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# Seismic Performance of Soft Storey using Carbon Strands and Steel Strands in a G+4 R.C Frame Building.

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***Abstract— Reinforced Concrete Frame Building are becoming increasingly common in urban India. Many such building constructed in recent times have a special feature - open ground storey for the purpose of parking. The presence of walls in upper stories makes building many times stiffer in the upper stories than in the open ground storey. During past earthquake several collapse had been observed due to soft storey effect. The strengthening of soft storey using shear walls and bracing is studied by many researchers. Alternative method to strengthen the soft storey by using carbon strands and steel strands has been studied. In the present study, the performance of carbon strands and steel strands is analysed by tying at first floor to ground with varying angle. The comparative study has been carried out using carbon strands and steel strands of a G+4 R.C Frame Building. The performance of building is assessed based on linear static and dynamic analysis using Etabs software.***

***Keywords— soft storey, carbon strands, steel strands, static analysis, response spectrum analysis, equivalent diagonal struts***

## I. INTRODUCTION

The multistorey building with an open ground storey parking is increasing in urban India. The soft storey effects reduce stiffness of the lateral load resisting system which leads to damage and collapse during earthquake. The damage experienced by many buildings during Bhuj Earthquake 2001 of magnitude 7.2 are due to soft storey effect in the building. Major collapse are observed even (approx.225km) away in the city of Ahmedabad, city alone has about 25,000 five storey building and about 1500 eleven storey buildings majority of them have open ground storey. The number of framed building collapsed in Ahmedabad was reported to be 60 and estimated death toll is placed at 750 among them Mansi Tower consist of four block out of it one block is totally collapsed and Shikhar tower consist of 10 storey H shaped resting on yellow soil, a part one of the four wing is collapsed totally. After the collapses of R.C frame buildings in Bhuj Earthquake the Indian Seismic Code 1893(Part-I) 2002 "Criteria for earthquake resistant design of structures" has included the special design provisions related to soft storey buildings.

## II. OBJECTIVES OF STUDY

The structure should have sufficient lateral strength, lateral stiffness and ductility to meet the requirements of safety during earthquake. Among the numerous structural system shear wall and bracing system is desired by the designers. Alternative method to remove soft storey effect by using carbon strands and steel strands also perform better during earthquake. Therefore this study has been undertaken to remove soft storey effect by strengthening the open ground storey in multi storey building using carbon strand and steel strands without affecting parking area which improve the lateral strength and aesthetic view of building.

## III. BUILDING MODELS STUDIED

*The plan layout of G+4 R.C frame building with open ground storey having dimension 19m x 16m and 19.5m height, chosen for this study is shown in fig. 1 and side elevation for different arrangement is shown in fig. 2. The building is symmetrical in plan having five bays in x-direction and four bays in y-direction.*

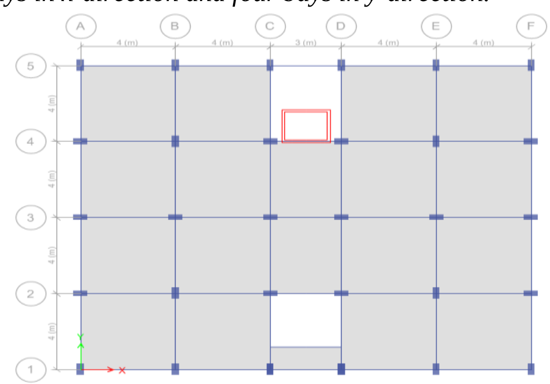

Fig. 1 Plan Layout of G+4 R.C frame Building

 

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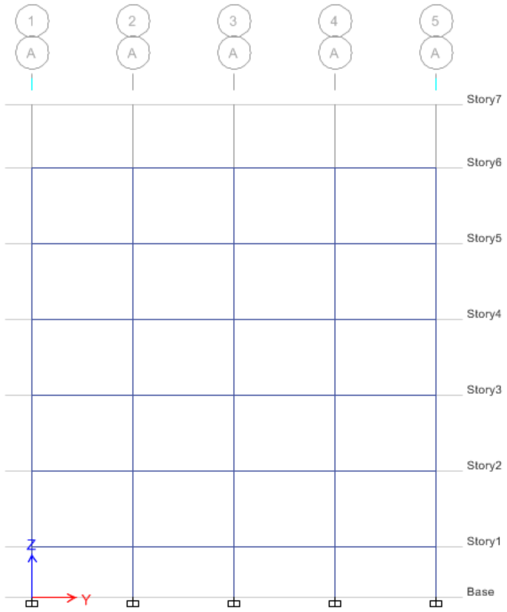
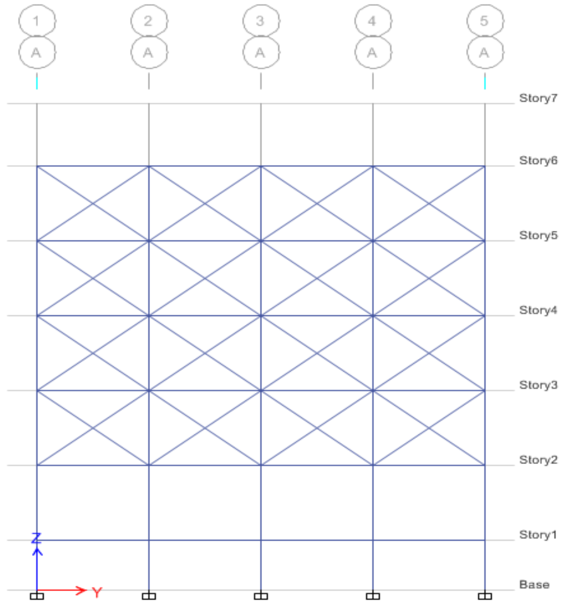
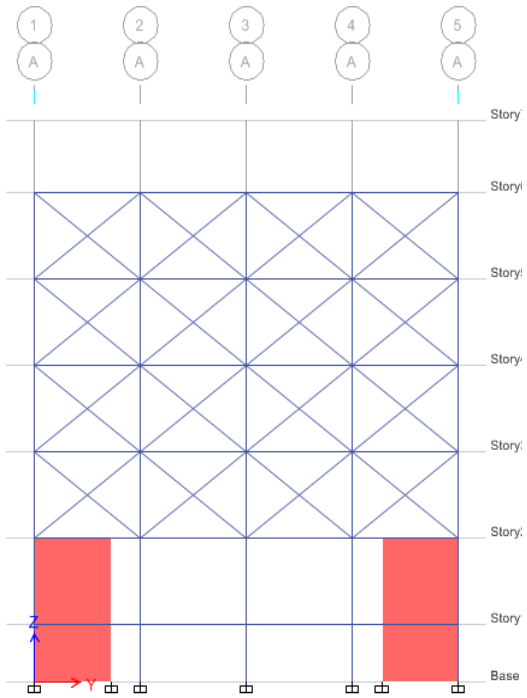


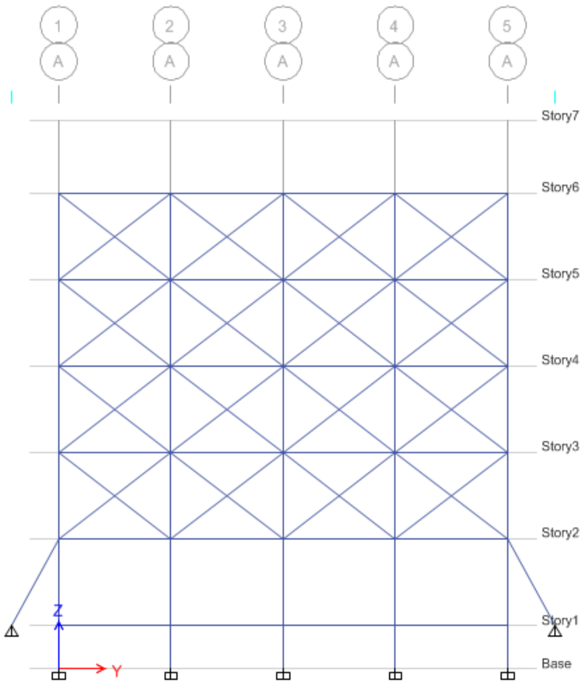

(a) Elevation of Bare Frame




(b) Open ground storey with infill in upper stories



(c) Open ground storey and infill in upper stories with shear walls




(d) Open ground storey and infill in upper stories with carbon & steel strands using an angle 30, 35° & 40°.

Fig. 2 Elevation of different building models arrangement

Nine different models of building are studied (fig 2). These are:

Model - I Bare frame model including masses of the infill walls.

Model - II Open ground storey with infill walls in upper stories.

Model - III Open ground storey with infill walls in upper stories and shear walls from foundation to ground storey.

Model - IV Open ground storey with infill walls in upper stories and carbon strands tied at ground floor using an angle 30°. Here the number of strand used are 08 each per external columns.

Model - V Open ground storey with infill walls in upper stories and carbon strands tied at ground floor using an angle 35°. Here the number of strand used are 06 each per external columns.

Model - VI Open ground storey with infill walls in upper stories and carbon strands tied at ground floor using an angle 40°. Here the number of strand used are 05 each per external columns.

Model - VII Open ground storey with infill walls in upper stories and steel strands tied at ground floor using an angle 30°. Here the number of strand used are 08 each per external columns.

Model - VIII Open ground storey with infill walls in upper stories and steel strands tied ground floor using an angle 35°. Here the number of strand used are 06 each per external columns.

Model - IX Open ground storey with infill walls in upper stories and steel strands tied at ground floor using an angle 40°. Here the number of strand used are 05 each per external columns.

TABLE I
DESCRIPTION OF THE MODEL

| Sr No | Items | Description |
|---|---|---|
| 1. | No of storey | G + 4 |
| 2. | Floor height | 3000mm |
| 3. | Plinth height | 2000mm |
| 4. | Stilt height | 3000mm |
| 5. | Shear wall thickness | 115mm |
| 6. | Infill external wall thickness | 230mm |
| 7. | Infill internal wall thickness | 115mm |
| 8. | Live Load on typical floor | 2 $kN/m^2$ |
| | Live Load on terrace | 1.5 $kN/m^2$ |
| 9. | Floor finish | 1.5 $kN/m^2$ |
| | Water proofing | 2 $kN/m^2$ |
| 10. | Dimension of lift | 1800mm x 1500mm |
| 11. | Size of column | 300mm x 600mm |
| 12 | Size of beam | 300mm x 450mm |
| 13. | Size of Door (opening) | 1000mm x 2100mm |
| 14. | Size of Window (opening) | 1000mm x 1000mm |
| 15. | Slab thickness | 115mm |
| 16. | Grade of concrete | M20 |
| 17. | Grade of steel | Fe 415 |
| 18. | Elastic Modulus of concrete | 22360.67 Mpa |
| 19. | Elastic Modulus of masonry | 5500 Mpa |
| 20. | Poison Ratio of concrete | 0.20 |
| 21. | Poison Ratio of masonry | 0.15 |
| 22. | Specific weight of concrete | 25 kN $/m^3$ |
| 23. | Specific weight of masonry | 20 kN/ $m^3$ |
| 24. | Type of soil | Medium |
| 25. | Zone | III |
| 26. | Response Spectrum | IS 1893 – 2002 |
| 27 | Carbon strands | Description (As per Tokyo Rope Ltd Japan) |
| | Diameter | 40mm |
| | Tensile Strength | 2690 Mpa |
| | Elastic Modulus | 155 GPa |
| | Poisson ratio | 0.23 |
| | Specific Gravity | 1.5 $g/cm^3$ |
| | Coefficient of linear expansion | 0.6 x $10^{-6}$ / °C |
| 28 | Steel strands | Description (As per Usha Martin Ltd Kolkata) |
| | Diameter | 40mm |
| | Tensile Strength | 1770 Mpa |
| | Elastic Modulus | 195GPa |
| | Poisson ratio | 0.30 |
| | Specific Gravity | 7.8 $g/cm^3$ |
| | Coefficient of linear expansion | 12 x $10^{-6}$ / °C |
| 29 | Width of Equivalent Diagonal struts | (thickness x depth) |
| | External walls (X direction) | 230mm x 454.29mm |
| | External walls (Y direction) | 230mm x 395.48mm |
| | Internal walls (X direction) | 115mm x 345.98mm |
| | Internal walls (Y direction) | 115mm x 301.19mm |

## IV. ANALYSIS OF THE BUILDING

Seismic analysis is a major tool in earthquake engineering which is used to understand the response of building in a simple way. It is a part of structural analysis and design where earthquake is predominant. The analysis process can be classified on the basis of three factors: the external action, behaviour of structure or material and type of structural model selected. The seismic method of analysis based on Indian standard 1893 (Part-1) code "Criteria for Earthquake Resistant Design of Structures".

### *A. Static Analysis*

Static analysis is used for regular structures with limited height. The base shear which is the total horizontal force on the structure is calculated on the base of structure mass and natural fundamental period and mode shape. The base shear is distributed along the height of structure in terms of lateral forces.

### *B. Response Spectrum Analysis*

This method permits the multiple modes of response of a building. This method is applicable for a structure symmetrical and asymmetrical or irregularity in their linear range behaviour. Software analysis can be used to determine multi modes for a structure. For each mode, a response is obtained from the design spectrum, corresponding to the modal frequency and modal mass and can be combined to estimate the total response.

## V. RESULTS AND DISCUSSIONS

The displacement from the static analysis method are consistently larger by about 13% than those from dynamic analysis method.

**Storey Stiffness**

The storey stiffness of ground and first floor are shown in Table II.

TABLE II

STOREY STIFFNESS OF GROUND AND FIRST STOREY FOR DIFFERENT MODELS

| **1.** | **Storey Stiffness (kN/mm) @ Ground & First Floor** | | | | |
|---|---|---|---|---|---|
| **Sr.No** | **Building Model** | **Y Direction** | | **X Direction** | |
| | | **Ground** | **First** | **Ground** | **First** |
| 1 | Bare Frame including Mass of Infill | 540.83 | 488.84 | 577.77 | 523.26 |
| 2 | Open Ground Storey + Infill in Upper Stories | 732.08 | 1376.90 | 787.87 | 1303.99 |
| 3 | Open Ground Storey + Infill + Shear Wall | 2270.43 | 2204.57 | 2188.51 | 2124.48 |
| 4 | Open Ground Storey + Infill + Carbon Strands at $30^0$ @ Ground Floor | 2309.1 | 2353.65 | 2225.51 | 2265.31 |
| 5 | Open Ground Storey + Infill + Carbon Strands at $35^0$ @ Ground Floor | 2397.55 | 2323.53 | 2294.78 | 2285.80 |
| 6 | Open Ground Storey + Infill + Carbon Strands at $40^0$ @ Ground Floor | 2332.36 | 2323.71 | 2203.79 | 2221.30 |
| 7 | Open Ground Storey + Infill + Steel Strands at $30^0$ @ Ground Floor | 2385.77 | 2395.87 | 2208.91 | 2269.81 |
| 8 | Open Ground Storey + Infill + Steel Strands at $35^0$ @ Ground Floor | 2377.05 | 2376.36 | 2262.56 | 2275.34 |
| 9 | Open Ground Storey + Infill + Steel Strands at $40^0$ @ Ground Floor | 2315.79 | 2335.93 | 2257.82 | 2252.68 |

The stiffness irregularity in ground storey building models with bare frame is about 10% more that of first storey. And for Open ground storey with infill walls in upper stories is about 50% of that of first storey. The use of shear wall in Model-III and carbon & steel strands with different angles for Model IV V, VI, VII, VIII and IX in ground storey reduces the stiffness irregularity.

**Natural Periods**

As per IS – 1893 2002 and Etabs natural periods of building models are shown in Table III. It seen that software results do not tally with empirical formula as per code. The bare frame and Open ground storey with infill walls in upper stories has over estimation of natural period compared to other models. For shear walls and carbon & steel strands values are closure to each other.

TABLE III
NATURAL PERIOD OF DIFFERENT MODELS

| 2. | Fundamental Natural Period (sec) | | | | |
|---|---|---|---|---|---|
| Sr.No | Building Model | Transverse | | Longitudinal | |
| | | Code | Software | Code | Software |
| 1 | Bare Frame including Mass of Infill | 0.695 | 0.799 | 0.695 | 0.732 |
| 2 | Open Ground Storey + Infill in Upper Stories | 0.438 | 0.401 | 0.402 | 0.46 |
| 3 | Open Ground Storey + Infill + Shear Wall | 0.438 | 0.287 | 0.402 | 0.306 |
| 4 | Open Ground Storey + Infill + Carbon Strands at $30^0$ @ Ground Floor | 0.438 | 0.278 | 0.402 | 0.305 |
| 5 | Open Ground Storey + Infill + Carbon Strands at $35^0$ @ Ground Floor | 0.438 | 0.28 | 0.402 | 0.303 |
| 6 | Open Ground Storey + Infill + Carbon Strands at $40^0$ @ Ground Floor | 0.438 | 0.28 | 0.402 | 0.307 |
| 7 | Open Ground Storey + Infill + Steel Strands at $30^0$ @ Ground Floor | 0.438 | 0.273 | 0.402 | 0.301 |
| 8 | Open Ground Storey + Infill + Steel Strands at $35^0$ @ Ground Floor | 0.438 | 0.275 | 0.402 | 0.301 |
| 9 | Open Ground Storey + Infill + Steel Strands at $40^0$ @ Ground Floor | 0.438 | 0.278 | 0.402 | 0.300 |

**Maximum Storey Displacements**

The lateral displacement of various models for two different analysis performed in this study are shown in Table IV.

The ground storey lateral displacement in building models for bare frame and Open ground storey with infill walls in upper stories is very severe. By the use of shear wall in Model –III and carbon & steel strands in Model – IV V, VI, VII,VIII and IX, displacement drastically reduce is about 25%

TABLE IV
MAXIMUM STOREY DISPLACEMENT OF DIFFERENT MODELS

| 3. | Maximum Storey Displacement (mm) @ Ground Floor | | | | |
|---|---|---|---|---|---|
| Sr.No | Building Model | Static Analysis @ Ground Floor | | Dynamic Analysis @ Ground Floor | |
| | | Y Direction | X Direction | Y Direction | X Direction |
| 1 | Bare Frame including Mass of Infill | 2.433 | 2.572 | 1.809 | 2.262 |
| 2 | Open Ground Storey + Infill in Upper Stories | 1.443 | 1.681 | 1.658 | 1.597 |
| 3 | Open Ground Storey + Infill + Shear Wall | 0.429 | 0.498 | 0.334 | 0.426 |
| 4 | Open Ground Storey + Infill + Carbon Strands at $30^0$ @ Ground Floor | 0.457 | 0.535 | 0.350 | 0.537 |
| 5 | Open Ground Storey + Infill + Carbon Strands at $35^0$ @ Ground Floor | 0.446 | 0.511 | 0.332 | 0.509 |
| 6 | Open Ground Storey + Infill + Carbon Strands at $40^0$ @ Ground Floor | 0.430 | 0.532 | 0.341 | 0.528 |
| 7 | Open Ground Storey + Infill + Steel Strands at $30^0$ @ Ground Floor | 0.436 | 0.498 | 0.487 | 0.484 |
| 8 | Open Ground Storey + Infill + Steel Strands at $35^0$ @ Ground Floor | 0.417 | 0.495 | 0.480 | 0.478 |
| 9 | Open Ground Storey + Infill + Steel Strands at $40^0$ @ Ground Floor | 0.433 | 0.485 | 0.472 | 0.469 |

**Maximum Storey Drift**

The storey drift of various models for two different analysis performed in this study are shown in fig 3

The ground storey drift in building models for bare frame and Open ground storey with infill walls in upper stories is very severe. By the use of shear wall in Model –III and carbon & steel strands in Model –IV V, VI, VII,VIII and IX drift is drastically reduced is about 30%

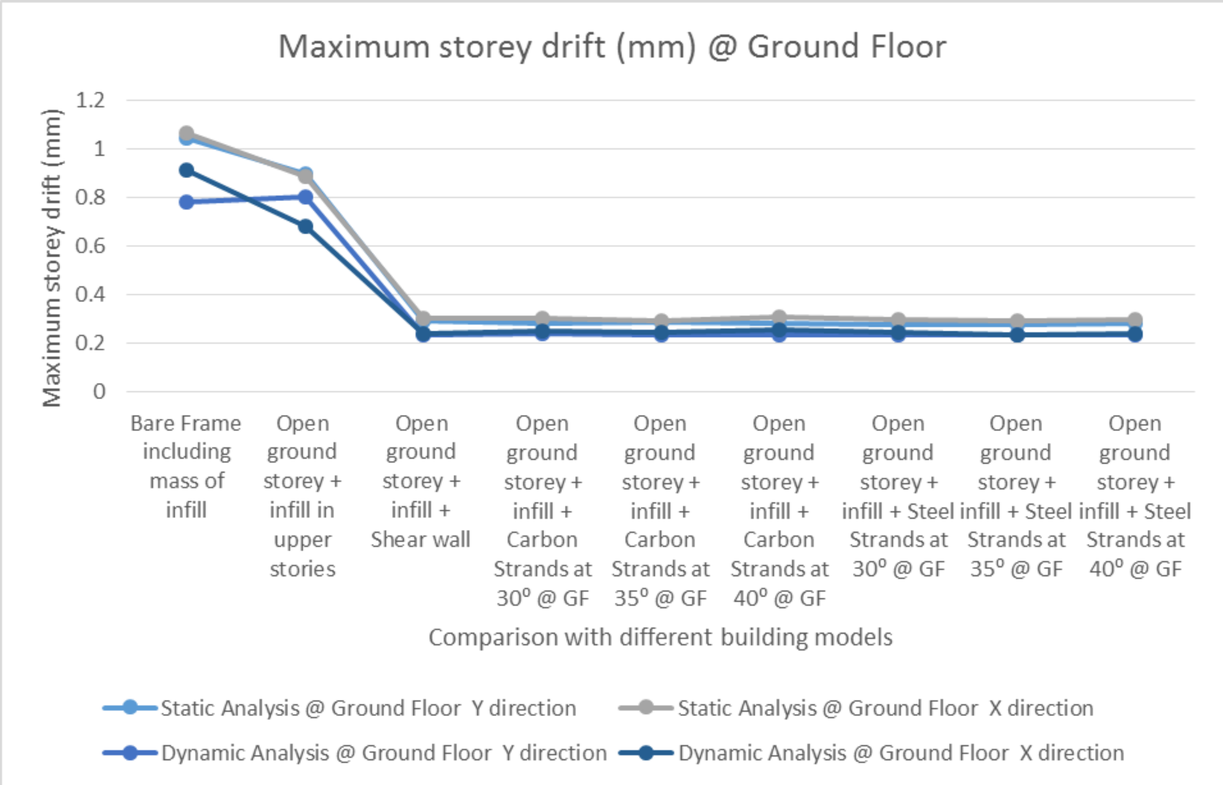



Fig 3 Maximum storey drift

**Maximum Moment**

Maximum moment for corner columns for ground storey are shown in Table V.

The bending moments are severely higher in bare frame and Open ground storey with infill walls in upper stories which is 31% than in other models. The use of shear walls and carbon & steel strands reduce the moments in corner columns.

TABLE V
MAXIMUM MOMENTS FOR CORNER COLUMNS FOR GROUND FLOOR

| 5. | Maximum Moment for Corner Columns (KNm) @ Ground Floor | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sr.No | Building Model | Column C1 | | Column C6 | | Column C7 | | Column C12 | |
| | | Y Direction | X Direction | Y Direction | X Direction | Y Direction | X Direction | Y Direction | X Direction |
| 1 | Bare Frame including mass of infill | 51.31 | 31.39 | 53.07 | 25.02 | 41.71 | 23.58 | 42.9 | 22.07 |
| 2 | Open ground storey + infill in upper stories | 31.27 | 19.97 | 32.34 | 17.61 | 35.7 | 20.006 | 34.78 | 19.39 |
| 3 | Open ground storey + infill + Shear wall | 7.981 | 2.737 | 8.007 | 2.92 | 8.51 | 2.83 | 8.617 | 3.33 |
| 4 | Open ground storey + infill + Carbon Strands at 30° @ GF | 9.707 | 7.78 | 10.87 | 6.174 | 8.41 | 7.064 | 8.007 | 7.078 |
| 5 | Open ground storey + infill + Carbon Strands at 35° @ GF | 10.13 | 8.02 | 10.47 | 6.866 | 8.9 | 7.406 | 8.981 | 7.59 |
| 6 | Open ground storey + infill + Carbon Strands at 40° @ GF | 9.82 | 8.59 | 10.36 | 7.13 | 9.73 | 7.93 | 9.12 | 8.01 |
| 7 | Open ground storey + infill + Steel Strands at 30° @ GF | 11.28 | 8.077 | 12.8 | 6.345 | 7.86 | 7.63 | 7.557 | 7.141 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | Open ground storey + infill + Steel Strands at 35° @ GF | 11.48 | 8.27 | 12.1 | 6.59 | 9.48 | 7.811 | 8.28 | 7.439 |
| 9 | Open ground storey + infill + Steel Strands at 40° @ GF | 11.311 | 8.96 | 12.43 | 7.59 | 9.8 | 8.51 | 9.061 | 8.28 |

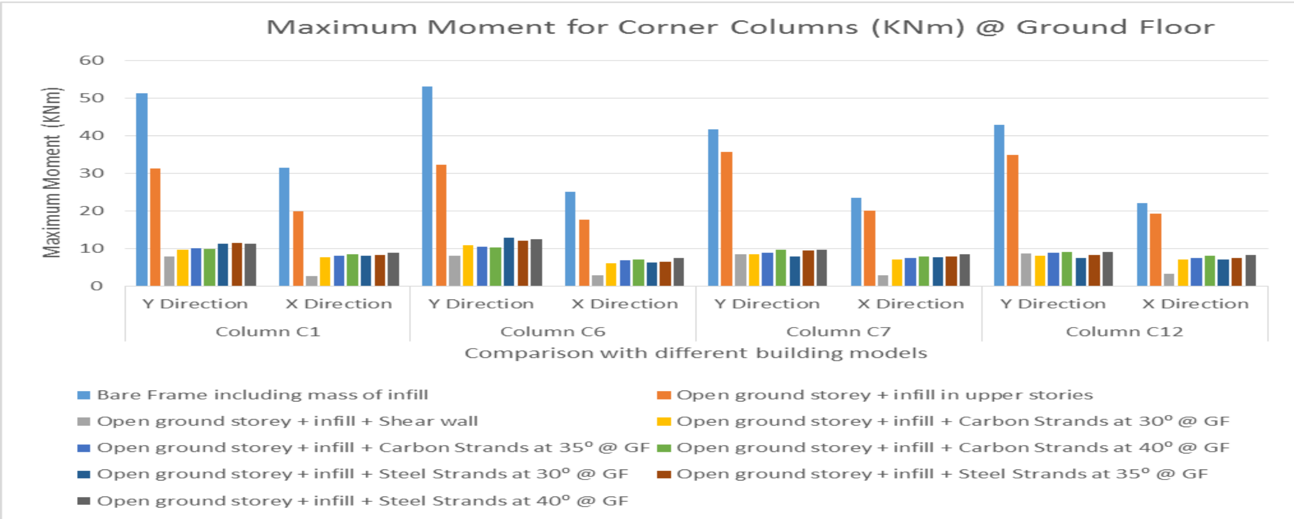



Fig 4 Maximum Moment for corner columns

**Maximum Shear Force**

Maximum shear force for corner columns for ground storey are shown in Table VI.

The shear forces are severely higher in bare frame and Open ground storey with infill walls in upper stories which is 42% than in other models. The use of shear walls and carbon & steel strands reduce the shear forces in corner columns.

TABLE VII

MAXIMUM SHEAR FORCES FOR CORNER COLUMNS FOR GROUND FLOOR

| **6.** | **Maximum Shear Forces for Corner Columns (KN) @ Ground Floor** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sr.No** | **Building Model** | **Column C1** | | **Column C6** | | **Column C7** | | **Column C12** | |
| | | **Y Direction** | **X Direction** | **Y Direction** | **X Direction** | **Y Direction** | **X Direction** | **Y Direction** | **X Direction** |
| 1 | Bare Frame including mass of infill | 22.12 | 32.6 | 11.36 | 33.68 | 17.93 | 20.2 | 7.27 | 20.96 |
| 2 | Open ground storey + infill in upper stories | 14.74 | 24.48 | 9.08 | 25.36 | 15.46 | 18.14 | 9.68 | 18.69 |
| 3 | Open ground storey + infill + Shear wall | 1.36 | 3.99 | 1.829 | 4.003 | 1.38 | 5.37 | 2.149 | 5.46 |
| 4 | Open ground storey + infill + Carbon Strands at 30° @ GF | 5.36 | 7.93 | 1.466 | 8.631 | 5.29 | 1.34 | 1.251 | 2.106 |
| 5 | Open ground storey + infill + Carbon Strands at 35° @ GF | 5.88 | 8.4 | 0.911 | 8.38 | 5.72 | 1.34 | 0.803 | 1.33 |
| 6 | Open ground storey + infill + Carbon Strands at 40° @ GF | 6.3 | 8.05 | 1.13 | 8.32 | 6.171 | 1.017 | 0.925 | 0.939 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7 | Open ground storey + infill + Steel Strands at 30⁰ @ GF | 5.45 | 8.75 | 1.85 | 9.69 | 5.561 | 2.241 | 1.73 | 3.219 |
| 8 | Open ground storey + infill + Steel Strands at 35⁰ @ GF | 5.98 | 9.28 | 1.25 | 9.25 | 5.8 | 1.8 | 0.87 | 2.05 |
| 9 | Open ground storey + infill + Steel Strands at 40⁰ @ GF | 6.48 | 8.75 | 1.26 | 9.42 | 6.447 | 1.835 | 1.23 | 2.303 |

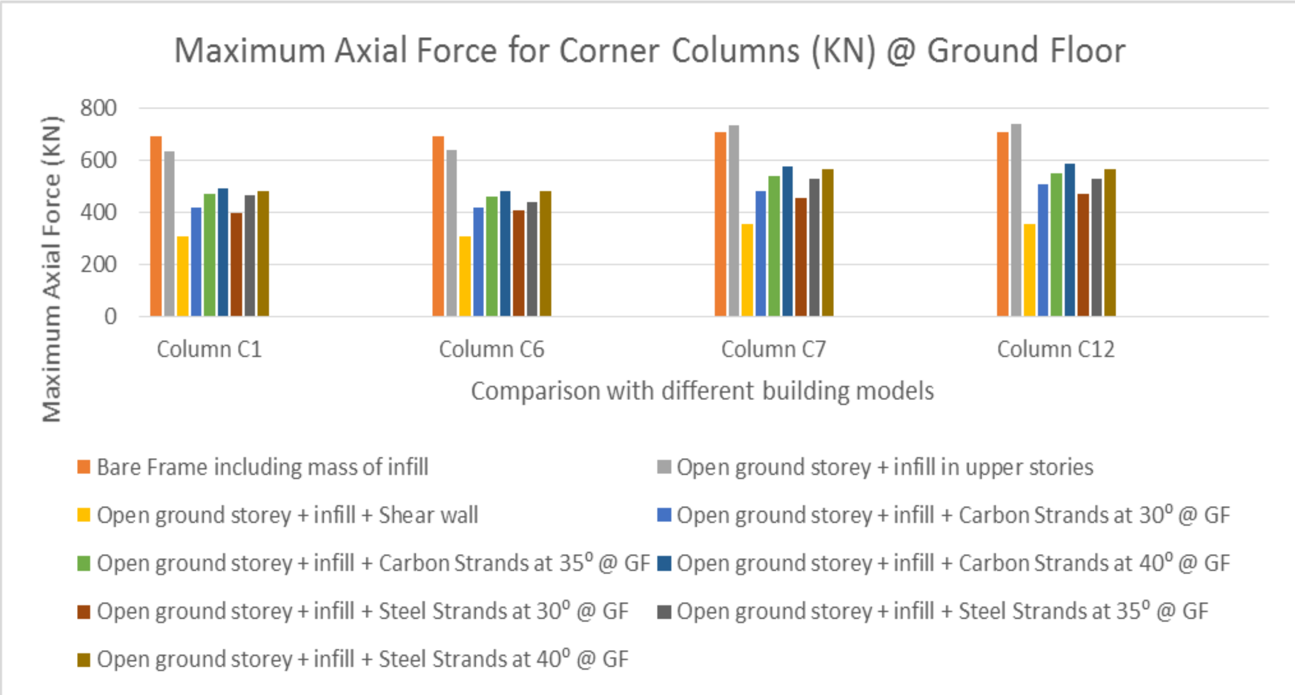



Fig 5 Maximum Shear Force for corner columns

**Maximum Axial Force**

Maximum axial forces for corner columns in ground storey are shown in fig. 6.The axial forces are severely higher in bare frame and Open ground storey with infill walls in upper stories which is 23% than in other models. The use of shear walls and carbon & steel strands reduce the axial forces in columns.

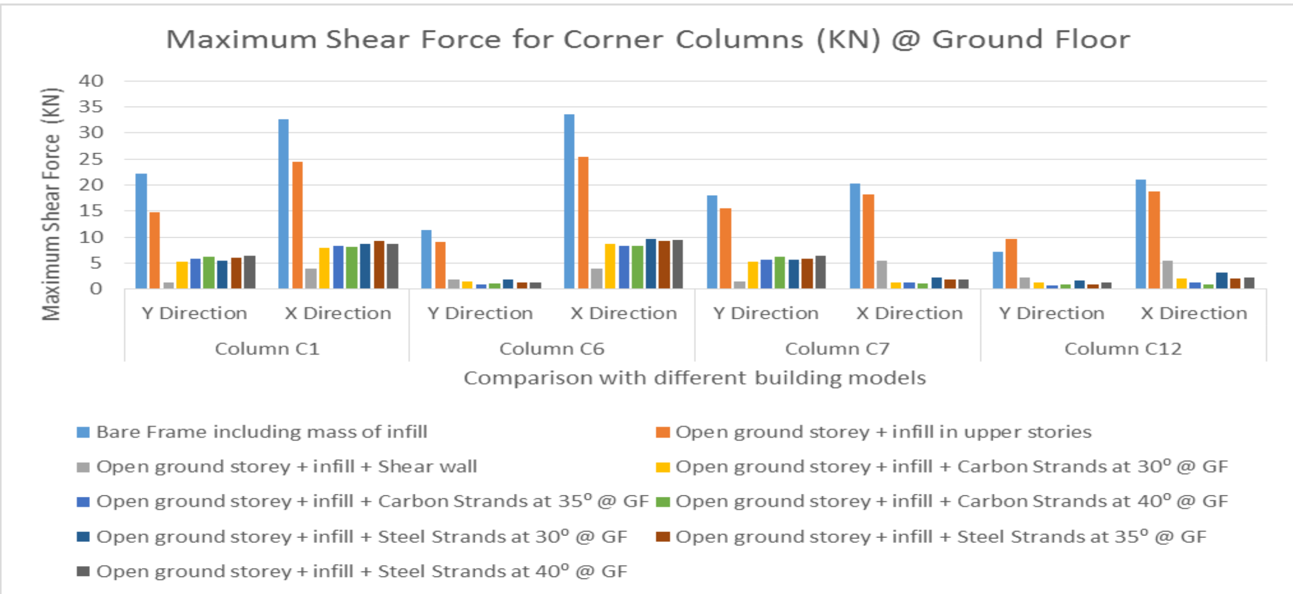



Fig 6 Maximum Axial Force for corner columns

**Maximum Torsion**

Maximum torsion for corner columns in ground storey are shown in fig. 7.The torsion values are severely higher in bare frame and Open ground storey with infill walls in upper stories which is 19% than in other models. The use of shear walls and carbon & steel strands reduce the torsion in columns.

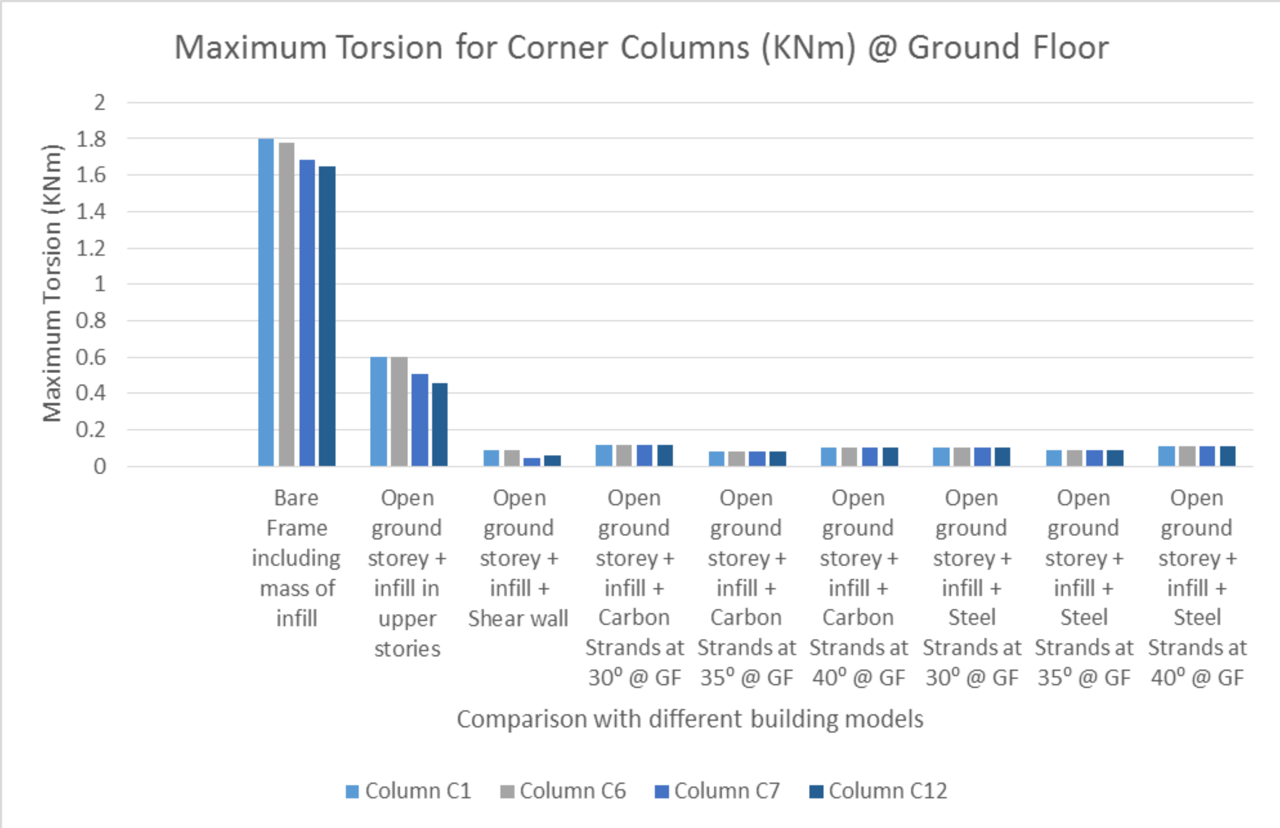



Fig 7 Maximum Torsion for corner columns

## VI. Conclusions

Soft storey effect in RC frame building is very vulnerable during earthquake. The Lateral displacement, Storey drift & Time period are higher for open ground storey. Necessity of open ground storey in urban society cannot be avoidable. Thus Alternative measures adopted to increase the strength of storey by provision of carbon & steel strands. Here base shear is slightly decreased by 2% using strands than shear walls. Maximum Moment for corner columns are higher in steel strands is about 12% than carbon strands & shear forces for steel strands is about 3% higher than carbon strands. Thus during earthquake, the seismic performance of carbon strands is more effective.

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