B1.1 Determination of Wind Loads for Use in Analysis

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A PARAMETERS FOR DETERMINING DESIGN WIND SPEEDS

1 General

Wind loading standards provide procedures for determining the loads on specific structures in specific locations for specific conditions and needs. They start with general (or neutral) conditions and move towards the specific.

The neutral data about the wind speeds is usually defined in terms of averaging period, return period, height above ground, topography and ground roughness. Thus, in the OAS/NCST/BAPE "Code of Practice for Wind Loads for Structural Design"[1] the definition reads:

> *"The basic wind speed V is the 3-second gust speed estimated to be exceeded on the average only once in 50 years ..... at a height of 10 m above the ground in an open situation ....."*

The basic (or reference) wind speed is then adjusted for specific cases using various parameters including averaging period, return period, ground roughness, height, topography and size of structure in order to obtain the design wind speeds for the particular cases.

In some cases, *eg* CUBiC[2], the apparent starting point for computation is the basic wind pressure. In such cases the basic wind pressure has been predetermined by the standards writer from the basic wind speed. OHPT-1[3] shows the Basic Wind Pressure map from CUBiC.

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[1]BNS CP28 - Code of Practice for Wind Loads for Structural Design; sponsored by the Organization of American States, the National Council for Science & Technology and the Barbados Association of Professional Engineers; prepared by Tony Gibbs, Herbert Browne and Basil Rocheford; November 1981.

[2]The Caribbean Uniform Building Code

[3]Overhead projector transparency number 1

The manner and order in which standards progress from basic wind speeds to design wind speeds differ but, all other things being equal, the end results should be the same. (Of course, all other things are never the same.)

2 Averaging Period

Direct measurements of wind speeds are made by anemometers. These instruments vary in the way they sample the wind and in the way they report the results. One of the characteristics of mechanical anemometers is the response time. This is a function of the inertia of the system. The shortest response time for mechanical anemometers is 1-3 seconds. OHPT-2 shows the anemometer record of 3-second gust speeds during the most severe part of Hurricane Georges at V C Bird International Airport in Antigua in 1998. OHPT-3 shows 15-second average wind speeds from a CPACC[4] record from St Kitts during the same Hurricane Georges.

Several countries have adopted the 3-second gust as the averaging period for the basic wind speed. These countries include Australia, the USA (post 1995)[5] and Barbados. The UK used the 3-second gust up to 1995 when they changed to the 1-hour average.

A wind speed for any particular averaging period may be converted to a wind speed for any other averaging period using relationships determined experimentally and analytically. These relationships can be presented by a semi-log **S** curve. OHPT-4 shows the Durst curve which has been in use since the 1960s. In the 1990s Krayer and Marshall proposed an adjusted **S** curve for tropical cyclone regions. This adjustment was refuted in 1998 by the work of Peter Vickery. At present, therefore, we use the Durst curve for both tropical and extra-tropical cyclones.

Public advisories from meteorological offices usually quote “sustained” wind speeds which, I understand, are meant to be 1-minute averages. The Saffir-Simpson scale is based on these 1-minute averages. OHPT-5 gives the various characteristics of the Saffir-Simpson scale.

3 Return Period

Wind speeds are amenable to statistical analysis. It could be argued that the historical record is not sufficiently long for such analyses to be reliable. Nevertheless it is common practice for statistical analyses of historical information, adjusted on theoretical bases, to be used in determining the relative wind-speeds expected to occur over different periods of time.

The semi-log graph in OHPT-6 is taken from BNS CP28. It shows relationships for return periods from 2 years to 200 years. The shortest return period (2 years) is recommended for temporary

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[4] Caribbean Planning for Adaptation to Global Climate Change, tel: (246) 417 4580

[5] Some USA codes still use “fastest mile” wind speeds. These have averaging periods which depend, in turn, on the wind speeds.

structures and for (incomplete) structures during erection. The illustration has two sets of curves. The less-severe curve is for the conventional 63% probability level. The more-severe curve is for a 10% probability level. These two curves provide a further opportunity to fine-tune the design for the particular requirements of a project.

In general, the longer the return period chosen and the lower the probability level chosen, the more conservative will be the design wind speed.

As part of the USAID-OAS Caribbean Disaster Mitigation Project wind speed maps[6] have been prepared for the entire Caribbean region.

4 Ground Roughness

The roughness of the surface over which the wind passes has two effects on the wind – speed and turbulence. The rougher the surface the lower the wind speed but the greater the turbulence.

It should be pointed out that so-called smooth flow never occurs. Smooth flow is really a comparative phrase. OHPT-7 shows horizontal and vertical wind speed measurements taken at great height over the Atlantic Ocean east of Barbados during the BOMEX[7] project in 1969.

Ground roughness is affected by surface objects such as buildings (including the sizes and density of the buildings in the area) and trees. It used to be thought that the sea surface provided a "reference" smooth surface. Present thinking is that during a severe cyclone the sea surface is sufficiently disturbed as to render it meaningfully less smooth than the surface of lakes. Thus in ASCE 7-98 Exposure Category **D** is reserved for lakes and inland waterways only.

5 Height

Ground roughness is usually combined with height above ground in wind-loading standards. OHPT-8 shows the variations of wind speeds with height for different categories of ground roughness. The curves are determined experimentally and analytically. Experimental measurements are few however.

Curves are usually based on either the power law or the logarithmic law. Both approaches give acceptable results, bearing in mind the large uncertainties in all aspects of defining the wind. Nevertheless, the proponents of each approach find much to argue about at scientific meetings.

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[6]Atlas of Probable Storm Effects in the Caribbean Sea - Charles Watson and Ross Wagenseil, January 2000

[7]Barbados Oceanographic and Meteorological Experiment (Prof Bill Gray spent 3 months in Barbados as a member of the project team. Prof Mark Donelan of Grenada, another member of the team, provided the anemometer records to Tony Gibbs in 1969.)

Recent experimental evidence from dropsondes suggest that convective effects in hurricanes may bring the higher wind speeds closer to the surface than hitherto thought likely. So far, however, the amount of data is insufficient for changing the standards. OHPT-9 shows results from dropsondes in Hurricane Georges.

6 Topography

The topographic effect is now well recognised in most wind-loading standards. Wind-tunnel modelling and large-scale tests in the real environment have been carried out. OHPT-10 shows the island of Nevis being subjected to wind-tunnel tests at the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario. OHPT-11 shows a summary of the main findings from that study.

In general, structures located at the crests of ridges and near the edges of escarpments experience higher wind speeds than the "ambient" wind. There are also cases of reductions in wind speeds due to sheltering in enclosed basins and on the leeward sides of ridges.

The topographic effect has been codified in a variety of ways in different wind-loading standards. OHPT-12 shows the approach in CUBiC whereas OHPT-13 shows the approach in BNS CP28.

Large-scale topographic effects may be incorporated into the basic wind speed. Where this is done there would be the need to be cautious in order to avoid double counting or the omission of important features. An example of large-scale wind-field mapping incorporating topography is illustrated in the RMS[8] map of Hurricane Georges as it traversed Puerto Rico in 1998 (OHPT-14).

7 Size of Structure

The size of the structure for which the design wind speed is required also affects that design wind speed. This is so because of the spacial variations within a cyclone. A gust has a "size", a relatively small size. Therefore a gust cannot envelope an entire structure even of modest scale. Gust loading is therefore relevant to components such as cladding panels, windows and small elements such as purlins and individual rafters.

This parameter is accounted for in different ways in different standards. In some cases, *eg* BNS CP28, size is considered along with ground roughness and height as illustrated in the table in OHPT-15. In other cases, *eg* CUBiC, the effect is applied at the stage of determining pressure coefficients (OHPT-16).

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[8] Risk Management Solutions, London office (Map provided to Tony Gibbs in 1998 by Craig Miller.)

B BNS:CP28, CUBiC:Part-2:Section-2 and ASCE:7-98

1 Background

Wind engineering, as we now call it, is a relatively new discipline. The remarkable work by Jensen in Denmark at the turn of the century might be regarded as the start of wind engineering. Considerable momentum has developed over the past three decades. This scientific and technological work has had a noticeable influence on wind-loading standards worldwide. This influence has varied markedly in its rapidity of acceptance in various countries. Britain and Australia are in the forefront, belatedly followed by continental Europe. America, too, is trying to catch up with the leaders.

The current wind-loading standards in Australia, Japan, Europe, North America and the Caribbean are now sophisticated documents, much more advanced than the standards in pre-Andrew USA and pre-Eurocodes, continental Europe. There has been a quantum leap in the past three decades. Nevertheless, the major standards in the above-named countries differ meaningfully in approaches and even in end results. There is a move to bring these disparate documents closer together without having a single “world standard”. The International Codification Forum (of which the author is one of its 27 members) is in the forefront of this initiative.

This presentation outlines some of the main features of the standards in use in the Caribbean. This outline follows a pattern proposed by The International Codification Forum and based on the comparative studies of John D Holmes and Kenny C S Kwok[9].

2 The Standards

Barbados Standard BNS CP28

In the late 1960s the British Standards Institution was undertaking a major rewriting of their wind loads standard. The early drafts of the proposed code became available to engineers in the Caribbean who welcomed the more rational, first-principles approach as contrasted with that of the then popular South Florida Building Code which tended to be quasi-prescriptive. The recently formed Council of Caribbean Engineering Organisations (CCEO) commissioned its constituent member, the Barbados Association of Professional Engineers (BAPE), to prepare a wind-loading standard for the Caribbean.

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[9] “Comparisons Between the Wind Load Provisions of ISO 4354, EVN 1991-2-4, ASCE 7-95, AIJ Recommendations and AS1170.2" by John D Holmes and Kenny C S Kwok, Australasian Structural Engineering Conference, Auckland, NZ, Sep/Oct 1998

A draft document "Wind Loads for Structural Design" was published in 1970 and quickly received wide-spread acceptance in the engineering community. This draft document was based on the new (draft) British Standard but contained a much more extensive series of tables of pressure coefficients than the UK standard. The draft document also contained appendices with a substantial amount of background material and commentary. In particular, the derivation of basic wind speeds for the various parts of the Caribbean received special attention. This was the first comprehensive meteorological study to be carried out aimed directly at wind-engineering applications in the Caribbean. The authors of the 1970 document were engineer A R Matthews, meteorologist H C Shellard and Tony Gibbs.

By the start of the 1980s the need to revise the 1970 "Wind Loads for Structural Design" was evident. The meteorological section was reviewed and revised taking into account another decade of reliable data. Some of the pressure coefficients were revised. A new appendix on dynamic response was added. This revised document was published in 1981 and became a textbook for the undergraduate course in civil engineering at The University of the West Indies (UWI). (This revised document is known as the OAS/NCST/BAPE "Wind Loads for Structural Design". It is also a Barbados standard BNS CP28.)

Once again its acceptance and widespread use in the Caribbean was rapid. The authors of the 1981 revision were engineer H E Browne, meteorologist B Rocheford and Tony Gibbs.

It is a comprehensive standard consisting of 16 pages of procedures, 30 pages of force and pressure coefficients and 36 pages of commentary. This standard aims to provide the user with an understanding of the elements that go into the determination of wind forces on buildings and other structures.

The major English-language, wind-loading standards are the International Organization for Standardisation ISO 4354, the European ENV 1991-2-4, the USA's ASCE 7, the Australian AS1170.2, the Japanese AIJ recommendations (English translation), the Caribbean's CUBiC part 2 Section 2 and the Barbadian BNS CP28.

ISO 4354 and CUBiC

The standards used by ISO and CUBiC were drafted contemporaneously in the 1980s by Prof Alan Davenport. Whereas CUBiC became an accepted standard by 1985, the ISO standard remained in draft form until 1997. Because of the contemporaneous drafting by the same person, it is not surprising that there are great similarities in format and approach in the two documents. ISO 4354 is not, however, a complete standard. It is a standard to guide those who are preparing their own standards. For example, no listing of basic wind speeds (or pressures) is given. In CUBiC such information is provided in the form of "reference pressures". Of course, these reference pressures are themselves derived from basic wind speeds. In both ISO 4354 and CUBiC basic wind speeds are assumed to be 10-minute averages. In both ISO 4354 and CUBiC guidance is given for the conversion of wind speeds with different averaging times to 10-minute averages.

These standards provide for two approaches - simplified and detailed. Most buildings can be dealt with by the first method. The detailed method is intended for wind-sensitive structures.

ASCE 7-98

This is the most-recent edition of the standard. The standard includes earthquake, gravity, rain and snow loads as well as wind loads. The SEI[10] has published a "Special Edition" of ASCE 7-98 which excludes earthquake loads. ASCE 7-98 is the base document for the proposed new Dominican Republic standard for wind loads. It may also become the standard, adopted by reference, in the proposed revision of the Caribbean Uniform Building Code.

The wind loads section of ASCE 7 is the shortest of all of the standards reviewed in this paper. Significant departures from pre-1995 USA standards are the use of the 3-second gust instead of the "fastest mile" for basic wind speeds and the incorporation of topographic effects. This standard, by itself, has no legal standing. However it is adopted by reference in several jurisdictions in the USA.

3 Basic Wind Speeds or Pressures

The table below summarises the basic wind speeds used in the reviewed standards. In all cases the reference height is 10 metres and the exposure is flat, open country. In the cases of ISO and CUBiC, reference pressures (derived from basic wind speeds) are the starting point for computation.

Standard	Averaging Time	Return Period(s)
ISO 4354	10 minutes	50 years
CUBiC	10 minutes	50 years
ASCE 7-98	3 seconds	50 years
BNS CP28	3 seconds	50 years

All of the standards require the basic wind speeds to be modified for topography, terrain roughness and height. In the cases of ISO, CUBiC and ASCE the modifications are applied to dynamic pressure rather than to wind speed.

The modifications for height use a logarithmic law in BNS CP28, a power law in ASCE and either logarithmic or power laws are possible in ISO and CUBiC.

Importance factors are explicit in ASCE 7 and BNS CP28. They are implicit in ISO and CUBiC.

[10] Structural Engineering Institute, a specialised division of the American Society of Civil Engineers

The differences and similarities for calculating design (as distinct from basic) wind speeds and dynamic pressures are illustrated in the following table. With the exception of the CUBiC and BNS CP28 rows, the information was obtained through Holmes and Kwok.

Standard	**Speed**	**Pressure**	**Building Pressure/Force**
ISO 4354	V	$q_{ref} = (½)\rho V^2$	$w = (q_{ref})(C_{exp})(C_{fig})(C_{dyn})$
CUBiC	V	$q_{ref} = (½)\rho V^2$	$w = (q_{ref})(C_{exp})(C_{shp})(C_{dyn})$
ASCE 7-98	V	$q_z = (½)\rho K_z K_{zt} V^2 I$	$p = q(GC_p)$
BNS CP28	V	$q = (½)\rho(VS_1S_2S_3)^2$	$p = qC_{pe}$

4 External Pressures

The table above also shows the general equations for calculating external pressures on wall or roof surfaces.

There is wide variation between the various standards when it comes to information on force and pressure coefficients. All of the standards provide coefficients for orthogonal wind directions on regular-shaped buildings. The main differences are present when considering less standard shapes. The Barbados standard provides a significantly wider range of shape coefficients than the others.

There are also differences in the resulting design loads when comparing one standard with another.

The various shape coefficients come from a variety of sources, the earliest of which is the work done by Akeret in Switzerland in the mid-1950s. Those particular results were not obtained in boundary-layer wind tunnels but in smooth-flow tunnels. The quality and reliability of the various sources is far from uniform. There is the need for a comprehensive review of the readily-available information. It could then be consolidated and normalised into a universal data base. That data base could be added to and revised as more and better information becomes available. Such a data base would be of immense value to the design community.

The following table summarises the shape coefficients included for structures in the four reviewed standards. It does not have rows for the universally-available enclosed rectangular buildings. With the exception of the CUBiC and BNS CP28 columns, the information was obtained through Holmes and Kwok.

Building Shape or Type	**ISO 4354**	**CUBiC**	**ASCE 7-98**	**BNS CP28**
stepped roofs	no	no	yes	yes
free-standing walls, hoardings	yes	yes	yes	no
free-standing roofs (canopies)	no	no	no	yes
attached canopies	no	no	no	yes
multispan roofs (enclosed)	no	no	yes	yes
multispan canopies	no	no	no	no
arched roofs	yes	yes	yes	yes
domes	no	no	no	no
bins, silos, tanks	yes	yes	no	no
circular sections	yes	yes	yes	yes
polygonal sections	no	no	no	yes
structural angle sections	yes	yes	no	yes
bridge decks	no	yes	no	no
lattice sections	yes	yes	yes	yes
flags	no	no	no	no
spheres	no	yes	no	yes

B1.2 Determination of Earthquake Forces for Use in Analysis

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1 Introduction and History

Many methods have been used for determining the earthquake forces on buildings. These methods can be categorised as follows:

- Historical observations of successes and failures
- Equivalent static forces
- Dynamic analysis

Early practices in earthquake-resistant design amounted to trial and error over periods measured in generations. Typically the earthquake forces so determined increased with each damaging event in a particular location. To some extent this approach still applies, as can be seen with revisions of standards after each catastrophe. In addition to increasing the design loads, several jurisdictions also placed limits on building heights and on the use of certain vulnerable materials.

Examples are:

- In Italy a lateral force coefficient of 0.083 was imposed following the devastating earthquake in Messina in 1909.
- In Italy the coefficient was soon after increased to 0.125 for the lowest storey.
- In Japan a lateral force coefficient of 0.1 was imposed following the devastating earthquake in 1923.

In the USA (principally in California) the early evolution of lateral forces was as follows:

- The San Francisco earthquake of 1906 led to the requirement to design for a wind force of 30 pounds per square foot.
- The 1925 Santa Barbara earthquake led to the first introduction of simple Newtonian concepts in the 1927 Uniform Building Code (UBC). That code required a lateral force coefficient of 0.075 for buildings on hard ground and 0.1 for buildings on soft ground.
- These rules of thumb were extended after the 1933 Long Beach earthquake.
- The 1935 UBC stipulated a lateral force coefficient of 0.08 applied not only to dead loads but also to 50% of the live loads. This was for hard ground conditions. For soft ground the coefficient was doubled.

The recognition of dynamic response (or flexibility) of buildings began to be codified in California (Los Angeles) in 1943 when lateral force coefficients were related to the number of stories in the building:

$$C = 60/(N = 4.5)$$

where:

C = % of dead load
N = number of storeys (limited to 13)

This was later changed to:

$$C = 4.6\ S/\{N + 0.9(S - 8)\}$$

where:

S = number of storeys in buildings with more than 13 storeys

In 1948 there was the important formation in San Francisco of a Joint Committee on Lateral Forces of the San Francisco Section of the ASCE[11] and the Structural Engineers Association of Northern California. This was the identifiable beginning of the SEAOC "Blue Book"[12] which has had the greatest influence on earthquake-resistant design practices in the Caribbean.

The Joint Committee introduced the estimation or calculation of the fundamental period of the structure and also the K factor for different structural systems:

$$C = K/T$$

where:

K = 0.015 for buildings and 0.025 for other structures
T = period

All of the above developments in California relied on an "equivalent static force" approach. This is still the prevalent approach in present-day practice and almost the only approach employed in design offices in the Caribbean.

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[11] American Society of Civil Engineers

[12] Recommended Lateral Force Requirements of the Seismology Committee of the Structural Engineers Association of California - first edition 1959, most recent edition 1996.

Since 1985 the "official" standard in the Commonwealth Caribbean has been the Caribbean Uniform Building Code (CUBiC) - Part 2: Structural Design Requirements - Section 3: Earthquake Load. The principal authors of this document were Principia Mechanica of London and the provisions were based essentially on SEAOC 1980 with some influences from UBC, ATC-3[13] and the New Zealand code.

2 Design Philosophy

Most earthquake design standards are aimed at protecting lives rather than property. Thus the design forces computed from these standards are much less than those expected during the "design" event. The SEAOC "Blue Book" states:

> ".....structures designed in conformance with the provisions and principles set forth therein should, in general, be able to:
>
> 1 resist minor earthquakes without damage;
> 2 resist moderate earthquakes without structural damage, but with some nonstructural damage;
> 3 resist major earthquakes, of the intensity of severity of the strongest experienced in (the target area), without collapse, but with some structural as well as nonstructural damage."

This philosophy is being challenged by users of critical facilities and by the catastrophe insurance industry.

3 CUBiC - Part 2 - Section 3

The equivalent static force in CUBiC is determined from the simple equation:

$$V = ZCIKSW$$

where:

V = the total lateral force or shear at the base of the building (the base shear);
Z = the zone factor related to the seismic hazard of the target location;
C = the coefficient related to the period (T) of the building: $C = 1/(15\sqrt{T})$;
I = the importance factor depending on the occupancy and use of the building;
K = the coefficient related to the structural system and the materials of construction;
S = the coefficient related to soil-structure interaction;
W = the dead load and applicable portions of other loads.

[13] Applied Technology Council - Tentative Provisions for the Development of Seismic Regulations for Buildings.

3.1 Zones

The zoning for CUBiC was based largely on the work of the Seismic Research Unit (SRU) of The University of the West Indies, St Augustine, Trinidad. The reality is that zones in all parts of the world are subject to revision as more and better information becomes available. It is expected that the SRU will be preparing new seismic hazard maps for the Caribbean before the end of 2001. In the meanwhile designers must use the best, accepted scientific information available to them. In the Commonwealth Caribbean we are not justified in using less than the provisions of CUBiC.

The range of zone factors in CUBiC is from 0.00 in most of Guyana to 0.75 in south Belize, Jamaica, the north-east islands and north-west Trinidad.

3.2 Natural Frequency of the Structure

The design load depends on the natural frequency or the natural period of the building. These cannot be correctly determined before the building is completely designed. CUBiC provides a method of determining the period (T) using the structural properties and deformational characteristics of the resisting elements (from the interim design). This can now be done by many general-purpose analysis programs such as the popular Staad-III and Staad Pro.

CUBiC, like most standards, also provides simple formulae for calculating T in the absence of a properly substantiated analysis. For moment-resisting frames this is:

$$T = C_T\, h_n^{0.75}$$

where:

C_T = 0.035 for steel and 0.025 for concrete (There is a misprint in CUBiC.)
h_n = height in feet above the base to the highest level of the building

For all other buildings:

$$T = 0.05\, h_n/(\sqrt{L})$$

where:

L = the overall length in feet of the building at the base in the direction considered

The value of C is then determined from:

$$C = 1/(15\sqrt{T})$$

3.3 Importance Factors

Some buildings are clearly more important to the community (as a whole) than others. These would include hospitals, public utilities and fire stations.

Some buildings have (potentially) a larger occupancy than others. These would include schools and theatres.

CUBiC recognises these differences by allocating factors of 1.5 and 1.2 to such buildings.

3.4 Structural Systems and Materials

Some systems and some materials are known to perform better in earthquakes than others. Such favourable systems and materials are given favourable treatment in CUBiC (and other standards) by assigning lower K values to them. Structural systems benefiting in this way include those exhibiting:

- a high degree of redundancy
- good ductility
- good damping

In general, ductile, moment-resisting space frames are treated more favourably than non-ductile shear walls and braced frames.

With respect to materials, steel comes out on top followed by conventional in-situ concrete with prestressed concrete and reinforced masonry making up the rear.

CUBiC provides relative ranking of systems and materials through the K-factor tables 2.305.2 - A (for steel and concrete) and B (for timber). The range in values is from 0.64 for steel ductile frames with adequate number of possible plastic beam hinges to 3.00 for two or three-storey prestressed concrete buildings with diagonal bracing capable of plastic deformation in tension only.

3.5 Soils Factor

Soil-structure interaction is an important parameter in the determination of earthquake loads. S depends on the relative values of the natural periods of the soil and the structure. Thus the first consideration is the determination of T/T_s where T_s = the characteristic site period.

For $T/T_s = 1.0$ or less, $S = 1.0 + T/T_s - 0.5\,(T/T_s)^2$

For T/T_s = greater than 1.0, $S = 1.2 + 0.6\,T/T_s - 0.3\,(T/T_s)^2$

(There are misprints in these formulae in CUBiC.)

The value of T_s may be established from properly established geological data and must be within the range prescribed by CUBiC for use in that standard.

3.6 Vertical Distribution of Lateral Forces

In the 1970s it was conventional to use a triangular distribution (largest at the top) of lateral forces supplemented by a point load at the top. The triangular distribution would be represented by the generic formula:

$$F_x = (V - F_t)\, w_x\, h_x/(\Sigma w_i\, h_i)$$

CUBiC adopted the more accurate approach of ATC-3 through the introduction of the exponent k which is related to the building period T.

Thus in CUBiC:

$$F_x = C_{vx}\, V$$

and

$$C_{vx} = w_x\, h_x^k/(\Sigma w_j\, h_j^k)$$

where:

F_x = the lateral force at level x
w_x and w_j = the portions of W assigned to levels x and j
h_x and h_j = heights in feet to levels x and j
k = 1 for buildings with T less than or equal to 0.5 seconds
k = 2 for buildings with T more than or equal to 2.5 seconds

CUBiC gives a value of 2 for k for buildings with T between 0.5 and 2.5. This is not a good idea. Interpolation between k = 1 and k = 2 is preferable.

3.7 Other Issues

CUBiC goes on to deal with:

- overturning moments, horizontal shear and torsion;
- forces on components;
- drift.

3.8 Dynamic Analysis

CUBiC requires dynamic analysis for buildings with highly irregular shapes, large differences in lateral resistance or stiffness between adjacent storeys, or other unusual features. The methods of dynamic analysis permitted are:

- modal analysis;
- direct integration.

A modal analysis procedure is given in CUBiC.

3.9 Design and Detailing

CUBiC encourages symmetry in structures.

In recognition of the disparity between "code" forces and actual forces, CUBiC provides guidance on detailing of structures to achieve adequate ductility. This includes specific information on reinforced masonry and timber.

Guidance is given in CUBiC on restraints to pile caps and caissons.

4 IBC 2000

Model codes in the USA used to be produced by three competing organisations:

- International Conference of Building Officials (ICBO - UBC)
- Southern Building Code Congress International (SBCCI - Standard Code)
- Building Officials and Code Administrators International (BOCA - National Code)

These three organisations now combine to produce one model code for the USA - the International Building Code. The first edition was launched this year, hence the acronym IBC 2000.

There is a possibility that IBC 2000 would form the basis for the next generation of CUBiC. Because of this, a later part of this course is devoted to the earthquake provisions in IBC 2000.

earthquake forces on buildings.

- Historical observations of successes and failures
- Equivalent static forces
- Dynamic analysis

Los Angeles (1943): $C = 60/(N = 4.5)$

where:

C = % of dead load

N = number of storeys (limited to 13)

LA (later): $C = 4.6\ S/\{N + 0.9(S - 8)\}$

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Joint Committee on Lateral Forces: $C = K/T$

where:

K = 0.015 for buildings and 0.025 for other structures

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Design Philosophy:

1 resist minor earthquakes without damage;
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Soils Factor

For T/T_s = 1.0 or less:

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For T/T_s = greater than 1.0:

$$S = 1.2 + 0.6\,T/T_s - 0.3\,(T/T_s)^2$$

Vertical Distribution

1970s triangular distribution plus a point load at the top
The triangular distribution:

$$F_x = (V - F_t)\, w_x\, h_x/(\Sigma w_i\, h_i)$$

CUBiC (after ATC-3):

$$F_x = C_{vx}\, V$$

and

$$C_{vx} = w_x\, h_x^{\,k}/(\Sigma w_j\, h_j^{\,k})$$

where:
F_x = the lateral force at level x
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