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Parametric Studies on Dynamic Effects Due To Wind on Buildings of Different Base Configurations

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Abstract—Most international codes and standards provide guidelines and procedures for assessing the along-wind effects on tall structures. The paper presents the comparison between IS 875 (PART - 3) : 1987 and IS 875 (PART - 3) : 2015 considering the effect of static wind loads and dynamic wind loads on high rise buildings. Due to the effect of these loads the forces on columns are derived for different load combinations. This study helps to estimate critical load combinations for column forces.

Keywords— along-wind effects, static wind load, dynamic wind load, high rise, load combinations, etc.

I. INTRODUCTION

Understanding of dynamic effects due to wind and estimation of the correct along wind load is very important in the design of high rise structures. Section 7.0 & 8.0 of IS875 part III governs the criteria for estimation of this load. The dynamic wind effects in reference to wind induced oscillations are to be examine for a building and close structure with height to minimum lateral dimension ratio more than 5.0 and buildings and close structures whose natural frequency in 1st mode is less than 1.0hz.

The natural frequency is estimated by the empirical formula given in the code and it may vary with the structure as it depends on the stiffness and weight of the structure. Though the code has specified for examination of structures with height to minimum lateral dimension more than 5.0 there can also be severe effects on structures with the ratio 4 or 4.5. The exact natural frequency may also significantly alter the estimation of along wind load.

For the estimation of along wind load we are also expected to refer many graphs and tables in section 7.0 and 8.0 of IS875 partIII. Digitization of the graphs and understanding limitations of the charts is very important. In view of this it is realize to carry out parametric studies on the high rise buildings with different base configurations.

II. COMPARISON BETWEEN IS875 (PART 3):1987 AND IS875(PART 3):2015

A) STATIC EFFECTS

IS 875 (PART - 3) : 1987	IS 875 (PART - 3) : 2015
Vz = Vb x K1 x K2 x K3	Vz = Vb x K1 x K2 x K3 x K4
Pd = Pz = 0.6 x Vz^2	Pd = Kd x Ka x Kc x (Pz = 0.6 x Vz^2)
For K2 Calculation : Terrain category and Class of structure	For K2 Calculation : Terrain category only.

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Table 2 Values (K2 calculation)	Change in values of Table 2 (K2 calculation)
K4 is not introduced	K4 = 1 (clause no. 6.3.4)
Kd , Ka , Kc are not introduced	Kd = 0.9, Ka = 0.9, Kc = 0.9

K4 = Importance Factor For Cyclonic Region,
Kd = Wind Directionality Factor,
Ka = Area Averaging Factor,
Kc = Combination Factor

COMPARISION		**IS 875:1987**		**IS 875:2015**		
SR.NO.	HT.	K2	Pz = Pd	K2	Pz	Pd
1.	30	0.88	1.59	0.91	1.24	0.91
2.	20	0.94	1.44	0.97	1.41	1.03
3.	15	0.98	1.325	1.01	1.53	1.12
4.	10	1.03	1.159	1.06	1.69	1.23

B) DYNAMIC EFFECTS

SR.NO.	IS:875 (PART 3)-1987	IS:875 (PART 3)- 2015
1) motion due to vortex shedding	$\eta = (SV_d/b)$ a)Circular structure- S=0.20 for bVz not greater than 7 and =0.25 bVz greater than 7 and b)Rectangular structure- S=0.15 for all values of bVz	$fs = (S_t V_{zH}/b)$ a)Circular structure- St=0.20 for DV_{zH} less than 6 m^2/sec and =0.25 for DV_{zH} more than or equal to 6m^2/sec b)Rectangular structure- St= 0.10
2) Along wind load	$F_Z = C_f A_e P_z G$	$F_Z = C_{fz} A_z P_d G$
3) Gust factor	$G = 1 + g_f r \sqrt{\left[B(1+\phi)^2 + \frac{SE}{\beta}\right]}$	$= 1 + r\sqrt{\left[g_v^2 B_s (1+g)^2 + \frac{H_s g_R^2 SE}{\beta}\right]}$
4) background factor	Calculated from fig no 9 pg. no. 50	$= \frac{1}{\left[1 + \frac{\sqrt{0.26(h-s)^2 + 0.46 b_{sh}^2}}{L_h}\right]}$
5) peak factor	$g_f r$= calculated from fig no 8 page no. 50	$= \sqrt{[2\ln(3600 f_a)]}$
6) L_h	Calculated from fig no. 8 page no. 50	$L_h = 85(h/10)^{0.25}$ -for terrain category 1 to 3 $= 70(h/10)^{0.25}$ -for terrain category 4
7) size reduction factor	Calculated from fig no. 10 page no. 51	$= \frac{1}{\left[1 + \frac{3.5 f_a h}{\bar{V}_{h,d}}\right]\left[1 + \frac{4 f_a b_{0h}}{\bar{V}_{h,d}}\right]}$
8) Gust energy factor	Calculated from fig no. 11 page no. 52	$= \frac{\pi N}{(1 + 70.8 N^2)^{5/6}}$
9) peak accleration	$a = (2\pi f_0)^2 \bar{x} g_f r \sqrt{\frac{SE}{\beta}}$	$\hat{\ddot{x}} = (2\pi f_a)^2 \bar{x} g_R r \sqrt{\frac{SE}{\beta}}$

C) MANUAL CALCULATIONS OF DYNAMIC WIND FORCE ON STRUCTURES (IS 875 (PART 3):1987)-

DYNAMIC EFFECTS

a. Buildings and closed structures with a height to minimum lateral dimension ratio of more than about 5.0.
b. Buildings and closed structures whose natural frequency in the first mode is less than 1.0 Hz.

Any building or structure which does not satisfy either of the above two criteria shall be examined for dynamic effects of wind.

Calculation of Time Period

a) For moment .resisting frames without bracing or shear walls for resisting the lateral loads T = 0.1 n, where n = number of storeys including basement storeys;
b) For all others T= 0.09 H /√ d, where *H* - total height of the main structure of the building in metres, and d = maximum base dimension of building in meters in a direction parallel to the applied wind force.

8. Gust Factor or Gust Effectiveness Factor Method
8.3 Along Wind Load - Along wind load on a structure on a strip area (Ae) at any height (z) is given by:

$$F_z = C_f A_e p_z G$$

where
F_z = along wind load on the structure at any height z corresponding to strip area
C_f = force coefficient for the building,
A_e = effective frontal area considered for the structure at height z,
p_z = design pressure at height z due to hourly mean wind obtained as 0.6 $V_z{}^2$(N/m^2),
G is given by:

$$G = 1 + g_f r \sqrt{\left[B(1+\phi)^2 + \frac{SE}{\beta}\right]}$$

g_f = peak factor defined as the ratio of the expected peak value to the root mean value of a fluctuating load, and
r = roughness factor which is dependent on the size of the structure in relation to the ground roughness.
The, value of g_f r is given in Fig. 8,
B **=** background factor indicating a measure of slowly varying component of fluctuating wind load and is obtained from
Fig. 9,
SE /β measure of the resonant component of the fluctuating wind load,
S = size reduction factor (see Fig. 10),
E **=** measure of available energy in the wind stream at the natural frequency of the structure (see Fig. 11),
β = damping coefficient (as a fraction of critical damping) of the structure (see Table 34), and

$$\phi = \frac{g_f r \sqrt{B}}{4}$$

is to be accounted only for buildings less than 75 m high in terrain Category 4 and for buildings less than 25 m high in terrain Category 3, and is to be taken as zero in all other cases.

D) MANUAL CALCULATIONS OF DYNAMIC WIND FORCE ON STRUCTURES (IS 875 (PART 3):2015)-

DYNAMIC EFFECTS

a) Buildings and closed structures with a height to minimum lateral dimension ratio of more than about 5.0.
b) Buildings and closed structures whose natural frequency in the first mode is less than 1.0 Hz.

Any building or structure which does not satisfy either of the above two criteria shall be examined for dynamic effects of wind.

Calculation of Time Period

a. For moment .resisting frames without bracing or shear walls for resisting the lateral loads T = 0.1 n, where n = number of storeys including basement storeys;
b. For all others T= 0.09 H /√ d, where *H* - total height of the main structure of the building in metres, and d = maximum base dimension of building in meters in a direction parallel to the applied wind force.

Gust Factor or Gust Effectiveness Factor Method
10.2 Along Wind Load - Along wind load on a structure on a strip area (Ae) at any height (z) is given by:

$$F_z = C_{fz} A_z P_d G \quad \text{(pg no 47)}$$

where

F_z = along wind load on the structure at any height z corresponding to strip area
C_{fz} = force coefficient for the building (pg no 35)
A_z = effective frontal area considered for the structure at height z,
P_d = design pressure at height z due to hourly mean wind obtained as 0.6 $V_{zd}{}^2$(N/m^2),

G is given by: (pg no 47)

$$= 1 + r\sqrt{\left[g_v^2 B_s (1+g)^2 + \frac{H_s g_R^2 SE}{\beta}\right]}$$

Where,

r = roughness factor which is twice the longitudinal turbulence intensity (l_h) (see 6.5 pg no 9)

g_v = peak factor for upwind velocity fluctuation
= 3.0 for category 1 & 2 terrain and
= 4.0 for category 3 & 4 terrains

Bs = Background factor (pg no 47)

$$= \frac{1}{\left[1 + \frac{\sqrt{0.26(h-s)^2 + 0.46 b_{sh}^2}}{L_h}\right]}$$

Where,

b_{sh} = avg breadth of the building/structure between ht s and h
l_h = measure of effective turbulence length scale at ht h, in m
= 85(h/10)$^{0.25}$ for terrain category 1 to 3
= 70(h/10)$^{0.25}$ for terrain category 4

Ø = factor to account for the second order turbulence intensity

$$= \frac{g_v I_{h,i} \sqrt{B_s}}{2}$$

Hs = ht factor for resonance response (pg no 48)
= 1+(s/h)^2

S = Size reduction factor given by (pg no 48)

$$= \frac{1}{\left[1 + \frac{3.5 f_a h}{\bar{V}_{h,d}}\right]\left[1 + \frac{4 f_a b_{0h}}{\bar{V}_{h,d}}\right]}$$

Where,
b_{0h} = av breadth of the building/structure bet 0 and h

E = spectrum of turbulence in the approaching wind stream (pg no 48)

$$= \frac{\pi N}{(1 + 70.8 N^2)^{5/6}}$$

Where,

N = effective reduced frequency
= (fal_h / V_{hd})

Where,

fa = first mode natural frequency of the building/structure in along wind direction in Hz
V_{hd} = design hourly mean wind speed at ht h in m/s (see 6.4)

β = damping coeff of building/structure (see table 36) (pg no 48)

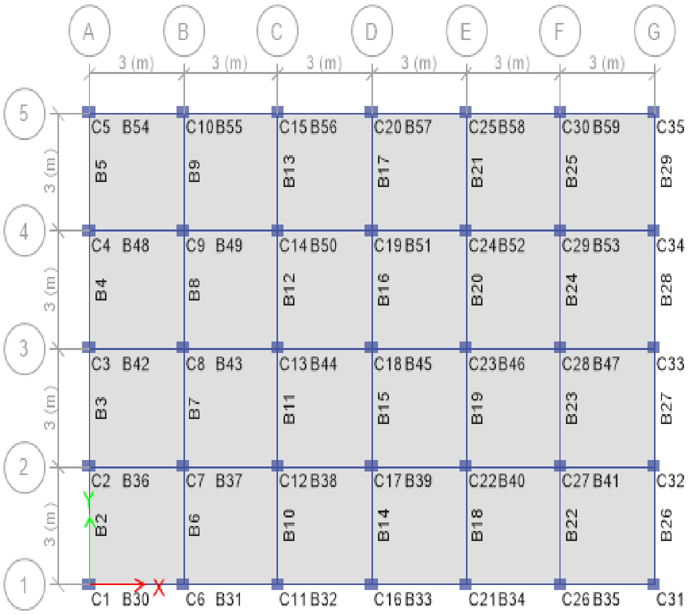
g_R = peak factor for resonant response (pg no 48)

$$= \sqrt{[2\ln(3600 f_a)]}$$

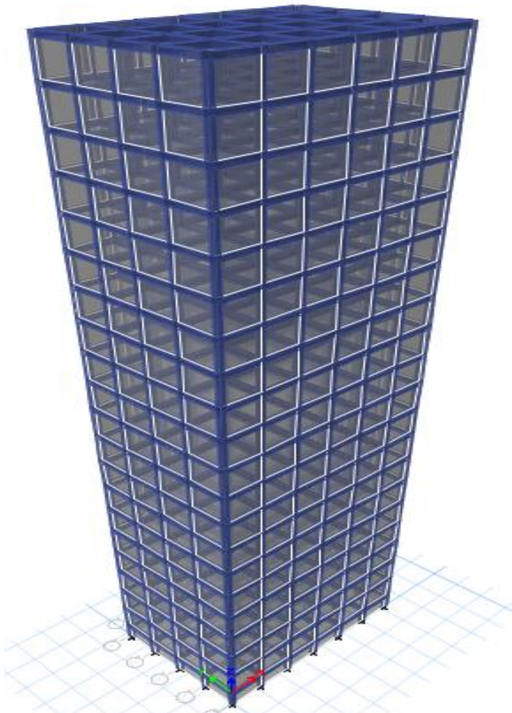
III. MODELLING OF STRUCTURE

SPECIFICATIONS OF STRUCTURE:-

1) Height of the structure= 60m
2) No of stories= 20
3) Height of story= 3m
4) Width of structure = 18m
5) Depth of the structure in wind direction= 12m
6) Height to min lateral dimension ratio= 60/12 = 5



PLAN



3D VIEW

IV. ANALYSIS

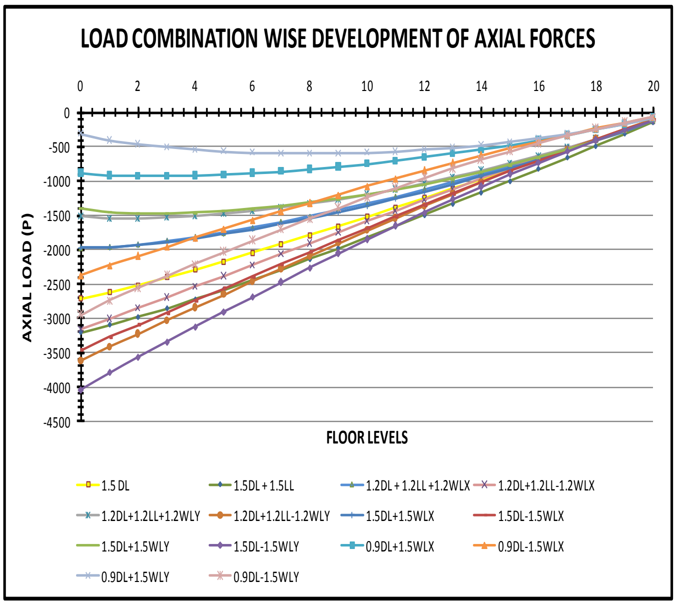
The above structure is analysed by using ETAB software. The results are as follows-

GRAPHICAL REPRESENTATION-

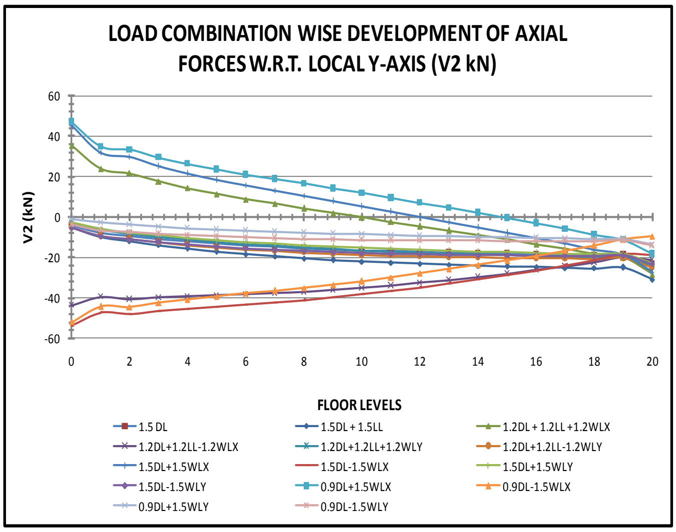
1)For corner column c1-

On the basis of analysis various forces are calculated on the column c1 which are as follows-

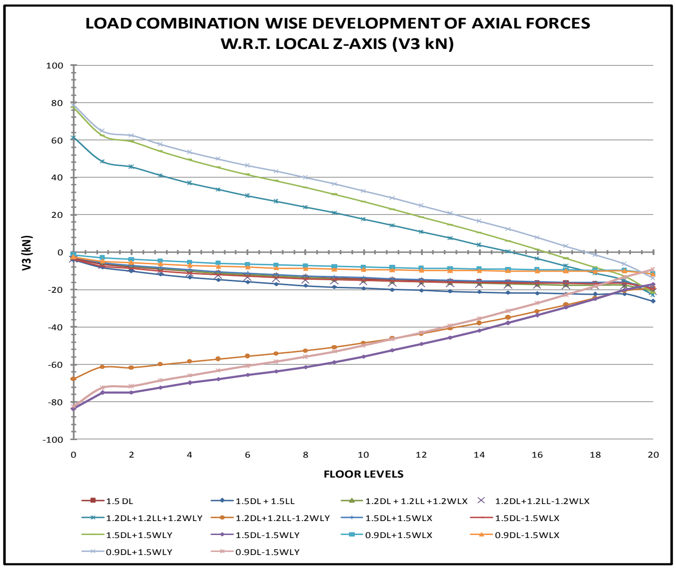
a) Axial force w.r.t. local X-axis (P kN)



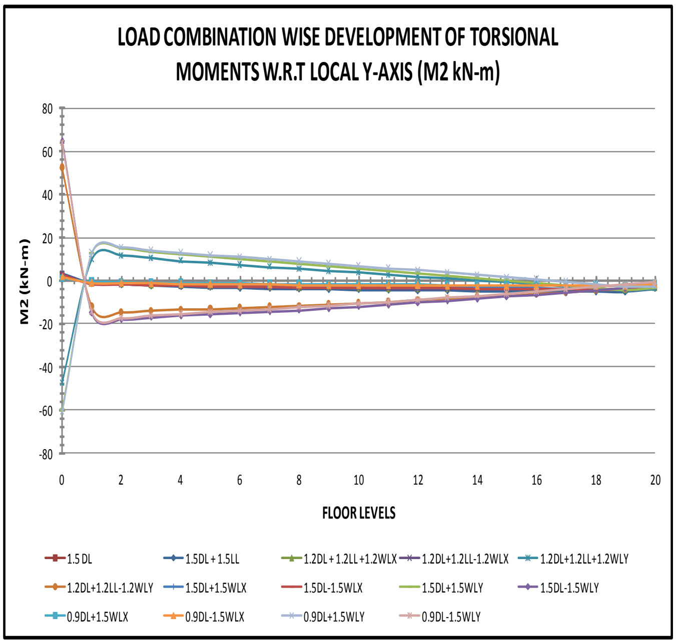
b) Axial force w.r.t. local Y-axis (V2 kN)



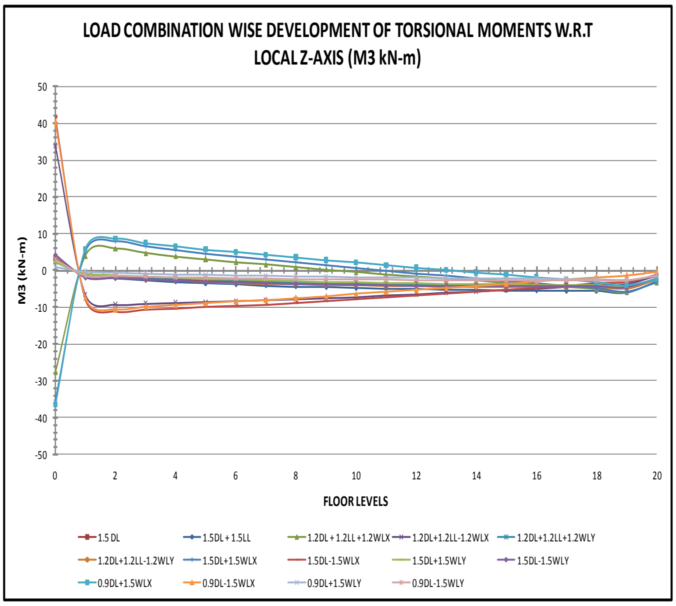
c) Axial force w.r.t. local Z-axis (V3 kN)



d) Torsional moments w.r.t. local Y-axis (M2 kN-m)

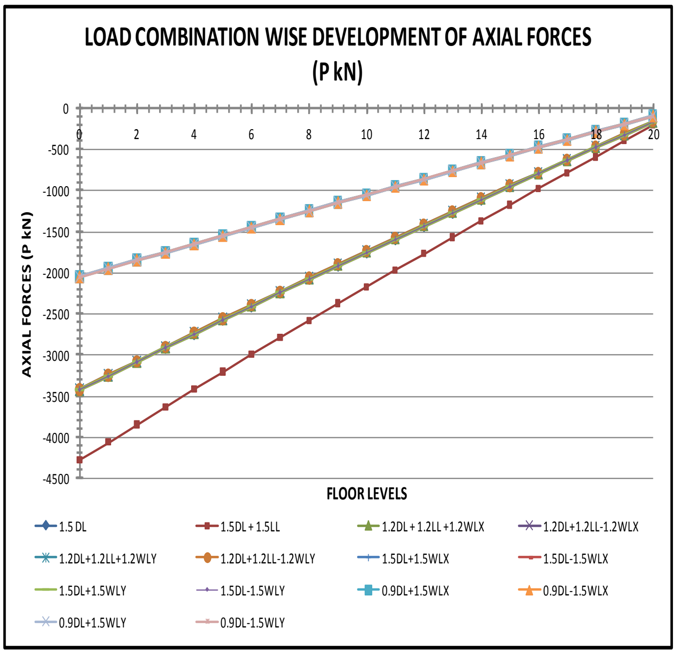


e) Torsional moments w.r.t. local Z-axis (M3 kN-m)

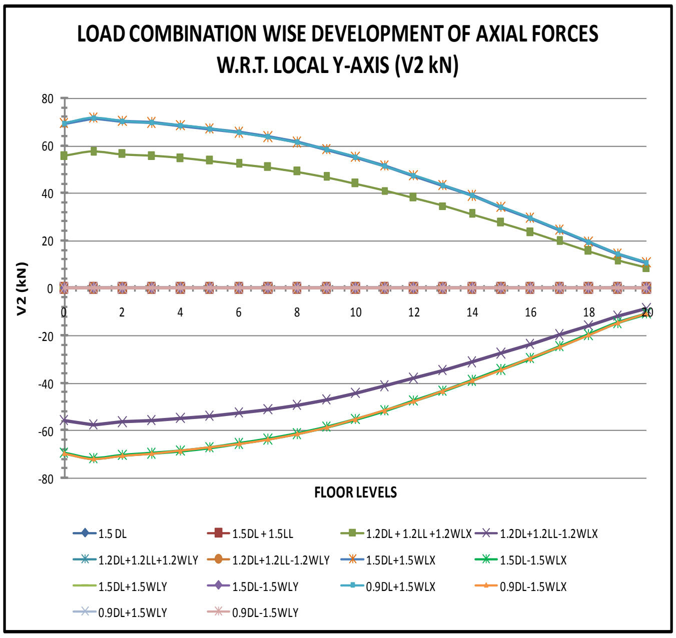


2)For central column c18-

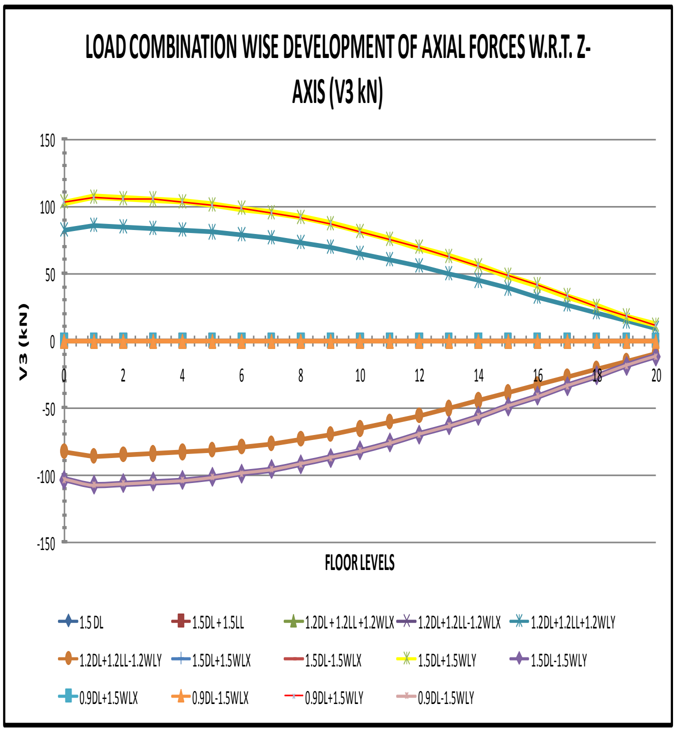
a) Axial force w.r.t. local X-axis (P kN)



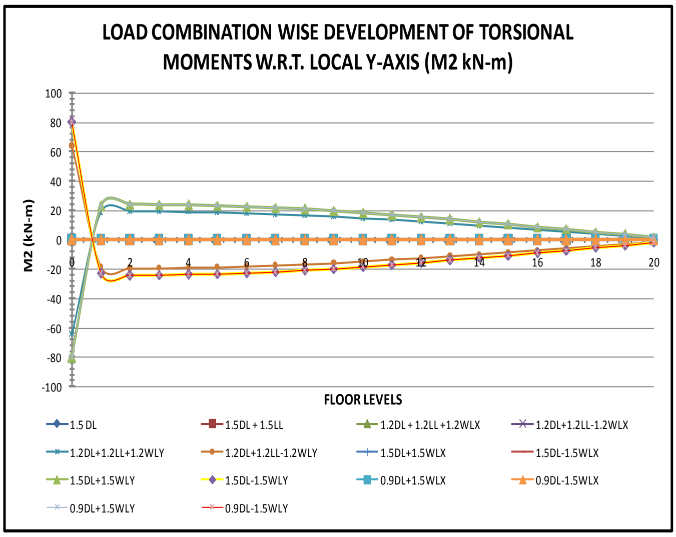
b) Axial force w.r.t. local Y-axis (V2 kN)



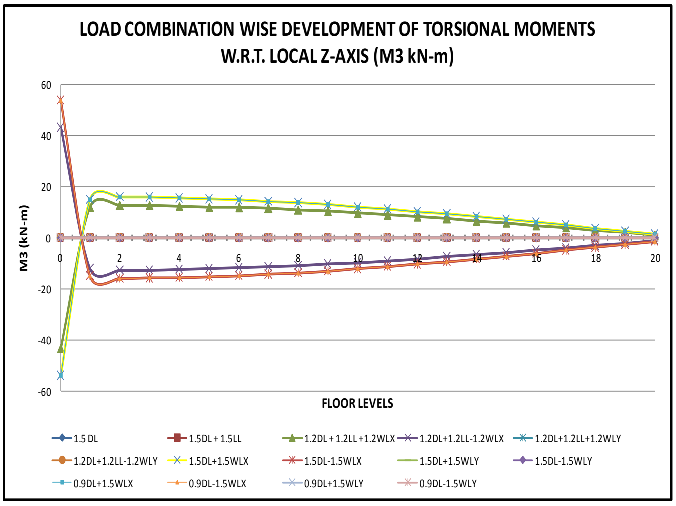
c) Axial force w.r.t. local Z-axis (V3 kN)



d) Torsional moments w.r.t. local Y-axis (M2 kN-m)



e) Torsional moments w.r.t. local Z-axis (M3 kN-m)



V. DISCUSSION AND CONCLUSION-

- There is huge difference between IS875 (part 3):1987 and IS875 (part 3):2015
- In IS875 (part 3):1987 the dynamic wind forces are calculated by using various graphs while in IS875 (part 3):2015 direct empirical formulas
- On the basis of above graphical representation the conclusion are as follows in which the load combinations are listed which gives the maximum forces-

1)For corner column c1-

a) Axial force w.r.t. local X-axis (P kN)

1. 1.5DL-1.5WLY
2. 1.2DL+1.2LL-1.2WLY
3. 1.5DL-1.5WLX
4. 1.5DL + 1.5LL
5. 1.2DL+1.2LL-1.2WLX
6. 0.9DL-1.5WLY

b)Axial force w.r.t. local Y-axis (V2 kN)

1. 1.5DL-1.5WLX
2. 0.9DL-1.5WLX
3. 0.9DL+1.5WLX
4. 1.2DL+1.2LL-1.2WLX
5. 1.5DL+1.5WLX
6. 1.2DL + 1.2LL +1.2WLX

c)Axial force w.r.t. local Z-axis (V3 kN)

1. 1.5DL-1.5WLY
2. 0.9DL-1.5WLY
3. 0.9DL+1.5WLY
4. 1.5DL+1.5WLY
5. 1.2DL+1.2LL-1.2WLY
6. 1.2DL+1.2LL+1.2WLY

d)Torsional moments w.r.t. local Y-axis (M2 kN-m)

1. 0.9DL-1.5WLY
2. 1.5DL-1.5WLY
3. 0.9DL+1.5WLY
4. 1.5DL+1.5WLY
5. 1.2DL+1.2LL-1.2WLY
6. 1.2DL+1.2LL+1.2WLY

e)Torsional moments w.r.t. local Z-axis (M3 kN-m)

1. 1.5DL-1.5WLX
2. 0.9DL-1.5WLX
3. 1.5DL+1.5WLX
4. 0.9DL+1.5WLX
5. 1.2DL+1.2LL-1.2WLX
6. 1.2DL + 1.2LL +1.2WLX

1)For central column c18-

a) Axial force w.r.t. local X-axis (P kN)

1. 1.5DL + 1.5LL
2. 1.2DL + 1.2LL +1.2WLX
3. 1.2DL+1.2LL-1.2WLX
4. 1.2DL+1.2LL+1.2WLY
5. 1.2DL+1.2LL-1.2WLY
6. 1.5 DL

b)Axial force w.r.t. local Y-axis (V2 kN)

1. 1.5DL+1.5WLX
2. 1.5DL-1.5WLX
3. 0.9DL+1.5WLX
4. 0.9DL-1.5WLX
5. 1.2DL + 1.2LL +1.2WLX
6. 1.2DL+1.2LL-1.2WLX

c)Axial force w.r.t. local Z-axis (V3 kN)

1. 1.5DL+1.5WLY
2. 1.5DL-1.5WLY
3. 0.9DL+1.5WLY
4. 0.9DL-1.5WLY
5. 1.2DL+1.2LL+1.2WLY
6. 1.2DL+1.2LL-1.2WLY

d)Torsional moments w.r.t. local Y-axis (M2 kN-m)

1. 1.5DL+1.5WLY
2. 1.5DL-1.5WLY
3. 0.9DL+1.5WLY
4. 0.9DL-1.5WLY
5. 1.2DL+1.2LL+1.2WLY
6. 1.2DL+1.2LL-1.2WLY

e)Torsional moments w.r.t. local Z-axis (M3 kN-m)

1. 1.5DL+1.5WLX
2. 1.5DL-1.5WLX
3. 0.9DL+1.5WLX
4. 0.9DL-1.5WLX
5. 1.2DL + 1.2LL +1.2WLX
6. 1.2DL+1.2LL-1.2WLX

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