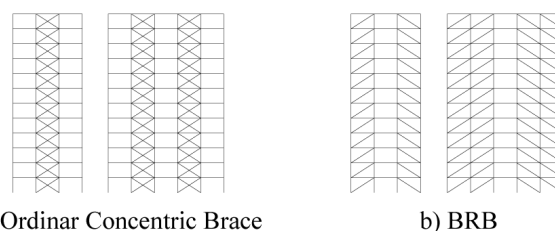


Fig. 1. Schematic representative of 12 stories frames

loading.

2) Restrained non-yielding segment, which is surrounded by the casing and mortar is usually an extension of the restrained yielding segment but with an enlarged area to ensure elastic response. This can be achieved by widening the restrained yielding segment.

3) Unrestrained non-yielding segment is usually an extension of the restrained non-yielding segment, except that it projects from casing and mortar for connection to the frame.

4) Considering flexibility approach to construct the element stiffness matrices, which allows for the variation of the contra flexure point.

5) Implementing general hysteretic model that is capable of accounting for the three main behavior patterns in RC components: stiffness degradation, strength deterioration and pinching.

6) Utilizing non-symmetric three-linear envelope curve that distinguishes cracking and yielding.

7) Determination of the three-linear envelope parameters using empirical or mechanical models for core segment.

8) Response statistics is based on the Park-Ang damage model so that an interpretation of the damage sustained by the structure is possible.

9) Connections of brace to beams and column are simple.

10) To simplify the model and remove the interaction between soil and structure, rigid connection to foundation is considered.

11) Beams and Columns have been modeled with Fiber-Section and displacement based elements in software OPENSEES.

12) Axial force transfer from the core to the mortar and casing does not occur and both compressive and tensile axial force to be tolerated by the core alone.

In addition, the program can extract response information on selected sub-assemblages and output specified displacement, drift and story shear histories.

2- 1- Results of nonlinear static analysis

Selected frames have analyzed using nonlinear static analysis method (push-over) with the first mode distribution. As a criteria, structural failure was considered where sudden drop in resistance shown in the obtained capacity curve.

In this study, stiffness and strength has specified and compared for each frame. The results show five-bay frames have higher strength and stiffness with

respect to the same three-bay frames. It also shows, in the 8, 12 and 16 storey frames, the greatest strength will be for BRB and then ORB frames. However, the four-storey braced frame with conventional braces exhibit most resistant. This is due to the high stiffness of this frame with respect to the other frames.

2- 2- Compare the studied frames resistance

According to the obtained results, resistance of the ordinary braced frame system with four-storey and three-bays is greater than the other of the system and resistance of the moment frame without the bracing system is less than the others, but almost close to resistance of BRB frame system.

This result also has seen in four-storey and five-bay frames. In eight-storey frames, resistance of both conventional and buckling restrained bracing are very close together. Among all frames with twelve and sixteen stories, strength of buckling restrained bracing systems is more than the other systems. Considering these points it can be conclude that the resistance of the buckling restrained bracing frame with respect to other systems (conventional braces and frame without braces), is further increased with increased in height. In fact, this system is more resistant than the other two systems in the structures with an average height and above. This result is more evident in five-bay frames.

Considering the results, it is clear that the stiffness of conventional braced systems with four and eight-storey is more than the other systems (This difference is particularly evident in the four-storey frame) and the stiffness of the moment frame without bracing is less than the other. With increasing height, stiffness of buckling restrained bracing systems will increase more than the other systems. As has already been pointed out, one of the methods for calculating behavior factor is use of the idealized bilinear structural capacity curve. In this study, the capacity curves of structures with buckling restrained brace have obtained and idealized by a bilinear curve according to the 360 instructions for the performance level of life safety (LS). The goal is to calculate and compare with the behavior factor obtained from these results. In all four, eight, twelve and sixteen storey frames ductility coefficient (μ) of buckling restrained braced frame is higher than the other systems. However, this coefficient in the frame without the bracing is less than the other systems.

The average of this coefficient for buckling

restrained braced frames is around 5 and for frames with conventional braces is around 4 and for frames without braces is about 2.5 which represents buckling restrained braced frames have higher ductility with respect to other systems and exhibit suitable ductile behavior.

In addition, this result indicates that generally over strength coefficient of conventional braces and buckling restrained braced systems, almost are the same; however, the coefficients on both these systems are higher than the system without braces. Therefore, these two systems show more resistance to achieve maximum strength after the formation of first plastic hinge in the structure. Moreover, without the bracing system, shortly after the first plastic hinge formation its maximum strength (for this type of system, the coefficient of over strength is approximately 1).

Ductility reduction factor for non-braced systems is greater than the other systems. In some frames with conventional braces system, ductility reduction factor is more than buckling restrained braced systems.

An important result obtained for this coefficient is that this coefficient is inversely proportional to the maximum strength of structure as well as the other have a direct impact on behavior factor.

Structure will work best where; this value is not too high and not too low. According to the initial design of the structures with assumptions of the behavior factor, if the coefficient was small, indicating that the structure is over designed and base shear force is not enough reduced; and if this value was large, it means that the strength of the structure is low and level of base shear is less. With this interpretation can conclude that braced frames (buckling restrained and conventional) have better condition than moment frames without bracing. Having obtained these parameters, the behavior factor can be estimated.

The calculated behavior factor is corresponded to the ultimate limit state if multiplied by 1.4, the behavior factor for allowable stress would be obtained. These results have summarized in Table 1.

Using the above results average behavior factor obtained for buckling restrained braced frames is about eight that was near the initial behavior coefficient considered for design of this system.

Notably, AISC recommendation for behavior factor of steel frames with buckling restrained brace is eight in the ultimate limit state.

Table 1. Values of R_w for all frames

Frame characteristics				
No. of storey	No. of bay	BRB	ORB	NOB
4	3	7.9	9.6	8.4
8	3	8.6	10.1	11.9
12	3	8.3	10.8	9.3
16	3	10.6	9.7	8.1
4	5	6.4	8.3	10.0
8	5	7.9	9.9	10.9
12	5	6.8	9.8	10.3
16	5	5.7	10.6	10.4

3- Conclusions

In this study, 24 numbers of reinforced concrete frames in three structural systems with conventional brace, buckling restrained brace and without bracing, having four, eight, twelve and sixteen stories have been designed according to Iranian national building code-Part 9. All systems have been analyzed using nonlinear static analysis method. Then the parameters influencing the behavior factor have evaluated for all frames. From this study the following conclusions are drawn:

- 1) Among all the studied frames, ductility coefficient of buckling restrained braced frames is greater than the other systems.
- 2) Ductility coefficient of non-braced frames is less than the other systems.
- 3) Average ductility coefficient of buckling restrained braced frame and conventional braced frames is around five whereas for non-braced frame is about 2.5.
- 4) Over strength factor of braced systems with conventional and buckling restrained braces are close together and is minimum for non-braced frames.
- 5) Average response modification factor is about eight for buckling restrained braced frames.

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