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A Comparative Analysis of Multi-Storeyed RCC Structures Considering Cyclonic Factor

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Abstract:
Rapid growth of the urban population in both developed and developing countries and lack of open space high rise structures construction has become a feasible solution to the issues related with urban society instead of single storied constructions. Tall buildings are flexible slender structures and need to be investigated to ascertain the importance of wind induced oscillations or excitations along and across the direction of wind. Correct estimation of the wind forces acting on tall buildings is very essential for the safe design of structural elements as well as safe living of inhabitants. In this paper, a 32 storied RCC framed MS building of 96m high having plan dimension 18m x 24m located at Vishakhapatnam in cyclonic region has been taken for wind load analysis using both the Existing code IS 875 (part-3)- 1987[2]and proposed draft code [4] for IS: 875 (Part 3)-1987. This paper highlights the changes incorporated in the Proposed Draft code regarding wind load analysis

Keywords: Tall buildings, Static method, Gust factor method, Dynamic response factor method, cyclonic Forces, Along wind response.

I. INTRODUCTION

The Indian Standard Code of Practice for Wind loads on buildings and Structures (IS 875-Part-III) contains methods of evaluating the dynamic effects of wind on flexible structures that can oscillate in the wind. The wind on earth's surface is turbulent in nature that gives rise to randomly varying wind pressures about a certain value associated with the mean wind speed. The dynamic part of the wind pressures set up oscillations in a flexible structure, which may be defined as one having the fundamental time period of vibration more than 1.0 second. Oscillations will thus be caused in the along-wind direction. Furthermore, flexible structures also respond in the across-wind direction on account of vortex shedding. In this paper, only the former wind induced oscillation in tall buildings is discussed. To obtain the along-wind response of a flexible structure, the design wind pressure (p_z) has to be obtained for the hourly mean wind speed instead of the 3-second gust speed. The static wind pressure thus obtained is then multiplied by the Gust Factor, G. This approach is based on the stochastic response of an elastic structure acted upon by turbulent wind producing random pressures. The structure is considered to vibrate in its fundamental mode of vibration. The gust factor, G, includes the effect of non-correlation of the peak pressures by defining a size reduction factor, S. It also accounts for the resonant and the non-resonant effects of the random wind force. The equation for G contains two terms, one for the low frequency wind speed variations called the non-resonant or 'background' effects, and the other for resonance effects. The first term accounts for the quasi-static dynamic response below the natural frequency of vibration of the structure while the second term depends on the gust energy and aerodynamic admittance at the natural frequency of vibration as well as on the damping in the system. A lot of change has been incorporated in the empirical formulae for calculation of Gust Factor, G in the proposed draft code [4] as compared to the existing code implemented in the year 1987. Four charts (Figures 8 to 11of existing code) for calculation of background factor "Bs", size reduction factor "S" and Gust Energy factor "E" has been replaced with other empirical expressions in the proposed draft code [4]. The roughness factor r together with the peak factor g_f (a measure of the turbulence intensity present in the wind) as well as a measure of turbulence length scale, L_h found from Fig. 8 in old code has also been replaced with suitable empirical relation. The provisions of the proposed draft code [4] are compared with the present IS code. The draft code also discusses about the two methods the static method and dynamic response factor method.

II. DESIGN PROCEDURE:

A. Static method:

As per IS: 875 (part-3)-1987 the basic wind speed (V_b) for any site shall be obtained from Fig.1 (clause 5.3 of IS: :875 (part 3) -1987) and shall be modified to include the following effects to obtain design wind speed (V_z) in m/s at height z for the chosen structure. V_z given as:

$$\mathbf{V_z = V_b \,.\, k_1 .\, k_2 .\, k_3}$$

As per Draft code for IS: 875 (part-3)-1987 sec. 5.3 has suggested to incorporate a cyclonic area importance factor to obtain design wind speed (V_z) at any height z by following equation:

$$\mathbf{V_z = V_b \,.\, k_1 .\, k_2 .\, k_3 \,.\, K_4}$$

Where:

V_z = Design wind speed (in m/s) at height z
V_b =Regional basic wind speed in m/s
k_1 =Probability factor or risk coefficient (sec.5.3.2 table -1)

k_2 =Terrain, height and structure size. (Sec.5.3.2 table -2)
k_3 = Topography factor. (sec.5.3.3)
K_4= Importance factor for the cyclonic region. (Draft code sec.5.3.4)

B. DESIGN WIND PRESSURE (p_Z):

As per Existing code[2] [Clause 5.4 of IS:875(part 3) -1987] the design wind pressure at any height z above mean ground level shall be obtained by the following relationship between wind pressure and wind speed. p_z given by:

$$p_z = 0.6 V^2 z$$

Where
P_z = Design Wind Pressure in N/ m^2 at height z
V_z= Design wind velocity (in m/s) at height *z*
As per proposed draft code [4] sec. 5.4 the design wind pressure p_d can be obtained as

$$p_d = K_d\ K_a\ K_c\ p_z$$

where:
K_d =Wind directionality factor, K_a = Area averaging factor, K_c =Combination factor

C. ALONG WIND LOAD:

There are major changes of computing along-wind load between Existing code[2] and proposed draft code [4] prepared by IIT Kanpur (Revision-IITK) under Gujrat State Disaster Management Authority Project (GSDMA Project) which are summarized below:-

(i). Gust effectiveness factor method as per IS:875 (part 3) – 1987

Hourly mean wind:
The variation of hourly mean wind speed with height shall be calculated as follows:

$$\bar{V}z = V_b K_1 \overline{K_2} K_3$$

Where,
$\bar{V}_z$ =hourly mean wind speed in m/s, at height Z.
V_b =Regional basic wind speed in m/s
K_1 =Probability factor
$\overline{K_2}$ =Terrain and height factor
K_3 =Topography factor
These factors are given in the code [2]
Existing code[2] gives only the method of calculating along wind load (drag load) by using gust factor method. Further the code uses hourly mean wind speed factor (K_2) for computation of gust factor
Along wind load on the structure on a strip area (A_e) 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 (A_e)
C_f = force coefficient for the building,
A_e = effective frontal area considered for the structure at height z
(G) = Gust factor = peak load/mean load and is given by:

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

The values of Constants and parameters (g_f r, B,S,E) used for gust factor analysis are interpolated from the figures 8, 9, 10, 11 in the present code of practice.
Ø = g_f r √ B/4 and 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.
β = Damping coefficient as given in table -34 in the code of practice.

(ii) As per Proposed draft code [4]:

Proposed draft code [4] for wind code IS: 875(part-3)-1987" has suggested to obtain the along wind load using gust factor method which is very much similar to revised Australian Code AS/NZ 1170.2 – 02. The gust factor is renamed as Dynamic Response Factor (Cdyn) and is computed using 3 sec gust speed and gives a set of expressions which do not involve use of figures or charts. Thus the calculations are rather straight forward and simple.

Along wind load on the structure on a strip area (A_e) at any height z is given by:

$$F_z = C_f\ A_e\ p_z\ C_{dyn}$$

Where:
Cdyn = Dynamic Response Factor (= total load/ mean load), and is given by:

$$C_{dyn} = \frac{1 + 2I_h \left[g_v^2 B_s + \frac{H_s g_R^2 SE}{\beta} \right]^{0.5}}{\left(1 + 2 g_v I_h\right)}$$

Where:
I_h = turbulence intensity(As per proposed draft code [4] for IS: 875 (part 3) -1987 table 31)
g_v = peak factor for the upwind velocity fluctuations, which shall be taken as 3.5
B_s = B_s is back ground factor, which is a measure of the slowly varying background component of the fluctuating response, caused by the low frequency wind speed variations given as follows.
H_s = Height factor for the resonant response
g_R = Peak factor for the resonant response (1 hour period)
S = size reduction factor
E = ($\pi/4$) times the spectrum of turbulence in the approaching wind stream given as follows
V_h = design wind speed at height h
N = reduced frequency
b_{sh} = Average width of the structure between heights 0 and h
L_h = Measure of the integral turbulence length scale at height h =100 $(h/10)^{0.25}$
f_0 = First mode natural frequency of vibration of a structure in the along wind direction in hertz.
β = Ratio of structural damping to critical damping of a structure as given in table 32 of draft code.

Table.1. summarizes the expressions for gust factors:

Along-wind response
$C_{dyn} = \dfrac{1+2I_h\left[g_v{}^2 B_s + \dfrac{H_s g_R{}^2 SE}{\beta}\right]^{0.5}}{(1+2g_v I_h)}$
$B_s = \dfrac{1}{1+\dfrac{\left[36(h-s)^2+64b_{sh}{}^2\right]^{0.5}}{2L_h}}$
$E = \dfrac{\pi N}{(1+70N^2)^{5/6}}$
$N = \dfrac{f_0 L_h\left[1+(g_v I_h)\right]}{V_h}$
I_h = turbulence intensity obtained from table 31)
g_V = 3.5
$H_s = 1+\left(\dfrac{s}{h}\right)^2$
$g_R = \sqrt{\left[2\log_e(3600 f_o)\right]}$
$S = \dfrac{1}{\left[1+\dfrac{4f_0 h(1+g_v I_h)}{V_h}\right]\left[1+\dfrac{4f_0 b_{sh}(1+g_v I_h)}{V_h}\right]}$

Table .2. Parameters considered for study

Physical parameters	
Length	24 m
Breadth	18 m (Sea front)
Height	96 m
Storey height	3 m
No. of storey	32
Frame spacing	6 m c/c
Wind data	
Wind zone	V (Basic wind speed = 50m/s)
Terrain category	
i) Sea face	TC I
ii) other faces	TC IV
Topography	Flat
Life of structure	50 years
Building location	Vishakhapatnam (cyclone prone area)
Building orientation	Smaller dimension facing Sea
Building constructed	200m inside Sea front
Fetch length	200m, developed height hx =35m in TC 3. Up to 35m, K2as per TC-3,above 35m K2as per TC 1

III. DETAILS OF PRESENT STUDY:

The present study deals with the computation of static and dynamic wind pressure on a 32 storied RCC framed MS building of 96m high located at Vishakhapatnam located in cyclonic region by using both the Existing code[2] IS 875 (part-3)- 1987 and proposed draft code [4] for IS: 875 (Part 3)-1987.The details are as follows:

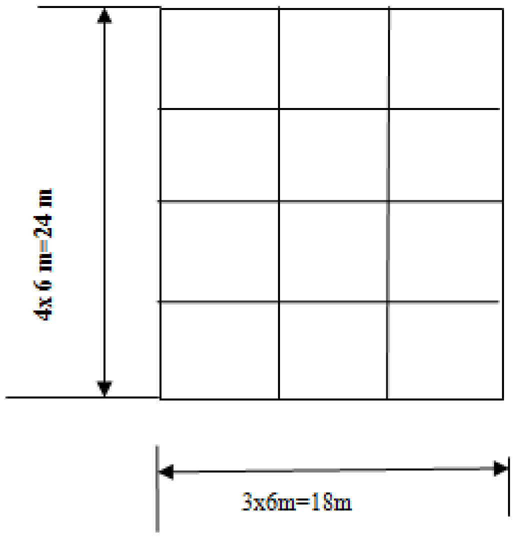

Figure. 1. PLAN

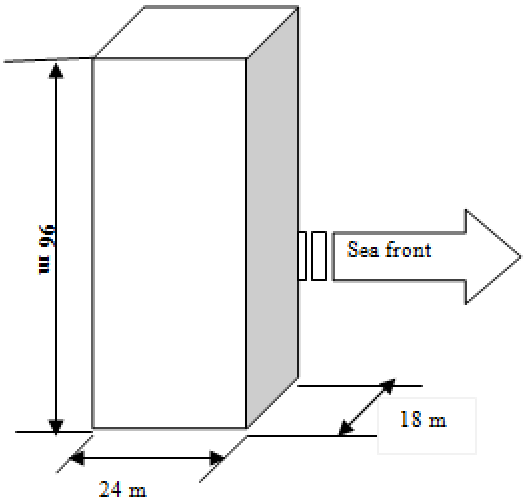

Figure.2. Schematic diagram of MS building

A. STATIC WIND PRESSURE AS PER IS: 875 (PART-3) -1987 (calculated as per table-3)

One face of the building, i.e. sea face is exposed to terrain category 1 which transforms into terrain category 3 at a distance of 200 m . On the other hand, other faces are exposed to terrain category 4, since they are located in a commercially developed area having high rise buildings. Therefore we have to calculate a combined wind profile as per Appendix—B of IS:875-pt.3, Sec 5.3.2.4 from table 3 for fetch length X= 200m, developed height in terrain category 3 is 35m. Therefore up-to a height of 35m, the k_2 factor shall be as per TC 3 and above 35m it will be as per TC 1

Design factors:

Basic wind speed (Vishakhapatnam) V_b = 50 m/s
Probability factor or risk coefficient k_1 = 1.0
Terrain, height and structure size k_2 = varies with height and terrain category given in table -2
Topography factor k_3 = 1.0

B. STATIC WIND PRESSURE AS PER PROPOSED DRAFT CODE [4]: (calculated as per table-4)

Design factors:

Basic wind speed (Vishakhapatnam) V_b = 50 m/s
Probability factor or risk coefficient k_1 = 1.0

Terrain, height and structure size k_2 = varies with height and terrain category given in table -2
Topography factor k_3 = 1.0
Importance factor for the cyclonic region K_4= 1.3 (Vishakhapatnam) (Draft code sec.5.3)
C. GUST FACTOR METHOD AS PER IS: 875 (PART-3): (As per table-6)
Along Wind Response: (As per IS:875-pt.3, Sec 8.2 and 8.3)
Calculation for Gust factor (G) corresponding to top of building are as under:
Case 1: When wind is on sea face i.e.(long after-body orientation)
h = 96m, b =18m, d = 24m, Fundamental natural period "T" =0.09 H/√d = 0.09*96/√24 = 1.764sec,
Natural frequency f_0 = 1/T = 1/1.76 =0.567 Hertz, λ = C_y b /C_z h = 10*18/12*96 = 0.156
And = C_z h/L(h) = 12*96/2000 = 0.576, Reduced frequency F_0 = C_z f_0 h/V_h = 12*0.567*96/49.26 = 13.26
[f0 L (h)] / Vh =0.567*2000/49.26 = 23.021 , Vh= hourly mean speed at height 96 m (Sea face from table 5 =49.26)
g_f. r = 0.75 and L(h) =2000 (Fig – 8, page – 50) (for terrain Category – 1 and building height – 96 m)
B = 0.75 load (From Fig 9, page – 50), S=0.145 (From Fig 10, page – 51), Constant ϕ = 0
E = 0.074 (From Fig 11), β =0.16 from Table 34
G = 1 + [g_f r [SQRT (B (1 + ϕ) 2 + (S E) / β)]] =1+0.75*[0.75*(1+0] ^{2}+ (0.145*0.074)/0.016]$^{0.5}$ = **1.894**
Case 2: When wind is on wider face (ie short after-body orientation)
h = 96m, b =24m, d = 18m, Fundamental natural period "T" =0.09 H/√d = 0.09*96/√18 = 2.036 sec. Natural frequency f_0 = 1/T = 1/2.036 =0.491 Hz, λ = C_y*b/C_z* h = 10*24/ 12*96 = 0.208
F_0 = C_z* f_0*h/Vh = 12*0.491*96/28.02 = 20.186, C_z h/L(h) = 12*96/1250 = 0.9216
[f0 L (h)] / Vh =0.491*1250/28.02 =21.9, Vh= hourly mean speed at height 96 m (wider face from table 5) =28.02
g_f. r = 1.75 and L(h) =1250 (Fig – 8, page – 50) for terrain Category – 4 and building height – 96 m
B = 0.65 (From Fig 9, page – 50), S=0.145 (From Fig 10, page – 51), Constant ϕ =0, E = 0.0762 (From Fig 11)
β = 0.016
Gust factor G=1+g_f r [B(1+ø)^2+SE/ β]$^{0.5}$ =1+1.75* [0.65*(1+0]^2 +(0.059*0.0762)/0.016]$^{0.5}$= **2.688**
Case 3: When wind is on narrow face opposite to sea face (For Terrain category 4)
h = 96m, b =18m, d = 24m, f_0 =1/T = √24/(0.09*96)=0.567 Hz
λ= C_y*b*/C_z* h = 10*18/12*96 = 0.156,
F_0 = C_z* f_0*h/Vh = 12*0.567*96/28.02 = 23.31, C_z*h/L(h) = 12*96/1250 = 0.9216
f_0*L(h)/V_h =0.567*1250/28.02 = 25.29
Vh= hourly mean speed at height 96 m (Narrow face from table 5, TC-4) =28.02
g_f. r = 1.75 and L(h) =1250, B = 0.644, S=0.085, Constant ϕ =0, E = 0.0696, β = 0.016
G=1+g_f r [B(1+ø)^2+SE/ β]$^{0.5}$, = 1+1.75*[0.644*(1+0]^2 +(0.0696*0.069)/0.016]$^{0.5}$= **2.70**

D. DYNAMIC RESPONSE FACTOR CACULATION AS PER PROPOSED DRAFT CODE [4] (As per table-7)

a) Along wind:
Risk coefficient=1.0
Terrain, height and structure size k_2 =as per table 4
Topography factor k_3 =1.0
Importance factor for the cyclonic region (Vishakhapatnam) K_4 =1.3
Design wind speed V_z = 50*1* k_2 *1*1.3= 65 k_2
Design pressure p_z = 0.6 $V^2{}_z$ =0.6*(65K2)^2 =2535 $K^2$2

a) wind onto wider face:
h=96m, b_{sh} =24m, d= 18m, L_h=100(96/10)$^{0.25}$=176.02m
$$f_0 = \frac{1}{T} = \frac{\sqrt{18}}{0.09 \times 96} = 0.491 \text{ Hz}, \ \beta = 0.02$$
i) For base floor(S=0)
Bs =0.367, Hs = 1.0, g_R = 3.8671, G_v = 3.5, $V_{h,}$ =77.48 (From table 4 above) , S= 0.087
E = 0.057, I_h =0.235 (For TC 4 at height 96m from table 31of Proposed draft code [4]), **C_{dyn} =0.887**
ii) Floor level at mid height (S=48)
Bs =0.504, Hs =1.25**, C_{dyn} =0.962**
iii) Floor level at mid height (S=96)
Bs =0.6471, Hs =2.0, **C_{dyn} =1.074**

b) wind onto smaller face:
h=96m, b_{sh} =18m, d=24m, L_h=100 (96/10)$^{0.25}$ =176 .02
$$f_0 = \frac{1}{T} = \frac{\sqrt{24}}{0.09 \times 96} = 0.567 \text{ Hz}, \ \beta = 0.02,$$
I_h =0.11 (For TC 1 at height 96m from table 31 of Proposed draft code [4])
i) For base floor (s=0)
I_h =0.11 (For TC 1at height 96m from table 31of Proposed draft code [4]),
B_s =0.372, H_s = 1.0, g_R = 3.904, S = 0.126, N = 1.69, E = 0.0639, **C_{dyn} =0.971**
ii) Floor level at mid height (S=48)
Bs =0.522, Hs =1.25, **C_{dyn} =1.031**
iii) Floor level at mid height (S=96)
Bs =0.7097, Hs =2.0, **C_{dyn} =1.134**

IV. RESULTS AND DICUSSIONS:

The results of the wind load analysis of Rcc multi-storeyed building are discussed herein. Variation of static pressure with height:

A. *Static pressure as per IS code [2]*
Table 3 shows that the value of static design wind pressures varies from 1.242 KN/m^2 at 3m height to 2.363 KN/m^2 at a height of 96m.The variation is about 90% from bottom to top level of 32 storeys.

B. Static pressure as per Proposed Draft:
Table 4 shows that the static design wind pressure calculated as per Proposed draft code [4] increases from 1.889 KN/m^2 at 3m height to 3.595 KN/m^2 at a height of 96m. Showing an increase of nearly 90% from bottom to top level of 32 storey.

C. Comparison of Static Pressures as per IS code and Proposed Draft
As per the proposed draft code [4] cyclone area importance factor k_4 has been introduced in the formula for the design of wind speed in coastal area. Also to obtain the design wind pressure, various modifications through factors like wind directionality factor K_d, area averaging factor K_a and combination factor K_c are applied. Because of these factors, the design wind pressures p_d obtained as per the Proposed draft code [4] are more than those obtained by Existing code[2]. If the structure does not fall under non- cyclonic

region, the factor K_4 is taken as 1.0. Hence there is no change in the design static wind pressure as per Existing code[2] and proposed draft code [4]. As the Vishakhapatnam city falls under cyclonic region, the importance factor k4 for structures of post cyclonic importance is taken as 1.30. Table 4 as per the Proposed draft code [4] which shows that design static wind pressure is 1.889 KN/m^2 at 3m height and as per Existing code[2] (as per table 2) is 1.242 KN/m^2 The variation is about 52%. similarly for 32 storey the variation is same as 52%. This variation is shown in Fig.3

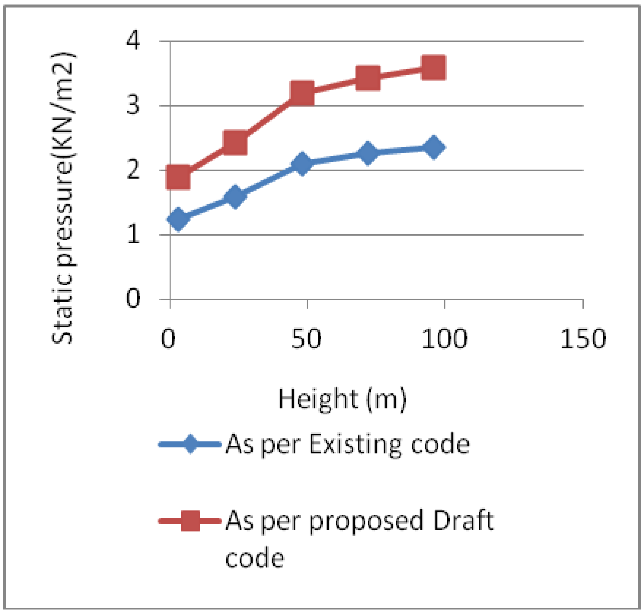

Figure.3. Variation of Static Wind Pressures with height located at Visakhapatnam

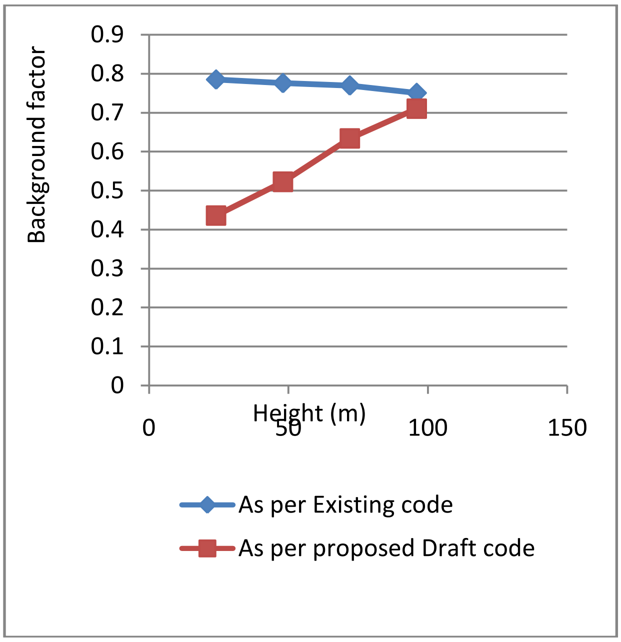

Figure. 4. Variation of background factor with height

V. GUST METHOD

A. Background Effect on Gust Factor

As per IS code [2] the value of Background factor for a frame remains constant throughout the height of the structure. .But as per Fig.9 of Existing code[2], the value of Background factor decreases with increase in height of the frame. Under terrain category I (When wind is on Sea face) the background factor decreases by 5 % from 16 storied to 32 storied frames. But as per proposed draft, the background factor increases with increase in height of the frame. The Background factor under terrain category I (When wind is on Sea face) is increasing by about 36% from 16 storied frames to 32 storied frames. The variation of background factor with height as per IS code [2] and proposed draft is shown in Fig. 4.

B. Effect of Size Reduction Factor

As per Fig.10 of Existing code[2] the size reduction factor (S) depends on the reduced frequency F_0 (C_z f_0 h/Vh) for a given λ value (C_y b/C_z h) and height (h) for a given building. The reduced frequency decreases with the height of the building and as a result the size reduction factor(S) gets increased with the height of building. As per the proposed draft code [4] the size reduction factor (S) depends on the first mode natural frequency of vibration of a structure along-wind direction in Hertz (f_0),turbulence intensity (I_h) and design wind speed at height h (V_h). The size reduction factor(S) can be obtained by an empirical formula as given in the draft code [4]. The size reduction factor(S) increases with the increase in height of building and decreases with increase in breadth of the structure for frames C. As per the IS code [2] the gust effectiveness factor is computed as equal to the mean value plus the effect of overall fluctuation. The fluctuation part is computed by combining the background and resonance effect with gf r. gfr combines gf with r, g_f is termed as the peak factor defined as the ratio of the expected peak value to a root mean square value of the fluctuating pressure. R, roughness factor takes into account the ground roughness and the size of the structure. The values of gfr are given in Fig: 8 of IS code [2] and is clear that as the building height increases, the value of gfr decreases. As per proposed draft code [4] the dynamic response factor is computed as equal to the mean value plus the effect of overall fluctuation. The fluctuation part is computed by combining the background factor with peak factor (gv) for the upwind velocity fluctuations and resonance effect with peak factor for resonant response g_R (one hour period). The peak factor (gv) for upwind velocity is taken a constant value of 3.5. For calculating peak factor for resonant response an empirical formula is given by the draft code, which depends on the natural frequency of vibration of the frame. As the height of the frame increases natural frequency decreases, the peak factor for resonant response decreases with the increase in the height of the frame.

D. *Height Factor for Resonant Response*

There is no provision for height factor in the Existing code[2] whereas the draft code(4) has considered the effect of height factor (Hs) for resonant response by introducing a height factor H_s. For obtaining this, an empirical formula is given by $(Hs=1+s/h)^2$. The height factor (H_s) for resonant response increases with increase in the height of the frame.

E. *Variation of Gust Factor with Height of Buildings*

As per the I.S. Code [2], Gust Factor decreases with the height of building. In case of 16 storey building the gust factor is 1.92 and in the case of 32 storey building it is 1.83. It is clear that the building height increases its flexibility also increases. The fundamental frequencies decreases and the overall Gust Factor decreases. Also with the increase in the width of the frame the Gust factor decreases because of the increase in frequency.

F. *Variation of Dynamic Response Factor with Height*

As per draft code [2], the dynamic response factor increases with the height of the frame. This is because of the height factor and the peak factor for the resonant response. The dynamic response factor for the 16 storey is 1.03 and the value becomes 1.13 for 32 storey.

G. *Comparison of Gust Factor and Dynamic Response Factor*

As per the Existing code[2] the Gust factor "G" decreases with the height of the frame whereas according to Proposed draft code [4] the dynamic response factor (C_{dyn}) is increasing with the height of the frame. As the height of building increases the frame becomes flexible and fundamental frequency decreases. As the fundamental frequency decreases gust factor also decreases. As per proposed draft code [4] the dynamic response factor (C_{dyn}) which is affected by the increase in the slowly varying background component of the fluctuating response as a result the dynamic response factor is increasing with height.

H. Variation of Gust Pressure with Height

As per IS code [2]the gust Pressure increases with the height in case of multi-storey Rcc framed building of different heights. Table 6 shows that the gust pressure increases from 0.710 kN/m2 at 3m to 2.267 kN/m2 at 48m (16 storied frames). The increase in pressure is about 219 % over a height of 3.0 m to 48m for 16 storied frame. In the case of 32 storey frame, the increase in gust pressures is 288 % over a height of 96m. Hence, it is clear that the gust pressures increases with height of the frames. As per proposed draft, the Gust Pressure as per Dynamic Response Factor method, Table 7 shows that the gust pressure increases from 2.381 kN/m2 at 3.0m to 4.025m kN/m2 at 48m (16 storied frame). The variation in pressure is about 69 % over a height of 3.0m to 48m for16 storied frame. Similarly the gust pressure increases is found to be 90 % over a height of 3 m to 96m.

I. *Comparison of Gust Pressures as per IS code [2] and Proposed Draft.*

From table 6 and 7 it is clear that the Gust Pressures increases with the height by either Gust Effectiveness Factor Method or by the Dynamic Response Factor Method. In the case of 16 storied the Gust pressure as per IS code [2] is 2.267 kN/m2 and as per proposed draft is 4.025 kN/m2. The difference is about 77%. Similarly the difference in Gust Pressures in the case of 32 stories is 64%. Thus as per the proposed draft the values of Gust pressures are higher in comparison to existing wind code[2]. This is because of the importance factor introduced n the formula for cyclonic regions instead the various figures used in earlier Existing code[2] which were difficult to interpolate. The variation in gust pressures is shown in Fig 5. Pressures are higher in comparison to existing wind code[2]. This is because of the importance factor introduced in the formula for cyclonic regions instead the various figures used in earlier Existing code[2] which were difficult to interpolate. The variation in gust pressures is shown in Fig 5.

K. *Comparison of Static and Gust Pressures as per IS code and Proposed Draft.*

From table 3 and 6 as per IS code [2][(2)] the Static and Gust pressure at the top of 16 storied frame are 2.1kN/m^2 and 2.267kN/m^2. The Gust pressure is more than static pressure by about 8%. Similarly for 32 storied frame the Static and Gust pressure is 2.363 KN/m^2 and 2.758 KN/m^2. The gust pressure difference is 17 %. The variation is shown in Fig.6.From table 3 & 7 as per proposed draft code [4] in the case of 16 storied frames the Static and Gust pressure at the top are 2.1kN/m^2 and 4.025kN/m^2.

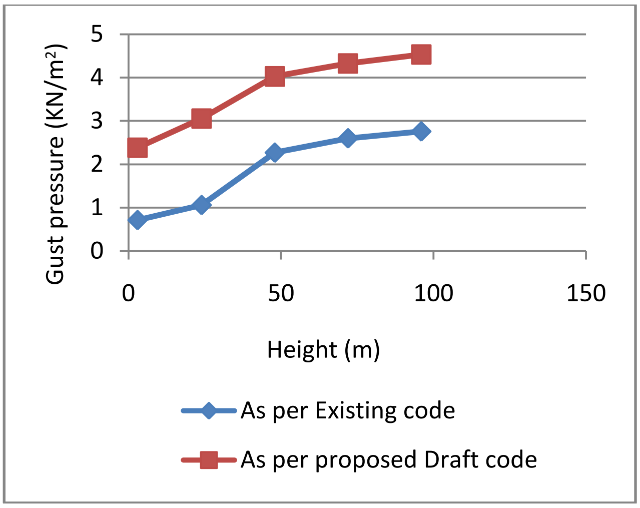

Figure.5. Variation of Gust Pressure with Height

The Gust pressure is more than static pressure by about 92%. Similarly for 32 storied frame the Static and Gust pressure is 2.363 KN/m^2 and 4.529 KN/m^2. The gust pressure difference is 92 %. The variation is shown in Fig.7.

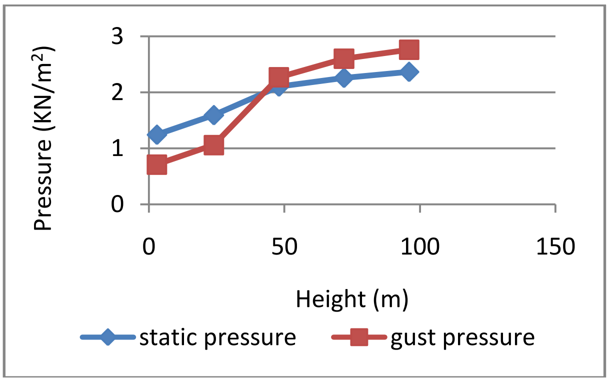

Figure.6. Variation of Static pressure and Gust Pressures with height as per Existing IS code [2]

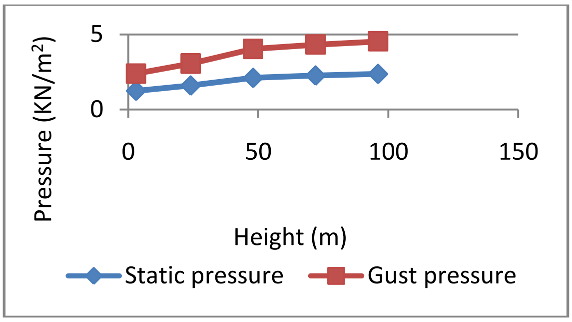

Figure.7. Variation of Static pressure and Gust Pressures with height as per proposed draft code [4]

V. CONCLUSIONS:

- In order to ensure greater safety of the structures located within regions (60 Km wide on the east coast as well as on the Gujrat coast) a new variable K_4 known as importance factor for cyclonic region has been introduced in the proposed draft. So the static pressures in the coastal regions of the country calculated by the proposed draft are much more in comparison to the Existing code[2].
- Classification of structures into B and C classes as given in existing code have been deleted and accordingly the modification factor, *k*2 is renamed as terrain roughness and height factor in Proposed draft code [4].

- The values of K_2 factor corresponding to previous classification class "A" type structures as taken in Existing code are retained in Proposed draft code [4]
- There is no provision for height factor in the Existing code[2], But Proposed draft code[4] has considered the effect of height factor (Hs) for resonant response by introducing a height factor H_s. For obtaining this, an empirical formula is given by $(Hs=1+s/h)^2$. The height factor (H_s) for resonant response increases with increase in the height of the frame.
- The basic wind speed map of India has been updated based on the R & D studies in the country.
- As per IS code [2] the computation of along-wind load is cumbersome and difficult to program as it uses various charts. Further present code uses hourly mean wind speed which is not consistent with other international codes while Proposed draft code [4] specifies 3 sec gust duration is used for computation of Gust factor (Dynamic Response factor) and gives a set of expressions to evaluate the Gust factor and hence the along wind load factor. The 3-sec gust gives slightly higher values of design wind speed.
- In proposed draft code [4] design wind pressure decreases with increasing tributary area of the structures
- Gust factor method of IS:875 (part3)-1987 gives design basis for calculating Along wind force only. While the Dynamic response Method of the proposed draft code [4] takes into account along wind as well as cross-wind forces, though the design for along wind appears to suffice for the cross-wind forces too.
- As per the Existing code[2] the value of background factor (B) remains same for a particular structure along its height. But as per the proposed draft code [4] the background factor varies along the height of the structure. This is because the draft code considers the effect at every level along the height of the frame structure.
- The gust pressures computed using draft code are more compared to the present IS code [2]because of the introducing importance factor and the change in the terrain roughness and height factor
- As per Fig. 4 of Existing code[2] the background factor (B) decreases with increase in the height of the frame. This is because of increase in the L(h) value as the height of the frame increases. Due to increase in L(h) value the ratio (C_z h/L_h) also increases with the height of frame and as per Fig.9, the curve for λ value is steeply falling. But as per the proposed draft code [4] the background factor increases with the increase in the height of the frame. This is due to the increase in the L(h).

Table.3. Variation in Design Wind Speed and pressure with Height as per IS: 875 (part 3)-1987

Height from ground (m)	K_2		V_Z (m/s)		P_z (KN/m2)		P_d (KN/m2)
	Sea face*	Other faces **	sea face	Other faces	sea face	Other faces	For all faces***
Up to 9m	0.91	0.800	45.5	40	1.242	0.960	1.242
At 12m	0.934	0.800	46.7	40	1.309	0.960	1.309
24m	1.03	0.868	51.5	43.40	1.591	1.130	1.591
36m	1.083+	1.009	54.167	50.45	1.760	1.527	1.760
48m	1.183	1.087	59.167	54.35	2.100	1.772	2.100
60m	1.212	1.120	60.6	56	2.203	1.882	2.203
72m	1.226	1.144	61.32	57.2	2.256	1.963	2.256
84m	1.241	1.168	62.04	58.4	2.309	2.046	2.309
96m	1.255	1.192	62.76	59.6	2.363	2.131	2.363

** up to 35m,K2 as per TC 3, above 35m, K2 as per TC 1 , **: For terrain category 4*
****: for cladding, only higher wind speed is used for all four faces.*
+ effect of terrain category changes from TC 3 to TC 1 above this height.
*(At 35 m for terrain category 1, 1.06+(1.12-1.06)*5/20 =1.075.*
*At 36 m, 1.075+(1.2-1.075)*1/15 =1.083)*

Table .4. Variation in Design Wind Speed and pressure with Height as per proposed draft code [4]

Height from ground (m)	K_2		V_Z (m/s)		P_z (KN/m^2)		P_d For building (KN/m^2)		P_d for cladding (KN/m^2)*
	Sea face	Other faces	Sea face	Other faces	Sea face	Other faces	Sea face	Other faces	All faces
Up to 9m	0.91	0.800	59.150	52.000	2.099	1.622	1.511	1.168	1.889
At 12m	0.934	0.800	60.710	52.000	2.211	1.622	1.592	1.168	1.990
24m	1.03	0.868	66.950	56.420	2.689	1.910	1.936	1.375	2.420
36m	1.083+	1.009	70.417	65.585	2.975	2.581	2.142	1.858	2.678
48m	1.183	1.087	76.917	70.655	3.401	2.889	2.449	2.080	3.061
60m	1.212	1.120	78.780	72.800	3.724	3.180	2.681	2.290	3.351
72m	1.226	1.144	79.716	74.360	3.813	3.318	2.745	2.389	3.432
84m	1.241	1.168	80.652	75.920	3.903	3.458	2.810	2.490	3.513
96m	1.255	1.192	81.588	77.480	3.994	3.602	2.876	2.593	3.595

*For cladding, only higher wind speed is used for all four faces(p_z *0.9*1.0)

Table.5. Variation in design wind speed and design pressure with height based on hourly mean wind speed

Height from ground(m)	K_2		Vz (m/s)		Pz KN/M^2	
	Sea face *	Other face**	Sea face	Other face	Sea face	Other face
Up to 9m	0.500	0.240	25	12	0.375	0.086
At 12m	0.520	0.240	26	12	0.406	0.086
24	0.610	0.280	30.5	14	0.558	0.118
36	0.673+	0.373	33.667	18.65	0.680	0.209
48	0.893	0.439	44.667	21.95	1.197	0.289
60	0.942	0.474	47.1	23.7	1.331	0.337
72	0.956	0.503	47.82	25.14	1.372	0.379
84	0.971	0.532	48.54	26.58	1.414	0.424
96	0.985	0.560	49.26	28.02	1.456	0.471

** up to 35m,K2 as per TC 3, above 35m, K2 as per TC 1*
***: For terrain category 4*
+ effect of terrain category changes from TC 3 to TC 1
*above this height. (At 35 m for terrain category 1= .64+(0.70-0.64)*5/20 =0.655.*
*At 36 m =0 .655+(0.93-0.655)*1/15 =0.673)*

Table.6. Variation of design wind pressure with height using Gust factor method

Height from ground(m)	P_z [KN/m2]		P_d [KN/m2]			P_d for cladding [KN/m2]
	Sea face	Other face	Sea face, G=1.894	Opp. sea face G=2.70	Wide face G=2.688	All faces
Up to 9m	0.375	0.086	0.710	0.233	0.232	0.710
At 12m	0.406	0.086	0.768	0.233	0.232	0.768
24m	0.558	0.118	1.057	0.318	0.316	1.057
36m	0.680	0.209	1.288	0.563	0.561	1.288
48m	1.197	0.289	2.267	0.781	0.777	2.267
60m	1.331	0.337	2.521	0.910	0.906	2.521
72m	1.372	0.379	2.599	1.024	1.019	2.599
84m	1.414	0.424	2.678	1.145	1.139	2.678
96m	1.456	0.471	2.758	1.272	1.266	2.758

Table.7. Variation of design wind pressure with height using Dynamic Response Factor method

height from ground(m)	P_z [KN/m2]		P_d [KN/m2]			P_d for cladding [KN/m2]
	Sea face	other faces	Sea face, G=1.134	opp. sea face G=1.134	Wide Faces G=1.074	All faces
Up to 9m	2.099	1.622	2.381	1.840	1.742	2.381
At 12m	2.211	1.622	2.508	1.840	1.742	2.508
24m	2.689	1.910	3.050	2.166	2.051	3.050
36m	2.975	2.581	3.374	2.927	2.772	3.374
48m	3.550	2.995	4.025	3.397	3.217	4.025
60m	3.724	3.180	4.223	3.606	3.415	4.223
72m	3.813	3.318	4.324	3.762	3.563	4.324
84m	3.903	3.458	4.426	3.922	3.714	4.426
96m	3.994	3.602	4.529	4.085	3.868	4.529

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