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IS:875 (Part 3) - 1987

A Commentary on Indian Standard Code of practice for design loads (other than earthquake) For buildings and structures Part 3 Wind Loads (Second Revision)

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Foreword

0.1 This Indian Standard (Part 3) (Second Revision) was adopted by the Bureau of Indian Standards on 13 November 1987, after the draft finalized by the Structural Safety Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 A building has to perform many functions satisfactorily. Amongst these functions are the utility of the building for the intended use and occupancy, structural safety, fire safety and compliance with hygienic, sanitation, ventilation and daylight standards. The design of the building is dependent upon the minimum requirements prescribed for each of the above functions. The minimum requirements pertaining to the structural safety of buildings are being covered in loading codes by way of laying down minimum design loads which have to be assumed for dead loads, imposed loads, wind loads and other external loads, the structure would be required to bear. Strict conformity to loading standards, it is hoped, will not only ensure the structural safety of the buildings and structures which are being designed and constructed in the country and thereby reduce the hazards to life and property caused by unsafe structures, but also eliminate the wastage caused by assuming unnecessarily heavy loadings without proper assessment.

0.3 This standard was first published in 1957 for the guidance of civil engineers, designers and architects associated with the planning and design of buildings. It included the provisions for the basic design load.% (dead loads, live loads, wind loads and seismic loads) to be assumed in the design of the buildings. In its first revision in 1964, the wind

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pressure provisions were modified on the basis of studies of wind phenomenon and its effect on structures, undertaken by the special committee in consultation with the Indian Meteorological Department. In addition to this, new clauses on wind loads for butterfly type structures were included; wind pressure coefficients for sheeted roofs, both curved and sloping were modified; seismic load provisions were deleted (separate code having been prepared) and metric system of weights and measurements was adopted.

0.3.1 With the increased adoption of this Code, a number of comments were received on provisions on live load values adopted for' different occupancies. Simultaneously, live load surveys have been carried out in America and Canada to arrive at realistic live loads based on actual determination of loading (movable and immovable) in different occupancies. Keeping this in view and other developments in the field of wind engineering, the Structural Safety Sectional Committee[1] decided to prepare the second revision of IS : 875 in the following five parts:

Part 1 Dead loads Part

Part 2 Imposed loads Part

Part 3 Wind loads Part

Part 4 Snow locals Part

Part 5 Special loads and load combinations

Earthquake load is covered in a separate standard, namely, IS -1893-1984[2] which should be considered along with the above loads.

0.3.2 This Part (Part 3) deals with wind loads to be considered when designing buildings, structures and components thereof. In this revision, the following important modifications have been made from those covered in the 1964 version of IS : 875:

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a) The earlier wind pressure maps (one giving winds of shorter duration and an excluding winds of shorter duration) have been replaced by a single wind map giving basic maximum wind speed in m/s (peak gust velocity averaged over a short time interval of about 3 seconds duration). The wind speeds have been worked out for 50 years return period based on the up to-date wind data of 43 dines pressure tube (DPT) anemograph stations and study of other related works available on the subject since 1964. The map and related recommendations have been provided in the code with the active cooperation of Indian Meteorological Department (IMD). Isotachs (lines of equal velocity) have not been given as in the opinion of the committee; there is still not enough extensive meteorological data at close enough stations in the country to justify drawing of isotachs.

b) Modification factors to modify the basic wind velocity to take into account the effects of terrain, local topography, size of structure, etc, are included.

c) Terrain is now classified into four categories based on characteristics of the ground surface irregularities.

d) Force and pressure coefficients have been included for a large range of clad and unclad buildings and for individual structural elements.

e) Force coefficients (drag coefficients) are given for frames, lattice towers, walls and hoardings.

f) The calculation of force on circular sections is included incorporating the effects of Reynolds number and surface roughness.

g) The external and internal pressure coefficients for gable roofs, lean-to roofs, curved roofs, canopy roofs (butterfly type structures) and multi-span roofs have been rationalised.

h) Pressure coefficients are given for combined roofs, roofs with sky light, circular silos, cylindrical elevated structures, grandstands, etc.

i) Some requirements regarding study of dynamic effects in flexible slender

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structures are included.

j) Use of gust energy method to arrive at the design wind load on the whole structure is now permitted.

0.3.3 The Committee responsible for the revision of wind maps while reviewing available meteorological wind data and response of structures to wind, felt the paucity of data on which to base wind maps for Indian conditions on statistical analysis. The Committee, therefore, recommends to all individuals and organizations responsible for putting-up of tall structures to provide instrumentation in their existing and new structures (transmission towers, chimneys, cooling towers, buildings, etc) at different elevations (at least at two levels.) to continuously measure and monitor wind data. The instruments are required to collect data on wind direction, wind speed and structural response of the structure due to wind (with the help of accelerometer, strain gauges, etc). It is also the opinion of the committee that such instrumentation in tall structures will not in any way affect or alter the functional behaviour of such structures. The data so collected will be very valuable in evolving more accurate wind loading of structures.

0.4 The Sectional Committee responsible for the preparation of this standard has taken into account the prevailing practice in regard to loading standards followed in this country by the various authorities and has also taken note of the developments in a number of other countries. In the preparation of this code, the following overseas standards have also been examined.-

a) BSCP 3 : 1973 Code of basic data for design of buildings: Chapter V Loading, Part 2 Wind loads.

b) AS 1170, Part 2-1983 SAA Loading code Part 2 - Wind forces.

c) NZS 4203-1976 Code of practice for general structural design loading for buildings.

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d) ANSI A58.1-1972 American Standard Building code requirements for minimum design loads in buildings and other structures.

e) Wind resistant design regulations, A World List. Association for Science Documents Information, Tokyo

0.5 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS - 2-1960[3]. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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1. – Scope

1.1 -

This standard gives wind forces and their effects (static and dynamic) that should be taken into account when designing buildings, structures and components thereof.

1.1.1–

It is believed that ultimately wind load estimation will be made by taking into account the random variation of wind speed with time but available theoretical methods have – not matured sufficiently at present for use in the code. For this reason, static wind method of load estimation which implies a steady wind speed, which has proved to be satisfactory for normal, short and heavy structures, is given in 5 and 6. However, a beginning has been made to take account of the random nature of the wind speed by requiring that the along-wind or drag load on structures which are prone to wind induced oscillations, be also determined by the gust factor method (see 8) and the more severe of the two estimates be taken for design.

A large majority of structures met with in practice do not however, suffer wind induced oscillations and generally do not require to be examined for the dynamic effects of wind, including use of gust factor method. Nevertheless, there are various types of structures or their components such as some tall buildings, chimneys, latticed towers, cooling towers, transmission towers, guyed masts, communication towers, long span

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C1.1–

This Code provides information on wind effects for buildings and structures, and their components. Structures such as chimneys, cooling towers, transmission line towers and bridges are outside the scope of this Code. There are Indian Standards dealing with chimneys and cooling towers separately. Information on bridges (only static forces) is given in Indian Railway Specifications (IRS) and Indian Road Congress (IRC) Specifications. For aerodynamics of bridges, specialist literature may be consulted. With substantial work being done worldwide in the area of wind engineering, there is a growing body of new information. The user of this Code is advised to consult specialist literature for the design of large or important projects involving various types of structures.

C1.1.1 _

Wind is not a steady phenomena due to the natural turbulence and gustiness present in it. However, when averaged over a sufficiently long time duration (from a few minutes to an hour), a mean component of wind speed can be defined which would produce a static force on a structure. Superimposed on the mean/static component is the time varying component having multiple frequencies spread over a wide band.

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bridges, partially or completely solid faced antenna dish, etc, which require investigation of wind induced oscillations. The use of 7 shall be made for identifying and analysing such structures.

1.1.2 –

This code also applies to buildings or other structures during erection/construction and the same shall be considered carefully during various stages of erection/construction. In locations where the strongest winds and icing may occur simultaneously, loads on structural members, cables and ropes shall be calculated by assuming an ice covering based on climatic and local experience.

1.1.3–

In the design of special structures, such as chimneys, overhead transmission line towers, etc, specific requirements as specified in the respective codes shall be adopted in conjunction with the provisions of this code as far as they are applicable. Some of the Indian Standards available for the design of special structures are:

IS: 4998 (Part 1)-1975 Criteria for design of reinforced concrete chimneys- Part I Design criteria (first revision)

IS : 6533-1971 Code of practice for design and construction of steel chimneys

IS : 5613 (Part I/Sec 1).1970 Code of practice for design, installation and maintenance of overhead power lines- Part I Lines up to and including II kV, Section I Design

IS : 802 (Part 1)-1977 Code of practice for use of structural steel in overhead transmission line towers: Part I Loads and permissible stresses (second revision)

IS : 11504-1985 Criteria for structural design of reinforced concrete natural

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C1.1.2 _

The construction period of a structure is much smaller than its expected life. Therefore, a smaller return period of 5 to 10 years may be considered for arriving at the design factor (factor k_1) for construction stages/period of a structure depending on its importance. In areas where snowfall and icing occurs, wind loads have to be assessed accordingly. Elements such as cables and ropes can undergo a dynamic response in such cases and have to be examined for the same.

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draught cooling towers

NOTE I - This standard does not apply to buildings or structures with unconventional shapes, unusual locations, and abnormal environmental conditions that have not been covered in this code. Special investigations are necessary in such cases to establish wind loads and their effects. Wind tunnel studies may also be required in such situations.

NOTE 2 - In the case of tall structures with unsymmetrical geometry, the designs may have to be checked for torsional effects due to wind pressure.

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2. – Notations

2.1–

The following notations shall be followed unless otherwise specified in relevant clauses:-

- A = surface area of a structure or part of a structure;
- A_e = effective frontal area;
- Az = an area at height z;
- B = breadth of a structure or structural member normal to the wind stream in the horizontal plane;
- C_f = force coefficient/drag coefficient;
- C_{fn} = normal force coefficient;
- C_{ft} = transverse force coefficient;
- C_f' = frictional drag coefficient;
- C_p = pressure coefficient;
- C_{pe} = external pressure coefficient;
- C_{pl} = internal pressure coefficient;
- d = depth of a structure or structural member parallel to wind stream;
- D = diameter of cylinder;
- F = force normal to the surface;
- F_n = normal force;
- F_t = transverse force;
- F' = frictional force;
- h = height of structure above mean ground level;
- h_x = height of development of a velocity profile at a distance x down wind from a change in terrain category;
- $\left.\begin{matrix} k_1 \\ k_2 \\ k_3 \end{matrix}\right\}$ = multiplication factors;
- K = multiplication factor;
- l = length of the member or greater horizontal dimension of a building;
- p_d = design wind pressure;
- p_z = design wind pressure at height Z,
- p_e = external pressure;

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C 2.0 –

Notations have been defined also in the text at their first appearance. A few of the notations have more than one definition, having been used for denoting different parameters.

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p_i = internal pressure;
R_e = Reynolds number;
S = strouhal number;
V_b = regional basic wind speed;
V_z = design wind velocity at height z;
$\overline{V}_z$ = hourly mean wind speed at height z;
w = lesser horizontal dimension of a building, or a structural member;
w′ = bay width in multi-bay buildings;
x = distance down wind from a change in terrain category;
θ = wind angle from a given axis;
α = inclination of the roof to the horizontal;
β = effective solidity ratio;
η = shielding factor or shedding frequency;
ϕ = solidity ratio;
z = a height or distance above the ground; and
ε = average height of the surface roughness.

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3. – Terminology

For the purpose of this code, the following definitions shall apply.

Angle of Attack- - Angle between the direction of wind and a reference axis of the structure,

Breadth - Breadth means horizontal dimension of the building measured normal to the direction of wind.

NOTE - Breadth and depth are dimensions measured in relation to the direction of the wind, whereas length and width are dimensions related to the plan.

Depth - Depth means the horizontal dimension of the building measured in the direction of the wind.

Developed Height - Developed height is the height of upward penetration of the velocity profile in a new terrain. At large fetch lengths, such penetration reaches the gradient height, above which the wind speed may be taken to be constant. At lesser fetch lengths, a velocity profile of a smaller height but similar to that of the fully developed profile of that terrain category has to be taken, with the additional provision that the velocity at the top of this shorter profile equals that of the unpenetrated earlier velocity profile at that height.

Effective Frontal Area -The projected area of the structure normal to the direction of the wind.

Element of Surface Area - The area of surface over which the pressure coefficient is taken to be constant.

Force Coefficient - A non-dimensional coefficient such that the total wind force on a body is the product of the force coefficient, the dynamic pressure of the incident design wind speed and the reference area over which the force is required.

NOTE - When the force is in the direction of the incident wind, the non-dimensional coefficient will

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be called its 'drag coefficient'. When the force is perpendicular to the direction of incident wind, the non-dimensional coefficient will be called as 'lift coefficient'.

Ground Roughness - The nature of the earth's surface as influenced by small scale obstructions such as trees and buildings (as distinct from topography) is called ground roughness.

Gust - 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.

Peak Gust - Peak gust or peak gust speed is the wind speed associated with the maximum amplitude.

Fetch Length - Fetch length is the distance measured along the wind from a boundary at which a change in the type of terrain occurs. When the changes in terrain types are encountered (such as, the boundary of a town or city, forest, etc), the wind profile changes in character but such changes are gradual and start at ground level, spreading or penetrating upwards with increasing fetch length.

Gradient Height- Gradient height is the height above the mean ground level at which the gradient wind blows as a result of balance among pressure gradient force, coriolis force and centrifugal force. For the purpose of this code, the gradient height is taken as the height above the mean ground level, above which the variation of' wind speed with height need not be considered.

Mean Ground Level - The mean ground level is the average horizontal plane of the area enclosed by the boundaries of the structure.

Pressure Coefficient - Pressure coefficient is the ratio of the difference between the pressure acting at a point on a surface and the static pressure of the incident wind to the design wind pressure, where the static and design wind pressures are determined at the height of the point considered after taking

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into account the geographical location, terrain conditions and shielding effect. The pressure coefficient is also equal to $\left[1-\left(Vp/Vz\right)^2\right]$, where V_p is the actual wind speed at any point on the structure at a height corresponding to that of V_z.

NOTE - Positive sign of the pressure coefficient indicates pressure acting towards the surface and negative sign indicates pressure acting away from the surface.

Return Period - Return period is the number of years, the reciprocal of which gives the probability of extreme wind exceeding a given wind speed in any one year.

Shielding Effect - Shielding effect or shielding refers to the condition where wind has to pass along some structure(s) or structural element(s) located on the upstream wind side, before meeting the structure or structural element under consideration. A factor called shielding factor' is used to account for such effects in estimating the force on the shielded structures.

Suction - Suction means pressure less than the atmospheric (static) pressure and is taken to act away from the surface.

Solidity Ratio - Solidity ratio is equal to the effective area (projected area of all the individual elements) of a frame normal to the wind direction divided by the area enclosed by the boundary of the frame normal to the wind direction.

NOTE - Solidity ratio is to be calculated for individual frames.

Terrain Category - Terrain category means the characteristics of the surface irregularities of an area which arise from natural or constructed features. The categories are numbered in increasing order of roughness.

Velocity Profile - The variation of the horizontal component of the atmospheric wind speed at different heights above the mean ground level is termed as velocity profile.

Topography - The nature of the earth's surface as influenced the hill and valley configurations.

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4. – GENERAL

4.1 -

Wind is air in motion relative to the surface of the earth. The primary cause of wind is traced to earth's rotation and differences in terrestrial radiation. The radiation effects are primarily responsible for convection either upwards or downwards. The wind generally blows horizontal to the ground at high wind speeds. Since vertical components of atmospheric motion are relatively small, the term 'wind' denotes almost exclusively the horizontal wind, vertical winds are always identified as such. The wind speeds are assessed with the aid of anemometers or anemographs which are installed at meteorological observatories at heights generally varying from 10 to 30 metres above ground.

4.2 –

Very strong winds (greater than 80 km/h are generally associated with cyclonic storms, thunderstorms, dust storms or vigorous monsoons. A feature of the cyclonic storms over the Indian area is that they rapidly weaken after crossing the coasts and move as depressions/lows inland. The influence of a severe storm after striking the coast does not in general exceed about 60 kilometres, though sometimes, it may extend even up to 120 kilometres. Very short duration hurricanes of very high wind speeds called Kal Baisaki or Norwesters occur fairly frequently during summer months over North East India.

4.3 –

The wind speeds recorded at any locality are extremely variable and in addition to steady wind at any time, there are effects of gusts which may last for a few seconds. These gusts cause increase in air pressure but their effect on stability of the building may not be so important; often, gusts affect only part of the building and the increased local pressures may be more than balanced by a momentary reduction in the pressure elsewhere. Because of the inertia of the building, short period gusts may not cause

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C4.1 -

For the purpose of this Code, wind speed has been considered as that occurring at 10 m height above the general ground level. Several new recording stations have been established in the country by the Indian Meteorological Department over the last two decades, the information from which can help upgrade the wind zoning map of India. However, more extensive data are needed to make this exercise meaningful.

C4.2 -

Several atmospheric phenomena are responsible for wind storms. Cyclonic storms, that hit some of the coastal regions of India, are the most devastating due to extremely high wind speeds in these storms accompanied by sea surge and flooding. These can last several hours.

Tornados, which are a narrow band phenomenon of limited time duration, often occur during the summer, mostly in Northern parts of India. These, however, have extremely high wind speeds, often higher than in the severest cyclones.

C4.3 -

The Code specifies the basic wind speed as that of a gust of 3 second duration; or in other words, the wind speed averaged over a 3-second period. Higher the intensity of a gust, lower is its duration and area of influence. As explained in the code, an increase in pressure due to a gust in one location may be balanced by a decrease elsewhere. Thus this may not affect the overall stability of the structure.

Contrary to this, one may consider wind effects over a limited (small) area of the surface. This is

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any appreciable increase in stress in main components of the building although the walls, roof sheeting and individual cladding units (glass panels) and their supporting members such as purlins, sheeting rails and glazing bars may be more seriously affected. Gusts can also be extremely important for design of structures with high slenderness ratios.

4.4 –

The liability of a building to high wind pressures depends not only upon the geographical location and proximity of other obstructions to air flow but also upon the characteristics of the structure itself.

4.5 –

The affect of wind on the structure as a whole is determined by the combined action of external and internal pressures acting upon it. In all cases, the calculated wind loads act normal to the surface to which they apply.

4.6 –

The stability calculations as a whole shall be done considering the combined effect, as well as separate effects of imposed loads and wind loads on vertical surfaces, roofs and other part of the building above general roof level.

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particularly important near the edges and ridge of a structure or sharp corners elsewhere in a building, where large suctions occur due to separation of flow and generation of eddies. The area of influence being small, there is better correlation within these areas. These local area effects are treated elsewhere in the Code.

C4.4 -

The dynamic characteristics of a flexible structure defined by its time period of vibration and damping would affect its response to the gustiness or turbulence in wind, which itself gets modified due to the pressure of other structures/ obstructions, particularly those in the close vicinity of the structure. This modification is often termed the ‘interference’ effect. Results of many wind tunnel studies to quantify the same are available in the literature, though a generalization of ‘interference’ values is difficult, given the variabilities involved in the problem. It is suggested that relevant literature be consulted and specialist advice be taken when dealing with important projects. It is further adviced that in such cases wind tunnel model testing may be carried out.

C4.5 -

The pressures created inside a building due to access of wind through openings could be negative or positive, and, of the same order of intensity. Those outside may also vary in magnitude with possible reversals. Thus the design value of pressure shall be taken as the algebraic sum of the internal and external values in appropriate/concerned direction.

C4.6 -

The stability of a structure shall be checked both with and without the wind loads, as there may be reversal of the forces under wind besides a reduced factor of safety considered with the wind loads.

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4.7 –

Buildings shall also be designed with due attention to the effects of wind on the comfort of people inside and outside the buildings.

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C4.7 -

Comfort of the inhabitants of a tall flexible building can be affected by large wind induced deflections or accelerations, particularly the latter. There is no criterion included in this Code for control on these parameters. Since there is no real tall building activity yet in India, the problem has not attained importance. Likewise, at the plaza level around a tall building, there may be accentuated flow conditions, particularly if the building has other similar structures adjacent to it. Thus the pedestrians at the plaza level can be put to inconvenience. A wind tunnel model study is required to determine the flow pattern and to carryout the design accordingly.

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5. – WIND SPEED AND PRESSURE

5.1 - Nature of wind in Atmosphere

In general, wind speed in the atmospheric boundary layer increases with height from zero at ground level to a maximum at a height called the gradient height. There is usually a slight change in direction (Ekman effect) but this is ignored in the code. The variation with height depends primarily on the terrain conditions. However, the wind speed at any height never remains constant and. it has been found convenient to resolve its instantaneous magnitude into an average or mean value and a fluctuating component around this average value. The average value depends on the averaging time employed in analysing the meteorological data and this averaging time varies from a few seconds to several minutes. The magnitude of fluctuating component of the wind speed which is called gust, depends on the averaging time. In general, smaller the averaging interval, greater is the magnitude of the gust speed.

C5.1 -

As is explained in the Code, wind speed can be taken to comprise of a static (mean) component and a fluctuating component, with the magnitude of the latter varying with time interval over which the gust is averaged. Thus with reduction in the averaging time, the fluctuating component of wind speed would increase. The fluctuating part of wind speed is normally expressed in terms of turbulence intensity which is the ratio of the standard deviation to the mean wind speed and is expressed in percentage.

5.2 – Basic Wind Speed

Figure 1 gives basic wind speed map of India, as applicable to 10 m height above mean ground level for different zones of the country. Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain (Category 2). Basic wind speeds presented in Fig. 1 have been worked out for a 50 year return period. Basic wind speed for some important cities/towns is also given in Appendix A.

C5.2 -

Code defines the basic wind speed as the peak gust wind speed averaged over a period of 3 seconds. It includes both the mean and the fluctuating components of the turbulent wind. To obtain hourly mean wind speed, the 3-second value may be multiplied by a factor 0.65. In the case of an open terrain category, since wind speed varies with height, ground roughness, local topography and return period of the storm, besides the wind zone of the country, the conditions for which V_b is defined have been specified in this clause. The country has been divided into six wind zones.

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5.3 –Design Wind Speed *(V_z)*

Design Wind Speed (V_z)- The basic wind speed (V_b) for any site shall be obtained from Fig. 1 and shall be modified to include the following effects to get design wind velocity at an height (V_z) for the chosen structure:

a) Risk level;
b) Terrain roughness, height and size of structure; and
c) Local topography.

It can be mathematically expressed as follows:

$$V_z = V_b k_1 k_2 k_3$$

where

V_z = design wind speed at any height z in m/s;

k_1 = probability factor (risk coefficient) (see 5.3.1);

k_2 = terrain, height and structure size factor (see 5.3.2); and

k_3 = topography factor (see 5.3.3

NOTE - Design wind up to 10 in height from mean ground level shall be considered constant.

5.3.1 – Risk Coefficient (k_1)

Figure 1 gives basic wind speeds for terrain Category 2 as applicable at 10 m above ground level based on 50 years mean return period. The suggested life period to be assumed in design and the corresponding k_1 factors for different class of structures for the purpose of design is given in Table 1. In the design of all buildings and structures, a regional basic wind speed having a mean return period of 50 years shall be used except as specified in the note of Table 1.

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C5.3 -

The basic wind speed V_b corresponds to certain reference conditions. Hence to account for various effects governing the design wind speed in any terrain condition, modifications in the form of factors k_1, k_2, and k_3 are specified.

C5.3.1 -

The peak wind speed considered for design is based on the probability of occurrence of the maximum/severest storm over the design life of the structure. It is known that storms of greater violence are less frequent, that is, such storms have a longer return period. Thus for economical design of structures, the design wind speed has been related to the return-period of storms, with V_b defined for 50-years return period considering the generally acceptable value of probability of exceedence as 0.63 for the design wind speed over the life of the structure. This has been termed as the risk level P_N in N consecutive years (Table –1) and the corresponding value of the risk coefficient, k_1, for N taken as 50 years, would be 1.0. The values of k_1 for N taken as 5, 25 and 100 years, and for various zones of the country, are given in Table-1. The designer may, however, use a higher value of N or k_1, if it is considered necessary to reduce the risk level of an important structure.

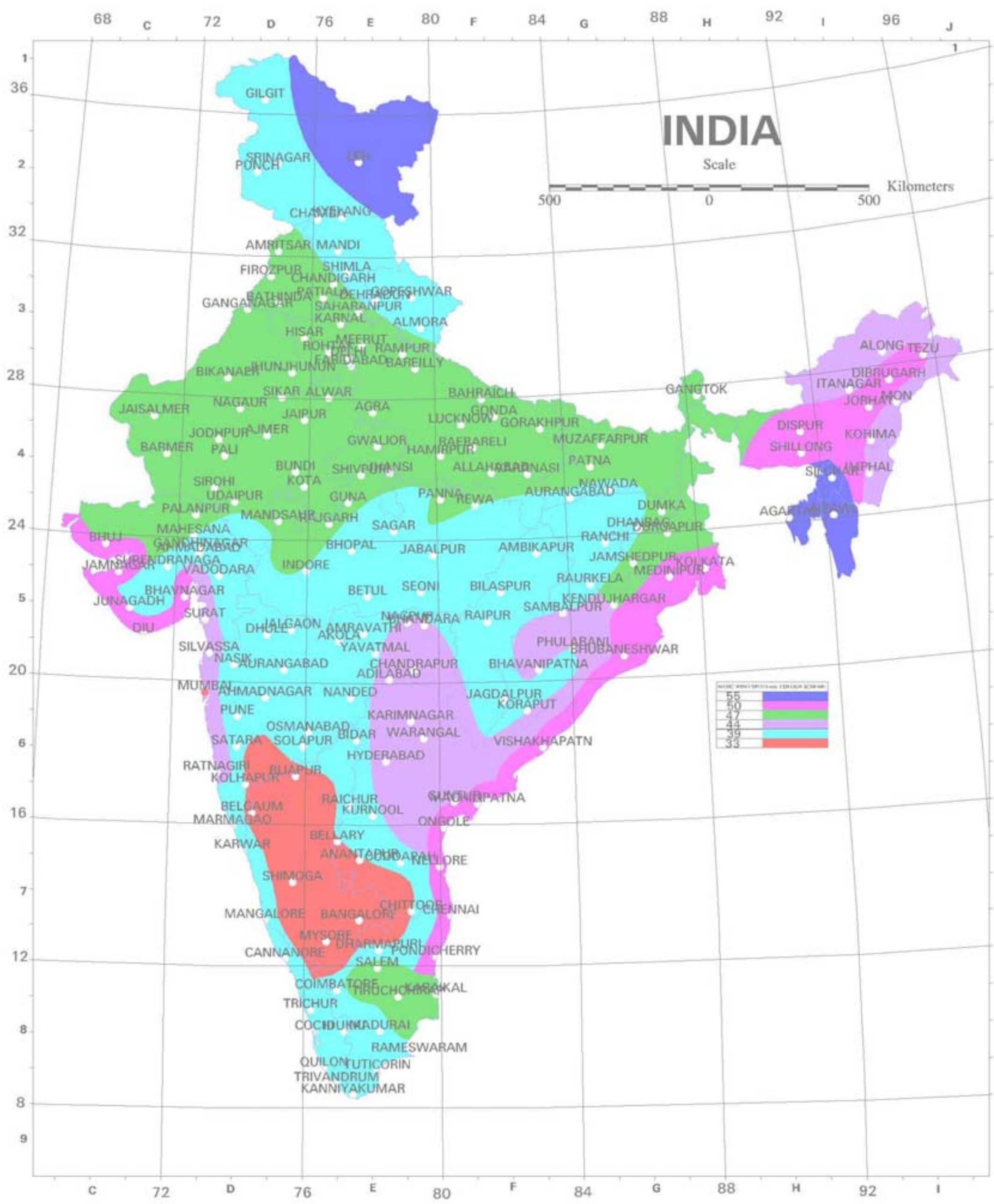


Figure 1: Basic wind speed in m/s (based on 50 year return period)

Table 1: Risk coefficients for different classes of structures in different wind speed zones [*Clause 5.3.1*]

Class of Structure	Mean Probable design life of structure in years	k_1 factor for Basic Wind Speed (m/s) of					
		33	39	44	47	50	55
All general buildings and structures	50	1.0	1.0	1.0	1.0	1.0	1.0
Temporary sheds, structures such as those used during construction operations (for example, formwork and false work), structures during construction stages, and boundary walls	5	0.82	0.76	0.73	0.71	0.70	0.67
Buildings and structures presenting a low degree of hazard to life and property in the event of failure, such as isolated towers in wooded areas, farm buildings other than residential buildings, etc.	25	0.94	0.92	0.91	0.90	0.90	0.89
Important buildings and structures such as hospitals, communication buildings, towers and power plant structures	100	1.05	1.06	1.07	1.07	1.08	1.08

NOTE - The factor k_1 is based on statistical concepts which take account of the degree of reliability required and period of time in years during which these will be exposure to wind, that is, life of the structure. Whatever wind speed is adopted for design purposes, there is always a probability (however small) that it may be exceeded in a storm of exceptional violence; the greater the period of years over which these will be exposure to the wind, the greater is the probability. Higher return period, raging from 100 to I 000 years (implying lower risk level) in association with greater periods of exposure may have to be selected for exceptionally important structures, such as, nuclear power reactors and satellite communication towers. Equation given below may be used in such cases to estimate k_l factors for different periods of exposure and chosen probability of exceedance (risk level). The probability level of 0,63 is normally considered sufficient for design of buildings and structures against wind effects and the values *of k_1* corresponding to this risk level are given above.

$$k_1 = \frac{X_{N,P_N}}{X_{50,\,0.63}} = \frac{A - B\left[\ln\left\{-\frac{1}{N}\ln\left(1 - P_N\right)\right\}\right]}{A + 4B}$$

where

N = mean probable design life of the structure in years;

P_N = risk level in N consecutive years (probability that the design wind speed is exceeded at least once in N successive years), nominal value = 0.63;

$X_{N,P}$ = extreme wind speed for given value of N and P_N; and

$X_{50,0.63}$ = extreme wind speed for N = 50 years and P_N = 0.63

A and B are coefficients having the following values for different basic wind speed zones:

Zone	A	B
33 m/s	83.2	9.2
39 m/s	84.0	14.0
44 m/s	88.0	18.0
47 m/s	88.0	20.5
50 m/s	88.8	22.8
55 m/s	90.8	27.3

TABLE 2 k_2 FACTORS TO OBTAIN DESIGN WIND SPEED VARIATION WITH HEIGHT IN DIFFERENT TERRAINS FOR DIFFERENT CLASSES OF BUILDINGS/STRUCTURES

(*Clause* 5.3.2.2)

HEIGHT	TERRAIN CATEGORY 1 CLASS			TERRAIN CATEGORY 2 CLASS			TERRAIN CATEGORY 3 CLASS			TERRAIN CATEGORY 4 CLASS		
m	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
10	1·05	1·03	0·99	1·00	0·98	0·93	0·91	0·88	0·82	0·80	0·76	0·67
15	1·09	1·07	1·03	1·05	1·02	0·97	0·97	0·94	0·87	0·80	0·76	0·67
20	1·12	1·10	1·06	1·07	1·05	1·00	1·01	0·98	0·91	0·80	0·76	0·67
30	1·15	1·13	1·09	1·12	1·10	1·04	1·06	1·03	0·96	0·97	0·93	0·83
50	1·20	1·18	1·14	1·17	1·15	1·10	1·12	1·09	1·02	1·10	1·05	0·95
100	1·26	1·24	1·20	1·24	1·22	1·17	1·20	1·17	1·10	1·20	1·15	1·05
150	1·30	1·28	1·24	1·28	1·25	1·21	1·24	1·21	1·15	1·24	1·20	1·10
200	1·32	1·30	1·26	1·30	1·28	1·24	1·27	1·24	1·18	1·27	1·22	1·13
250	1·34	1·32	1·28	1·32	1·31	1·26	1·29	1·26	1·20	1·28	1·24	1·16
300	1·35	1·34	1·30	1·34	1·32	1·28	1·31	1·28	1·22	1·30	1·26	1·17
350	1·37	1·35	1·31	1·36	1·34	1·29	1·32	1·30	1·24	1·31	1·27	1·19
400	1·38	1·36	1·32	1·37	1·35	1·30	1·34	1·31	1·25	1·32	1·28	1·20
450	1·39	1·37	1·33	1·38	1·36	1·31	1·35	1·32	1·26	1·33	1·29	1·21
500	1·40	1·38	1·34	1·39	1·37	1·32	1·36	1·33	1·28	1·34	1·30	1·22

NOTE 1 — *See* 5.3.2.2 for definitions of Class A, Class B and Class C structures.

NOTE 2 — Intermediate values may be obtained by linear interpolation, if desired. It is permissible to assume constant wind speed between 2 heights for simplicity.

CODE

5.3.2 – Terrain, Height and Structure Size Factor (k_2 Factor)

5.3.2.1 –

Selection of terrain categories shall be made with due regard to the effect of obstructions which constitute the ground surface roughness. The terrain category used in the design of a structure may vary depending on the direction of wind under consideration. Wherever sufficient meteorological information is available about the nature of wind direction, the orientation of any building or structure may be suitably planned.

Terrain in which a specific structure stands shall be assessed as being one of the following terrain categories:

a) Category I - Exposed open terrain with few or no obstructions and in which the average height of any object surrounding the structure is less than 1.5 m.

NOTE - This category includes open sea-coast and flat treeless plains.

b) Category 2 - Open terrain with well scattered obstructions having heights generally between 1-5 to 10 m.

COMMENTARY

C5.3.2.1 –

The Code defines 4 types of terrains and explains that a structure may effectively lie in two different types of terrain for two different wind directions. In addition, the designer shall keep in mind, the future development of the surrounding area which may alter the ground roughness and hence the terrain category. It may be noted that Category 2 has been considered as the datum with respect to which the other terrain categories have been defined. In a given situation, the effect of terrain condition, if deviated from the above reference terrain, is accounted for through the factor, k_2.

Photographs CP1 to CP4 (Cook 1985) are given to demonstrate how terrain categories 1 to 4 may be assigned. This is merely for guidance purpose.

CODE

NOTE - This is the criterion for measurement of regional basic wind speeds and includes airfields, open parklands and undeveloped sparsely built-up outskirts of towns and suburbs. Open land adjacent to sea coast may also be classified as Category 2 due to roughness of large sea waves at high winds.

c) Category 3 - Terrain with numerous closely spaced obstructions having the size of building-structures up to 10 m in height with or without a few isolated tall structures.

NOTE I - This category includes well wooded areas, and shrubs, towns and industrial areas full or partially developed.

NOTE 2 -It is likely that the next higher category than this will not exist in most design situations and that selection of a more severe category will be deliberate.

NOTE 3 - Particular attention must be given to performance of obstructions in areas affected by fully developed tropical cyclones. Vegetation which is likely to be blown down or defoliated cannot be relied upon to maintain Category 3 conditions. Where such situation may exist, either an inter mediate category with velocity multipliers midway between the values for Category 2 and 3 given in Table 2, or Category 2 should be selected having due regard to local conditions.

d) Category 4 - Terrain with numerous large high closely spaced obstructions.

NOTE - This category includes large city centres, generally with obstructions above 25 m and well developed industrial complexes.

5.3.2.2 –

Variation of wind speed with height for different sizes of structures in different terrains (k_2 factor) - Table 2 gives multiplying factors (k_2) by which the basic wind speed given in Fig. 1 shall be multiplied to obtain the wind speed at different heights, rise each terrain category for different sizes of buildings/structures.

The buildings/structures are classified into the following three different classes depending upon their size:

Class A - Structures and/or their components such as cladding, glazing, roofing, etc, having maximum dimension (greatest horizontal or vertical dimension) less than 20 m.

COMMENTARY

C5.3.2.2 -

The variation of wind speed with height is also dependent upon the ground roughness and is thus different for each terrain category, as can be visualized from Fig. C1. Wind blows at a given height, with lesser speed in rougher terrains and with higher speeds in smoother terrains. Further, in any terrain, wind speed increases along the height upto the gradient height and the values of the gradient heights are higher for rougher terrains. By definition, wind speeds beyond gradient heights in all terrains are equal. At any height in a given terrain, the magnitude of wind speed depends on the averaging time. Shorter the averaging time, the higher is the mean wind speed.

Also it takes quite a distance, called fetch length, for wind to travel over a typical terrain to fully develop a stable velocity profile idealized for that

CODE

Class B - Structures and/or their components such as cladding, glazing, roofing, etc, having maximum dimension (greatest horizontal or vertical dimension) between 20 and 50 m.

Class C - Structures and/or their components such as cladding, glazing, roofing, etc, having maximum dimension (greatest horizontal or vertical dimension) greater than 50 m.

5.3.2.3 –

Terrain categories in relation to the direction of wind - The terrain category used in the design of a structure may vary depending on the direction of wind under consideration. Where sufficient meteorological information is available, the basic wind speed may be varied for specific wind direction.

5.3.2.4 –

Changes in terrain categories – The velocity profile for a given terrain category does not develop to full height immediately with the commencement of that terrain category but develop gradually to height (h,) which increases with the fetch or upwind distance (x).

a) Fetch and developed height relationship – The relation between the developed height (h,) and the fetch (x) for wind-flow over each of the four terrain categories may be taken as given in Table 3.

b) For structures of heights greater than the developed height (h.) in Table 3, the velocity profile may be determined in accordance with the following:

COMMENTARY

terrain category.

The wind speed over a buildings surface is distributed in a random fashion, the correlation reducing with the size of the building. This effect is built into factor k_2.

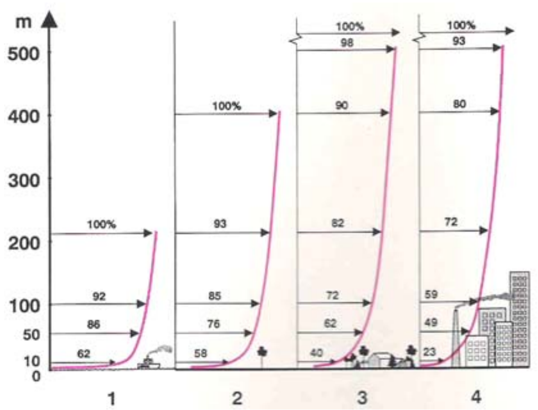


Figure C1 – Boundary Layer Profile for Different Approach Terrains

C5.3.2.3 -

Ground obstructions in the path of wind may be different for different directions of the wind.

C5.3.2.4 -

Self explanatory.

CODE

i. The less or least rough terrain, or

ii. The method described in Appendix B.

5.3.3 *Topography (k_3 Factor)* -

The basic wind speed V_b, given in Fig. 1 takes account of the general level of site above sea level. This does not allow for local topographic features such as hills, valleys, cliffs, escarpments, or ridges which can significantly affect wind speed in their vicinity. The effect of topography is to accelerate wind near the summits of hills or crest of cliffs; escarpments or ridges and decelerate the wind in valleys or near the foot of cliffs, steep escarpments, or ridges.

COMMENTARY

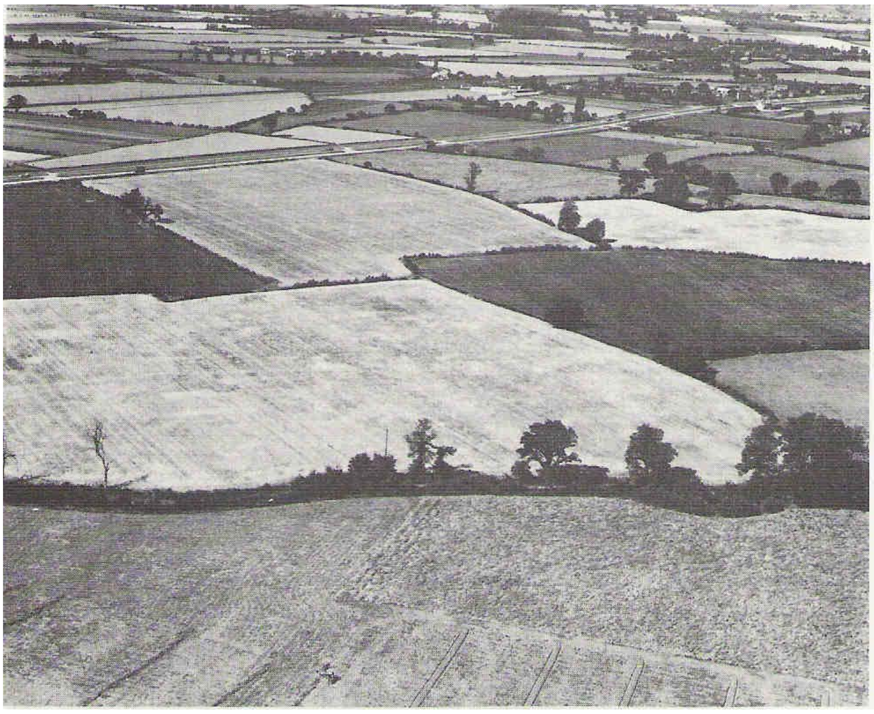
C5.3.3

The factor k_3 is a measure of the enhancement that occurs in wind speeds over hills, cliffs and escarpments

Table 3: Fetch and developed height relationship [*Clause 5.3.2.4*]

Fetch (*x*) *(km)*	**Developed Height h_x *(m)***			
	Terrain Category 1	**Terrain Category 2**	**Terrain Category 3**	**Terrain Category 4**
(1)	(2)	(3)	(4)	(5)
0.2	12	20	35	60
0.5	20	30	55	95
1	25	45	80	130
2	35	65	110	190
5	60	100	170	300
10	80	140	250	450
20	120	200	350	500
50	180	300	400	500

CP1 – Photograph Indicative of Terrain Category 1 Features



CP2 – Photograph Indicative of Terrain Category 2 Features

CP3 – Photograph Indicative of Terrain Category 3 Features

CP4 – Photograph Indicative of Terrain Category 4 Features

CODE

5.3.3.1 –

The effect of topography will be significant at a site when the upwind slope (θ) is greater than about 3^o, and below that, the value of kg may be taken to be equal to 1.0. The value of k_s is confined in the range of 1-0 to 1-36 for slopes greater than 3. A method of evaluating the value of kg for values greater than 1-0 is given in Appendix C. it may be noted that the value of kg varies with height above ground level, at a maximum near the ground, and reducing to 1-0 at higher levels.

5.4 – Design Wind Pressure

Design Wind Pressure - The design wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind velocity:

$$p_z = 0.6 V_Z^2$$

where

p_z = design wind pressure in N/m^2 at height z, and

V_z = design wind velocity in m/s at height z.

NOTE - The coefficient 0.6 (in SI units) in the above formula depends on a number of factors and mainly on the atmospheric pressure and air temperature. The value chosen corresponds to the average appropriate Indian atmospheric conditions.

5.5- Off Shore Wind Velocity –

Cyclonic storms form far away from the sea coast and gradually reduce in speed as they approach the sea coast. Cyclonic storms generally extend up to about 60 kilometres inland after striking the coast. Their effect on land is already reflected in basic wind speeds specified in Fig. 1. The influence of wind speed off the coast up to a distance of about 200 kilometres may be taken as 1.15 times the value on the nearest coast in the absence of any definite wind data.

COMMENTARY

C5.3.3.1–

No increase in wind speed is indicated for upwind ground slopes upto 3^o, while a maximum increase of 36% is specified for slopes beyond 17^o. Maximum effect is seen to occur at the crest of a cliff or escarpment and reduces gradually with distance from the crest. Also, locally k_3 reduces from the base of a structure to its top.

C5.4–

The relationship between design wind speed V_z and the pressure produced by it assumes the mass density of air as 1.20 kg/m^3, which changes somewhat with the atmospheric temperature and pressure. The change is however not accounted for in the code.

C5.5 -

The cyclonic storms are formed away from the coasts and have wind speeds much higher than recorded on the coasts. Wind speeds reduce gradually as the storm moves over the sea towards the coast. There is a faster reduction after landfall. At least 15% higher wind speed than at the coast may be considered for distances upto about 200 kilometers into the sea in the affected regions.

CODE | COMMENTARY

6. – WIND PRESSURES AND FORCES ON BUILDINGS/STRUCTURES

6.1 – General

General - The wind load on a building shall be calculated for:

a) The building as a whole,

b) Individual structural elements as roofs and walls, and

c) Individual cladding units including glazing and their fixings.

C6.1 -

A major purpose of the Code being commented upon is to determine forces and pressures on components of a building or a structure as required for design purposes. For clad buildings, pressures on the cladding are required in order to design the cladding and its supporting elements, from which the forces get transferred to the framework. Thus the building frame experiences the cumulative effect of pressures produces forces on different parts of the cladding – both on the walls as well as the roof as the case may be. These forces are used in designing the framework. The Code provides values of pressure coefficients for a variety of cases covered. Besides, force coefficients are given for (i) clad buildings and (ii) unclad structures and (iii) elements. These coefficients can be used to determine forces on an element, or an assembly of members or a framework. This information is not adequate for the design of cladding (or its supporting elements).

Both pressure and force coefficients are derived on the basis of models tested in wind tunnels.

6.2 - Pressure Coefficients

The pressure coefficients are always given for a particular surface or part of the surface of a building. The wind load acting normal to a surface is obtained by multiplying the area of that surface or its appropriate portion by the pressure coefficient (C_p) and the design wind pressure at the height of the surface from the ground. The average values of these pressure coefficients for some building shapes are given in **6.2.2 and 6.2.3**.

Average values of pressure coefficients are given for critical wind directions in one or more quadrants. In order to determine the maximum wind load on the building, the total load should be calculated for each of the

C6.2/6.2.1– Pressure Coefficients

Wind causes pressure or suction normal to the surface of a building or structure. The nature and magnitude of these pressures/suctions is dependent upon a large number of variables, namely, the geometry, the nature of the incident wind, direction of wind incidence, etc., which determine the nature of wind flow over or around a building/structure. As mentioned in C 6.1.2, separation of the flow at the edges and corners and formation of vortices generates suctions, often large in magnitude. The pressures caused are also often quite sensitive to changes in geometry and the angle of wind incidence. The most common approach to the determination of pressure distribution on different building forms is to test geometrically similar rigid models in a

CODE

critical directions shown from all quadrants. Where considerable variation of pressure occurs over a surface, it has been subdivided and mean pressure coefficients given for each of its several parts.

In addition, areas of high local suction negative pressure concentration) frequently occurring near the edges of walls and roofs are separately shown. Coefficients for the local effects should only be used for calculation of forces on these local areas affecting roof sheeting, glass panels, individual cladding units including their fixtures. They should not be used for calculating force on entire structural elements such as roof, walls or structure as a whole.

NOTE I - The pressure coefficients given in different tables have been obtained mainly from measurement on models in wind - tunnels, and the great majority of data available has been obtained in conditions of relatively smooth flow. Where sufficient field data exists as in the case of rectangular buildings, values have been obtained to allow for turbulent flow.

NOTE 2 - In recent years, wall glazing and cladding design has been a source of major concern. Although of less consequence than the collapse of main structures, damage to glass can be hazardous and cause considerable financial losses.

NOTE 3 - For pressure coefficients for structures not covered here, reference may be made to specialist literature on the subject or advise may be sought from specialists in the subject.

COMMENTARY

simulated wind environment in wind tunnels. This is generally done by making 'point' pressure measurements over the model and averaging the pressure values over a specified tributary area. Early wind tunnel work did not recognize the importance of simulating the 'boundary layer' flow of wind and its characteristics, primarily the turbulence. However, there has been a realization of the importance of such simulation over the last 3-4 decades. The body of information that has thus emerged is expected to better represent the wind effects expected in the field. The lack of adequacy of the database, however, remains because of the large variability involved both, with respect to the wind – its structure and directionality - as well as the building geometry.

Typically, pressure coefficient contours over a gable roof may be as seen in Figure C2. Obviously, it will be ideal to divide the roof into a large number of zones to specify the pressures for each zone. This would increase accuracy but will create difficulties in practical design work. Making a coarser grid-work will lead to averaged out values such as in Figure C 3. The approach adopted in practice is to go by the latter and use area averages which, in an overall analysis, may be on the conservative side.

Pressure coefficients are commonly based on the quasi – steady assumption, whereby the pressure coefficient is taken to be the ratio of mean pressure measured over a point divided by the dynamic pressure ($\frac{1}{2}\rho V^2$) for the mean speed of incident wind. Here ρ is the mass density of air and V the wind speed. The approach followed in the present Indian Code as well as the proposed revision (and several other Codes) is to take V as the peak gust value. Some Codes use the mean wind speed averaged over a longer period. The approach used implicitly assumes that the fluctuations in pressure follow directly those in the speed. This of course may not be true, since the wind turbulence gets modified as it approaches the structure, and eddies form at separation. However, the method has the advantage of simplicity, though it may not be suitable for very large structures. This is for two reasons – (i) the increasing lack of correlations over an extended area, and (ii) the dynamics of a large structural system.

CODE

COMMENTARY

Pressures are caused both on the exterior as well as the interior surfaces, the latter being dependent on openings (or permeability) in the structure, mostly in the walls. The following sections, namely 6.2.2 and 6.2.3, respectively give values of pressure coefficients for the interior and exterior surfaces.

6.2.1 – Wind Load on Individual Members

When calculating the wind load on individual structural elements such as roofs and walls, and individual cladding units and their fittings, it is essential to take account of the pressure difference between opposite faces of such elements or units. For clad structures, it is, therefore, necessary to know the internal pressure as well as the external pressure. Then the wind load, F, acting in a direction normal to the individual structural element or cladding unit is:

$$F = \left(C_{pe} - C_{p1}\right) A\ p_d$$

where

C_{pe} = external pressure coefficient,

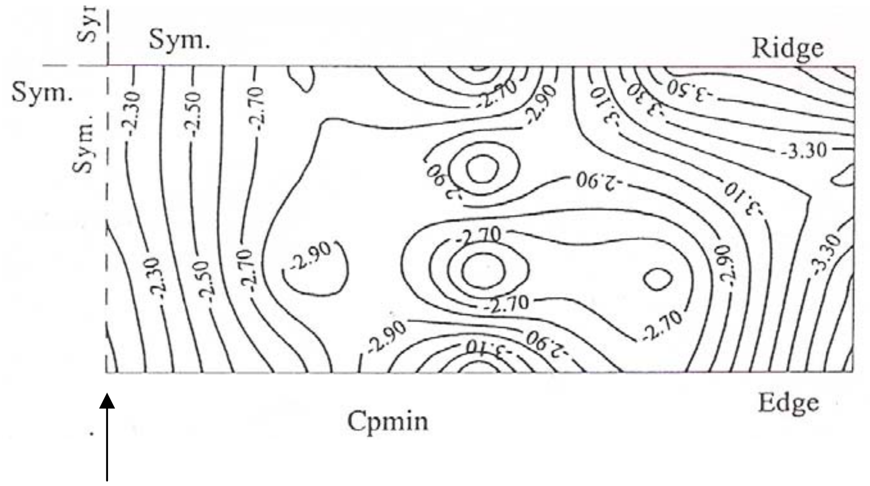
C_{p1} = internal pressure-coefficient,

A = surface area of structural element or cladding unit, and

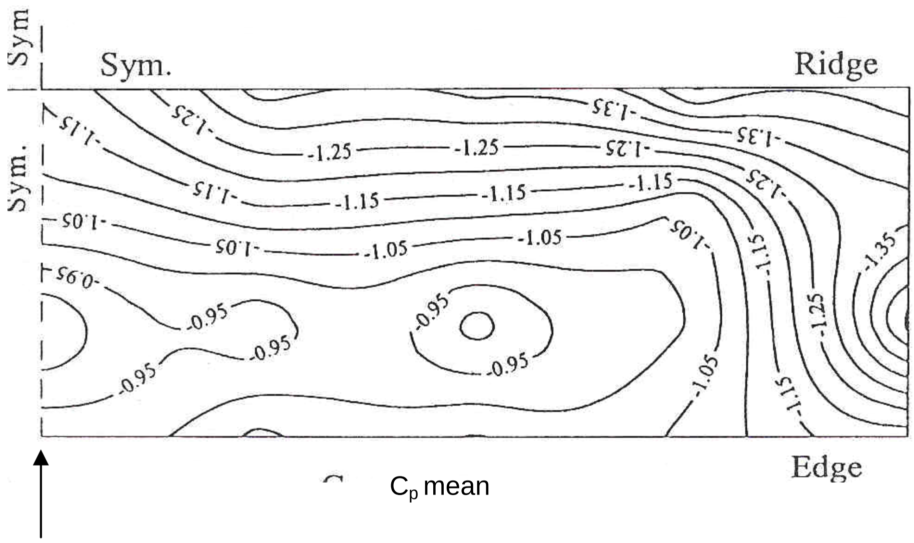
p_d = design wind pressure.

NOTE 1 – If the surface design pressure varies with height, the surface areas o*f the structural element may* be sub-divided so that the specif2ed pressures are taken over appropriate areas.

NOTE 2 - Positive Wind load indicates the force acting towards the structural element and negative away from it.



(a)



(b)

Figure C 2 : Contours of Pressure Coefficients over a Pitched Roof (a) $C_{p\ min}$ (b) $C_{p\ mean}$

Note : Axes of Symmetry are for the Structure and not for the Contours.

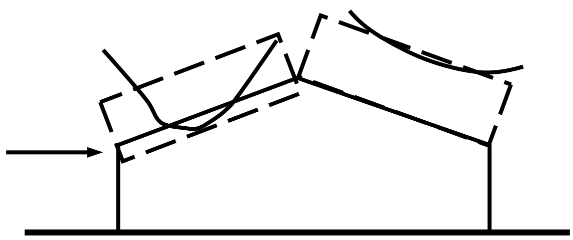


Figure C 3 : Variation of Pressure over a Pitched Roof (——) and the Average Value (- -)

CODE

6.2.2 – External Pressure Coefficients

6.2.2.1 –

Walls - The average external pressure coefficient for the walls of clad buildings of rectangular plan shall be as given in Table 4. In addition, local pressure concentration coefficients are also given.

6.2.2.2—

Pitched roofs of rectangular clad buildings - The average external pressure coefficients and pressure concentration coefficients for pitched roofs of rectangular clad building shall be as given in Table 5. Where no pressure concentration coefficients are given, the average coefficients shall apply. The pressure coefficients on the under side of any overhanging roof shall be taken in accordance with 6.2.2.7.

NOTE I - The pressure concentration shall be assumed to act outward (suction pressure) at the ridges, eaves, cornices and 90 degree corners of roofs see 6.2.2.7).

NOTE 2 - The pressure concentration shall not be included with the net external pressure when computing overall load.

COMMENTARY

C6.2.2 –

It has been explained in C 6.2/6.2.1 as to how pressure coefficients are obtained. Pressure coefficients for various shapes of buildings and structures are contained in subsequent sub-sections.

C6.2.2.1 –

Table 4 provides mean pressure coefficients for walls of closed rectangular buildings with different aspect ratios. Local pressure coefficients at the edges of the wall, which have relevance to the design of the cladding and its connections to the supporting framework, are also given in the Table. Information on force coefficients for free standing walls is given separately in 6.3.2.3.

C6.2.2.2 –

This clause provides information on the roofs of clad buildings, which are perhaps the most commonly used. Table 5 gives pressure coefficients for pitched roofs with different aspect ratios and varying roof pitch for two directions of wind incidence - 0^o and 90^o. The roof surface is divided into different zones for the purpose of specifying the design pressure coefficients. The values on the leeward slope are not affected much by the variations in geometry, which is not so for the windward slope where values vary from large pressures to suctions. Local pressure coefficients (for the design of cladding and its connections) at the edges and ridge are also given – these act upwards, i.e., suction. It is now known that wind directions other than 0^o and 90^o can give values higher than those at 0^o and 90^o. However, values are given here for 0^o and 90^o only, for simplicity in design.

For hipped roofs also the pressure coefficients can be taken from Table 5, for the applicable roof slope. It has, however, been shown that hipped roofs experience smaller suction as compared to pitched roofs of corresponding geometry (see Fig. C4 and also C5).

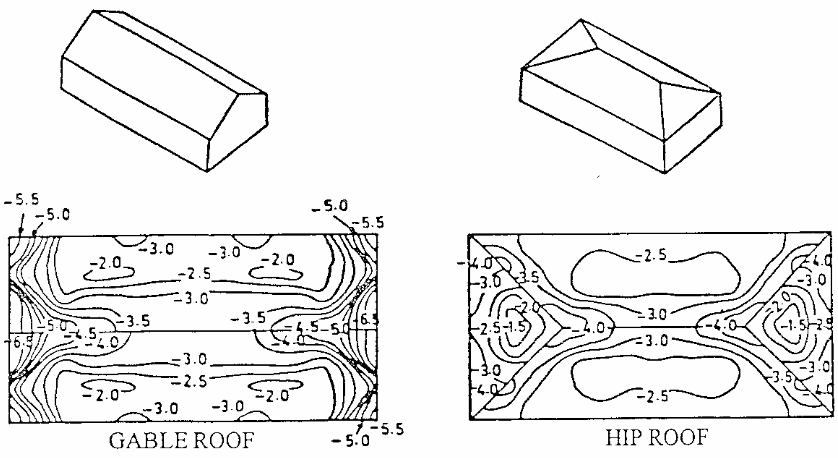
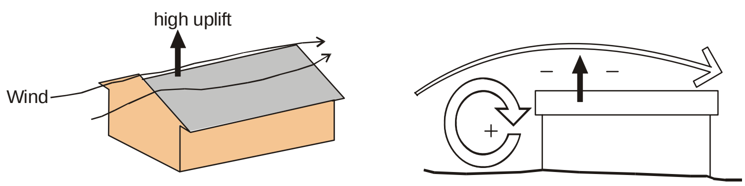
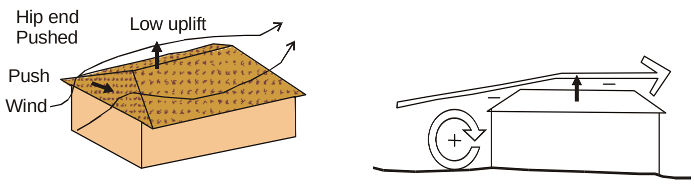


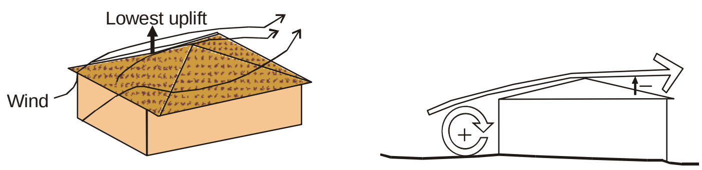
Figure C 4 : Worst Peak Negative Pressure Coefficients – all azimuths (Meecham 1992)



(a) Gable ended roofs gets high uplift



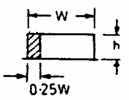
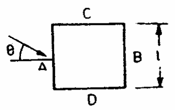
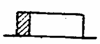
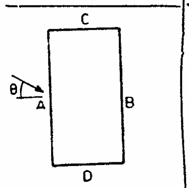
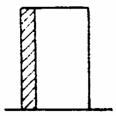
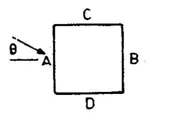
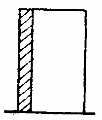
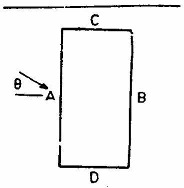
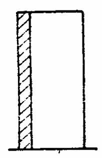
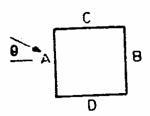
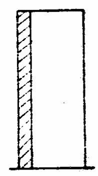
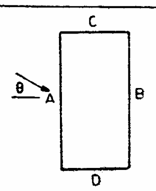
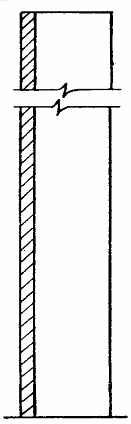
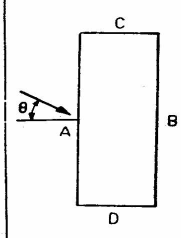
(b) Hip roofs gets lower uplift



(c) Pyramidal roofs gets lowest uplift

Figure C 5 : Effects of Roof Architecture on Uplifts

Table 4 External Pressure Coefficients (C_{pe}) for Walls of Rectangular Clad Buildings (*Clause 6.2.2.1*)

Building Height Ratio	Building Plan Ratio	Elevation	Plan	Wind Angle θ	C_{pe} for Surface A	B	C	D	Local C_{pe}
				degrees					
$\frac{h}{w} < \frac{1}{2}$	$1 < \frac{l}{w} < \frac{3}{2}$			0 90	+0·7 −0·5	−0·2 −0·5	−0·5 +0·7	−0·5 −0·2	−0·8
	$\frac{3}{2} < \frac{l}{w} < 4$			0 90	+0·7 −0·5	−0·25 −0·5	−0·6 +0·7	−0·6 −0·1	−1·0
$\frac{1}{2} < \frac{h}{w} < \frac{3}{2}$	$1 < \frac{l}{w} < \frac{3}{2}$			0 90	+0·7 −0·6	−0·25 −0·6	−0·6 +0·7	−0·6 −0·25	−1·1
	$\frac{3}{2} < \frac{l}{w} < 4$			0 90	+0·7 −0·5	−0·3 −0·5	−0·7 +0·7	−0·7 −0·1	−1·1
$\frac{3}{2} < \frac{h}{w} < 6$	$1 < \frac{l}{w} < \frac{3}{2}$			0 90	+0·8 −0·8	−0·25 −0·8	−0·8 +0·8	−0·8 −0·25	−1·2
	$\frac{3}{2} < \frac{l}{w} < 4$			0 90	+0·7 −0·5	−0·4 −0·5	−0·7 +0·8	−0·7 −0·1	−1·2
$\frac{h}{w} > 6$	$\frac{l}{w} = \frac{3}{2}$			0 90	+0·95 −0·8	−1·85 −0·8	−0·9 +0·9	−0·9 −0·85	−1·25
	$\frac{l}{w} = 1·0$			0 90	+0·95 −0·7	−1·25 −0·7	−0·7 +0·95	−0·7 −1·25	−1·25
	$\frac{l}{w} = 2$			0 90	+0·85 −0·75	−0·75 −0.75	−0·75 +0·85	−0·75 −0·75	−1·25

NOTE — h is the height to eaves or parapet, l is the greater horizontal dimension of a building and w is the lesser horizontal dimension of a building.

CODE

6.2.2.3– *Monoslope roofs of rectangular clad buildings* - The average pressure coefficient and pressure concentration coefficient for monoslope (lean-to) roofs of rectangular clad buildings shall be as given in Table 6.

6.2.2.4 *Canopy roofs with* $\left(\frac{1}{4} < \frac{h}{\omega} < 1 \, and \, 1 < \frac{L}{\omega} < 3\right)$ - The pressure coefficients are w given in Tables 7 and 8 separately for mono- pitch and double pitch canopy roofs such as open-air parking garages, shelter areas, outdoor areas, railway platforms, stadiums and theatres. The coefficients take account of the combined effect of the wind exerted on and under the roof for all wind directions; the resultant is to be taken normal to the canopy. Where the local coefficients overlap, the greater of the two given values should be taken. However, the effect of partial closures of one side and or both sides, such as those due to trains, buses and stored materials shall be foreseen and taken into account.

The solidity ratio ϕ is equal to the area of obstructions under the canopy divided by the gross area under the canopy, both areas normal to the wind direction. ϕ = 0 represents a canopy with no obstructions underneath. ϕ = 1 represents the canopy fully blocked with contents to the downwind eaves. Values of Cp for intermediate solidifies may be linearly interpolated between these two extremes, and apply upwind of the position of maximum blockage only. Downwind of the position of maximum blockage the coefficients for ϕ = 0 may be used.

In addition to the pressure forces normal to the canopy, there will be horizontal loads on the canopy due to the wind pressure on any fascia and to friction over the surface of the canopy. For any wind direction, only the greater of these two forces need be taken into account. Fascia loads should be calculated on the area of the surface facing the wind, using a force coefficient of 1.3. Frictional drag should be calculated using the coefficients given in 6.3.1.

COMMENTARY

C 6.2.2.3

Clad buildings with monoslope roofs are covered in Table 6. Pressure coefficients for different angles of wind incidence are given therein.

C6.2.2.4-

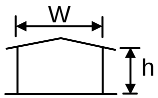
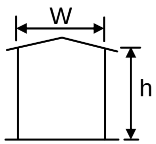
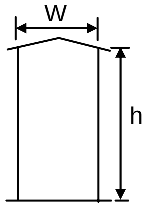
Pressure coefficients for canopy roof are given in Tables 7 to 14 ϕ = 0 implies no obstruction under the roof and ϕ = 1 is the case of full blockage. The material is self-explanatory.

CODE

NOTE - Tables 9 to 14 may be used to get internal and external pressure coefficients for pitches and troughed free roofs for some specific cases for which aspect ratios and roof slopes have been specified. However, while using Tables 9 to 14 any significant departure from it should be investigated carefully. No increase shall be made for local effects except as indicated.

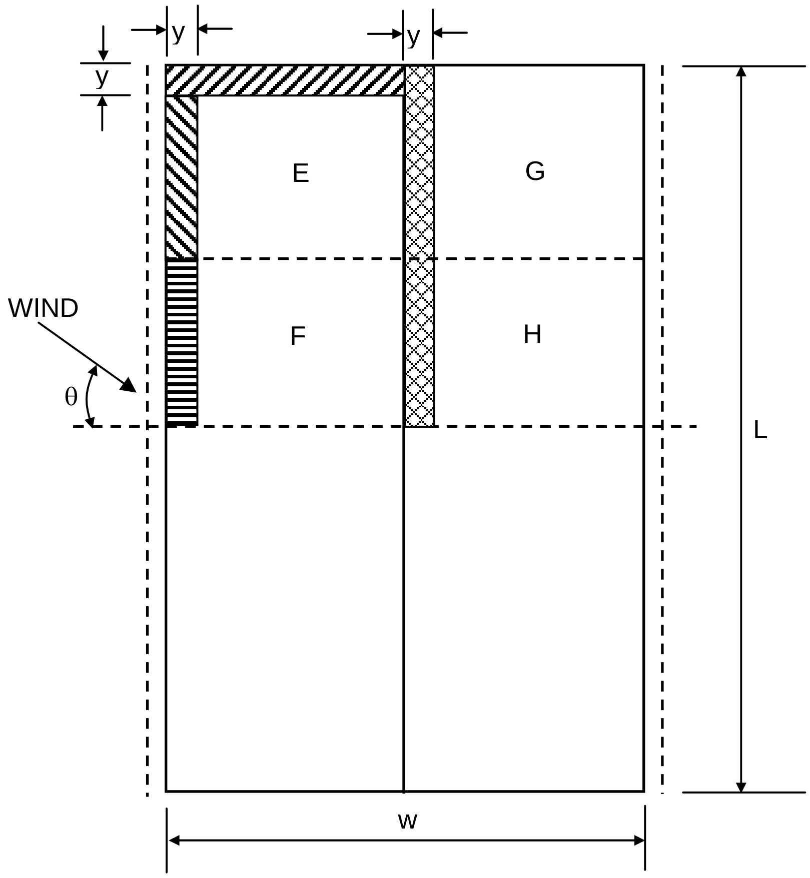
COMMENTARY

Table 5 External Pressure Coefficients (C_{pe}) for Pitched Roofs of Rectangular Clad Buildings *(Clause 6.2.2.2)*

Building Height Ratio		Roof Angle α	Wind angle θ 0^o		Wind angle θ 90^o		Local Coefficients			
		Degrees	EF	GH	EG	FH				
$\frac{h}{w} \le \frac{1}{2}$		0	-0.8	-0.4	-0.8	-0.4	-2.0	-2.0	-2.0	---
		5	-0.9	-0.4	-0.8	-0.4	-1.4	-1.2	-1.2	-1.0
		10	-1.2	-0.4	-0.8	-0.6	-1.0	-1.4		-1.2
		20	-0.4	-0.4	-0.7	-0.6	-0.8			-1.2
		30	0	-0.4	-0.7	-0.6				-1.1
		45	+0.3	-0.5	-0.7	-0.6				-1.1
		60	+0.7	-0.6	-0.7	-0.6				-1.1
$\frac{1}{2} < \frac{h}{w} \le \frac{3}{2}$		0	-0.8	-0.6	-1.0	-0.6	-2.0	-2.0	-2.0	---
		5	-0.9	-0.6	-0.9	-0.6	-2.0	-2.0	-1.5	-1.0
		10	-1.1	-0.6	-0.8	-0.6	-2.0	-2.0	-1.5	-1.2
		20	-0.7	-0.5	-0.8	-0.6	-1.5	-1.5	-1.5	-1.0
		30	-0.2	-0.5	-0.8	-0.8	-1.0			-1.0
		45	+0.2	-0.5	-0.8	-0.8				
		60	+0.6	-0.5	-0.8	-0.8				
$\frac{3}{2} < \frac{h}{w} < 6$		0	-0.7	-0.6	-0.9	-0.7	-2.0	-2.0	-2.0	---
		5	-0.7	-0.6	-0.8	-0.8	-2.0	-2.0	-1.5	-1.0
		10	-0.7	-0.6	-0.8	-0.8	-2.0	-2.0	-1.5	-1.2
		20	-0.8	-0.6	-0.8	-0.8	-1.5	-1.5	-1.5	-1.2
		30	-1.0	-0.5	-0.8	-0.7	-1.5			
		40	-0.2	-0.5	-0.8	-0.7	-1.0			
		50	+0.2	-0.5	-0.8	-0.7				
		60	+0.5	-0.5	-0.8	-0.7				

Contd…………

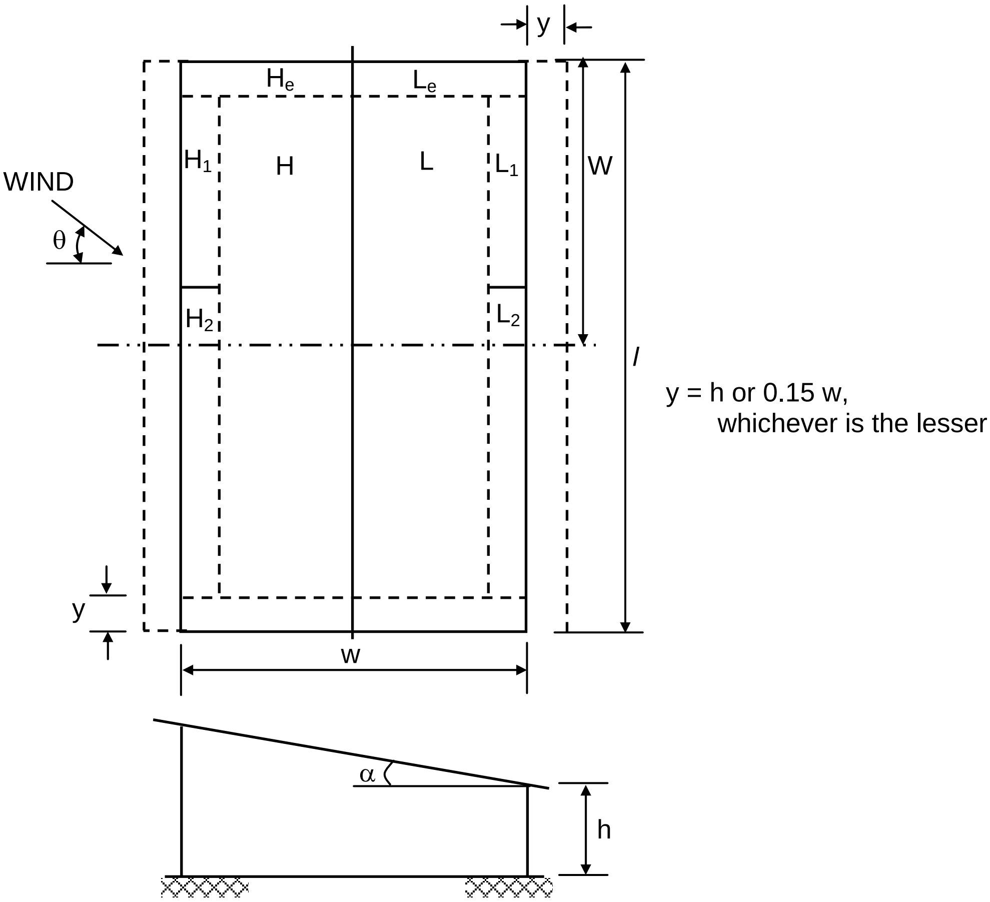
NOTE 1 – h is the height to eaves or parapet and w is the lesser plan dimension of a building.
NOTE 2 – Where no local coefficients are given, the overall coefficients apply.
NOTE 3 – For hipped roofs the local coefficient for the hip ridge may be conservatively taken as the central ridge value.



KEY PLAN

Y = h or 0.15 w,
whichever is the smaller

Table 6 External Pressure Coefficients (C_{pe}) for Monoslope Roofs for Rectangular Clad Buildings with $\frac{h}{w} < 2$ (*Clause 6.2.2.3*)

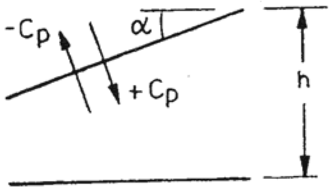


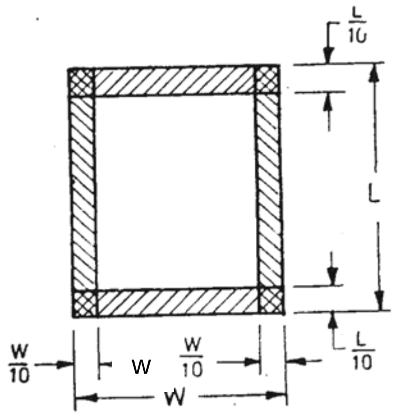
Note: Area H and area L refer to the whole quadrant

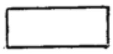
Roof Angle α	Wind Angle θ										Local C_{pe}					
	0°		45°		90°		135°		180°							
Degree	H	L	H	L	H&L	H&L	H	L	H	L	H_1	H_2	L_1	L_2	H_e	L_e
					Applies to Length w/2 from wind ward end	Applies to remainder										
5	-1.0	-0.5	-1.0	-0.9	-1.0	-0.5	-0.9	-1.0	-0.5	-1.0	-2.0	-1.5	-2.0	-1.5	-2.0	-2.0
10	-1.0	-0.5	-1.0	-0.8	-1.0	-0.5	-0.8	-1.0	-0.4	-1.0	-2.0	-1.5	-2.0	-1.5	-2.0	-2.0
15	-0.9	-0.5	-1.0	-0.7	-1.0	-0.5	-0.6	-1.0	-0.3	-1.0	-1.8	-0.9	-1.8	-1.4	-2.0	-2.0
20	-0.8	-0.5	-1.0	-0.6	-0.9	-0.5	-0.5	-1.0	-0.2	-1.0	-1.8	-0.8	-1.8	-1.4	-0.2	-2.0
25	-0.7	-0.5	-1.0	-0.6	-0.8	-0.5	-0.3	-0.9	-0.1	-0.9	-1.8	-0.7	-0.9	-0.9	-0.2	-2.0
30	0.5	-0.5	-1.0	-0.6	-0.8	-0.5	-0.1	-0.6	0	-0.6	-1.8	-0.5	-0.5	-0.5	-0.2	-2.0

Note – h is the height to eaves at lower side, l is the greater horizontal dimension of a building and w is the smaller horizontal dimension of a building.

Table 7 Pressure Coefficients for Monoslope Roofs (*Clause 6.2.2.4*)

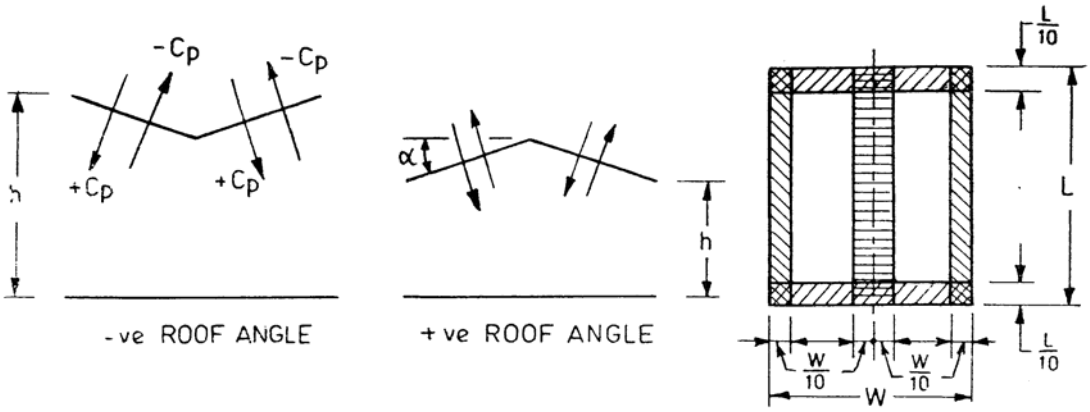




Roof Angle (Degrees)	Solidity Ratio	Maximum (Largest + ve) and Minimum (Largest − ve) Pressure Coefficients			
		Overall Coefficients	Local Coefficients		
					
0	All values of ϕ	+0·2	+0·5	+1·8	+1·1
5		+0·4	+0·8	+2·1	+1·3
10		+0·5	+1·2	+2·4	+1·6
15		+0·7	+1·4	+2·7	+1·8
20		+0·8	+1·7	+2·9	+2·1
25		+1·0	+2·0	+3·1	+2·3
30		+1·2	+2·2	+3·2	+2·4
0	ϕ=0	−0·5	−0·6	−1·3	−1·4
	ϕ=1	−1·0	−1·2	−1·8	−1·9
5	ϕ=0	−0·7	−1·1	−1·7	−1·8
	ϕ=1	−1·1	−1·6	−2·2	−2·3
10	ϕ=0	−0·9	−1·5	−2·0	−2·1
	ϕ=1	−1·3	−2·1	−2·6	−2·7
15	ϕ=0	−1·1	−1·8	−2·4	−2·5
	ϕ=1	−1·4	−2·3	−2·9	−3·0
20	ϕ=0	−1·3	−2·2	−2·8	−2·9
	ϕ=1	−1·5	−2·6	−3·1	−3·2
25	ϕ=0	−1·6	−2·6	−3·2	−3·2
	ϕ=1	−1·7	−2·8	−3·5	−3·5
30	ϕ=0	−1·8	−3·0	−3·8	−3·6
	ϕ=1	−1·8	−3·0	−3·8	−3·6

NOTE — For monopitch canopies the centre of pressure should be taken to act at 0·3 w from the windwar edge.

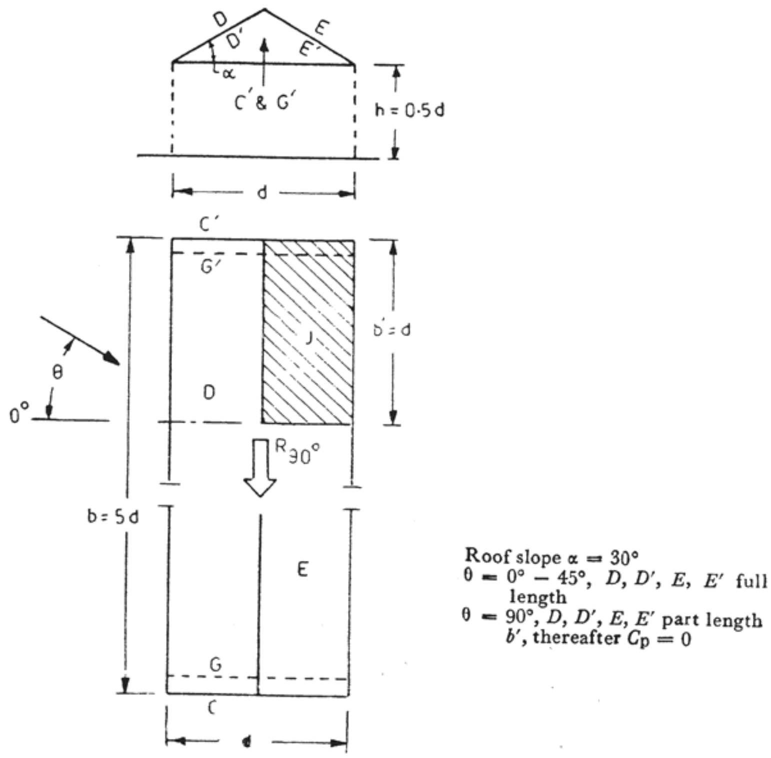
Table 8 Pressure Coefficients for Free Standing Double Sloped Roofs ***(Clause 6.2.2.4)***



Roof Angle (Degrees)	Solidity Ratio	Maximum (Largest +ve) and Minimum (Largest − ve) Pressure Coefficients				
		Overall Coefficients	Local Coefficients			
−20	All values of ϕ	+0·7	+0·8	+1·6	+0·6	+1·7
−15		+0·5	+0·6	+1·5	+0·7	+1·4
−10		+0·4	+0·6	+1·4	+0·8	+1·1
−5		+0·3	+0·5	+1·5	+0·8	+0·8
+5		+0·3	+0·6	+1·8	+1·3	+0·4
+10		+0·4	+0·7	+1·8	+1·4	+0·4
+15		+0·4	+0·9	+1·9	+1·4	+0·4
+20		+0·6	+1·1	+1·9	+1·5	+0·4
+25		+0·7	+1·2	+1·9	+1·6	+0·5
+30		+0·9	+1·3	+1·9	+1·6	+0·7
−20	$\phi=0$	−0·7	−0·9	−1·3	−1·6	−0·6
	$\phi=1$	−0·9	−1·2	−1·7	−1·9	−1·2
−15	$\phi=0$	−0·6	−0·8	−1·3	−1·6	−0·6
	$\phi=1$	−0·8	−1·1	−1·7	−1·9	−1·2
−10	$\phi=0$	−0·6	−0·8	−1·3	−1·5	−0·6
	$\phi=1$	−0·8	−1·1	−1·7	−1·9	−1·3
−5	$\phi=0$	−0·5	−0·7	−1·3	−1·6	−0·6
	$\phi=1$	−0·8	−1·5	−1·7	−1·9	−1·4
+5	$\phi=0$	−0·6	−0·6	−1·4	−1·4	−1·1
	$\phi=1$	−0·9	−1·3	−1·8	−1·8	−2·1
+10	$\phi=0$	−0·7	−0·7	−1·5	−1·4	−1·4
	$\phi=1$	−1·1	−1·4	−2·0	−1·8	−2·4
+15	$\phi=0$	−0·8	−0·9	−1·7	−1·4	−1·8
	$\phi=1$	−1·2	−1·5	−2·2	−1·9	−2·8
+20	$\phi=0$	−0·9	−1·2	−1·8	−1·4	−2·0
	$\phi=1$	−1·3	−1·7	−2·3	−1·9	−3·0
+25	$\phi=0$	−1·0	−1·4	−1·9	−1·4	−2·0
	$\phi=1$	−1·4	−1·9	−2·4	−2·1	−3·0
+30	$\phi=0$	−1·0	−1·4	−1·9	−1·4	−2·0
	$\phi=1$	−1·4	−2·1	−2·6	−2·2	−3·0

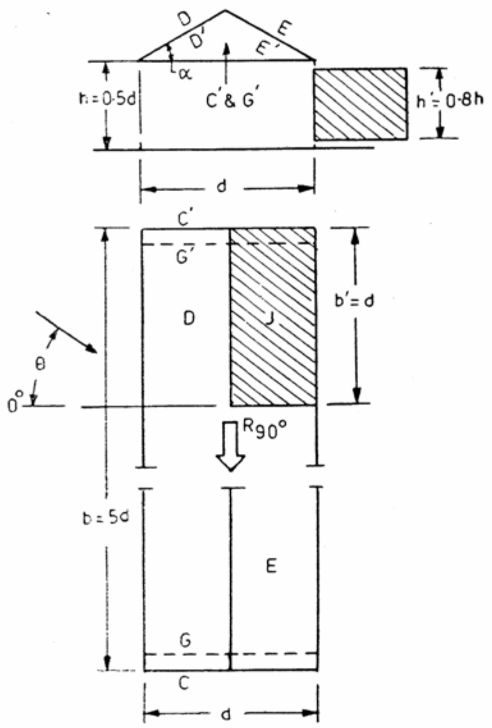
Each slope of a duopitch canopy should be able to withstand forces using both the maximum and the minimum coefficients, and the whole canopy should be able to support forces using one slope at the maximum coefficient with the other slope at the minimum coefficient. For duopitch canopies the centre of pressure should be taken to act at the centre of each slope.

Table 9 Pressure Coefficients (Top and Bottom) for Pitched Roofs, α = 30° *(Clause 6.2.2.4)*



θ	Pressure Coefficients, C_p							
	D	D'	E	E'	End Surfaces			
					C	C'	G	G'
0	0·6	−1·0	−0·5	−0·9				
45°	0·1	−0·3	−0·6	−0·3				
90°	−0·3	−0·4	−0·3	−0·4	−0·3	0·8	0·3	0·4

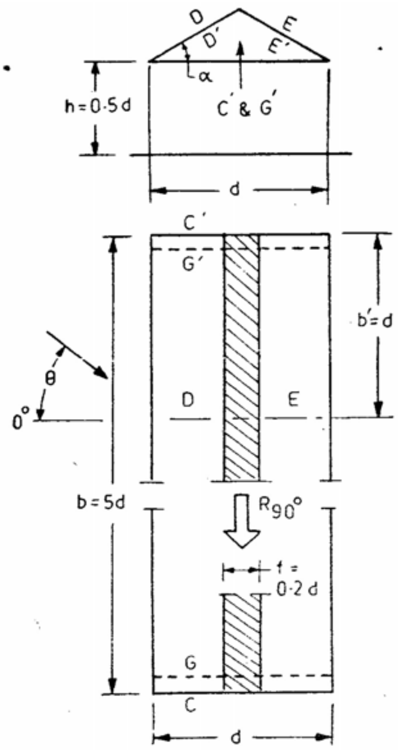
Table 10 Pressure Coefficients (Top and Bottom) for Pitched Free Roofs, α = 30° ***with Effects of Train or Stored Materials (Clause 6.2.2.4)***



Roof slope $\alpha = 30°$
Effects of trains or stored materials:
$\theta = 0° - 45°$, or $135° - 180°$, D, D', E, E' full length
$\theta = 90°$, D, D', E, E' part length b', thereafter $C_p = 0$

θ	Pressure Coefficients, C_p							
	D	D'	E	E'	End Surfaces: C	C'	G	G'
0°	0·1	0·8	−0·7	0·9	−0·3	0·8	0·3	−0·4
45°	−0·1	0·5	−0·8	0·5				
90°	−0·4	−0·5	−0·4	−0·5				
180°	−0·3	−0·6	0·4	−0·6				
45°	For j : C_p top = −1·5; C_p bottom = 0·5							
90°	Tangentially acting friction: $R_{90°} = 0·05\ p_d bd$							

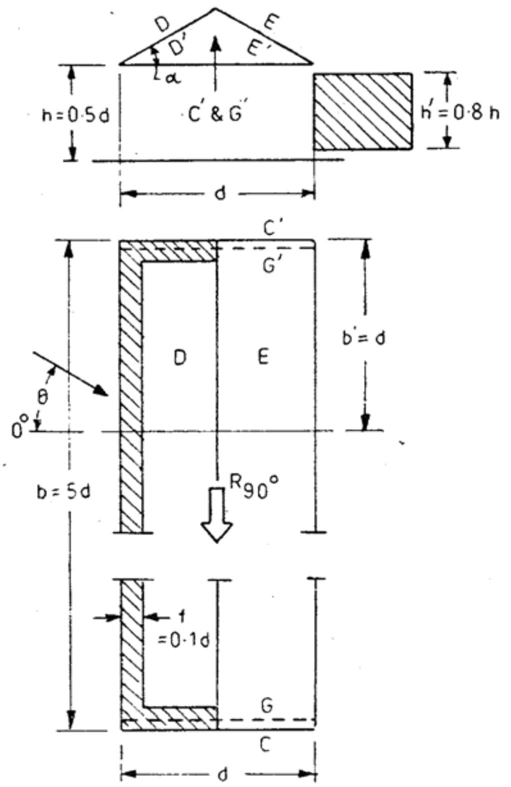
Table 11 Pressure Coefficients (Top and Bottom) for Pitched Free Roofs, α = 10°
(Clause 6.2.2.4)



Roof slope $\alpha = 10°$
$\theta = 0° - 45°$, D, D', E, E' full length
$\theta = 90°$, D, D', E, E' part length b', thereafter $C_p = 0$

θ	Pressure Coefficients, C_p							
	D	D'	E	E'	End Surfaces			
					C	C'	G	G'
0°	−1·0	0·3	−0·5	0·2				
45°	−0·3	0·1	−0·3	0·1				
90°	−0·3	0	−0·3	0	−0·4	0·8	0·3	−0·6
0°	For f: C_p top = −1·0; C_p bottom = 0·4							
0° − 90°	Tangentially acting friction, $R_{90°} = 0·1\ p_d b d$							

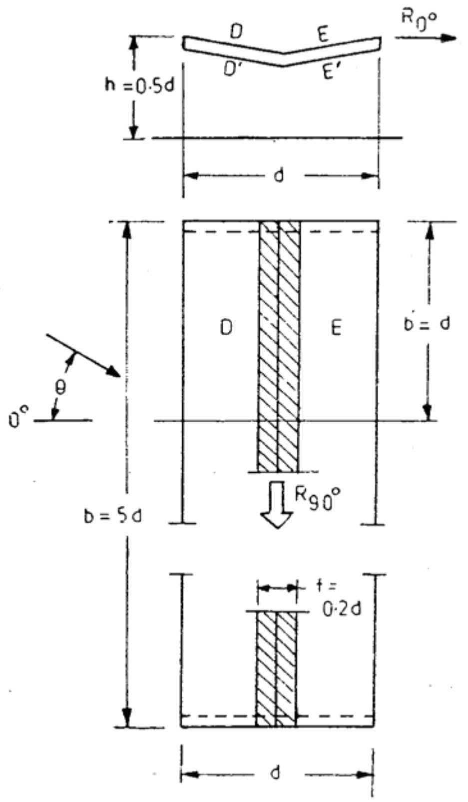
Table 12 Pressure Coefficients (Top and Bottom) for Pitched Free Roofs, α = 10^{o} with Effects of Train or Stored Materials *(Clause 6.2.2.4)*



Roof slope α = 10°
Effects of trains or stored ma
θ = 0° − 45°, or 135° − 180°
D, D', E, E' full length
θ = 90°, D, D', E, E' part le
thereafter C_p = 0

θ	Pressure Coefficients, C_p						
	D	D'	E	E'	End Surfaces C	End Surfaces C'	End Surfaces G
0°	−1·3	0·8	−0·6	0·7			
45°	−0·5	0·4	−0·3	0·3			
90°	−0·3	0	−0·3	0	−0·4	0·8	0·3
180°	−0·4	−0·3	−0·6	−0·3			
0°	For f: C_p top = −1·6; C_p bottom = 0·9						
0° − 180°	Tangentially acting friction: $R_{90°}$ = 0·1 $p_d bd$						

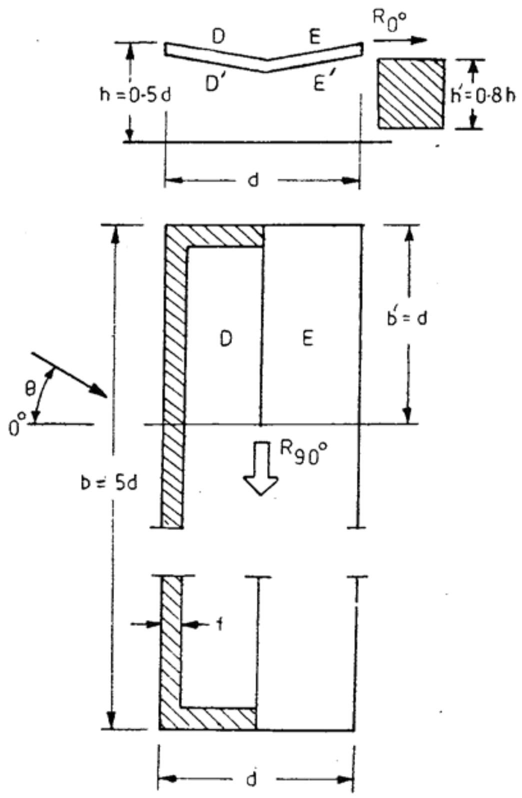
Table 13 External Pressure Coefficients for Troughed Free Roofs, $\alpha = 10^o$
(Clause 6.2.2.4)



Roof slope $\alpha = 10°$
$\theta = 0° - 45°$, D, D', E, length
$\theta = 90°$, D, D', E, E' par b', thereafter $C_p = 0$

θ	Pressure Coefficients, C_p			
	D	D'	E	E'
0°	0·3	−0·7	0·2	−0·9
45°	0	−0·2	0·1	−0·3
90°	−0·1	0·1	−0·1	0·1
0°	For f : C_p top = 0·4; C_p bottom = −1·5			
0° − 90°	Tangentially acting friction $R_{90°} = 0·1\ p_d b d$			

Table 14 Pressure Coefficients (Top and Bottom) for Troughed Free Roofs, α = 10° with Effects of Train or Stored Materials *(Clause 6.2.2.4)*



Roof slope α = 10°
Effects of trains or stored materials:
θ = 0° – 45°, or 135° – 180°, D, D', E, E' full length
θ = 90°, D, D', E, E', part length b' thereafter C_p = 0

θ	Pressure Coefficients, C_p			
	D	*D′*	*E*	*E′*
0°	−0·7	0·8	−0·6	0·6
45°	−0·4	0·3	−0·2	0·2
90°	−0·1	0·1	−0·1	0·1
180°	−0·4	−0·2	−0·6	−0·3
0°	For f: C_p top = −1·1; C_p bottom = 0·9			
0°−180°	Tangentially acting friction: $R_{90°}$ = 0·1 $p_d bd$			

CODE

6.2.2.5– Curved roofs –

For curved roofs, the external pressure coefficients shall be as given in Table 15. Allowance for local effects shall be made in accordance with Table 5.

6.2.2.6 – Pitched and saw-tooth roofs of multi- span buildings - For pitched and saw-tooth roofs of multi-span buildings, the external average pressure coefficients and pressure concentration coefficients shall be as given in Tables 16 and 17 respectively. provided that all spans shall be equal and the height to the eaves shall not exceed the span.

NOTE - Evidence on multi-span buildings is fragmentary; any departure given in Tables 16 and 17 should be investigated separately

6.2.2.7 – Pressure coefficients on overhangs from roofs - The pressure coefficients on the top overhanging portion of the roofs shall be taken to be the same as that of the nearest top portion of the non-overhanging portion of the roofs. The pressure coefficients for the underside surface of the overhanging portions shall be taken as follows and shall be taken as positive if the overhanging portion is on the windward side:

a) 1.25 if the overhanging slopes,

b) 1.00 if the overhanging is horizontal, and

c) 0.75 if the overhanging slopes upwards.

For overhanging portions on sides other than the windward side, the average pressure coefficients on adjoining walls, may be used.

COMMENTARY

C6.2.2.5 –

This clause specifies values of pressure coefficients on curved convex roof surfaces, which are perhaps the most common amongst curved roofs. Most part of the roof exterior is subjected to suction. A variety of other curved shapes have been used in roofs, such as, domical, singly curved concave, saucer shaped, and doubly curved (hyperbolic paraboloid). Values of wind pressure coefficients are available for such shapes, more as a result of case specific studies, and are contained in the literature (Krishna, 1989). Considering that these roof shapes are not a common occurrence, these are not covered in this Code or in other International Codes.

C 6.2.2.6 –

The clause covers roof surfaces of multispan pitched and sawtooth roofs and the information is self explanatory. Considerable amount of work on such roofs has since been carried out and published [Stathopoulos & Saathoff, 1991 & 1992] and the user is adviced to consult the same

C6.2.2.7 –

Overhangs from a building are affected by wind pressure acting from underneath. These combined with pressures (or suctions) on the top surface often create a severe design condition

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6.2.2.8 *Cylindrical structures* –

For the purpose of calculating the wind pressure distribution around a cylindrical structure of circular cross-section, the value of external pressure coefficients given in Table 18 may be used provided that the Reynolds number is greater than 10 000. They may be used for wind blowing normal to the axis of cylinders having axis normal to the ground plane (that is, chimneys and silos) and cylinders having their axis parallel to the ground plane that is, horizontal tanks provided that the clearance between the tank and the ground is not less than the diameter of the cylinder.

h is height of a vertical cylinder or length of a horizontal cylinder. Where there is a free flow of air around both ends, *h* is to be taken as half the length when calculating h/D ratio.

In the calculation of the resultant load on the periphery of the cylinder, the value of C_{pi} shall be taken into account. For open ended cylinders, C_{pi} shall be taken as follows:

a) 0.8 where h/D is not less than 0.3, and

b) 0.5 where h/D is less than 0.3.

6.2.2.9 **–** Roofs and bottoms of cylindrical elevated structures - The external pressure coefficients for roofs and bottoms of cylindrical elevated structures shall be as given in Table 19 (see also Fig. 2). The total resultant load (P) acting on the roof of the structure is given by the following formula:

$$P = 0.785D^2\left(p_1 - C_{pe}p_d\right)$$

The resultant of P for roofs lies at 0.I D from the centre of the roof on the wind word side.

6.2.2.10 **–** *Combined roofs and roofs with a sky light* - The average external pressure coefficients for combined roofs and roofs with a sky light is shown in Table 20.

COMMENTARY

C6.2.2.8 –

Wind effects on cylindrical structures are influenced by the Reynold's Number, Re given by VD/ν, where V is the velocity of wind, D the diameter, and ν the kinematic viscosity of air. The values given in the Code are for Re greater than 10,000, a value commonly achieved in practice. These are given for different proportions of a cylinder, and values of C_{pi} are specified for open ended cylinders.

Slender cylinders, such as those with h/D greater than 5 may experience aerodynamic effects in the along-wind as well as across-wind direction. These are dealt with later in Sections 7 and 8.

C6.2.2.9 –

The clause specifies forces on roofs over a cylindrical structure, placed on ground or elevated. The roof may be flat, sloping or domical. While Table 19 gives the overall force coefficients, detailed pressure distribution over a conical roof is given in Fig. 2.

In addition to the external pressures/forces, internal pressure may also occur on the roof of a container. This may be due to the vapour of the liquid stored, or due to wind where there is a degree of permeability to allow entry to the wind. C_{pi} should be taken as zero for an R.C.C. water tank, as the roof is made monolithic with the walls and the opening in roof is always kept closed.

C6.2.2.10 –

This clause deals with a situation often found in practice – that of a pitched roof with a porch (or a car park), both open and closed. The clause takes

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COMMENTARY

recourse to the use of clauses 6.2.2.2 and 6.2.2.7 for assigning pressure coefficients on roof slopes and on overhangs respectively. Two principal wind directions are covered for the building with varying geometrical proportions.

Roofs with skylights are also covered.

6.2.2.11 *Grandstands* - The pressure coefficients on the roof (top and bottom) and rear wall of a typical grandstand roof which is open on three sides is given in Table 21. The pressure coefficients are valid for a particular ratio of dimensions as specified in Table 21 but may be used for deviations up to 20 percent. In general, the maximum wind load occurs when the wind is blowing into the open front of the stand, causing positive pressure under the roof and negative pressure on the roof.

C6.2.2.11 –

The clause gives pressure coefficients for grandstand structure and the corresponding Table –21 is self explanatory

6.2.2.12 *Upper surface of round silos and tanks* -The pressure coefficients on the upper surface of round silos and tanks standing on ground shall be as given in Fig. 2.

C6.2.2.12 –

The clause gives pressure coefficients and the corresponding figures/tables are self explanatory.

6.2.2.13 *Spheres* - The- external pressure coefficients for spheres shall be as given in Table 22.

6.2.3 Internal Pressure Coefficient - Internal air pressure in a building depends upon the degree of permeability of cladding to the flow of air. The internal air pressure may be positive or negative depending on the direction of flow of air in relation to openings in the buildings.

C6.2.3 –

Internal pressures are not influenced much by the external shape or geometry of the building but are primarily a function of the openings in it. These can be positive or negative and have to be combined algebraically with the external values, C_{pe}, to obtain the critical design combination. Internal pressures vary with the degree of permeability, specified herein as small, medium and large. Small permeability implies upto 5% openings and may be deemed to occur even with doors and windows closed, since flow can take place through slits and recesses in doors, windows, etc. Buildings with one large opening may be treated as per Fig. 3 in the Code.

6.2.3.1 In the case of buildings where the claddings permit the flow of air with openings not more than about 5 percent of the wall

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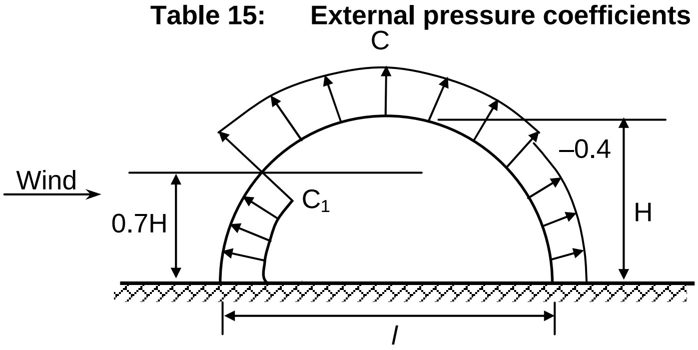
area but where there are no large openings, it is necessary to consider the possibility of the internal pressure being- positive or negative. Two design conditions shall be examined, one with an internal pressure coefficient of +0.2 and another with an internal pressure coefficient of -0.2.

The internal pressure coefficient is algebraically added to the external pressure coefficient and the analysis which indicates greater distress of the member shall be adopted. In most situations a simple inspection of the sign of external pressure will at once indicate the proper sign of the internal pressure coefficient to be taken for design.

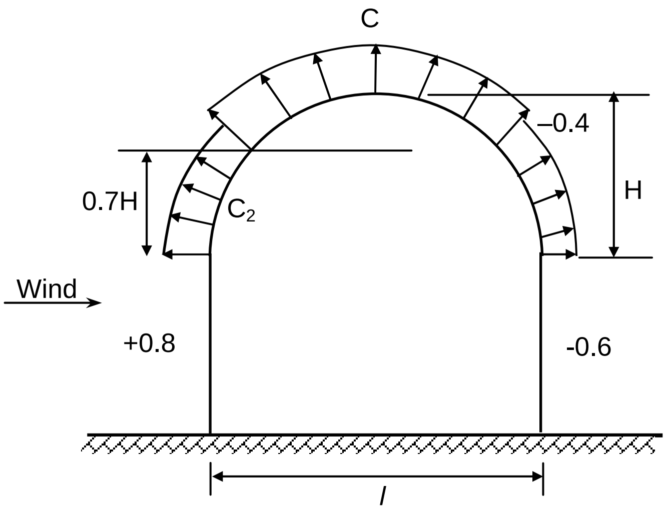
NOTE - The term normal permeability relates to the flow of air commonly afforded by cladding not only through open windows and doors, but also through the slits round the closed windows and doors and through chimneys, ventilators and through the joints between roof coverings, the total open area being less than 5 percent of area of the walls having the openings.

COMMENTARY

Table 15: External pressure coefficients for curved roofs. *[Clause 6.2.3.5]*



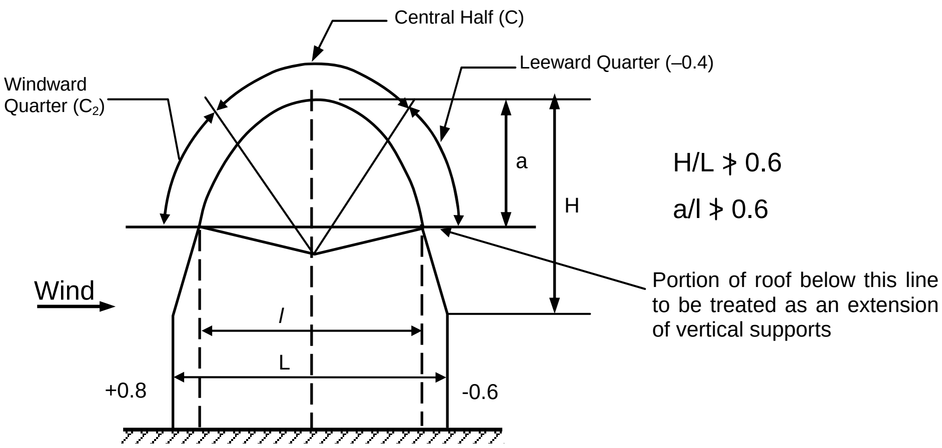
(a) Roof springing from ground level



(b) Roof on elevated structure

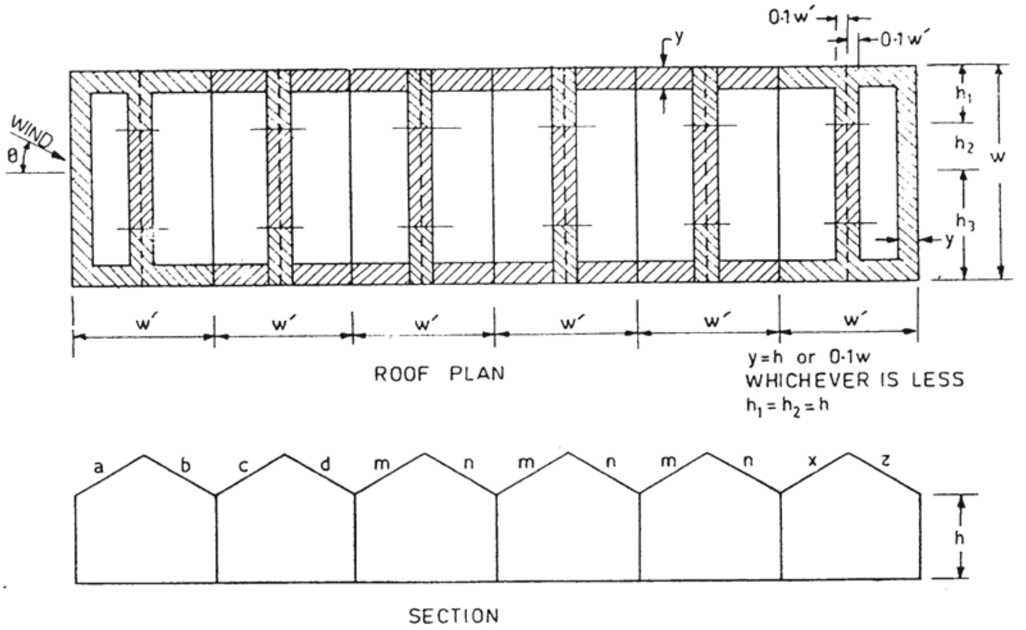
H/l	***C***	***C_1***	***C_2***
0.1	-0.8	+0.1	-0.8
0.2	-0.9	+0.3	-0.7
0.3	-1.0	+0.4	-0.3
0.4	-1.1	+0.6	+0.4
0.5	-1.2	+0.7	+0.7

NOTE – When the wind is blowing normal to gable ends, C_{pe} may be taken as equal to –0.7 for the full width of the roof over a length of *l/2* from the gable ends and –0.5 for the remaining portion.



(c) Doubly curved roofs

Table 16 External pressure coefficients (C_{pe}) for pitched roofs of multispan buildings (All Spans Equal) with h > w′. *[Clause 6.2.2.6]*



Roof Angle α	Wind Angle θ	First Span a	First Span b	First Intermediate Span c	First Intermediate Span d	Other Intermediate Span m	Other Intermediate Span n	End Span x	End Span z	Local Coefficient (cross-hatched)	Local Coefficient (hatched)
degrees	degrees										
5	0	−0·9	−0·6	−0·4	−0·3	−0·3	−0·3	−0·3	−0·3	−2·0	−1·5
10		−1·1	−0·6	−0·4	−0·3	−0·3	−0·3	−0·3	−0·4		
20		−0·7	−0·6	−0·4	−0·3	−0·3	−0·3	−0·3	−0·5		
30		−0·2	−0·6	−0·4	−0·3	−0·2	−0·3	−0·2	−0·5		
45		+0·3	−0·6	−0·6	−0·4	−0·2	−0·4	−0·2	−0·5		

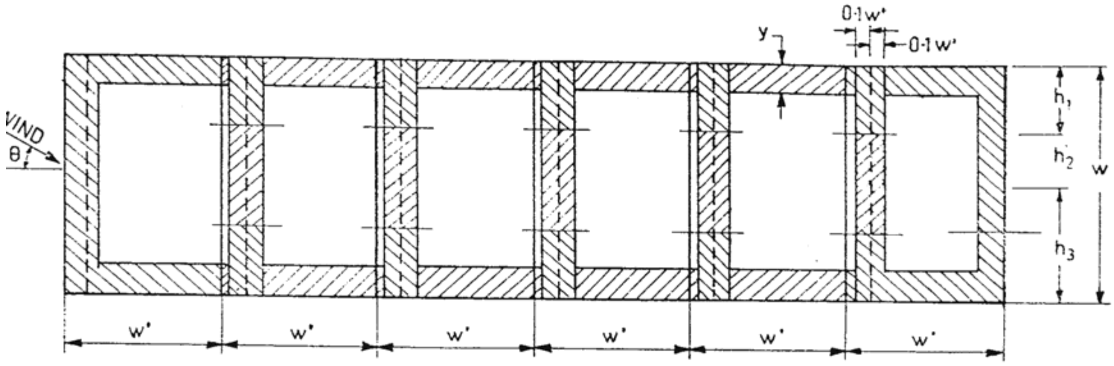
Roof Angle α degrees	Wind Angle θ degrees	Distance h_1	Distance h_2	Distance h_3
Up to 45	90	−0·8	−0·6	−0·2

Frictional drag: When wind angle θ = 0°, horizontal forces due to frictional drag are allowed for in the above values; and

when wind angle θ = 90°, allow for frictional drag in accordance with **6.3.1**.

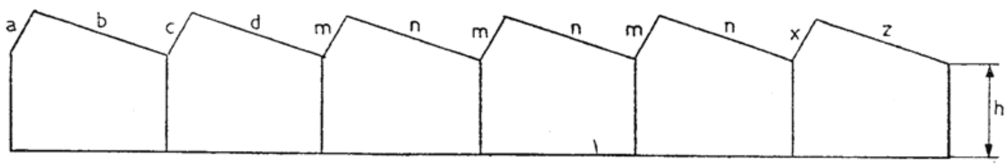
NOTE — Evidence on these buildings is fragmentary and any departure from the cases given should be investigated separately.

Table 17 External pressure coefficients (C_{pe}) for saw tooth roofs of multispan buildings (All Spans Equal) with h > w′. *[Clause 6.2.2.6]*

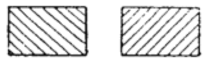


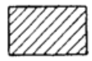
ROOF PLAN

$y = h$ or $0{\cdot}1\,w$ whichever is the less
$h_1 = h_2 = h$



SECTION



Wind Angle θ	First Span		First Intermediate Span		Other Intermediate Spans		End Spans		Local Coefficient 	
	a	b	c	d	m	n	x	z		
degrees										
0	+0·6	−0·7	−0·7	−0·4	−0·3	−0·2	−0·1	−0·3	−2·0	−1·5
180	−0·5	−0·3	−0·3	−0·3	−0·4	−0·6	−0·6	−0·1		

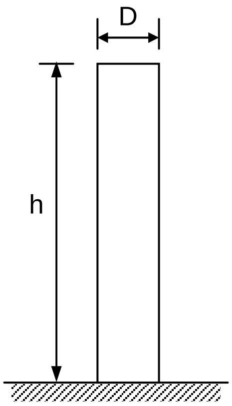
Wind Angle θ degrees	Distance h_1	h_2	h_3
90	−0·8	−0·6	−0·2
270	Similarly, but handed		

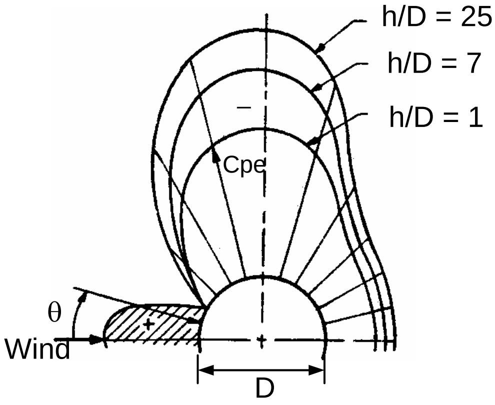
Frictional drag: When wind angle θ = 0°, horizontal forces due to frictional drag are allowed for in the above values; and

when wind angle θ = 90°, allow for frictional drag in accordance with **6.3.1**.

NOTE — Evidence on these buildings is fragmentary and any departures from the cases given should be investigated separately.

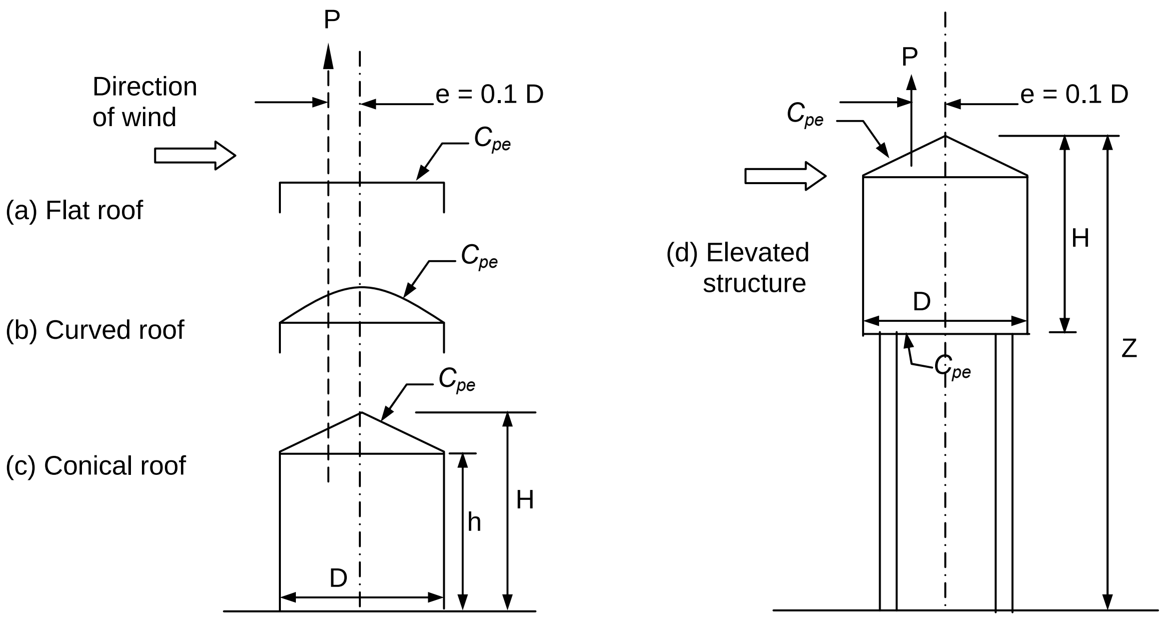
Table 18 External pressure distribution coefficients around cylindrical structures
[Clause 6.2.2.8]





Position of Periphery θ *(degrees)*	Pressure Coefficients, C_{pe}		
	***h/D* = 25**	***h/D* = 7**	***h/D* = 1**
0	1.0	1.0	1.0
15	0.8	0.8	0.8
30	0.1	0.1	0.1
45	-0.9	-0.8	-0.7
60	-1.9	-1.7	-1.2
75	-2.5	-2.2	-1.6
90	-2.6	-2.2	-1.7
105	-1.9	-1.7	-1.2
120	-0.9	-0.8	-0.7
135	-0.7	-0.6	-0.5
150	-0.6	-0.5	-0.4
165	-0.6	-0.5	-0.4
180	-0.6	-0.5	-0.4

Table 19 External pressure coefficients for roofs and bottoms of cylindrical buildings ***[Clause 6.2.3.9]***



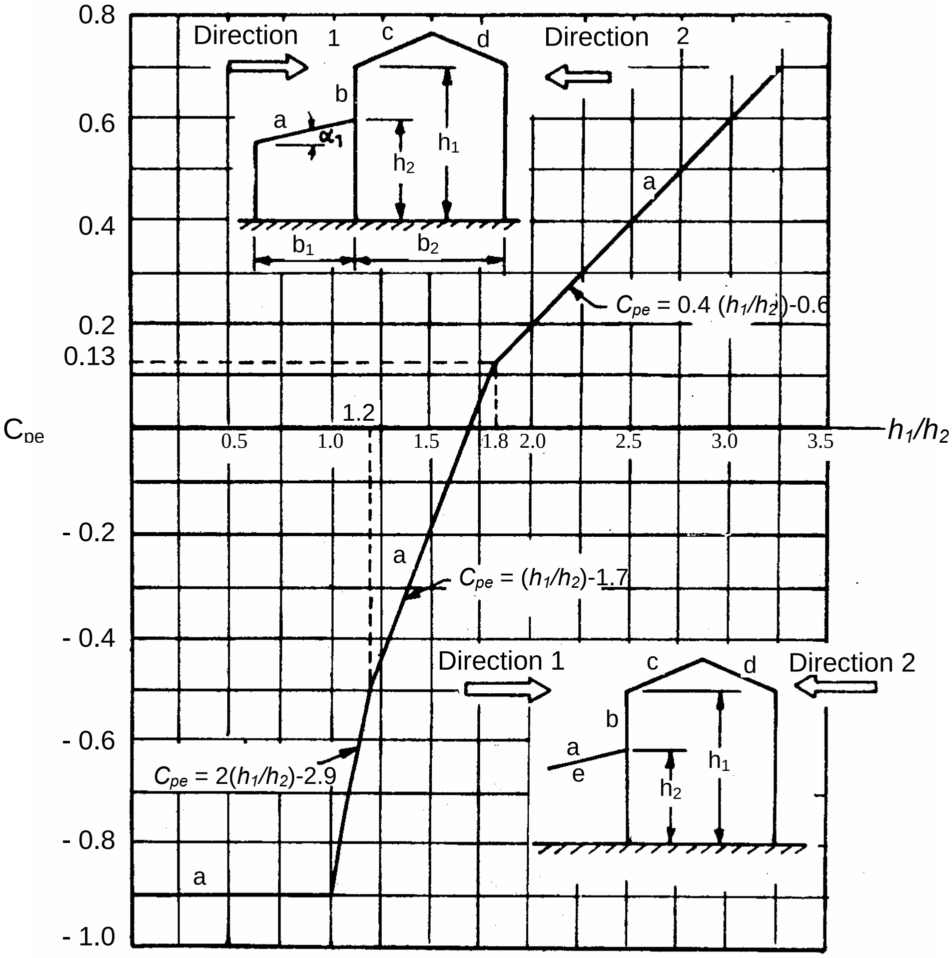
Coefficient of External Pressure, C_{pe}

Structure According to Shape				
a, b and c		**D**		
H/D	Roof	(z/H)-1	Roof	Bottom
0.5	-0.65	1.00	-0.75	-0.8
1.00	-1.00	1.25	-0.75	-0.7
2.00	-1.00	1.50	-0.75	-0.6

Total force a acting on the roof of the structure, $P = 0.785\ D^2\ (p_1 - C_{pe}p_d)$

The resultant of P lies eccentrically, e = 0.1 D

Table 20 External pressure coefficients, C_{pe} for combined roofs and roofs with a sky light. *[Clause 6.2.2.10]*

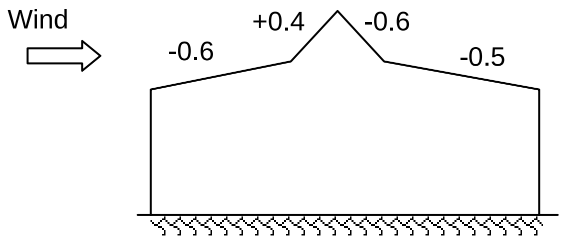


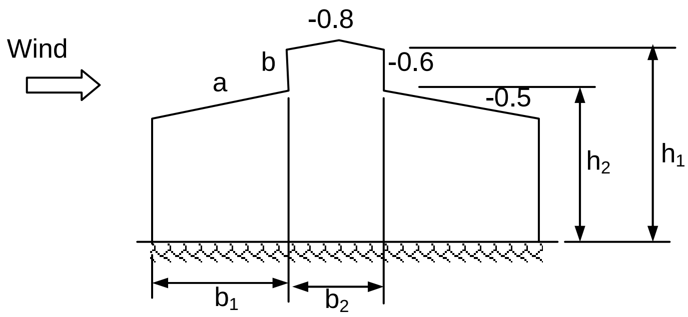
Values of C_{pe}

Portion	Direction 1	Direction 2
a	From the Diagram	-0.4
b	C_{pe} = -0.5, (h_1/h_2) ≤ 1.7 C_{pe} = +0.7, (h_1/h_2) > 1.7	
c and d	See Table 5	
e	See 6.2.2.7	

Contd……….

Table 20 External pressure coefficients, C_{pe} for combined and roofs with a skylight. ---------- Contd.

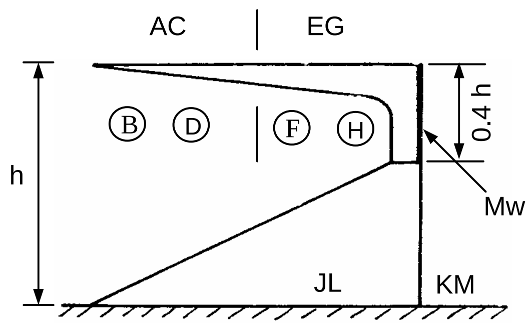




	$b_1 > b_2$		$b_1 \leq b_2$
Portion	a	b	a and b
C_{pe}	-0.6	+0.7	See Table for combined roofs

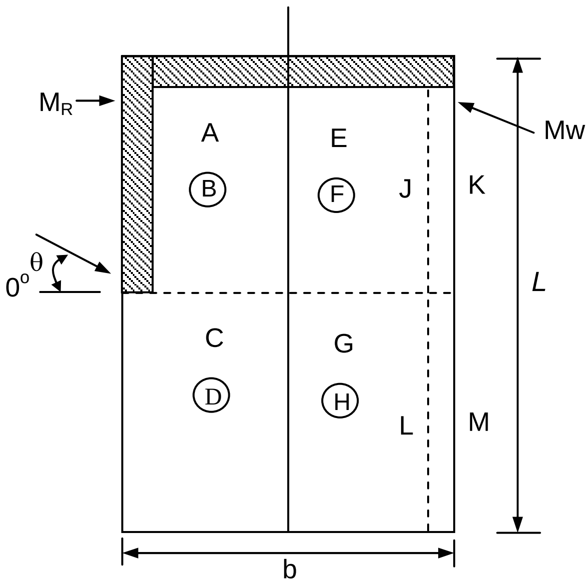
Table 21 Pressure coefficients at top and bottom of roof of grandstands open three sides (roof angle up to 5°) *[Clause 6.2.2.11]*

(h:b:*l* = 0.8 : 1 : 2.2)



Front and Back of Wall

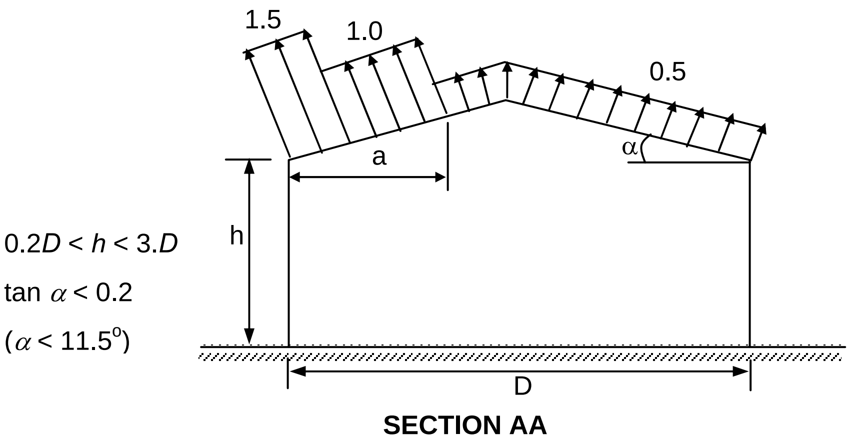
θ	J	K	L	M
0°	+0.9	-0.5	+0.9	-0.5
45°	+0.8	-0.6	+0.4	-0.4
135°	-1.1	+0.6	-1.0	+0.4
180°	-0.3	+0.9	-0.3	+0.9
60°	'M$_W$' – C_p of K = - 1.0			
60°	'M$_W$' – C_p of J = + 1.0			

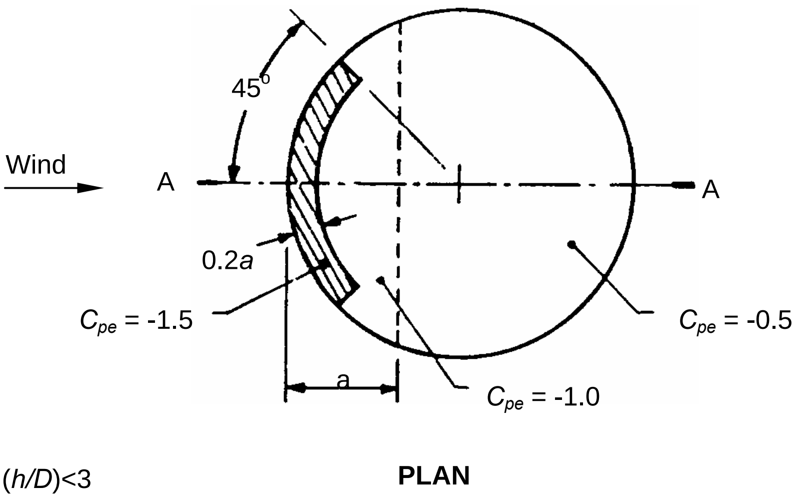


(Shaded area to scale)

Top and Bottom of Roof

θ	A	B	C	D	E	F	G	H
0°	-1.0	+0.9	-1.0	+0.9	-0.7	+0.9	-0.7	+0.9
45°	-1.0	+0.9	-0.7	+0.4	-0.5	+0.8	-0.5	+0.3
135°	-0.4	-1.1	-0.7	-1.0	-0.9	-1.1	-0.9	-1.0
180°	-0.6	-0.3	-0.6	-0.3	-0.6	-0.3	-0.6	-0.3
45°	'M_R' = C_P (top) = - 2.0							
45°	'M_R' = C_P (bottom) = + 1.0							





a = 0.5*D* for 2< (*h/D*)<3
= 0.15*h* + 0.2*D* for 0.2 < (*h/D*) < 2

(For Force Coefficient Corresponding to Shell Portion, See Table 23)

Figure 2 : External pressure coefficient on the upper roof surface of a singular circular structure standing on ground.

CODE

6.2.3.2 *Buildings with medium and large openings* - Buildings with medium and large openings may also exhibit either positive or negative internal pressure depending upon the direction of wind. Buildings with medium openings between about 5 to 20 percent of wall area shall be examined for an internal pressure coefficient of +0.5 and later with an internal pressure coefficient of -0.5, and the analysis which produces greater distress of the members shall be adopted. Buildings with large openings, that is, openings larger than 20 percent of the wall area shall be examined

COMMENTARY

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once with an internal pressure coefficient of +0.7 and again with an internal pressure coefficient of -0.7, and the analysis which produces greater distress on the members shall be adopted.

Buildings with one open side or opening exceeding 20 percent of wall area may be assumed to be subjected to internal positive pressure or suction similar to those for buildings with large openings. A few examples of buildings with one sided openings are shown in Fig. 3 indicating values of internal pressure coefficients with respect to the direction of wind.

6.2.3.3 In buildings with roofs but no walls, the roofs will be subjected to pressure from both inside and outside and the recommendations shall be as given in 6.2.2.

6.3 Force Coefficients - The value of force coefficients apply to a building or structure as a whole, and when multiplied by the effective frontal area A_e, of the building or structure and by design wind pressure, p_d gives the total wind load on that particular building or structure.

$$F = C_f A_e p_d$$

where F is the force acting in a direction specified in the respective tables and C_f is the force coefficient for the building.

NOTE 1 - The value of the force coefficient differs for the wind acting on different faces of a building or structure. In order to determine the critical load, the total wind load should be calculated for each wind direction.

NOTE 2 - If surface design pressure varies with height, the surface area of the building/structure may be sub-divided so that specified pressures are taken over appropriate areas.

NOTE 3 - In tapered buildings/structures, the force coefficients shall be applied after sub-dividing the building/structure into suitable number of strips and the load on each strip calculated individually, taking the area of each strip as A_e.

NOTE 4 - For force coefficients for structures not, covered above, reference may be made to specialist literature on the subject or advise may be sought from specialists in the subject.

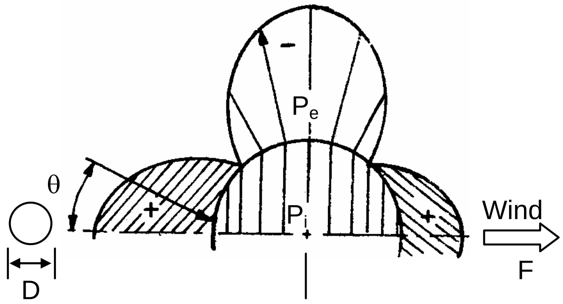
COMMENTARY

C6.3 -

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. Since the pressure over a surface varies, the computation of force over an area can be done by dividing the surface into small tributary areas, and then summing up the forces over these small areas. In other words, a force over an element of a structure, or the structure as a whole is obtained as an integration of the term ‘pressure × area’, as relevant. Such a force can be obtained on a clad building, or an unclad building or its components and can be expressed in terms of a force coefficient, as in this clause. In deducing the force coefficient the direction of the force has to be specified. A force taken to act in the direction of the wind is called ‘drag’, while that in a direction perpendicular to it is called ‘lift’.

Whereas the use of the force coefficients as given will only help in determining the overall force system on the structure and its foundation in order to design the framework or to compute stability; the distribution of pressure (and hence the local pressure coefficient) is essentially required for designing the fasteners, cladding, and its support system.

Table 22 **External pressure distribution coefficients around spherical structures *[Clause 6.2.2.13]***



Position of Periphery, θ in Degrees	C_{pe}	**Remarks**
0	+1.0	C_f = 0.5 for $DV_d < 7$
15	+0.9	= 0.2 for $DV_d \geq 7$
30	+0.5	
45	-0.1	
60	-0.7	
75	-1.1	
90	-1.2	
105	-1.0	
120	-0.6	
135	-0.2	
150	+0.1	
165	+0.3	
180	+0.4	

CODE

6.3.1 *Frictional Drag* - In certain buildings of special shape, a force due to frictional drag shall be taken into account in addition to those loads specified in 6.2. For rectangular clad buildings, this addition is necessary only where the ratio $\frac{d}{h}$ or $\frac{d}{b}$ greater than 4. The frictional drag force, F', in the direction of the wind is given by the following formulae:

If

$$h < b, F' = C_f^{'}(d - 4h)bp_d + C_f^{'}(d - 4h)2hp_d,$$

and

If

$$h > b, F' = C_f^{'}(d - 4h)bp_d + C_f^{'}(d - 4b)2hp_d,$$

The first term in each case gives the drag on the roof and the second on the walls. The value of $C_f^{'}$ has the following values

$C_f^{'} = 0.01$ for smooth surfaces without corrugations or ribs across the wind direction,

$C_f^{'} = 0.02$ for surfaces with corrugations across the wind direction, and

$C_f^{'} = 0.04$ for surfac6s with ribs across the wind direction.

For other buildings, the frictional drag has been indicated, where necessary, in the tables of pressure and force coefficients.

6.3.2 *Force Coefficients for Clad Buildings*

6.3.2.1 *Clad buildings of uniform section* - The overall force coefficients for rectangular clad buildings of uniform section with flat roofs in uniform flow shall be as given in Fig. 4 and for other clad buildings of uniform section (without projections, except where otherwise shown) shall be as given in Table 23.

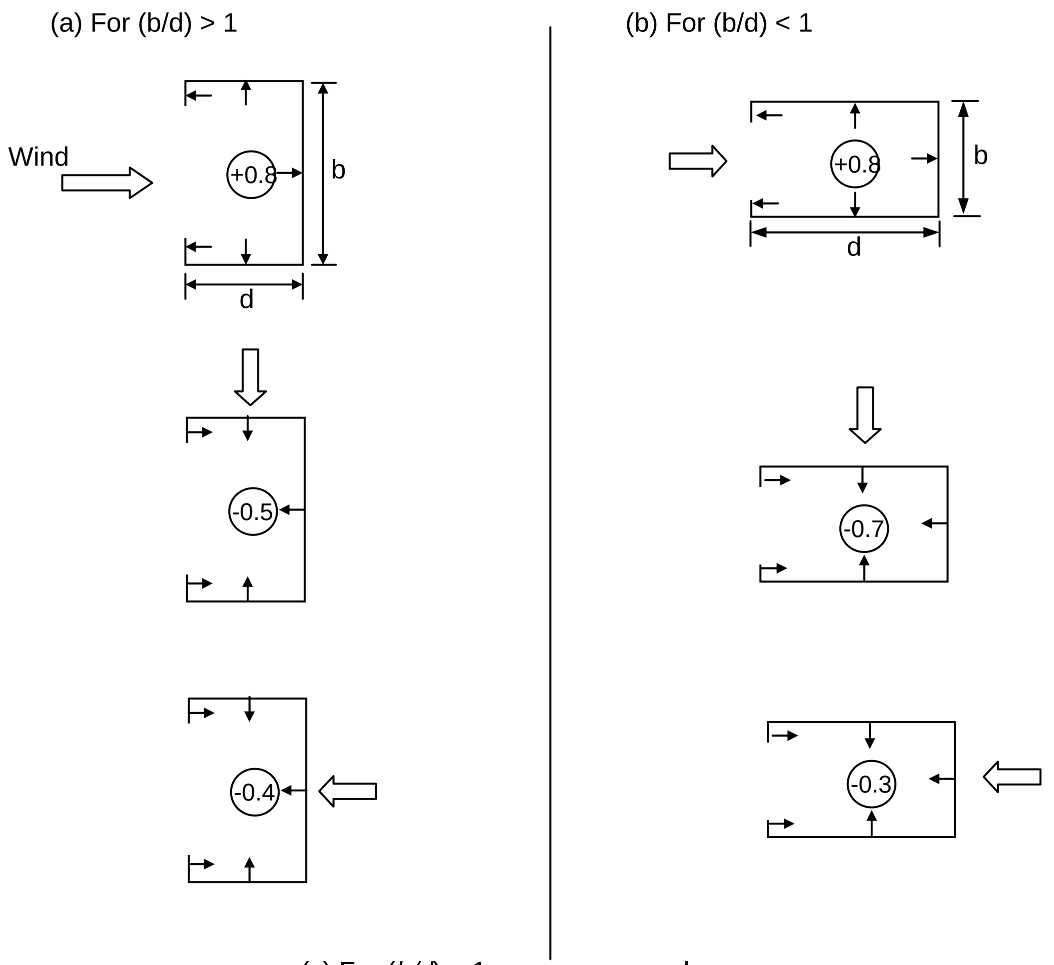
COMMENTARY

C6.3.1 –

The flow of wind around/over a structure, as mentioned already, causes surface pressures. In addition, there is friction between the surface of the structure and the wind flowing over it. This results in a frictional force in the direction of wind. This clause specifies the frictional drag for a rectangular clad building.

C6.3.2 –

Clad rectangular buildings with different proportions are covered in this clause in addition to buildings of a variety of other shapes, both with sharp edges as well as rounded corners. For cases where the edges are sharp, or nearly so, the Reynolds number has only a limited influence on the wind pressures or forces. However, for rounded edges, or for shapes which are circular or near circular, Reynolds number has a marked effect. This has been accounted for in Table 23 by specifying the applicable range of $V_d b$. The force values are also a function of the aspect ratio.



(c) For (*b/d*) = 1, use average values

Arrows indicate direction of wind.

Figure 3: Large opening in buildings (values of coefficients of internal pressure) with top closed

CODE

6.3.2.2 Buildings of circular shapes - Force coefficients for buildings circular cross-section shapes shall be as given in Table 23. However, more precise estimation of force coefficients for circular shapes of infinite length can be obtained from Fig. 5 taking into account the average height of surface roughness E. When the length is finite, the values obtained from Fig. 5 shall be reduced by the multiplication factor K *(see also* Table 25 and Appendix D).

6.3.2.3 *Low walls and hoardings -* Force coefficients for low walls and hoardings less than 15m high shall be as given in Table 24 provided the height shall be measured from the ground to the top of the walls or hoarding, and provided that for walls or hoarding above

COMMENTARY

CODE

ground the clearance between the wall or hoarding and the ground shall be not less than 0.25 times the vertical dimension of the wall or hoarding.

To allow for oblique winds, the design shall also be checked for net pressure normal to the surface varying linearly from a maximum of 1.7 C_f at the up wind edge to 0.44 C_f at the down wind edge.

The wind load on appurtenances and supports for hoardings shall be accounted for separately by using the appropriate net pressure coefficients. Allowance shall be made for shielding effects of one element or another.

6.3.2.4 *Solid circular shapes mounted on a surface* - The force coefficients for solid circular shapes mounted on a surface shall be as given in Fig. 6

6.3.3 *Force Coefficients for Unclad Buildings*

6.3.3.1 *General* - This section applies to permanently unclad buildings and to frameworks of buildings while temporarily unclad. In the case of buildings whose surface are well rounded, such as those with elliptic, circular or ovoid cross- sections, the total force can be more at wind speeds much less than the maximum due to transition in the nature of boundary layer on them. Although this phenomenon is well known in the case of circular cylinders, the same phenomenon exists in the case of many other well-rounded structures, and this possibility must be checked.

6.3.3.2 *Individual members*

a) The coefficients refer to the members of infinite length. For members of finite length, the coefficients be multiplied by a factor K that depends on the ratio l/b where I is the length of the member and *b* is the width across the direction of wind. Table 25 gives the required values of K. The following special cases must be noted while estimating K.

i. Where any member abuts onto a plate or wall in such a way that free flow of air around that end of the member is prevented, then the ratio of l/b shall be doubled for the purpose of determining *K*;

COMMENTARY

C 6.3.3 –

Force coefficients in this section are given for skeletal frameworks or individual elements, which imply considerations of their shape, aspect ratio, Reynolds number effect and shielding amongst members. The angle of wind incidence can also affect the coefficients.

C6.3.3.2 –

For a member of finite length, held in free space, wind would escape at the two ends of the member. Thus there is a reduction in the overall wind force acting on the member. The shorter the member the greater is this reduction. Table 25 gives the reduction factors. In reckoning the length of the member, the end conditions play a role. For example, if a member is connected into plates at the ends, its length is to be treated as infinite, with reduction factor becoming 1.0.

Table 26 provides the coefficients for flat–sided members, in which Reynolds number will not have an influence. Table 27 likewise gives the values for wires and cables, for which Reynolds number will have a marked influence. Wind forces will also be influenced by the surface roughness.

CODE

ii. When both ends of a member are so obstructed, the ratio l/b shall be taken as infinity for the purpose of determining A7.

b) Flat-sided members - Force coefficients for wind normal to the longitudinal axis of flat-sided structural members shall be as given in Table 26.

The force coefficients are given for two mutually perpendicular directions relative to a reference axis on the structural member. They are designated as C_{fn} and C_{ft}, give the forces normal and transverse, respectively to the reference plane as shown in Table 26.

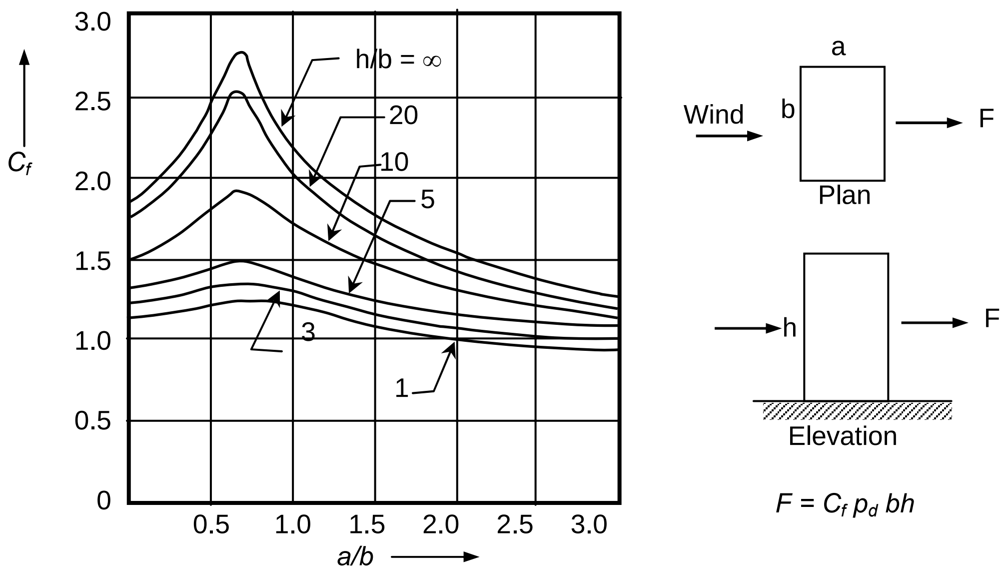
Normal force, $F_n = C_{fn} p_d K l b$

Transverse force, $F_t = C_{ft} p_d K l b$

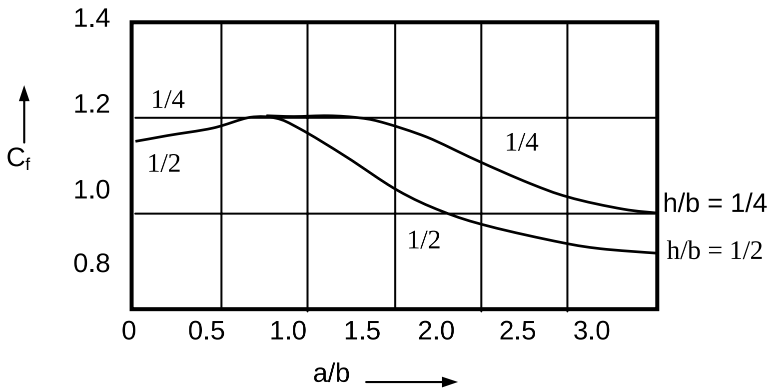
c) Circular sections - Force coefficients for members of circular section shall be as given in Table 23 (see also Appendix D)

d) Force coefficients for wires and cables shall be as given in Table 27 according to the diameter (D), the wind speed V_d and the surface roughness.

COMMENTARY



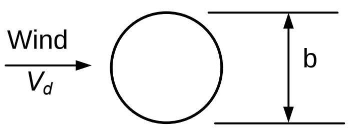
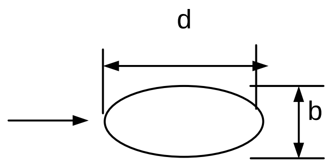
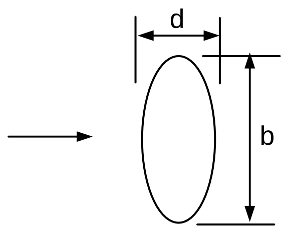
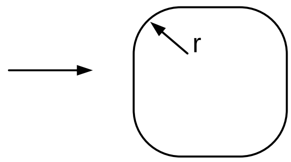
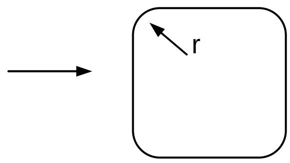
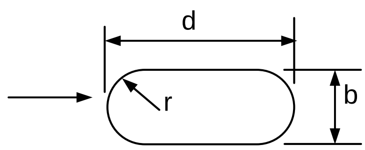
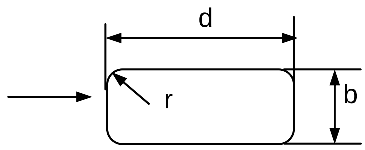
4A Values of C_f versus a/b for $h/b \geq 1$

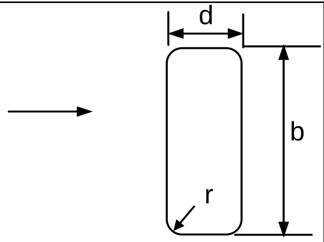
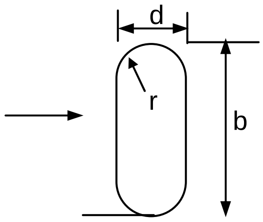
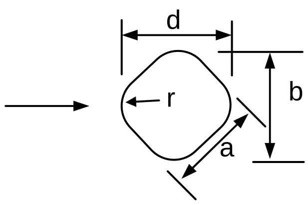
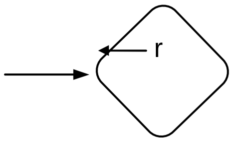
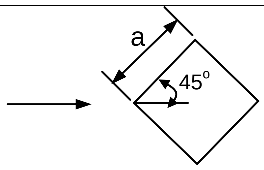
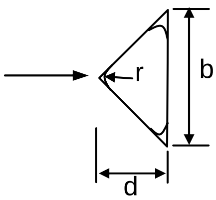
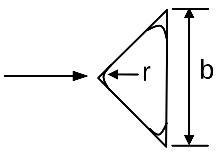


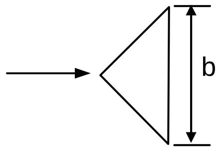
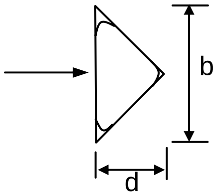
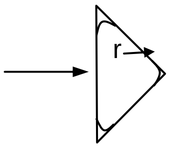
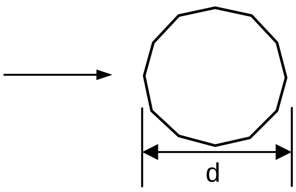
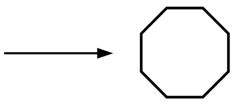
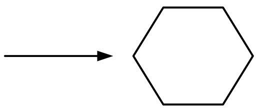
4B Values of C_f versus a/b for $h/b < 1$

Figure 4: Force coefficients for rectangular clad buildings in uniform flow

Table 23 Force coefficients C_f for clad buildings of uniform section (acting in the direction of wind) [*Clause 6.3.2.1, 6.3.2.2 and 6.3.3.2(c)*]

<table>
<tr><th colspan="2" rowspan="2">Plan Shape</th><th rowspan="2">$V_d b$
m^2/s</th><th colspan="7">C_f for Height / Breadth Ratio</th></tr>
<tr><th>Up to 1/2</th><th>1</th><th>2</th><th>5</th><th>10</th><th>20</th><th>∞</th></tr>
<tr><td rowspan="3"></td><td>All Surfaces</td><td>< 6</td><td rowspan="2">0.7</td><td rowspan="2">0.7</td><td rowspan="2">0.7</td><td rowspan="2">0.8</td><td rowspan="2">0.9</td><td rowspan="2">1.0</td><td rowspan="2">1.2</td></tr>
<tr><td>Rough or with projections</td><td>≥ 6</td></tr>
<tr><td>Smooth</td><td>≥ 6</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.6</td><td>0.6</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Ellipse
b/d = 1/2</td><td>< 10</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.6</td><td>0.6</td><td>0.7</td></tr>
<tr><td>≥ 10</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Ellipse
b/d = 2</td><td>< 8</td><td>0.8</td><td>0.8</td><td>0.9</td><td>1.0</td><td>1.1</td><td>1.3</td><td>1.7</td></tr>
<tr><td>≥ 8</td><td>0.8</td><td>0.8</td><td>0.9</td><td>1.0</td><td>1.1</td><td>1.3</td><td>1.5</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">b/d = 1
r/b = 1/3</td><td>< 4</td><td>0.6</td><td>0.6</td><td>0.6</td><td>0.7</td><td>0.8</td><td>0.8</td><td>1.0</td></tr>
<tr><td>≥ 4</td><td>0.4</td><td>0.4</td><td>0.4</td><td>0.4</td><td>0.5</td><td>0.5</td><td>0.5</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">b/d = 1
r/b = 1/6</td><td>< 10</td><td>0.7</td><td>0.8</td><td>0.8</td><td>0.9</td><td>1.0</td><td>1.0</td><td>1.3</td></tr>
<tr><td>≥ 10</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.6</td><td>0.6</td><td>0.6</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">b/d = 1/2
r/b = 1/2</td><td>< 3</td><td>0.3</td><td>0.3</td><td>0.3</td><td>0.3</td><td>0.3</td><td>0.3</td><td>0.4</td></tr>
<tr><td>≥ 3</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.2</td><td>0.3</td><td>0.3</td><td>0.3</td></tr>
<tr><td></td><td>b/d = 1/2
r/b = 1/6</td><td>All values</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.6</td><td>0.6</td><td>0.7</td></tr>
</table>

	b/d = 2 r/b = 1/12	All values	0.9	0.9	1.0	1.1	1.2	1.5	1.9
	b/d = 2 r/b = ¼	< 6	0.7	0.8	0.8	0.9	1.0	1.2	1.6
		≥ 6	0.5	0.5	0.5	0.5	0.5	0.6	0.6
	r/a = 1/3	< 10	0.8	0.8	0.9	1.0	1.1	1.3	1.5
		≥ 10	0.5	0.5	0.5	0.5	0.5	0.6	0.6
	r/a = 1/12	All values	0.9	0.9	0.9	1.1	1.2	1.3	1.6
	r/a = 1/48	All values	0.9	0.9	0.9	1.1	1.2	1.3	1.6
	r/b = ¼	< 11	0.7	0.7	0.7	0.8	0.9	1.0	1.2
		≥ 11	0.4	0.4	0.4	0.4	0.5	0.5	0.5
	r/b = 1/12	All values	0.8	0.8	0.8	1.0	1.1	1.2	1.4

	r/b = 1/48	All Values	0.7	0.7	0.8	0.9	1.0	1.1	1.3
	r/b = ¼	< 8	0.7	0.7	0.8	0.9	1.0	1.1	1.3
		≤ 8	0.4	0.4	0.4	0.4	0.5	0.5	0.5
	1/48 < r/b < 1/12	All Values	1.2	1.2	1.2	1.4	1.6	1.7	2.1
	12-sided polygon	< 12	0.7	0.7	0.8	0.9	1.0	1.1	1.3
		≥ 12	0.7	0.7	0.7	0.7	0.8	0.9	1.1
	Octagon	All values	1.0	1.0	1.1	1.2	1.2	1.3	1.4
	Hexagon	All values	1.0	1.1	1.2	1.3	1.4	1.4	1.5

Structures that, are in the supercritical flow regime because of their size and design wind speed, may need further calculation to ensure that the greatest loads do not occur at some wind speed below the maximum when the flow will be sub-critical.

The coefficients are for buildings without projections, except where otherwise shown. In this table $V_d b$ is used as an indication of the airflow regime.

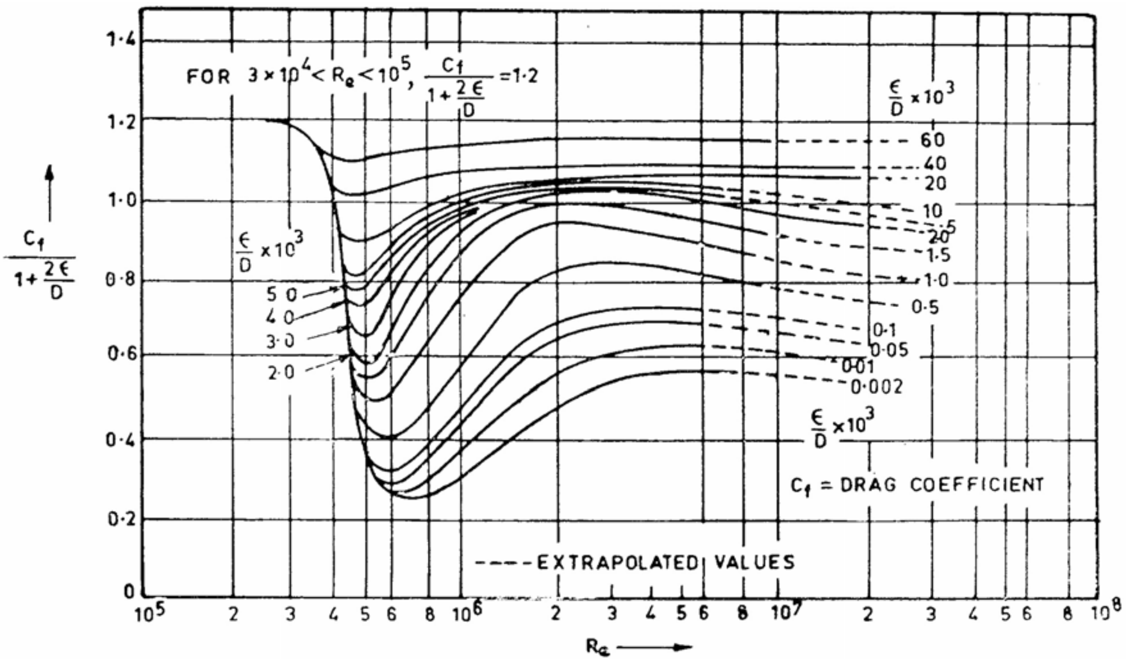
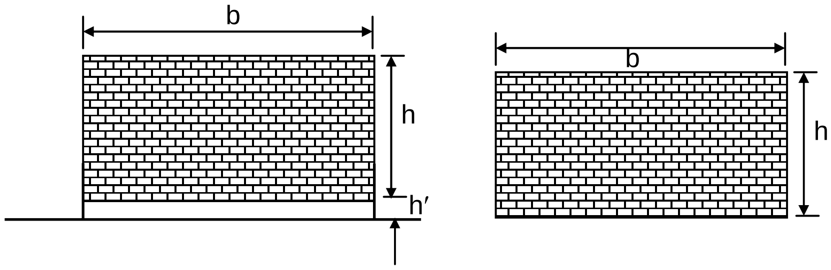


Figure 5 Variation of $\dfrac{C_f}{1+\dfrac{2\in}{D}}$ with R_e (> 3×10^4) for Circular Sections

Table 24 Force coefficients for low walls or hoardings (< 15 m high). [*Clause 6.3.2.3*]



Above Ground h′ ≥ 0.25 h

One edge on Ground

Width to Height Ratio, *b/h*		**Drag Coefficient, C_f**
Wall above Ground	**Wall on Ground**	
From 0.5 to 6	From 1 to 12	1.2
10	20	1.3
16	32	1.4
20	40	1.5
40	80	1.75
60	120	1.8
80 or more	160 or more	2.0

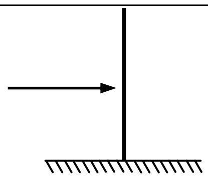
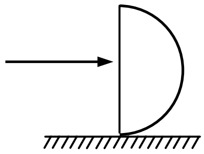
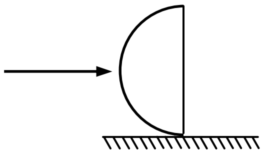
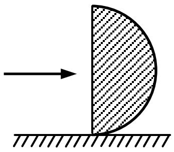
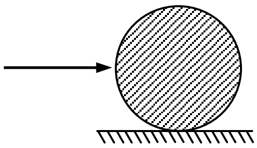
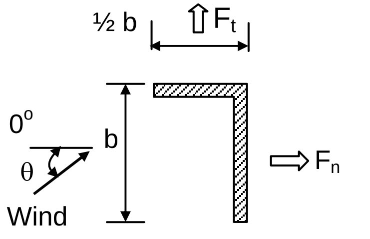
SIDE ELEVATION	DESCRIPTION OF SHAPE	C_f
	CIRCULAR DISC	1.2
	HEMISPHERICAL BOWL	1.4
	HEMISPHERICAL BOWL	0.4
	HEMISPHERICAL SOLID	1.2
	SPHERICAL SOLID	0.5 FOR $V_dD < 7$ 0.2 FOR $V_dD \geq 7$

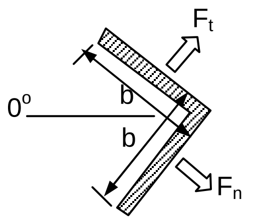
Figure 6 Force coefficients for solid shapes mounted on a surface

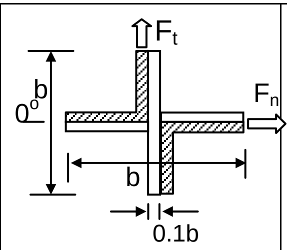
Table 25 : Reduction factor K for individual members. *[Clause 6.3.2.2 and 6.3.3.2 (a)]*

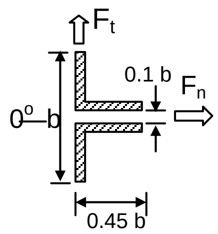
l /b* or *l /D	**2**	**5**	**10**	**20**	**40**	**50**	**100**	**∞**
Circular cylinder, subcritical flow	0.58	0.62	0.68	0.74	0.82	0.87	0.98	1.00
Circular cylinder, supercritical flow ($DV_d \geq 6$ m^2/s)	0.80	0.80	0.82	0.90	0.98	0.99	1.00	1.00
Flat plate perpendicular to wind ($DV_d \geq 6$ m^2/s)	0.62	0.66	0.69	0.81	0.87	0.90	0.95	1.00

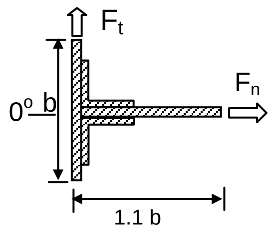
Table 26: Force coefficients (C_f) for individual structural members of infinite length [*Clause 6.3.3.2(b)*]

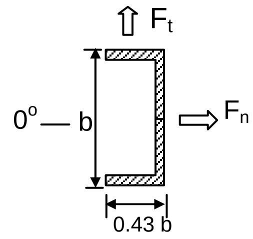




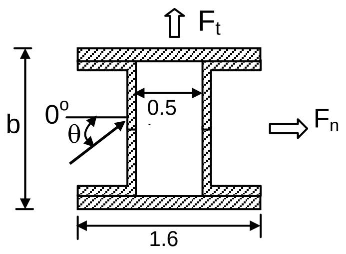


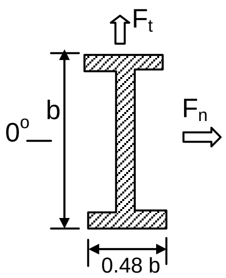


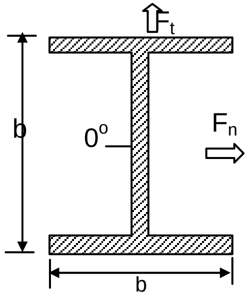


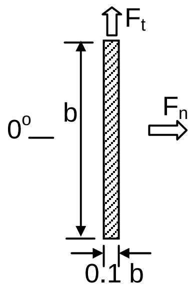


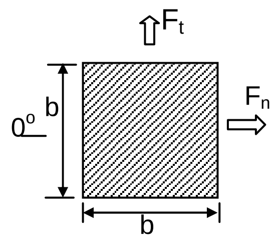
θ	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}
Degrees												
0	+1.9	+0.95	+1.8	+1.8	+1.75	+0.1	+1.6	0	+2.0	0	+2.05	0
45	+1.8	+0.8	+2.1	+1.8	+0.85	+0.85	+1.5	-0.1	+1.2	+0.9	+1.85	+0.6
90	+2.0	+1.7	-1.9	-1.0	+0.1	+1.75	-0.95	+0.7	-1.6	+2.15	0	+0.6
135	-1.8	-0.1	-2.0	+0.3	-0.75	+0.75	-0.5	+1.05	-1.1	+2.4	-1.6	+0.4
180	-2.0	+0.1	-1.4	-1.4	-1.75	-0.1	-1.5	0	-1.7	±2.1	-1.8	0











θ	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}	C_{fn}	C_{ft}
Degrees										
0	+1.4	0	+2.05	0	+1.6	0	+2.0	0	+2.0	0
45	+1.2	+1.6	+1.95	+0.6	+1.5	+1.5	+1.8	+0.1	+1.55	+1.55
90	0	+2.2	+0.5	+0.9	0	+1.9	0	+0.1	0	+2.0

NOTE: In this table, the force coefficient C_f is given in relation to the dimension b and not, as in other cases, in relation to effective frontal area A_e.

Table27: Force coefficients for wires and cables (*l/D* =100). *[Clause 6.3.3.2(d)]*

Flow Regime	Force Coefficients, C_f for			
	Smooth Surface	Moderately Smooth Wire (Galvanized or Painted)	Fine Stranded Cables	Thick Stranded Cables
$DV_d < 0.6$ m²/s	--	--	1.2	1.3
$DV_d \geq 0.6$ m²/s	--	--	0.9	1.1
$DV_d < 6$ m²/s	1.2	1.2	--	--
$DV_d \geq 6$ m²/s	0.5	0.7	--	--

CODE

6.3.3.3 Single frames - Force coefficients for a single frame having either:

a) all flat sided members, or

b) all circular members in which all the members of the frame have either:

   i. D V_d less than 6, or m²/s, or

   ii. D V_d greater than 6 m²/s

shall be as given in Table 28 according to the type of the member, the diameter (D), the design wind speed (V_d) and the solidity ratio (ϕ)

COMMENTARY

C 6.3.3.3 –

Force coefficients for single frames are given for flat sided members or members of circular section, the latter being influenced by the flow regime. Where a frame consists of both flat sided members and members of circular cross-section, the coefficients for these respective shapes may be taken from Table 28.

The solidity ratio of the frame also affects the value of C_f. The solidity ratio implies the ratio of net exposed area of the frame members divided by the gross area bound by these members. See Fig. C6.

$$\phi = \frac{Shaded\ area}{Area\ \ a\,b\,c\,d}$$

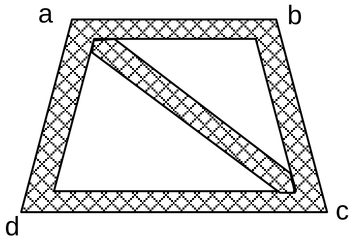


Figure C6

For latticed steel towers ϕ varies typically between about 0.1 and 0.3. For lattice frames see 6.3.3.5.

Table 28 Force coefficients for single frames

Solidity Ratio ϕ	Force Coefficients, C_f		
	Flat-sided members	For Circular Members	
		Sub-critical flow ($DV_d < 6$ m^2/s)	Supercritical flow ($DV_d \geq 6$ m^2/s)
(1)	(2)	(3)	(4)
0.1	1.9	1.2	0.7
0.2	1.8	1.2	0.8
0.3	1.7	1.2	0.8
0.4	1.7	1.1	0.8
0.5	1.6	1.1	0.8
0.75	1.6	1.5	1.4
1.00	2.0	2.0	2.0
Linear interpolation between the values is permitted.			

CODE

Force coefficients for a single frame not complying with the above requirements shall be calculated as follows:

$$C_f = \gamma C_{f\,super} + (1-\gamma)\frac{A_{circ\,sub}}{A_{sub}} + (1-\gamma)\frac{A_{flat}}{A_{sub}} C_{f\,flat}$$

where

$C_{f\,super}$ = force coefficient for the super critical circular members as given in Table 28 or Appendix D.

$C_{r\,subr}$ = force coefficient for sub critical circular members as given in Table 28 or Appendix D,

$C_{f\,flat}$ = force coefficient for the flat sided members as given in Table 28.

$A_{circ\,sub}$ = effective area of subcritical circular members,

A_{flat} = effective area of flat-sided members,

A_{sub} = $A_{circ\,sub} + A_{flat}$

γ = $\left(\frac{\text{Area of the frame in supercritical flow}}{A_e}\right)$

COMMENTARY

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6.3.3.4 *Multiple frame buildings* – This section applies to structures having two or more parallel frames where the windward frames may have a shielding effect upon the frames to leeward side. The windward frame and any unshield parts of other frames shall be calculated in accordance with 6.3.3.3, but the wind load on the parts of frames that are sheltered should be multiplied by a shielding factor which is dependent upon the solidity ratio of the windward frame, the types of the members comprising the frame and the spacing ratio of the frames. The values of the shielding factors are given in Table 29.

COMMENTARY

C6.3.3.4 –

During the construction of a clad building, a situation will often occur when the framework will still be unclad (This may occur for a structure or a part of it even permanently). For such unclad frames, or parts thereof, force coefficients can be taken as in 6.3.3.3. If there are multiple frames, as envisaged in this clause, and as will occur commonly, one frame may shield the other. The manner of accounting for this shielding, and its extent, is clearly explained in the Clause.

Table 29: Shielding factor η for multiple frames

Effective Solidity Ratio, β	Frame Spacing Ratio				
	<0.5	1.0	2.0	4.0	> 8.0
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*
0	1.0	1.0	1.0	1.0	1.0
0.1	0.9	1.0	1.0	1.0	1.0
0.2	0.8	0.9	1.0	1.0	1.0
0.3	0.7	0.8	1.0	1.0	1.0
0.4	0.6	0.7	1.0	1.0	1.0
0.5	0.5	0.6	0.9	1.0	1.0
0.7	0.3	0.6	0.8	0.9	1.0
1.0	0.3	0.6	0.6	0.8	1.0
Linear interpolation between values is permitted.					

CODE

Where there are more than two frames of similar geometry and spacing, the wind load on the third and subsequent frames should be taken as equal to that on the second frame. The loads on the various frames shall be added to obtain total load on the structure.

a) The frame spacing ratio is equal to the distance, centre to centre of the frames, beams or girders divided by the least overall dimension of the frame, beam or girder measured at right angles to the direction of the wind. For triangular

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framed structures or rectangular framed structures diagonal to the wind, the spacing ratio should be calculated from the mean distance between the frames in the direction of the wind.

b) Effective solidity ratio, β:

$\beta = \phi$ *for flat-sided members.*

β is to be obtained from Fig. 7 for members of circular cross-sections.

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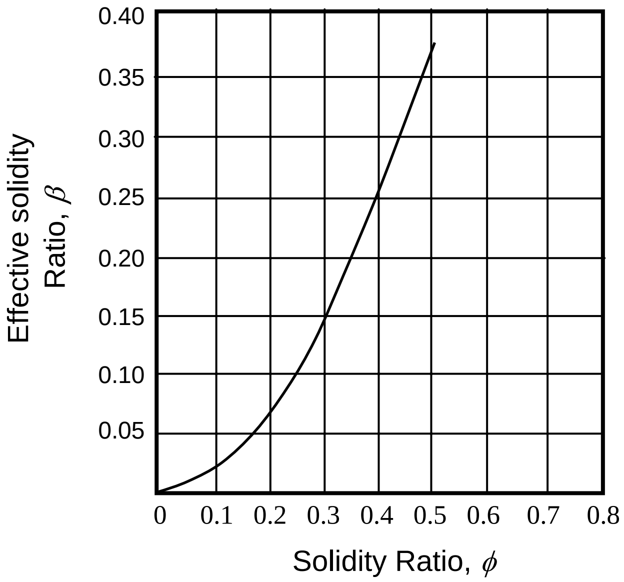

Figure 7: Effective solidity ratio, β for round section members

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6.3.3.5 *Lattice towers*

Force coefficient for lattice towers of square or equilateral triangle section with flat-sided members for wind blowing against any face shall be as given in Table 30.

COMMENTARY

C6.3.3.5 –

The clause provides for force coefficients for square as well as triangular based latticed towers with flat-sided or circular sections used for the members. Such towers often taper from the base towards the top. The frontal area exposed to the wind as well as the solidity ratio therefore goes on changing. It may thus become necessary to divide the tower into several smaller parts along the height and compute forces on each part separately. (a), (b) and (c) deal with towers with flat sided members, while (d) and (e) address towers with circular members. For square based towers, it is pertinent to distinguish between 'wind onto face' or 'onto corner'. Former is critical for the design of bracings while the latter for tower legs.

Table 30 Overall force coefficient for towers composed of flat-sided members

Solidity Ratio	Force Coefficient for	
ϕ	Square Towers	Equilateral Triangular Towers
(1)	(2)	(3)
0.1	3.8	3.1
0.2	3.3	2.7
0.3	2.8	2.3
0.4	2.3	1.9
0.5	2.1	1.5

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(b) For square lattice towers with flat-sided members the maximum load, which occurs when the wind blows into a corner, shall be taken as 1.2 times the load for the wind blowing against a face.

(c) For equilateral-triangle lattice towers with flat-sided members, the load may be assumed to be constant for any inclination of wind to a face.

(d) Force coefficients for lattice towers of square section with circular members, all in the same flow regime, may be as given in Table 31.

(e) Force coefficients for lattice towers of equilateral-triangle section with circular members all in the same flow ragime may be as given, in Table 32.

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Table 31 Overall force coefficient for square towers composed of rounded members [*Clause 6.3.3.5(d)*]

Solidity Ratio of Front Face	Force Coefficient for			
	Sub-critical flow ($DV_d < 6$ m²/s)		Supercritical flow ($DV_d \geq 6$ m²/s)	
	Onto face	*Onto corner*	*Onto face*	*Onto corner*
(1)	(2)	(3)	(4)	(5)
0.05	2.4	2.5	1.1	1.2
0.1	2.2	2.3	1.2	1.3
0.2	1.9	2.1	1.3	1.6
0.3	1.7	1.9	1.4	1.6
0.4	1.6	1.9	1.4	1.6
0.5	1.4	1.9	1.4	1.6

Table 32: Overall force coefficient for equilateral-triangular towers composed of rounded members [*Clause 6.3.3.5 (e)*]

Solidity Ratio of Front Face ϕ	Force Coefficient for	
	Subcritical Flow ($DV_d < 6$ m²/s)	Supercritical Flow ($DV_d \geq 6$ m²/s)
0.05	1.8	0.8
0.1	1.7	0.8
0.2	1.6	1.1
0.3	1.5	1.1
0.4	1.5	1.1
0.5	1.4	1.2

CODE

6.3.3.6 *Tower appurtenances* - The wind loading on tower appurtenances, such as ladders, conduits, lights, elevators, etc, shall be calculated using appropriate net pressure coefficients for these elements. Allowance may be made for shielding effect from other elements.

COMMENTARY

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7. DYNAMIC EFFECTS

7.1 General - Flexible slender structures and structural elements shall be investigated to ascertain the importance of wind induced oscillations or excitations along and across the direction of wind.

In general, the following guidelines may be used for examining the problems of' wind induced oscillations:

a) Buildings and closed structures with a height to minimum lateral dimension ratio of more than about 5.0, and

b) Buildings and closed structures whose natural frequency in the first mode is less than 1.0 Hz. building or structure which does not satisfy either of the above two criteria shall be examined for dynamic effects of wind.

NOTE I - The fundamental time period (T) may either be established by experimental observations on similar buildings or calculated by any rational method of analysis. In the absence of such data, T may be determined as follows for multi-storied buildings:

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; and

b) For all others

$$T = \frac{0.09H}{\sqrt{d}}$$

where

H = total height of the main structure of the building in metres, and

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

NOTE 2 - If preliminary studies indicate that wind-indicated oscillations are likely to be significant, investigations should be persuade with the aid of analytical methods or, if necessary, by means of wind tunnel tests on models.

NOTE 3 - Cross-wind motions may by due to

COMMENTARY

C7.1 –

This Section 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 would 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.

The dynamic response induced by wind can be attributed to the following actions of wind:

(a) Non-correlation of the fluctuating along-wind pressures over the height and width of a structure.

(b) Resonant vibrations of a structure.

(c) Vortex shedding forces acting mainly in a direction normal to the direction of wind causing across-wind as well as torsional response.

The fluctuating wind pressures are random in nature and have a wide range of frequencies. The frequencies away from the natural frequencies of vibration of a structure (about ± 20% on either sides) have relatively very small dynamic effect and the associated wind pressures are almost static in nature while those in the narrow bands around the natural frequencies of vibration of the structure produce a large response that is essentially dynamic and limited only by damping in the system. At the same time, the lower frequency components of the wind speed and pressures have the greatest energy, so that the higher frequency modes of a structure would be subjected to lower excitation forces. Thus, generally the major dynamic response of a flexible structure due to wind is confined only to the fundamental mode of vibration of the structure. This is particularly true of tall buildings and towers, the contribution from higher modes of vibration being rarely significant.

The dynamic along-wind response of a structure comprises of a non-resonant component and a

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lateral gustiness of the wind, unsteady wake How (for example, vertex shedding), negative aerodynamic damping Or to A Combination of these effects. These cross-wind motions can become critical in the design of tall buildings/structures.

NOTE 4 - Motions in the direction of wind (known also as buffeting) are caused by fluctuating wind force associated with gusts. The excitation depend on gust energy available at the resonant frequency.

NOTE 5 - The wake shed from an upstream body may intensify motions in the direction of the wind, and may also affect crosswind motions,

NOTE 6 - The designer must be aware of the following three forms of wind induced motion which are characterized by increasing amplitude of oscillation with the increase of wind speed.

a) Galloping-Galloping is transverse oscillations of some structures due to the development of aerodynamic forces which are in phase with the motion. It is characterized by the progressively increasing amplitude of transverse vibration with increase of wind speed. The crow-section which are particularly prone to this type of excitation include the following:

   i. All structures with non-circular cross-sections, such as triangular, square, polygons, as well as angles, crosses, and T-sections.

   ii. Twisted cables and cables with ice encrustations.

b) Flutter - Flutter is unstable oscillatory motion of a structure due to coupling between aerodynamic force and elastic deformation of the structure. Perhaps the most common form is oscillatory motion due to combined bending and torsion. Although oscillatory motions in each degree of freedom may be damped, instability can set in due to energy transfer from one mode of oscillation to another, and the structure is seen to execute sustained or divergent oscillations with a type of motion which is a combination of the individual modes of motion. Such energy transfer takes place when the natural frequencies of modes, taken individually, are close to each other (ratio, being typically less than 2.0). Flutter can set in at wind speeds much less than those required for exciting the individual modes of motion. Long span suspension bridge decks or any member of a structure with large values of d/t (where d is the depth of a structure or structural member parallel to wind stream and t is the least lateral dimension of the member) are prone to low speed flutter. Wind tunnel testing is required to determine critical flutter speeds and the likely structural response. Other types of flutter are

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resonant component, on which is superimposed a static component due to the mean wind speed. Thus the total along-wind response (deflection, force, etc.) is obtained as the sum of ‘mean’ value and a ‘peak’ value. The latter can be determined by applying the theory of distribution of random variables and expressed in terms of standard deviation, also called as the root mean square (rms) value, by the following expression:

$$x_{pk} = \bar{x} + g\sigma$$

where x_{pk}, $\bar{x}$ and σ are the peak, mean and standard deviation respectively of the variable x and g is called the peak factor having a value between 3.5 and 4.0.

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single degree of freedom stall flutter, torsional flutter, etc.

c) *Ovalling* – this walled structures with open ends at one or both ends such as oil storage tanks, and natural draught cooling towers in which the ratio of the diameter of minimum lateral dimension to the wall thickness is of the order of 100 or more, are prone to ovalling oscillations. These oscillations are characterized by periodic radial deformation of the hollow structure.

NOTE 7 - Buildings and structures that may be subjected to serious wind excited oscillations require careful investigation. It is to be noted that wind induced oscillations may occur at wind speeds lower than the static design wind speed for the location.

NOTE 8 - Analytical methods for the response of dynamic structures to wind loading can be found in the following publications:

i. Engineering Science Data, Wind Engineering Sub-Series (4 volumes), London, ESDU Inter national
ii. ‘Wind Engineering in the Eighties’, Construction Industry Research and Information Association, 1961, London.
iii. ‘Wind Effects on Structures' by E. Simiu and R.H. Scanlan, New York, John Wiley and Sons, 1978.
iv. Supplement to the National Building Code of Canada. 1980. NRCC, No. 17724, Ottawa, National Research Council of Canada, 1980.
v. Wind forces on structures by Peter Sachs. Pergamon press.
vi. Flow induced vibration by Robert D. Clevins, Von Nostrand Reinfold Co.
vii. Appropriate Indian Standards (see 1.1.3)

NOTE 9 - In assessing wind loads due to such dynamic phenomenon as galloping, flutter and ovalling, if the required information is not available either in the references of Note a or other literature, specialist advise shall be sought, including experiments on models in wind tunnels.

7.2 – Motion Due to Vortex Shedding

C 7.2 –

Flexible structures also respond in the across-wind direction on account of vortex shedding. In the cross-wind direction, a flexible structure would tend

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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 present code does not lay down any specific procedure for determining the design wind force related to the cross-wind motion.

The across-wind response has zero mean and involves a different mechanism of excitation (vortex shedding) and is more structure specific, needing calculation models that are based on spectra generated from wind-tunnel studies.

7.2.1 ***Slender Structures*** - For a structure, the shedding frequency, η shall be determined by the following formula-

$$\eta = \frac{SV_d}{b}$$

where

S = Strouhal number,

V_d = design wind velocity, and

b = breadth of a structure or structural members in the horizontal plane normal to the wind direction.

a) *Circular Structures* - For structures circular in cross-section:

S = 0.20 for bV_z not greater than 7, and

= 0.25 for bV_z greater than 7.

b) *Rectangular Structures* - For structures of rectangular cross-section:

S = 0.15 for all values of $b\,V_z$.

NOTE 1 - Significant cross wind motions may be produced by vortex shedding if the natural frequency, of the structure or structural element is equal to the frequency of the vortex shedding within the range of expected wind velocities. In such cases, further analysis should be carried out on the basis of references given in Note 8 of 7.1.

C7.2.1 –

Expression for the frequency of vortex shedding by a structure / member has been given. Strouhal number values for shapes often encountered are also given. Explanatory notes 1 to 4 give more information on the phenomenon and its effect. It is suggested that analysis be carried out on the basis of references given in Note 8 of Section 7.1. However, these references are inadequate and subsequent literature beyond 1981 may have to be referred for specific cases. The Australian Code AS/NZS 1170.2-2002

"Structural Design Actions –Part 2: Wind Actions" particularly contains information on rectangular shaped buildings.

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NOTE 2 - Unlined welded steel chimney stacks and similar structures are prone to excitation by vortex shedding.

NOTE 3 - Intensification of the effects of periodic vortex shedding has been reported in cases where two or more similar structures are located in close proximity. for example, at less than 20 b apart, where b is the dimension of the structure normal to the wind.

NOTE 4 - The formulae given in 7.2.1 (a) and (b) are valid for infinitely long cylindrical structures. The value of S decreases slowly as the ratio of length to maximum transverse width decreases; the reduction being up to about half the value, if the structure is only three times higher than its width. Vortex shedding need not be considered if the ratio of length to maximum transverse width is leas than 2.0.

8. Gust Factor (*GF*) or Gust Effectiveness Factor (*GEF*) Method

8.1 *Application* - Only the method of calculating load along wind or drag load by using gust factor method is given in the code since methods for calculating load across-wind or other components are not fully matured for all types of structures. However, it is permissible for a designer to use gust factor method to calculate all components of load on a structure using any available theory. However, such a theory must take into account the random nature of atmospheric wind speed.

NOTE - It may be noted that investigations for various types of wind induced oscillations outlined in 7 are in no way related to the use of gust factor method given in 8 although the study of 7 is needed for using gust factor method.

C8.1 –

To obtain the along-wind response of a flexible structure (time period > 1.0 sec) the design wind pressure $\bar{p}_z$ has to be obtained for the hourly mean wind speed $\bar{V}_z$ (Table 33) instead of the 3-second gust speed V_z. The static wind pressure p_z 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 pressures.

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

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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 B_s may be small resulting in reduced wind forces obtained from dynamic analysis as compared to the static analysis.

The roughness factor r together with the peak factor g_f is a measure of the turbulence intensity present in the wind. Thus g_f. r is equivalent to twice the turbulence intensity.

8.2 *Hourly Mean Wind* - Use of the existing theories of gust factor method require a knowledge of maximum wind speeds averaged over one hour at a particular location. Hourly mean wind speeds at different heights in different terrains is given in Table 33.

NOTE - It must also be recognized that the ratio of hourly mean wind (HMW) to peak speed given in Table 33 may not be obtainable in India since extreme wind occurs mainly due to cyclones and thunderstorms, unlike in UK and Canada where the mechanism is fully developed pressure system. However Table 33 may be followed at present for the estimation of the hourly mean wind speed till more reliable values become available.

8.2.1 *Variation of Hourly Mean Wind Speed with Height* - The variation of hourly mean wind speed with height shall be calculated as follows:

$$\overline{V}_z = V_b k_1 \overline{k_2} k_3$$

where

$\overline{V}_z$ = hourly mean wind speed in m/s, at height C;

V_b = regional basic wind speed in m/s (see Fig. 1);

k_1 = probability factor (see 5.3.1);

$\overline{k_2}$ = terrain and height factor (see Table 33); and

k_3 = topography factor (see 5.3.3).

Table 33 Hourly Mean Wind Speed Factor k_2 in Different Terrains for Different Heights *[Clause 8.2 and 8.2.1]*

Height m	Terrain category 1	Terrain category 2	Terrain category 3	Terrain category 4
(1)	(2)	(3)	(4)	(5)
Upto to 10	0.78	0.67	0.50	0.24
15	0.82	0.72	0.55	0.24
20	0.85	0.75	0.59	0.24
30	0.88	0.79	0.64	0.34
50	0.93	0.85	0.70	0.45
100	0.99	0.92	0.79	0.57
150	1.03	0.96	0.84	0.64
200	1.06	1.00	0.88	0.68
250	1.08	1.02	0.91	0.72
300	1.09	1.04	0.93	0.74
350	1.11	1.06	0.95	0.77
400	1.12	1.07	0.97	0.79
450	1.13	1.08	0.98	0.81
500	1.14	1.09	0.99	0.82

CODE

8.3 *Along Wind Load* - Along wind load on a structure on a strip area (A_e) at any height (z) is given by:

$$F_z = C_f A_e \bar{p}_z G$$

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,

$\bar{p}_z$ = design pressure at height z due to hourly mean wind obtained as 0.6 $\bar{V}_Z^2$ (N/m^2),

G = gust factor (= peak load/mean load), peak load and is mean given by:

COMMENTARY

CODE

COMMENTARY

$$G = 1 + g_1 \, r \sqrt{\left[B(1+\phi)^2 + \frac{SE}{\beta} \right]}$$

where

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 '$g_1 r$' 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,

$\frac{SE}{\beta}$ = 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

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

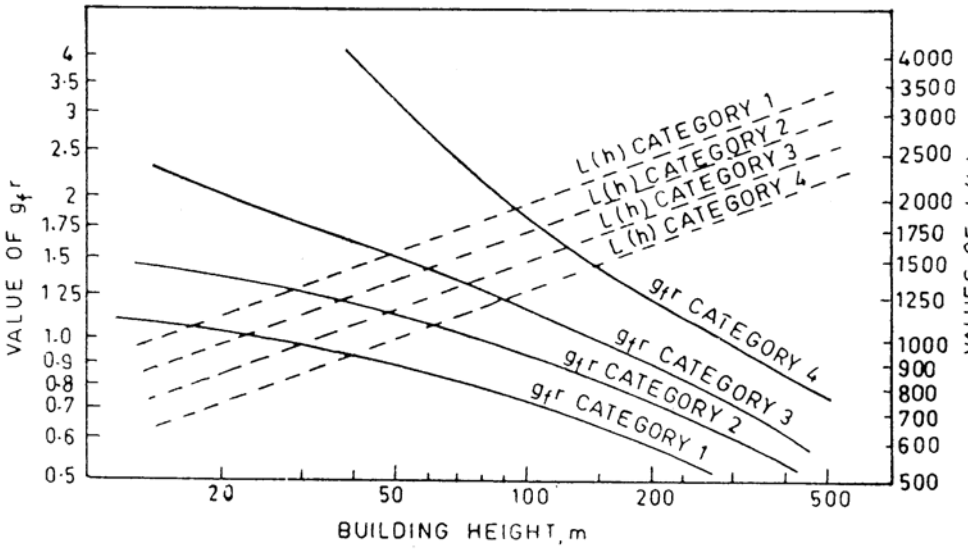


FIG. 8 VALUES OF $g_f r$ AND $L(h)$

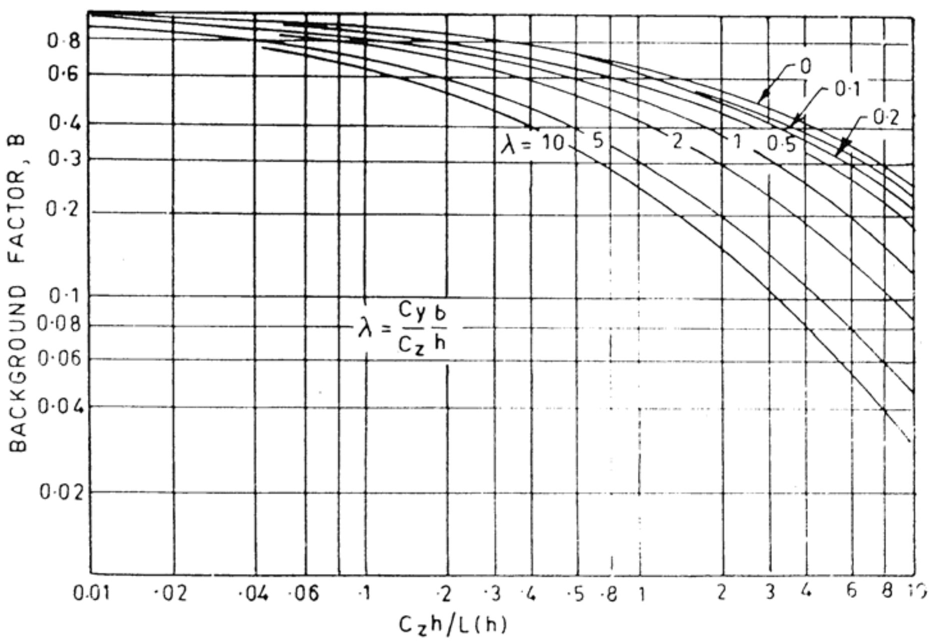


Figure 9 Background Factor

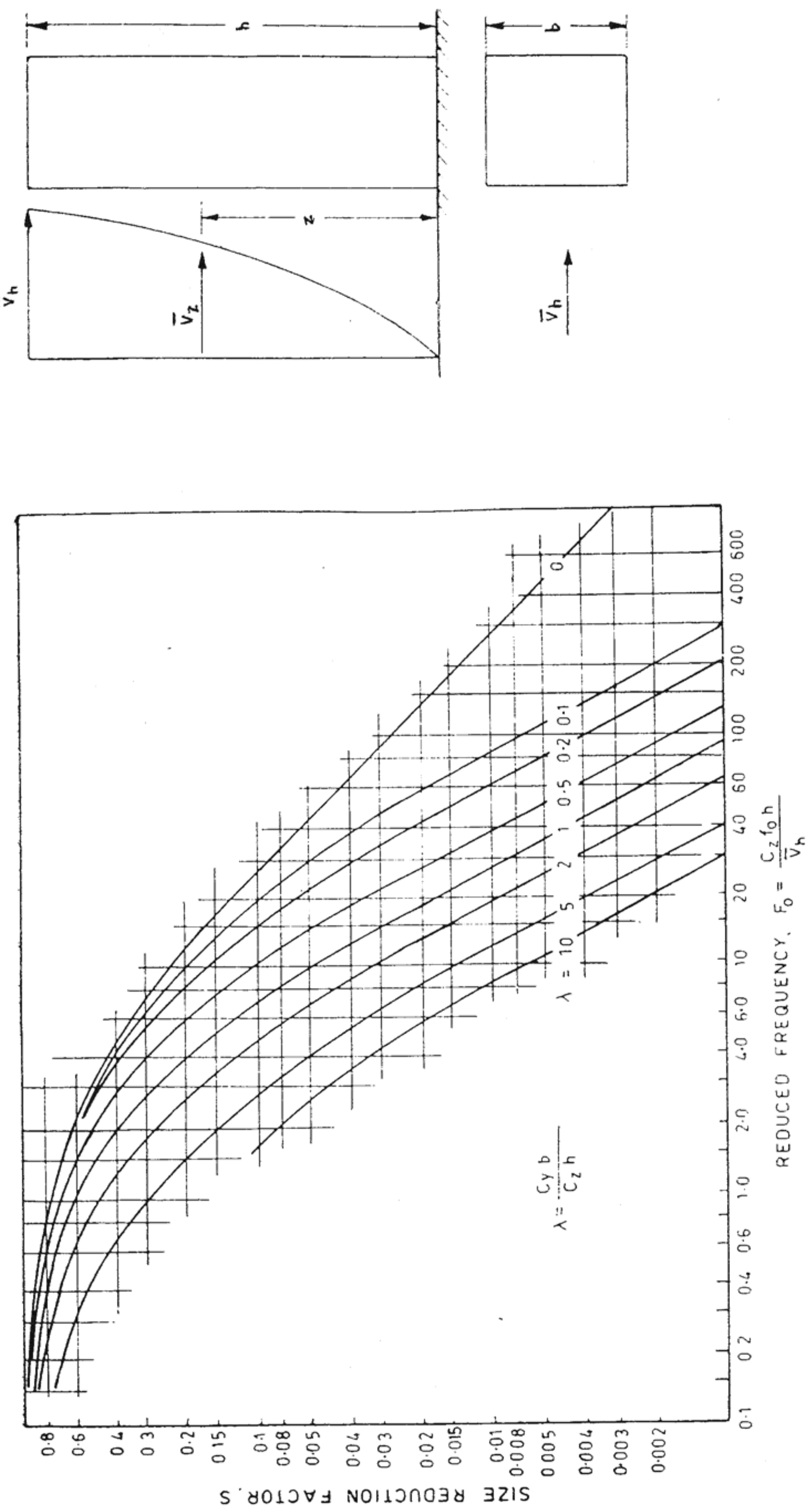


Figure 10 Size Reduction Factor, *S*

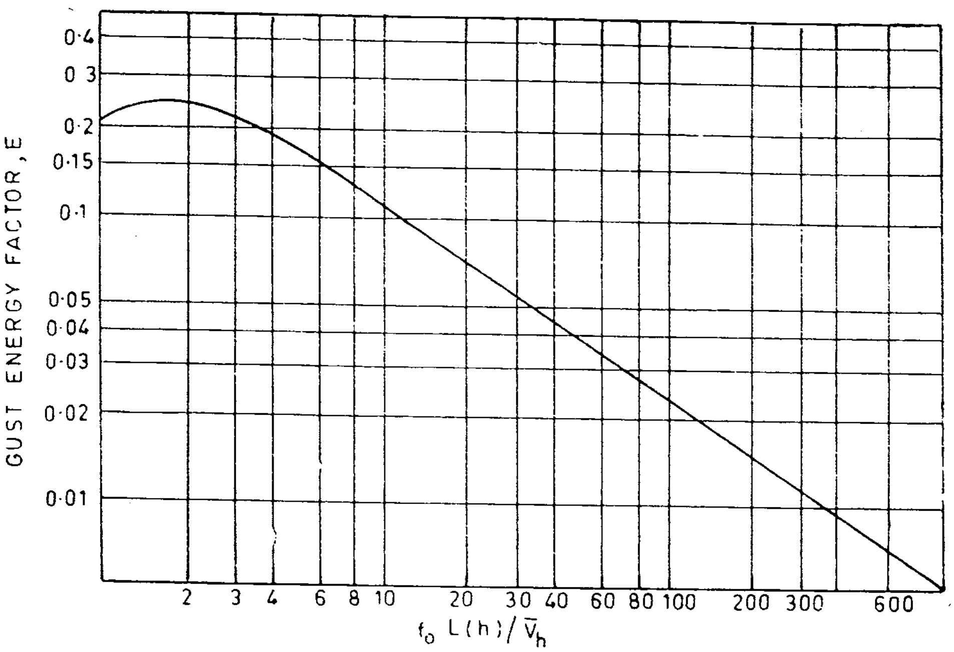


Figure 11 Gust Energy Factor, *E*

CODE

In figures 8 to 11

$$\lambda = \frac{C_y b}{C_z h} \text{ and } F_o = \frac{C_z f_o h}{\bar{V} h}$$

where

C_y = lateral correlation constant which may be taken as 10 in the absence of more precise load data,

C_z = longitudinal correlation constant which may be taken as 12 in the absence of more precise load data,

b = breadth of a structure normal to the wind stream,

h = height of a structure,

$\bar{V}_h - \bar{V}_z$ = hourly mean wind speed at height z,

f_0 = natural frequency of the structure, and

$L_{(h)}$ = a measure of turbulence length scale (see Fig. 9).

COMMENTARY

Table 34 Suggested Values of Damping Coefficient *[Clause 8.3]*

Nature of Structure	Damping Coefficient, β
(1)	(2)
Welded steel structures	0.010
Bolted steel structures	0.020
Reinforced concrete structures	0.016

CODE

8.3.1 The peak acceleration along the wind direction at the top of the structure is given by the following formula:

$$a = (2\pi f_o)^2 \bar{x} g_f r \sqrt{\frac{SE}{\beta}}$$

where

$\bar{x}$ = mean deflection at the position where the acceleration is required. Other notations are same as given in 8.3.

COMMENTARY

Appendix A

(Clause 5.2)

Basic Wind Speed at 10m Height for some Important Cities/Towns

City/Town	Basic Wind Speed (m/s)	City/Town	Basic Wind Speed (m/s)
Agra	47	Kanpur	47
Ahmedabad	39	Kohima	44
Ajmer	47	Kolkata	50
Almora	47	Kurnool	39
Amritsar	47	Lakshadweep	39
Asansol	47	Lucknow	47
Aurangabad	39	Ludhiana	47
Bahraich	47	Madurai	39
Bangalore	33	Mandi	39
Barauni	47	Mangalore	39
Breilly	47	Moradabad	47
Bhatinda	47	Mumbai	44
Bhilai	39	Mysore	33
Bhopal	39	Nagpur	44
Bhubaneshwar	50	Nainital	47
Bhuj	50	Nasik	39
Bikaner	47	Nellore	50
Bokaro	47	Panjim	39
Calicut	39	Patiala	47
Chandigarh	47	Patna	47
Chennai	50	Pondicherry	50
Coimbatore	39	Port Blair	44
Cuttack	50	Pune	39
Darbhanga	55	Raipur	39
Darjeeling	47	Rajkot	39
Dehra Dun	47	Ranchi	39
Delhi	47	Roorkee	39
Durgapur	47	Rourkela	39
Gangtok	47	Shimla	39
Guwahati	50	Srinagar	39
Gaya	39	Surat	44
Gorakhpur	47	Tiruchirapalli	47
Hyderabad	44	Trivandrum	39
Imphal	47	Udaipur	47
Jabalpur	47	Vadodara	44
Jaipur	47	Varanasi	47
Jamshedpur	47	Vijaywada	50
Jhansi	47	Visakhapatnam	50
Jodhpur	47		

Appendix B

[*Clause 5.3.2.4 (b)(ii)*]

Changes in Terrain Categories

B–1 **Low To High Number**

B–1.1 In case of transition from a low category number (corresponding to a low terrain roughness) to a high category number (corresponding to a rougher terrain), the speed profile over the rougher terrain shall be determined as follows:

(a) Below height h_x, the speeds shall be determined in relation to the rougher (nearby) terrain; and

(b) Above height h_x, the speeds shall be determined in relation to the less rough (more distant) terrain.

B–2 High To Low Number

B–2.1 In case of transition from a more rough to a less rough terrain, the speed profile shall be determined as follows:

(a) Above height h_x, the speeds shall be determined in accordance with the rougher (more distant) terrain; and

(b) Below height h_x, the speed shall be taken as the lesser of the following:

i. That determined in accordance with the less rough (nearby) terrain, and

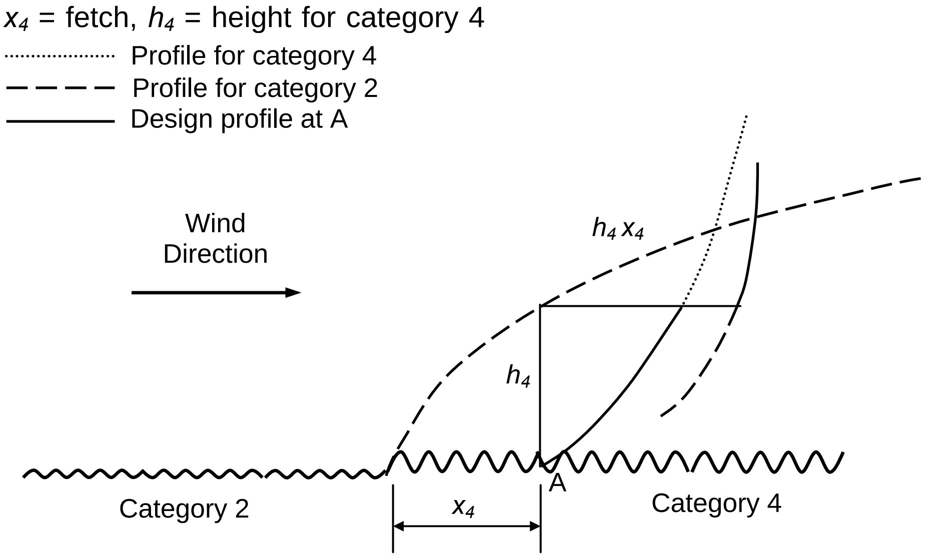
ii. The speed at height h_x, as determined in relation to the rougher (more distant) terrain.

NOTE: Examples of determination of speed profiles in the vicinity of a change in terrain category are shown in Fig. 12 a and 12 b.

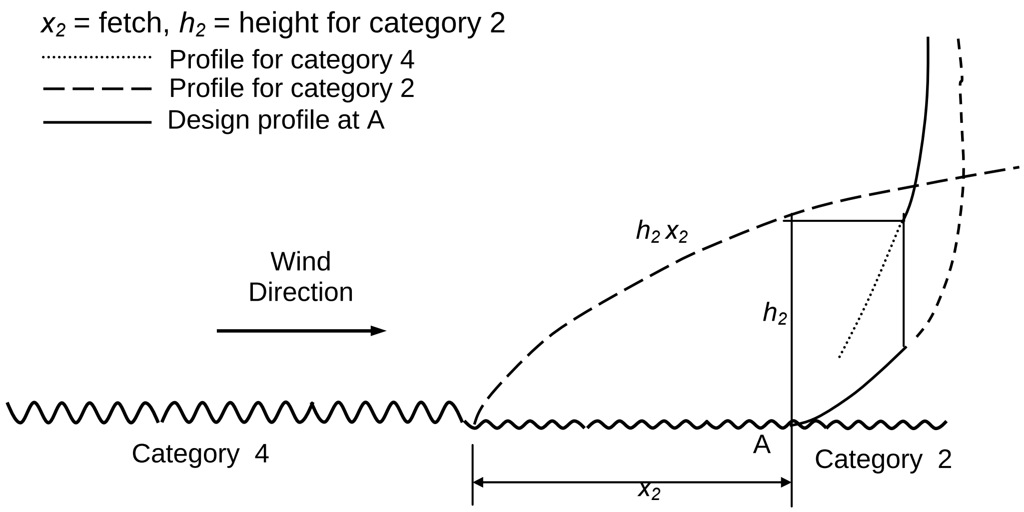
B–3 More Than One Category

B–3.1 Terrain changes involving more than one category shall be treated in similar fashion to that described in B-1 and B-2.

NOTE: Example involving three terrain categories is shown in Fig. 12 c.



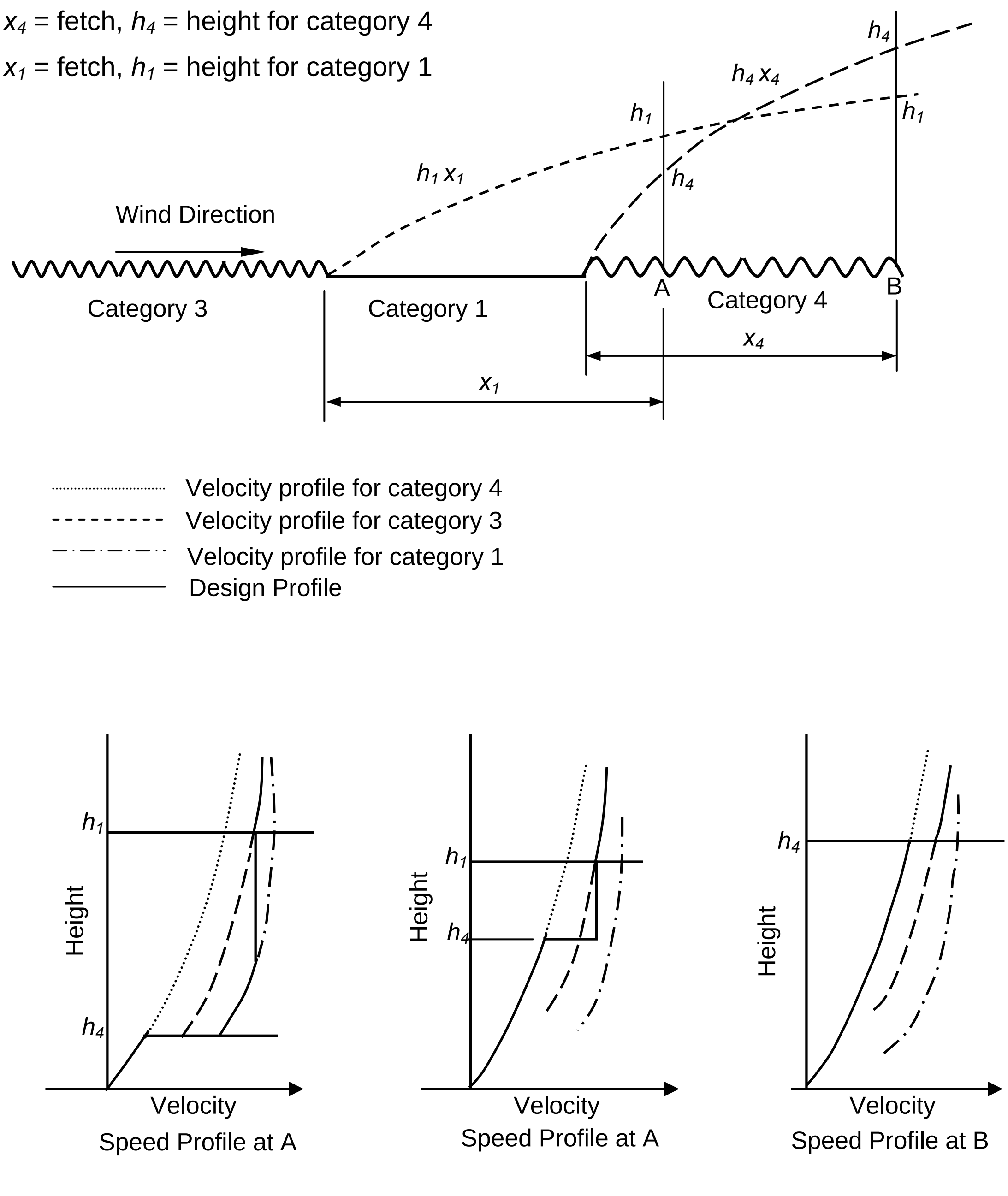
(a) Determination of Speed Profile near a change in Terrain Category from less rough to more rough.



(b) Determination of Speed Profile near a change in Terrain Category (more rough to less rough)

Figure 12 Velocity Profile in the vicinity of a change in Terrain Category

Contd………



(c) Determination of Design Profiles involving more than one change in Terrain Category

Figure 12 Velocity Profile in the vicinity of a change in Terrain Category

Appendix C

[*Clause 5.3.3.1*]

Effect of a Cliff or Escarpment on Equivalent Height above Ground

(k_3 FACTOR)

C-1. The influence of the topographic feature is considered to extend 1.5 L_e upwind and 2.5 L_e downwind of the summit of crest of the feature where L_e is the effective horizontal length of the hill depending on slope as indicated below (see Fig. 15).

Slope	L_e
$3^o < \theta \leq 17^o$	L
$> 17^o$	$Z/0.3$

where

L = actual length of the upwind slope in the wind direction,

Z = effective height of the feature, and

θ = upwind slope in the wind direction.

If the zone downwind from the crest of the feature is relatively flat ($\theta < 3^o$) for a distance exceeding L_e, then the feature should be treated as an escarpment. If not, then the feature should be treated as a hill or ridge. Examples of typical features are given in Figure 16.

NOTE:1–No difference is made, in evaluating k_3 between a three dimensional hill and a two dimension ridge.

NOTE: 2 – In an undulating terrain, it is often not possible to decide whether the local topography to the site is significant in terms of wind flow. In such cases, the average value of the terrain upwind of the site for a distance of 5 km should be taken as the base level to assess the height Z, and the upwind slope θ, of the feature.

C-2. Topography Factor, k_3

The topography factor k_3 is given by the following:

$$k_3 = 1 + C \cdot s$$

where C has the following values:

Slope	***C***
$3^o < \theta \leq 17^o$	1.2 (z/L)
$> 17^o$	0.36

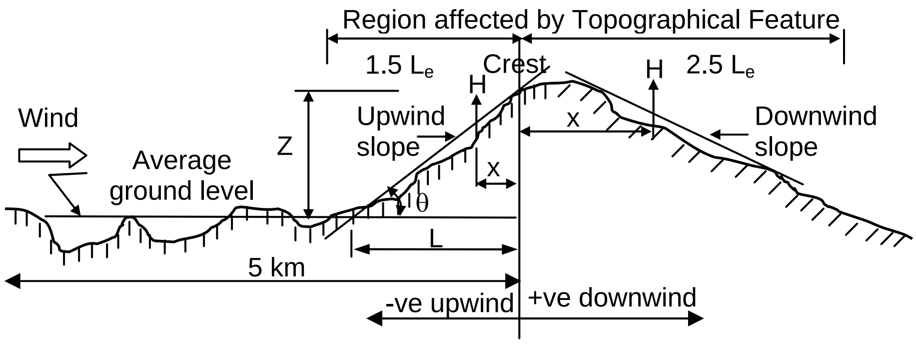
and s is a factor derived in accordance with C-2.1 appropriate to the reference height, H on the structure above the mean local ground level, and the distance, x from the summit or crest, relative to the effective length, L_e.

C-2.1 The factor, s, should be determined from:

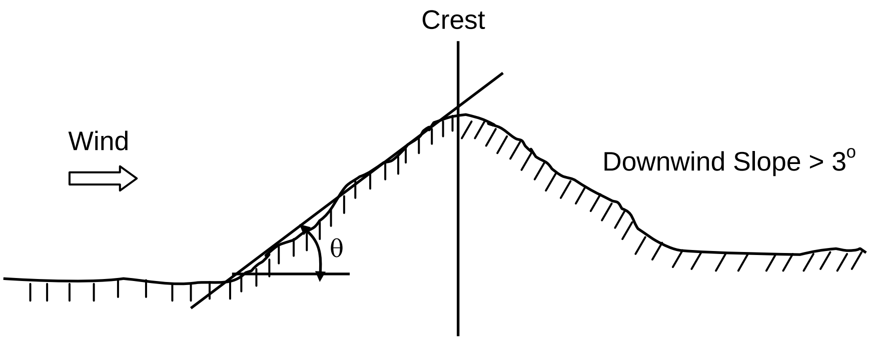
(a) Fig. 17 for cliffs and escarpments, and

(b) Fig. 18 for hills and ridges.

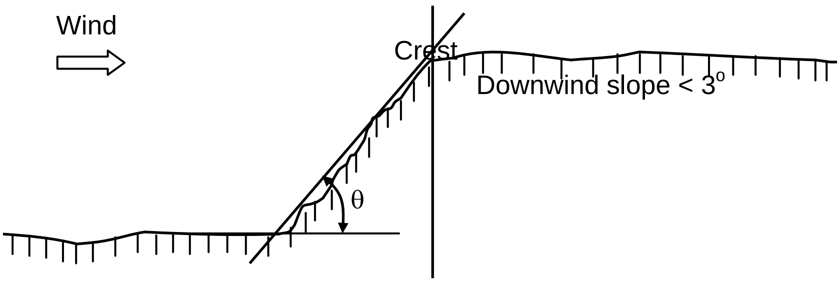
NOTE: Where the downwind slope of a hill or ridge is greater than 3^o, there will be large regions of reduced accelerations or even shelter and it is not possible to give general design rules to cater for these circumstances. Values of s from Fig. 18 may be used as upper bound values.



(a) General Notations



(b) Hill and Ridge



(c) Cliff and Escarpment

Figure 13 Topographical dimensions

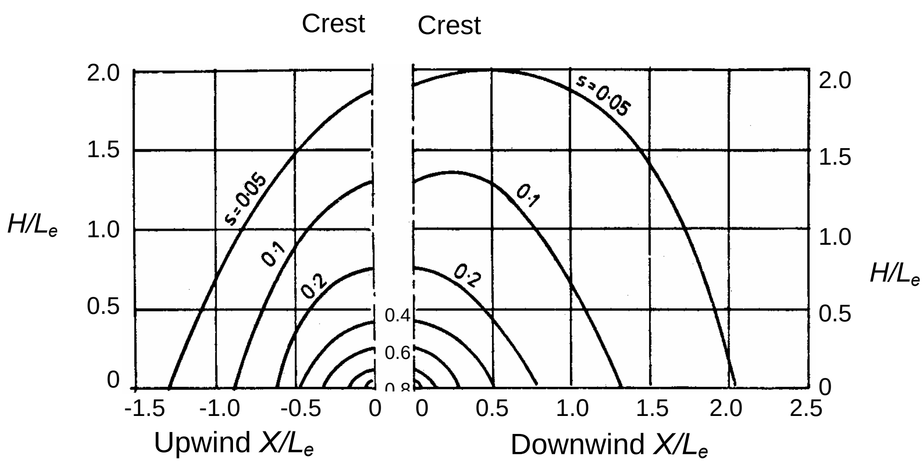


Figure 14 Factor s for cliff and escarpment

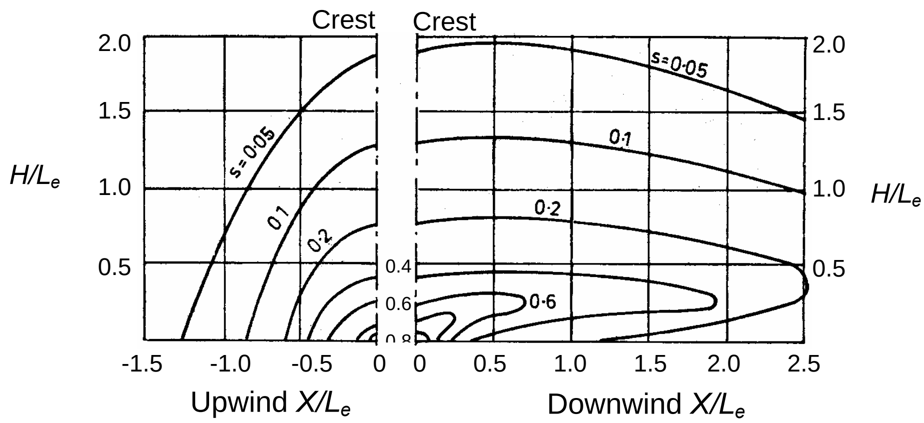


Figure 15 Factor s for ridge and hill

Appendix D

[*Clause 6.3.2.2, 6.3.3.2 (c) and 6.3.3.3 (b)]*

Wind Force on Circular Sections

D-1. The wind force on any object is given by:

$$F = C_f A_e p_d$$

where

C_f = force coefficient,

A_e = effective area of the object normal to the wind direction, and

p_d = design pressure of the wind.

For most shapes, the force coefficient remains approximately constant over the whole range of wind speeds likely to be encountered. However, for objects of circular cross-section, it varies considerably.

For a circular section, the force coefficient depends upon the way in which the wind flows around it and is dependent upon the velocity and kinematic viscosity of the wind and diameter of the section. The force coefficient is usually quoted against a non-dimensional parameter, called the Reynolds number, which takes account of the and viscosity of the flowing medium (in the wind), and the member diameter.

Reynolds number, $R_e = \dfrac{DV_d}{\gamma}$

where

D = diameter of the member,

V_d = design wind speed, and

γ = kinematic viscosity of the air which is 1.46 × 10^{-5} m^2s at 15^oC and standard atmospheric pressure.

Since in most natural environments likely to found in India, the kinematic viscosity of the air is fairly constant, it is convenient to use DV_d the parameter instead of Reynolds numbers and this has been done in this code.

The dependence of a circular section's force coefficient or Reynolds number is due to the change in the wake developed behind the body.

At a low Reynolds number, the wake is as shown in Fig. 16 and ihe force coefficient is typically 1-2. As Reynolds number is increased, the gradually changes to that shown in Fig. 17, that is,- the wake width d_w, decreases and the separation point, S, moves from front to the back body.

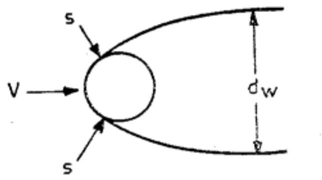


Figure 16 Wake in Subcritical Flow

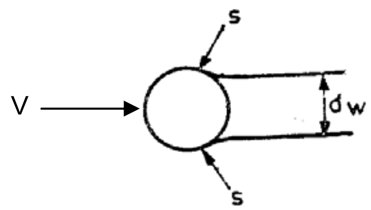


Figure 17 Wake in Supercritical Flow

As a result, the force coefficient shows a rapid drop at a critical value of Reynolds number, followed by a gradual rise as Reynolds number is increased still further.

The variation of C_f with parameter DV_d is shown in Fig. 5 for infinitely long circular cylinders having various values of relative surface roughness (ε/D) when subjected to wind having an intensity and scale of turbulence typical of build-up urban areas. The curve for a smooth cylinder $(\varepsilon/D) = 1\times10^{-5}$ in a steady air- stream, as found in a low-turbulence wind tunnel, is shown for comparison.

It can be seen that the main effect of free-stream turbulence is to decrease the critical value of the parameter DV_d. For sub-critical flows, turbulence can produce a considerable reduction in C_f below the steady air-stream values. For supercritical flows, this effect becomes significantly smaller.

If the surface of the cylinder is deliberately roughened such as by incorporating flutes, riveted construction, etc, then the data given in Fig. 5 for appropriate value of ε/D > 0 shall be used.

NOTE - in case of uncertainty regarding the value of ε to be used for small roughnesses, ε/D shall he taken as 0'001.

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