Vol. 1, Issue 4, pp. 1515-1521

Displacement Control of High Rise Structures with the Provision of Shear Wall

Onkar V. Sapate*, Dr. A. M. Pande**

*(Department of Civil Engineering, YCCE, Nagpur)
**(Department of Civil Engineering, YCCE, Nagpur)

ABSTRACT

Tall buildings are required to be analyzed for the effects of both earthquake and wind forces. It is necessary to study the effects i.e., displacements of nodes of the structure due to these forces. In this paper, G+15 storeyed building is analyzed for all load combinations considering earthquake and wind using STAAD PRO. The effect is also studied with and without shear wall. Results of displacements of column are compiled and analyzed. The critical load combinations are observed in case of displacements for earthquake and wind respectively. Then the floor wise percentage reductions in displacements, if shear wall is provided are calculated. There is significant reduction in the displacements at various floor levels.

It is also observed that critical wind loads are much higher than critical earthquake loads in this particular structure for Earthquake zone II. Thus, the displacements due to critical wind loads are higher than those due to critical earthquake loads. The performance of mathematical models developed correlating various parameters are found to be very significant. Guidelines from IS 1893 (part 1):2002 and IS 875 (part 3):1987 are followed in the seismic and wind analysis of building respectively.

Keywords - displacement control, shear wall, seismic and wind analysis, critical load combinations, mathematical models

I. INTRODUCTION

The control of displacements of nodes of building due to earthquake and wind is always been a concern to Civil Engineers around the globe. There are various methods adopted worldwide to achieve this like use of dampers, liquid columns, addition of shear wall, etc. Tall buildings are required to be analyzed for the effect of earthquake and wind forces. It becomes necessary to study the effects of these forces on the structure i.e., displacements of nodes for the safety and smooth workability of individuals living in that structure.

The principal objectives of the paper are:

- Critical review of displacement reduction mechanism for tall buildings and its interpretation
- To develop the mathematical models using various parameters

In this paper, G+15 storeyed building is analyzed for all load combinations considering earthquake and wind loads using STAAD PRO. The effect is also seen with and without shear wall. All the results of axial forces and displacements of column are compiled and analyzed.

Following load combinations were considered while applying earthquake load as recommended by IS 1893 (part1):2002

1. 1.5 (DL + LL)
2. 1.5 (DL + EQX)
3. 1.5 (DL - EQX)
4. 1.5 (DL + EQZ)
5. 1.5 (DL - EQZ)
6. 1.2 (DL + LL + EQX)
7. 1.2 (DL + LL - EQX)
8. 1.2 (DL + LL + EQZ)
9. 1.2 (DL + LL - EQZ)
10. 0.9DL + 1.5EQX
11. 0.9DL - 1.5EQX
12. 0.9DL + 1.5EQZ
13. 0.9DL - 1.5EQZ

Load combinations considered while applying wind load as recommended by IS 875 (part 3):1987

1. 1.5 (DL + WLX+)
2. 1.5 (DL + WLX-)
3. 1.5 (DL + WLZ+)
4. 1.5 (DL + WLZ-)
5. 1.2 (DL + LL + WLX+)
6. 1.2 (DL + LL + WLX-)
7. 1.2 (DL + LL + WLZ+)
8. 1.2 (DL + LL + WLZ-)

In general, the critical load combinations are found out to be (-1.5EQZ + 1.5DL), (-1.5EQX + 1.5DL) and (1.5WLX + 1.5DL) in case of displacements for earthquake and wind respectively. Then the floor wise percentage reductions in displacements, if shear wall is provided are calculated. The displacements are found to reduce by nearly 70% in case of wind and 60% in case of earthquake.

It is also observed that critical wind loads are much higher than critical earthquake loads in this particular structure in Earthquake zone II. Thus, the displacements due to critical wind loads are higher than those due to critical earthquake loads. The performance of mathematical models developed correlating various parameters are found to be very significant.

The proposed model for shear wall in 3 dimensioned structures is useful and effective in predicting the inelastic behavior of wall frame structures, J. Fu, et.al. [1].

II. ABOUT THE STRUCTURE

A R.C.C. (G+15) residential building with brick infills having parking at basement is considered for the study purpose. The total area of one floor of the building is nearly 4000 sq.ft. having storey height of 3m. The building is situated in earthquake zone II i.e., zone factor 0.10. The wind speed considered is 39 m/s with category 2 and class A. Soil is of type II (medium) and Importance factor considered is 1 with building frame system as OMRF. Basically there was no shear walls in original building but later 2 "L shaped" and "2 U shaped" shear walls were added from basement to topmost floor in the model.

The following loads are considered / applied on the building:

1) Dead load of the building i.e., Self weight of all R.C.C. members and brickwork
2) Live load for all the floors = 3KN/m^2
3) Earthquake load
4) Wind load

III. ANALYSIS OF DATA GENERATED

Critical load combinations for displacements

In case of Earthquake:

(-1.5EQZ + 1.5DL) & (-1.5EQX + 1.5DL)

In case of Wind:

(1.5WLX + 1.5DL)

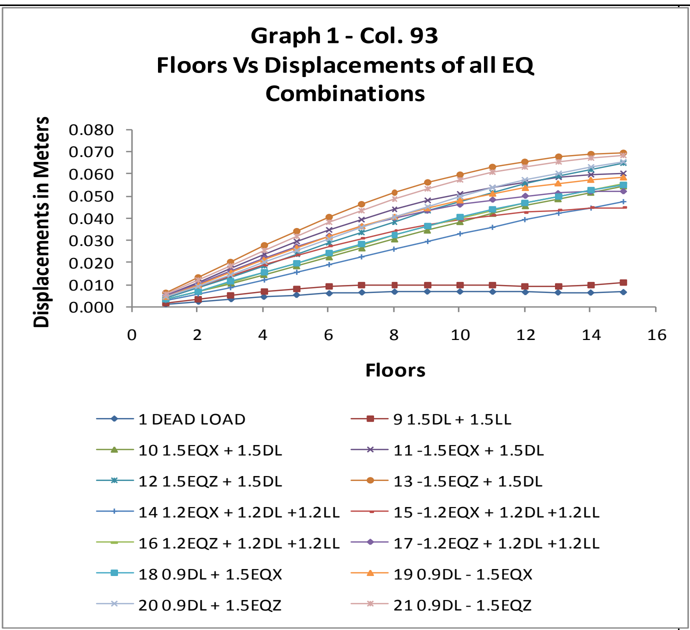
4 columns are selected from different locations in the building for detailed study

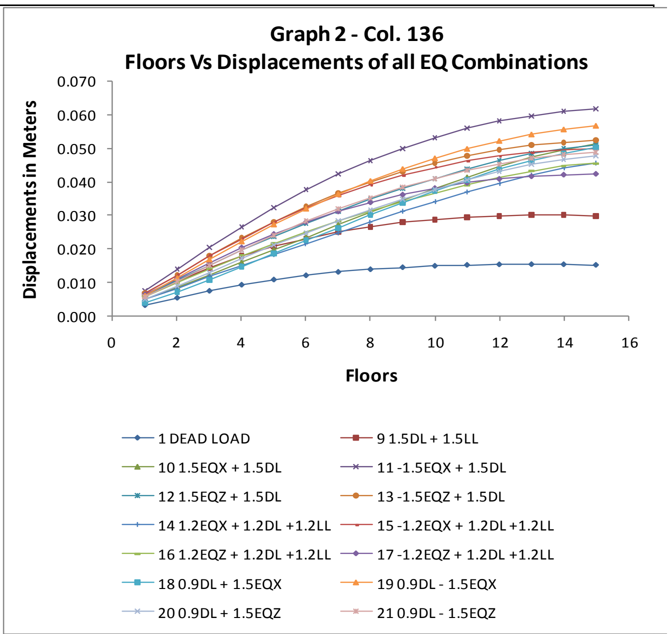
Column No. 93	Position: Corner
Column No. 136	Position: Outside
Column No. 175	Position: Inside
Column No. 257	Position: Middle

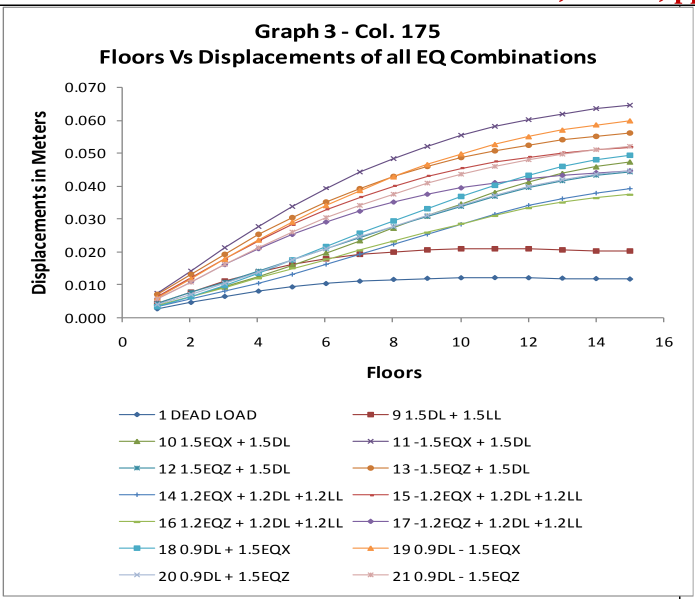
Results of floor wise displacements of all 4 columns with all combinations of earthquake and wind are assembled for the making of graphs.

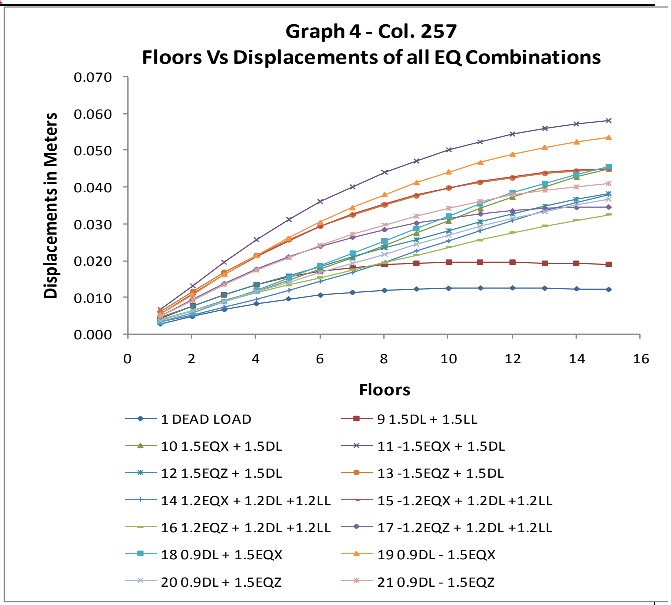
Following analysis is done by using STAAD PRO results:

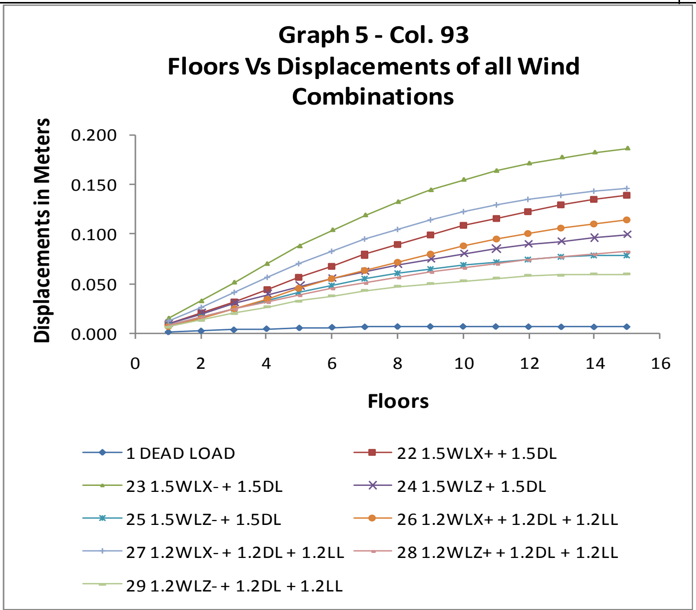
1) Floor wise displacements for all combinations of earthquake and wind (with and without shear wall)
2) Floor wise axial forces for all combinations of earthquake and wind (with and without shear wall)
3) Floor wise percentage reduction in displacements due to shear wall in critical combinations of both earthquake and wind
4) Floor wise displacements due to critical wind load with shear wall, critical earthquake loads with and without shear wall against the displacements due to wind load without shear wall only.

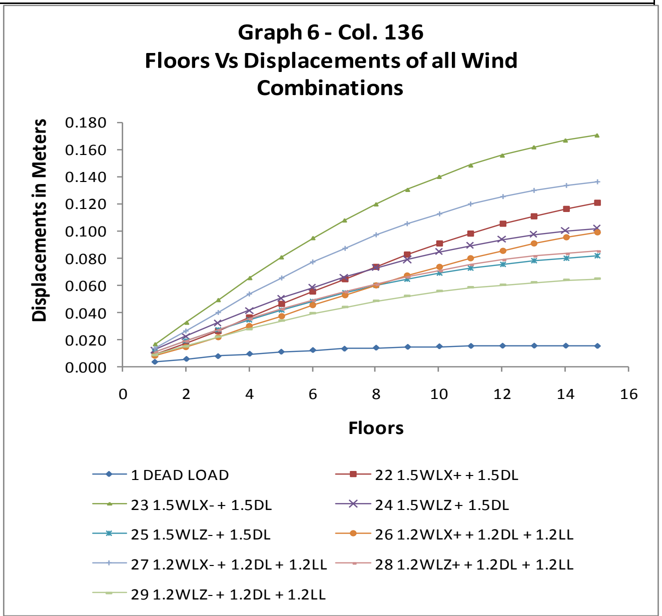


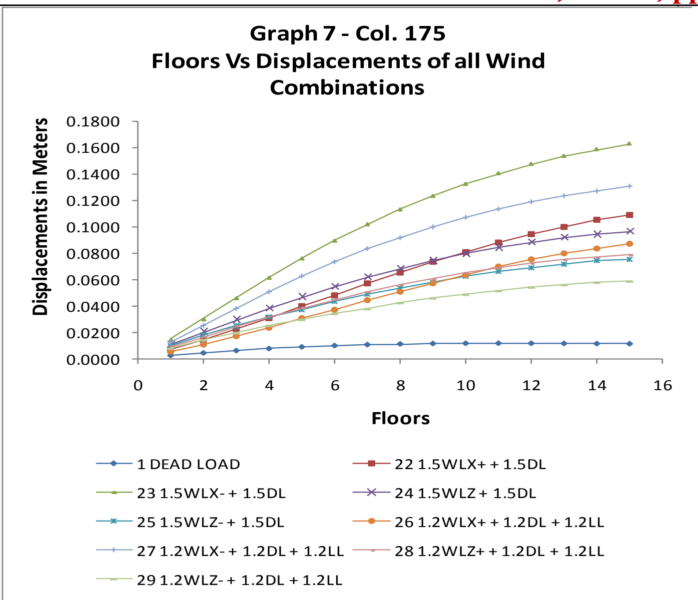


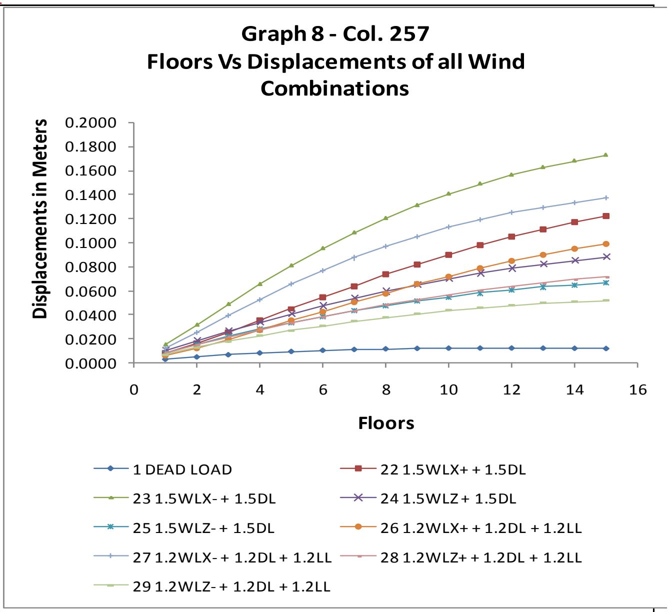

Graph 3 - Col. 175
Floors Vs Displacements of all EQ Combinations
Displacements in Meters
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
0 2 4 6 8 10 12 14 16
Floors
1 DEAD LOAD
9 1.5DL + 1.5LL
10 1.5EQX + 1.5DL
11 -1.5EQX + 1.5DL
12 1.5EQZ + 1.5DL
13 -1.5EQZ + 1.5DL
14 1.2EQX + 1.2DL +1.2LL
15 -1.2EQX + 1.2DL +1.2LL
16 1.2EQZ + 1.2DL +1.2LL
17 -1.2EQZ + 1.2DL +1.2LL
18 0.9DL + 1.5EQX
19 0.9DL - 1.5EQX
20 0.9DL + 1.5EQZ
21 0.9DL - 1.5EQZ

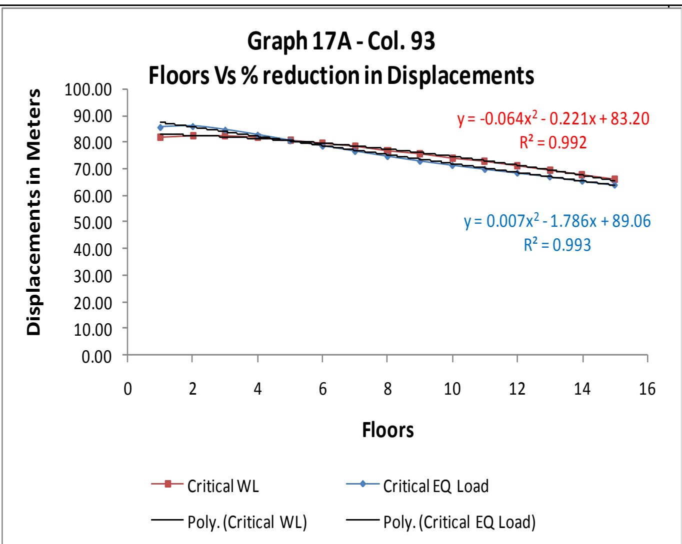

Graph 4 - Col. 257
Floors Vs Displacements of all EQ Combinations
Displacements in Meters
0.070
0.060
0.050
0.040
0.030
0.020
0.010
0.000
0 2 4 6 8 10 12 14 16
Floors
1 DEAD LOAD
9 1.5DL + 1.5LL
10 1.5EQX + 1.5DL
11 -1.5EQX + 1.5DL
12 1.5EQZ + 1.5DL
13 -1.5EQZ + 1.5DL
14 1.2EQX + 1.2DL +1.2LL
15 -1.2EQX + 1.2DL +1.2LL
16 1.2EQZ + 1.2DL +1.2LL
17 -1.2EQZ + 1.2DL +1.2LL
18 0.9DL + 1.5EQX
19 0.9DL - 1.5EQX
20 0.9DL + 1.5EQZ
21 0.9DL - 1.5EQZ

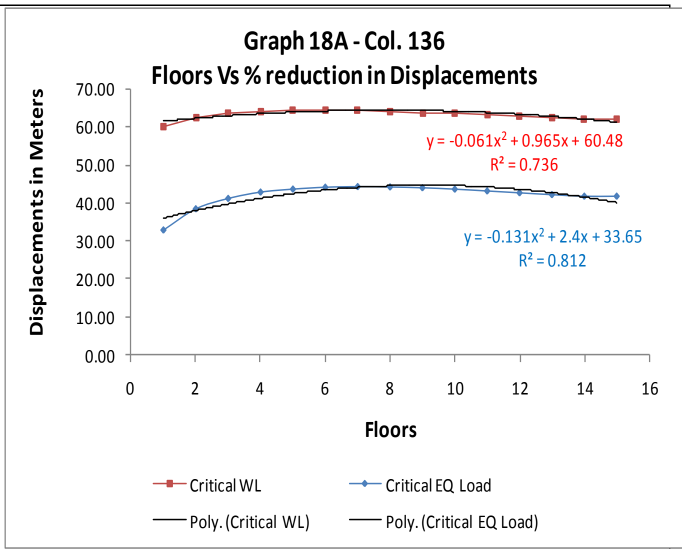

Graph 5 - Col. 93
Floors Vs Displacements of all Wind Combinations
Displacements in Meters
0.200
0.150
0.100
0.050
0.000
0 2 4 6 8 10 12 14 16
Floors
1 DEAD LOAD
22 1.5WLX+ + 1.5DL
23 1.5WLX- + 1.5DL
24 1.5WLZ+ 1.5DL
25 1.5WLZ- + 1.5DL
26 1.2WLX+ + 1.2DL + 1.2LL
27 1.2WLX- + 1.2DL + 1.2LL
28 1.2WLZ+ + 1.2DL + 1.2LL
29 1.2WLZ- + 1.2DL + 1.2LL

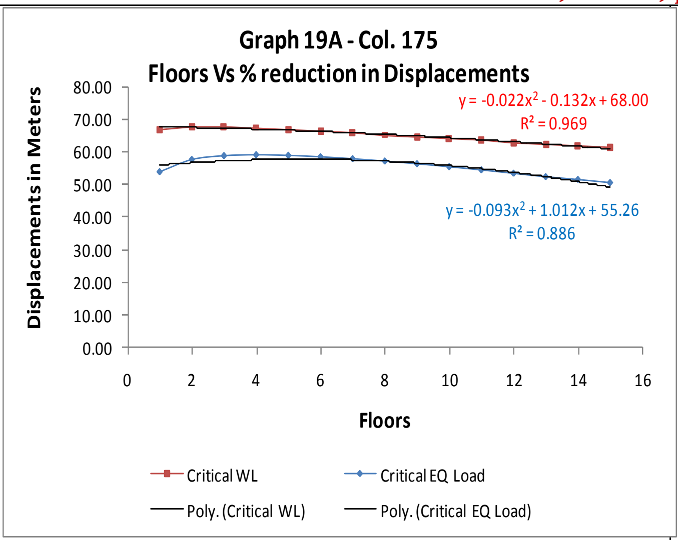

Graph 6 - Col. 136
Floors Vs Displacements of all Wind Combinations
Displacements in Meters
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0 2 4 6 8 10 12 14 16
Floors
1 DEAD LOAD
22 1.5WLX+ + 1.5DL
23 1.5WLX- + 1.5DL
24 1.5WLZ+ 1.5DL
25 1.5WLZ- + 1.5DL
26 1.2WLX+ + 1.2DL + 1.2LL
27 1.2WLX- + 1.2DL + 1.2LL
28 1.2WLZ+ + 1.2DL + 1.2LL
29 1.2WLZ- + 1.2DL + 1.2LL

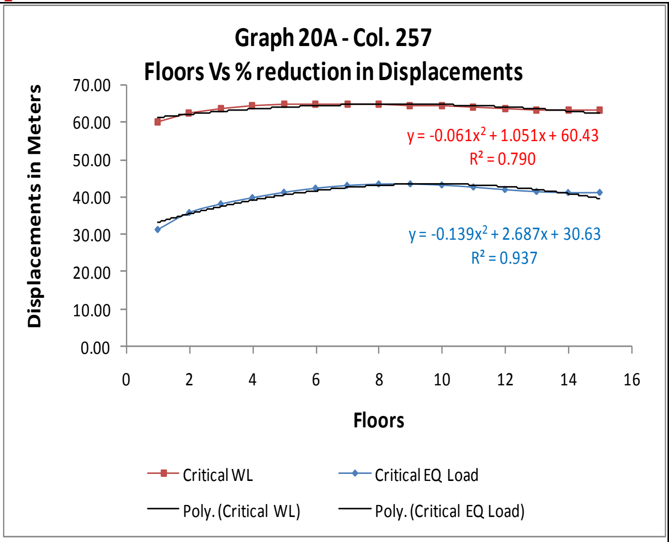

Graph 7 - Col. 175
Floors Vs Displacements of all Wind Combinations
Displacements in Meters
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
0
2
4
6
8
10
12
14
16
Floors
1 DEAD LOAD
22 1.5WLX+ + 1.5DL
23 1.5WLX- + 1.5DL
24 1.5WLZ+ 1.5DL
25 1.5WLZ- + 1.5DL
26 1.2WLX+ + 1.2DL + 1.2LL
27 1.2WLX- + 1.2DL + 1.2LL
28 1.2WLZ+ + 1.2DL + 1.2LL
29 1.2WLZ- + 1.2DL + 1.2LL

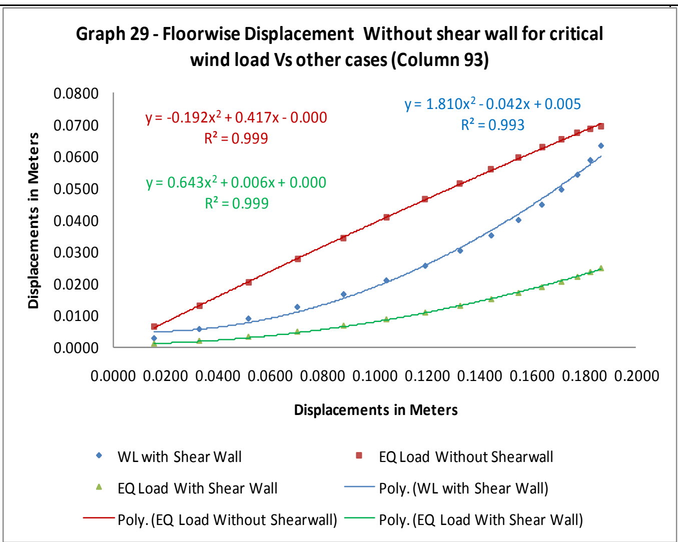

Graph 8 - Col. 257
Floors Vs Displacements of all Wind Combinations
Displacements in Meters
0.2000
0.1800
0.1600
0.1400
0.1200
0.1000
0.0800
0.0600
0.0400
0.0200
0.0000
0
2
4
6
8
10
12
14
16
Floors
1 DEAD LOAD
22 1.5WLX+ + 1.5DL
23 1.5WLX- + 1.5DL
24 1.5WLZ+ 1.5DL
25 1.5WLZ- + 1.5DL
26 1.2WLX+ + 1.2DL + 1.2LL
27 1.2WLX- + 1.2DL + 1.2LL
28 1.2WLZ+ + 1.2DL + 1.2LL
29 1.2WLZ- + 1.2DL + 1.2LL

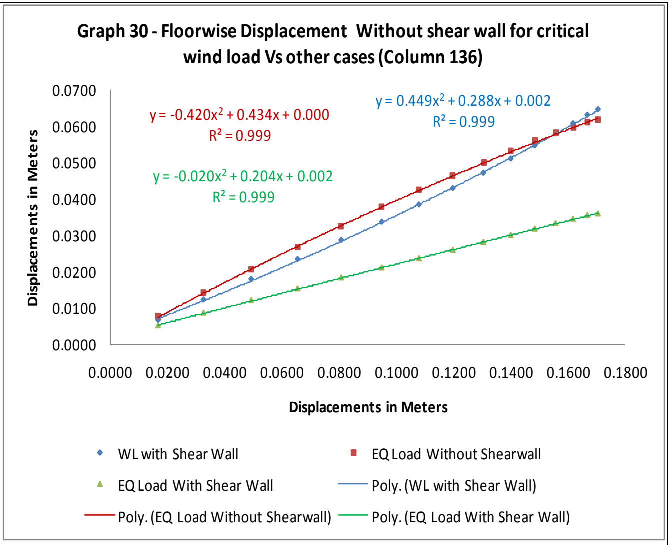

Graph 17A - Col. 93
Floors Vs % reduction in Displacements
Displacements in Meters
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
y = -0.064x² - 0.221x + 83.20
R² = 0.992
y = 0.007x² - 1.786x + 89.06
R² = 0.993
0
2
4
6
8
10
12
14
16
Floors
Critical WL
Critical EQ Load
Poly. (Critical WL)
Poly. (Critical EQ Load)

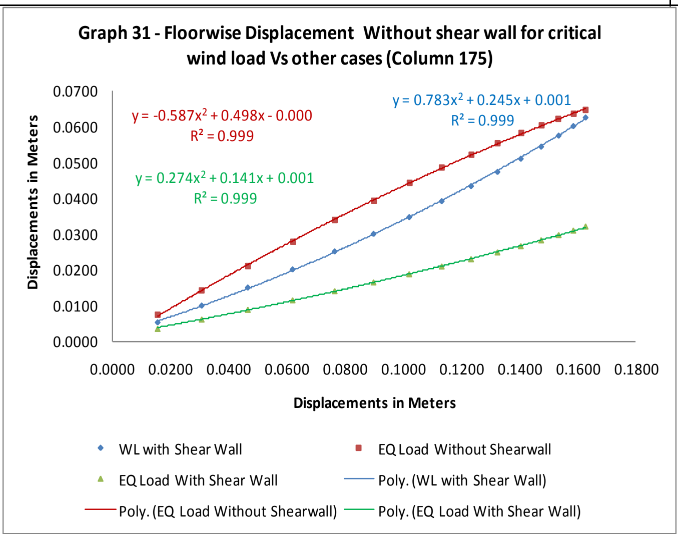

Graph 18A - Col. 136
Floors Vs % reduction in Displacements
Displacements in Meters
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
y = -0.061x² + 0.965x + 60.48
R² = 0.736
y = -0.131x² + 2.4x + 33.65
R² = 0.812
0
2
4
6
8
10
12
14
16
Floors
Critical WL
Critical EQ Load
Poly. (Critical WL)
Poly. (Critical EQ Load)


Graph 19A - Col. 175
Floors Vs % reduction in Displacements
y = -0.022x² - 0.132x + 68.00
R² = 0.969
y = -0.093x² + 1.012x + 55.26
R² = 0.886
Displacements in Meters
Floors
Critical WL
Critical EQ Load
Poly. (Critical WL)
Poly. (Critical EQ Load)


Graph 20A - Col. 257
Floors Vs % reduction in Displacements
y = -0.061x² + 1.051x + 60.43
R² = 0.790
y = -0.139x² + 2.687x + 30.63
R² = 0.937
Displacements in Meters
Floors
Critical WL
Critical EQ Load
Poly. (Critical WL)
Poly. (Critical EQ Load)


Graph 29 - Floorwise Displacement Without shear wall for critical wind load Vs other cases (Column 93)
y = -0.192x² + 0.417x - 0.000
R² = 0.999
y = 1.810x² - 0.042x + 0.005
R² = 0.993
y = 0.643x² + 0.006x + 0.000
R² = 0.999
Displacements in Meters
Displacements in Meters
WL with Shear Wall
EQ Load Without Shearwall
EQ Load With Shear Wall
Poly. (WL with Shear Wall)
Poly. (EQ Load Without Shearwall)
Poly. (EQ Load With Shear Wall)


Graph 30 - Floorwise Displacement Without shear wall for critical wind load Vs other cases (Column 136)
y = -0.420x² + 0.434x + 0.000
R² = 0.999
y = 0.449x² + 0.288x + 0.002
R² = 0.999
y = -0.020x² + 0.204x + 0.002
R² = 0.999
Displacements in Meters
Displacements in Meters
WL with Shear Wall
EQ Load Without Shearwall
EQ Load With Shear Wall
Poly. (WL with Shear Wall)
Poly. (EQ Load Without Shearwall)
Poly. (EQ Load With Shear Wall)


Graph 31 - Floorwise Displacement Without shear wall for critical wind load Vs other cases (Column 175)
y = -0.587x² + 0.498x - 0.000
R² = 0.999
y = 0.783x² + 0.245x + 0.001
R² = 0.999
y = 0.274x² + 0.141x + 0.001
R² = 0.999
Displacements in Meters
Displacements in Meters
WL with Shear Wall
EQ Load Without Shearwall
EQ Load With Shear Wall
Poly. (WL with Shear Wall)
Poly. (EQ Load Without Shearwall)
Poly. (EQ Load With Shear Wall)

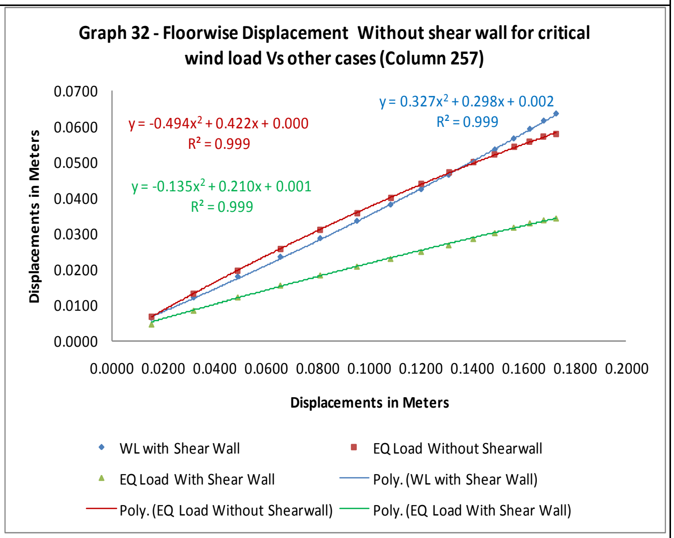

Graph 32 - Floorwise Displacement Without shear wall for critical wind load Vs other cases (Column 257)
y = -0.494x² + 0.422x + 0.000
R² = 0.999
y = 0.327x² + 0.298x + 0.002
R² = 0.999
y = -0.135x² + 0.210x + 0.001
R² = 0.999
Displacements in Meters
Displacements in Meters
WL with Shear Wall
EQ Load Without Shearwall
EQ Load With Shear Wall
Poly. (WL with Shear Wall)
Poly. (EQ Load Without Shearwall)
Poly. (EQ Load With Shear Wall)

TABLE NO. 1 - Mathematical models developed for calculation of floor displacement for three cases from known floor displacements for critical wind load consideration without shear wall

Column Type	Column No.	Case	Mathematical Model	R^2 Value	Validity of model
Corner	93	Critical WL With Shear Wall	$y = 1.810x^2 - 0.042x + 0.005$ This model may not be successful at lower levels as the displacements are too low.	0.993	93.33% predictions within 85% confidence limit
		Critical EQ Load Without Shear Wall	$y = -0.192x^2 + 0.417x$	0.999	100% predictions within 95% confidence limit
		Critical EQ Load With Shear Wall	$y = 0.643x^2 + 0.006x$ This model may not be successful at lower levels as the displacements are too low.	0.999	66.67% predictions within 85% confidence limit
Outside	136	Critical WL With Shear Wall	$y = 0.449x^2 + 0.288x + 0.002$	0.999	100% predictions within 95% confidence limit
		Critical EQ Load Without Shear Wall	$y = -0.420x^2 + 0.434x$	0.999	100% predictions within 90% confidence limit
		Critical EQ Load With Shear Wall	$y = -0.020x^2 + 0.204x + 0.002$	0.999	100% predictions within 95% confidence limit
Inside	175	Critical WL With Shear Wall	$y = 0.783x^2 + 0.245x + 0.001$	0.999	100% predictions within 90% confidence limit
		Critical EQ Load Without Shear Wall	$y = -0.587x^2 + 0.498x$	0.999	100% predictions within 95% confidence limit
		Critical EQ Load With Shear Wall	$y = 0.274x^2 + 0.141x + 0.001$	0.999	100% predictions within 90% confidence limit
Middle	257	Critical WL With Shear Wall	$y = 0.327x^2 + 0.298x + 0.002$	0.999	100% predictions within 90% confidence limit
		Critical EQ Load Without Shear Wall	$y = -0.494x^2 + 0.422x$	0.999	100% predictions within 90% confidence limit
		Critical EQ Load With Shear Wall	$y = -0.135x^2 + 0.210x + 0.001$	0.999	100% predictions within 85% confidence limit

IV. OBSERVATIONS

Following observations are drawn from the tables and graphs:

1) The critical load combinations for displacements are found to be (-1.5EQZ + 1.5DL) or (-1.5EQX + 1.5DL) in case of earthquake. This depends on the position of respective column and its orientation.

2) For wind loads, the critical load combination for displacements is found to be (1.5WLX- + 1.5DL).

3) By providing shear walls, reduction in displacement at various levels of column is substantial (reduced nearly by 70% in wind and 55% in earthquake). Graphs 17A to 20A gives details of floor wise percentage reduction in displacement by providing shear walls.

4) Data analysis could result into significant correlation between the displacements due to critical wind load without shear wall only, against the displacements for critical wind loads with shear wall, critical earthquake loads with and without shear wall. This can be seen from graph 29 to 32.

V. CONCLUSIONS

1) Providing shear walls at adequate locations substantially reduces the displacements due to earthquake and wind loads.

2) In earthquake zone II, if the wind velocity is 39 m/s, then critical wind loads are much higher than critical earthquake loads. Thus, the displacements due to critical wind loads are higher than critical earthquake loads.

3) Mathematical models developed can predict the displacements for critical wind loads with shear wall, critical earthquake loads with and without shear wall from the displacements at any level due to wind loads in the building without shear wall.

4) The validity of mathematical models suggests greater amount of interrelationships between the displacements at any level due to wind, earthquake loads with or without providing shear wall.

ACKNOWLEDGEMENTS

I have a great pleasure to express my deep sense of gratitude of my guide Dr. A. M. Pande for his eminent guidance and generous encouragement throughout my project work. I would like to express my deepest appreciation to my parents, the most precious people in my life.

REFERENCES

1) J.Fu, A.Shibata, J.I. Shibuya and T.Saito, 3D inelastic earthquake response of RC frames with shear wall, *Earthquake engineering, tenth world conference*, 1992, Balkema, Rotterdam

2) Lih Shing Fur, Henry T.Y.Yang and Sesashayee Ankireddi, Vibration control of tall buildings under seismic and wind loads

3) Y. Tamura, Wind and tall buildings, *EACWE 5*, 2009, Florence, Italy

4) P. Mendis, T. Ngo, N. Haritos, A. Hira, B. Samali, J. Cheung, Wind loading on tall buildings, *EJSE Special Issue: Loading on Structures*, 2007