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Comparative Study on Construction Sequence Analysis on Steel Structure without and with Floating Columns

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ABSTRACT

This paper presents the construction sequence analysis on the setback steel structure. In this study, the proposed building is eleven-storey setback steel structure. The length of the proposed building is 78ft and width is 66ft. The effective height of proposed building is 142ft. This building is located in seismic destructive zone V, Mandalay. The basic wind speed is 80mph. The structure is composed of special moment resisting frame (SMRF). Structural elements are designed according to AISC 360-10. Load consideration and stability checking for proposed building are based on ASCE 7-10. The proposed building is analysed and designed with the help of ETABS 2016 version 16.2.1 software. After response spectrum analysis (RSA) has done for the checking of the stability, then construction sequence analysis (CSA) is considered. And then the structural analysis results of the proposed building are studied such as axial force, shear force and bending moment of the structural frame elements. The effect of floating columns with CSA on axial force for the selected columns of proposed building is more influence from first to sixth floor level.The value of shear force with CSA is abruptly increased at the floated columns level and the other level are gradually decreased. The value of bending moment at the floated columns level is abruptly increased due to the effect of floating columns with CSA and the other level are gradually decreased.

KEYWORDS: *Setback steel structure, Construction sequence analysis, Structural analysis results, ETABS*

I. INTRODUCTION

In recent times, multi-storey buildings are required to have free space due to shortage of space, population growth and also for aesthetic and functional requirements. Many multi-storey buildings are planned and constructed with variety of architectural requirements such as planning of irregular configurations. Setback structures include common types of vertical irregularity structures. In particulars such a setback form provides adequate daylight and ventilation for the lower storey and urban locality with closely spaced tall buildings. Speed of construction is the most important benefit offered by steel construction, which leads to financial, management and other logistical benefits.

Many multi-storey and commercial buildings in Myanmar are planned and constructed with architectural complexities. Nowadays, many buildings in which floating columns are already adopted at hotels or office, so that more open space is available. That open space may be required for assembly hall, meeting room, reception, etc.

A more practical and accurate method of analysis which takes into account the various stages in which load is applied on the frame, by analysis for strength and stability at the end of each step. The phenomenon known as construction sequence analysis (CSA) is used to analyse the structure at each storey. The proposed building is analysed and designed by using CSA. And then the analysis results of proposed building are investigated with CSA.

II. Construction Sequence Analysis (CSA)

A comprehensive construction sequence analysis (CSA) involves some essential steps which are not generally performed during linear static analysis. In order to get the sequential effects manually using software, each storey should be analysed with its prior stories assigning the vertical and lateral loads till that floor from bottom of whole structure. Eventually outcomes will represent the structural response of building till that floor. Each storey follows the same procedure in the construction sequence analysis. Nowadays, analysis software are sufficiently developed to auto perform the construction sequence analysis easily. After grouping the software eventually ask for which facility should be taken and then the outcomes could be comparing among different conditions. Stage formation in construction sequence analysis is shown in Figure 1.

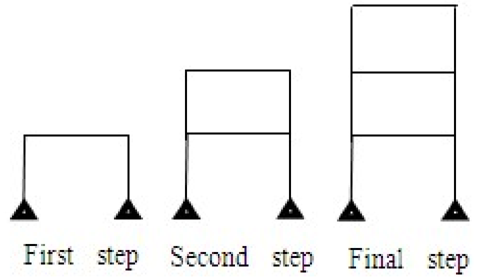

Figure1. Stage Formation in Construction Sequence Analysis (CSA)

Procedures used for CSA in ETABS are as follows;

1. Define the static load to be used in the analysis
2. Define dynamic function need to be used
3. Define auto construction sequence load case with scale factor one and 28 days duration.
4. Run the model for basic linear dynamic analysis and CSA
5. Study structural results with CSA

III. Data Preparation For Proposed Building

To analyse and design the proposed building, the required data such as site location, structural system, material properties and loading considerations are collected as follows.

A. Site Location and Structural System

The proposed building is eleven-storey setback steel structure (hotel building). The location of proposed building is in Zone V. The maximum dimension is 66ft in X-direction and 78ft in Y-direction. The effective height of the structure is 142ft. The structure is composed of special moment resisting frame (SMRF).

B. Material Properties

The strength of a structure must be adequate to resist the applied loads and the strength of material depends on the type of material used. So, the material properties for structural data are as followed.

Analysis property data
Weight per unit volume of steel = 490 pcf
Modulus of elasticity, E_s = 29000 ksi
Poisson's ratio, μ = 0.3
Coefficient of thermal expansion = 6.5×10^{-6} in/ in /° F
Design property data
Yield strength of structural steel, F_y = 50 ksi
Ultimate strength of structural steel, F_u = 65 ksi

C. Loading Considerations

The applied loads are gravity loads and lateral loads. Gravity loads include dead loads, superimposed dead loads and live loads. Lateral loads of wind load and earthquake load are considered according to ASCE7-10 and MNBC-2016.

1. Dead Load

9 inches thick brick wall weight = 100 psf
4.5 inches thick brick wall weight = 55 psf
Weight of finishing = 15 psf
Weight of ceiling = 10 psf
Slab (6'' thick) = Deck slab

2. Live Load

Live load on private rooms & corridors serving private area = 40 psf
Live load on assembly rooms & corridors serving public area = 100 psf
Live load on stair = 100 psf
Live load on flat roof = 20 psf
Weight of lift = 3 tons
Unit weight of water = 62.4 pcf

3. Wind Load

Exposure type = B
Basic wind speed = 80 mph
Topographic factor, K_{zt} = 0.85
Gust-effect factor, G = 0.85
Wind Important factor, I = 1.0

4. Earthquake Load

Seismic zone = V
Occupancy category = II
Spectral response acceleration (0.2s), S_s = 2.01
Spectral response acceleration (1.0s), S_1 = 0.8
Seismic important factor, I = 1.0
Soil profile type = S_D
Response modification coefficient, R = 8
System over strength factor, Ω_o = 3
Deflection amplification factor, C_d = 5.5

5. Load Combinations

The effective height of proposed building is 142ft and it is irregular structure. So, the proposed building is analysed and designed with RSA. The designed load combinations for RSA are considered according to AISC 360-10 and ASCE 7-10.

1. 1.4DL + 1.4SD
2. 1.2DL + 1.2SD + LL
3. 1.2DL + 1.2SD + 1.6LL
4. 1.2DL + 1.2SD + LL + WX
5. 1.2DL + 1.2SD + LL – WX
6. 1.2DL + 1.2SD + LL + WY
7. 1.2DL + 1.2SD + LL – WY
8. 1.2DL + 1.2SD + 0.5WX
9. 1.2DL + 1.2SD – 0.5WX
10. 1.2DL + 1.2SD + 0.5WY
11. 1.2DL + 1.2SD – 0.5WY
12. 0.9DL + 0.9SD + WX
13. 0.9DL + 0.9SD – WX
14. 0.9DL + 0.9SD + WY
15. 0.9DL + 0.9SD – WY
16. 1.2DL + 1.2SD + LL + SPECX
17. 1.2DL + 1.2SD + LL – SPECX
18. 1.2DL + 1.2SD + LL + SPECY
19. 1.2DL + 1.2SD + LL – SPECY
20. 0.9DL + 0.9SD + SPECX
21. 0.9DL + 0.9SD – SPECX
22. 0.9DL + 0.9SD + SPECY
23. 0.9DL + 0.9SD – SPECY

Figure 2 and Figure 3 show floor plan and 3D view of the proposed building respectively.

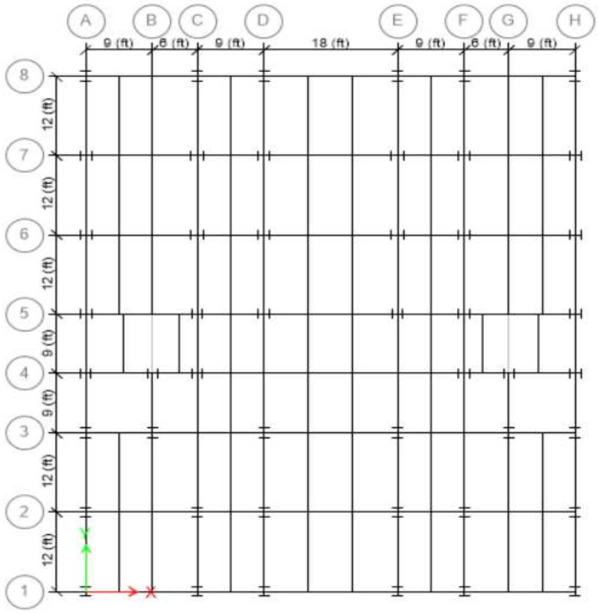

Figure2. Floor Plan of Proposed Building

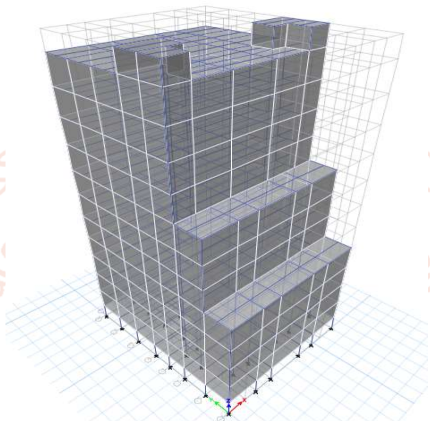

Figure3. 3D View of Proposed Building

In this study, the proposed building is setback at the fifth floor and eight floor.

IV. Analysis and Design Results

A. Design Sections of Proposed Building without floating Columns

In this study, the sections of the beam W10x54, W14x53, W14x68 and W14x132 are used in proposed building. The sections of the column W14x132, W14x159, W14x176, W14x193, W14x211 and W14x233 are used in proposed building. Design results for frame elements are shown in Tables 1 and 2 respectively. For the proposed building, Figure 4 shows beam layout plan and the column layout plans are shown in Figure 5.

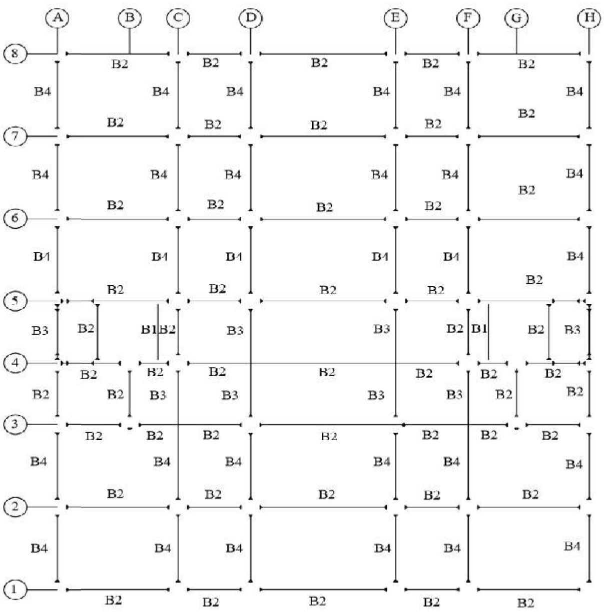

Figure4. Beam Layout Plan without Floating Columns

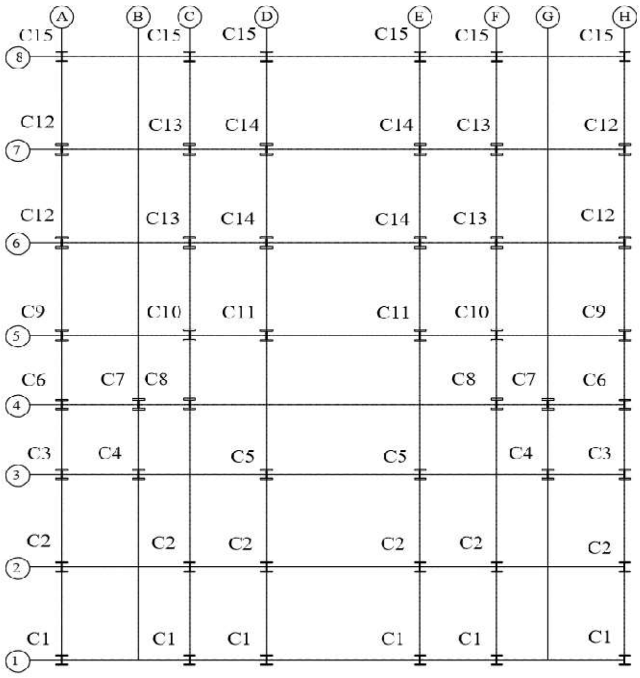

Figure5. Column Layout Plan without Floating Columns

TABLE I
COLUMN SECTIONS WITHOUT FLOATING COLUMNS

Column Types	Storey Level	Section (in x lb/ft)	Column Types	Storey Level	Section (in x lb/ft)
C1	4F to TRF	-	C9	GF to 4F	W 14x211
C2	GF to 7F	W 14x211		4F to RF	W 14x176
	7F to TRF	-		RF to TRF	W 14x132
C3	GF to RF	W 14x211	C10	GF to 7F	W 14x211
	RF to TRF	W 14x159		7F to RF	W 14x193
C4	GF to 3F	W 14x233		RF to TRF	W 14x132
	3F to 7F	W 14x211	C11	GF to 3F	W 14x233
	7F to RF	W 14x176		3F to 10F	W 14x211
	RF to TRF	W 14x159		10F to RF	W 14x132
C5	GF to 3F	W 14x233	C12	GF to 10F	W 14x211
	3F to 7F	W 14x211		10F to RF	W 14x176
	7F to RF	W 14x176	C13	GF to 1F	W 14x233
C6	GF to 4F	W 14x211		1F to 10F	W 14x211
	4F to RF	W 14x176		10F to RF	W 14x176
	RF to TRF	W 14x159	C14	GF to 3F	W 14x233
C7	GF to 3F	W 14x233		3F to 10F	W 14x211
	3F to 7F	W 14x211		10F to RF	W 14x176
	7F to RF	W 14x176	C15	GF to 3F	W 14x211
	RF to TRF	W 14x132		3F to 10F	W 14x193
C8	GF to 7F	W 14x211		10F to RF	W 14x132

TABLE II BEAM SECTIONS WITHOUT FLOATING COLUMNS

Beam Types	Storey Level	Size (in x lb/ft)
B_1	Landing Beam	W 10x54
B_2	All storey	W 14x53
B_3	All storey	W 14x68
B_4	All storey	W 14x132

B. Stability Checking Without Floating Columns

The structural stability checking for the proposed building is considered according to ASCE 7-10. Five types of structural stability checking are overturning moment, sliding, torsional irregularity, storey drift and P-delta. Table 3 shows the stability checking for proposed building.

TABLE III CHECKING FOR STABILITY OF THE PROPOSED BUILDING

Checking Item	X-direction	Y-direction	Limit	Remark
Overturning Moment	7.34	7.59	≥ 1.5	OK
Sliding	4.12	3.22	≥ 1.5	OK
Torsional Irregularity	1.16	1.009	≤ 1.2	OK
Storey Drift	2.07in	1.19 in	≤ 2.88	OK
P-delta	0.01	0.005	≤ 0.1	OK

In both X and Y directions, all stabilty checkings for proposed building are within limitations. Therefore, the proposed building without floating columns is satisfied according to the stability checking.

C. Analysis and Design with CSA

After the structural stability checking of the proposed building without floating columns is done for RSA, CSA is considered with gravity loads and lateral loads on steel structure. In CSA, auto construction sequence load case is defined with 28 days duration. Finally, design sections of column and beam from CSA are not changed that obtained from RSA.

D. Design Sections of Proposed Building without floating Columns

After the proposed building with floating columns is analysed with RSA, columns sections are required to change the columns at the floated storey level. The columns are floated not only four columns of the grid line D-6, D-7, E-6, E-7 at the second floor but also two columns of the grid line E-2, F-2 at the third floor of the proposed building.After placing the floating columns along the grid line 6 and 7 at the second floor, the column dimensions of the grid line C-6, C-7, F-6, F-7 of the size W 14x211 are required to change the size of W 14x233 at the second floor and third floor. The column dimensions of the grid line E-1 and F-1 of the size W 14x159 are required to change the size of W 14x176 from the first to third floor. All other columns sizes are the same as without floating columns of the proposed building. All beams sizes are the same as without floating columns of the proposed building. Seventeen types of columns sections are obtained for this building with floating columns for RSA. The obtained design sections of column and beam are not required to change the sections from RSA without floating columns. Design results for frame elements are shown in Tables 4. For the proposed building with floating columns, Figure 6 shows column layout plans with floating columns.

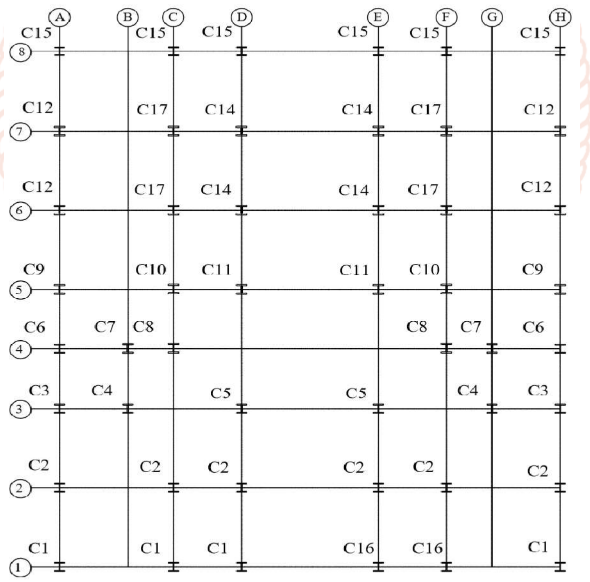

Figure6. Column Layout Plan without Floating Columns

TABLE IV COLUMN SECTIONS WITH FLOATING COLUMNS

Column Types	Storey Level	Section (in x lb/ft)		Storey Level	Section (in x lb/ft)
C1	GF to 3F	W 14x159		GF to 4F	W 14x211
	3F to 4F	W 14x132		4F to RF	W 14x176
	4F to TRF	-		RF to TRF	W 14x132
C2	GF to 7F	W 14x211		GF to 7F	W 14x211
	7F to TRF	-		7F to RF	W 14x193
C3	GF to RF	W 14x211		RF to TRF	W 14x132
	RF to TRF	W 14x159		GF to 3F	W 14x233
C4	GF to 3F	W 14x233	C11	3F to 10F	W 14x211
	3F to 7F	W 14x211		10F to RF	W 14x132
	7F to RF	W 14x176	C12	GF to 10F	W 14x211
	RF to TRF	W 14x159		10F to RF	W 14x176

C5	GF to 3F	W 14x233	C13	-	-
	3F to 7F	W 14x211	C14	GF to 3F	W 14x233
	7F to RF	W 14x176		3F to 10F	W 14x211
C6	GF to 4F	W 14x211		10F to RF	W 14x176
	4F to RF	W 14x176	C15	GF to 3F	W 14x211
	RF to TRF	W 14x159		3F to 10F	W 14x193
C7	GF to 3F	W 14x233		10F to RF	W 14x132
	3F to 7F	W 14x211	C16	GF to 3F	W 14x176
	7F to RF	W 14x176		3F to 4F	W 14x132
	RF to TRF	W 14x132		4F to RF	-
C8	GF to 7F	W 14x211	C17	GF to 3F	W 14x233
	7F to RF	W 14x176		3F to 10F	W 14x211
	RF to TRF	W 14x132		10F to RF	W 14x176

E. Stability Checking With Floating Columns

The structural stability checking for the proposed building is considered according to ASCE 7-10. Five types of structural stability checking are shown in Table 5.

TABLE V CHECKING FOR STABILITY OF THE PROPOSED BUILDING

Checking Item	X-direction	Y-direction	Limit	Remark
Overturning Moment	7.34	7.64	≥ 1.5	OK
Sliding	4.12	3.24	≥ 1.5	OK
Torsional Irregularity	1.16	1.009	≤ 1.2	OK
Storey Drift	2.19in	1.195 in	≤ 2.88	OK
P-delta	0.01	0.005	≤ 0.1	OK

In both X and Y directions, all stabilty checkings for proposed building are within limitations. Therefore, the proposed building with floating columns is satisfied according to the stability checking.

F. Analysis and Design with CSA

After the structural stability checking of the proposed building with floating columns is done for RSA, CSA is considered with gravity loads and lateral loads on steel structure. In CSA, auto construction sequence load case is defined with 28 days duration. Finally, design sections of column and beam from CSA are not changed that obtained from RSA.

V. Structural Analysis Results of Csa

The structural analysis results of CSA such as internal forces on selected frame members are studied. Selected columns and beams are shown in Figure 7.

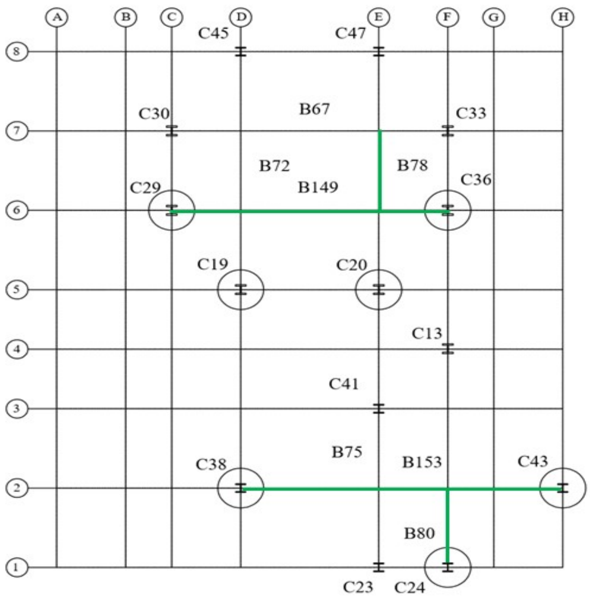

Figure7. Selected Columns and Beams Location

A. Axial Force on Columns

The columns C19, C20, C23 and C43 are selected for comparison of axial forces. The selected columns C23 and C43 are located at the irregular level of the proposed building. The axial force results are shown in Figure 8 to Figure 9.

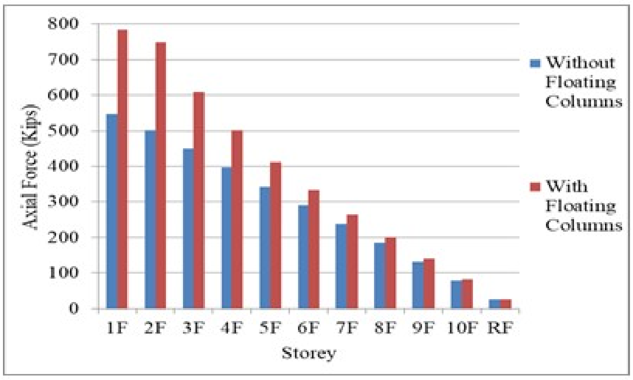

Figure8. Axial Force for C19 with CSA

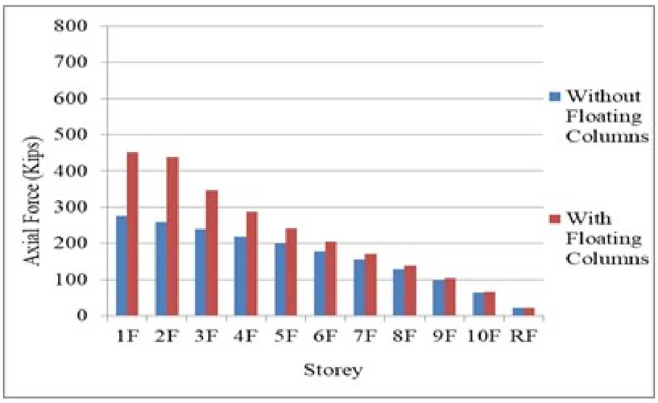

Figure 9. Axial Force for C20 with CSA

The amounts of increased percentage variation at the second floor are 62% in C29, 41% in C36, 49% in C19 and 69% in C20 because the numbers four columns are floated at the second floor.

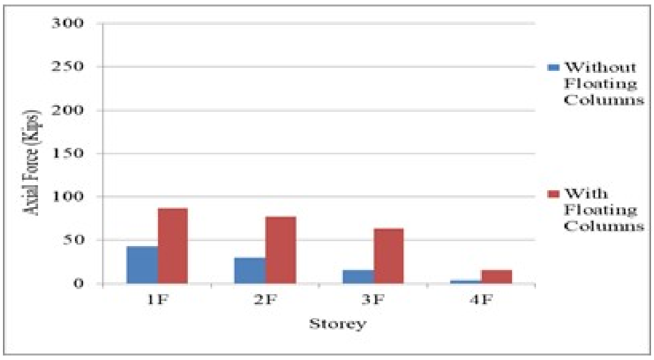

Figure10. Axial Force for C24 with CSA

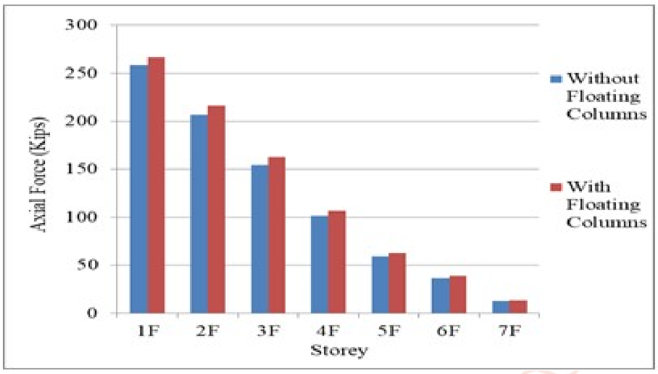

Figure11. Axial Force for C38 with CSA

The maximum increased percentage of axial forces is occurred at the third floor of selected columns because the numbers of two columns are floated at the third floor level.

B. Shear Force in Beams

The beams B149, B78, B153 and B80 are selected for shear forces. The shear force results of selected beams are shown in Figure 12 to Figure 13.

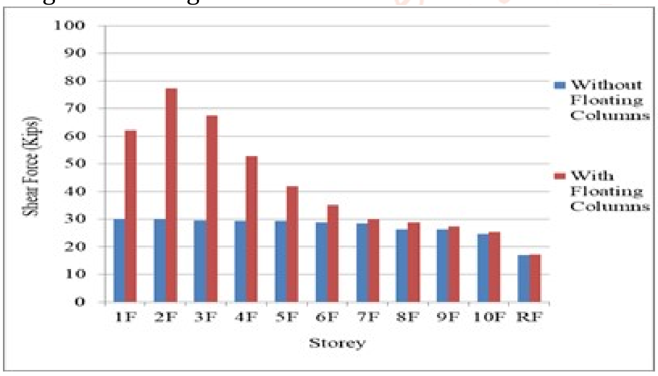

Figure12. Shear Force for B149with CSA

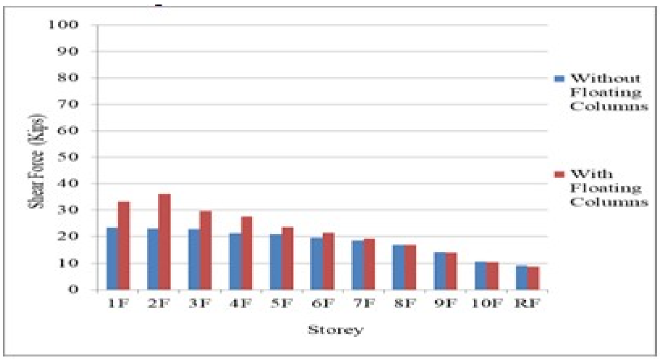

Figure13. Shear Force for B78 with CSA

The amounts of increased percentage variation at the second floor is 56% in B78. The value of the shear forces at the second floor for B149 of the proposed building with floating columns are over two times as large as without floating columns.

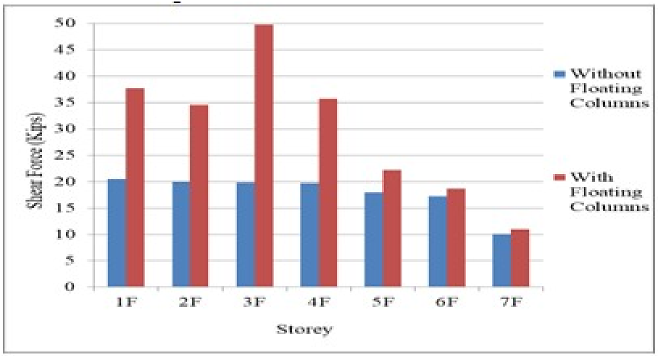

Figure14. Shear Force for B153 with CSA

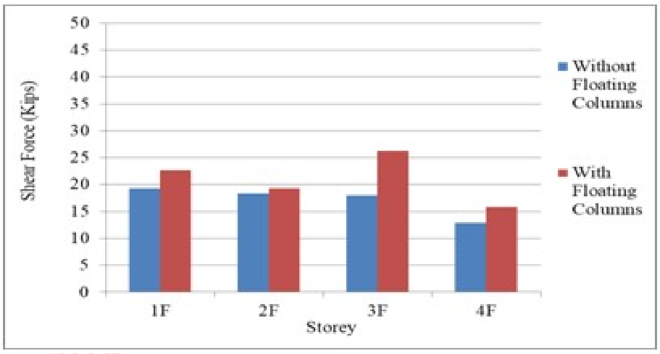

Figure15. Shear Force for B80 with CSA

The amount of increased percentage variation at the third floor is 46% in B80. The value of the shear force for selected beam B153 at the third floor of the proposed building with floating columns are over two times as large as without floating columns because the numbers of two columns are floated at the third floor.

C. Bending Moment in Beams

The internal forces of bending moment in selected beams are shown in Figure 16 to Figure 19.

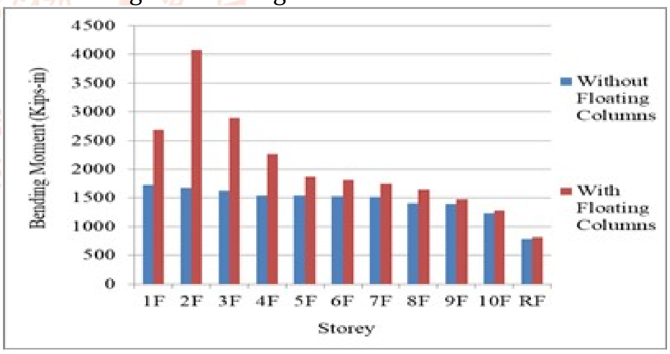

Figure16. Bending Moment for B149 with CSA

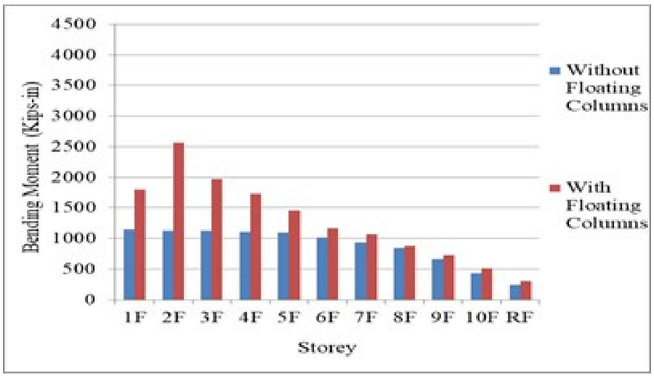

Figure17. Bending Moment for B78 with CSA

The value of the bending moment for B78 of the proposed building with floating columns at second floor are about two times as large as without floating columns. The value of the bending moment for long span transfer beam B149 of the proposed building with floating columns are over two-and-one-half times as large as without floating columns at the floated columns level because the floating columns effect with CSA on long span transfer beams are more influence than the short span beam.

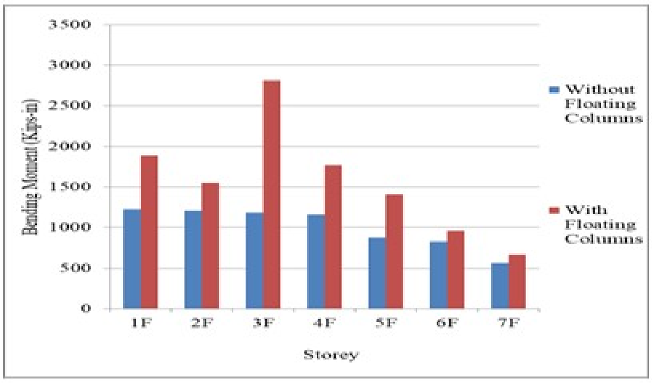

Figure18. Bending Moment for B153 with CSA

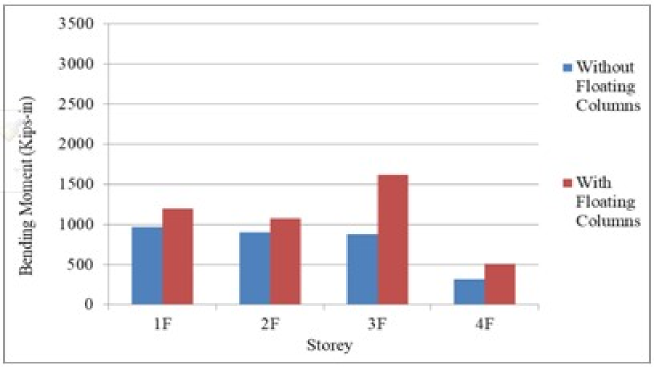

Figure19. Bending Moment for B80 with CSA

The value of the bending moments for B153 of the proposed building with floating columns at the third floor are about three times as large as without floating columns because B153 is situated at abrupt reduction level of proposed setback structure. The value of the bending moments for B80 of the proposed building with floating columns at the third floor are about two times as large as without floating columns.

VI. Conclusions

In this study, the CSA of the eleven-storey setback steel structure is presented. This structure is situated in destructive zone V. The proposed building is analysed and designed with the help of ETABS 2016 software and ASCE 7-10 specifications. After RSA is done for the checking of the stability, then CSA is considered with gravity loads plus lateral loads. The effect of floating columns with CSA on axial force for the selected columns of proposed building is more influence from first to sixth floor level.The value of shear force with CSA is abruptly increased at the floated columns level and the other level are gradually decreased. The maximum value of the shear forces for selected beams of the proposed building with floating columns at second and third floors are over two times as large as without floating columns. The value of bending moment at the floated columns level is abruptly increased due to the effect of floating columns with CSA and the other level are gradually decreased.In this study, it can be concluded that the setback structure with floating columns should be considered the effect of CSA according to structural analysis results.

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