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Analysis of a 7-storied RC Building with Different Patterns of Cross Bracing System

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Abstract— In this study, the seismic analysis of reinforced concrete (RC) buildings with different bracing patterns namely, no bracing, full bracing, partial bracing, alternate floor bracing and alternate partial bracing is studied. The bracing is provided for peripheral columns and any two parallel sides of building model. A seven-storey (mid-rise) residential building situated in Dhaka city is analyzed for seismic zone II as per BNBC 2006 using ETABS 9.6.0 and ANSYS 10.0 softwares. The percentage reduction in maximum storey displacement is found out. It is found that the X type of concrete bracing significantly contributes to the structural stiffness and reduces the maximum storey drift of the frames. The bracing system improves not only the stiffness and strength capacity but also the displacement capacity of the structure.

Index Terms— ANSYS, ETABS, cross bracing system, finite element modeling, nonlinear static analysis, reinforced concrete building, storey displacement.

1 Introduction

THE preliminary purpose of all kinds of structural elements used in RC frames is to transfer the gravity loads (dead load, live load, etc.) effectively. Besides the gravity loads, buildings are also subjected to lateral loads caused by wind, blasting or earthquake [1]. These lateral loads can develop high stresses, produce sway movement and/or cause vibration. Therefore, it is very important to design RC structures to have sufficient strength against vertical loads together with adequate stiffness to resist lateral forces.

In recent years many developments have been made in the area of structural braces – the elements in RC structures which resist and control the applied lateral loads. Braced-frame systems tend to be more economical than moment-resisting frames when material, fabrication, and erection costs are considered. These effciencies are often offset by reduced flexibility in floor plan layout, space planning, and electrical and mechanical routing, encountered as a result of the space requirements for the brace members. Braced frames are, therefore, typically located in walls that stack vertically between floor levels. For example, in a typical office building, these walls generally occur in the "core" area around stair and elevator shafts, central restrooms, and mechanical and electrical rooms. This generally allows for greater architectural flexibility in articulating vertical modulations of the building envelope [2].

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The controlling seismic design parameters for braced frames have also changed considerably during the past few decades depending on the plan location and the size of the core area of the building, the torsional resistance offered by the braced frames and hence the concept of special concentric braced frames (CBFs) has been introduced [3]. However, there is a lack of research background on the seismic response of such frames to verify the proposed design provisions for Bangladesh. Differential drift between stories at the building perimeter must be considered with the type of layout, as rotational displacements of the floor diaphragms may impose deformation demands on the cladding system and other nonstructural elements of the building [4].

In this paper, the seismic response of CBFs is investigated for a mid-rise (7-storied) residential building situated in Dhaka city, Bangladesh with 5 distinct bracing patterns, namely, no bracing, full bracing, partial bracing, alternate floor bracing and alternate partial bracing. This investigation focuses on the response evaluation of RC frames designed in accordance with the BNBC 2009 seismic provision for cross bracings using multi-story building analysis and design software ETABS and FEM programming software called ANSYS. Furthermore, this research provides practitioners with a better understanding of the seismic behavior of CBFs and lays the foundation for future full-scale experimental tests to further validate the current design requirements for earthquake prone areas.

2 Background of the Study

Braced frames may be grouped into two categories as either concentric braced frames (CBF) or eccentric braced frames (EBFs). In CBFs, the axes of all members, that is, columns, beams, and braces intersect at a common point such that the member forces are axial without signifcant moments [5]. On the other hand, EBFs, utilize axis offsets to deliberately introduce flexure and shear in preselected beam segments to increase ductility.

Concentric bracing may be arranged in several different configurations – such as X, K or one-directional diagonal bracing – and the bracing members may be designed to act in tension or compression or both. Balanced diagonal bracing is the most common for medium-rise structures because it provides the same strength in both directions [6].

Shan – Hau Xu & Di – Tao Niu [7] had worked on seven reinforced concrete (RC) braced frame, one reinforced concrete frame and one reinforced concrete shear wall are tested under vertical loading and reversed cyclic loading. They focused mainly on the failure mechanism, strength, degradation in stiffness, and hysteresis loop of the RC braced frame. According to their study, in braced frames, not only lateral resistance and stiffness enhanced, but also energy dissipation amount increased significantly.

A.R. Khaloo and M. Mahdi Mohseni [7] had worked on nonlinear seismic behaviour of RC Frames with RC Braces. This study focuses on evaluation of strength, stiffness, ductility and energy absorption of reinforced concrete braced frames and comparison with similar moment resisting frames and frames with shear wall.

J. P. Desai, A. K. Jain and A. S. Arya [7] had worked on two-bay, six-story frame designed by limit state method subjected to artificial earthquake and bilinear hysteresis model was assumed for girders, elasto-plastic model was assumed for columns and simple triangular hysteresis model was assumed for reinforced concrete bracing. It is concluded that the inelastic seismic response of X and K braced concrete frames with intermediate bracing members is satisfactory.

3 Modelling

The RC frame used in this study corresponds to a typical floor layout with the following data taken for analysis.

TABLE 1
STRUCTURAL DETAILS OF THE MODEL

Type of building	Residential
Type of frame	Special Moment Resisting Frame
Number of storey	7
Storey height	3m
Number of Bays	4 bays in both directions
Spacing of Bays	4 m in both direction
Beam Size	300x450 mm
Column size	300x600 mm
Bracing size	300x300 mm
Grade of Materials	M25 and Fe 415
Slab Thickness	150mm
Thickness of wall	250mm
Dead Load (including Floor finish and Partition wall)	5 kN/m2
Live load	2 kN/m2
Seismic Zone (Z)	II
Importance factor (I)	1
Response reduction factor (R)	8
Soil strata	Medium

4 Methodology

According to Bangladesh National Building Code (BNBC), the lateral seismic forces of RC framed structures shall be calculated either by Equivalent Static Method or by Dynamic Response Method. In this study, Equivalent Static Method is applied to calculate the lateral seismic forces of a 7-storied (mid-rise) residential building as standard structure. The equivalent static lateral force method is a simplified technique to substitute the effect of dynamic loading of an expected earthquake by a static force distributed laterally on a structure for design purposes. The total applied seismic force V is generally evaluated in two horizontal directions parallel to the main axes of the building. It assumes that the building responds in its fundamental lateral mode. For this to be true, the building must be mid-rise and must be fairly symmetric to avoid torsional movement under ground motions. The structure must be able to resist effects caused by seismic forces in either direction, but not in both directions simultaneously.

5 Results

TABLE 2
MAXIMUM STOREY DISPLACEMENTS FOR DIFFERENT BRACING CONDITIONS (BY ANSYS)

Storey Height, ft	No Bracing	Full Bracing	Partial Bracing at End Span	Alternate Floor Bracing at End Span	Alternate Partial Bracing
70	1.1215	0.12936	0.23703	0.51787	0.47177
60	1.04E+00	0.11125	0.20438	0.48451	0.44698
50	9.23E-01	9.22E-02	0.16842	0.39811	0.36321
40	7.66E-01	7.19E-02	0.1299	0.35366	0.33007
30	5.80E-01	5.14E-02	9.06E-02	0.2245	0.20399
20	3.74E-01	3.16E-02	5.32E-02	0.17745	0.16875
10	1.61E-01	1.37E-02	2.11E-02	0.02806	2.06E-02

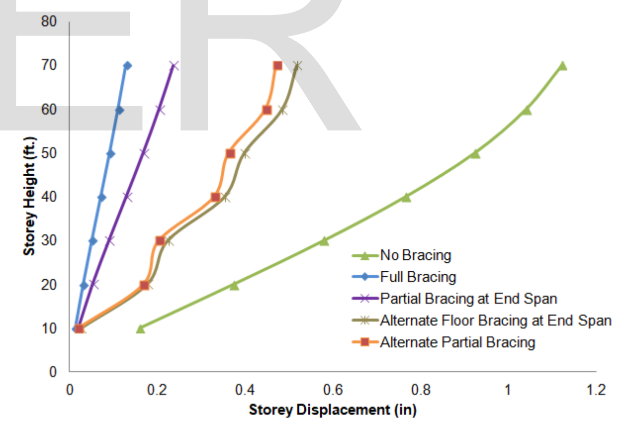

Fig 1. Maximum deflection at different storey levels for various bracing condition (by ANSYS).

TABLE 3
MAXIMUM STOREY DISPLACEMENTS FOR DIFFERENT BRACING CONDITIONS (BY ETABS)

Storey Height, ft	No Bracing	Full Bracing	Partial Bracing at End Span	Alternate Floor Bracing at End Span	Alternate Partial Bracing
70	1.1238	0.3349	0.4439	0.681	0.66
60	1.0476	0.3043	0.4028	0.6404	0.601
50	0.9266	0.2635	0.3481	0.5419	0.53
40	0.7687	0.2149	0.283	0.473	0.46
30	0.5821	0.161	0.2107	0.3235	0.31
20	0.3758	0.1045	0.1353	0.2409	0.25
10	0.1616	0.0482	0.0609	0.066	0.069

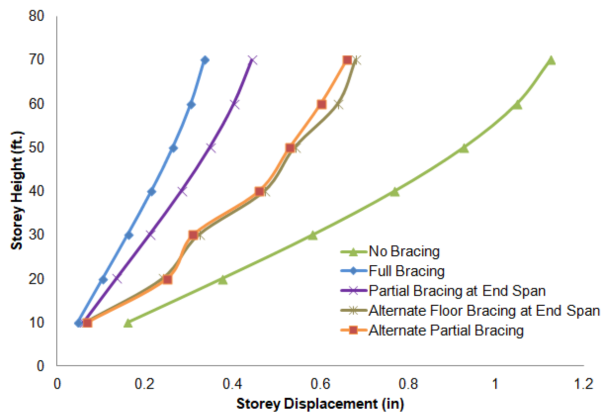

Fig 2. Maximum deflection at different storey levels for various bracing condition (by ETABS).

TABLE 4
MAXIMUM BENDING MOMENT FOR DIFFERENT BRACING CONDITIONS (BY ANSYS)

Storey Height, ft	No Bracing	Full Bracing	Partial Bracing at End Span	Alternate Floor Bracing at End Span	Alternate Partial Bracing
70	1.1238	0.3349	0.4439	0.681	0.66
60	1.0476	0.3043	0.4028	0.6404	0.601
50	0.9266	0.2635	0.3481	0.5419	0.53
40	0.7687	0.2149	0.283	0.473	0.46
30	0.5821	0.161	0.2107	0.3235	0.31
20	0.3758	0.1045	0.1353	0.2409	0.25
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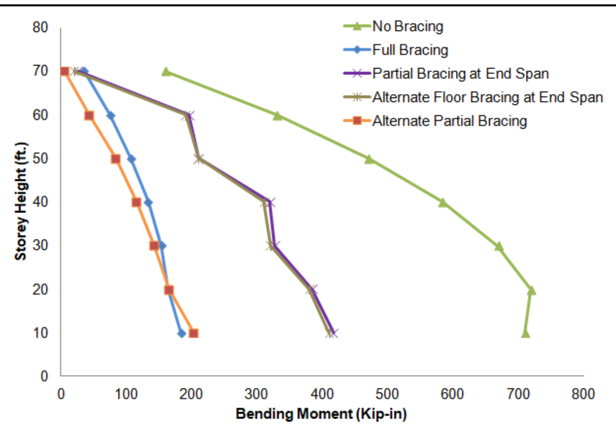

Fig. 3. Maximum bending moment at different storey levels for various bracing condition (by ANSYS).

TABLE 5
MAXIMUM BENDING MOMENT FOR DIFFERENT BRACING CONDITIONS (BY ETABS)

Storey Height, ft	No Bracing	Full Bracing	Partial Bracing at End Span	Alternate Floor Bracing at End Span	Alternate Partial Bracing
70	1.1238	0.3349	0.4439	0.681	0.66
60	1.0476	0.3043	0.4028	0.6404	0.601
50	0.9266	0.2635	0.3481	0.5419	0.53
40	0.7687	0.2149	0.283	0.473	0.46
30	0.5821	0.161	0.2107	0.3235	0.31
20	0.3758	0.1045	0.1353	0.2409	0.25
10	0.1616	0.0482	0.0609	0.066	0.069

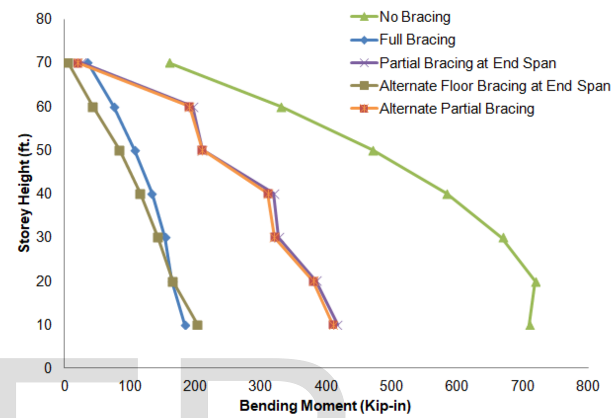

Fig. 4. Maximum bending moment at different storey levels for various bracing condition (by ETABS).

6 CONCLUSION

From the comparative study of various parameters, it is observed that the building with bracings demonstrate better performance over the building without bracings. The following conclusion has been drawn based on the results obtained from the present study.

- Storey forces are reduced in the building frame with bracings, which gives the stability of the building. Subsequently the use of bracings is viewed as more secure than the without bracings in the building.
- Cross bracing proved to be the most economical and efficient forms of bracing. Since when cross bracing is used lateral force from one direction induces tension in one member while in other bracing system, tension in induced when the force is reversed.
- The maximum deflection without any bracing is 1.1215″ and for a full bracing this value is reduced to 0.12936″ i.e. 99.214% less. Again in alternate bracing and alternate partial bracing the values are 0.47177″ and 0.51787″ respectively. But the most economical and safe bracing system is the partial bracing system which gives the maximum deflection value of 0.23703″ i.e. 88.447% less.
- Additionally the moment of structure without any bracing is 717.091 Kip-in and for a full bracing this value

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is reduced to 183.73 Kip-in which is minimal. Again in alternate bracing and alternate partial bracing the values are 416.338 Kip-in and 416.338 Kip-in respectively. Here also the partial bracing system turns out to be the most economical and safe bracing system by reducing the maximum bending moment to 202.757 Kip-in.

- Results of the simulations were compared between the ETABS and ANSYS, the variations of maximum storey displacement and bending moment value are 0-15%.
- From the results, adding bracings to the RC moment resisting frame, it will increase strength and stiffness to the structure.

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