Aerodynamic Modification and Shape Optimization of Tall Buildings

Ms. Ameena M Ansary[1], Mr. M V Varkey[2], Ms. Jiji Thomas[3]

[1]Student (M Tech), Dept. of Civil Engineering, Amal Jyothi College of Engineering, Kanjirappally, Kerala, India
[23]Assistant Professor, Dept. of Civil Engineering, Amal Jyothi College of Engineering, Kanjirappally, Kerala, India

---

Abstract - *High rise structures are in demand due to scarcity of land in urban areas, economic growth, technological advancement, etc. The tall buildings in addition to gravity loads have to resist lateral loads resulting from wind, earthquake etc. The aerodynamic modifications on building could be made to improve the performance of buildings. The main objective of the present study is to evaluate the effect of corner modification, setback and stepping on tall buildings. Building models with a constant plan area of 1024 sq.m is considered for corner modification study and an area of 2500 sq.m for studying stepping and setback. The models are compared in different aspects such as storey drift, storey displacement, column force, beam force, shell force, etc for different modifications.*

Key Words: **Corner modification, setback, stepping, storey drift, storey displacement, column force, beam force, shell force**

1. INTRODUCTION

A building having height more than 15 m as per National Building Code 2005 of India is called a high rise building. Vertical growth of buildings has become an ultimate option available due to the rapid growth of population, the high cost of land, for improvement in aesthetic view of city and restriction in horizontal growth due to less space. The Wind can be defined as the large-scale horizontal movement of free air. It plays an important role in the design of tall structures due to the impact of lateral loads exerted on the buildings. The response of structures to wind depends on the characteristics of wind.

The wind is the most powerful and unpredictable force, which affects tall buildings. A tall building can be defined as a mast anchored in the ground, bending and swaying in the wind. The wind produces drift, and it should be kept within acceptable limits. Moreover, for a well-designed tall building, the wind drift should not exceed the height of the building divided by 500.Wind loads on buildings increase with the increase in building heights. The speed of wind increases with height, and the wind pressures increase as the square of the wind speed. As a result of this, wind effects on a tall building are compounded as its height increases. Innovations in architectural treatment, increase the strength of materials, and advances in the method of analysis, the tall building has become more efficient and lighter. Despite all the engineering sophistication performed with computers, the wind is still a complex phenomenon, causing many problems. Unlike the dead loads and live loads, wind loads change rapidly and even abruptly, causing effects, which are much larger than when the same loads were applied gradually, and also they limit building accelerations below human perception.

Many types of research and studies are conducted to reduce building excitations, and this helps in improving the performance of tall buildings against wind loads & earthquake loads. Modifications of building's corner geometry and its cross-sectional shape is an important and effective design approach which can mitigate building excitation.

Architects mitigate wind effect on tall buildings by designing the form aerodynamically or by utilizing aerodynamic modifications, which are categorized as macro and micro-modifications or major and minor modifications.

Minor modifications: aerodynamic modifications having negligible effects on the structural and architectural concept. This includes corner modifications like the fitting of fins, fitting of vented fins, slotted corners, corner recession (single, double, triple recession) chamfered corners, the roundness of corners and orientation of building about the most frequent strong wind direction.

Major modifications: aerodynamic modifications having greater effects on the structural and architectural concept. This includes setbacks along the height, tapering effects, opening at the top, sculptured building tops, varying the shape of buildings, setbacks, twisting of the building, etc.

The main objectives are:

- To evaluate the effect of corner modification on buildings to resist the wind load.
- To evaluate the effect of setback on a building to resist the wind load.

2. METHODOLOGY

The scheme of the project work is given as follows:

- Selection of various types of models considered for the study by providing a constant value for the plan area.
- Reviewing of the journal papers related to my area of study.
- Three dimensional models of the building structure is created using the software ETABS.
- Material properties and member properties are defined and assigned to the models.
- Base of the models are fixed for simplicity.
- Loads are assigned to the building structure.
- Linear static analysis is carried out.
- The values of storey displacement, storey drift, shell stress, column force are determined.
- The obtained results were then analyzed and a detailed report was prepared.

3. DESCRIPTION OF RC FRAME BUILDING

In the first part of the study, buildings with constant plan area of 1024 m^2 with different corner modifications has been modeled and analyzed using ETABS. The corner modifications considered for the study are basic, single, double and triple recession. The building consists of G+9 stories. The columns are assumed to be fixed at the base. The height of each floor is 3 m. The building is considered to be situated in Chennai, seismic zone III, terrain category4 and structure class B .Zone factor is 0.16 and response reduction factor is 5. The basic wind speed is taken as 50 m/s. The size used of beam is 500mm*300mm and column is 700mm*300 mm. The bay widths of models considered for studying the corner modification are

Basic - 6.4 m, Single recession -6.98 m, Double recession -6.05 m, Triple recession-6.4 m.

In the second part of the study, buildings with constant plan area of 2500 m^2 have been modeled and analyzed using ETABS. The major modifications considered are stepping and setback. The building consists of G+14 stories. The columns are assumed to be fixed at the base. The height of each floor is 3 m. The building is considered to be situated in Chennai, seismic zone III, terrain category4 and structure class B .Zone factor is 0.16 and response reduction factor is 5. The basic wind speed is taken as 50 m/s. The size used for beam is 500mm*300mm and column is 750mm*300 mm. The bay width of models considered for studying setback and stepping is 5m.

4. MODELS CONSIDERED FOR ANALYSIS

For studying the corner modification basic model ,model with single, double and triple recessions are considered.

4.1 Models considered for studying corner modification

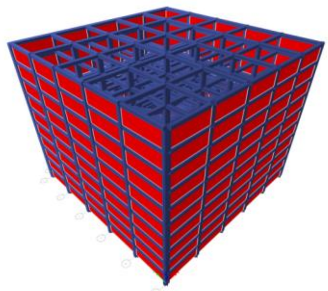

Fig -1 : Basic model

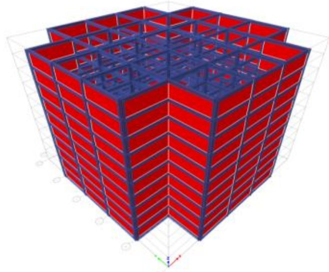

Fig -2 : Single recession

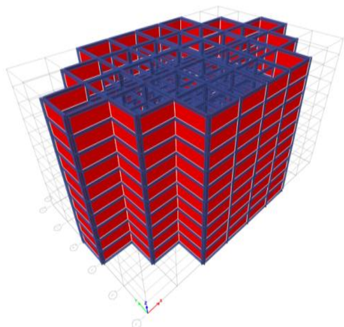

Fig -3 : Double recession

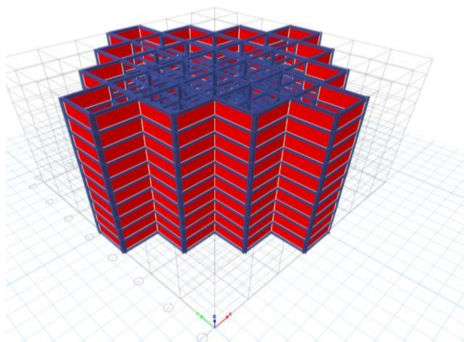

Fig -4 : Triple recession

4.2 Models considered for studying setback

For studying setback a basic model, Setback 5,5,5; Setback 5,10; Setback 10,5 are considered.

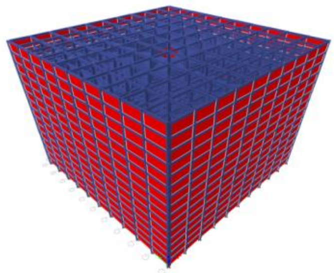

Fig -5 : Setback basic

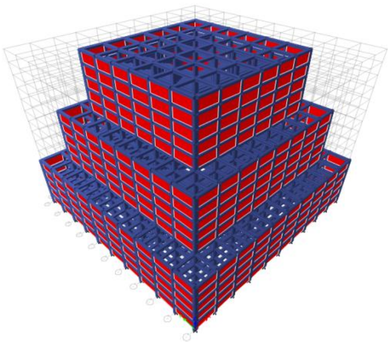

Fig -6 : Setback 5,5,5

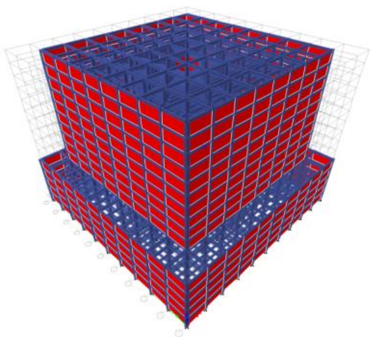

Fig -7 : Setback 5,10

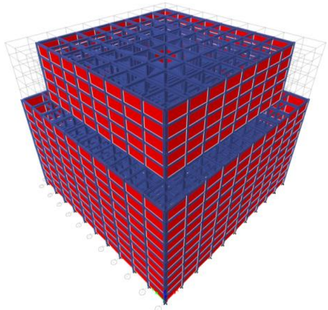

Fig -8 : Setback 10,5

4.2 Models considered for studying stepping

For studying stepping a basic model, Stepping 3,3,3,3,3 Stepping 5,5,5; Stepping 5,10; Stepping 10,5 are considered.

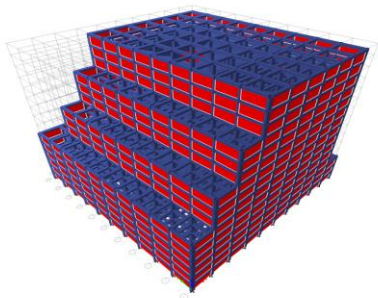

Fig -9 : Stepping 3,3,3,3,3

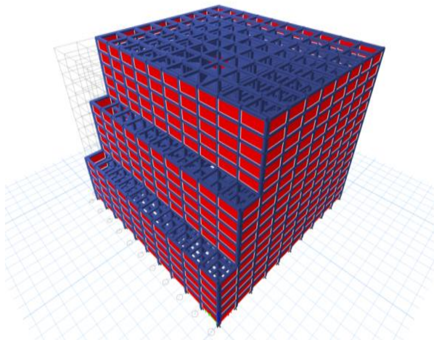

Fig -10 : Stepping 5,5,5

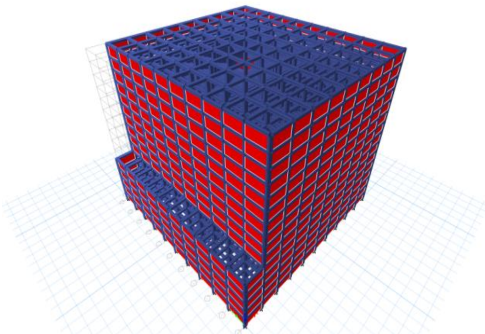

Fig -11 : Stepping 5,10

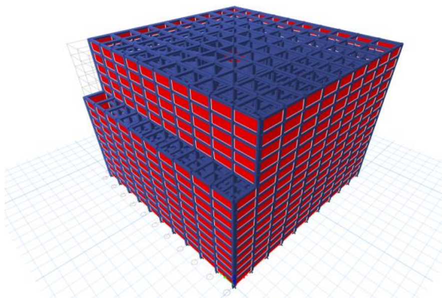

Fig -12 : Stepping 10,5

4. LOADS APPLIED ON THE STRUCTURE FOR ANALYSIS

1) Dead load
   Total weight of wall = 13.2 kN/m
   Parapet load = 2.64 kN/m
   Total load of slab on each beam =4 kN/m(basic, double, triple recession)
   =5.5 kN/m(single)
   =3.5 kN/m(setback, stepping)
2) Live load on each beam= 5 kN/m (basic, triple)
   = 5.5 kN/m (single)
   = 4.5 kN/m (double)
   =4 kN/m(setback, stepping)
3) Wind load
   Basic wind speed =50 m/s
   Wind pressure coefficient=0.7
4) Earthquake load
   Response reduction factor , R =5
   Zone factor =0.16
   Importance factor = 1

4.1 Load Combinations

1)1.2(DL+LL+WLX+WLY)
2) 1.2(DL+LL-WLX-WLY)
3) 1.5(DL+WLX+WLY)
4)1.5(DL –WLX-WLY)

5. RESULTS AND DISCUSSION

5.1 Results of Corner Modification

The results of story displacement are compared and the building with triple recession has lower value of story displacement.

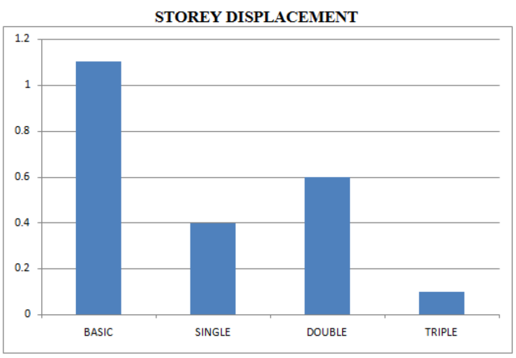

***Chart* -1** Storey displacement values for corner modification

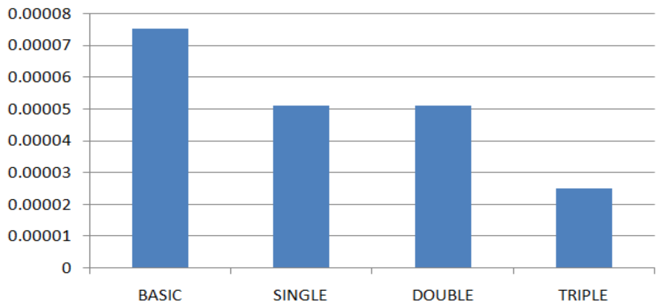

***Chart* -2** Storey drift values for corner modification

From the results it is found that corner modifications improve the performance of building against wind. The corner modification is like softening the building corner and it allows wind to move smoothly. Among the studied corner modification triple recession is most effective in reducing storey displacement, followed by single recession and double recession.

Table -1 Corner modification results

Corner Modifi-cation	Storey displa-cement (mm)	Storey drift (mm)	Column force (kN)	Beam force (kN)	Shell Force (kN/m)	Shell stress (MPa)
Basic	1.11	0.000075	8.32	22.92	734.31	18.46
Single	0.41	0.000051	7.81	14.42	1081.7	7.93
Double	0.56	0.000051	7.96	31.65	1094.2	8.5
Triple	0.10	0.000025	7.93	25.08	1306.9	6.59

5.2 Results of Setback

With the provision of setback, the width of building is varied along the height. As a result of this the vortices generated shed at different frequency at different height. The setback reduces the volume of building with the increase in height.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 06 | June -2017 www.irjet.net p-ISSN: 2395-0072

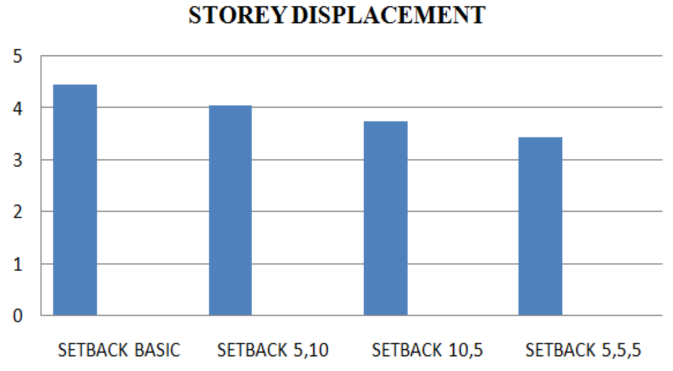

***Chart* -3** Storey displacement values for setback

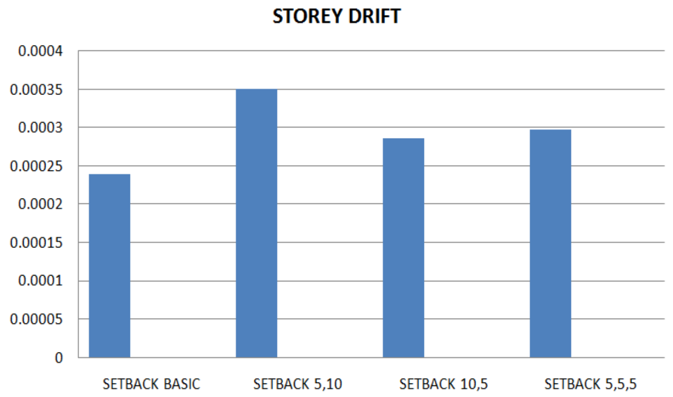

***Chart* -4** Storey drift values for setback

Table -2 Setback results

Modifi-cation type	Storey displa-cement (mm)	Storey drift (mm)	Column force (kN)	Beam force (kN)	Shell force (kN/m)	Shell stress (MPa)
Basic	4.45	0.00024	37.6873	55.755	1097.42	45.19
Setback 5,10	4.05	0.00035	106.082	408.546	723.735	57.41
Setback 10,5	3.74	0.00029	36.8827	343.892	709.535	56.69
Setback 5,5,5	3.45	0.00029	66.3403	340.264	460.461	48.41

5.3 Results of Stepping

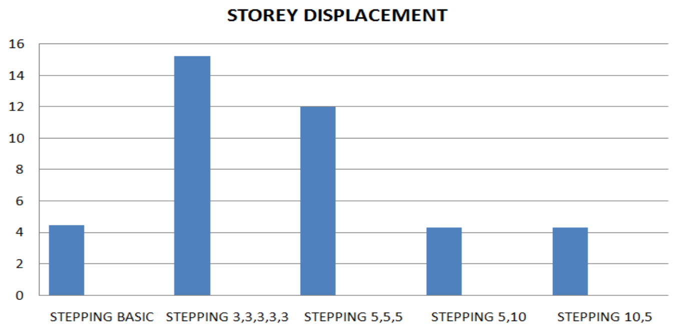

***Chart* -5** Storey displacement values for stepping

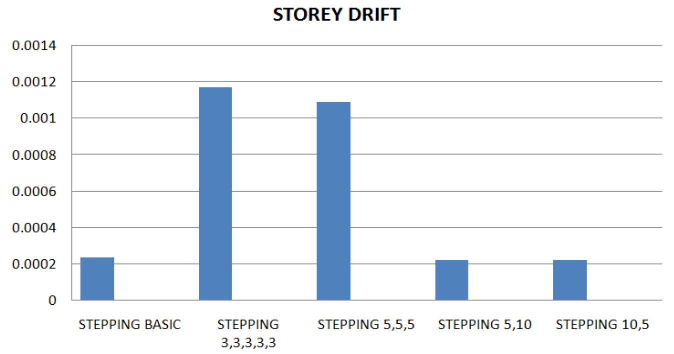

***Chart* -6** Storey drift values for stepping

Table -3 Stepping results

Modifi-cation type	Storey displa-cement (mm)	Storey drift (mm)	Column force (kN)	Beam force (kN)	Shell force (kN/m)	Shell stress (MPa)
Basic	4.45	0.00024	37.687	55.755	1097.417	45.19
Stepping 3,3,3,3,3	15.225	0.00117	321.988	804.046	2023.302	11.03
Stepping 5,5,5	12.019	0.00109	129.908	754.321	1250.582	10.73
Stepping 5,10	4.3146	0.00022	675.901	53.981	3713.09	57.65
Stepping 10,5	4.2913	0.00022	1628.74	52.067	6126.023	58.32

The provision of stepping does not have greater influence in reducing storey displacement. Thus the modification stepping is not much effective. In some cases the modifications become ineffective and have adverse effect on building. The modifications are not capable of totally eliminating wind excitation of tall building. Thus care should be taken to engineer modifications and they should produce desired effects only.

6. CONCLUSIONS

In this work the effect of corner modifications, setback and stepping on tall buildings are studied. For studying the effect of corner modification four models with a constant plan area of 1024 m^2 and for studying the effect of setback and stepping eight models are considered.

The following conclusions are obtained from the analysis

- The storey displacement value for basic model is 1.11 mm,0.41mm for single recession,0.56 for double and 0.1 for triple recession. There is 90% reduction in storey displacement by the provision of triple recession. The storey displacement has reduced by 63%,60.5% for single and double recession respectively. Thus recession has positive effects on the building.
- The maximum reduction in storey displacement for setback model is for setback 5, 5, 5.There is a reduction of 22% in storey displacement in comparison with base model. Thus setback also has positive effects on the building.
- The results of stepping showed that in some cases the displacement value becomes higher than that of the base model .Thus stepping is ineffective. So care should be taken to engineer modifications and they should produce desired effects only.

REFERENCES

[1] Arvind.Y.Vyavahare, Godbole.P.N, Trupti Nikose "Analysis of tall building for across wind response", International Journal Civil and Structural Engineering, 2,979-986,2012.

[2] C. M. Chan, M. F. Huang, K. C. S. Kwok "Stiffness Optimization for Wind-Induced Dynamic Serviceability Design of Tall Buildings", Journal of Structural Engineering,135,985-997,2009.

[3] Hossein Moravej, Mahdi Hatami, Reza Naghshbandi, Yaser Mousavi Siamakani "Wind load analysis of buildings in hill-shape zone", Int. Journal of Applied Sciences and Engineering Research, 4, 94-101, 2015.

[4] Jiming Xie "Aerodynamic optimization of super-tall buildings and its effectiveness assessment",Journal of Wind Engineering and Industrial Aerodynamics, 30,88-98,2014.

[5] J. M. Ding, X. Zhao, H. H. Sun "Structural Design of Shanghai Tower for Wind Loads", Procedia Engineering,14,1759-1767,2011.

[6] Maryam Asghari, Mooneghi Ramtin, Kargarmoakhar "Aerodynamic Mitigation and Shape Optimization of Buildings",Journal of Building Engineering, 36,225–235,2016.

[7] M. Alaghmandan, M. Elnimeiri "Reducing impact of wind on tall buildings through design and aerodynamic modifications",Journal of civil engineering,5,847-856,2013.

[8] M. R. Wakchaure, Sayali Gawali "Effects Of Shape On The Wind-instigate Response Of High Rise Buildings",International Journal of Research in Engineering and Technology, 4, 65-74,2015.

[9] Ravinder Ahlawat, Ashok K. Ahuja " Wind loads on 'Y' plan shape tall building", International Journal of Engineering and Applied Sciences,2,80-83,2015.

[10] Ryan Merrick, Girma Bitsuamlak "Shape Effects On The Wind-Induced Response Of High-Rise Buildings", Journal of Wind and Engineering, 6,1-18,2009.

[11] Sanjay Kulkarni, Sanket Lohade "Shape Effects of Wind-Induced Response on Tall Buildings Using CFD", International Journal of Engineering and Applied Sciences, 3,25-28, 2016.

[12] Vikram. M. B, Chandradhara G.P, Keerthi Gowda B.S " A Study On Effect Of Wind On The Static And Dynamic Analysis", International Journal of Emerging Trends in Engineering and Development,3,885-890,2014.

[13] Wagdi G.Habashi, Yue Zhang, Rooh A.Khurram "Predicting wind-induced vibrations of high-rise buildings using unsteady CFD and modal analysis", J. Wind Eng. Ind. Aerodyn,136,165–179,2015.