Influence of wind speed on a Reinforced Concrete tall building

P Krishnam Raju¹, V Ravindra², V Susmitha³

¹Department of Civil Engineering, Gayatri Vidya Parishad College of Engineering (A), Visakhapatnam - 530048, INDIA,
²Department of Civil Engineering, Jawaharlal Nehru Technological University Kakinada, Kakinada - 533003, INDIA,
³Department of Civil Engineering, Gayatri Vidya Parishad College of Engineering (A), Visakhapatnam - 530048, INDIA,
E-mail: drpkraju1962@gmail.com

Abstract. This study is conducted to assess the influence of wind on a 17-storey multipurpose Reinforced Concrete Tall Building according to the revised wind code of IS 875 (Part 3): 2015 compared to its previous version i.e., IS 875 (Part 3): 1987. The study covers all basic wind speeds of 33, 39, 44, 47, 50 and 55m/s as specified in the Indian standards. Dynamic effects due to ‘Along wind’ and ‘across wind’ are considered in the analysis using ETABS evaluation software. The Lateral load, Lateral sway and Longitudinal Rebar Percentage (LRP) are found to be increased as per the revised version. The LRP in the Middle, Edge and Corner columns are also reported. An increase of total Rebar quantity by about 3.7% (beams and columns) in the entire structure for a basic wind speed of 50m/s is observed.

1. Introduction

Tall buildings are being constructed in major cities for the optimum utilization of limited land area and also to accommodate commercial, residential and corporate space in a single building. Tall building construction nowadays is an indication of prosperity, socio-economic status, technological and engineering advancement. Therefore, the effect of wind load must be considered to obtain the strength and stability of the structure to resist wind in addition to gravity loads. Gordan et al. [1] studied about wind interaction on the Tall building and concluded that ‘across wind response’ is greater than ‘along wind response’ because of vortex shedding due to which the lateral displacement in ‘across wind direction’ is more than ‘along wind direction’.

Halder and Dutta [2] suggested that the buildings with the number of storeys more than 25 and aspect ratio < 0.5 in Terrain category 3 should be analysed by the gust factor method to predict the response of the building. Likewise, they suggested a method to be preferred in other terrain categories also. Kumar and Rajan [3] observed that the Gust Response Factor values on the windward side are almost comparable at all levels of the building considered while on the leeward side, fewer values are obtained at 8th level than other. This may be due to the terrain roughness factor and vortex shedding phenomenon.

Mendis et al. [4] discussed the advanced levels of wind design, in the context of the Australian Wind Code and different flow situations that arise due to the interaction of wind with the structure and concluded that significant dynamic response can result from both buffeting and across wind loading excitation mechanisms.
Zhou and Kareem [5] derived the advantage of Gust loading factor method while assigning the wind loads to a tall structure based on Base bending moment over the traditional Gust loading factor which is based on displacement approach.

An earlier revision of IS 875 (Part 3): 1987 [6] has only accommodated the provisions for along wind load in gust factor method in which dynamic parameters like peak factor, roughness factor, background factor, size reduction factor, turbulence length scale and measure of available energy are derived from graphs and across wind load procedure is not mentioned.

Importance factor, wind directionality factor, area averaging factor and combination factor are now introduced in IS 875 (Part 3): 2015 [7] in addition to across wind load in gust factor method. Dynamic parameters in along wind response are now obtained using formulae and procedures as given in codes. The study aims to compare the impact of wind on a Tall Building as per the revised provisions of the IS 875 (Part 3): 2015 [7] code and its previous version IS 875 (Part 3): 1987 [6]. The objective of the study is to compare the Code provisions of IS 875 (Part 3): 1987 [6] and IS 875 (Part 3): 2015 [7] that influence the Structural Design. Further, Lateral sway and its pattern are evaluated as per the above Codes for all the basic wind speed values of 33, 39, 44, 47, 50 and 55m/s.

The Longitudinal Rebar Percentage (LRP) is assessed for Middle column, Edge column and Corner column. The total longitudinal rebar quantity is estimated for all the columns and beams in the entire building for a basic speed of 50m/s using the above-mentioned codes.

The study aims to compare the impact of wind on a Tall Building as per the revised provisions of the IS 875 (Part 3): 2015 [7] code and its previous version IS 875 (Part 3): 1987 [6]. The objective of the study is to compare the Code provisions of IS 875 (Part 3): 1987 [6] and IS 875 (Part 3): 2015 [7] that influence the Structural Design. Further, Lateral sway and its pattern are evaluated as per the above Codes for all the basic wind speed values of 33, 39, 44, 47, 50 and 55m/s.

The design of the structure was carried out for combinations of wind in addition to dead and live loads as per IS 875 (Part 1) [8] and IS 875 (Part 2) [9] under a limit state of Collapse and Serviceability as per IS 456: 2000 [10].

Pressure coefficient method and Gust factor method were adopted for the analysis of the structure to assess the Lateral load, Lateral sway and Longitudinal Rebar Percentage and Quantity in the superstructure. ETABS Evaluation Version software is used for analysis and design.

### 2. Building configuration

A multipurpose 17 storey building consisting of two parking, two commercial and 13 residential floors with M30 grade concrete and Fe500 steel is considered for the study.

The total height of the building is about 53m from the plinth level including its basements. The overall plan dimensions of the building are 29.0m × 37.5m. The Typical floor plan of the building is shown in figure 1.

The total height of the building =53m > 50m
Height of the building = 53
Width of the building = \( \frac{29}{1.82} = 1.82 < 6 \)

According to the above criteria, the building is categorised as a tall structure as per Cl.4.13 of IS 875 (Part 3): 2015 [7].

Dimensions of the members were fixed to cater for all basic wind speeds satisfying the reinforcement and serviceability limitations. The member sizes adopted in the structure are given in Table 1.

**Table 1. Cross-sectional dimensions of structural elements**

| Description            | Size                              |
|------------------------|-----------------------------------|
| Column Size (mm × mm)  | 530 × 910, 450 × 910, 380 × 910, 450 × 830, 380 × 830 |
| Beam Size (mm × mm)    | 380 × 760, 300 × 760, 300 × 610, 300 × 530 and 300 × 450 |
|                        | 230 × 580, 300 × 450, 380 × 630 and 300 × 760 |
| Slab Thickness (mm)    | 125                               |

Three typical columns viz., Middle column (MC), Edge column (EC), and Corner column (CC) in the building are considered for the study as shown in figure 1.
3. Results and Discussion

The results are presented in terms of Lateral load, Lateral Sway, Longitudinal Rebar Percentage and Quantity of reinforcement. Comparison is made with the results obtained from the analysis as per IS 875 (Part 3): 1987 [6] and IS 875 (Part 3): 2015 [7] and design as per IS 456: 2000 [10].

3.1. Lateral load due to wind

The lateral load due to wind is estimated taking a basic wind speed of 50 m/s as per IS 875 (Part 3): 1987 [6] and IS 875 (Part 3): 2015 [7] for both ‘along’ and ‘across’ winds in X and Y directions are shown in figure 2.

The wind load ‘Along wind’ is gradually increased above ground level in both X and Y directions and the maximum is observed at 16th storey.

The maximum increase is found to be 12% and 13% in X and Y directions as per IS 875 (Part 3): 2015 [7] compared to its earlier version. However, as per IS 875 (Part 3): 1987 [6] the lateral load is found shot up at the roof level of the ground floor and same is due to the changes as adopted in hourly mean wind speed factor.

The wind load due to ‘Across wind’ is gradually increased and reached to about 13kN and 10kN in X and Y directions respectively at the roof level which is an additional load as per IS 875 (Part 3): 2015 [7]. A similar trend is observed for the remaining wind zones also.

Figure 1. Typical floor plan with Column positions and Beam layout (All dimensions are in m)

MC: Middle Column; EC: Edge Column; CC: Corner Column
3.2. Lateral sway

Lateral sway results obtained are absolute maximum from load combinations of Limit state of serviceability and the same is reported in Table 2. These values are below the permissible limit of 106mm as per Clause 20.5 of IS 456: 2000 [10]

| Table 2. Maximum Lateral sway (mm) for various basic wind speeds |
|---------------------------------------------------------------|
| IS 875(Part 3) | \( V_b \) as 33 (m/s) | \( V_b \) as 39 (m/s) | \( V_b \) as 44 (m/s) | \( V_b \) as 47 (m/s) | \( V_b \) as 50 (m/s) | \( V_b \) as 55 (m/s) |
|-----------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| 1987 rev.       | 21.2                    | 30.5                    | 40.2                    | 46.2                    | 53.3                    | 66.4                    |
| 2015 rev.       | 25.0                    | 35.7                    | 45.4                    | 54.8                    | 59.5                    | 73.0                    |

There is an increase in lateral sway obtained as per IS 875 (Part 3): 2015 [7] compared to its previous version. This increase is found to be 18, 17, 13, 19, 12 and 10% respectively for \( V_b \) as 33, 39, 44, 47, 50 and 55 m/s. However, the maximum lateral sway obtained at the top storey for all the basic wind speeds considered is within the permissible limits.

3.3. Longitudinal rebar percentage (LRP) in columns

The change in wind parameters from the IS 875 (Part 3): 1987 [6] to the IS 875 (Part 3): 2015 [7] also resulted in changes to the reinforcement in beams and columns.
The Longitudinal Rebar Percentage in three typical columns viz., Middle Column (MC), Edge Column (EC) and Corner Column (CC) for basic wind speeds of 33, 39, 44, 47, 50 and 55m/s are shown in figure 3, figure 4 and figure 5 respectively.

3.3.1 Middle Column (MC). From figure 3, it is observed that the Longitudinal rebar percentage with $V_b$ as 33m/s is the same up to the 7th storey and also from 15th to 17th storey. A maximum difference of 7.7% is observed in the 13th storey. For $V_b$ as 39m/s, LRP is same up to the 5th storey. The variation is noticed from 6th to the 16th storey in which a maximum of 9% is observed in the 14th storey. For $V_b$ as 44, 47, 50 and 55m/s, the maximum percentage increase of LRP are found to be 8%, 15%, 13% and 11% respectively in 15th storey.

3.3.2 Edge Column (EC). From figure 4, an increase of 2.2% is observed in storey 6, whereas rebar percentage in all other storeys remained the same for both the codes with a basic wind speed of 33m/s. LRP due to previous code has increased up to the maximum of 7.5% in 12th storey and it remains same above 13th storey for $V_b$ as 39m/s. For basic wind speed of 44m/s, 47m/s and 50m/s, the maximum percentage difference is 9.5%, 10.4% and 9% respectively at 14th storey. However, it remains the same up to the top of the building. For $V_b$ as 55m/s, the maximum variation in LRP is 9% in 14th storey while no variation is observed in 16th and 17th storey.

**Figure 3.** Longitudinal Rebar Percentages in Middle Column (MC)
3.3.3 Corner Column (CC). A zigzag variation is seen in Corner Column throughout the building height for all the basic wind speeds as shown in Figure 5. An increase in the percentage of longitudinal rebar of 6% is observed in 6th storey. Then after, no difference in LRP is observed for a basic wind speed of 33 m/s.
For $V_b$ as 39 m/s, a maximum increase of 8% is obtained in both 6th and 13th storey. Similarly, there is an increase of LRP by 14% as seen in 14th storey for $V_b$ of 44 m/s whereas the maximum difference of 13% and 11% are obtained respectively for a basic wind speed of 47 and 50 m/s in both 12th and 14th storey.
For $V_b$ of 55 m/s, an increased by 17% is observed in the 15th storey. Around 10% increase is observed until 14th storey.

Figure 4. Longitudinal Rebar Percentages in Edge Column (EC)
3.3.4 Quantity of longitudinal rebar in columns. Variation in the Quantity of longitudinal rebar in columns in terms of mass is estimated in the entire building and presented in Table 3 for the basic wind speeds of 33 m/s, 39 m/s, 44 m/s, 47 m/s, 50 m/s and 55 m/s and found that there is an increase of 1.0, 2.5, 3.5, 5.0, 4.7 and 5.1% respectively.

### Table 3. Total Rebar quantity in Columns for the entire building

| Basic wind speed | IS 875(Part 3): 1987 | IS 875(Part 3): 2015 | Percentage increase |
|------------------|-----------------------|-----------------------|---------------------|
| 33 m/s           | 84722 kg              | 85578 kg              | 1.0                 |
| 39 m/s           | 86969 kg              | 89185 kg              | 2.5                 |
| 44 m/s           | 90633 kg              | 93847 kg              | 3.5                 |
| 47 m/s           | 93620 kg              | 98275 kg              | 5.0                 |
| 50 m/s           | 97304 kg              | 101851 kg             | 4.7                 |
| 55 m/s           | 105086 kg             | 110475 kg             | 5.1                 |

3.3.5 Quantity of longitudinal rebar in beams. The total rebar quantity in beams for the entire structure is estimated for a basic wind speed of 50 m/s (Visakhapatnam). The total rebar quantity for all the beams in the entire building is presented in Table 4.
It can be observed from Table 4 that the total rebar quantity in beams for the entire building for a basic wind speed of 50 m/s increases by 2.7%.

### Table 4. Quantity of Longitudinal rebar (kg) in beams

| Storey | IS 875 (Part 3): 1987 | IS 875 (Part 3): 2015 | Percentage increase |
|--------|-----------------------|-----------------------|---------------------|
| 17     | 3922                  | 3920                  | -0.1                |
| 16     | 5195                  | 5248                  | 1.0                 |
| 15     | 5253                  | 5480                  | 4.3                 |
| 14     | 5195                  | 5412                  | 4.2                 |
| 13     | 5383                  | 5535                  | 2.8                 |
| 12     | 5580                  | 5700                  | 2.2                 |
| 11     | 5788                  | 5862                  | 1.3                 |
| 10     | 5788                  | 5962                  | 3.0                 |
| 9      | 5899                  | 6032                  | 2.3                 |
| 8      | 6088                  | 6153                  | 1.1                 |
| 7      | 6197                  | 6351                  | 2.5                 |
| 6      | 6268                  | 6410                  | 2.3                 |
| 5      | 6207                  | 6460                  | 4.1                 |
| 4      | 5680                  | 5850                  | 3.0                 |
| 3      | 4939                  | 5112                  | 3.5                 |
| 2      | 4989                  | 5160                  | 3.4                 |
| 1      | 4757                  | 4970                  | 4.5                 |
| Total  | 93127                 | 95615                 | 2.7                 |

#### 3.3.6 Total quantity of rebar. The total rebar quantity in both beams and columns excluding foundation and slabs is shown in Table 5. It is observed that the percentage increase in the total quantity of rebar (beams + columns) is 3.7% as per IS 875 (Part 3): 2015 [7] compared to IS 875 (Part 3): 1987 [6].

### Table 5. Total Rebar quantity of beams and columns (Vb as 50m/s)

| Structural element | IS 875(Part 3): 1987 | IS 875(Part 3): 2015 | % increase |
|--------------------|-----------------------|-----------------------|------------|
| Beams              | 93127 kg              | 95615 kg              | 2.7        |
| Columns            | 97304 kg              | 101851 kg             | 4.7        |
| Total quantity     | 190431 kg             | 197466 kg             | 3.7        |

### 4. Conclusions

The results are compared and conclusions on the following attributes are made.

#### 4.1 Conclusions on lateral load and lateral sway.

1. The wind load “Along wind” is gradually increased above 6 m onwards from ground level in both X and Y directions and maximum is at 16th storey in all basic wind speed cases whereas, the “Across wind” is an additional load on the structure as per IS 875 (Part 3): 2015 compared to its previous revision.

2. The lateral sway is increased by about 10% to 20% against basic wind speeds of 33 to 55 m/s as per the current revision (IS 875 (Part 3): 2015) of the code and same is due to changes in the dynamic analysis procedure.

#### 4.2 Conclusions on longitudinal rebar percentage.

The Longitudinal rebar percentage (LRP) and Quantity of steel reinforcement obtained in three typical columns viz., Middle column, Edge column and Corner column for various basic wind
speeds of 33m/s, 39m/s, 44m/s, 47m/s, 50m/s and 55m/s are compared between IS 875 (Part 3): 1987 [6] and IS 875 (Part 3): 2015 [7].

3. The overall quantity of rebar in the Middle column and Edge columns is increased up to 4% when basic wind speeds are increased to 55m/s.

4. The overall quantity of rebar in corner column is increased by 2.2%, 5.5%, 7%, 7.6%, 8% and 8.2% for basic wind speeds of 33, 39, 44, 47, 50 and 55m/s respectively.

5. The total Rebar quantity for the entire building (excluding foundations and slabs) is increased by 3.7% as per IS 875 (Part 3): 2015 compared to IS 875 (Part 3): 1987.

5. Recommendation

As the overall increase in rebar quantity on a 17-storey multi-purpose building is only 3.7%, as per the current wind code involving rigorous calculations in Dynamic analysis, the possibility of simplified methods may be explored.

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