6. *SOFTWARE FOR ANALYSIS OF CYCLONE FORCES*

6.1 GENERAL

There has been an increasing trend in the occurrence of hazardous events over the last few decades. Due to the improved disaster management and mitigation methods, loss of lives has reduced but the economic losses are still very high. Approximately 80 cyclones strike worldwide during a year. Asia–Pacific region is more prone to cyclones with approximately 45% of the cyclones striking in these regions only, while India experiences about 6 cyclones per year, mostly on the East Coast. High wind storms occur in many parts of India, the coastal states of Gujarat, Tamilnadu, Andhra, Orrisa and West Bengal are more seriously affected because of the occurrence of cyclonic storms.

This passage gives details of the various options of calculating wind forces in different situations. The present code IS:875 (1987) covers all possibilities for short as well as slender buildings. As buildings become more and more slender their response to wind forces changes drastically. Two methods of Gust Factor and Dynamic Response method have been automated in a software prepared in VC++ and presented here. The building is then analysed for these forces in SAP2000. Comparison of results for various options have been given at the end.

6.2 CYCLONE FORCES

The wind pressures and suction effects created by a Cyclone, on flat objects could be sufficient to lift them off and fly away from their place of rest unless adequately tied down to substantial supports. **Table 6.1** shows the aerofoil effects of some cyclonic wind speeds [87]. Wind velocities encountered during cyclones are higher than those specified in the current code on wind IS: 875 (Part

3)-1987. Hence it is proposed in the draft code, to incorporate a cyclonic area importance factor for design of structures in coastal areas.

Table 6.1 Effect of Wind Speed [GSDMA]

Wind Speed m/s	Typical Possible Effects
30-35	Roof sheets fixed to battens fly
35-40	Small aircrafts take off speed
40-45	Roof tiles nailed to battens fly
45-50	Garden walls blow over
50-55	Unreinforced brick walls fail
55-60	Major damage from flying debris
60-65	75 mm thick concrete slabs fly

This factor will be multiplied to the design wind velocity. The value of the cyclonic factor will vary from 1 to 1.3; 1.3 for structures with post cyclone importance, 1.15 for industrial structures. For all other structures the factor is 1.0 [88].

As a consequence of the wind pressures/suctions acting on elements obstructing the passage of wind the following types of damage are commonly seen to occur during high wind speeds:

- Uprooting of trees, which disrupt rail and road transportation.
- Failure of cantilever structures such as sign posts, electric poles, and transmission towers.
- Damage to improperly attached windows or window frames.
- Damage to roof projection, chhajjas and sunshades.
- Failure of improperly attached or constructed parapets.
- Overturning failures of compound walls of various types.
- Failure of weakly built walls and consequent failure of roofs and roof covering.
- Failure of roofing elements and walls along the gable end particularly due to high internal pressures.

- Failure of large industrial buildings with light weight roof coverings and long/tall walls due to combination of internal and external pressures.
- Brittle failure of asbestos – cement (AC) sheeting of the roofs of Industrial sheds; failure of AC sheets is generally along eaves, ridges, and gable ends.
- Punching and blowing off of corrugated iron roofing sheets attached to steel trusses.
- Though a thatch roof commonly employed in rural construction lacks durability, it provides greater permeability and attracts less forces of wind compared to an impermeable membrane.

Wind blowing past a body can be considered to be diverted in three mutually perpendicular directions, giving rise to forces and moments about the three directions.

Under the influence of dynamic wind loads, typical high-rise buildings oscillate in the along wind, across-wind and torsional directions as shown in **Fig 6.1** The along wind motion primarily results from pressure fluctuations on the windward and leeward faces, which generally follows the fluctuations in the approach flow, at least in the low frequency range. However, the across wind motion is introduced by pressure fluctuations on the side faces which are influenced by fluctuations in the separated shear layers and wake dynamics. Similarly, the wind-induced torsion effects result from an imbalance in the instantaneous pressure distribution on the building surface. These load effects are further amplified in asymmetric buildings as a result of inertial coupling. To find the across wind and torsional responses, the wind tunnel test is required for final design.
Most codes and standards recognize that wind tunnel tests can produce more reliable loading estimates, and incorporate provisions for this.

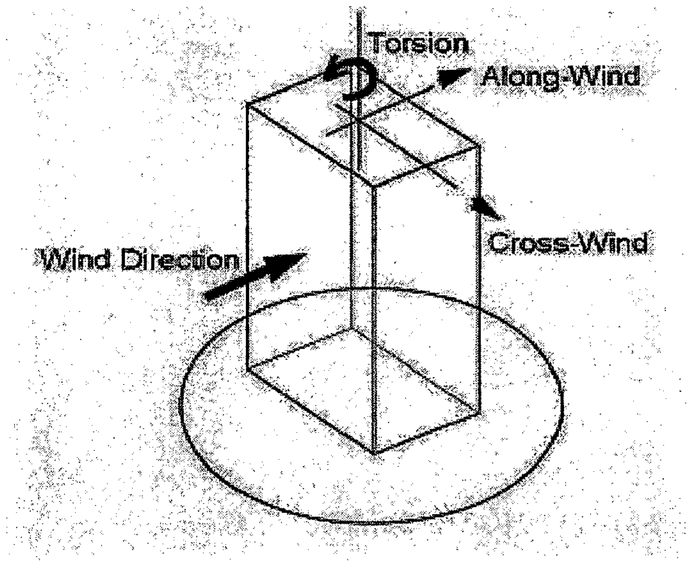


Fig. 6.1 Wind Force Components

The type of wind tunnel used for the testing of buildings and structures, is called a "Boundary layer wind tunnel" and it incorporates a long section upwind of where the model is placed in which floor roughness and turbulence generators are present. This is to simulate the natural drag of the Earth's surface (ground, vegetation, terrain, man-made objects) on the wind flowing over it. Care is taken to produce the correct change in wind speed and gustiness with height for each type of terrain over which the wind approaches the structure. In situations where the wind approaches the structure over mountainous terrain, a parallel study, using a smaller scale model of the topography to evaluate its effect on the approaching wind, might be needed.

6.3 EFFECT ON SLENDER BUILDINGS

Wind is turbulent in nature and the intensity of wind varies with time. A positive or negative departure of wind speed from its mean value, lasting for not more than, say, 2 minutes over a specified interval of time is called "gust". Peak gust speed is the wind speed associated with the maximum amplitude. When wind hits a body in its path, it transfers some of its energy to the body. The amount of energy transferred is called the "Gust Response Factor". Unlike the mean flow of wind, which can be considered as static, wind loads associated with gustiness change rapidly and even abruptly, creating effects much larger than if the same loads were applied gradually. Wind loads, therefore, need to be studied as if they were dynamic in nature.

The gusts can be considered as static loads if the wind load increases and vanishes in a time much longer than the natural period of the building. For example, a wind gust growing to its strongest pressure and decreasing to zero in 2 s is a dynamic load for a tall building with a period of, say, 5 to 10 s, but the same 2-s gust is a static load for a low-rise building with a period of less than 2 s.

According to IS:875 (Part 3)-1987 [5], any building or structure shall be examined for dynamic effects of wind if,

- Buildings and closed structures having height to minimum lateral dimension ratio of more than about 5.0.
- Buildings and closed structures whose natural frequency in the first mode is less than 1 Hz.

Natural Frequency is given by 1/T where T is the fundamental time period and is determined as follows:

$$T = 0.09H / (d)^{0.5} \quad \text{....(6.1)}$$

Where,

H = Total height of the main structure of the building in meters.

d = maximum base dimension of building in meters in a direction parallel to the applied wind force.

6.4 GUST FACTOR METHOD BY IS: 875 (PART 3) – 1987

The static wind methods given in the IS code to estimate steady wind speed and static wind load are proved to be satisfactory for normal, short and heavy structures, but for tall and flexible structures one cannot avoid the effect of dynamic force due to the random variation of wind speed with time. With this method one can find the along wind force using the 'Gust Factor'. A gust factor must be applied to the measured velocity to provide for the effect of turbulence in computing the design wind load.

6.4.1 Basic Wind Speed

Wind is not a steady phenomenon due to natural turbulence and gustiness present in it. However, when averaged over a sufficiently long time-duration (from few minutes to an hour), a mean component of wind speed can be defined which would produce a static force on a structure. Basic wind speed (Vb) for any site may be obtained from IS:875 (Part 3)-1987. These basic wind speeds have been worked out for a 50-year return period.

6.4.2 Hourly Mean Wind Speed and Design Wind Pressure

Wind velocity increases with height, and the wind pressure increases as the square of the velocity of wind. The wind pressure depends upon many factors like terrain roughness, height of building, topography etc. Wind speed is to be calculated first to find the design pressure. In this method the maximum wind speed is averaged over one hour for a particular location.

The mathematical expression of wind speed is as follow,

$$Vz = Vb \times k1 \times k2 \times k3 \quad \text{....(6.2)}$$

Where,

Vz = hourly mean wind speed in m/s. at height z.

k1 = probability factor.

k2 = terrain and height factor

k3 = topography factor

The wind pressure increases as the square of the velocity of wind. This value chosen corresponds to the average appropriate Indian atmospheric conditions.

$$Pz = 0.6 * Vz^{2}. \quad \text{....(6.3)}$$

Where Pz = Design wind pressure in N/m^2 at height z and Vz = Design wind velocity in m/s at height z

6.4.3 Along Wind Force

An obstruction to the flow of wind by an object results in creating a pressure on the surface of the object, in a direction normal to it. When multiplied by the area over which the pressure is acting, a force results. A force over an element of a structure, is obtained as an integration of the term 'pressure x area'.

The magnitude of the fluctuating component of the wind speed is called gust and to find the along wind load or "drag force" on the structure the force should be multiplied with gust factor which is described as,

Gust Factor, $G = 1 + gfr\,(B\,(1 + \phi)^2 + (S^*E)/\beta)^{0.5}$. ....(6.4)

Where G = gust factor = peak load / mean load and gfr is a peak factor, which is the ratio of the expected peak value to the root mean value of a fluctuating load. This mean value depends upon the averaging time. In general, smaller the averaging value greater is the magnitude. r is a roughness factor which is dependent on the size of the structure in relation to the ground roughness. B is background factor, which is a measure of the slowly varying component of fluctuating wind load. S is a size reduction factor. β is damping coefficient. Damping is a resistance to the motion of a vibrating body. It has different values for different structures like, β is 0.016 for reinforced concrete structures, and having value 0.02 for bolted structures and β is 0.01 for welded steel structures. E is measure of available energy in the wind stream at the natural frequency of the structure.

Thus, along wind load on a building or structure at any height z is given by,

$Fz = Cf \times Ae \times Pz \times G$ ....(6.5)

6.5 COMPUTER IMPLEMENTATION OF GFM

The programming for dynamic analysis for wind is developed in Visual C++ environment. This package is developed for R.C.C. building frames using IS: 875-1987 using Gust Factor Approach.

6.5.1 Flowchart for Gust Factor Method

The program follows the same steps as required by the present code for wind load analysis of slender structures. As compared to other international codes, IS:

875 does take into account along wind parameters but not across wind and torsion. Flowchart for evaluation for GFM is shown in **Fig. 6.2**

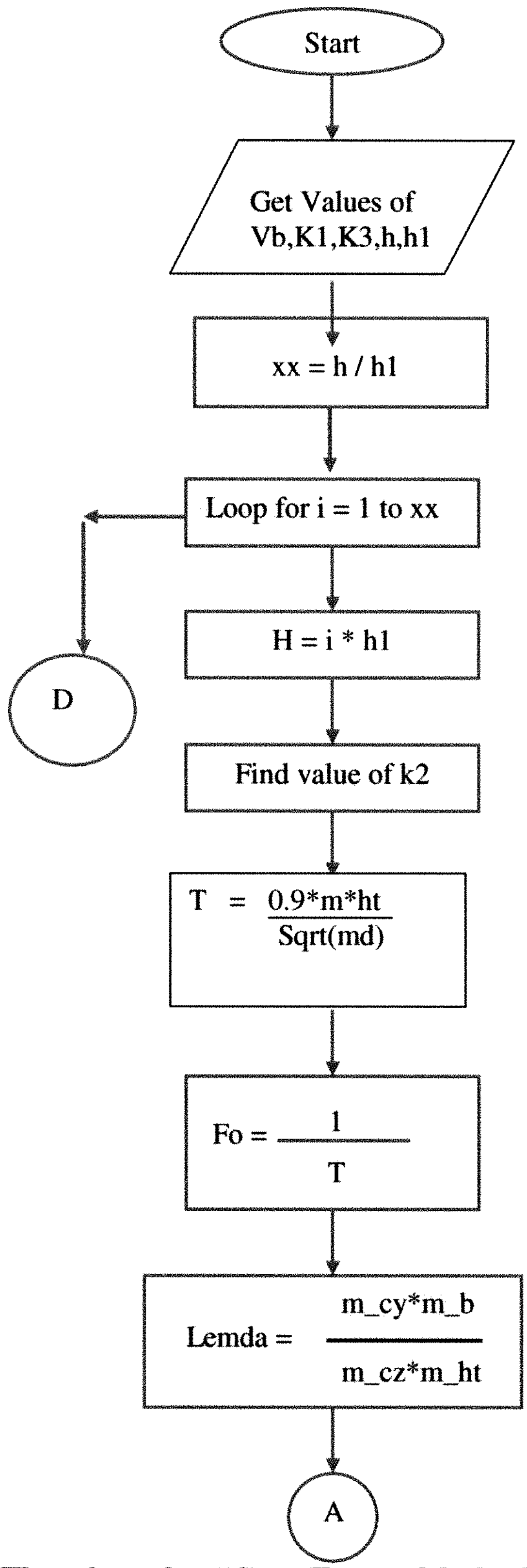
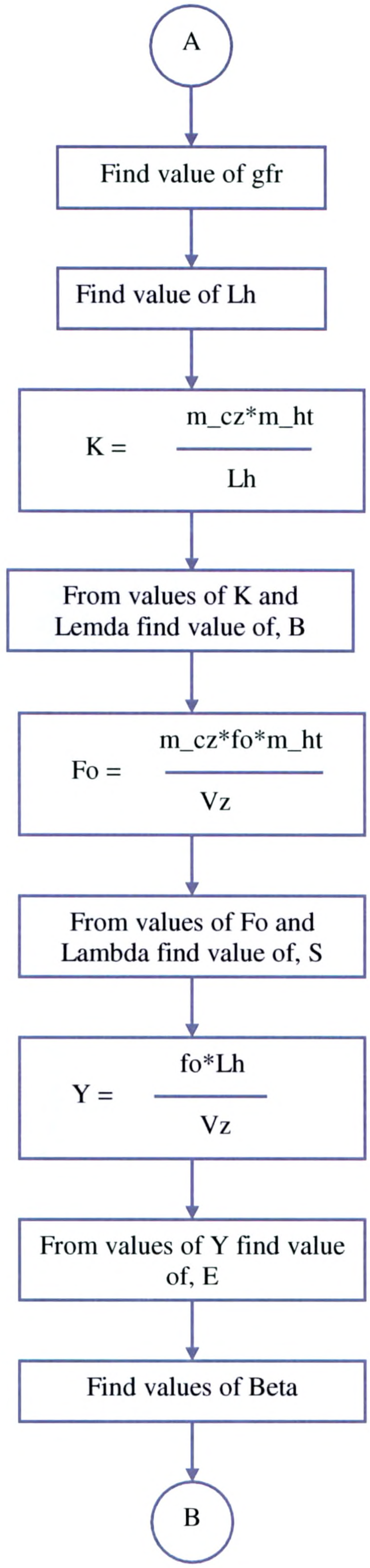
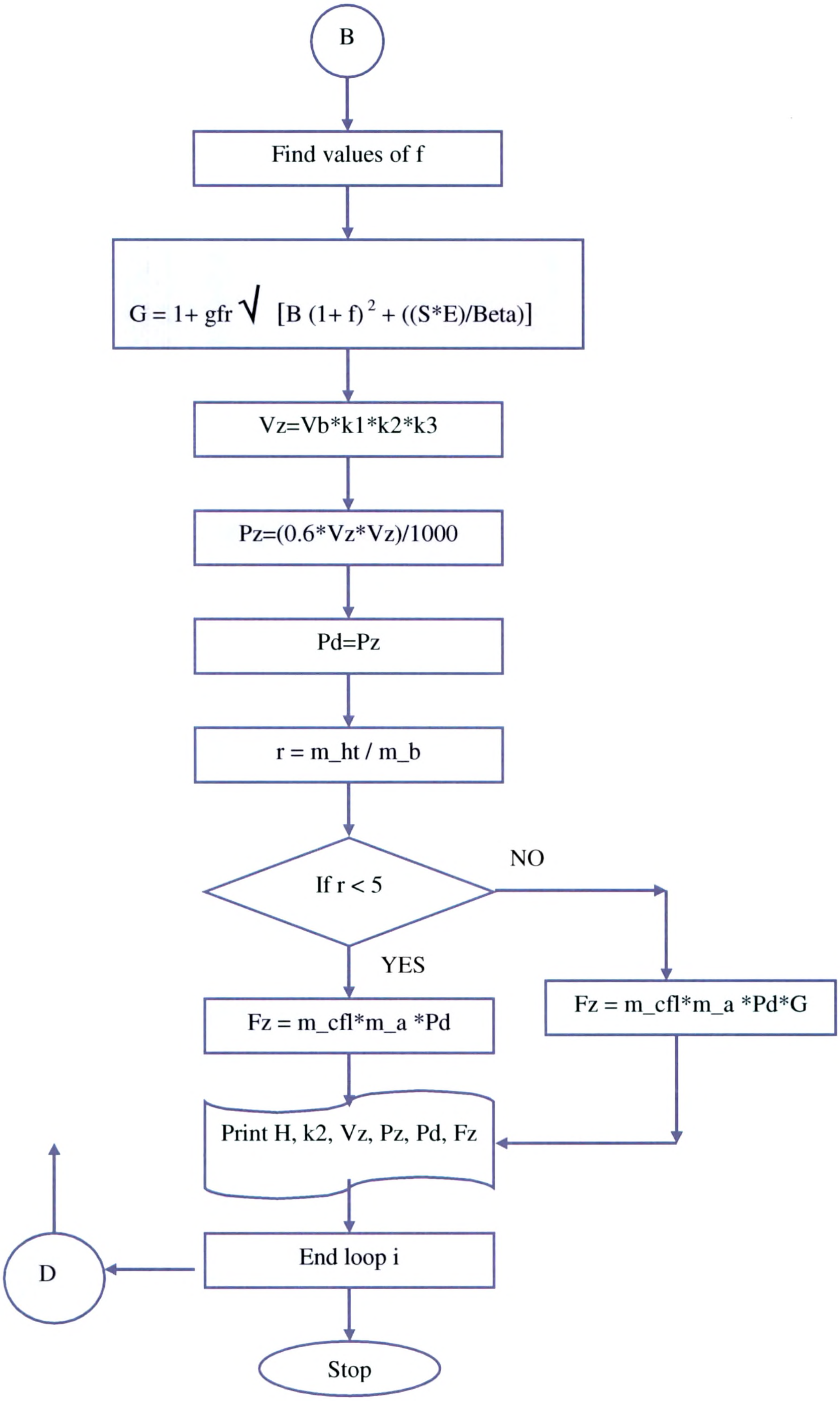


Fig. 6.2 Flowchart for "Gust Factor Method" Program Module


A
Find value of gfr
Find value of Lh
K = m_cz*m_ht / Lh
From values of K and Lemda find value of, B
Fo = m_cz*fo*m_ht / Vz
From values of Fo and Lambda find value of, S
Y = fo*Lh / Vz
From values of Y find value of, E
Find values of Beta
B


B
Find values of f
G = 1+ gfr √ [B (1+ f) 2 + ((S*E)/Beta)]
Vz=Vb*k1*k2*k3
Pz=(0.6*Vz*Vz)/1000
Pd=Pz
r = m_ht / m_b
If r < 5
NO
YES
Fz = m_cfl*m_a *Pd
Fz = m_cfl*m_a *Pd*G
Print H, k2, Vz, Pz, Pd, Fz
End loop i
D
Stop

The Australian and Japanese codes take all three into account, while the British and Euro codes can handle only very specific structures [89]. For any change in plan, terrain, topography or wind conditions, these codes cannot be applied and the only course left is to get results from wind-tunnel load studies. ASCE and the Canadian codes have given detailed descriptions and number of charts that make the choice of factors for various conditions simpler and easier.

6.5.2 Menu Resources Used in Program

Menus are normally displayed from a menu resource. After creating a SDI application with AppWizard, user will get an initial default menu for the view with an ID of IDR_MAINFRAME. The menu is displayed when the application is run, with the header items shown along the top of the editor window. The handler functions OnAnalysis( ) and OnResult( ) are created. The handler function can be implemented in any class whose objects will be passed the menu selection command message when the item is selected. i.e. by using function DoModal( ) and object C1 of Ccyclone class Dialog Box is attached with menu item "Analysis". During execution of program when user clicks on "Analysis" on the menu bar (**Fig. 6.3**), a Dialog Box will be displayed as shown in **Fig.6.4**. Similarly, the "Result .txt" file opens when the "Result" option is clicked on the menu bar.

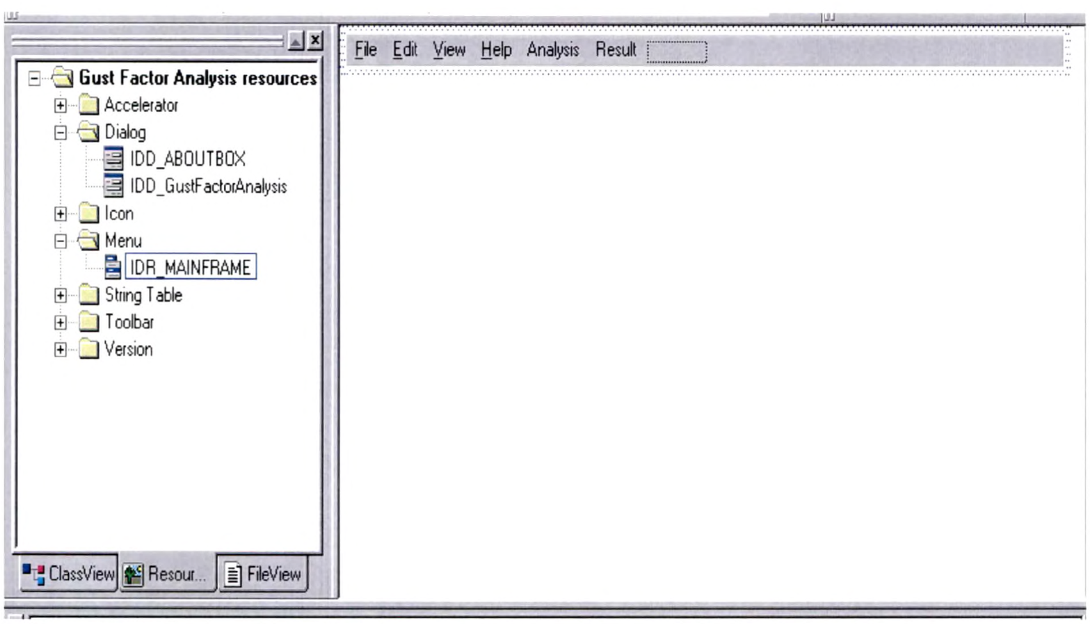


Fig.6.3 Main Menu Resource Indicating Modules on Menu Bar

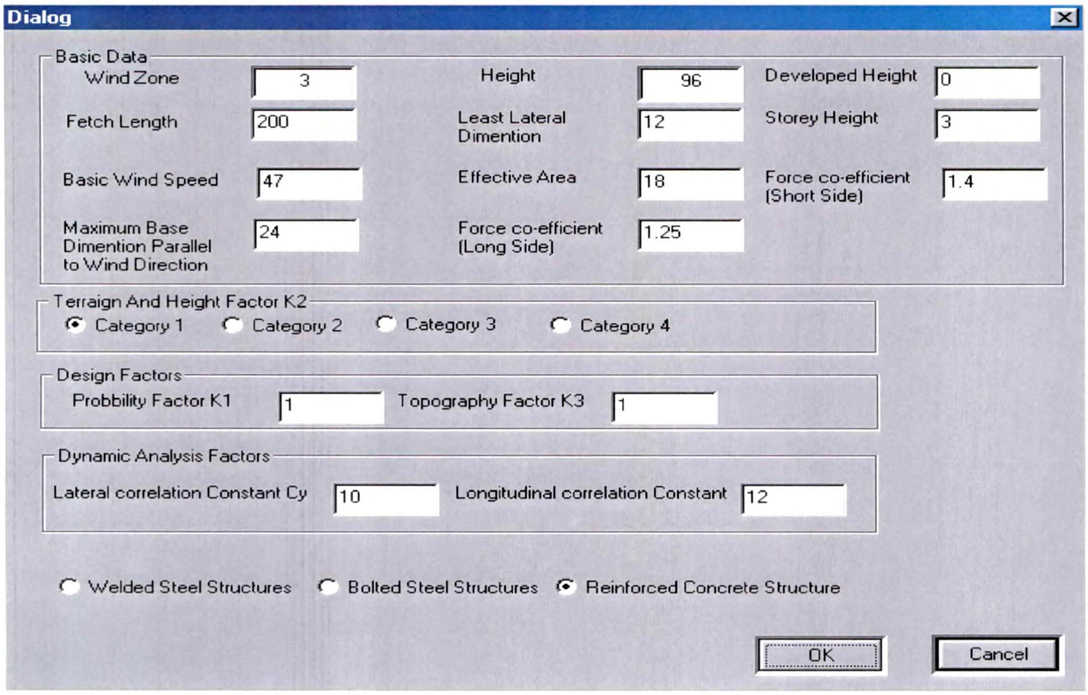


Fig. 6.4 Dialog Box for Along Wind Force by Gust Factor

6.6 DYNAMIC RESPONSE FACTOR METHOD

This method has been given in the proposed draft code IS; 875 under the GSDMA-IITK code revision program. This method has its parallels in major international codes such as the ATC 60 guidelines and the NBC of Canada. The dynamic part of the wind pressures would set up oscillations in a flexible structure. A flexible structure 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 the cross-wind direction, a flexible structure would tend to oscillate due to shedding of the eddies alternately from either sides of the structure at regular intervals, thus imposing a dynamic force that has a major component in a direction normal to that of the wind (lift) and only a small component along the direction of wind (drag). This force due to regular shedding of the eddies was first observed by Von Karman. The frequency of eddy shedding is dependent on structure size, shape and wind speed, all grouped into a non-dimensional parameter called Strouhal Number. The IS:875(Part 3) – 1987 Code does not lay down any specific procedure for determining the design wind force related to the cross-wind motion. Here dynamic response factor method (DRFM) as per IS:875-Proposed draft code is implemented and difference is highlighted.

To obtain the along wind response of a flexible structure (time period > 1.0 sec), the design wind pressure Pz has to be multiplied by the dynamic response factor Cdyn. The structure is considered to vibrate in its fundamental mode of vibration. The definition of dynamic response factor Cdyn, has changed from in the IS: 875-1987, which was applied to the wind loading due to hourly mean, wind speed, against the 3-sec gust speed. Smaller the averaging interval, greater is the magnitude of the gust speed. This method is also used to get the cross-wind response of tall enclosed buildings and towers of rectangular structure.

6.6.1 Basic Wind Speed

Basic wind speed (Vb) is same as given in gust factor method.

6.6.2 Design Wind speed and Design Wind Pressure

To get design wind speed the basic wind speed shall be multiplied by the following factors: Risk Level, Terrain roughness and height of structure, Local topography, Importance Factor.

Mathematical expression of design wind speed is given as,

$$Vz = Vb \times k1 \times k2 \times k3 \times k4 \quad \text{....(6.6)}$$

Where, k1, k2 and k3 factors are same as mentioned in Gust Factor Method. k2 factor is obtained from Table 2 of IS:875(part 3)-1987.

k4 = Importance factor for the cyclonic region.

According to the importance of the structure the values of k4 are follows:

Structure of post-cyclone importance	1.30
Industrial structures	1.15
All other structures	1.00

Speed of Cyclonic storms reduces gradually as they approach the seacoast. It generally extends up to about 60 km inland after striking the coast. So, the belt of approximately 60 km width near seacoast in certain parts of the country is identified to be affected by cyclonic storms. The peak wind speeds in these regions may exceed 70 m/s. Therefore, factor k4 has been introduced with a maximum value of 1.30. However, the highest value may be used only for structures of post-cyclone importance such as cyclone shelters, hospitals, school and community buildings, communication towers, power – plant structures and water tanks, while a lower value of 1.15 may be used for industrial structures, damage to which can cause serious economic losses. For reasons of economy, other structures may be designed for a k4 value of unity, that is, without considering the effect of the possible higher wind speeds in cyclonic storms. For non-cyclonic regions, the factor k4 shall be taken as 1.00.

Wind pressure Pz = 0.6 x $(Vz)^2$. ....(6.7)

Where, Pz = wind pressure in N/m^2 at height z ; Vz = design wind speed in m/s.

The design wind pressure can be obtained as follows:

Pd = Kd x Ka x Pz ....(6.8)

Where, Kd = Wind directionality factor; Ka = Area averaging factor

Wind is fluctuating in nature. So the wind directionality factor accounts for the reduced probability of maximum wind coming from any particular direction along with the probability of the maximum pressure coefficient occurring for that particular direction. For buildings, solid signs, open signs, lattice frameworks and trussed towers (triangular, square, rectangular) a factor of 0.90 may be used on the design wind pressure. For circular or near circular forms this factor may be taken as 1.00. For the cyclone affected regions also, the factor Kd shall be taken as 1.00.

Area averaging factor Ka is a result of averaging the measured pressure values over a given area. As the area becomes larger, the effect of pressure decreases and vice-versa. The area to be considered for any part of the building for computing the area reduction factor, Ka, shall be the surface area from which the wind pressure/forces get transferred to the element /part of the structure being designed. The values of Ka shall be taken from the **Table 6.2**

Table 6.2 Values of Ka

Tributary Area (A)(sq.m.)	Area Averaging Factor (Ka)
≤ 10	1.0
25	0.9
≥ 100	0.8

6.6.3 Along Wind Force

To calculate bending moment, shear forces, member forces at any height of building, the wind pressure on the structure should be multiplied by the dynamic response factor Cdyn.

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

$$Fz = Cf \times Ae \times Pz \times Cdyn \quad \text{....(6.9)}$$

Where, Fz = along wind load on the structure at any height z,

Cf = force co-efficient for the building,

Ae = effective frontal area considered for the structure at height z,

Pz = wind pressure at height z (N/m2),

Cdyn = Dynamic response factor (total load / mean load),

$$Cdyn = \frac{(1+2 \times Ih\,[(gv\,2 \times Bs) + ((Hs \times gr2 \times SE) / \beta]\,0.5)}{(1 + 2 \times gv \times Ih)} \quad \text{....(6.10)}$$

Where, Ih = Turbulence intensity,

gv = peak factor for upwind velocity fluctuations, taken as 3.5,

Bs = Background factor, which is a measure of the slowly varying background component of the fluctuating response, caused by low frequency wind speed variations and given by

$$Bs = \frac{1}{1 + \dfrac{[36\,(h-s)\,2 + 64 \times bsh\,2]\,0.5}{2 \times Lh}} \quad \text{....(6.11)}$$

Hs = height factor for the resonant response = $1 + (s / h)^2$,

$$gr = \sqrt{2 \times \log e\,(3600 \times fo)}, \quad \text{....(6.12)}$$

S = size reduction factor

$$= \frac{1}{\left[1 + \frac{4 \times fo \times h\,(1 + gv \times Ih)}{Vh}\right]\left[1 + \frac{4 \times fo \times boh\,(1 + gv \times Ih)}{Vh}\right]}$$

E = (π/4) times the spectrum of turbulence in the approaching wind stream
= πN / (1+70N2) 5/6,

β = Damping ratio,

Lh = measure of the integral turbulence length scale at height h = 100(h/10) 0.25

fo = first mode natural frequency of vibration of a structure in the along wind direction in Hz.

N = Reduced frequency
= fo x Lh [1+ (gv x Ih)]/ Vz and ....(6.13)

Vz = design wind speed at height h.

The equation for Cdyn 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.

The resonant response is insignificant for rigid structures (T < 1.0 sec). For flexible structures, the background factor Bs may be small resulting in reduced wind forces obtained from dynamic analysis as compared to the static analysis.

The equivalent cross-wind static force per unit height (We) as a function of z in Newton per meter height can be found out as: ....(6.14)

We (z) = 0.6*[Vz] 2*d*Cdyn

Where, d = Lateral dimension of the structure parallel to the wind stream.

Cdyn = 1.5*gr*(b/d)*(Km/ (1+gv*Ih) 2)*(z/h) k*((π*Cfs) / β) 0.5 ....(6.15)

Where, Km = mode shape correction factor for cross-wind acceleration
= 0.76+0.24k

Where again,

k = mode shape power exponent for the fundamental mode of vibration
= 1.5 for a uniform cantilever
= 0.5 for a slender framed structure (moment resistant)
= 1.0 for building with central core and moment resisting façade
= 2.3 for a tower decreasing in stiffness with height, or with a large mass at the top

Cfs = cross-wind force spectrum coefficient generalized for a linear mode shape (**Figs 6.5-6.8**)

and gv, gr, Ih and β are as defined above.

The turbulence intensity is obtained from the graphs (**Figs 6.5-6.8**) based on the reduced velocity as given by **eqn 6.16**

$$\text{Reduced velocity } Vn = \frac{Vz}{fo*b*(1+gv*Ih)} \qquad \text{....(6.16)}$$

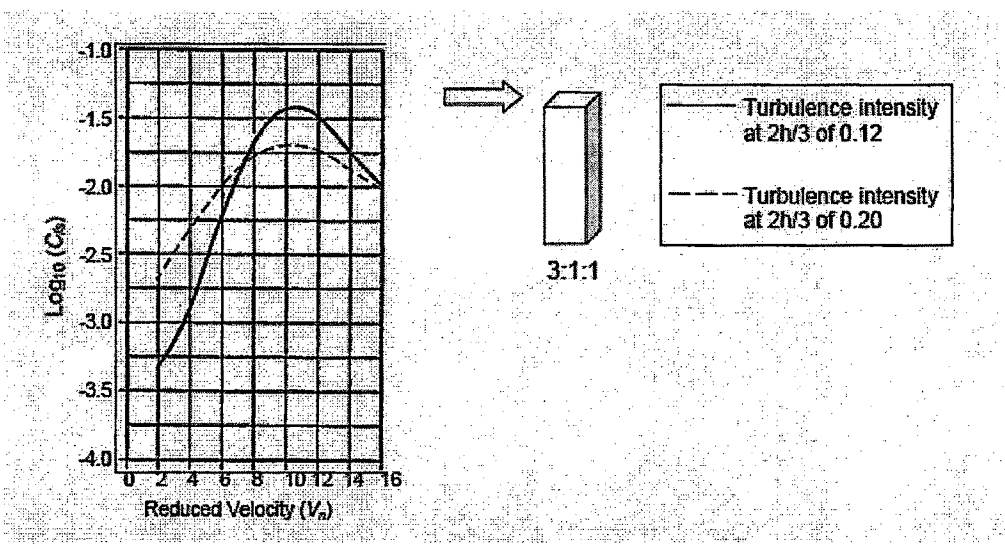


Fig. 6.5 Cross-Wind Force Co-efficient for a 3:1:1 Square Section

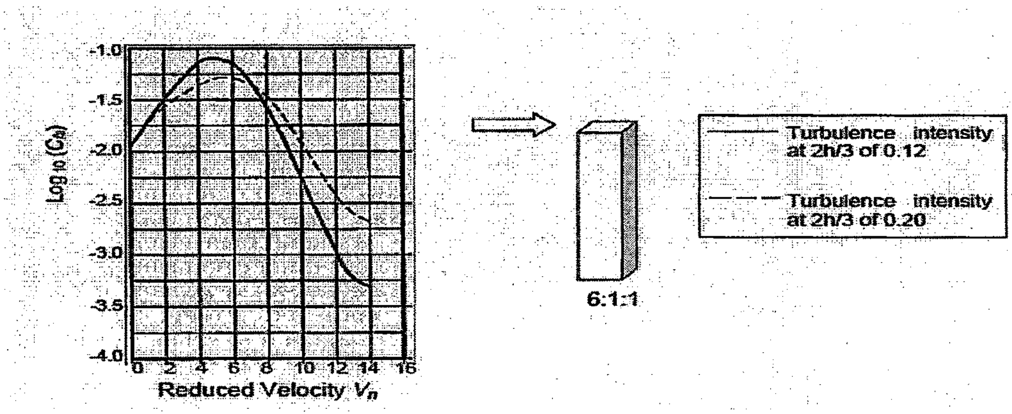


Fig. 6.6 Cross-Wind Force Co-efficient for a 6:1:1 Square Section

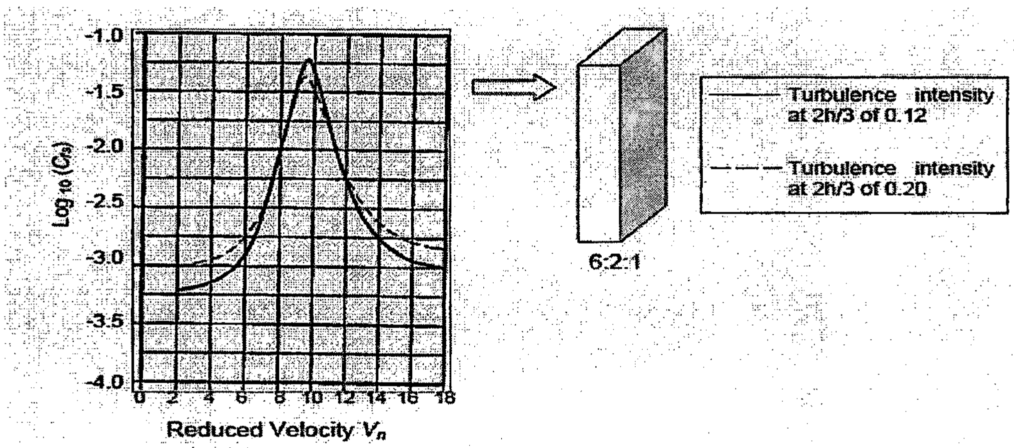


Fig. 6.7 Cross-wind Force Co-efficient for a 6:2:1 Rectangular Section

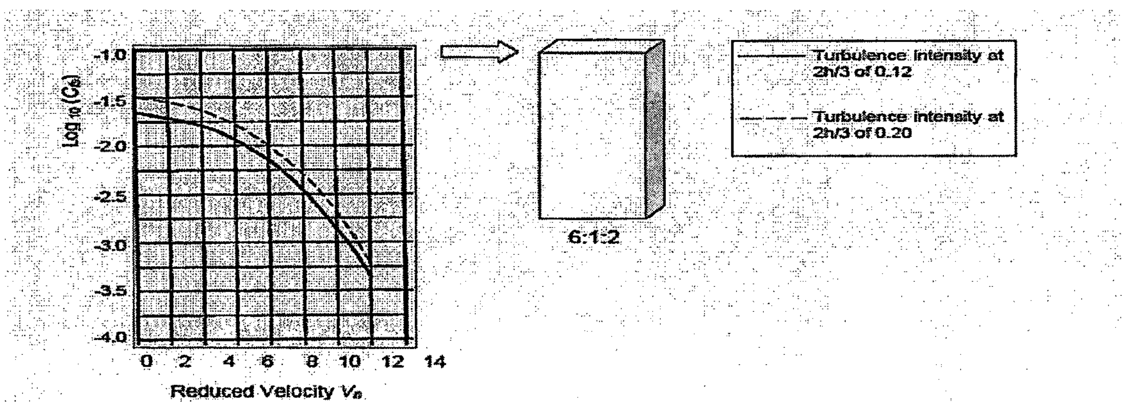


Fig. 6.8 Cross-wind Force Co-efficient for a 6:1:2 Rectangular Section

6.7 COMPUTER IMPLEMENTATION OF DRF METHOD

Program is developed based on Dynamic Response Factor Metod.During execution of program while clicking on "Analysis" on menu the Dialog Box (**Fig. 6.9**) will be displayed and the "result .txt" file is attached with item "Result" on Menu Resource (**Fig. 6.10**).

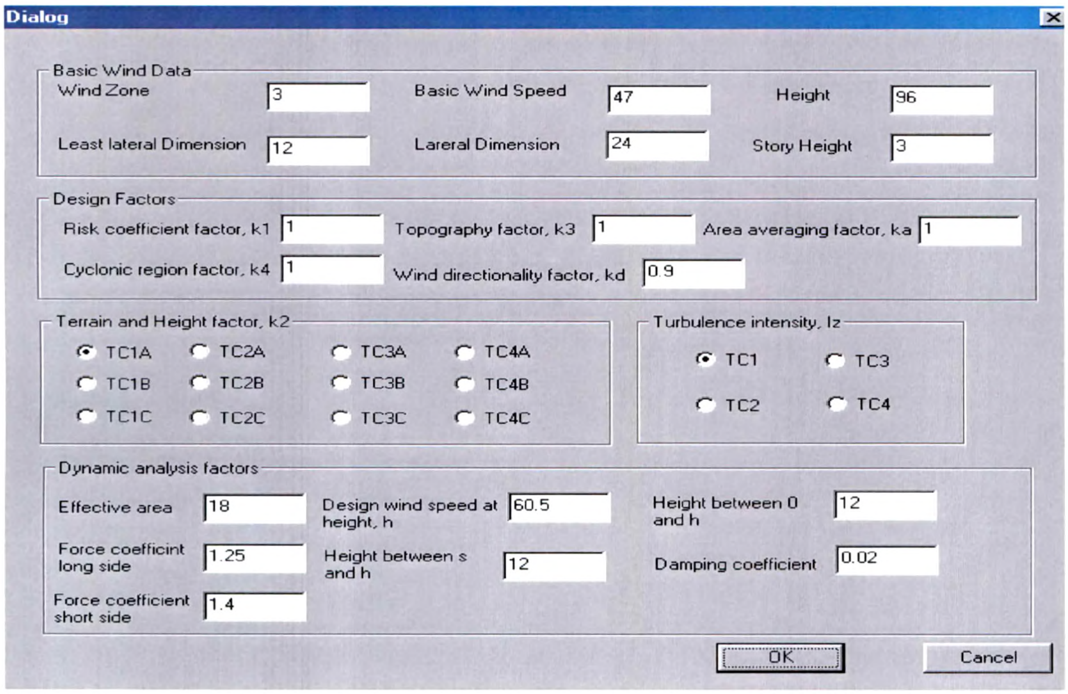


Fig. 6.9 Dialog Box of DRFmethod

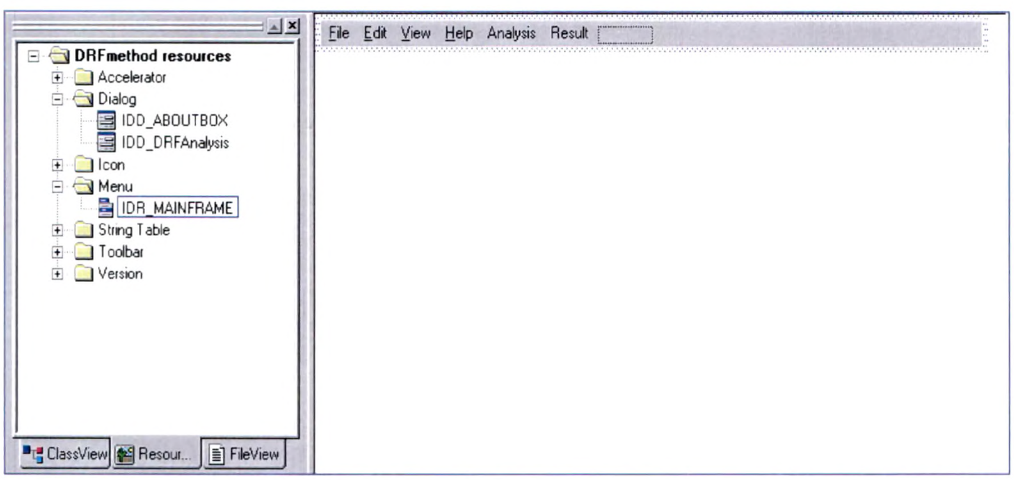
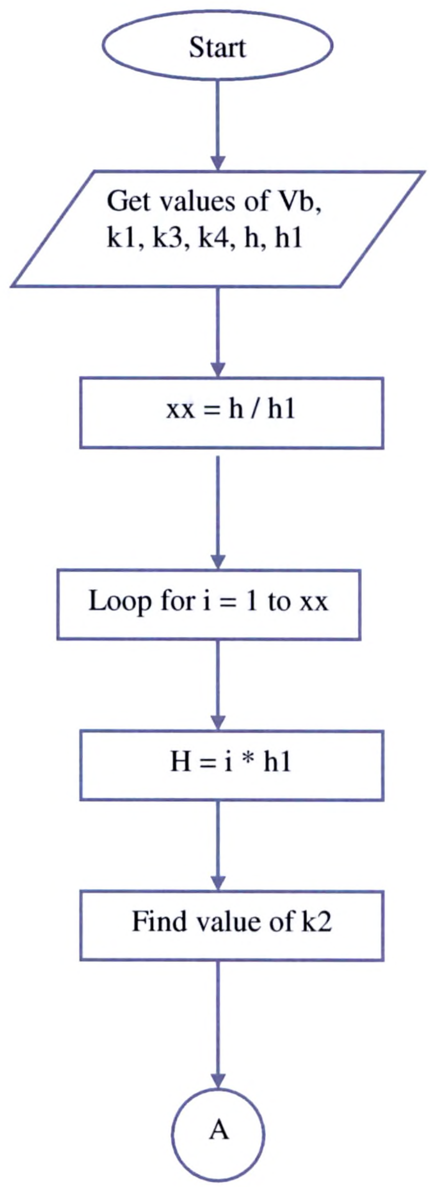
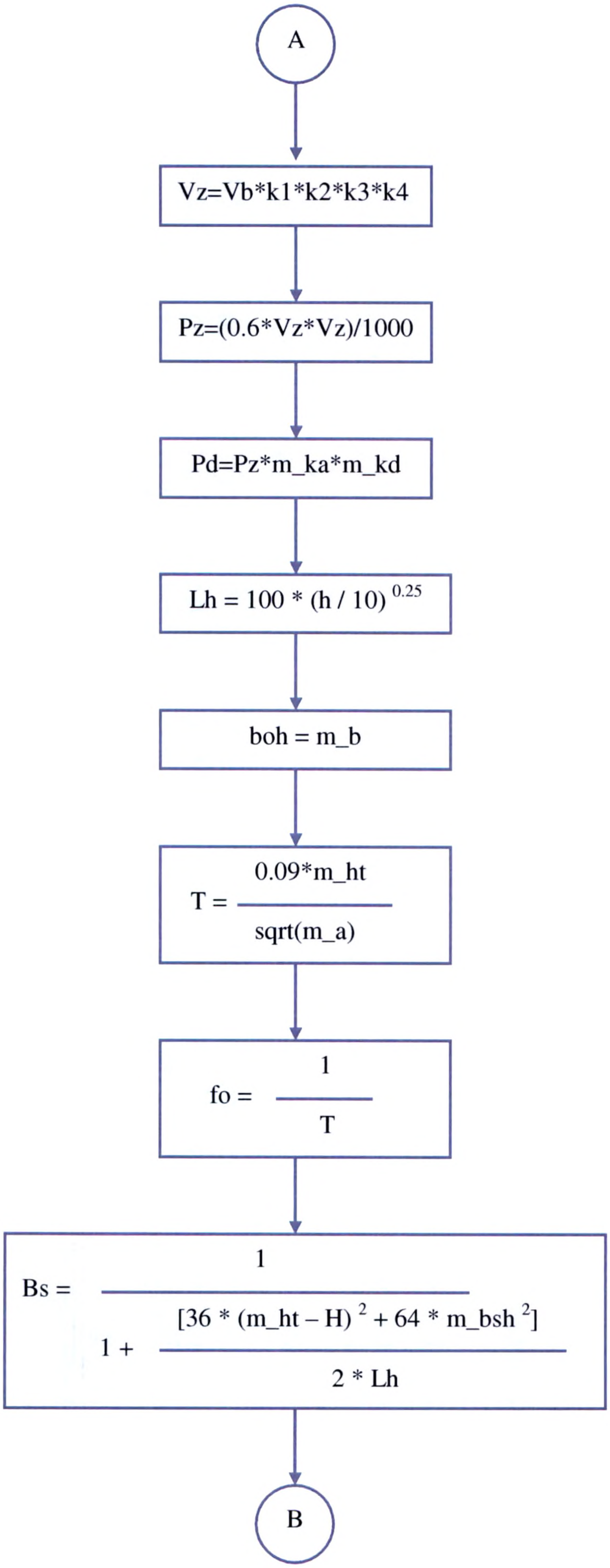
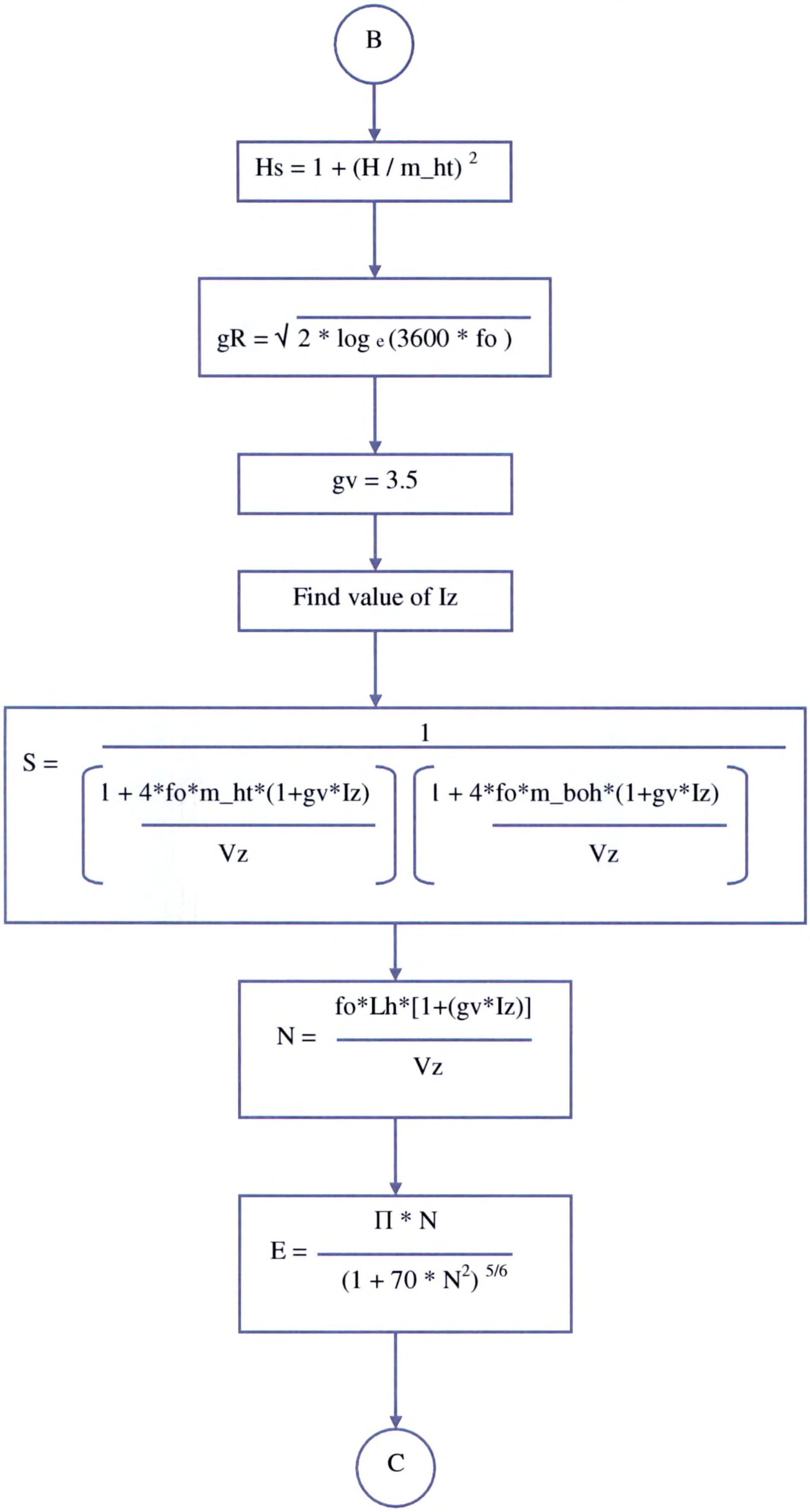


Fig. 6.10 Menu Resource of DRF Method

6.7.1 Flow chart of DRF Method




A
Vz=Vb*k1*k2*k3*k4
Pz=(0.6*Vz*Vz)/1000
Pd=Pz*m_ka*m_kd
Lh = 100 * (h / 10) 0.25
boh = m_b
T = 0.09*m_ht / sqrt(m_a)
fo = 1 / T
Bs = 1 / (1 + [36 * (m_ht – H) 2 + 64 * m_bsh 2] / 2 * Lh)
B


B
Hs = 1 + (H / m_ht) 2
gR = √ 2 * log e (3600 * fo)
gv = 3.5
Find value of Iz
S = 1 / [1 + 4*fo*m_ht*(1+gv*Iz) / Vz] [1 + 4*fo*m_boh*(1+gv*Iz) / Vz]
N = fo*Lh*[1+(gv*Iz)] / Vz
E = Π * N / (1 + 70 * N2) 5/6
C

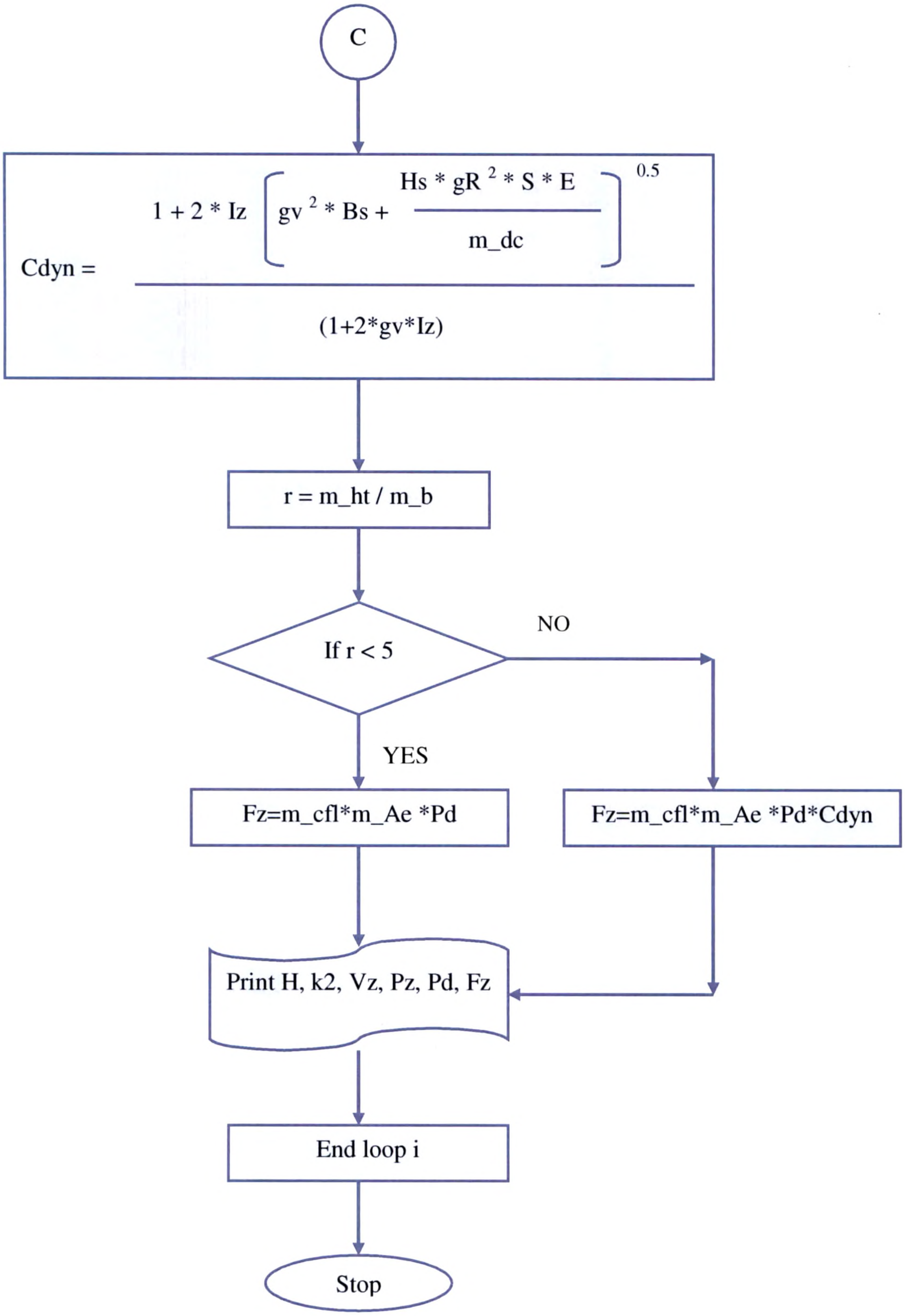


Fig. 6.11 Flowchart for DRF Method

6.7.2 Output of DRF Method Program

After execution of program (**Fig. 6.11**) a menu will display on screen as shown in **Fig. 6.12** On clicking "Analysis" on menu bar a Dialog Box will appear on screen. After clicking "OK" button, user has to click on "Result" on menu bar to get results.

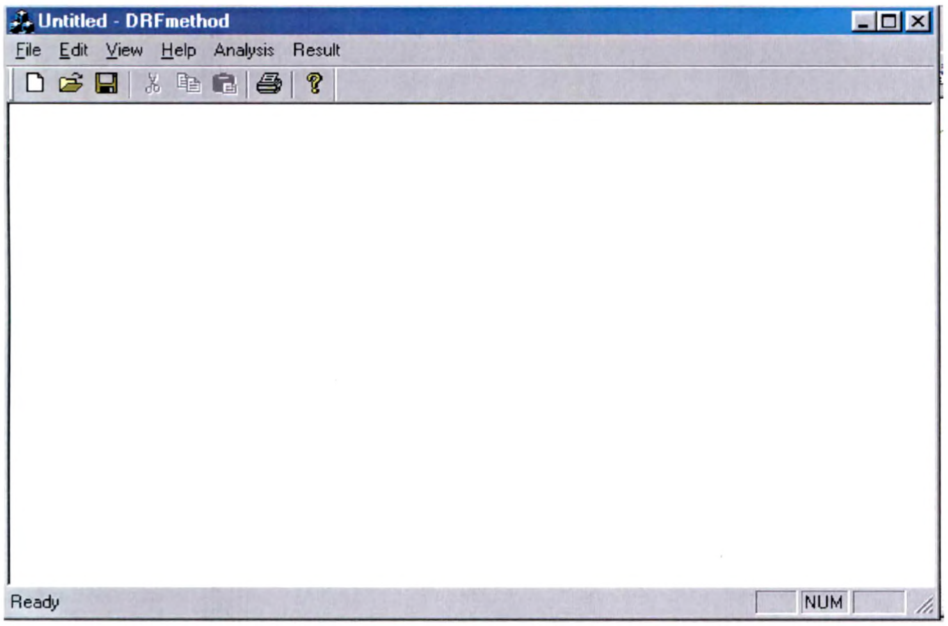


Fig.6.12 Menu Bar Displaying Main Menu Items

6.7.3 Results of "DRF Method"

6.7.3.1 Along wind response

With the help of "DRF Method" program developed in Visual C++ the nodal forces (Along wind response) with or without considering the dynamic effects can be obtained. **Table 6.3** shows the results "DRF method".

Table 6.3 Results of "DRF method"

Height (m)	k2	Vz (m/s)	Pz (kN/m2)	Pd (kN/m2)	Fz (kN)
3	0.9772	45.9284	1.26565	1.13909	22.0803
6	1.0108	47.5076	1.35418	1.21876	23.7763
9	1.0408	48.9176	1.43576	1.29218	25.4204
12	1.0672	50.1584	1.50952	1.35857	26.9732
15	1.09	51.23	1.57471	1.41724	28.3998
18	1.1092	52.1324	1.63067	1.46761	29.6714
21	1.1248	52.8656	1.67686	1.50918	30.7652
24	1.1368	53.4296	1.71283	1.54155	31.6655
27	1.1452	53.8244	1.73824	1.56442	32.3622
30	1.15	54.05	1.75284	1.57756	32.8498
33	1.17504	55.2271	1.83002	1.64702	34.6259
36	1.17962	55.442	1.84429	1.65986	35.1416
39	1.18412	55.6535	1.85838	1.67255	35.6697
42	1.18854	55.8616	1.87231	1.68508	36.2072
45	1.1929	56.0663	1.88606	1.69745	36.7463
48	1.19718	56.2676	1.89963	1.70967	37.2734
51	1.2014	56.4656	1.91302	1.72172	37.6967
54	1.20554	56.6602	1.92623	1.7336	38.2568
57	1.2096	56.8514	1.93925	1.74532	38.8208
60	1.2136	57.0392	1.95208	1.75687	39.3887
63	1.21752	57.2236	1.96473	1.76825	39.96
66	1.22138	57.4047	1.97718	1.77946	40.5345
69	1.22516	57.5823	1.98943	1.79049	41.1112
72	1.22886	57.7566	2.0015	1.80135	41.6891
75	1.2325	57.9275	2.01336	1.81202	42.2665
78	1.23606	58.095	2.02502	1.82252	42.8409
81	1.23956	58.2591	2.03648	1.83283	43.4086
84	1.24298	58.4199	2.04773	1.84296	43.9645
87	1.24632	58.5772	2.05877	1.8529	44.5017
90	1.2496	58.7312	2.06961	1.86265	45.0117
93	1.2528	58.8818	2.08024	1.87222	45.4857
96	1.25594	59.029	2.09065	1.88159	45.917

6.7.3.2 Cross-wind response

Cross wind response may be found using DRF method as mentioned below:

Height of building (h) = 96m, (2*h)/3 = 64.

Now one can find turbulent intensity at height 64m is 0.2 (dotted line)

from Fig.6.5 one can find value of Cfs with the help of Vn and Iz.

Log 10Cfs = -3.0

Cfs = 0.001

For wider face:

fo = (1/T) = (√ 12 / (0.09*96)) = 0.4Hz.

gr = √2 x log e (3600 x fo) = 3.814

Width of building (b) = 24m

Depth of building (d) = 12m

Damping coefficient (β) = 0.02

Km = 0.76 +0.24k

For k = 1, Km = 1.00

Table 6.4 shows further calculation of cross-wind response

Table 6.4 Cross-wind Response of DRF Method

Height (m)	k2 (TC4)	Vz (m/s)	Pz (kN/m2)	Ih	Vn	Cdyn	We (kN)
3	0.8	37.6	0.848	0.342	1.768	0.029	0.3
15	0.8	37.6	0.848	0.342	1.768	0.147	1.495
24	0.868	40.796	1.0	0.3272	1.965	0.246	2.953
33	0.9895	46.5065	1.298	0.302	2.336	0.369	5.739
51	1.102	51.794	1.610	0.2847	2.680	0.605	11.677
60	1.12	52.64	1.663	0.282	2.737	0.72	14.326
69	1.138	53.486	1.716	0.2793	2.794	0.834	17.172
78	1.156	54.332	1.771	0.2766	2.852	0.951	20.223
87	1.174	55.178	1.827	0.2739	2.910	1.072	23.489
96	1.192	56.024	1.883	0.2712	2.969	1.194	26.98

From Table 6.4 it is clear that the forces obtained from cross wind response are very small as compared to the along wind response. Hence one can safely neglect the effect of cross- wind response, as done in most of the international codes.

6.8 COMPARISON OF RESULTS OF GFM AND DRFM

Table 6.5 shows the comparison between the storey shear forces obtained by both the methods. It can be clearly seen the Gust Factor method gives conservative results compared to the DRF method. Besides the area averaging, wind directionality and other such factors in the DRF method give more realistic forces. The 3-sec gust wind speed adopted in the DRF is closer to international standards. The hourly averaging period in the Gust Factor Method would also contribute to higher forces.

Comparison of design wind speed, design wind pressure and along wind load is given in **Fig.6.13 -6.15**.

- IS code 875(part 3)-1987 uses hourly mean wind speed while Proposed Draft code 3 –sec gust speed is used. The 3-sec gust gives slightly higher values of design wind speed.
- The design wind speed is based on the importance of building in cyclone prone regions. It is derived by multiplying the basic wind speed with the importance factor (K4), introduced in proposed draft code. Thus the proposed code addresses te cyclone forces for the first time in India.
- Effect of wind randomness by taken care of by the wind directionality factor (Kd) introduced in proposed draft code.
- Pressure varies with variation in area on which it transfers. This is done by multiplying area-averaging factor (Ka) with the basic wind speed, introduced in proposed draft code.
- Gust factor method of IS: 875-1987, gives design basis for calculating along-wind force only. While the Dynamic Response Method of the proposed draft code 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. Torsional effect is totally ignored both in the 1987 version as well as the proposed code.

As per Fig.6.13 it can be seen that the values of design wind pressure are higher in DRF method than Gust Factor method due to 3-sec gust wind speed.

But due to the difference in factors used in dynamic calculation, we can see that the values of along wind forces of Gust Factor method are higher than the DRF method

Table 6.5 Comparison of Results of GFM and DRFM

Height (m)	Gust Factor Method as per IS: 875(part 3)-1987			Dynamic Response Factor as per Method Proposed in Draft Code		
	Vz (m/s)	Pd (kN/m2)	Fz (kN)	Vz (m/s)	Pd (kN/m2)	Fz (kN)
3	33.2384	0.662875	26.4573	45.9284	1.13909	22.0803
6	34.8176	0.727359	29.2598	47.5076	1.21876	23.7763
9	36.2276	0.787463	31.8887	48.9176	1.29218	25.4204
12	37.4684	0.842329	34.3011	50.1584	1.35857	26.9732
15	38.54	0.891199	36.4594	51.23	1.41724	28.3998
18	39.4424	0.933422	38.3307	52.1324	1.46761	29.6714
21	40.1756	0.968447	39.8874	52.8656	1.50918	30.7652
24	40.7396	0.995829	41.107	53.4296	1.54155	31.6655
27	41.1344	1.01522	41.9722	53.8244	1.56442	32.3622
30	41.36	1.02639	42.4708	54.05	1.57756	32.8498
33	42.4536	1.08138	44.9317	55.2271	1.64702	34.6259
36	42.6879	1.09336	45.4686	55.442	1.65986	35.1416
39	42.9168	1.10511	45.996	55.6535	1.67255	35.6697
42	43.1402	1.11664	46.5139	55.8616	1.68508	36.2072
45	43.3582	1.12796	47.0223	56.0663	1.69745	36.7463
48	43.571	1.13906	47.5213	56.2676	1.70967	37.2734
51	43.7787	1.14994	48.0108	56.4656	1.72172	37.6967
54	43.9813	1.16061	48.491	56.6602	1.7336	38.2568
57	44.1789	1.17107	48.9619	56.8514	1.74532	38.8208
60	44.3718	1.18131	49.4236	57.0392	1.75687	39.3887
63	44.5599	1.19135	49.8761	57.2236	1.76825	39.96
66	44.7433	1.20118	50.3195	57.4047	1.77946	40.5345

Table 6.5 Comparison of Results of GFM and DRFM (Cont..)

H m	Vz (m/s)	Pd (kN/m2)	Fz (kN)	Vz (m/s)	Pd (kN/m2)	Fz (kN)
72	45.0967	1.22023	51.1795	57.7566	1.80135	41.6891
75	45.2669	1.22945	51.5962	57.9275	1.81202	42.2665
78	45.4328	1.23848	52.0043	58.095	1.82252	42.8409
81	45.5946	1.24732	52.4039	58.2591	1.83283	43.4086
84	45.7524	1.25597	52.795	58.4199	1.84296	43.9645
87	45.9062	1.26443	53.1779	58.5772	1.8529	44.5017
90	46.0562	1.27271	53.5526	58.7312	1.86265	45.0117
93	46.2025	1.2808	53.9194	58.8818	1.87222	45.4857
96	46.3452	1.28873	54.2783	59.029	1.88159	45.917

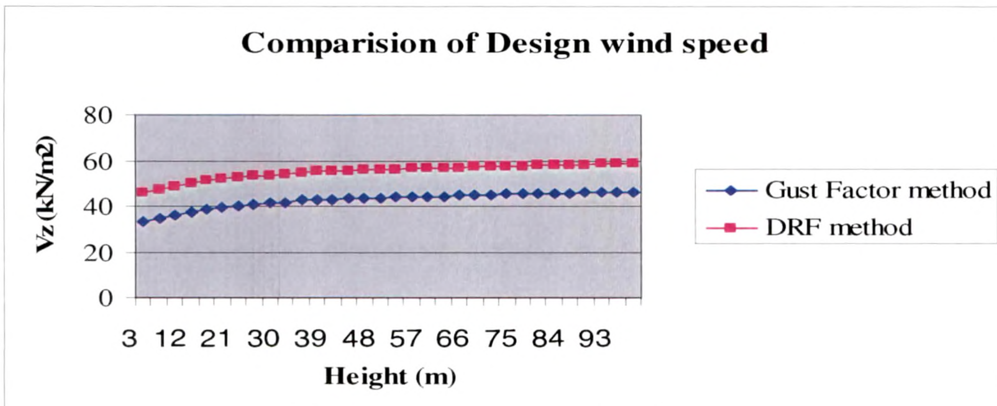


Fig. 6.13 Comparison of Design Wind Speed

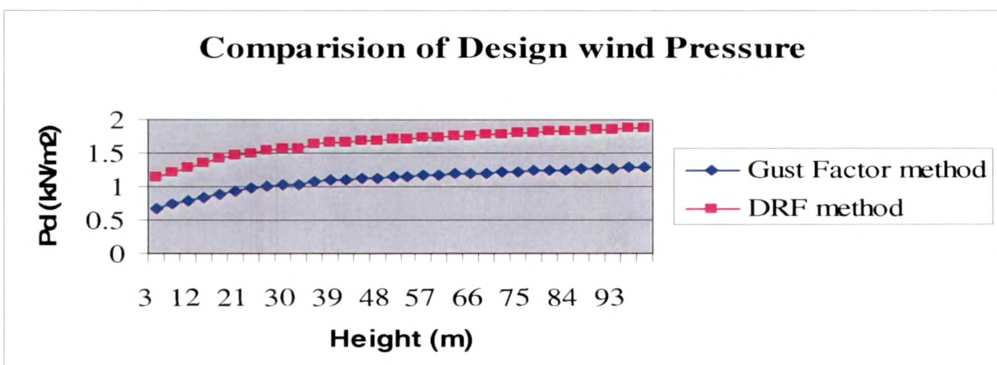


Fig. 6.14 Comparison of Design Wind Pressure

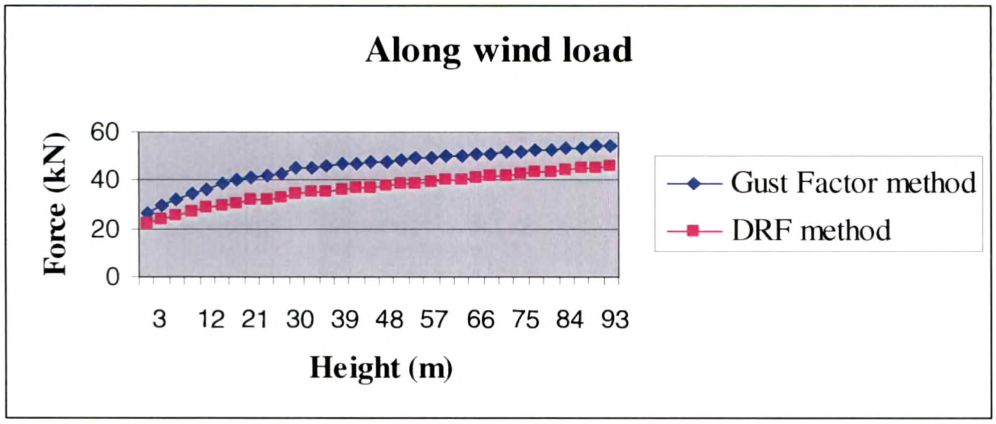


Fig. 6.13 Comparison of Along Wind Load

6.9 CLOSING REMARKS

Earthquake and cyclone are the two most devastating disasters facing this part of the world. After a comprehensive study of earthquakes, this part of the research is devoted to studying various aspects of high velocity windstorms and their effects on slender buildings. Wind has been taken as a load on buildings a static lateral load for a long time in India. As the height of buildings increases, wind becomes more and more critical and needs to be handled in its dynamic state which makes it complex. Besides this the coastal belts were not considered for the cyclone effects of wind that were perpetual in their devastation and yet not addressed by the codes. This work has been aimed at developing a software to handle wind as a static load, as a gust factor load on slender buildings as per IS-875 (1989) and also as per the international standards of Dynamic Response Factor (ATC – 60).The prepared software evaluates the wind forces for any user defined wind condition of static or dynamic condition. The force module is then used for analysis of the building using SAP2000 as seen in the next section.