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Study on the Effect of Response Spectrum Analysis and Construction Sequence Analysis on Setback Steel Structure

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ABSTRACT

This paper presents the effect of response spectrum analysis and 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 Mandalay. So it is situated not only destructive zone but also basic wind speed, 80mph. The structure is composed of special moment resisting frame (SMRF). Structural elements are designed according to AISC 360-10[2]. Load consideration and stability checking for proposed building are based on ASCE 7-10 [3]. The analysis and design of the proposed structure model is done with the help of ETABS 2016 version 16.2.1 software [6]. The present study involves response spectrum analysis (RSA) and construction sequence analysis (CSA), which are done on a setback steel structure and the structural analysis results such as storey displacement, maximum axial force, maximum shear force and maximum bending moment of the structural frame elements are compared. The maximum storey displacement with CSA is increased by 56% than the displacement with RSA. The maximum axial force on columns with CSA is increased by 48% than axial force with RSA. The maximum shear forces and bending moments with CSA are more than shear forces and bending moments with RSA.

Keywords: *Response spectrum analysis, Setback steel structure, Construction sequence analysis, 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 in vertical irregular 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.

The response spectrum analysis (RSA) is a linear dynamic analysis method which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. The method involves the calculation of the maximum value of the displacements and member forces in each mode using smooth design spectra that are the average of several earthquake motions.

The building model is analysed using response spectrum analysis with the assumption that the structure and change of the load transfer to all the loads or full loads in a single stretch when the whole structure is constructed completely [1].

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) which is used to analyse the structure at each storey [4]. To know the effect on setback steel structure, the response spectrum analysis and construction sequence analysis are used. And then the analysis results of proposed building are investigated with RSA and CSA.

I. 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. Once each storey follows the same procedure the complete construction sequence analysis could be visualized. 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 [5]. Stage formation in construction sequence analysis is shown in Figure 1.

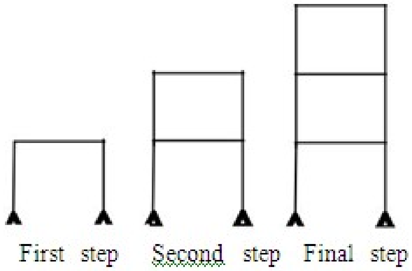


Figure 1. Stage Formation in Construction Sequence Analysis (CSA)

II. 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 function of the proposed building is eleven-storey setback steel structure (hotel building). The proposed building exists in Mandalay. 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 ASCE 7-10.

(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 designed load combinations 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.

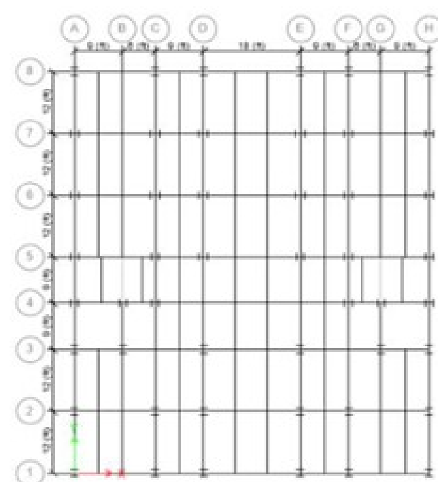


Figure 2. Floor Plan of Proposed Building

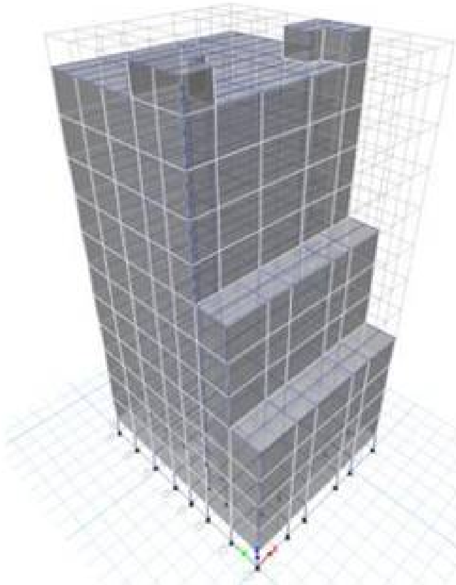


Figure 3. 3D View of Proposed Building

III. ANALYSIS AND DESIGN RESULTS OF PROPOSED BUILDING WITH RSA

Firstly, the proposed building is analysed and design for the load considerations and static load combinations. After the structural stability checking of the proposed building is done for linear static analysis, RSA is considered with gravity loads and lateral loads.

A. Design Sections of Proposed Building

In this study, the sections of beams W10x54, W14x53, W14x68 and W14x132 are used in proposed building.

The sections of columns 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, Figure 6, Figure 7 and Figure 8.
Figure 4. Beam Layout Plan for Proposed Building

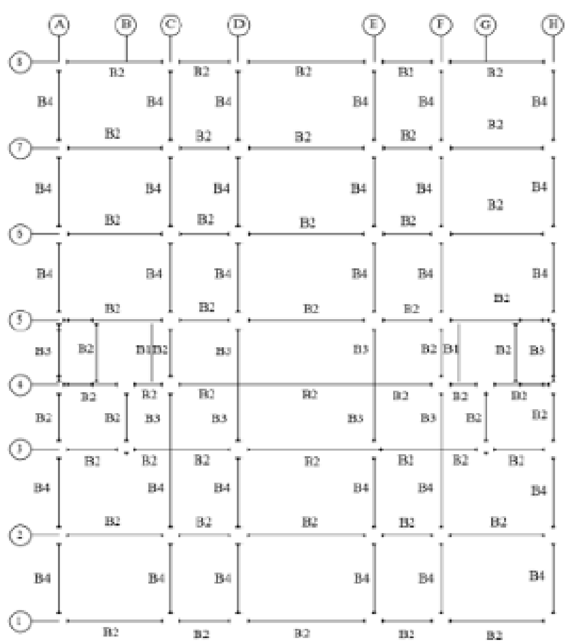


Figure 4. Beam Layout Plan for Proposed Building

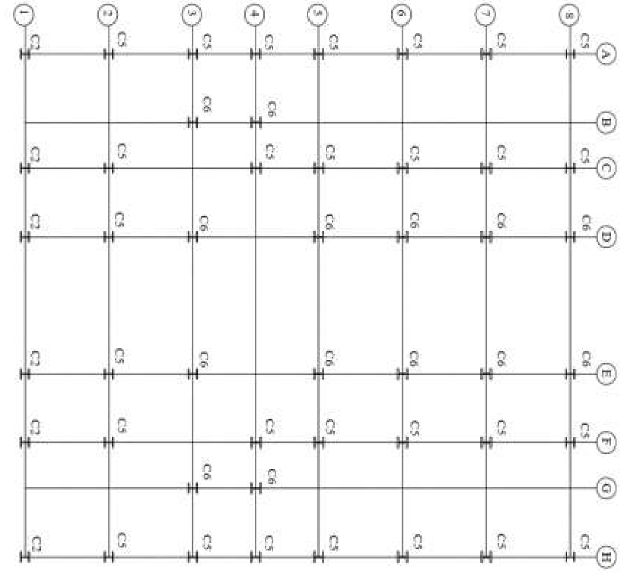


Figure 5. Column Layout Plan for 1F to 3F

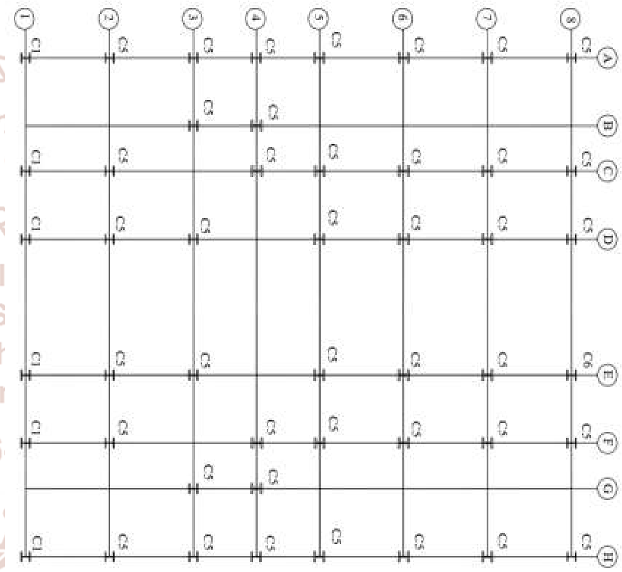


Figure 6. Column Layout Plan for 4F

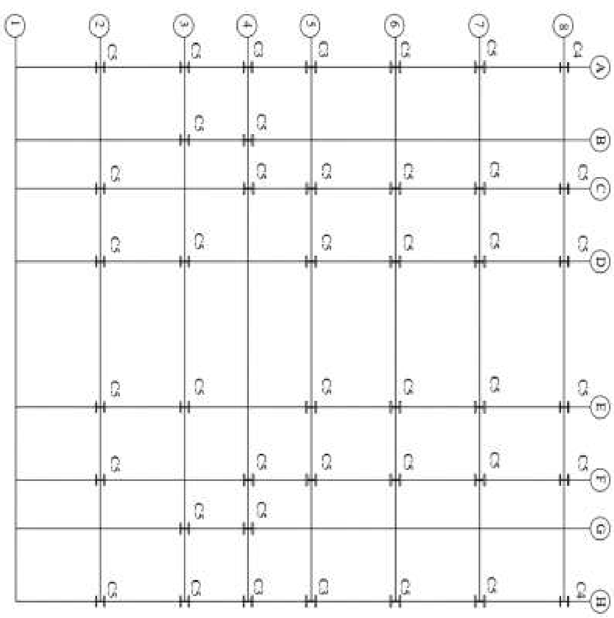


Figure 7. Column Layout Plan for 5F to 7F

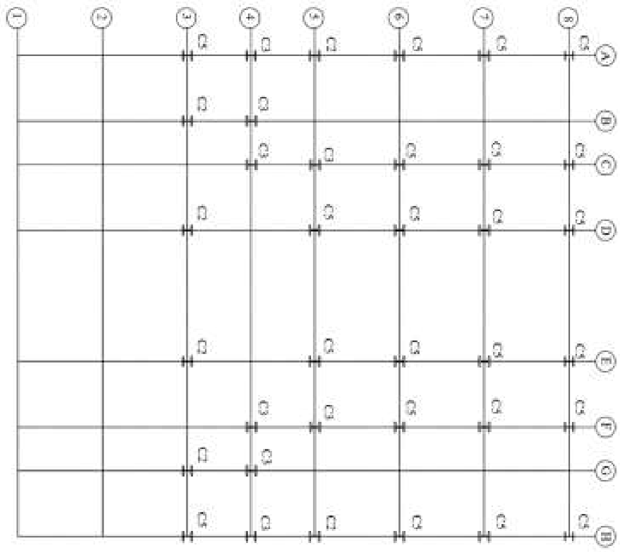


Figure 8. Column Layout Plan for 8F to 10F

TABLE I: COLUMN SIZES OF THE PROPOSED BUILDING

Columns Types	Storey Level	Size (in x lb/ft)
C1	4F and RF	W 14x132
C2	1F to 3F 8F to 10F	W 14x159
C3	5F to RF	W 14x176
C4	5F to 9F RF	W 14x193
C5	1F to 10F	W 14x211
C6	1F to 3F	W 14x233

Table II: Beam Sizes Of The Proposed Building

BeamTypes	Storey Level	Size (in x lb/ft)
B1	Landing Beam	W 10x54
B2	All storey	W 14x53
B3	All storey	W 14x68
B4	All storey	W 14x132

B. Stability Checking

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 [3]. 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	6.57	5.62	≥ 1.5	OK
Sliding	4.12	3.22	≥ 1.5	OK
Torsional Irregularity	1.16	1.009	≤ 1.2	OK
Storey Drift	2.064 in	1.194 in	≤ 2.88	OK
P-delta	0.010	0.005	≤ 0.1	OK

In both X and Y directions, the safety factors of overturning moment, sliding, torsional irregularity, storey drift and P-delta checking for the building are within limitations. Therefore, the proposed building is satisfied according to the stability checking.

C. Analysis and Design of CSA

After the structural stability checking of the proposed building is done for RSA, CSA is considered with gravity loads and lateral loads to know the effect of CSA on setback steel structure. Design sections of column and beam from CSA are not changed that obtained from RSA.

IV. COMPARATIVE RESULTS OF RSA AND CSA

To understand the effect of RSA and CSA on the setback steel structure, the structural responses such as storey displacement and internal forces on selected frame members are compared. Selected columns and beams are shown in Figure 9.

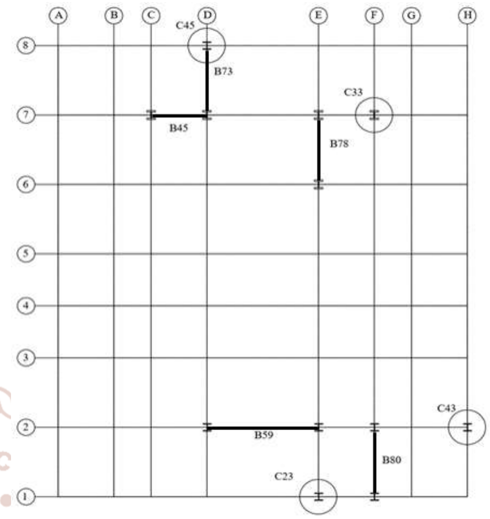


Figure 9. Selected Columns and Beams Location

A. Comparison of Storey Displacement

To know the structural responses due to RSA and CSA of setback steel structure with respect to floor level are compared. The comparative results in X and Y directions are illustrated in Figure 10 and Figure11.

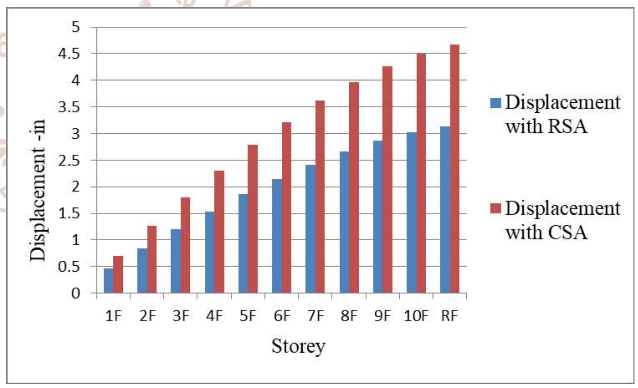


Figure 10. Storey Displacement for X-direction with RSA & CSA

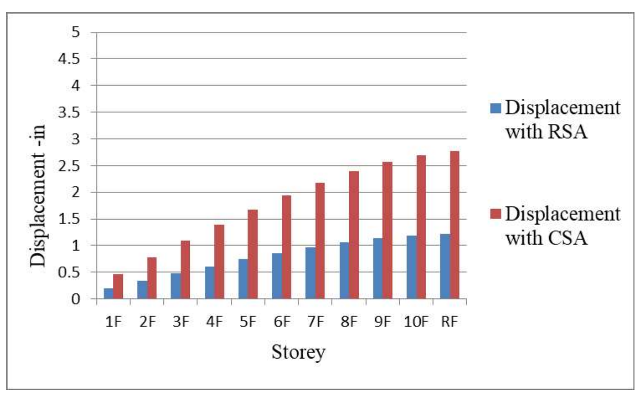


Figure 11. Storey Displacement for Y-direction with RSA & CSA

The maximum value of storey displacement is found at roof floor level with both RSA and CSA. The storey displacement in X-direction with CSA is increased by 49% than displacement with RSA. It can be seen that the storey displacement in Y-direction is smaller than that of X-direction due to both RSA and CSA because the proposed building is setback in Y-direction.

B. Comparison of Axial Force on Columns

The columns C45, C33, C23 and C43 are selected for comparison of axial forces with RSA and CSA. The selected columns C45 and C33 locate at the level of continuity of the proposed building. The selected columns C23 and C43 are located at the level of discontinuity of the proposed building. The comparison results are shown in Figure 12 to Figure 15.

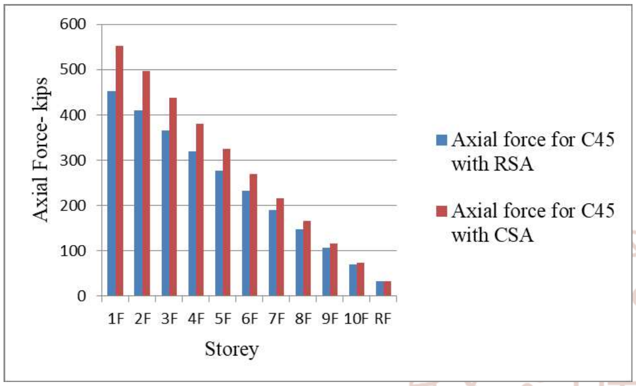


Figure 12. Axial Force for C45 with RSA & CSA

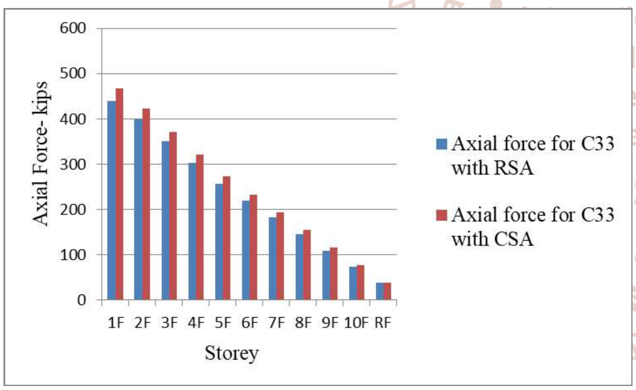


Figure 13. Axial Force for C33 with RSA & CSA

The axial forces of C45 and C33 are maximum values at first floor with RSA and CSA. The axial force values obtained for C45 with CSA is increased by 22% than axial force with RSA. The axial force values obtained for C33 with CSA is increased by 6% than axial force with RSA.

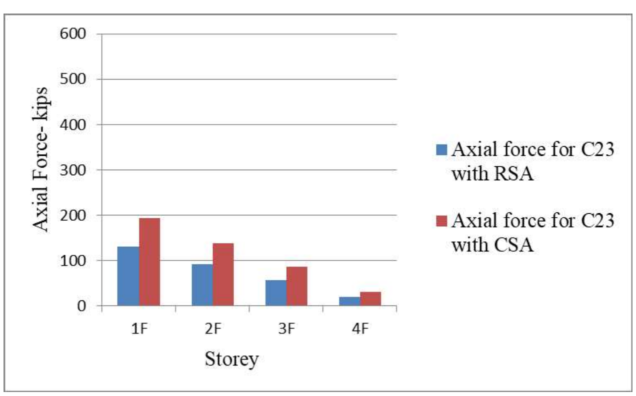


Figure 14. Axial Force for C23 with RSA & CSA

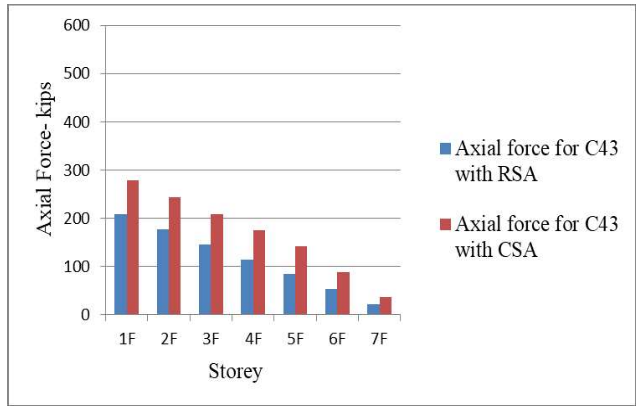


Figure 15. Axial Force for C43 with RSA & CSA

The axial force for C23 with CSA is increased by 48% than axial force with RSA. The result of axial force for C43 with CSA is increased by 33% than axial force with RSA. Above comparison, the difference of axial forces with RSA and CSA is significantly increased at the selected exterior columns C45, C23 and C43.

B. Comparison of Shear Force in Beams

To understand the internal forces in selected beams due to RSA and CSA of setback steel structure are compared. The beams B80, B59, B45, B78 and B73 are selected for comparison of shear forces. Comparative results of selected beams are illustrated in Figure 16 to Figure 20.

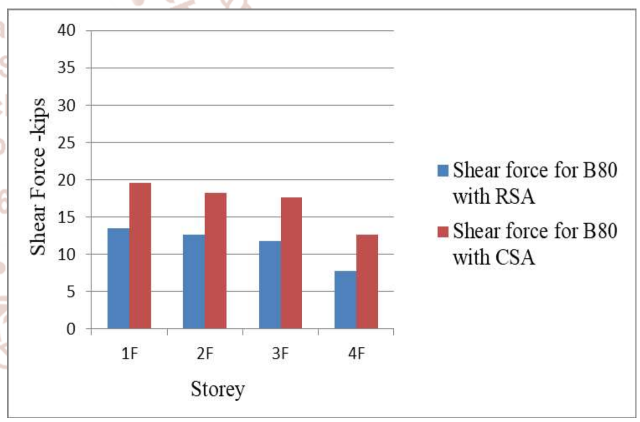


Figure 16. Shear Force for B80 with RSA & CSA

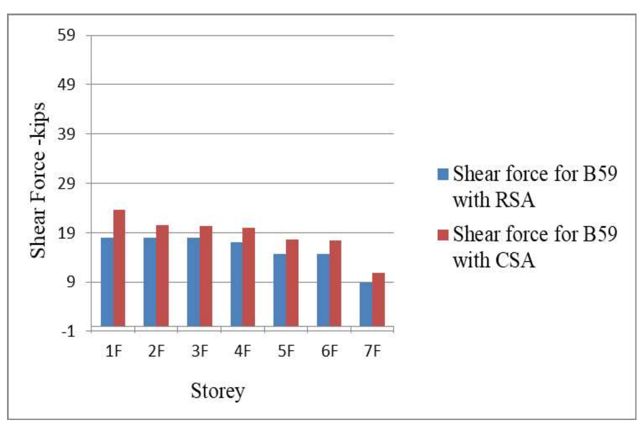


Figure 17. Shear Force for B59 with RSA & CSA

The shear force value obtained for B80 and B59 with CSA is increased by 46% and 32% than shear force with RSA respectively.

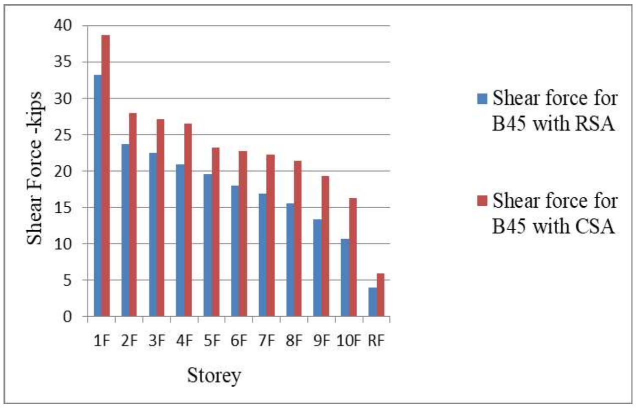


Figure 18. Shear Force for B45 with RSA & CSA

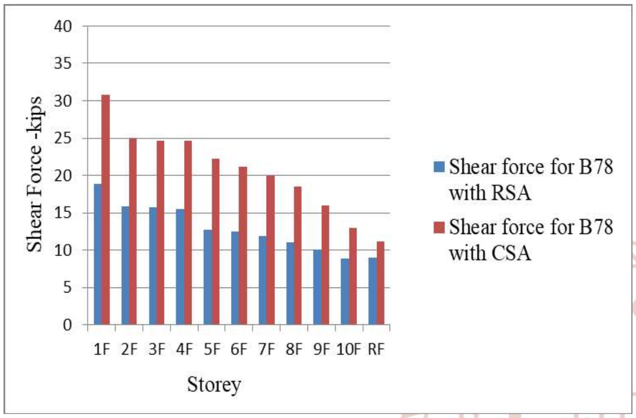


Figure 19. Shear Force for B78 with RSA & CSA

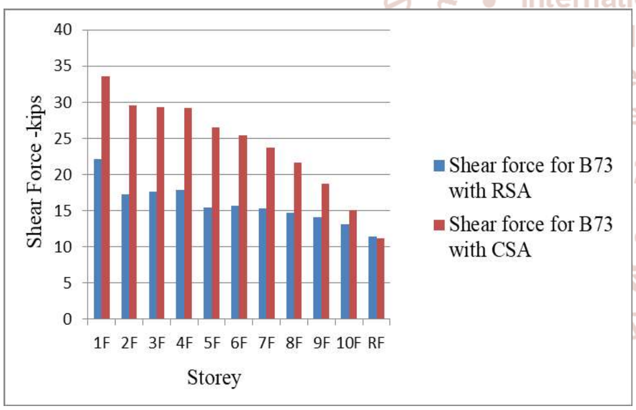


Figure 20. Shear Force for B73 with RSA & CSA

The shear force for B45 with CSA is increased by 16.2% than shear force with RSA. Shear force for B78 with CSA is increased by 64% than shear force with RSA. Shear force of B73 with CSA is increased by 52% than shear force with RSA. The difference values of shear forces in selected beams B78, B73, B80 due to RSA and CSA are nearly about 50% since these selected beams are located at setback in Y-direction. The maximum shear force is found at the first floor and minimum value is at the roof floor for selected beams. The shear forces for selected beams are significantly decreased at the level of discontinuity of the proposed building. The value of shear forces for all selected beams with CSA is larger than RSA.

D. *Comparison of Bending Moment in Beams*

To know the internal forces in selected beams due to RSA and CSA of setback steel structure are compared. The comparisons of bending moments in selected beams are shown in Figure 21 to Figure 25.

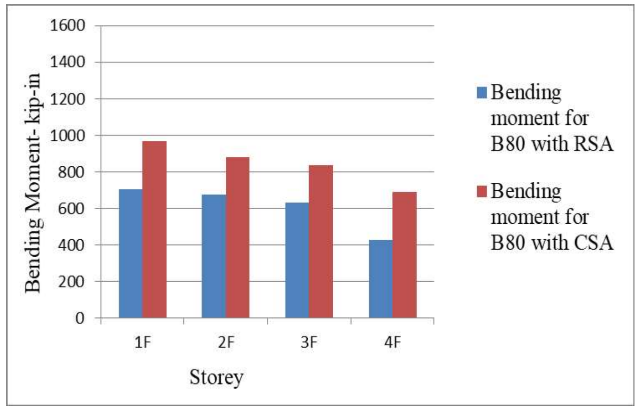


Figure 21. Bending Moment for B80 with RSA & CSA

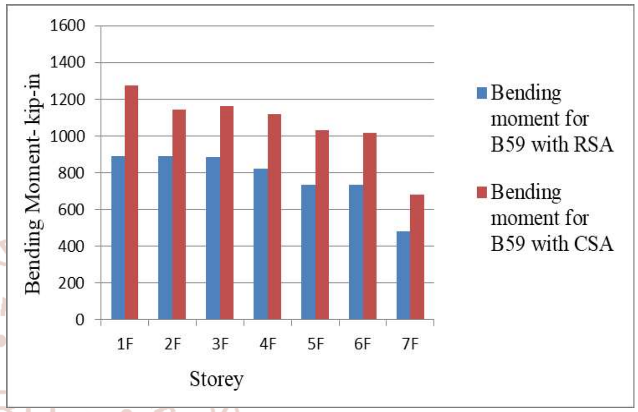


Figure 22. Bending Moment for B59 with RSA & CSA

The bending moment value obtained for B80 with CSA is increased by 37% than bending moment with RSA. Bending moment for B59 with CSA is increased in 43% of RSA.

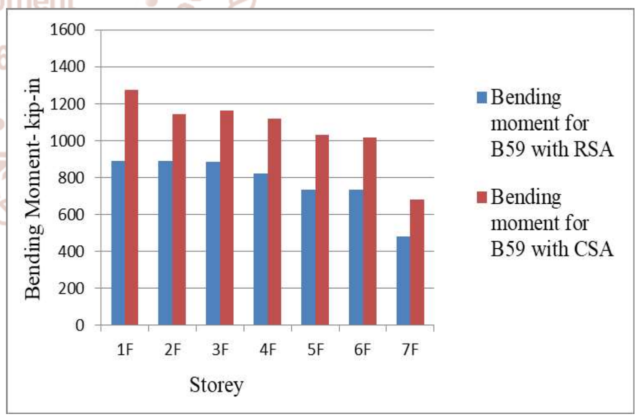


Figure 23. Bending Moment for B45 with RSA & CSA

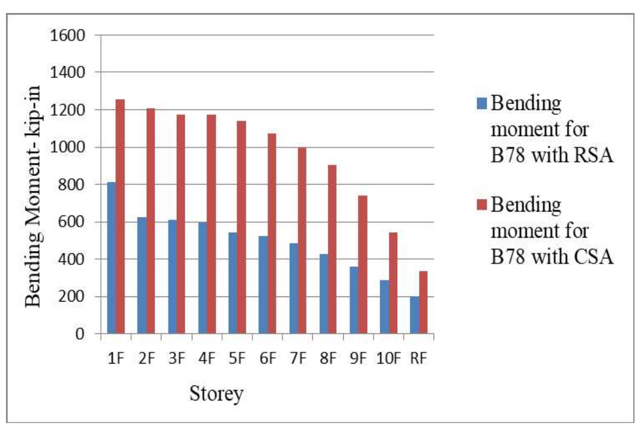
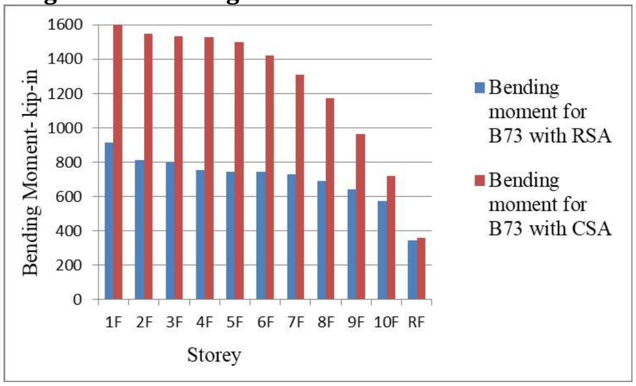


Figure 24. Bending Moment for B78 with RSA & CSA

Figure 25. Bending Moment for B73 with RSA & CSA



The result of bending moment for B45 with CSA is increased by 40% than bending moment with RSA. The bending moment values obtained for B78 with CSA is increased by 54% than bending moment with RSA. Selected beam B73 of the bending moment with CSA is nearly two times as large as RSA. The difference values of bending moments in selected beams B59, B78, B73 due to RSA and CSA are nearly about 50% . The bending moment values for all selected beams with CSA observe more than the bending moment values with RSA. The bending moment values both CSA and RSA are larger at the lower floor level and smaller at the upper floor.

V. CONCLUSIONS

The present study of the proposed building is eleven-storey setback steel structure. 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, CSA is considered with gravity loads plus lateral loads. The maximum storey displacement with CSA is increased by 56% than the displacement with RSA. The maximum axial forces values obtained for columns with CSA is increased by 48% than axial force with RSA. The maximum shear forces and bending moments with CSA are more than shear forces and bending moments with RSA. The shear force and bending moment for selected beams are significantly decreased at the level of discontinuity of the proposed building. Due to application of gradual load in CSA, loads are transferred to the lower storey. The lower floor is more sufferable than the upper floor. So, the maximum values of shear forces and bending moments of selected beams are observed at the first floor. Therefore, CSA is more effective than RSA on the setback steel structure. In this study, dead load and earthquake load control for the structural frame sections with CSA . Setbacks cause a sudden variation in earthquake forces of discontinuity . As a conclusion , CSA must consider not only multi-storey setback building but also location of building in seismic destructive zone.

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