International Journal of the Physical Sciences Vol. 6(17), pp. 4294-4301, 2 September, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.642
ISSN 1992 -1950 ©2011 Academic Journals

Full Length Research Paper

Effect of non sway and sway methods for analysis and design of reinforced concrete frames for multi-storey building

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Accepted 24 June, 2011

This paper investigates the numerical modelling analysis and design of non-sway and sway method for multi-storey reinforced concrete frames. Multi-storey buildings having a height of 57.7 and 23.5 m consisting of 15 storeys' and 6 storeys, respectively have been analysed for non-sway and sway condition by using software STAAD. Pro V8i. Column sizes have been changed in every three storeys interval and beam sizes kept constant for the convenience of making the analysis more economical and practical. Reinforced concrete building frames analyses have shown how the reinforcement of the beams and columns has changed with the effect of wind loading. According to the analysis of that reinforced concrete members, it can be seen that the reinforcement of the beams and columns have been increased significantly in sway frame compare to the non-sway frame. However, two multi-storey reinforced concrete building frames (one tall and another one short) analysis also indicated how the beam and column design is affected by the height of the building. This paper also highlighted the response of reinforced concrete multi-storey building frames that can be predicted effectively with the software analysis.

Key words: Non-sway, sway, reinforced concrete, building frames, beam, column, multi-storey, STAAD. Pro V8i.

INTRODUCTION

From as long as 7000 BC, concrete rises to the position of most widely used construction material by playing a major part in the shaping of civilisation. The foundations of the Colosseum, Rome AD82 which is the largest and most important amphitheatre in Rome were made of dense concrete and some of the arches and vaults had been made by light weight concrete as well. Concrete is such type of building material which is composed of cement, crushed rock or gravel, often with chemical admixtures and other materials and that was known to the earlier Neolithic civilisations, the Romans and the Egyptians' After the crumple of the Roman Empire, the secrets of concrete were almost lost. Indeed the modern development of concrete does not long for no more than 175 years. In 1824, the patent for the manufacture of the first Portland cement was placed which creates the most important milestones in concrete's history.

Concrete is one of the most versatile, durable and cost-effective building materials known to people. It has a vast role to play both in the construction industry for the improvement of our civil engineering work and infrastructure technology. It's great strength, durability and flexibility are the main properties normally utilised in the construction of buildings, roads, bridges, airports, railways, tunnels, ports and harbours and many other major infrastructure projects. Concrete is the material which provides the best fire resistance than any other

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building materials. When the concrete exposed to fire, it does not burn, cannot be 'set on fire' like other materials in a building and it does not emit any toxic fumes, smoke or drip molten particles. Concrete is making an intensive, synchronized effort to further reduce its environmental impact which includes the emergent use of recycled concrete in cement and concrete manufacture.

Having good durability quality, good strength in compression, casting in any shape according to architectural/structural requirement and also cost-effectiveness are some other major reasons for using concrete in the construction industry so much (The Concrete Centre, 2009). According to Wong et al. (2007), the modification of Muto's method has been approached for unbraced composite frames with semi-rigid beam-to-column connections in multi-storey frames for sway and non-sway conditions. Wang (1997) stated beneficial and detrimental effects of structural continuity for non-sway multi-storey frames on fire resistant design of steel columns. Li (2004) obtained some selected results from the full scale measurements of dynamic behaviour of a 63-storey reinforced concrete tall building. Ates (2000) approached a new design method to withstand the earthquake forces by designing earthquake resisting structures. Erdal (2009) has investigated a significant improvement of ductility and strength of unreinforced masonry walls by using fiber reinforced polymer (FRP) strips for low rise structures

In this paper, the numerical modelling analysis of the reinforced concrete multi-storied building frames for non-sway and sway method using Staad. Pro V8i software is investigated. Using the software, the 15 and 6 storey's building have been designed at the condition of without sway and with sway and the analysis results are compared for beams and columns. According to the result, it can be seen that amount of reinforcement has increased for the sway effect which implies that the cost of construction will be increased in sway method and vice versa for non sway condition.

METHODOLOGY

In reinforced concrete construction, effect of wind in the multi-storey building has played an important role. Sometimes, it may happen to change the mind to allow or not to allow wind loading in the structure (Hasan et al., 2011).

In non-sway buildings, wind loading may be resisted by shear walls, service cores, housing lifts services and stair cases in the building.

In sway buildings, wind loading will be resisted by the beams and the columns of the building which have to be designed considering the wind loading (Allen, 1988; Mosley and Bungey, 1990).

The main aim of this study is to analyse and design two multi-storey buildings in concrete (one tall and one short) both for non sway and sway condition and compare the results. Two multi-storey buildings have been designed by the software STAAD Pro V8i for the effect of sway and non sway. Design results have shown in a tabular format for these two conditions which is also compared with non sway and sway effect and with the effect of height of the two buildings.

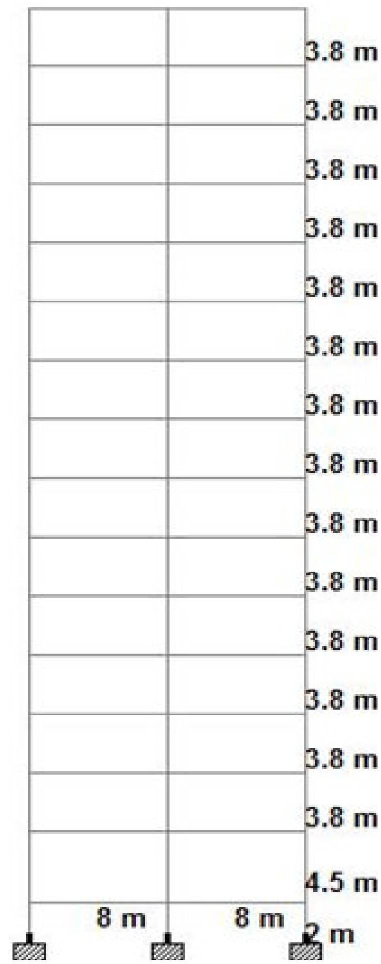

Figure 1. Sectional elevation (A-A) of the 15 storey building.

Figure 1, 2, 3 and 4 shows plan and sectional elevation of the 15 and 6 storey's building, respectively. Figure 5 and 6 shows the three dimensional rendered view of the 6 and 15 storey building subsequently.

ANALYSES AND DISCUSSION OF RESULTS

For 15 storey building frames

According to Table 1, it can be seen that middle column of middle frame without sway and with sway have the same amount of reinforcement in each floor. This is because, large amount of axial load from load combination 1.4 Dead Load + 1.6 Imposed Load is governing rather than the load combination 1.2 Dead Load + 1.2 Imposed Load + 1.2 Wind Load (British Standards Institution, 2002; Concrete Design (BS 8110-1: 1997); Wind Loads (BS 6399-2: 1997) and Weights of Building Materials).

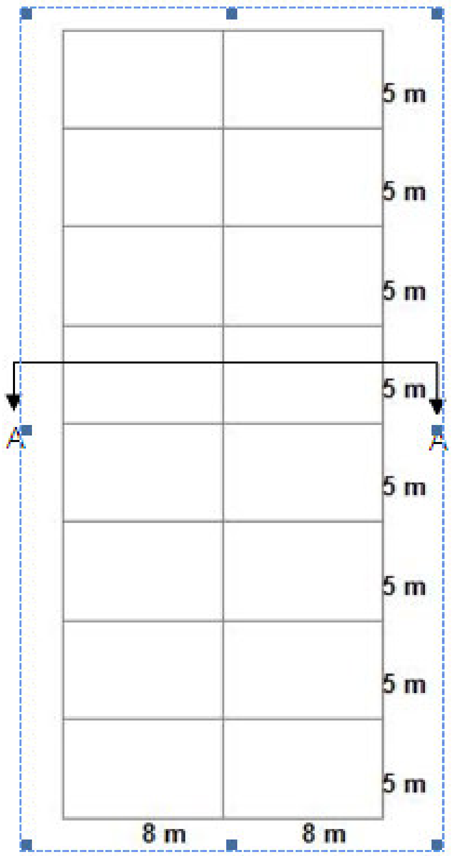

Figure 2. Plan view of the 15 storey building.

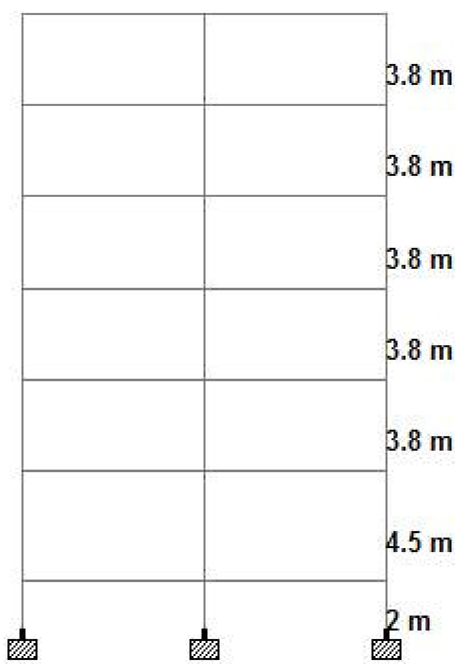

Figure 3. Sectional elevation (A-A) of the 6 storey building.

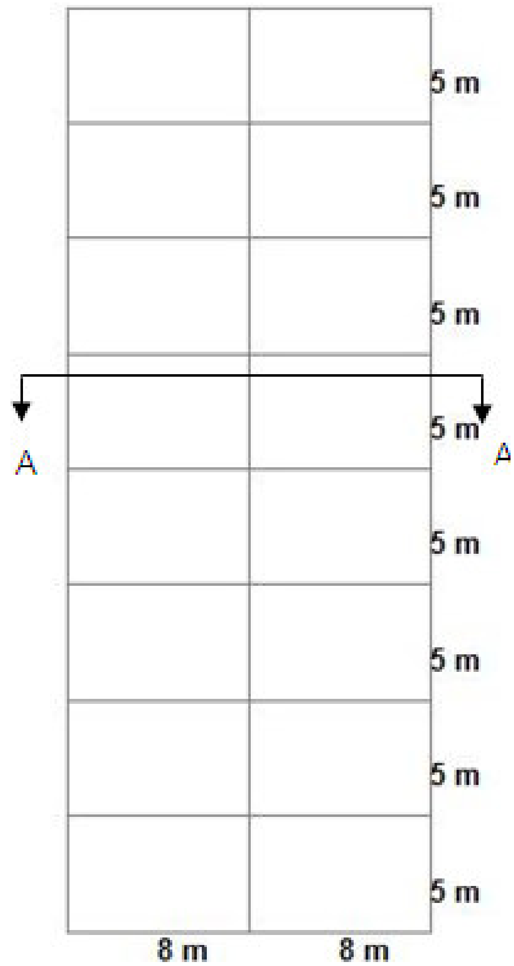

Figure 4. Plan view of the 6 storey building.

From Table 2, it can be seen that the reinforcement in the side column of middle frame has increased to 18 T 20 (5050 mm^2) in sway frame from 18 T 16 (3580 mm^2) at ground floor because of the governing load combination which includes wind load. And for all other side columns, though area of reinforcement has slightly (approximately 3%) increased, same size of bar are used.

From Table 3, it can be found that the bottom reinforcement at middle of the beam is almost the same in sway and non-sway cases but extra amount of reinforcement has provided in the left and right hand side bottom of the beam for sway cases except 9th and 12th floor. This happened so to develop the necessary moment of resistance because the moment has increased significantly (approximately 50 to 60%) due to wind loading. And in 9th and 12th floor, the amount of reinforcement (approximately 20%) has also increased for wind loading in sway cases.

According to Table 4, it can be seen that middle column of side frame without sway and with sway have the same amount of reinforcement in each floor. This is because,

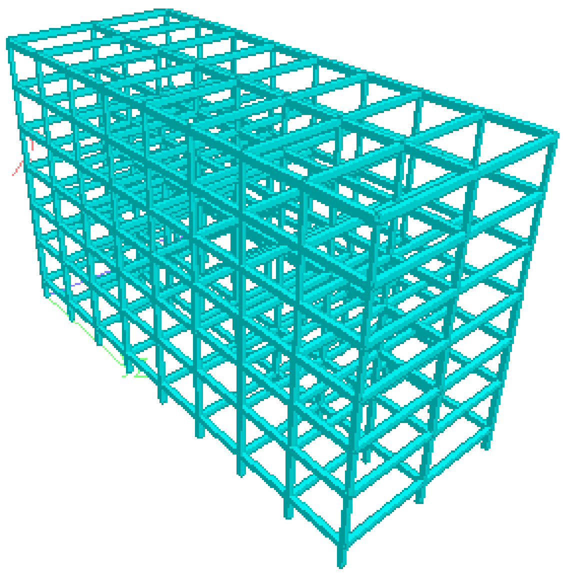

Figure 5. Three dimensional rendered view of the 6 storey building.

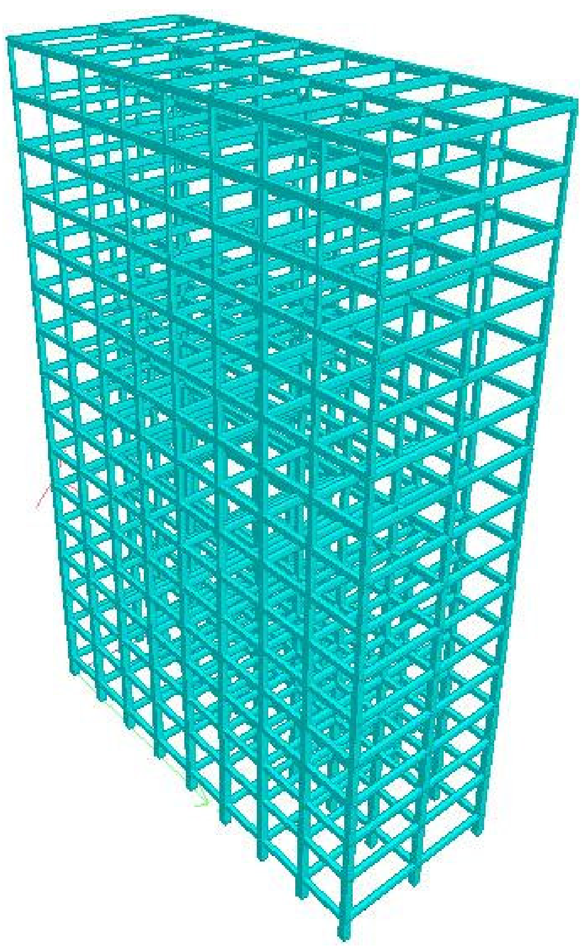

Figure 6. Three dimensional rendered view of the 15 storey building.

large amount of axial load by load combination 1.4 Dead Load + 1.6 Imposed Load is governing rather than the load combination 1.2 Dead Load + 1.2 Imposed Load + 1.2 Wind Load.

From Table 5, it can be observed that reinforcement has increased (approximately 33 to 83%) for all the side column of the side frame because of the governing wind load combination.

From Table 6, it can be found that the bottom reinforcement at middle of beam is almost the same in sway and non-sway cases but extra amount of reinforcement is needed in the left and right hand side bottom of the beam for sway cases. This is happened so to develop the necessary moment of resistance because the moment has increased significantly (approximately 20 to 50%) due to wind loading.

For 6 storey building frames

According to Tables 7 and 10, it can be found that in middle column of middle and side frame for sway and non-sway cases, the amount of reinforcement is same in each floor. This is because large amount of axial load by load combination 1.4 Dead Load + 1.6 Imposed Load is governing rather than the load combination 1.2 Dead Load + 1.2 Imposed Load + 1.2 Wind Load. And from Table 8, it can be observed that the amount of reinforcement has increased (approximately 4%) in sway cases for side column of middle frame because of wind loading.

According to Table 9, it can be observed that bottom reinforcement at middle of the beam and top reinforcement at right hand side of the beam are almost the same in sway and non-sway cases. But at ground floor, approximately 20% more top reinforcement is needed at right hand side of the beam in sway frame due to wind loading. And at 3rd floor, approximately 27% more top reinforcement is needed at right hand side of the beam and also extra amount of reinforcement (5T20) has been provided at right hand side bottom of the beam for sway cases due to wind loading.

From Table 11, it can be seen that the amount of reinforcement has increased significantly (approximately 100%) and slightly (approximately 4%) for ground floor and 3rd floor respectively due to wind loading.

From Table 12, it can be found that bottom reinforcement at middle of the beam is almost the same in both sway and non-sway condition. But at ground floor, approximately 52 and 25% more top reinforcement is needed at left and right hand side of the beam respectively in sway frame due to wind loading. At 3rd floor, approximately 25% more top reinforcement is needed at left hand side of the beam and also extra amount of reinforcement (5T16) has provided at left hand side bottom of the beam for sway cases due to wind loading.

Table 1. Comparison of middle column without sway and with sway for middle frame.

Floor	Column Size (Square) (m^2)	Middle column without sway			Middle column with sway		
		$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size	$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size
Ground floor	0.58	11931	12566	10 T 40	11931	12566	10 T 40
3rd Floor	0.51	9908	10053	8 T 40	9908	10053	8 T 40
6th Floor	0.44	7703	7854	4 T 50	7703	7854	4 T 50
9th Floor	0.37	5151	6434	8 T 32	5151	6434	8 T 32
12th Floor	0.26	2860	2945	6 T 25	2860	2945	6 T 25

Table 2. Comparison of side column without sway and with sway for middle frame.

Floor	Column size (Square) (m^2)	Side column without sway			Side column with sway		
		$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size	$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size
Ground floor	0.58	3580	3619	18 T 16	5050	5655	18 T 20
3rd Floor	0.51	3658	3770	12 T 20	3759	3770	12 T 20
6th Floor	0.44	3504	3770	12 T 20	3617	3770	12 T 20
9th Floor	0.37	3136	3142	10 T 20	3136	3142	10 T 20
12th Floor	0.26	2479	2945	6 T 25	2633	2945	6 T 25

Table 3. Comparison of beam (depth = 0.50 m and width = 0.40 m) for middle frame.

Floor	Without sway			With sway		
	Left hand side * (mm^2)	Middle * (mm^2)	Right hand side* (mm^2)	Left hand side* (mm^2)	Middle* (mm^2)	Right hand side* (mm^2)
Ground floor	6T20(1885)	5T16(1005)	4T25(1963)	3T40(3770) # 6T16(1206) ##	6T16(1206)	3T40(3770) # 6T16(1206) ##
3rd Floor	5T20(1571)	6T16(1206)	5T25(2454)	4T32(3217) # 6T16(1206) ##	6T16(1206)	3T40(3770) # 6T16(1206) ##
6th Floor	5T20(1571)	6T16(1206)	5T25(2454)	5T25(2454) # 6T16(1206) ##	6T16(1206)	4T32(3217)
9th Floor	5T20(1571)	6T16(1206)	5T25(2454)	6T20(1885) #	6T16(1206) ##	5T25(2454) #
12thFloor	6T20(1885)	5T20(1571)	5T16(1005)	6T20(1885) ##	5T20(1571) ##	6T16(1206) ##

*: In each row, # shows top reinforcement and ## shows bottom reinforcement of the beam.

Table 4. Comparison of middle column without sway and with sway for side frame.

Floor	Column size (square) (m^2)	Middle column without sway			Middle column with sway		
		$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size	$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size
Ground floor	0.58	4844	4909	10 T 25	4844	4909	10 T 25
3rd Floor	0.51	4267	4399	14 T 20	4267	4399	14 T 20
6th Floor	0.44	3607	3770	12 T 20	3607	3770	12 T 20
9th Floor	0.37	2716	2945	6 T 25	2716	2945	6 T 25
12th Floor	0.26	1842	1885	6 T 20	1842	1885	6 T 20

Table 5. Comparison of side column without sway and with sway for side frame.

Floor	Column size (square) (m^2)	Side column without sway			Side column with sway		
		$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size	$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size
Ground floor	0.58	1346	1358	12 T 12	1792	1810	16 T 12
3rd Floor	0.51	1040	1207	24 T 8	2104	2200	28 T 10
6th Floor	0.44	1007	1207	24 T 8	1735	1810	16 T 12
9th Floor	0.37	1475	1571	20 T 10	2574	2715	24 T 12
12th Floor	0.26	1616	1810	16 T 12	1989	2413	12 T 16

Table 6. Comparison of beam (depth = 0.50 m and width = 0.40 m) for side frame.

Floor	Without sway			With sway		
	Left hand side* (mm^2)	Middle* (mm^2)	Right hand side* (mm^2)	Left hand side* (mm^2)	Middle * (mm^2)	Right hand side* (mm^2)
Ground floor	6T16(1206)	8T10(628)	6T16(1206)	4T32(3217) # 7T12(792) ##	7T12(792)	4T32(3217) # 7T12(792) ##
3rd Floor	4T20(1257)	4T16(804)	3T20(942)	4T32(3217) # 7T12(792) ##	7T12(792)	5T25(2454) # 7T12(792) ##
6th Floor	5T20(1571)	6T12(679)	5T16(1005)	5T25(2454) # 6T12(679) ##	6T12(679)	6T20(1885) 6T12(679) ##
9th Floor	6T16(1206)	7T12(792)	7T12(792)	6T20(1885) #	7T12(792)	6T16(1206) # 7T12(792) ##
12thFloor	8T10(628)	3T20(942)	4T20(1257)	7T12(792) # 3T20(942) ##	3T20(942)	4T20(1257)

*: In each row, # shows top reinforcement and ## shows bottom reinforcement of the beam.

Table 7. Comparison of middle column without sway and with sway for middle frame.

Floor	Column size (square) (m^2)	Middle column without sway			Middle column with sway		
		$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size	$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size
Ground floor	0.36	5949	7540	6 T 40	5949	7540	6 T 40
3rd Floor	0.26	3078	3217	4 T 32	3078	3217	4 T 32

Table 8. Comparison of side column without sway and with sway for middle frame.

Floor	Column size (Square) (m^2)	Side column without sway			Side column with sway		
		$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ mm^2	Bar number and size	$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size
Ground floor	0.36	2208	2413	12 T 16	2423	2514	8 T 20
3rd Floor	0.26	1873	1885	6 T 20	1971	2945	6 T 25

Table 9. Comparison of beam (depth = 0.50 m and width = 0.40 m) for middle frame.

Floor	Without sway			With sway		
	Left hand side* (mm^2)	Middle* (mm^2)	Right hand side* (mm^2)	Left hand side* (mm^2)	Middle* (mm^2)	Right hand side* mm^2
Ground floor	5T25(2454)	6T16(1206)	5T20(1571)	5T25(2454)	6T16(1206)	6T20(1885)
3rd Floor	5T25(2454)	5T20(1571)	7T12(792)	5T25(2454)	5T20(1571)	5T16(1006)# 5T20(1571) ##

*: In each row, # shows top reinforcement and ## shows bottom reinforcement of the beam.

Table 10. Comparison of middle column without sway and with sway for side frame.

Floor	Column size (square) (m^2)	Middle column without sway			Middle column with sway		
		$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ mm^2)	Bar number and size	$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size
Ground floor	0.36	2325	2413	12 T 16	2325	2413	12 T 16
3rd Floor	0.26	1413	1885	6 T 20	1413	1885	6 T 20

Table 11. Comparison of side column without sway and with sway for side frame.

Floor	Column size (square) (m^2)	Side column without sway			Side column with sway		
		$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ (mm^2)	Bar number and size	$A_{s\ required}$ (mm^2)	$A_{s\ provided}$ mm^2	Bar number and size
Ground floor	0.36	518	604	12 T 8	1062	1207	24 T 8
3rd Floor	0.26	1224	1257	4 T 20	1433	1608	8 T 16

Table 12. Comparison of beam (depth = 0.50 m and width = 0.40 m) for side frame.

Floor	Without sway			With sway		
	Left hand side* (mm^2)	Middle* (mm^2)	Right hand side* (mm^2)	Left hand side* (mm^2)	Middle* (mm^2)	Right hand side* (mm^2)
Ground floor	7T12(792)	7T12(792)	4T20(1257)	6T16(1206)	7T12(792)	5T20(1571)
3rd floor	4T12(452)	5T16(1006)	5T20(1571)	5T12(565)# 5T16(1006) ##	5T16(1006)	5T20(1571)

*: In each row, # shows top reinforcement and #shows bottom reinforcement of the beam.

According to the design results of the 15 and 6 storey building, it can be seen that the middle column became same in both sway and non-sway cases. In 15 and 6 storey building, the amount of reinforcement has increased slightly (approximately 4%) in sway cases for side column of middle frame, but for side column of side frame, the reinforcement has increased significantly (approximately up to 100%) for both 15 and 6 storey building in sway cases due to wind loading. In 15 storey building, beam reinforcement has increased approximately up to 60% and in 6 storey building, it has increased approximately up to 30% in sway frame. This happened because of the significant effect of wind loading in 15 storey building.

Conclusion

The following conclusion can be made based on the analysis of the RC multi-storied building frames for non-sway and sway method using Staad. Pro V8i software:

1. Because of load increasing from top to bottom, the size

of column has also increased in every three storeys as economy is a big issue.

2. Because of symmetry, the design results of the right hand side and left hand side column of every frame is similar.

3. The design results of the left hand side and right hand side beams for all frames are the mirror of each other due to symmetry of load and plan of the building.

4. It can be observed that if the height of the building has shortened, column sizes become much smaller but beam size remained constant.

5. In sway and non-sway cases, the reinforcement of middle column remains constant but for side column, it has increased in sway cases due to wind loading. Side column of side frame of the building had shown more change of reinforcement in sway cases for wind loading.

6. The bottom middle reinforcement of the beam is almost the same for both sway and non-sway cases but extra amount of reinforcement had been provided at the left and right hand side of the beam for sway conditions due to wind loading.

7. Beam reinforcement has not changed significantly in the upper floors because of smaller effect of wind loading at the upper floors.

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