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Effect of span length on behavior of MRF accompanied with CBF and MBF systems

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Abstract

- The main objective of this study is to quantify effects of variations of aspect ratio (ratio of span length to story height) and lateral resisting system on response of high-rise steel structures. In the present research two goals of finding optimum aspect ratio in the smallest sensible system and suitable strengthening system have been followed. In order to compare sensitivity of different lateral systems, twelve 15-story structures equipped with the following three systems were modelled: a) special moment resisting frames (SMRFs), b) dual system of intermediate moment resisting frames and special concentrically braced frames (MRF-CBF) and c) dual system of intermediate moment resisting frames and mega braced frames (MRF-MBF). Analytical results show that using MRF-CBF system not only does not reduce lateral displacement and drift of the SMRF system, but also increases these parameters. If design is based on lateral displacement and drift, using the MRF-CBF system is not appropriate decision for reinforcement while the MRF-MBF system is extremely useful for this purpose.

Keywords: aspect ratio; steel special moment resisting frame; concentrically braced frame; mega braced frame

1. Introduction

In developing and developed countries, in order to keep up with the growth and development of urban services and quality of life it is necessary to build high-rise structures. Availability of new technologies for urban

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construction to structural and earthquake engineers as well as development of expert software for the design and analysis of buildings have paved the way for study and enhancement of the performance of high-rise buildings.

One of the structural systems commonly employed in steel buildings up to 30 stories is special moment resisting frame (SMRFs). In this structural form the combination of beams and columns not only imposes gravity loads but also bears lateral loads. Hence, sections of beams and columns are mainly large and elevated in these structures [1]. However, some references [1, 2] suggest that the dimensions of beams in these structures are smaller than dimensions employed in simple frame because these systems use rigid connections and redistribute maximum positive moment among bearings (supports) in the form of negative moment. There are many investigations on assessment of seismic behavior of SMRFs systems [3-6]. Although, SMRFs is categorized by high dissipation capacity, because of the large number of dissipative zones, but this system could be not able to provide adequate lateral stiffness, as required to fulfil the serviceability limit state [7]. Conversely, steel concentrically braced frames (CBFs) provide the maximum lateral stiffness when compared with any other structural system [8]. However, some uncertainty arises about the suitability of the CBF systems to assure collapse prevention under large deflection in the nonlinear behavior [9-13]. For this reason, the dual system of moment resisting frames and special concentrically braced frames (MRF-CBF) constitute a balanced combination solution to satisfy weakness of the MRFs and CBFs systems.

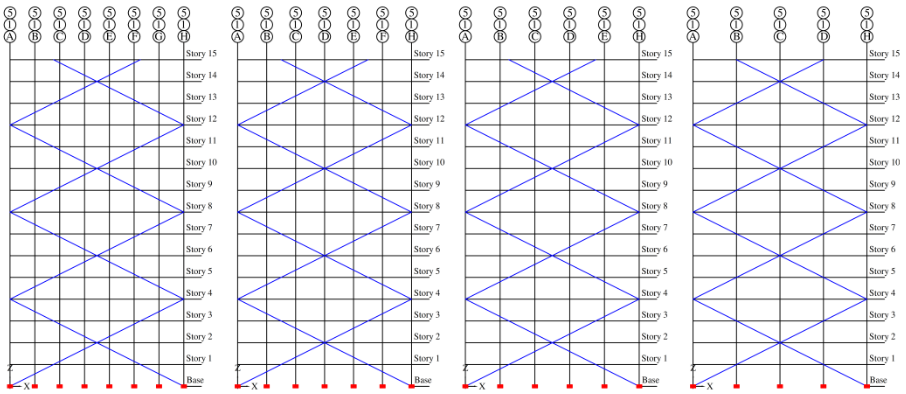
Although the dual systems are decent to control the drift and lateral displacement of multi-story structures, there are other ways to control these parameters. One of the best known ways to decrease the drift of structures is to apply mega braced frame (MBFs) which leads to increase in the strength and stiffness [14, 15]. The term, mega bracing, here refers to a brace that covers multi bays and multi stories as a one component. Different configurations and consequently, the number of this overall bracing can affect the structural responses such as, lateral displacement and seismic behaviour [15-17].

The difference between actual stress distribution due to flexural moment and that predicted by simple beam theory is called the shear lag effect. Shear lag causes axial forces to be distributed differently in columns comparing to ideal distribution. Shear lag index is defined as ratio of axial force of each column to axial force of middle column. Zahiri-Hashemi et al. [15] and Mazinani et al. [18] investigated the shear lag behaviour for different type of the structures. It is indicated that in term of shear lag there are significantly differences between different structural systems.

In the present research first, a steel special moment resisting frame (SMRFs) is designed assuming that the frame cannot meet some of the special design requirements. For example, it is not subjected to inelastic analysis aimed at controlling formation of plastic hinges in beams before columns. Next, the frame is strengthened using the two systems: CBFs and MBFs. In order to compare the behaviour of different lateral systems, the following three systems were modelled: a) SMRFs, b) dual system of intermediate moment resisting frames and special concentrically braced frames (MRF-CBF) and c) dual system of intermediate moment resisting frames and mega braced frames (MRF-MBF). The main objective of the present study is to assess effect of variations of aspect ratio of span length to story height (α) of different lateral resisting system (used for strengthening moment resisting frames) on the structural response of high-rise structures.

2. Description of the models

In order to quantify effect of aspect ratio of span length equal to story height, 12 structural 3 dimensional (3D) models including 4 SMRFs structures, 4 MRF-CBF structures, and 4 MRF-MBF structures were modelled. The structures under this study embraced 15 stories with heights of 3.5 m. The structures were modelled with three lateral load-resisting systems with aspect ratios of α=2.00, 1.60, 1.33 and 1.14, see Table 1. The structures were designed using ST37, which has the yield and ultimate stress values of 2400 kg/cm2 and 3700 kg/cm2 respectively. The columns, beams, and bracings were designed using HEB, IPE, and BOX sections, respectively. Calculations of base shear and story shear values were also performed in accordance with UBC-94 standard [19].



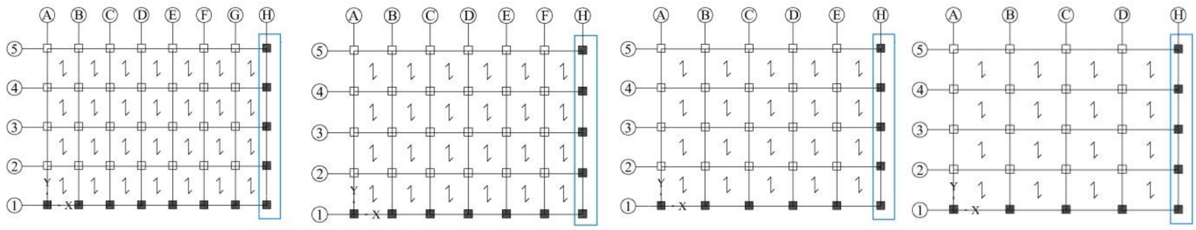
α=1.14 α=1.33 α=1.60 α=2.00

Fig. 1. MRF-MBF system with different values of aspect ratio (α) and similar bracing angles.

The analyses included one equivalent static analysis and one non-linear static analysis for selected frame. Locations of the studied frames are shown in Fig. 1. Lateral loads were applied in X direction.

Table 1. Geometric specifications and names of structures.

Structural system	Special Moment Resisting Frame				Moment Resisting Frame + Concentric Braced Frame				Moment Resisting Frame + Mega Braced Frame			
Abbreviation	SMRFs				MRF-CBF				MRF-MBF			
α=span length/story height	2.00	1.60	1.33	1.14	2.00	1.60	1.33	1.14	2.00	1.60	1.33	1.14



(a) α=1.14 (b) α=1.33 (c) α=1.60 (d) α=2.00

Fig. 2. Location of two studied frames with different aspect ratios (α = 1.14, 1.33, 1.6 and 2).

3. Results and discussion

3.1. Shear lag

In this section, SMRFs, MRF-CBF and MRF-MBF are investigated in order to compare the shear lag behavior of each system. All axial forces of each column in different stories are normalized to axial force in the middle column of the first story in SMRF with α=2. In this study, these ratios are named normalized shear lag index.

3.3.1 Comparison of systems

Fig. 2 depicts the normalized shear lag indexes in four different stories. Regarding the obtained results, in all three studied systems the shear lag index is decreased with increasing the number of stories. For example, the normalized shear lag indexes for the lateral columns in stories 1, 5, 10 and 15 of MRF-CBF with α=1.14 are 0.73, 0.55, 0.22 and 0.018, respectively, see Fig. 2a to d.

It is obtained that response curves of MRF-MBF demonstrate different patterns than those of two other systems. For example, MRF-MBF in stories 1, 5 and 10 gives the maximum axial forces at lateral columns while the other two systems give the maximum values at middle columns. MRF-MBF system is the only system yielding negative shear lag in the last story. As it could be seen in Fig. 2, MRF-CBF gives the maximum axial forces in all stories.

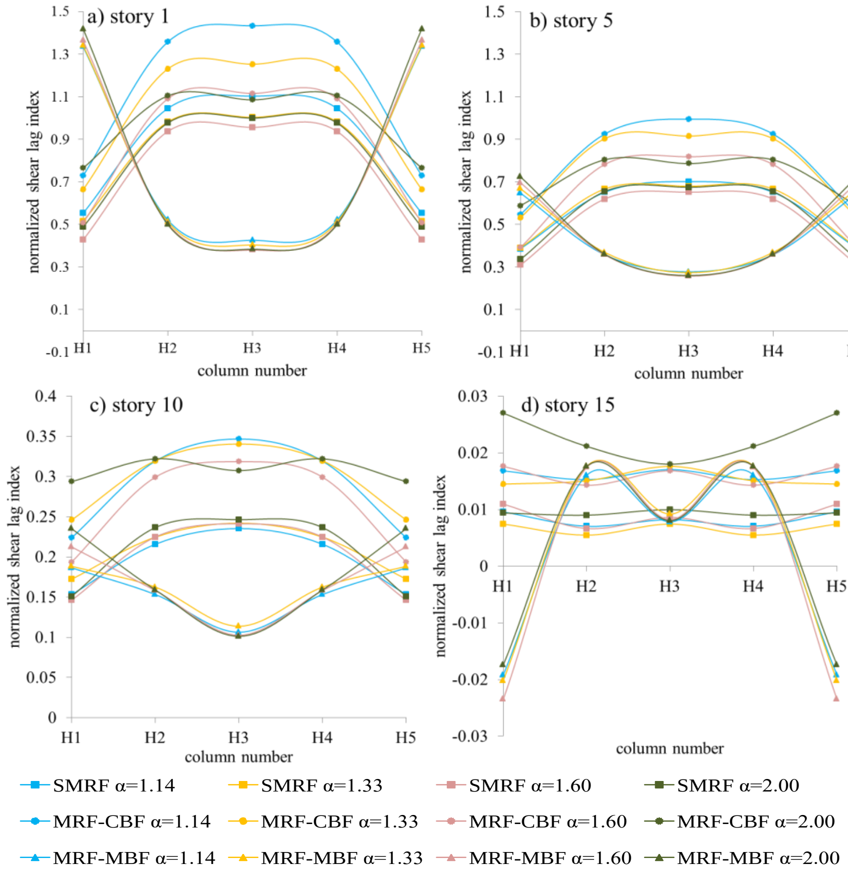


Fig. 3. Normalized shear lag indexes of frame B (see Fig. 1) in different stories.

3.3.2 Comparison of aspect ratios

Fig. 3 shows the effect of aspect ratio on the maximum normalized axial force. Increasing the aspect ratio has a different effect on different lateral systems. For MRF-MBF, increase in the aspect ratio leads to increase the maximum normalized axial force. For instance, the ratio of the maximum normalized axial force in the MRF-MBF with α=2 in comparison with α=1.14 in stories 1, 5, 10 and 15 is increased by 6%, 11%, 26%, and 9%, respectively. While, for two other systems (SMRF and MRF-CBF) increase in the aspect ratio reduces the maximum axial force. For example, for the model MRF-CBF with α=2, in comparison with α=1.14, in stories 1, 5, and 10 the axial forces are decreased by 23%, 20% and 18%, respectively.

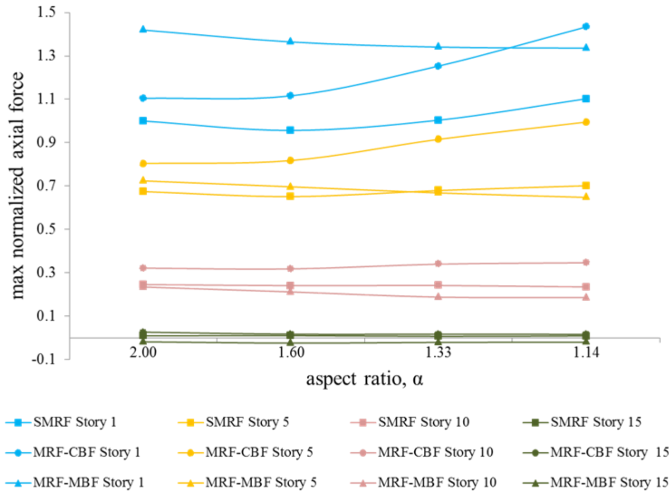


Fig. 4. Normalized maximized axial forces of columns in different stories and systems based on different aspect ratios.

3.2. Displacements and drifts

One of the objectives of strengthening of moment resisting frame systems might be to control excessive displacements and drifts. In this section, a comparison between displacements and drifts of the SMRF, MRF-CBF and MRF-MBF systems was made. Figs. 5a and b show the displacement and drift diagrams of 12 different systems normalized with the displacement of the roof in the SMRF with α=2. Results of this section are presented under comparison of systems, section 3.2.1, and comparison of aspect ratios, section 3.2.2.

3.2.1 Comparison of displacements and drifts

As it can be seen in Fig. 5a, lateral displacements of MRF-MBF systems in the all story levels are less than the other systems. Consequently, it could be concluded that in order to strengthening of SMRF systems both MRF-CBF and MRF-MBF could make enough elastic resistance. However, using only MRF-MBF can control the lateral displacements. For instance, the normalized displacement of the roof in the MRF-MBF with α=2 is 35% of the corresponding displacement in the SMRF with α=2. While, lateral displacement of MRF-CBF with α=2 is 10% larger than lateral displacement of SMRF with α=2.

The diagram in Fig. 5b depicts the drift of various systems normalized based on the roof drift in system SMRF with α=2. As seen in this Fig., the drift caused to the MRF-MBF system is less than the drifts in the two other systems. Moreover, the maximum drift in the MRF-CBF is larger than its corresponding value in the SMRF with the equal local aspect ratios. That is to say, the maximum drift in the SMRF with α=2 is 154% more than the corresponding drift in the MRF-MBF with α=2 and 13% less than the corresponding drift in the MRF-CBF with the same α value.

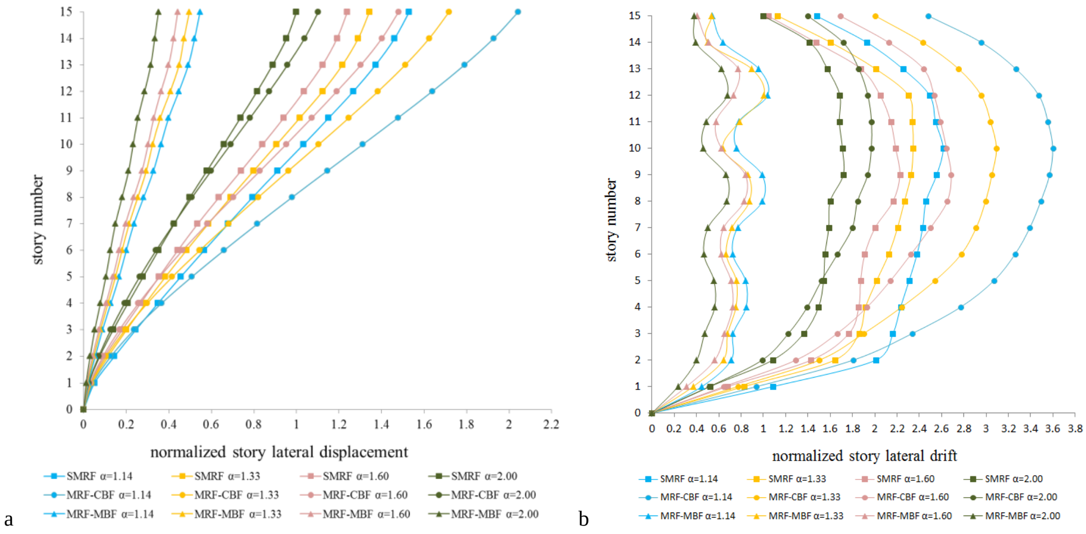


Fig. 5. a) Lateral displacements normalized with displacements of the roof in the MRF-α = 2.00 system, b) Drift normalized with the drift of the roof in the system MRF-α = 2.00.

3.3. Non-linear elastic analysis

The objective of the non-linear elastic analysis is to compare the results with designed structures using linear analysis. In other words, it is aimed at analyzing the non-linear elastic effect of variations of the local aspect ratios of the structures that were designed based on linear elastic analysis. In order to make a comparison among the systems, all of them are displaced by the target displacement (50 cm). The formation and development of plastic hinges were analyzed in different systems.

Fig. 6 shows the location of the hinges for frame number 2 (see Fig. 1) in the SMRF system with different amount of aspect ratio. As it is shown in in Fig. 6, increasing in the local aspect ratio leads to the growth of the number of hinges in columns. For instance, in the SMRF with α=1.14, hinges were appeared only in first story columns.

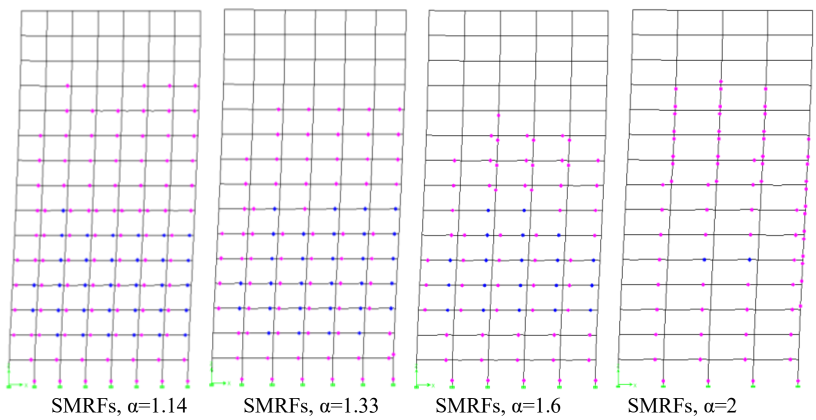


Fig. 6. Hinges distribution in frame number 2 (see Fig. 1) of SMRFs models with different α ratios.

On the other hand, in the SMRF with α=1.33, hinges were formed in the first story columns and one of the columns in the second story. In the SMRF with α=1.6 hinges were formed in columns installed in the first, eighth, ninth, and tenth stories while in the SMRF with α=2 hinges were formed in columns of the first, fourth, fifth, sixth, seventh, eighth, ninth, tenth, eleventh, twelfth, and thirteenth stories. As it mentioned already, it can be concluded that increasing in the local aspect ratio leads to increasing in the number of plastic hinges in the columns.

4. Conclusion

The main objective of this study was to simultaneously analyses the effects of variations of aspect ratio (α) and lateral resisting system on the parameters influencing the lateral response of high-rise structures. In order to compare sensitivity of different lateral systems, twelve 15-story structures equipped with the following three systems were modelled: a) special moment resisting frames (SMRFs), b) dual system of intermediate moment resisting frames and special concentrically braced frames (MRF-CBF) and c) dual system of intermediate moment resisting frames and mega braced frames (MRF-MBF). The following conclusions were drawn

- In all three studied systems the shear lag index is decreased with increasing the number of stories. MRF-MBF system is the only system yielding negative shear lag in the last story.
- According to obtained results, using MRF-CBF system not only does not reduce lateral displacement and drift of the SMRF system, but also increases these parameters. If design is based on lateral displacement and drift, using the MRF-CBF system is not appropriate decision for reinforcement while the MRF-MBF system is extremely useful for this purpose.
- The MRF-MBF and SMRF systems show the lowest level of susceptibility to variations of the local aspect ratio. Hence, architects and structural engineers can choose arbitrary aspect ratios considering drift and displacement in the design phase. However, the MRF-CBF system lacks this advantage.
- According to non-linear elastic analysis, for all three studied systems, increasing in the local aspect ratio leads to the growth of the number of plastic hinges formed in columns. Increasing the local aspect ratios from α=1.14 to 2 develops the distribution of the hinges from in the columns at the first floor to the thirteenth floor.

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