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BEHAVIOR OF SHEAR WALL CONVERTED TO STEEL BRACED FRAME USING PUSHOVER ANALYSIS

Dr. Gamal Mahmoud Hussin[1], Dr. Amgad Ahmed Talaat[2], Dr. Nasr Eid Nasr[2] and Eng. Ayman Osama[3]

1. Associate professor, Structural Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt
2. Assistant professor, Structural Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt
3. Structural Engineer, Engineering for the Petroleum and Process Industries Engineering Department

ملخص البحث

يتم إستخدام نظام حوائط القص الخرسانية و نظام الإطارات المثبتة في المباني العالية لقدرتها الفعالة على مقاومة احمال الزلازل و مع تعدد المتطلبات المعمارية و غيرها من الميكانيكية يستدعى ان يتم عمل فتحات خلال حوائط القص الخرسانية . يعتمد البرنامج النموذجي على دراسة التحليل اللاخطي لنظام حائط القص الخرساني المتحول إلى إطارات مثبتة حيث تم عمل تصميم لهذا النظام الإنشائي طبقا للكود الأمريكي و تم إدخال الزلازل بإستخدام طريقة ال Pushover static procedure طبقا للكود الامريكي ASCE 41-13 و هذه الطريقة تأخذ في الإعتبار الإنفعالات و الإجهادات المتولدة على العناصر الإنشائية للمبنى حيث تم عمل دراسة على 51 عينة تتكون من عدد 25 عينة مستخدمة للمباني من 10, 15, 20, 25, 30 دور ويختلف في كل مبنى منهم على عدد الادوار الذي يحتوي على الإطارات المثبتة و ذلك طبقا لقدرة القطاعات الحديدية المستخدمة في التثبيت و 20 عينة مستخدمة مع إختلاف سمك حوائط القص من 20سم إلى 40 سم و بالتبعية عدد الادوار الذي يحتوي على الإطارات المثبتة و ذلك للمبنى المتكون من 20 دور و تم استخدام 6 عينات بمختلف الأماكن للمبنى ال 20 دور لدراسة مدى تأثر النظام الإنشائي بوجود لا محورية. تم تصميم القطاعات الحديدية طبقا للكود AISC 360-10 الإطارات المثبتة. وقد بينت النتائج انه يمكن إستبدال 20 % من إرتفاع حوائط القص الخرسانية في الجزء الأخير من المبنى بنظام الإطارات المثبتة وذلك لخضوع عناصر التثبيت الحديدية لقدرة تحمل ضغط معين و بعد ذلك يحدث إنبعاج للعنصر الحديدي المستخدم في التثبيت , و أوضحت النتائج أيضا انه بزيادة سمك الحائط الخرساني يقل قيمة الإزاحة الأفقية للمبنى.

ABSTRACT

This paper aims to study shear wall converted to braced frame system using nonlinear analysis and obtain the limitation of using system according to the building height and the effect of the system on stiffness, members capacity according to (ACI318-11& AISC360-10). Drift values are obtained according to seismic codes (ASCE 7-10 & ECP 201-2012) and the results shows that concrete shear wall can be converted to braced frame at 20% of total building height starting from top which steel bracing can resist compression load and by increasing this percentage buckling failure can be occurs for the steel members, and by increasing thickness of shear wall the drift decreases as the lateral stiffness of building increasing and can resist lateral deformation that happened to the building due to earthquake load .

KEYWORDS: Shear wall; Braced frame; Equivalent static analysis; Nonlinear push over analysis; Lateral loads.

INTRODUCTION

Shear wall system are used in the most high-rise buildings due to low in cost and fast in construction and it is the major element resisting lateral loads, For architectural requirements which needs more openings at shear wall internally the building and changes the load path through the shear wall and also HVAC requirements such pipes and duct path needed, so we used braced frame system which it gives more space areas, The braced frame can absorb a greater degree of energy affected by earthquake loads and reduces the column and girder bending moments and also reduce the lateral deformation (Drift and horizontal displacement) due to earthquake loads. Bracing used is steel because of it ease and speed of construction and the ability to choose small sections that will not take more areas in braced frame system.

Nonlinear analysis is used in this system using nonlinear static procedure (static pushover) and P-delta effect as a geometric nonlinearity to study the effective behavior of the shear wall converted to braced frame system. The system is design according to (ACI 318-11) for concrete elements and (AISC360-10) for steel bracing by using nonlinear procedure (pushover analysis) in lateral loading for more accurate acting to the structure compared with equivalent static analysis. Verification was performed first to ensure the behavior of system and then 54 reinforced concrete shear walls converted to braced frames system case study building are analyzed and the results are obtained showing the different capacity values for different vertical members, stiffness, time periods and drifts which prescribed according to ASCE 7-10 by increasing drift value by [deflection amplification factor (Cd)/ Importance factor (Ie)] which Cd=4.5 and Ie=1.25 & ECP 201-2012 by increasing drift value by (0.7 R) which R=5 and the result are shown in graphs.

METHODOLOGY

The displacement obtained from equivalent static analysis according to (ASCE 7-10) put into target displacement for pushover procedure and the P-delta effect taken into consideration as a geometric nonlinearity and the vertical members are design according to (ACI 318-11) for concrete elements first then the building was pushed to the monitored displacement by divided the total displacement into steps and every step the base shear of building was determined and plotted in the pushover curve and the steel bracing members are design according to (AISC360-10). For pushover analysis is performed and fiber hinges are created according to (ASCE 41-13) for the shear wall with P-M3 fiber hinge and applied for each shear walls by integrating the behavior of each fiber element based on specific amount of reinforcement, the fiber hinge used for braced frame for columns of braced frame system fibers are defining coupled axial and biaxial-bending behavior in frame objects, for bracing fibers are defined as axial fiber hinge. The design was performed to the shear wall, braced frame elements and obtain the demand-capacity stress ratio.

VERIFICATION OF THE PUSHOVER NONLINEAR ANALYSIS

A verification for pushover analysis has been constructed to ensure the behavior of shear wall converted to braced frame system, for steel braced reinforced concrete frame system was tested by H. Ghaffarzadeh and M.R. Maheri, Department of Civil Engineering, Shiraz University, Shiraz, Iran, 2006, (Cyclic Tests on the Internally Braced RC Frames). The case study was braced frame tested from residential building with three bays and four stories that located in high seismic zone and was scaled to be controlled by laboratory tests with dimension 1.36m height and 1.76m width and frame cross section (140mm x 160mm) and total reinforcement 4M10 equal 400 mm^2. The steel bracing used was double angle cross section (2L 25x25x3.2mm), concrete compressive strength concrete is 55 MPa and the yield strength of reinforcement is 400 MPa and the brace members had yield strength of 300 MPa. The cyclic lateral force applied to the braced frame is shown in Figure (1&2). The double-angle bracing member yielding and at a load of 140kN (drift of 4.0%) a significant drop in the lateral load capacity was observed. This was noted to be due to the buckling of brace members. Following this, the lateral load capacity was mainly provided by the reinforced concrete frame. ETABS program is selected for pushover analysis that has been applied for the same case study and a drop of load capacity has been observed at load 135 KN with drift 4% this is due to the buckling of steel bracing as shown in figure (3) and the comparison is shown as in table (1).

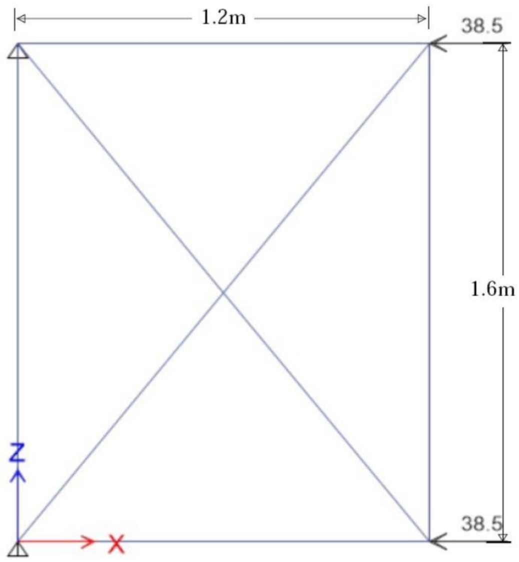

Figure (1) Gravity load assigned to the system

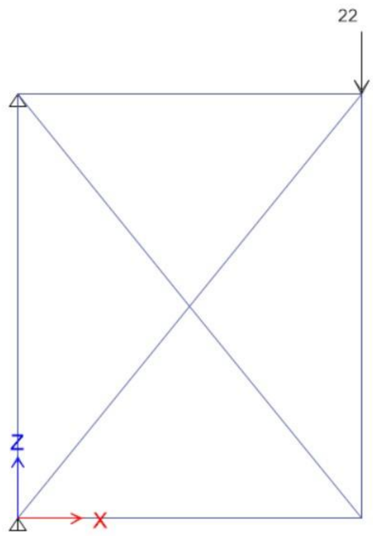

Figure (2) Earthquake loading applied by pushover analysis

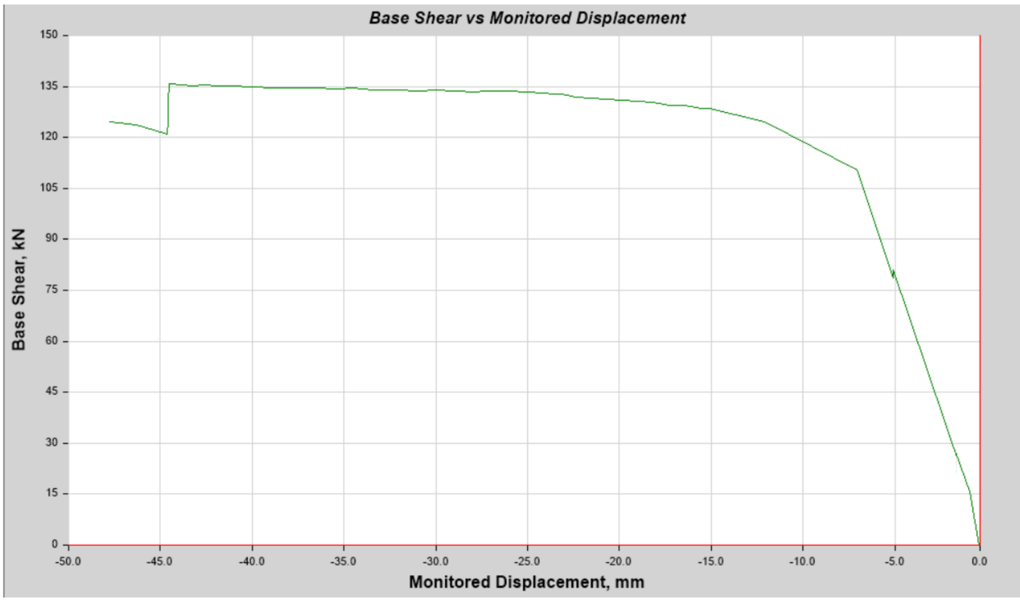

Figure (3) Pushover curve with dropped load for braced frame system due to buckling of steel bracing

Table (4-1):

Model	Ultimate Strength (KN)	Displacement at Ultimate Strength (%)	Displacement at Ultimate Strength (mm)
Experimental analysis	140	4	47.5
Pushover analysis	135	3.625	43.5

STRUCTURAL SYSTEM

This case study consists of 51 reinforced concrete shear wall converted to steel bracing reinforced concrete frame, 25 samples are analyzed with story height 3m which is varying from 10 to 30 stories and total building height varying from 30 meter to 90 meter, respectively and 20 samples are analyzed for building 20 stories with 50 meter height have various thickness of shear wall from 20 cm to 40 cm and 6 samples arranged with a large eccentricity, all samples are changed with number of braced frame stories till system capacity starting from roof level. The typical floor plan dimensions 44 x 27 m as shown in figure (4) and table (1,2 &3) shows the parameters are used in this study.

The building was design according (ACI 318-11) for vertical loads and lateral loads are design according to (ASCE 7-10) with response acceleration parameter S_{DS} = 0.4 & S_{D1} = 0.15, Site class C, short period transition = 4 second, Risk category (III), and for steel elements are design according to (AISC 360-10). The total dead load and live load assigned to building are 2 KN/m^2 and 4 KN/m^2 respectively and concrete compressive strength (fc') is 32 Mpa, the yield strength of reinforcement (Fy) is 400 Mpa and the brace members had yield strength (Fy) 360 Mpa. Young's modulus of concrete, reinforcement steel and steel member are 26600 MPa and 200,000 MPa, respectively. The flooring system are flat slab with 30 cm thickness rested on columns and shear walls, shear walls are replaced with braced frame every story starting from roof floor till the capacity of members exceed code limit.

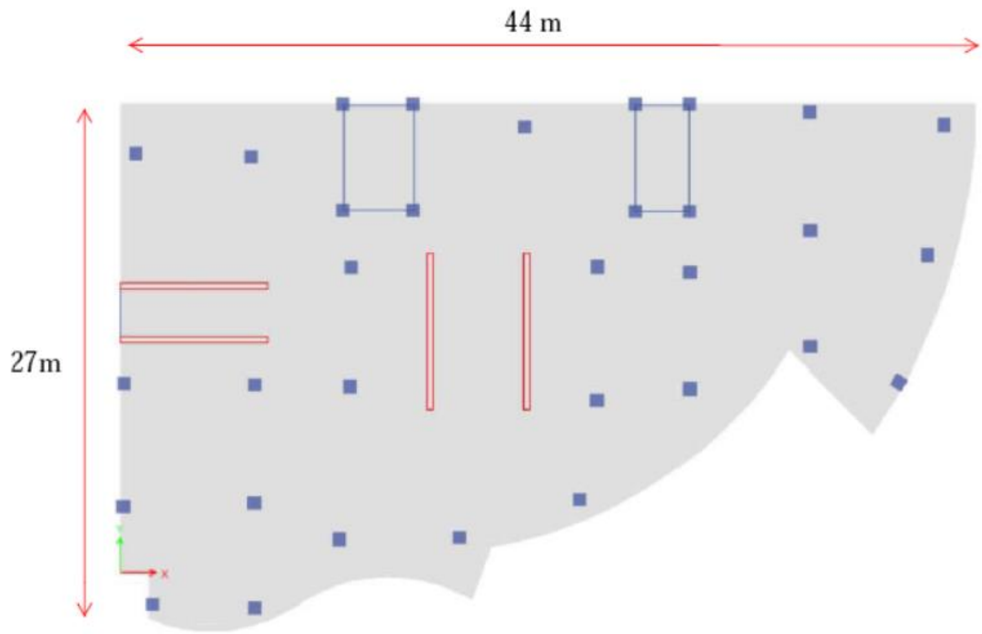

Figure (4) Building Plan

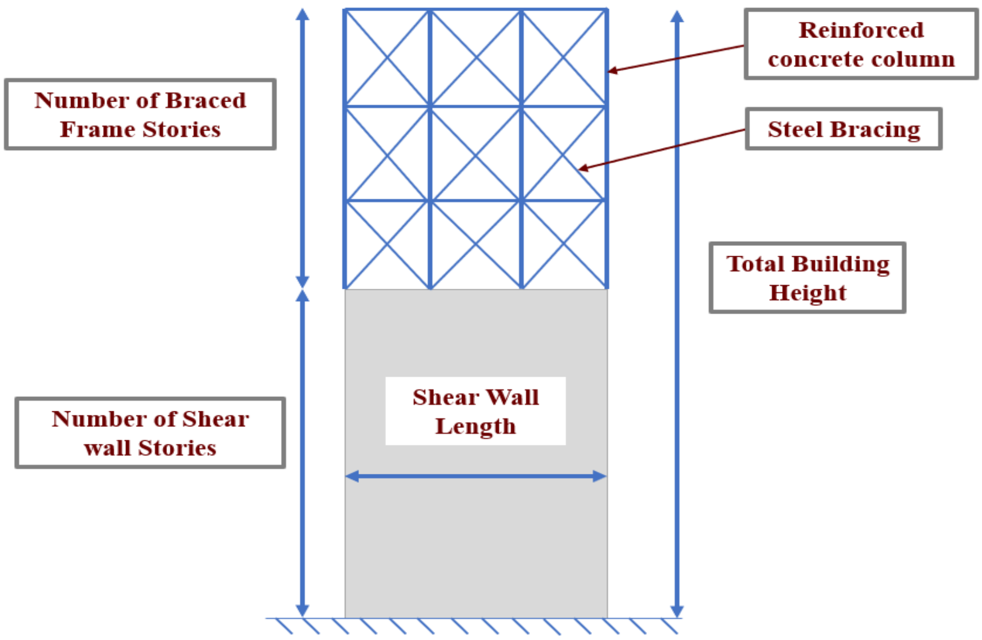

Figure (5) Structural elements of RC shear wall converted to steel braced RC frame

NONLINEAR PUSH OVER ANALYSIS

ETABS program are used for nonlinear static analysis (pushover analysis) for 51 reinforced concrete shear walls converted to braced frames system case study building by assuming plastic hinges at vertical elements in the ground floor and at braced frame members in the upper floors. For geometric nonlinearity P-delta effect are used based on 1.2 dead load and 1.0 live load as it gives more lateral displacement. For Mass source option lateral mass has been lumped at each story level from (Dead load + 0.5 live load), rigid diaphragm has been assigned for joints at each floor level, restrains has been assigned at the base as hinges. Push over analysis has been conducted until the displacement which obtained from equivalent static analysis using (ASCE 7-10) and design is performed for the members. The results are noted and shown in the figures from (7 to 22) and show the study parameters for shear wall converted to braced frame system.

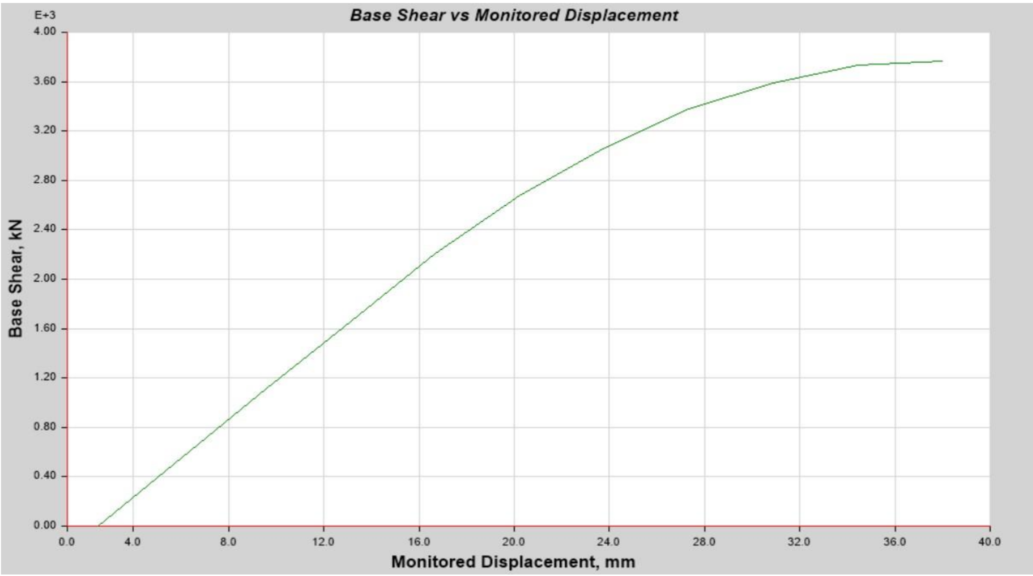

Figure (6) Pushover curve according to equivalent static displacement

Table (1): Showing buildings Parameters and their range.

Model	Length of walls in X direction (m)	Length of walls in Y direction (m)	Thickness of walls in X & Y direction with RFT. Ratio 1.5% (m)	Square Column Dim with RFT. Ratio 1.5%. (m)	Square Column Dim. of Braced Frame (m)	Steel Bracing Section Type	No. of stories	Height (m)	No. of Braced Frame Story from Roof
1	7.6	8	0.3	0.7	0.3	IPE120	10	30	1
2	7.6	8	0.3	0.7	0.3	IPE120	10	30	2
3	7.6	8	0.3	0.7	0.3	IPE120	10	30	3
4	8.6	9.5	0.3	0.85	0.3	IPE140	15	45	1
5	8.6	9.5	0.3	0.85	0.3	IPE140	15	45	2
6	8.6	9.5	0.3	0.85	0.3	IPE140	15	45	3
7	8.6	9.5	0.3	0.85	0.3	IPE140	15	45	4
8	9.6	9.5	0.3	1	0.3	IPE160	20	60	1
9	9.6	9.5	0.3	1	0.3	IPE160	20	60	2

10	9.6	9.5	0.3	1	0.3	IPE160	20	60	3
11	9.6	9.5	0.3	1	0.3	IPE160	20	60	4
12	9.6	9.5	0.3	1	0.3	IPE160	20	60	5
13	10.6	10.5	0.4	1.15	0.3	IPE220	25	75	1
14	10.6	10.5	0.4	1.15	0.3	IPE220	25	75	2
15	10.6	10.5	0.4	1.15	0.3	IPE220	25	75	3
16	10.6	10.5	0.4	1.15	0.3	IPE220	25	75	4
17	10.6	10.5	0.4	1.15	0.3	IPE220	25	75	5
18	10.6	10.5	0.4	1.15	0.3	IPE220	25	75	6
19	11.6	11.5	0.4	1.3	0.3	IPE240	30	90	1
20	11.6	11.5	0.4	1.3	0.3	IPE240	30	90	2
21	11.6	11.5	0.4	1.3	0.3	IPE240	30	90	3
22	11.6	11.5	0.4	1.3	0.3	IPE240	30	90	4
23	11.6	11.5	0.4	1.3	0.3	IPE240	30	90	5
24	11.6	11.5	0.4	1.3	0.3	IPE240	30	90	6
25	11.6	11.5	0.4	1.3	0.3	IPE240	30	90	7

Table (2): showing buildings Parameters and their range for 20 stories.

Model	Length of walls in X direction (m)	Length of walls in Y direction (m)	Thickness of walls in X & Y direction with RFT. Ratio 2% (m)	Square Column Dim. With RFT. Ratio 1.5% (m)	Square Column Dim. of Braced Frame (m)	Steel Bracing Section Type	No. of stories	Height (m)	No. of Braced Frame Story from Roof
26	9.6	9.5	0.2	1	0.3	IPE160	20	60	1
27	9.6	9.5	0.2	1	0.3	IPE160	20	60	2
28	9.6	9.5	0.2	1	0.3	IPE160	20	60	3
29	9.6	9.5	0.2	1	0.3	IPE160	20	60	4
30	9.6	9.5	0.25	1	0.3	IPE160	20	60	1
31	9.6	9.5	0.25	1	0.3	IPE160	20	60	2
32	9.6	9.5	0.25	1	0.3	IPE160	20	60	3
33	9.6	9.5	0.25	1	0.3	IPE160	20	60	4
34	9.6	9.5	0.3	1	0.3	IPE160	20	60	1
35	9.6	9.5	0.3	1	0.3	IPE160	20	60	2
36	9.6	9.5	0.3	1	0.3	IPE160	20	60	3
37	9.6	9.5	0.3	1	0.3	IPE160	20	60	4
38	9.6	9.5	0.35	1	0.3	IPE160	20	60	1
39	9.6	9.5	0.35	1	0.3	IPE160	20	60	2
40	9.6	9.5	0.35	1	0.3	IPE160	20	60	3
41	9.6	9.5	0.35	1	0.3	IPE160	20	60	4
42	9.6	9.5	0.4	1	0.3	IPE160	20	60	1
43	9.6	9.5	0.4	1	0.3	IPE160	20	60	2
44	9.6	9.5	0.4	1	0.3	IPE160	20	60	3
45	9.6	9.5	0.4	1	0.3	IPE160	20	60	4

Table (3): showing buildings Parameters and their range for 20 stories with Eccentricity.

Model	Length of walls in X direction (m)	Length of walls in Y direction (m)	Thickness of walls in X & Y direction	Wall RFT Ratio %	Eccentricity in X direction (m)	Eccentricity in Y direction (m)	Square Column Dim. (m)	Column RFT Ratio %	Square Column Dim. Of Braced Frame (m)	Steel Bracing Section Type	No. of stories	Height (m)	No. of Braced Frame Story from Roof
46	9.6	9.5	0.3	1.5	2.5	0	1	1.5	0.3	IPE160	20	60	1
47	9.6	9.5	0.3	1.5	2.5	0	1	1.5	0.3	IPE160	20	60	2
48	9.6	9.5	0.3	1.5	2.5	0	1	1.5	0.3	IPE160	20	60	3
49	9.6	9.5	0.3	1.5	0	3	1	1.5	0.3	IPE160	20	60	1
50	9.6	9.5	0.3	1.5	0	3	1	1.5	0.3	IPE160	20	60	2
51	9.6	9.5	0.3	1.5	0	3	1	1.5	0.3	IPE160	20	60	3

Analytical Results:

Figure (7) Relation between stress ratio and percentage of braced frame height to total building height for 10 stories in X-direction

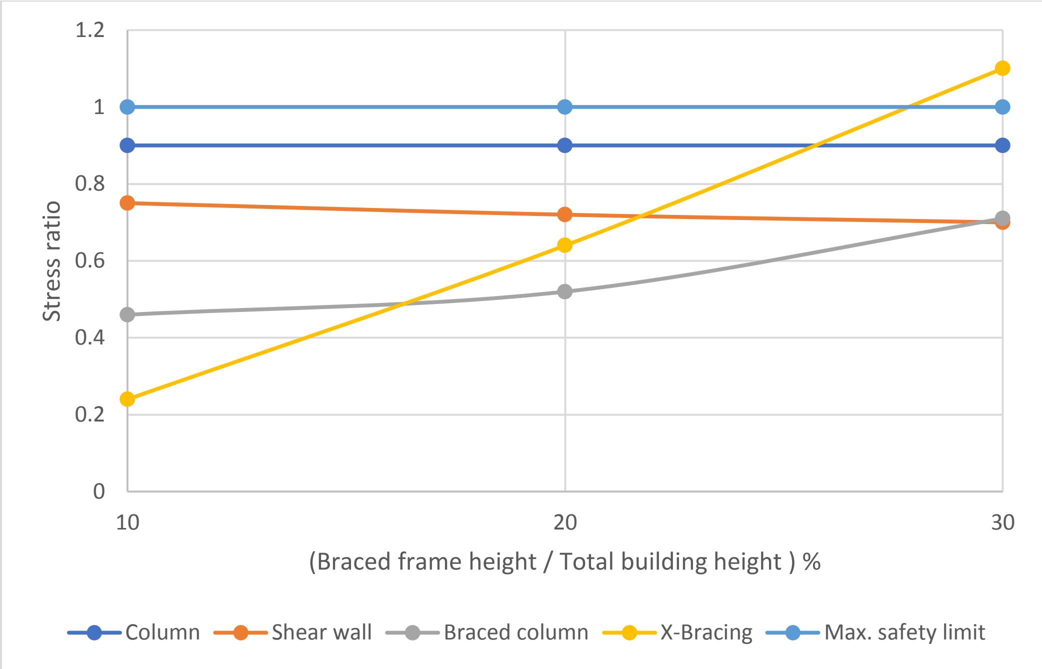

Figure (8) Relation between stress ratio and percentage of braced frame height to total building height for 10 stories in Y-direction

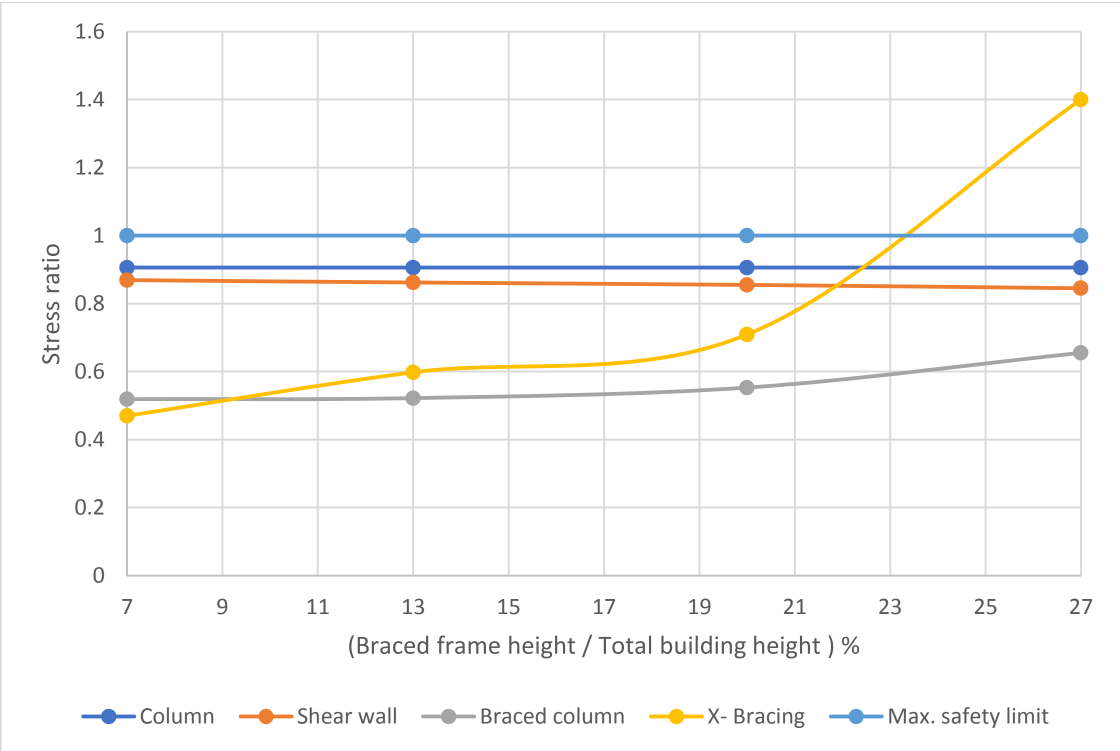

Figure (9) Relation between stress ratio and percentage of braced frame height to total building height for 15 stories in X-direction

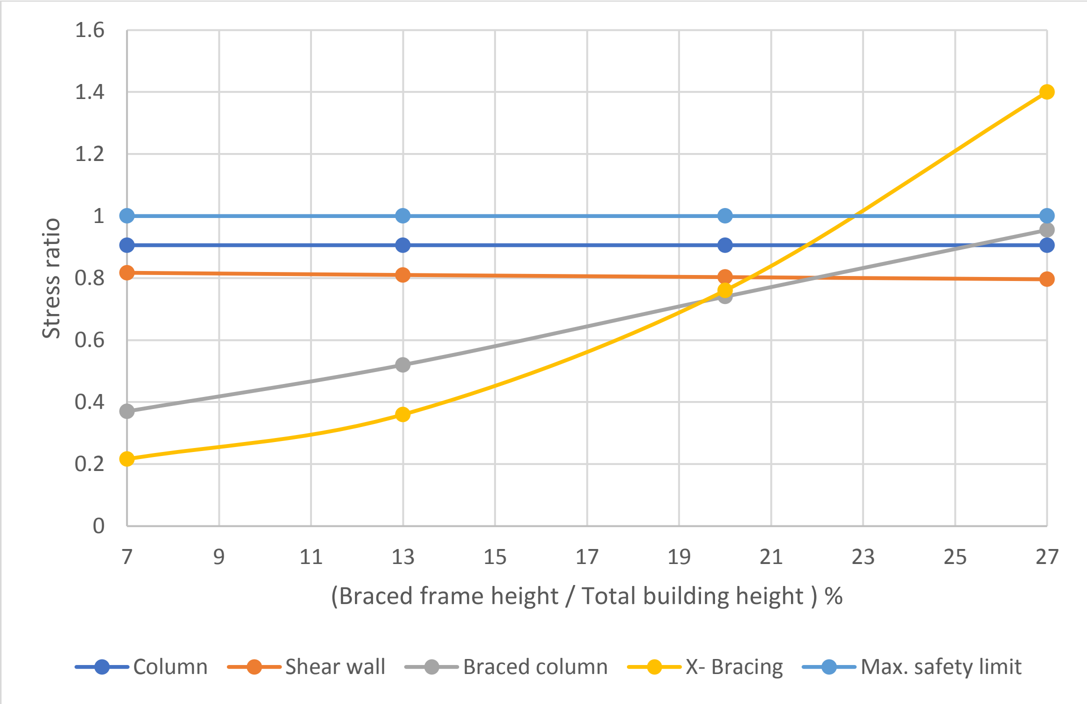

Figure (10) Relation between stress ratio and percentage of braced frame height to total building height for 15 stories in Y-direction

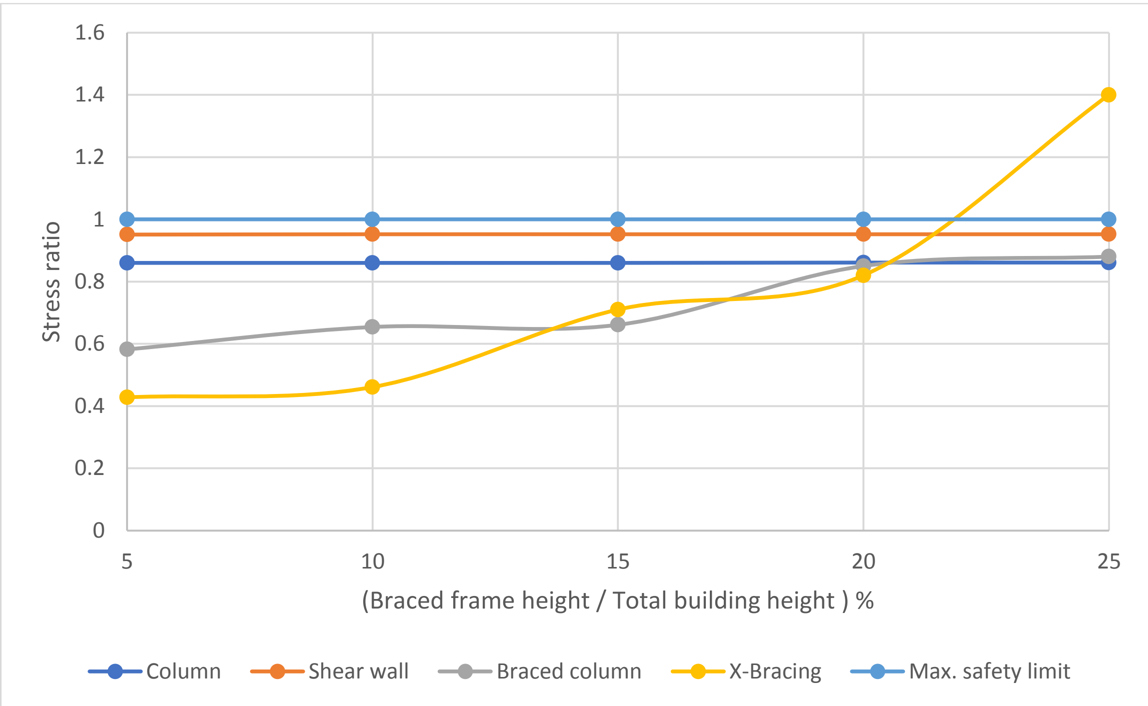

Figure (11) Relation between stress ratio and percentage of braced frame height to total building height for 20 stories in X-direction

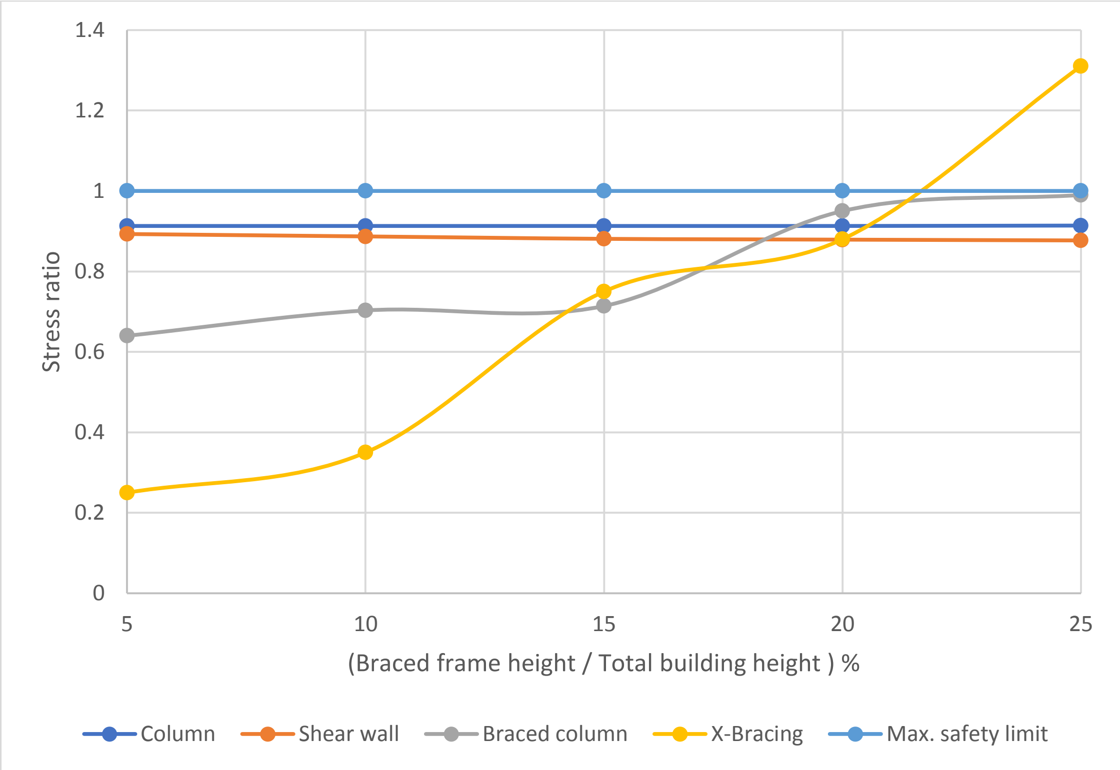

Figure (12) Relation between stress ratio and percentage of braced frame height to total building height for 20 stories in Y-direction

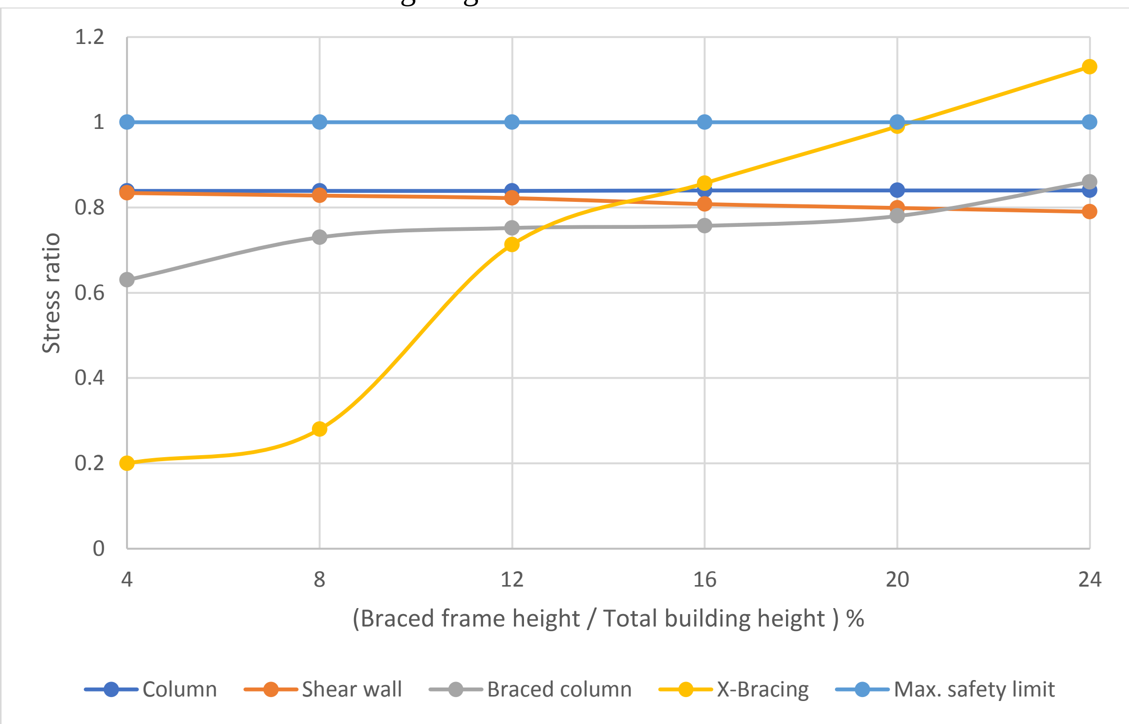

Figure (13) Relation between stress ratio and percentage of braced frame height to total building height for 25 stories in X-direction

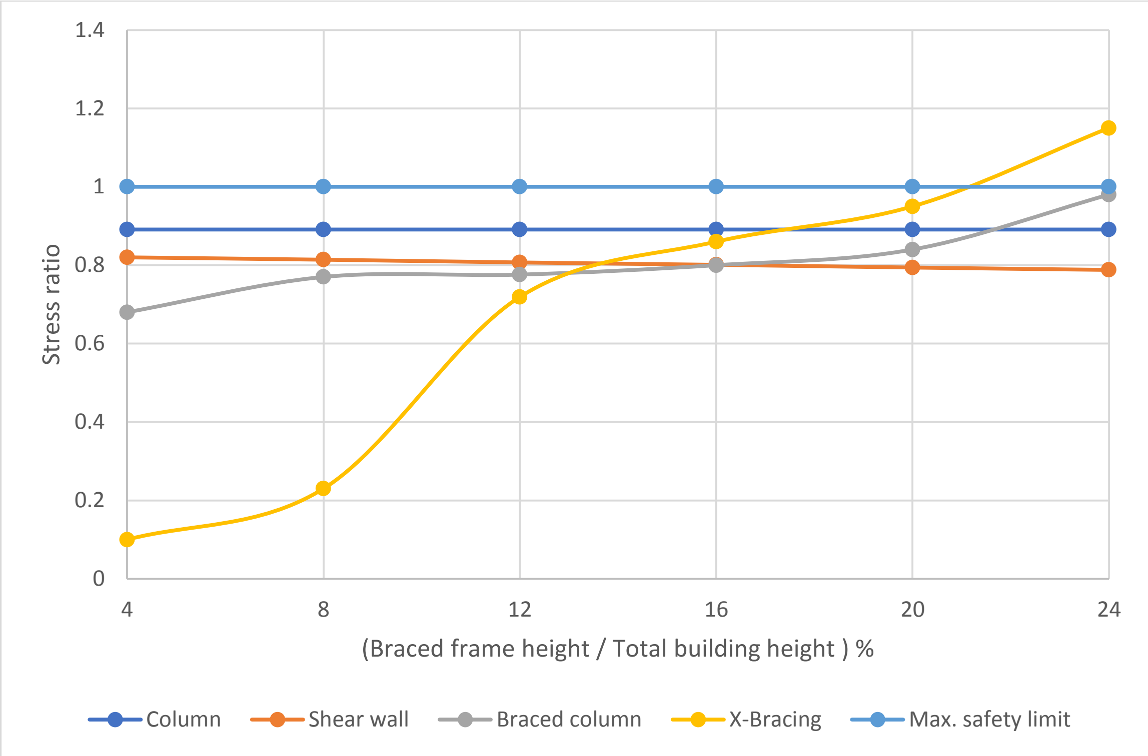

Figure (14) Relation between stress ratio and percentage of braced frame height to total building height for 25 stories in Y-direction

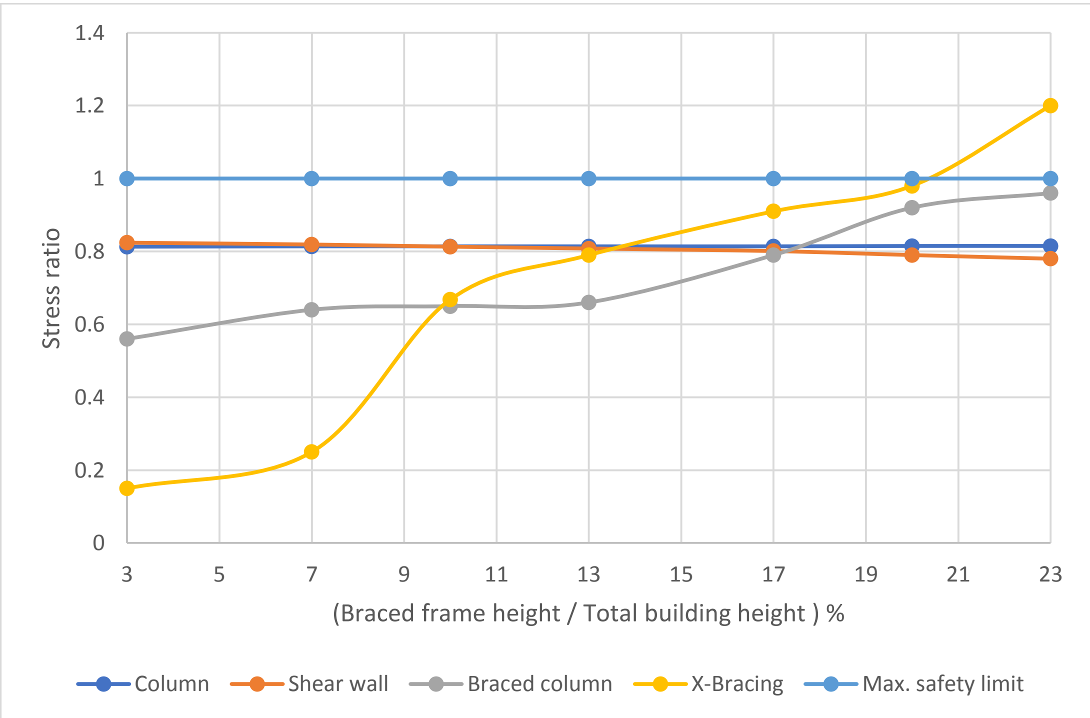

Figure (15) Relation between stress ratio and percentage of braced frame height to total building height for 30 stories in X-direction

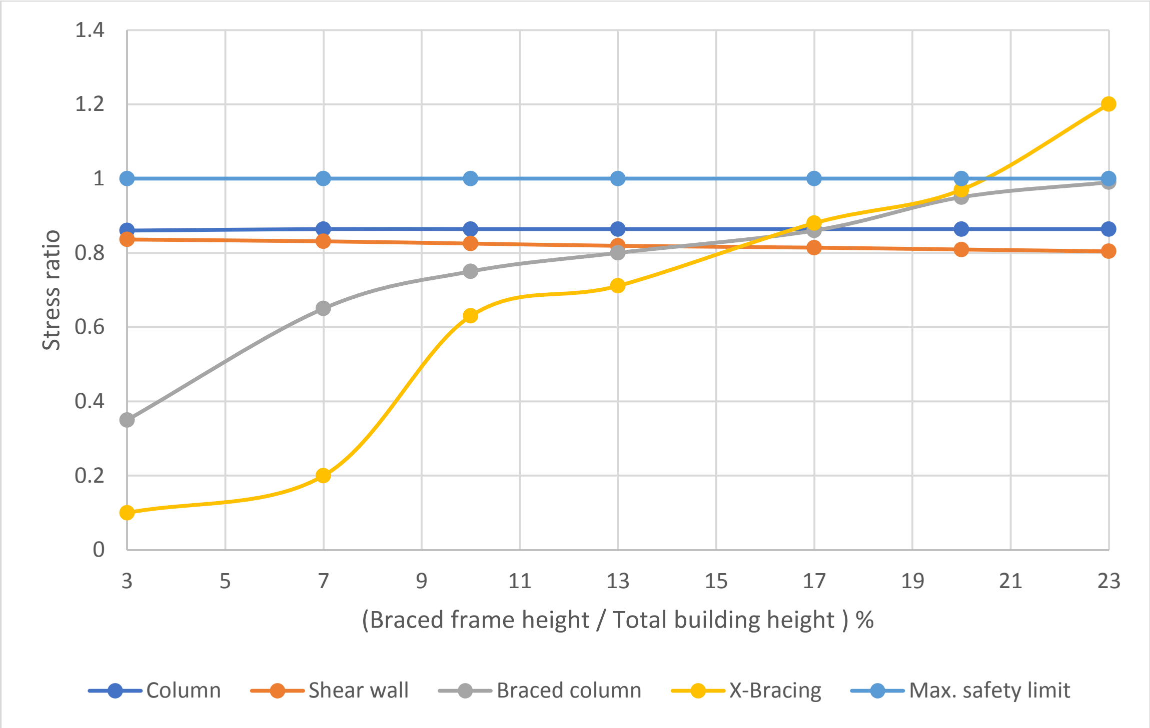

Figure (16) Relation between stress ratio and percentage of braced frame height to total building height for 30 stories in Y-direction

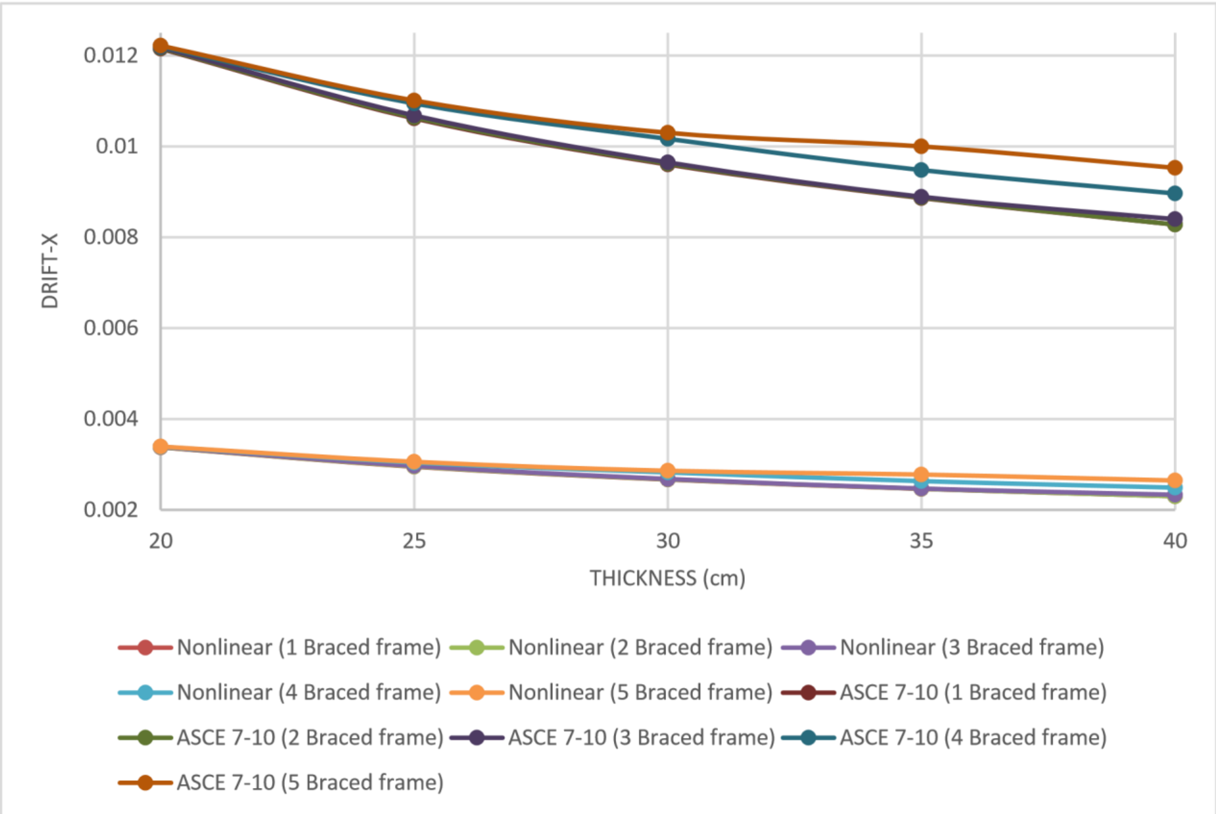

Figure (17) Relation between Thickness of shear wall and Drift value for 20 stories in X direction

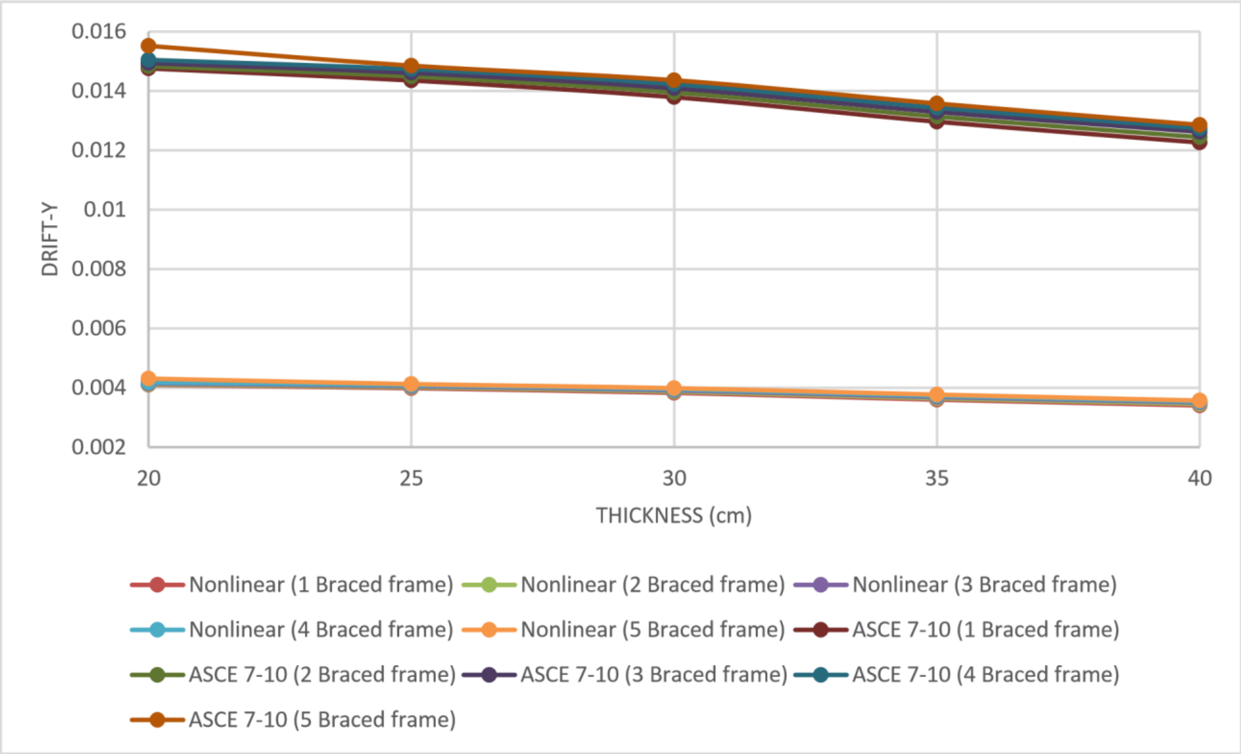

Figure (18) Relation between Thickness of shear wall and Drift value for 20 stories in Y direction

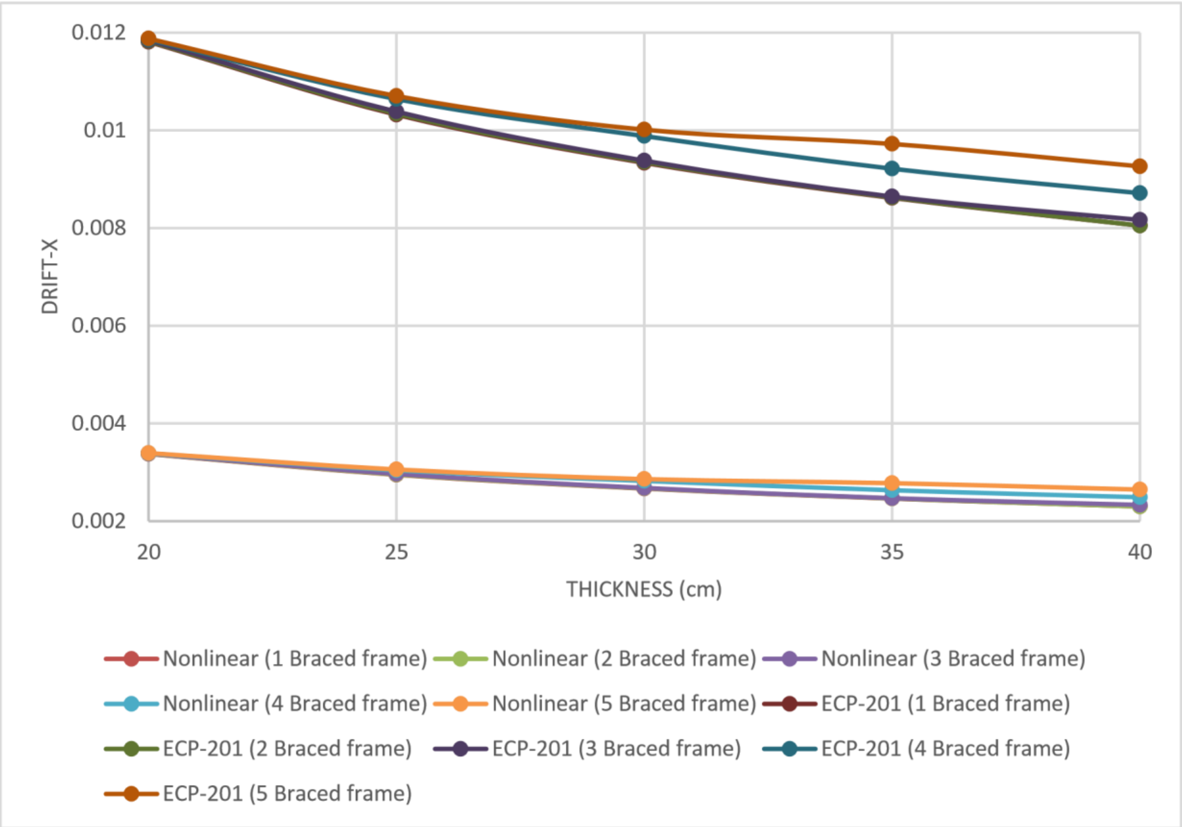

Figure (19) Relation between Thickness of shear wall and Drift value for 20 stories in X direction

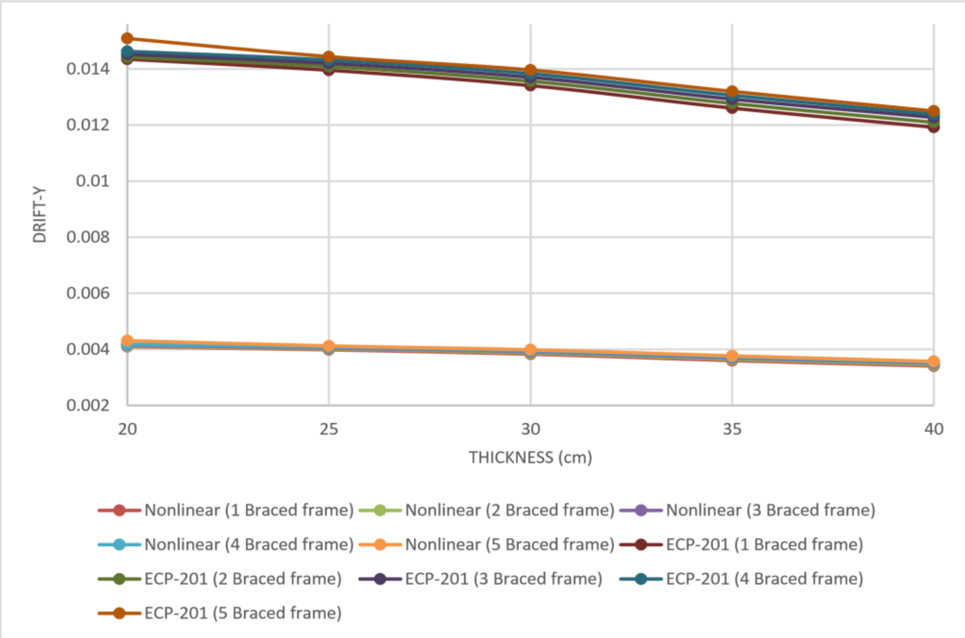

Figure (20) Relation between Thickness of shear wall and Drift value for 20 stories in Y direction

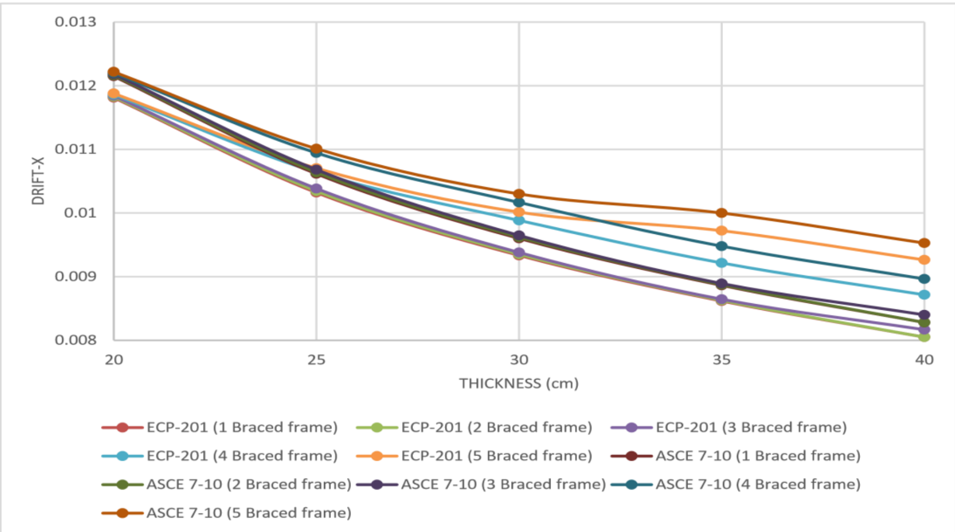

Figure (21) Relation between Thickness of shear wall and Drift value for 20 stories in X direction

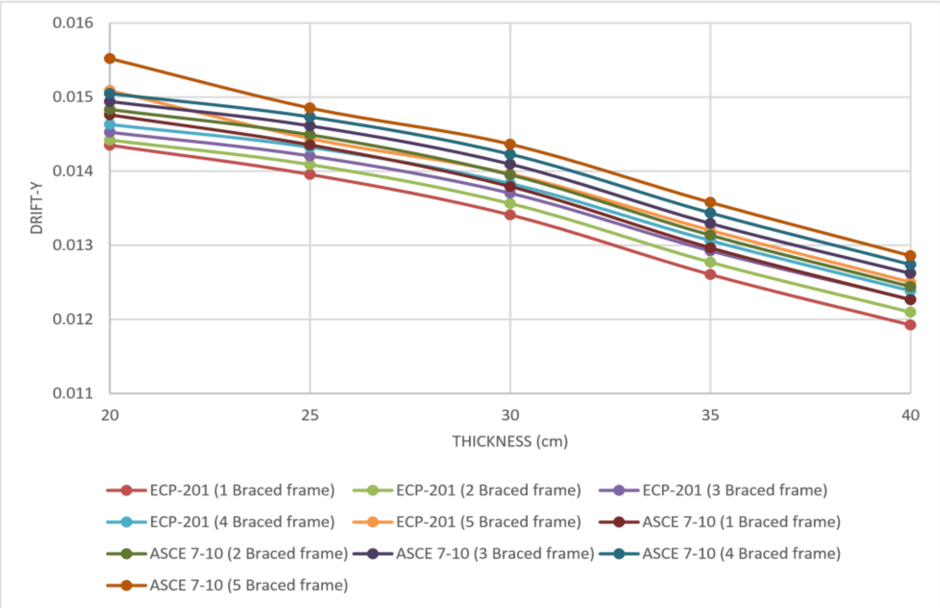

Figure (21) Relation between Thickness of shear wall and Drift value for 20 stories in Y direction

CONCLUSIONS

A nonlinear analysis has been performed for reinforced concrete shear wall converted to steel braced reinforced concrete frame, the following conclusions are drawn based on the results from nonlinear pushover analysis procedure:

1- Shear wall can be replaced with braced frame starting from building roof by approximate percentage by 20% from building height.
2- Braced frame above shear wall depending on the number of stories and total building height.
3- Braced frame capacity decrease with increasing the number of braced frame stories replaced with shear wall.
4- Shear wall capacity increase with increasing the number of braced frame replaced with shear wall as the stiffness of the lateral system decrease.
5- Columns of braced frame capacity decrease as the thickness of shear wall increase and the stiffness of shear wall increase so the bending moment of shear wall increase but, the reinforcement ratio is constant it increases shear wall capacity.
6- Increasing the distance between the center of mass and the center of rigidity decrease the capacity of studied system left side center of mass and increase the capacity for the other side of center of mass according to torsional moment created for the whole building.
7- The time period of the building increase by increasing the number of braced frame stories which replaced with shear wall.
8- Lateral drift of the system increased by increasing the number of braced frame replaced with shear wall.
9- Lateral drift decreases with increasing the thickness of shear wall.

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