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Boundary condition effect on response modification factor of X-braced steel frames

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KEYWORDS

Response modification factor;
Ductility reduction factor;
Overstrength factor;
Boundary conditions;
Brace frame;
Nonlinear static analysis "Pushover"

Abstract Design of the structures to resist seismic force depends on the theory of dissipation in elastic energy that already exists in response modification factor "*R*-factor". The main problem in codes gives a constant value for *R*-factor, since change in boundary conditions of building change in behavior of braced steel frame structures and that effects on *R*-factor. This study is an attempt to assess overstrength, ductility and response modification factor of X-braced steel frame under change in boundary conditions, as change in the direction of strong axis of column and connection support type of column besides variation in storey and bays numbers to be 21 frames and each frame has 8 different boundary conditions as sum of 168 cases for analysis. These frames were analyzed by using nonlinear static "pushover" analysis. As results of this study change in support type and direction of strong axis of column give large change in value of *R*-factor; the minimum value was 4.37 and maximum value 10.97. Minimum value is close to code value that's mean the code is more conservative in suggesting of *R*-factor and gives a large factor of safety. Change in the location of bracing gives change in value of *R*-factor for all boundary conditions. Change in direction of strong axis of columns and support type didn't give change in value of fundamental period, all boundary conditions.

Introduction

Steel frame structures should be designed to resist enough seismic waves of earthquake to provide more comfortable and peace of mind to the residents that live in the buildings. In other word, design philosophy in codes gives enough lateral stiffness for the structures to make a control in the deformations and transfer the force to foundation, besides ductility of the structures to dissipate a considerable amount of energy through inelastic behavior. Also, the residing in codes emphasizes that absolute safety and damage "Not collapse" in an earthquake with a reasonable probability of occurrence, can't be achieved letting some of non-structural and structural damage. Relying on the ability of structures to undergo high levels of plastic deformations and dissipate energy, current building codes design the structures to withstand much lower forces than that are caused by earthquakes to be economic design.

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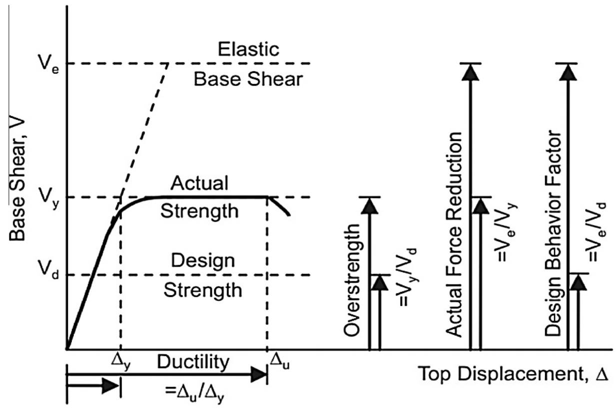

Figure 1 General structure response.

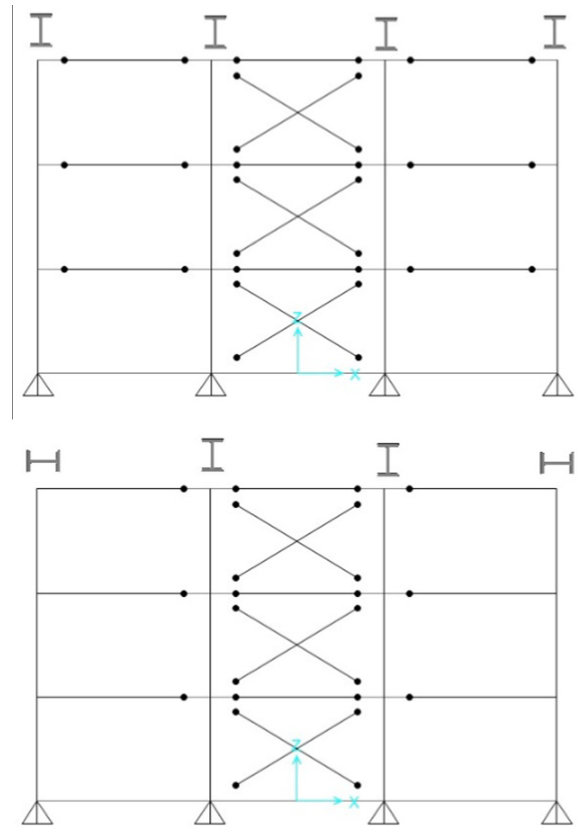

Figure 2 Direction of column and release connection.

A high level of life safety can be economically achieved in structures by allowing dissipation in elastic energy. Braced steel frame is one of the commonly and efficiently used to resist lateral load, especially for the structure having high or moderate seismic regions. The braced steel frames improve the stiffness and the lateral strength by inelastic deformation during an earthquake that leads to dissipation of seismic energy [1]. The lateral response of braced frame is mainly dominated by inelastic behavior for bracing members [2]. One of the factors that have effect on the capacity of dissipated energy of structures is response modification factor, and it has energy dissipation reflection within the boundary of plastic with respect to the lack of overturning and bid deformation. On the other hand, the architecture problems impose to change some of design criteria or design system of the structure. In addition to this, change in direction of column or position of bracing has an effect on dissipation energy and these already have effect on response modification factor and many of boundary conditions in steel structures have effect directly in dissipation energy, so, response modification factor is affected by boundary condition of the structure. Location of bracing, support type and direction of columns are sample of boundary conditions that have effect on response modification factor of the structures that have effect on economic design relaying upon [3]. Building codes assign the value of *R*-factor to structures according to many factors such as type of the material used in construction (i.e. steel, reinforcement concrete), statical system, and ductility level. However this value serves the same function in all building codes, and it differs widely from code to another.

Steel braces are defined as those frame members that develop seismic resistance primarily through axial forces. Braced frames act as vertical trusses where the columns are the chords and the beams and braces are the web members.

Concentric braced frames are very efficient structural systems in steel for resisting lateral forces due to wind or earthquakes because they provide complete truss action. However this framing system is not considered as ductile in design practice for earthquake resistance. The non-ductile behavior of these structures mainly results from early cracking and fracture of bracing members or connections during large cyclic deformations in the post-buckling range. The reason lies in the code philosophy. Instead of requiring the bracing members and their connections to withstand cyclic post-buckling deformations without premature failures (i.e., supply adequate ductility), the codes generally specify increased lateral design forces.

Brace slenderness can be reduced by adopting an X-bracing configuration. Theoretical and experimental studies by Picard and Beaulieu [4,5] showed that the tension acting brace can provide an efficient support at the brace intersecting point for the compression brace. For symmetrical bracing configuration, an effective length factor, *K*, of 0.5 was recommended for pin ended braces, for both in-plane and out-of-plane bucklings.

Response modification factors

Most codes used factor to reduce seismic force, and this factor has different name in codes, response modification factor in IBC 2012 [6] & Egyptian code (EC-201-2012) [7], behavior factor (*q*-factor) on Euro code (EC-2003) [5], response modification coefficient in ASCE [9], Seismic behavior factor and force reduction factor in other codes. Mazzolani and Piluso [10] addressed several theoretical approaches such as maximum plastic deformation approaches, energy approach and cycle fatigue to compute response modification factor. ATC-34 [11], ATC3-06 [12] and ATC-19 [13] proposed a simplified formulate to estimate the response modification factor. *R*-factor is product of three factors: Ductility reduction factor (R_μ), Overstrength reduction factor (R_S) and redundancy factor (R_R). Hence *R*-factor can be written as follows:

Table 1 Cross-sectional properties of steel frames.

Storey no.	9-storey			6-storey			3-storey		
	Beam	Colum	Bracing	Beam	Colum	Bracing	Beam	Colum	Bracing
9	IPE360	HE 200	TUBO 80 * 80 * 10						
8	IPE400	HE 220	TUBO 80 * 80 * 10						
7	IPE400	HE 220	TUBO 80 * 80 * 10						
6	IPE450	HE 300	TUBO 90 * 90 * 10	IPE360	HE 200	TUBO 80 * 80 * 10			
5	IPE450	HE 300	TUBO 90 * 90 * 10	IPE400	HE 200	TUBO 80 * 80 * 10			
4	IPE500	HE 340	TUBO 90 * 90 * 10	IPE450	HE 260	TUBO 90 * 90 * 10			
3	IPE500	HE 340	TUBO 100 * 100 * 10	IPE450	HE 260	TUBO 90 * 90 * 10	IPE360	HE 220	TUBO-D 139.7 * 4
2	IPE550	HE 400	TUBO 100 * 100 * 10	IPE500	HE 340	TUBO 100 * 100 * 10	IPE360	HE 220	TUBO-D 139.7 * 4
1	IPE550	HE 400	TUBO 100 * 100 * 10	IPE500	HE 340	TUBO 100 * 100 * 10	IPE360	HE 220	TUBO-D 139.7 * 4

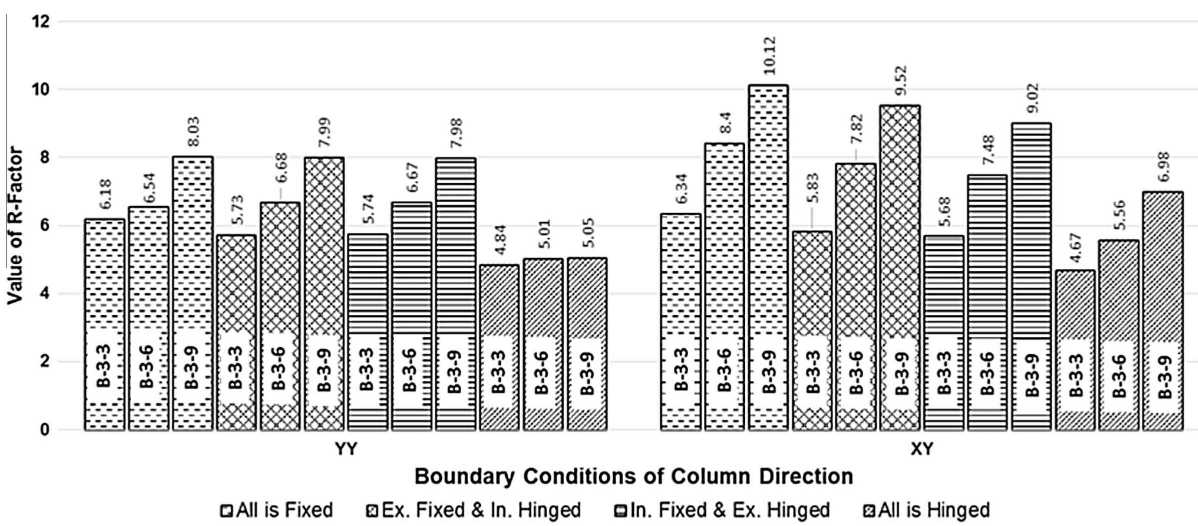

Figure 3 Values of *R*-factor with all different boundary conditions for different number of storey for frames "B-3-3", "B-3-6" & "B-3-9".

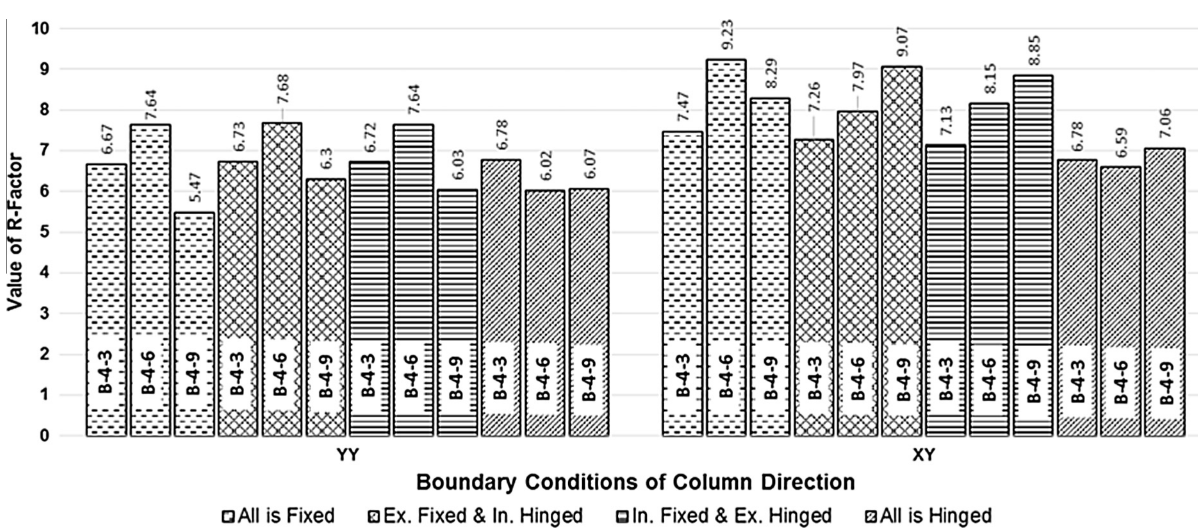

Figure 4 Values of *R*-factor with all different boundary conditions for different number of storey for frames "B-4-3", "B-4-6" & "B-4-9".

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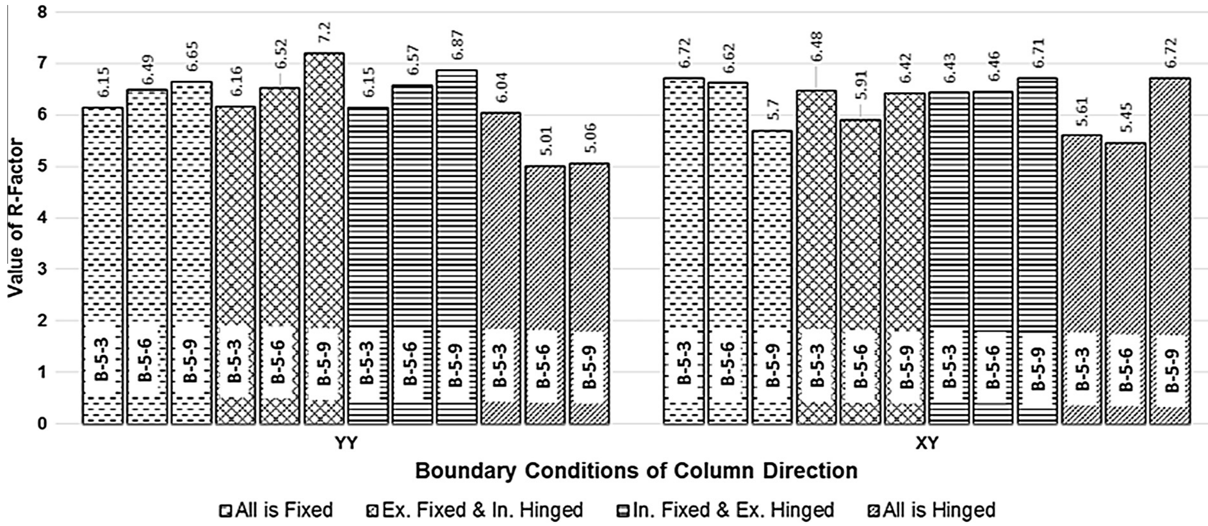

Figure 5 Values of *R*-factor with all different boundary conditions for different number of storey for frames "B-5-3", "B-5-6" & "B-5-9".

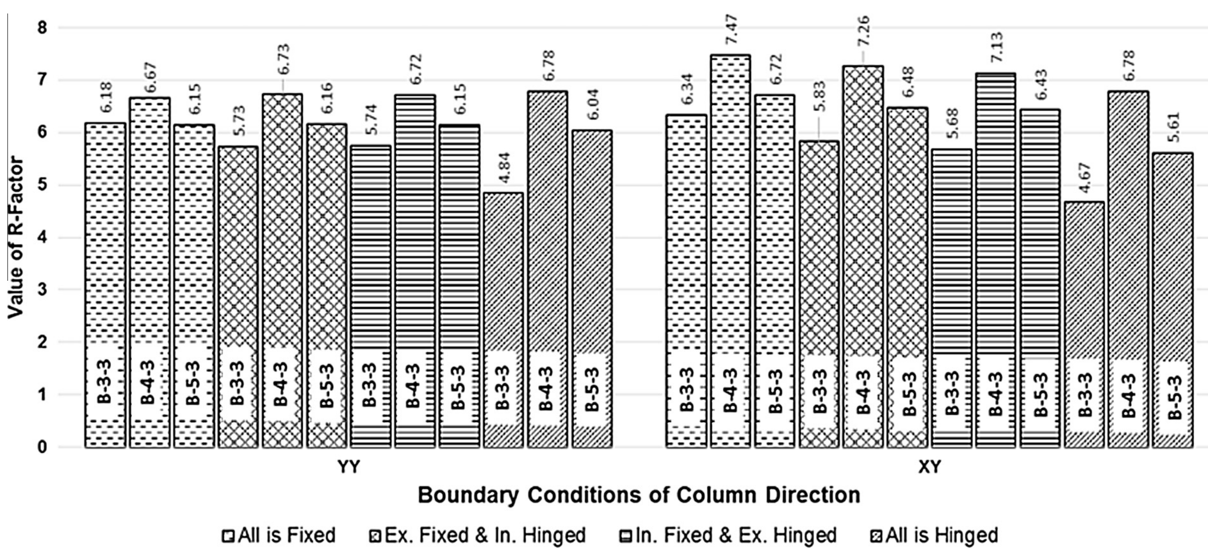

Figure 6 Values of *R*-factor with all different boundary conditions for different number of bays for frames "B-3-3", "B-4-3" & "B-5-3".

$$R = R_\mu * R_S * R_R \tag{1}$$

Uang [14], Freeman [15], Rahgozar and Humar, 1998 [16] and Balendra and Huang [18] considered the overstrength and the redundancy factor as one component. This is because the overstrength accounts to redundancy through redistribution of action, which leads to higher overstrength, representing these parameters in Fig. 1

2.1. Ductility reduction factor

The extent of inelastic deformation experienced by the structural system subjected to a given ground motion or a lateral loading is given by the displacement ductility ratio "μ" (ductility demand) and it is defined as the ratio of maximum absolute relative displacement to its yield displacement.

$$\mu = \frac{\Delta_{max}}{\Delta_{yield}} \tag{2}$$

R_μ is parameter to measure global nonlinear response of structure.

$$R_\mu = \frac{V_e}{V_y} \tag{3}$$

In the above equation, V_e is the maximum base shear considering elastic behavior and V_y is the maximum base shear in an elastic-perfectly plastic idealized response curve of the structure.

$$R_\mu = \frac{F_y(\mu = 1)}{F_y(\mu = \mu_i)} \tag{4}$$

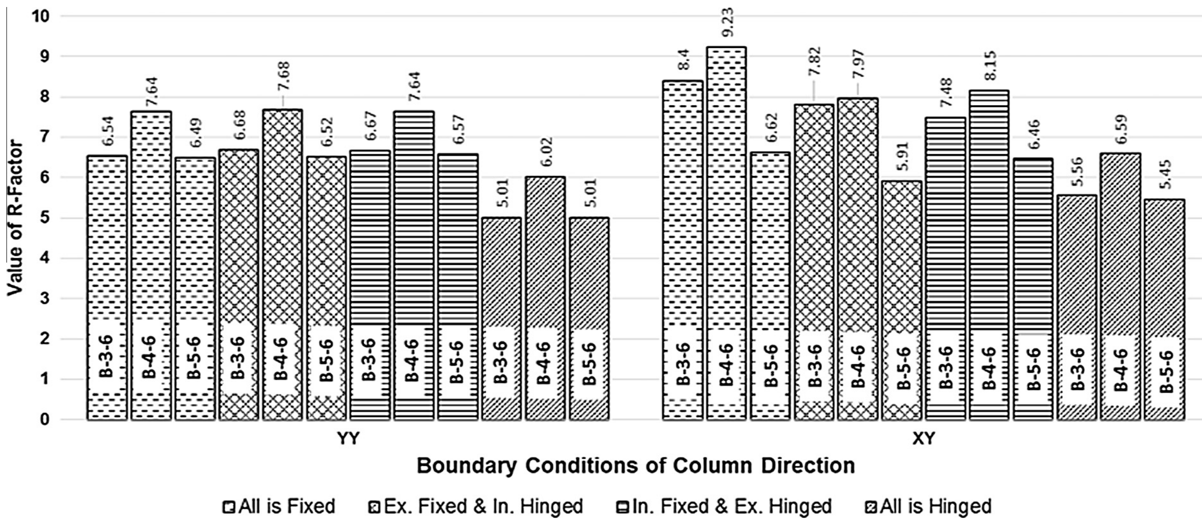

Figure 7 Values of *R*-factor with all different boundary conditions for different number of bays for frames "B-3-6", "B-4-6" & "B-5-6".

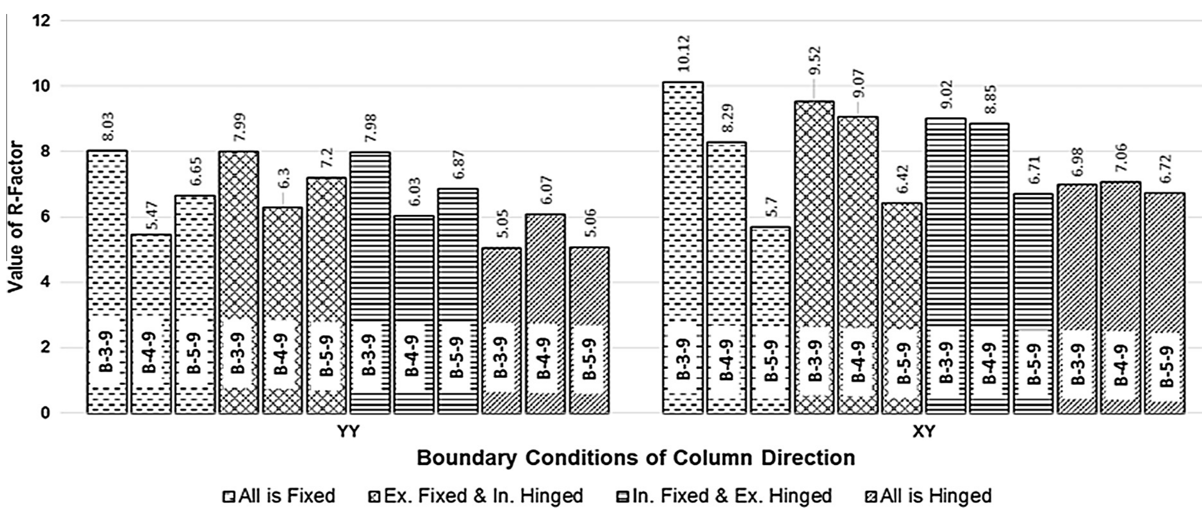

Figure 8 Values of *R*-factor with all different boundary conditions for different number of bays for frames "B-3-9", "B-4-9" & "B-5-9".

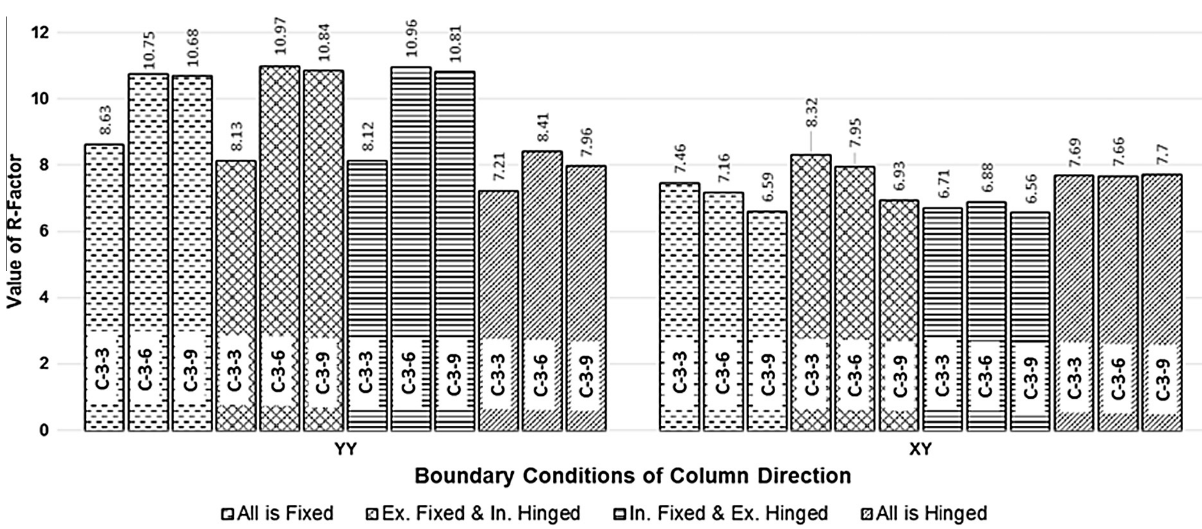

Figure 9 Values of *R*-factor with all different boundary conditions for different number of storey for frames "C-3-3", "C-3-6" & "C-3-9".

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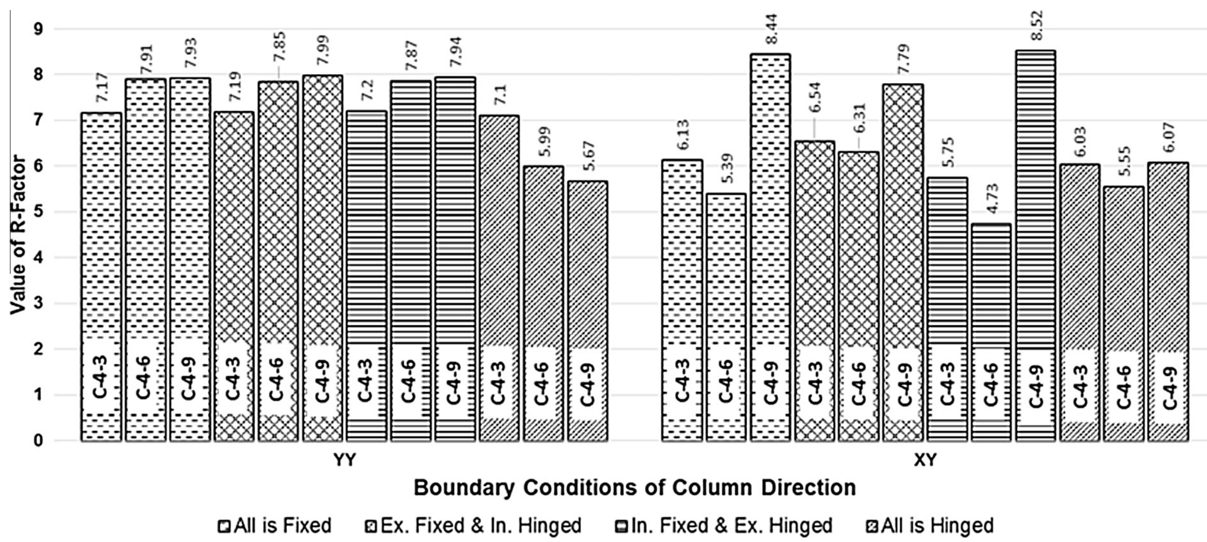

Figure 10 Values of R-factor with all different boundary conditions for different number of storey for frames "C-4-3", "C-4-6" & "C-4-9".

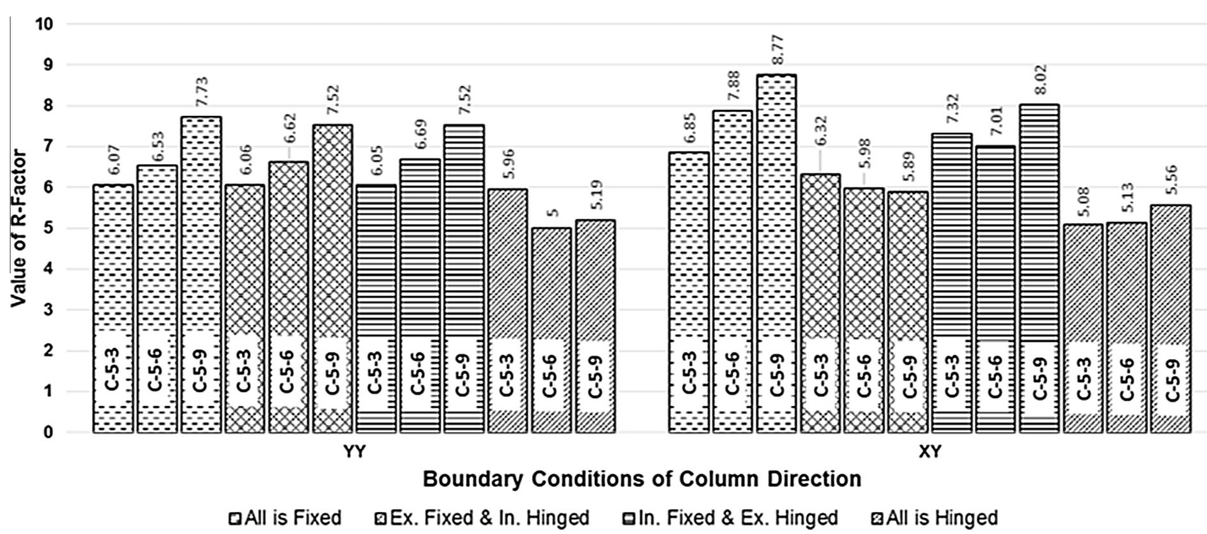

Figure 11 Values of R-factor with all different boundary conditions for different number of storey for frames "C-5-3", "C-5-6" & "C-5-9".

The "ductility reduction factor", in some studies is called as "strength reduction factor" (the reduction in strength demand due to post-elastic behavior), R_{μ}, is defined as the ratio of the $F_y(\mu = 1)$ (V_e) lateral yield strength required to maintain the system elastic to the $F_y(\mu = \mu_i)$ (V_y) lateral yield strength required to maintain the displacement ductility ratio μ less or equal to a predetermined target ductility ratio μ_i. Some of the previous studies about ductility reduction factors are reviewed by Newmark and Hall [17], Riddell and Newmark [19], Riddell et al. [20] and Miranda [21], For this study Newmark and Hall [17] used to calculate R_u.

Overstrength factor $\boldsymbol{R_S}$

R_S structural overstrength has an important role in collapse prevention of the buildings, overstrength helps the structure not only to stand safely against saver tremors but reduce the elastic strength demand, and as well as, this object is performed using the force reduction factor.

$$R_S = \frac{V_y}{V_d} \quad (5)$$

The overstrength factor was calculated to be equal to the maximum base sheer force of the yield level (V_y) divided by the design base shear (V_d).

3. Structural models

In this investigating study, steel frames are used to analyse, "X-braced Frame". This frame system has variations of 3, 6 and 9 stories with constant height of storey 3.2 m, in addition to variations of 3, 4 and 5 bays. Boundary conditions that are

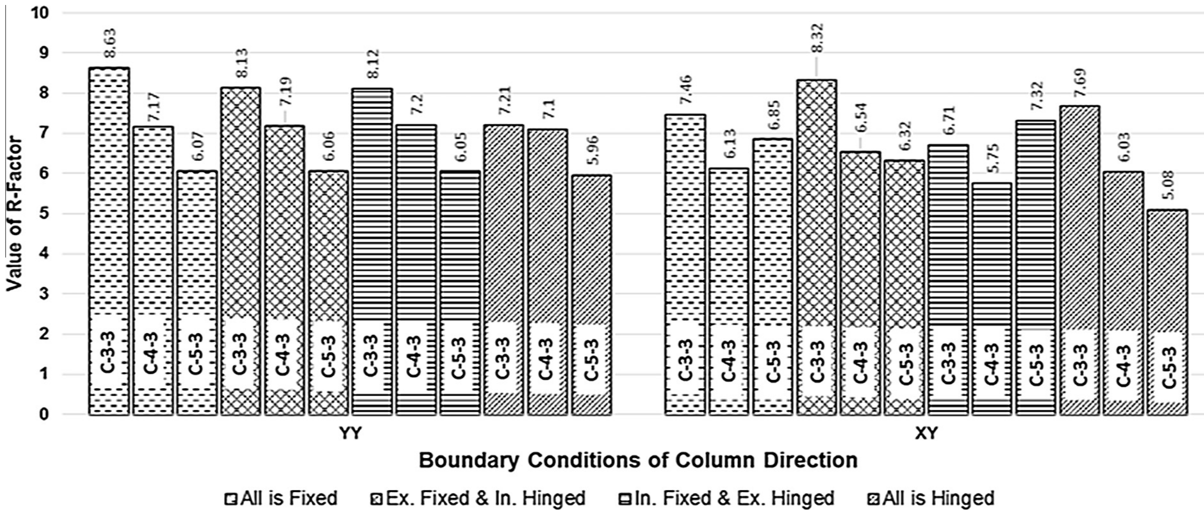

Figure 12 Values of *R*-factor with all different boundary conditions for different number of bays for frames "C-3-3", "C-4-3" & "C-5-3".

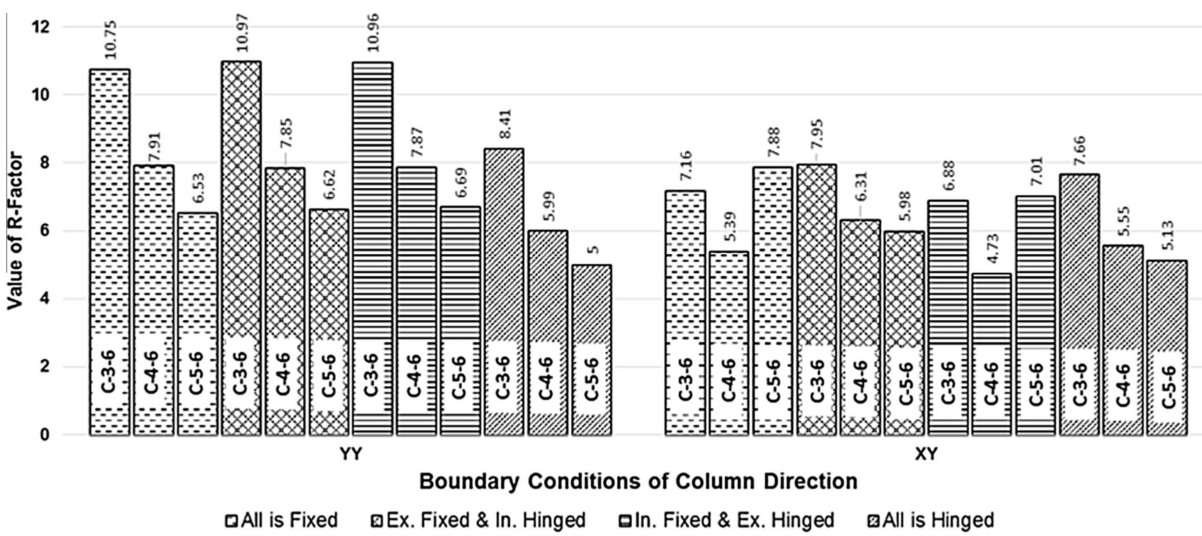

Figure 13 Values of *R*-factor with all different boundary conditions for different number of bays for frames "C-3-6", "C-4-6" & "C-5-6".

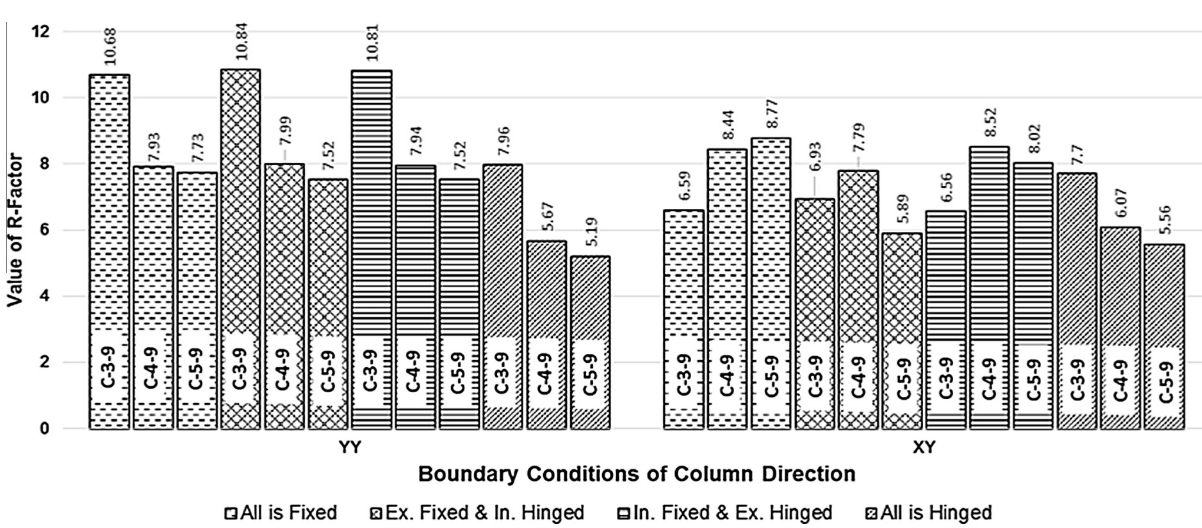

Figure 14 Values of *R*-factor with all different boundary conditions for different number of bays for frames "C-3-9", "C-4-9" & "C-5-9".

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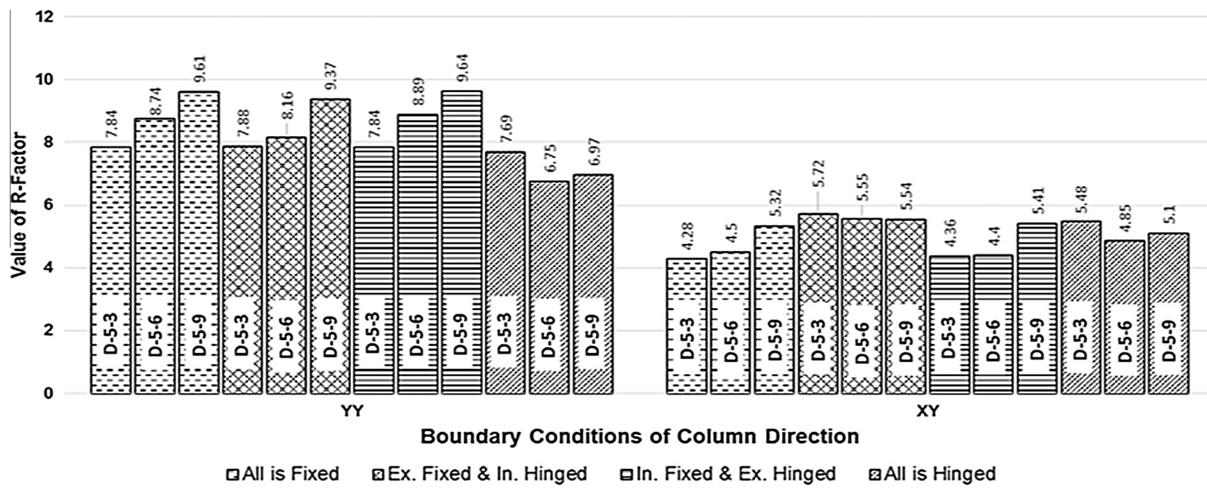

Figure 15 Values of *R*-factor with all different boundary conditions for different number of storey for frames "D-5-3", "D-5-6" & "D-5-9".

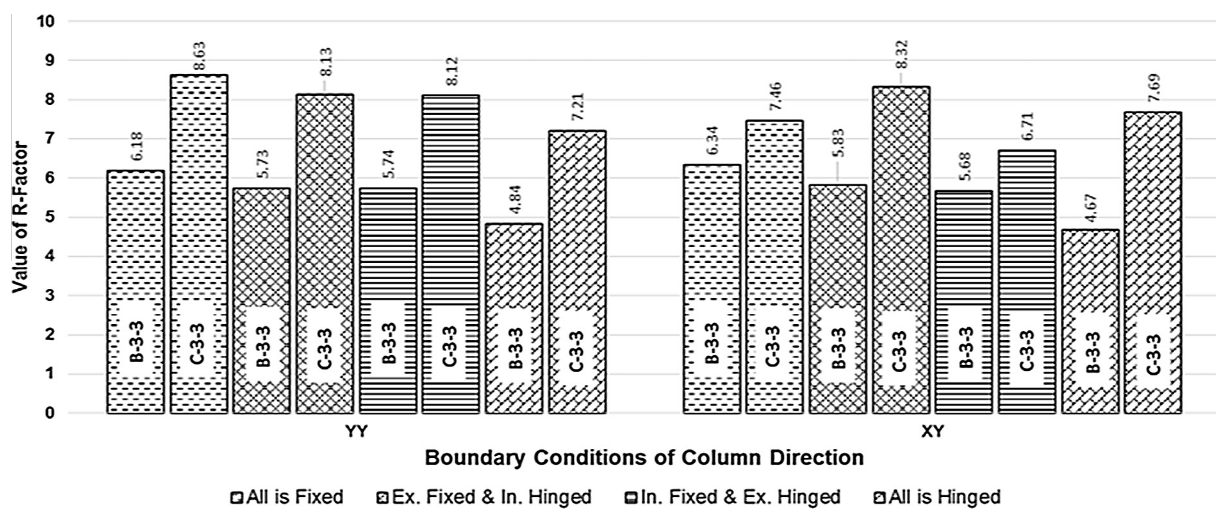

Figure 16 Values of *R*-factor with all different boundary conditions for different frame types of "B-3-3" & "C-3-3".

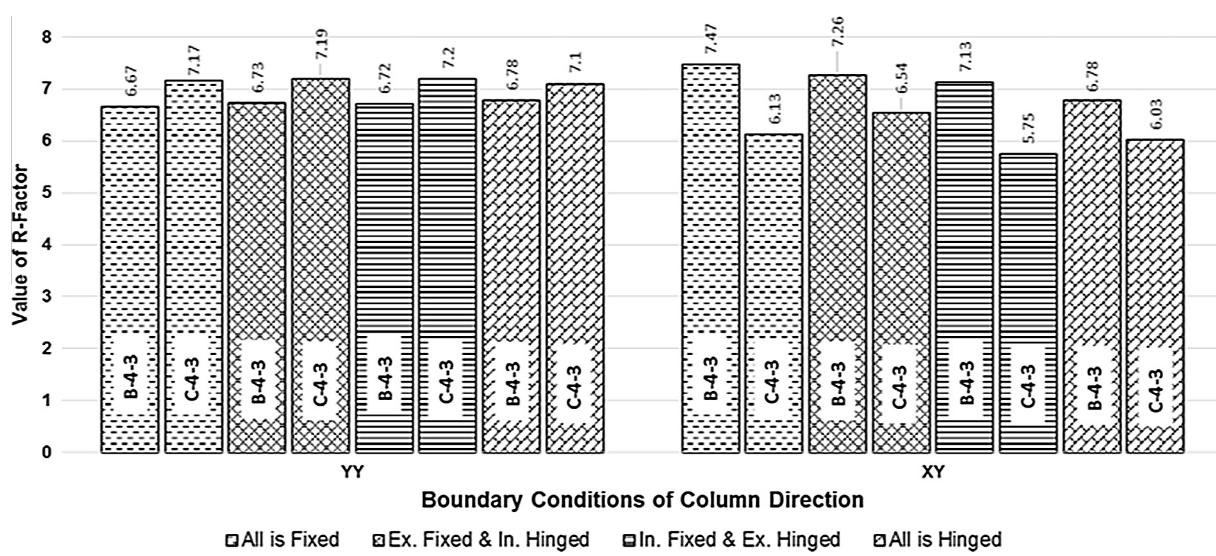

Figure 17 Values of *R*-factor with all different boundary conditions for different frame types of "B-4-3" & "C-4-3".

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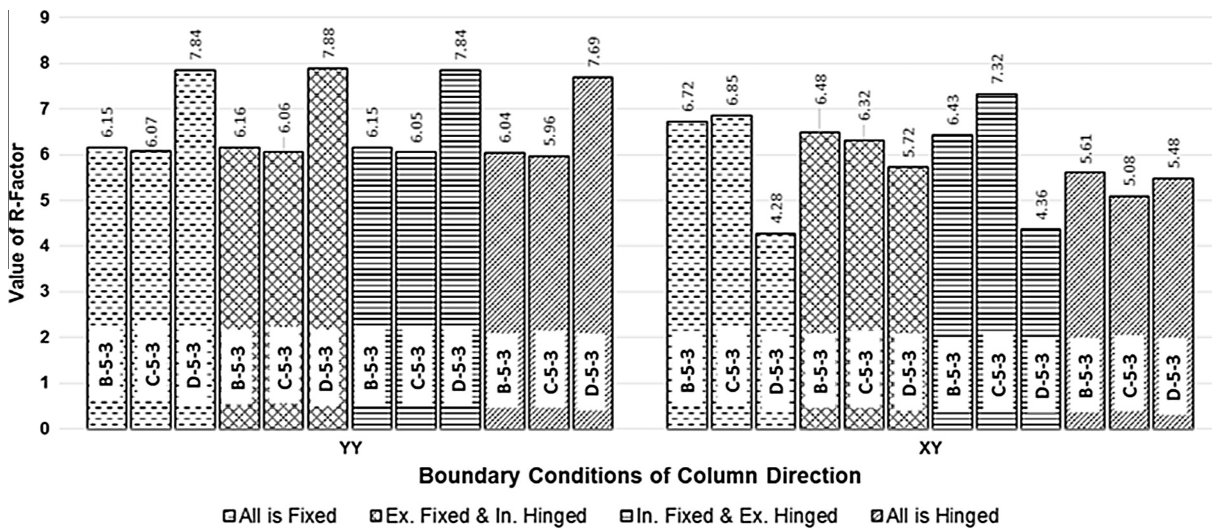

Figure 18 Values of *R*-factor with all different boundary conditions for different frame types of "B-5-3", "C-5-3" & "D-5-3".

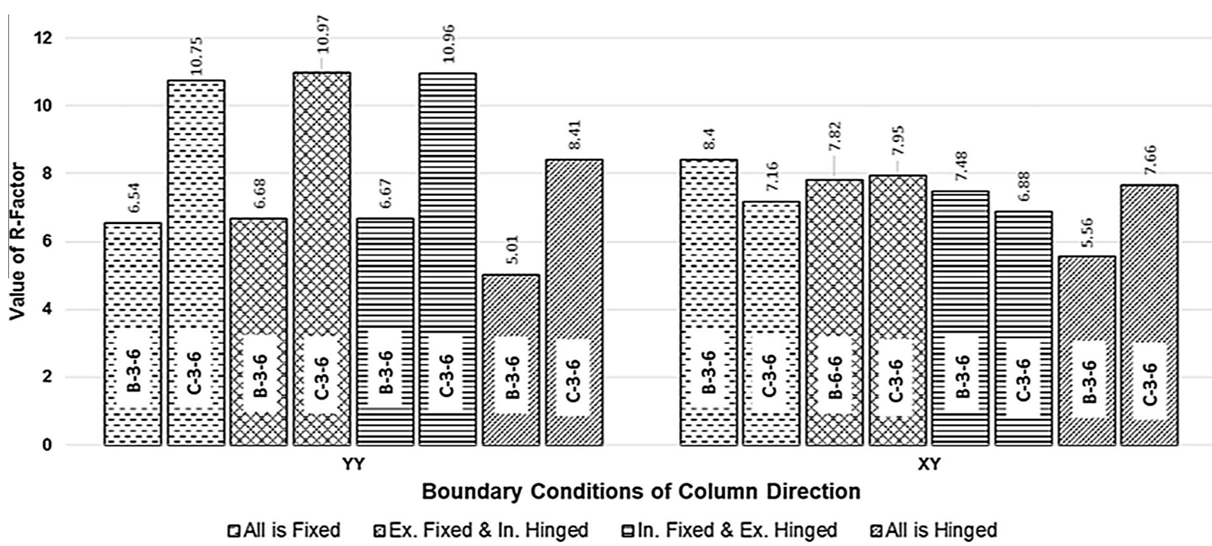

Figure 19 Values of *R*-factor with all different boundary conditions for different frame types of "B-3-6" & "C-3-6".

used for this study can be summarized in the direction of strong axis of columns and type of support connection. There are two possible probabilities in the direction of column; **YY**: All strong axis of column in *Y*-direction and, **XY**: Strong axis of Exterior column in *X*-direction & Interior Column in *Y*-direction. Addition to another boundary condition is type of support connection and has also four probabilities:

1. All supports are Fixed.
2. Exterior support of column is Fixed & Interior is Hinged.
3. Exterior support of column is Hinged & Interior is Fixed.
4. All supports are Hinged. The connection between columns and girders depends on the direction of strong axis of column as shown in Fig. 2 below. The Steel frames in this study are designed according to the Egyptian Code for Practice for Steel Construction and Bridges ECP-205 [22], and the calculation of the equivalent lateral load is based on Egyptian Code for calculation of loads for structures ECP-201 [7]. These frames have been designed for dead load 480 kg/m^2 and Live Load 250 kg/m^2. In a regions of moderate seismic (zone 3) moreover with importance factor 1.2 and third type of soil according to Egyptian Code for calculation of loads for structures ECP-201 [7]. For the steel applied, the modules of elasticity *E*, Yield strength and ultimate strength were considered 210 t/cm^2, 3.6 t/cm^2 and 5.2 t/cm^2 respectively. All steel frame structures were modeled in software of SAP2000 V15.1 [23] (see Table 1).

Nonlinear static analysis of model structure

Nonlinear static analysis "Pushover Analysis", has been developed in recent years and became a powerful analysis and performance; that is used in evaluation and procedure of design. It's has a simple procedure, and contain on approximations

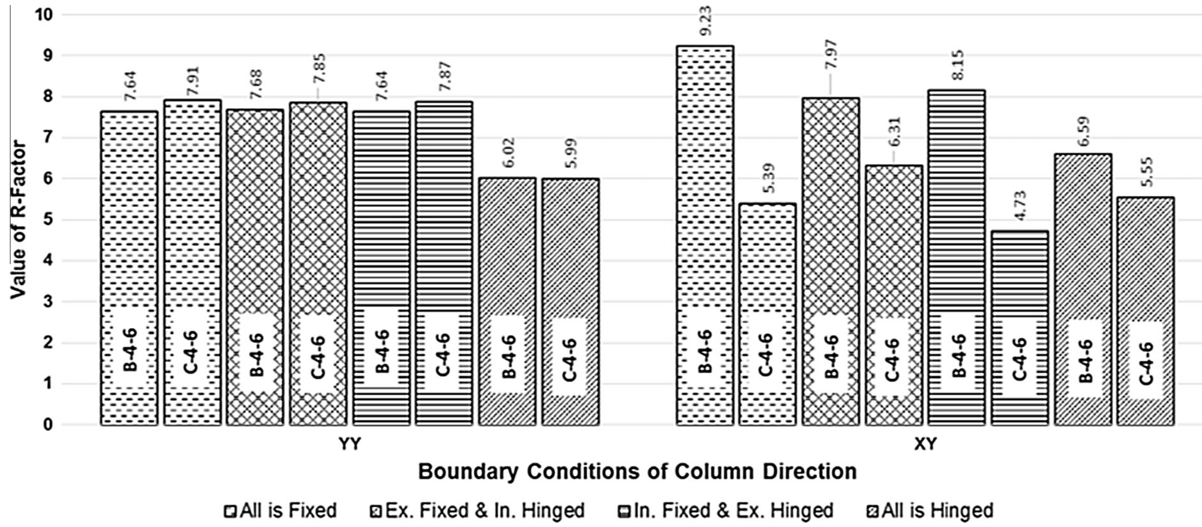

Figure 20 Values of *R*-factor with all different boundary conditions for different frame types of "B-4-6" & "C-4-6".

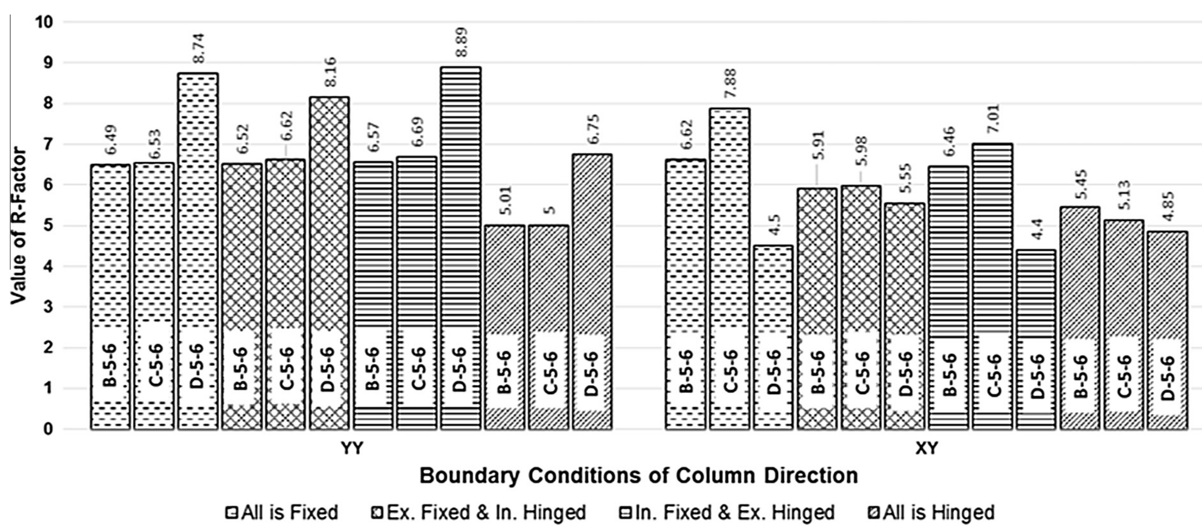

Figure 21 Values of *R*-factor with all different boundary conditions for different frame types of "B-5-6", "C-5-6" & "D-5-6".

and simplifications variable, that's mean need to some variations of exist seismic demand evaluation.

The pushover analysis of a structure is a static nonlinear analysis under permanent vertical distributed loads and gradually increasing lateral loads with invariant height-wise until a target displacement is reached. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure or storey drift is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure or collapse, and thus it enables determination of collapse load and ductility capacity on the structure sample.

Riddell et al. [20] evaluated the applicability of the inelastic dynamic analysis and the inelastic static analysis for steel frames with some variations in characteristics. As a result of study the inelastic dynamic analysis is more suitable for high-rise or long-period structures. In this study, nonlinear static analysis (Pushover analysis) has been used to determine the overstrength and ductility reduction factors.

Steel moment frames develop their seismic resistance through bending of steel beams and columns, and moment-resisting beam-column connections. Such frame connections are designed to develop moment resistance at the joint between the beam and the column. To this end, the behavior of steel moment-resisting frames is generally dependent on connection configuration and detailing. In FEMA-356 [24] various connection types are identified as fully-restrained or partially restrained. Fully Restrained (FR), commonly designated as "rigid-frame" (continuous frame), assumes that connections have sufficient stiffness to maintain the angles between intersecting members. Partially Restrained (PR), assumes that connections have insufficient stiffness to maintain the angles between intersecting members. In analysis and design of a steel-framed structure, the actual behavior of beam to-column connection is generally simplified to the two ideal models of either rigid-joint or pinned-joint behavior. Rigid joints, where no relative rotations occur between the connected members, transfer all internal actions to one another. On the

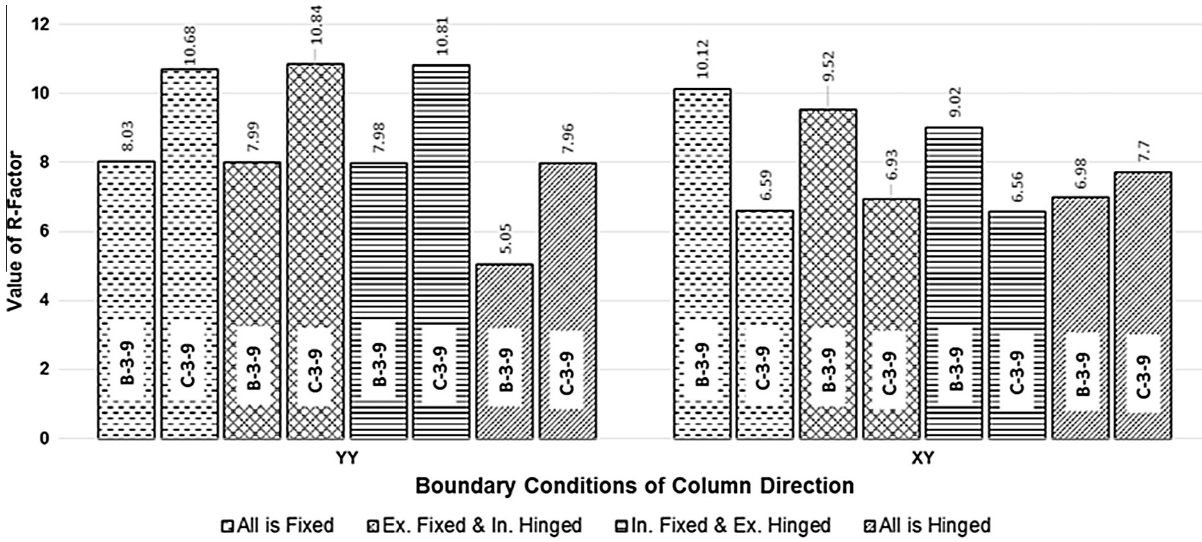

Figure 22 Values of *R*-factor with all different boundary conditions for different frame types of "B-3-9" & "C-3-9".

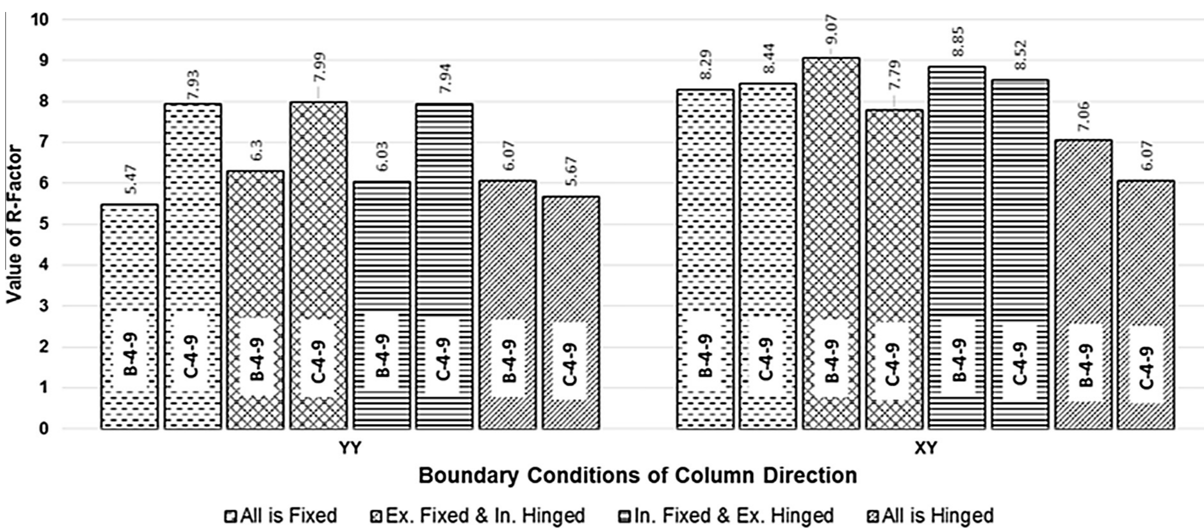

Figure 23 Values of *R*-factor with all different boundary conditions for different frame types of "B-4-9" & "C-4-9".

other hand, pinned joints are characterized by free rotation movement between the connected elements that prevent the transmission of bending moments. Such connections that possess moment capacity in between complete fixity and the pin connection are partially restrained connections.

To assess the response modification factor, nonlinear static (pushover) analysis is performed by SAP2000 [23] program is used. Lateral load pattern has main effect on pushover analysis. FEMA 356 code [24] recommended to use at least two load patterns and envelope the results. Guptu and Kunnath [25] recommended that trapezoidal or triangular shape provides a better fit to dynamics analysis. For this study envelops of uniform and invariant triangular load pattern have been used and envelops the result in the pushover analysis. In order to investigate the behavior of beams and columns beyond the elastic limit, discrete plastic hinges need to be assigned to the modeled frame elements. SAP2000 [23] allows assigning hinges to a frame element at any location along the element for only nonlinear static analysis and nonlinear direct integration time history analysis. In this study, plastic hinges are assigned at the two ends of each element. These plastic hinges can be specified for any number of degree of freedom. Moreover, the axial force and the bending moment can be coupled together in the same plastic hinge, for instance, P-M2, P-M3 and P-M2–M3. In this study, M3 hinges are assigned to beams, while P-M3 hinges are assigned to the columns. The plastic hinge properties in SAP2000 [23] are determined according to the provisions of FEMA 356 [24]. In the recent NEHRP guidelines [26], the seismic demands are computed by nonlinear static analysis of the structure subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Both the force distribution and target displacement are based on the assumptions that the response is controlled by the fundamental mode and that the

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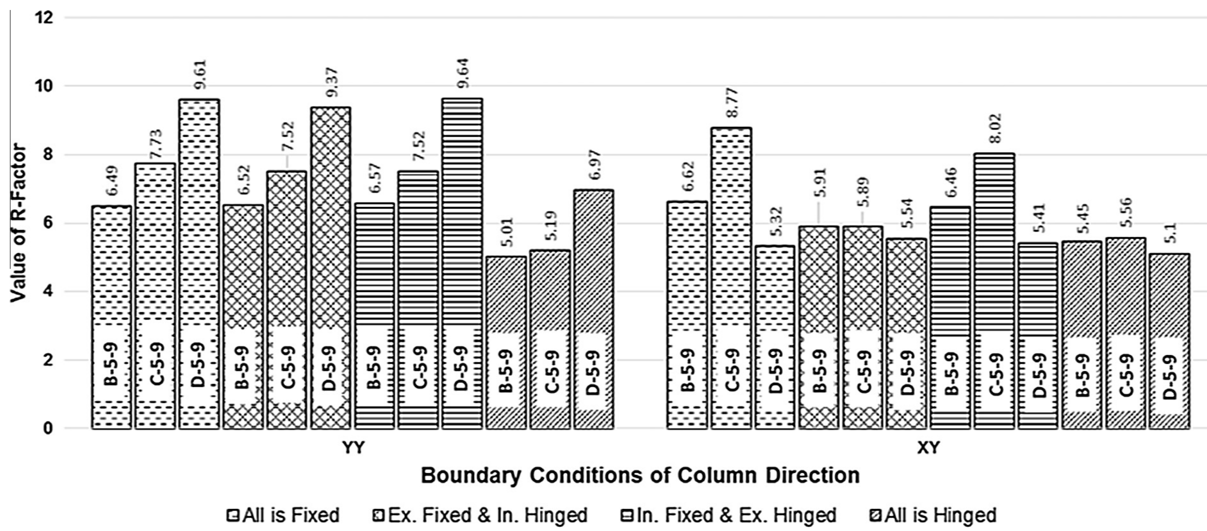

Figure 24 Values of *R*-factor with all different boundary conditions for different frame types of "B-5-9", "C-5-9" & "D-5-9".

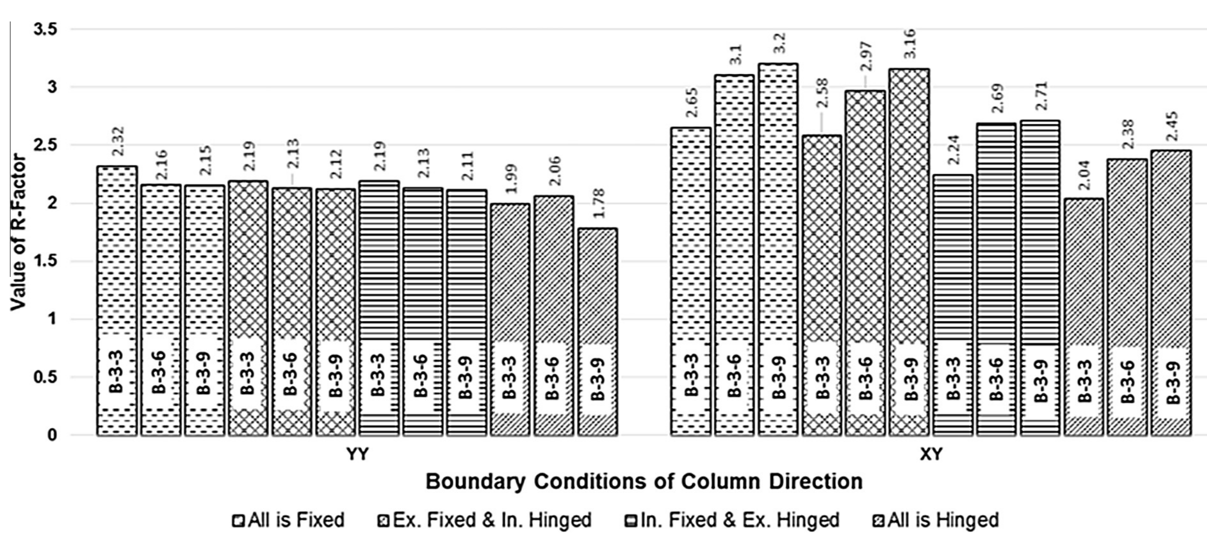

Figure 25 Values of overstrength factor with all different boundary conditions for different number of storey for bays "B-3-3", "B-3-6" & "B-3-9".

mode shape remains unchanged and both assumptions are approximate after the structure yields. SAP2000 can also perform pushover analysis as either force-controlled or displacement-controlled. The "Push to Load Level Defined by Pattern" option button is used to perform a force-controlled analysis. The pushover typically proceeds to the full load value defined by the sum of all loads included in the "Load Pattern" box (unless it fails to converge at a lower force value). "The Push To DisplacementMagnitude" option button is used to perform a displacement-controlled analysis. The pushover typically proceeds to the specified displacement in the specified control direction at the specified control joint (unless it fails to converge at a lower displacement value).

Steel moment frames develop their seismic resistance through bending of steel beams and columns, and moment-resisting beam-column connections. Such frame connections are designed to develop moment resistance at the joint between the beam and the column. To this end, the behavior of steel moment-resisting frames is generally dependent on connection configuration and detailing. In FEMA-356 [24] various connection types are identified as fully-restrained. In this study plastic hinge assigns at the start and the end of each member, and auto hinge assignment data are calculated from tables in FEMA-356 [24].

Results

*Response modification factor (**R**)*

Figs. 3–8 present the value of *R*-factor under effect of support type, direction of strong axis, bays number and storey number of frame "type B" (frame has bracing at middle span), since

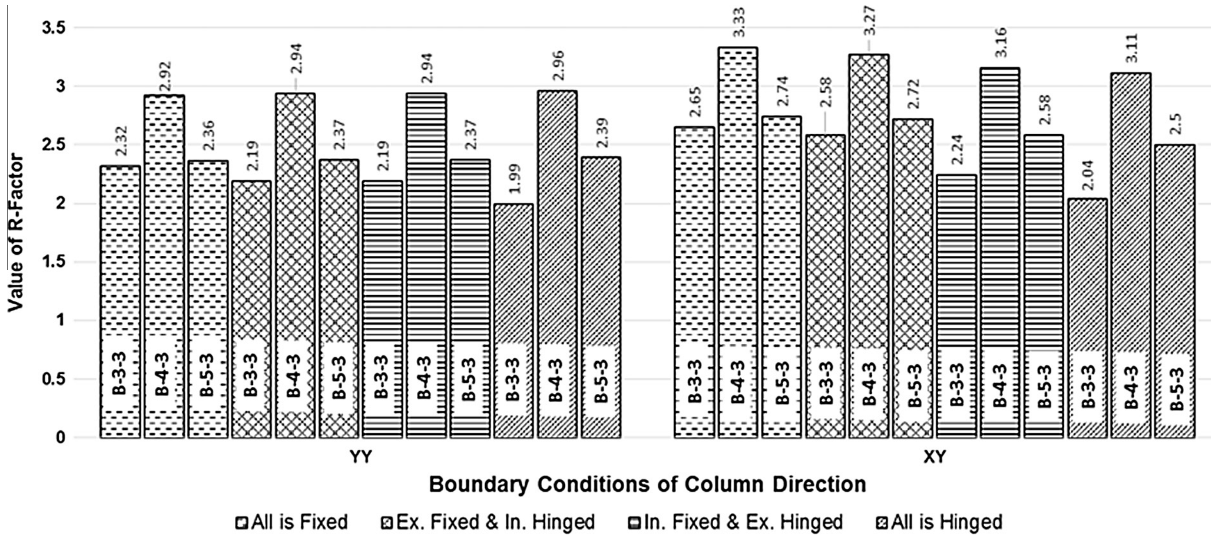

Figure 26 Values of overstrength factor with all different boundary conditions for different number of bays for frame "B-3-3", "B-4-3" & "B-5-3".

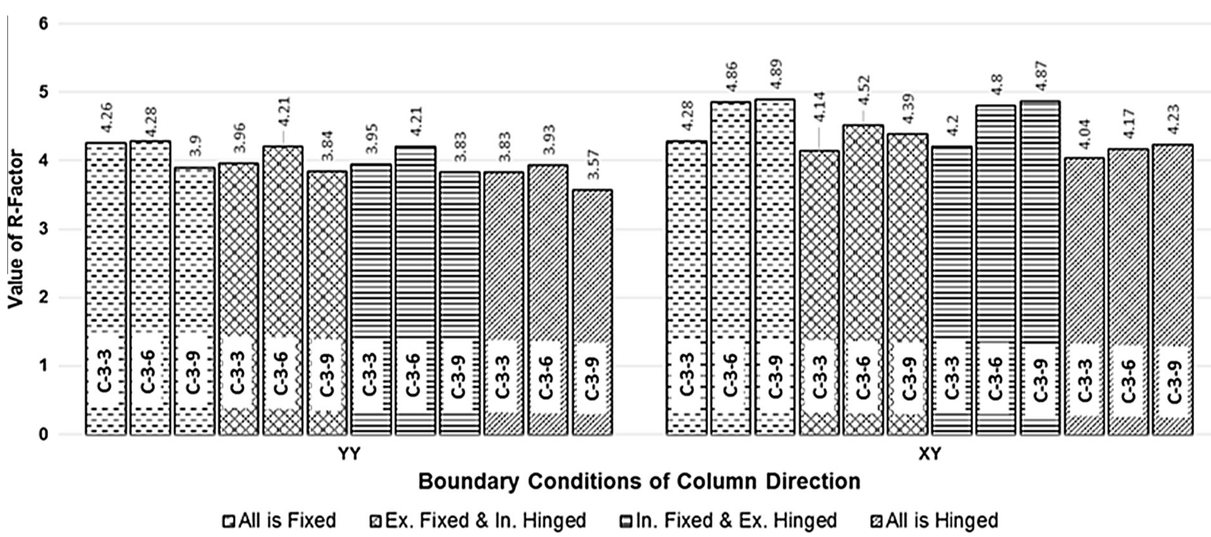

Figure 27 Values of overstrength factor with all different boundary conditions for different number of storey for frames "C-3-3", "C-3-6" & "C-3-9".

R-factor increases with increase in storey number for all boundary conditions. When increasing number of bays from 3 to 4 *R*-factor increases, and it decreases when increased from 4 to 5, and this change depends on the stiffens in structure. Change in support type and direction of strong axis of column give large change in value of *R*-factor; the minimum value was 4.37 and maximum value 10.97. Minimum value is close to code value that's mean the code is more conservative in suggesting of *R*-factor.

Figs. 9–15 represent the value of *R*-factor under effect of support type, direction of strong axis, bays number and storey number of frame "type C" (frame has bracing at edge span), as results of comparing *R*-factor do not have a constant rule for changing in storey number. *R*-factor decreases when increasing number of bays. Each change in boundary conditions gives change in *R*-factor, and any change in frame will give a new value of *R*-factor.

Fig. 15 shows the value of *R*-factor "Type D" (frame has bracing at edge and middle span) for different storey number, support type and the direction of strong axis of column, and this type of frame has constant bays number equal to 5. As results, *R*-factor increases when increasing storey number. Change in boundary conditions as support type and direction of strong axis of column give value between 9.64 as maximum value and 4.28 as minimum value for this type and this value is larger than code value.

Figs. 16–24 show the values of *R*-factor for all boundary conditions in addition to showing effects of the position of bracing on R-value for frame "Type B" versus "Type C" versus "Type D". As results change in the location of bracing

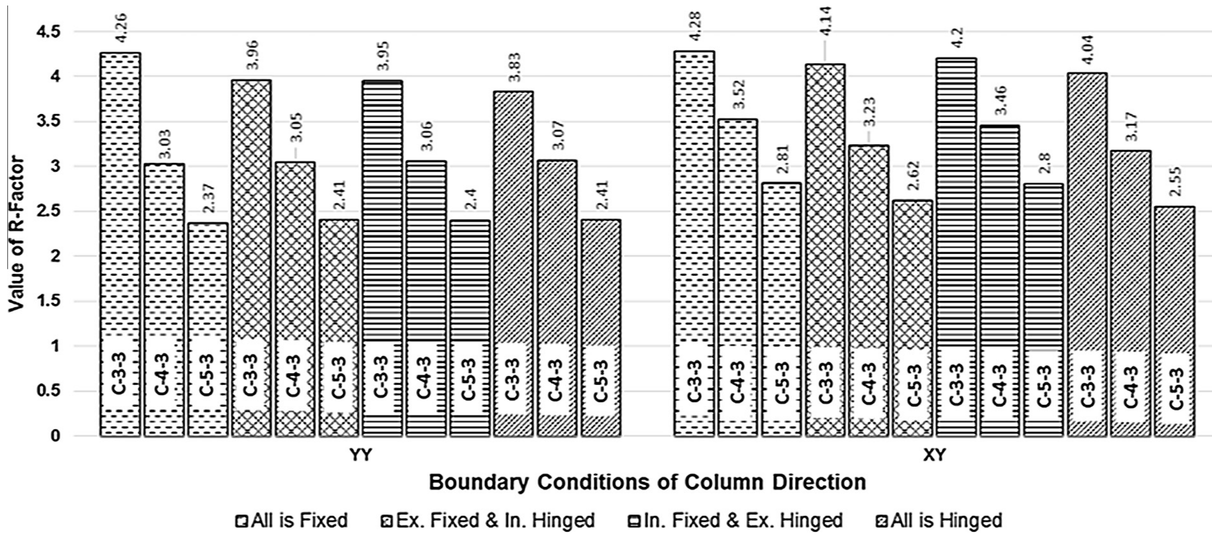

Figure 28 Values of overstrength factor with all different boundary conditions for different number of bays for frames "C-3-3", "C-4-3" & "C-5-3".

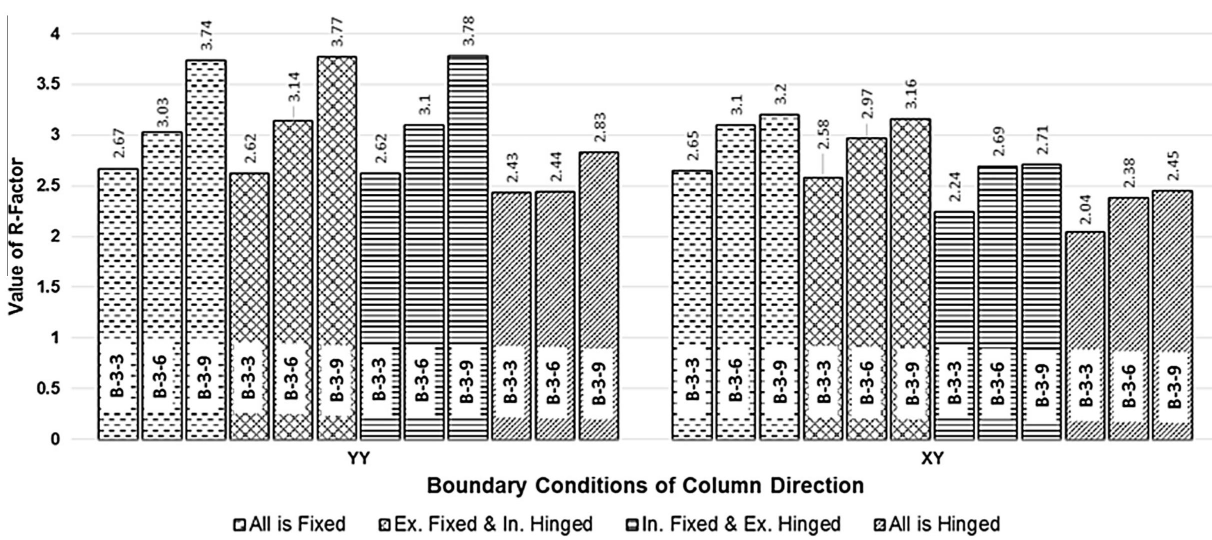

Figure 29 Values of ductility reduction factor with all different boundary conditions for different number of storey for frames "B-3-3", "B-3-6" & "B-3-9.

gives change in value of R-factor for all boundary conditions, and Frame "Type C" has values of R-factor larger than frame "Type B". When comparing three types of frame, there is frame "Type D has largest values of R-factor, since each boundary condition has rule different than others.

The final capacity of dissipated energy in every structure depends upon various factors such as structure's seismic parameters, characteristic of earthquake records and the environmental conditions of constructing place of structure. The response modification factor is the reflection of energy dissipation within the boundary of plastic with respect to the lack of overturning and big deformation in structure. So, there is change in boundary conditions in elastic dissipation of energy of the steel structures systems. As a summary of the aforesaid, each frame has sixteen boundary conditions and every boundary condition has single value of R-factor, minimum value may be near to code value, that's mean code takes minimum value to be more conservative and gives large factor of safety.

Overstrength factor (R_S)

Figs. 25 and 26 show the value of overstrength factor for frame "Type B" (Braced frame at middle span) for different number of storey and bays with all boundary conditions, and figures conclude the overstrength factor increases when increasing number of storey; when increasing number of bays from 3 to 4, overstrength factor increases, but it decreases when increasing number of bays from 4 to 5 for all frames in "Type B".

Figs. 27 and 28 show the value of overstrength factor for frame "Type C" (Braced frame at edge span) for different

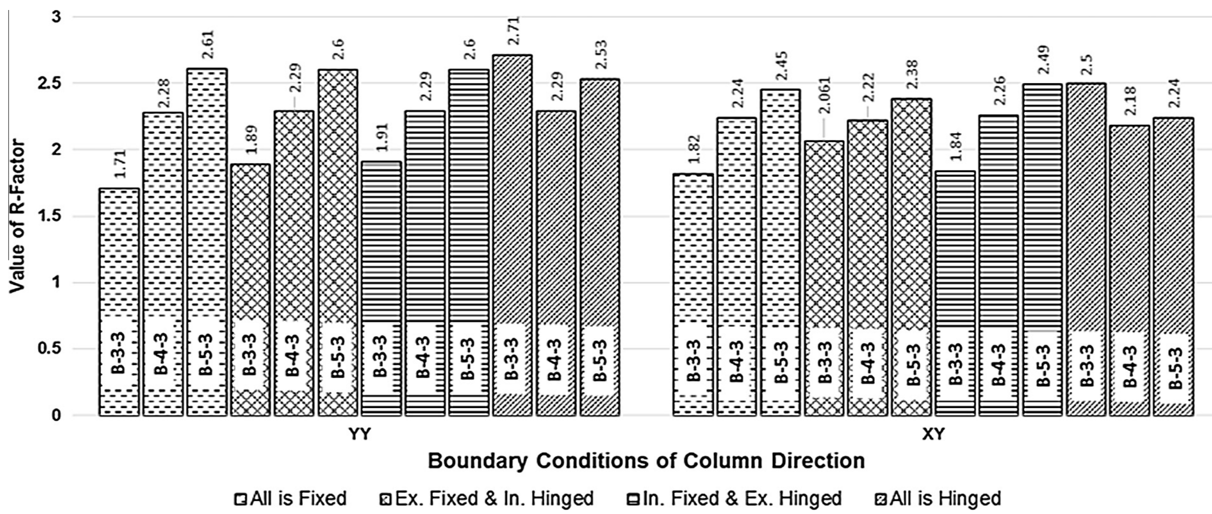

Figure 30 Values of ductility reduction factor with all different boundary conditions for different number of bays for frames "B-4-3", "B-4-3" & "B-5-3.

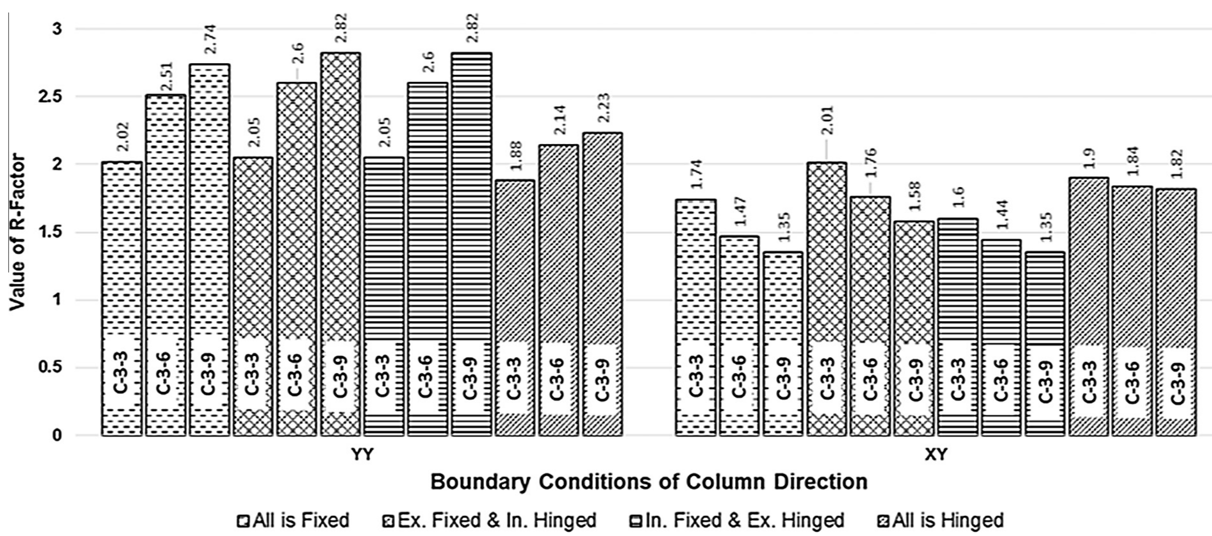

Figure 31 Values of ductility reduction factor with all different boundary conditions for different number of storey for frames "C-3-3", "C-3-6" & "C-3-9.

number of storey and bays with all boundary conditions, as results, Overstrength factor increases when increasing number of storey from 3 to 6 and it decreases when increasing number of storey from 6 to 9 for frame. Overstrength factor decreases when increasing number of bays.

Overstrength factor is defined as the ratio of the actual yield force to that one used in the design. For all results aforesaid, the change in overstrength depends on change in the actual yield force for the same frame with constant value of design force. In other word, change in the boundary conditions as column support type, direction of strong axis of column and position of bracing have effect directly on the theory of dissipation energy of the structural system, since each change in boundary conditions gives change in the stiffness of the structure to give new value of base shear versus roof displacement "pushover curve" after idealization the pushover curve can get yield force for each boundary conditions and the variable values are divided on a constant value of design force.

Ductility reduction factor (R_μ)

Figs. 29 and 30 show the value of ductility reduction factor for frame "Type B" (Braced frame at middle span) for different number of storey and bays with all boundary conditions, as results, ductility reduction factor increases when increasing number of storey. Change in number of bays has effect on Ductility factor, and ductility reduction factor increases when increasing number of bays.

Figs. 31 and 32 show the value of ductility reduction factor for frame "Type C" (Braced frame at edge span) for different number of storey and bays with all boundary conditions, as results, ductility reduction factor for frames has bracing at edge span "type C" don't have a constant rule for increasing number of storey and bays, and every boundary condition has different values.

Ductility reduction factor is the ratio between the elastic force at collapse and the force that causes the actual yield.

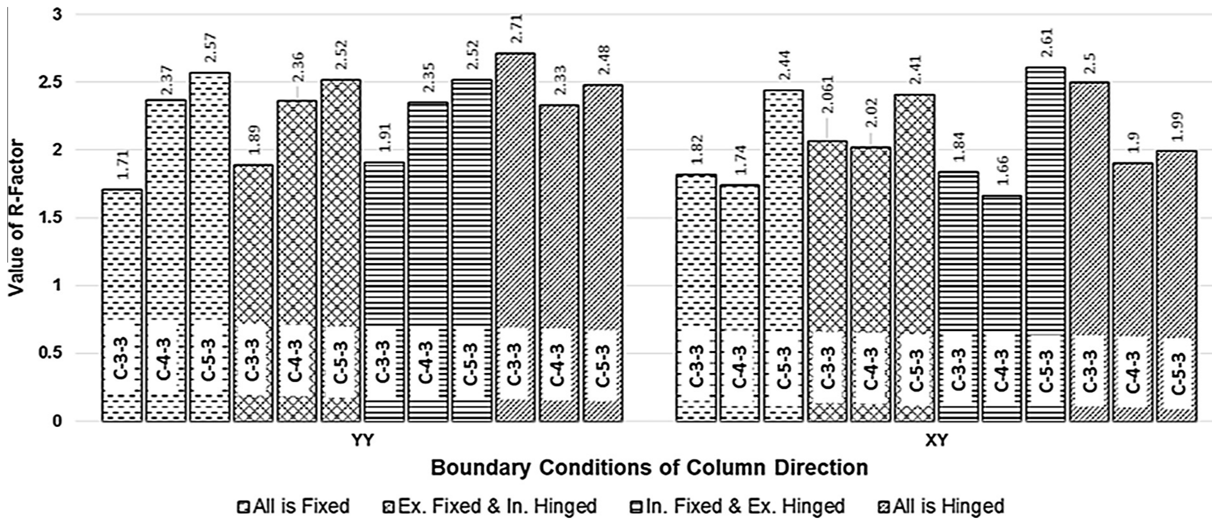

Figure 32 Values of ductility reduction factor with all different boundary conditions for different number of bays for frames "C-3-3", "C-4-3" & "C-5-3".

Table 2 Comparison of global ductility demand, and ductility dependent factor.

	Strong axis of column in *X*-direction				Strong axis of Ex. column in *Y*-direction & strong axis of In. column in *X*-direction			
Frame B-3-3								
R_u	2.67	2.62	2.62	2.43	2.39	2.26	2.53	2.29
u	6.48	5.97	6.02	4.67	4.79	4.03	5.68	4.08
Frame B-3-6								
R_u	3.03	3.14	3.10	2.44	2.71	2.23	2.78	2.34
u	4.01	4.21	4.15	2.98	3.64	3.49	3.78	2.92
Frame B-3-9								
R_u	3.74	3.77	3.79	2.83	3.16	3.01	3.33	2.85
u	3.74	3.78	3.78	2.84	3.25	3.09	3.41	2.91

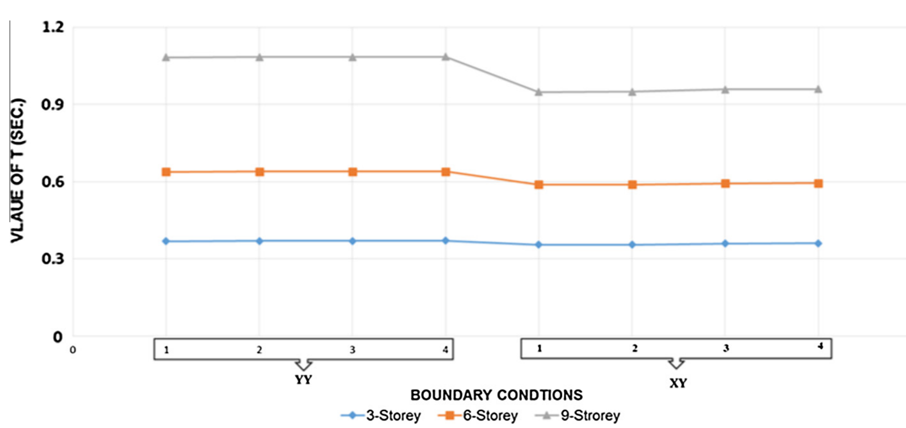

Figure 33 Values of fundamentals period with all different boundary conditions for different number of bays for frames "B-3-3", "B-3-6" & "B-3-9".

Many researchers have investigated the ductility reduction factor and its relationship with the system ductility μ, where μ is the ductility of the system and defined as the ratio of the maximum displacement to the yield displacement. For the above results in this study, changing in the boundary conditions of the structure gives change in pushover curve that gives change in maximum displacement and yields displacement. Fundamental period parameter has minor effect on ductility reduction factor according to Newmark and Hall (1973) [13]. On the other word, change in structural system or structural

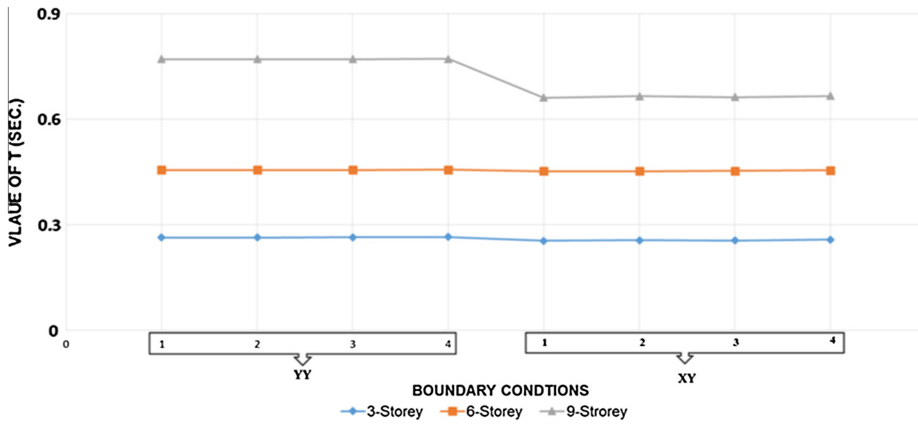

Figure 34 Values of fundamentals period with all different boundary conditions for different number of bays for frames "C-3-3", "C-3-6" & "C-3-9".

behavior gives change in the component of ductility reduction factor for same steel frame. Table 2 shows results of global ductility demand, and ductility dependent factor, since each frame has 8 values depending on boundary conditions.

Fundamentals period (T)

Figs. 33 and 34 show the value of fundamentals period versus boundary conditions for frame "Type B" and "Type C" for different number of bays. As results, change in direction of strong axis of columns and support type didn't give large change in value of fundamental period, that's mean change in boundary condition didn't have effect on fundamental period for bracing frame, because the stiffness of frame depends on bracing to resist seismic force.

Conclusion

- For the studied frames response modification factor "*R*-factor" has different value for same frame depending on boundary conditions of same frame, since change in boundary conditions has effect directly on value of *R*-factor.
- The values of *R*-factor in most codes have lowest value of all cases of one frame, that's mean the code takes minimum value to be more conservative on *R*-factor, and this value will be critical value of frame.
- *R*-factor for frame has bracing in middle span having value larger than that for braced frame has bracing in exterior span for all frame.
- Change in the location of bracing gives change in value of *R*-factor for all boundary conditions.
- All boundary conditions for all frames type didn't have major effect on fundamental period on braced frame.
- *R*-factor has different value depending on boundary conditions of same frame, since every change in boundary conditions has effect directly on value of *R*-factor.
- In this study, each frame has eight boundary conditions and every boundary condition has single value of *R*-factor, minimum value may be near to code value, that's mean code takes minimum value to be more conservative and gives large factor of safety.

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