Rules and Codes of Practice

B.W. Smith FEng
Senior Partner
Flint and Neill Partnership

Background

Codes of Practice in the civil and structural engineering field have been developed to provide designers with standards of good practice, to enable them to assess the loading appropriate to their particular structure – whether it be due to highway traffic for a bridge, live loading for an office or domestic building or for any form of structure the environmental effects such as wind, thermal actions, snow or earthquake. Such 'loading' codes then need to be used in conjunction with 'strength' codes which provide rules to assess the strengths of elements of the structure, whether they are of steel, concrete, timber or other material

In developed countries specific codes have been drafted by specialists in the particular discipline under the direction of technical committees set up through government by the national standards organizations. In the case of wind loading, national codes have been developed appropriate to the climatological information available, and based on wind tunnel testing to determine the appropriate drag coefficients for both components and overall structures For those structures which are particularly sensitive to wind actions, such as long span bridges, towers, chimneys or guyed masts, for example, specific wind loading codes have been developed

Such codes have generally been written, however, for stable wind environments and have concentrated on 'engineered' structures such as tall buildings or major bridges. They may be inappropriate for areas subject to tropical storms and for traditional buildings with little or no engineering input. This paper attempts to highlight how such 'traditional' codes need to be modified and/or adopted to those regions most susceptible to severe wind storm damage, and how they should be used in conjunction with appropriate design standards. Consideration is given to how the expertise and experience available in writing wind loading codes has been used to produce simple rules for more traditional buildings Finally, proposals are made for design guidance to be used in developing countries where even simple codes may be inappropriate

Range of Structures for which Codes are Needed

In developed countries wind loading codes apply over the whole range of the built environment, from domestic housing to major highway bridges; such codes are enforced through building regulations or client requirements and experience has shown that the codes perform reasonably well There is clearly a balance between acceptable damage in the extreme storm and the economic penalty of ensuring that the likelihood of that damage is reduced.

Broadly structures can be defined as 'engineered' – such as multi-storey buildings, bridges, towers and industrial plant, and 'non-engineered' – such as domestic housing, storage buildings, temporary shelters etc

Engineered structures will generally be designed using sophisticated techniques in which codes of practice will be used as the required criteria. Such codes have traditionally been dictated by the requirements of large buildings. For such structures each design is unique and involves a high input from the structural engineer The codes are complex reflecting the sophistication of the developed countries expertise; indeed present codes are being criticised as being too complex and having to rely on computer programs for their application. In such circumstances it is essential to ensure that such codes are appropriate for the wind regime of the site and that such complex codes are accepted as necessary in order to design both safely and cost-effectively. This is particularly important in those developing countries which rely on the codes of developed countries but without necessarily having comprehensive meteorological data, the technical background to these codes and the facilities to enforce their application as intended. The use of such codes is discussed below.

Non-engineered buildings in developing countries should be constructed so that they can safely withstand extreme winds but failures have generally occurred due to poor detailing or the use of inappropriate components [1] The greatest benefit in reducing the risk of damage would therefore appear to be in trying to devise wind-resistant details in terms of components and their fixings taking due account in a generic way of how they would perform under extreme winds. Rules as such would thus be used to develop appropriate standardized details, and possibly to highlight acceptable, and unacceptable, forms of construction, and to define sites particularly prone to wind damage. These would thus be "deemed to satisfy" rules without the builder necessarily having knowledge of their wind engineering basis.

Unfortunately there is a range of structures where engineering input would be deemed essential in, for example, the European environment, but may escape such practice in developing countries and, most importantly, in areas which may in fact be prone to severe tropical storms. Such structures may be deemed 'intermediate' in this context.

Simplified codes in such instances, have been developed, such as the Australian simplified code for use in tropical cyclone areas[2] and the Caribbean Uniform Building Code.[3] Unfortunately in any simplified rules it is inevitable that they will be conservative and hence economically penal. Upper bound blanket values need to be used to all the varying parameters which result in the over design of non-critical elements or components. In a country such as Australia this approach may be the most satisfactory, but even this simplified set of rules may not be workable in developing countries. A suggested format of this Codification procedure is set out in Table 1.

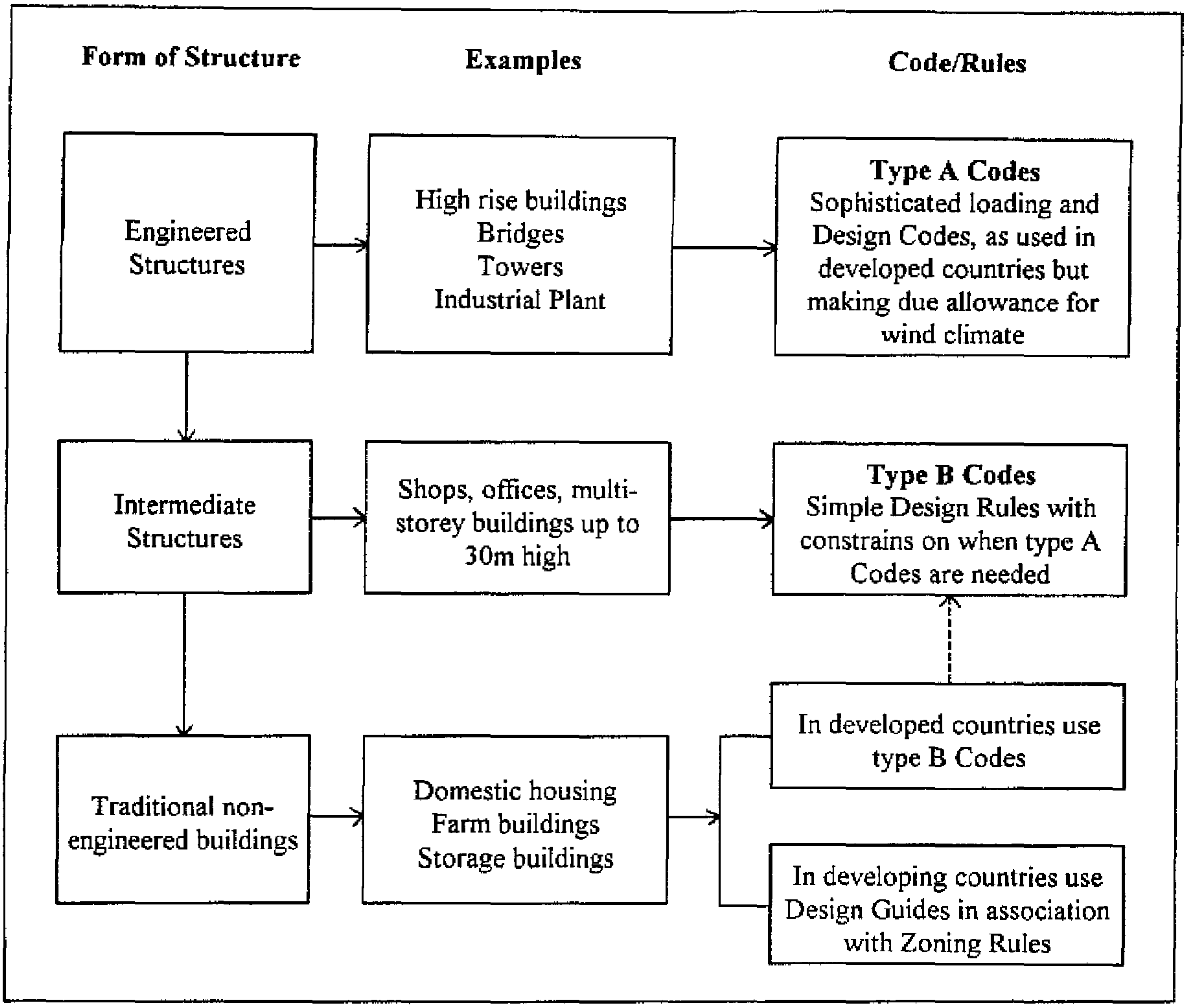
Codes of Practice for Engineered Structures in Regions Subject to Tropical Storms

GENERAL

Four 'steps' need to be established in deriving the wind loading to be used on a structure:

- **a.** appropriate wind speed predicted to occur at the site with a given probability of exceedance, taking into account both the wind climate and the terrain of the site;
- **b.** the 'resistance' of the structure to wind effects, defined through drag coefficients and effective areas of the element or structure being considered,
- **c.** the response of the structure to the wind which may vary from a static response, as for the majority of buildings, to dynamic response, for flexible forms of construction,
- **d.** the reliability of structures to withstand wind effects – when the code is used in conjunction with a design 'strength' code. This reliability is expressed in codified form through safety factors

Each of these steps will be examined in the context of their applicability to areas subject to tropical storms and to the form of construction to which they should apply



Form of Structure	Examples	Code/Rules
Engineered Structures	High rise buildings Bridges Towers Industrial Plant	**Type A Codes** Sophisticated loading and Design Codes, as used in developed countries but making due allowance for wind climate
Intermediate Structures	Shops, offices, multi-storey buildings up to 30m high	**Type B Codes** Simple Design Rules with constrains on when type A Codes are needed
Traditional non-engineered buildings	Domestic housing Farm buildings Storage buildings	In developed countries use type B Codes In developing countries use Design Guides in association with Zoning Rules

Table 1 Suggested format for wind codes in areas of tropical cyclone

METEOROLOGICAL PARAMETERS

Tropical cyclones always form over the sea and require:[4]

- **a.** the sea temperature to be above 27°C;
- **b.** the absence of inversions between the surface and an altitude of about 10km;
- **c.** slight divergence of atmosphere above 10km;
- **d.** significant rotational momentum to induce circulation sufficient to maintain the cyclone

Satisfaction of requirements *a* and *d* can only be met in latitudes about 10° to 15° either side of the equator and it is in these regions where codes of practice developed for stable frontal depressions, such as those from the Atlantic, need to be modified to provide appropriate meteorological information. Unfortunately , with several notable exceptions, the wind data available in regions subject to tropical cyclones is of poorer quality implying higher variability in the resulting design parameters which are based on such data

As the basic wind speed to be used in design is the most fundamental parameter required, and as the resulting load depends on the square of the speed, then the more accurately one can predict this basic speed, the more confidence one can have that the loading accurately represents the relevant wind regime with a predictable probability of exceedance

Once appropriate basic wind speeds for design purposes have been established consideration needs to be given to the other important parameters which affect the wind speed to be used for design of a building at a specific site

The distance of the site from the sea will generally have a beneficial effect in that the wind speed will be reduced, due to surface friction. Unfortunately, from the aspect of wind loading, most conurbations are built at, or close to, the coast and are therefore likely to be subject to the full force of the cyclone which is formed over the sea. Thus, while codes make allowance for reduction in wind speeds in country and town terrain, these may not be of help for sites adjacent to the coast. It is believed that near-surface wind speeds reduce with distance from the coastline more rapidly than is accounted for by loss of vigour of the cyclone resulting from cut-off of the driving mechanism; i.e. that the greater surface roughness makes itself felt to a similar degree to the change in profile which is relatively well explored in temperate storms. Much is known, but better exploration of the applicability of parameters established in temperate climates is still needed

The form of the terrain also has a significant effect on modifying the basic wind speed Topography in the form of an escarpment or hill commonly greatly modifies the actual wind speeds. The speed-up effect over the crest can be very serious; it is possible to double the wind load on a structure near the crest of the feature, and significant effect can extend over considerable areas. Fortunately this is now well understood, and current codes of practice provide rules to estimate what the 'speed up' due to topographic effects is likely to be.[5] It is anticipated that these factors established for temperate conditions can be applied in tropical cyclone regions.

In countries such as the United Kingdom strongest winds are in the prevailing wind direction but even here design to avoid exposure to such winds is usually not feasible and advantage of reduced wind speeds is not generally possible Shelter from other obstructions could provide a basis for using reduced wind speeds in design – provided the obstruction is permanent and, if man made, capable itself of withstanding the fully exposed wind However, it is relatively difficult to take positive advantage of shelter in design, although benefit is undoubtedly possible, because of the difficulty of ensuring coverage of all possible wind directions. Although the movement of the cyclone as a whole must mean that there is a bias for maximum wind to be limited to the broadly on-shore direction, the intense rotary pattern implies severe winds from any quarter.

For generality of buildings it is then sufficient to convert from the mean to an appropriate short-duration gust maximum speed. For 'engineered' structures more may be required, including the rate at which speeds increase with height above ground and a measure of the size of gusts, which influences the allowance to be made for correlation of the loads over a large structure and also the possible importance of dynamic response. This information has been difficult enough to obtain and interpret for temperate winds, calling for expensive and time-consuming outdoor experiments with arrays of anemometers. The most notable experiment of this kind in the tropics was conducted at Cap d'Aguilar, an exposed site on the south-east coast of Hong Kong. The indicated gust structure was very similar to the temperate pattern.

On the other hand, the balance of evidence is that the further increase of wind speed above the first few tens of metres from the ground is much less in the tropical cyclone than in the large temperate storms.[6, 7] There is a clear need for further research to bring together the evidence on gust structure and profile; although a universal gust structure created by the surface roughness is an attractive concept, this would be easier to accept given greater similarity of profile.

In summary the most vulnerable locations are likely to be near the coast and on the brows of hills, cliffs and escarpments. Whilst codes of practice can deal with these aspects, for non-engineered structures care has to be exercised in avoiding such locations wherever possible.

WIND 'RESISTANCE'

The resistance of a structure to wind actions is represented by non-dimensional loading coefficients, or shape factors, applied to reference areas of the structure – generally a face of the structure such as a wall or roof. Shape factors have been determined, normally by wind tunnel tests on models of elements or simplified building configurations. These would be applicable regardless of the location of the structure and codified values are available for a very wide range of structure, sufficient probably to embrace all but the most unusual configuration.

Unfortunately the pressure distribution over even the most simple building, such as a domestic house, varies dramatically making simplification without undue conservatism virtually impossible. However, for 'intermediate' structures where wind loading may only be governing components such as roofing elements or cladding, and for which each element is likely to be standardised regardless of its location within the structure, simple, upper bound factors are feasible. For overall loading of the structure, where local high pressure or suction zones will not have a significant effect, again simplified factors are possible without unacceptable economic penalty. This approach has been adopted in the 'simple' Australian code.

Study of pressure coefficients however also provides valuable insights into the more favourable shapes to use in design to minimise wind load effects. Thus for non-engineered structures favourable configurations could be set down and recommendations made to avoid wind sensitive details, as proposed above.

WIND RESPONSE

Most conventional building structures are stiff enough for wind effects to be determined by static methods Small structures moreover are such that the wind speed can be defined at a single point in space. This allows simple estimates of the load effects to be made using a peak wind pressure derived from a single value of gust wind speed Larger structures require the relevant wind data to allow for loss of spatial correlation of the gust over the structure; thus the overall loads are reduced from those appropriate to the peak gust. Elements of such buildings however still need to be designed for such peak loads. Codification for such structures is straightforward.

However structures which are not stiff enough to be assessed by static methods may require a full dynamic approach, with the associated added theoretical complexities Tall, slender buildings or towers or long span bridges are typical examples. Codes now include procedures to recognize this, such that the majority of structures, including even tall conventional high rise buildings can be designed using static methods by the incorporation of a dynamic 'magnification' factor.[4, 8] Such procedures would be applicable regardless of the location of the structure as the response is structure dependent, irrespective of the wind regime.

The guidance for non-engineered structures would need to provide simple limitation on, for example, slenderness to ensure that dynamic effects would not be an issue, or if such criteria were not satisfied, that specific design rules would need to be used.

RELIABILITY

The theoretical (notional) reliability of failure of any one of an identical family of structures, all to be assumed to be at the same site, may be defined in terms of statistical distributions of extreme loads and of the frequency distribution of the strength of the structures, or elements, in relation to the value of strength assumed in design. If the distribution of loading and strength are known the risk of failure can be varied by modifying the relative locations of these distributions, i.e. adjusting the safety factors.

Generally codes of practice incorporate a single partial load factor for wind loading, which when used in conjunction with a partial factor on design strength provides, on average, acceptable reliability, uniform over the structures covered by the code.

In the context of potential hazards due to wind storms however, and in particular the means to deal with the aftermath of a disaster, logic would dictate that certain engineered structures should have higher factors of safety than others to try to provide a basic infrastructure capable of handling the rescue and possible evacuation operations

Thus major highway arteries should possibly have structures designed to higher reliability levels than, say, small access bridges. Likewise

Region	**US South Coast**	**Miami**	**Jamaica**	**Trinidad**
$q = \frac{1}{2} \rho V^2_{50}$ (kN/m²)	0.30°	0.80*	0 8+	0 4+
Central Load Factor $\overline{\gamma}$	2.20	2.95	3.6	4.8
Design γ	1.65	2.35	3.0	4.3
Ultimate $q = \gamma q_{50}$ (kN/m²)	0 50	1.90	2.4	1.7

° based on hourly mean speeds   * based on gust speeds   + based on 10 minute mean speeds

Table 2 Safety factors in areas of tropical cyclones, compared with UK

telecommunication facilities used for summoning and directing emergency services should be designed with higher safety factors than would be the case where multiple facilities exist for the provision of such communications.

Variable reliability classes have already been incorporated in existing codes of practice,[9] but inevitably quantifying the increased reliability required poses two questions:

a. an assessment of the economic consequences of failure;

b. an assessment of the risk to life in the event of failure.

To enable a judgement to be made as to how the factor of safety should be increased, quantification of both these matters needs to be made. As far as quantification of the economic consequences of failure is concerned, this would govern if the risk to loss of life, in the event of failure, were small The procedures adopted to determine the target notional reliability have been discussed elsewhere in this seminar [10]

Of equal importance is the fact that the safety factors that are required to achieve a desired reliability in the United Kingdom, for example, have been shown *not* to be adequate for typhoon areas, due to the different mechanisms of such storms The greater dispersion of typhoon wind speeds necessitates load factors increasing from say 1.4 in the United Kingdom to about 2.0 in a typhoon area to provide the same notional reliability. Likewise construction methods may incur a wider variability of quality than that experienced in those areas for which the design codes were formulated. Increased variability of strength implies that higher safety factors would be required to achieve the same reliability. In fact each tropical cyclone area may have different characteristics, requiring different safety factors to provide the same reliability. For example, by comparing the 50 year dynamic pressures given in the Caribbean Uniform Building Code for various locations with those for the U.K. and assuming a target reliability given by a ß index of 3, the mean and 'conventional' load factors are given in Table 2, assuming log normal distributions for strength and other aerodynamic parameters. From this it can be seen that global safety factors (that is including partial load and material factors) need to be enhanced considerably from the U.K. value of about 1.7 to as great as over 4 for Trinidad The resulting factored wind pressures are consequently considerably higher, as may be seen from Table 2, partly due to the higher 1 in 50 year return values and partly due to the enhanced safety factors. Thus even for engineered structures care has to be taken in extrapolating existing codes for application to regions subject to tropical storms, or for different standards of construction

The possibility of failure due to fatigue has not been discussed but invariably wind actions, by their fluctuating nature will induce stress reversals in components leading to possible fatigue damage. Indeed fatigue damage of fixings was prevalent in cyclone Tracy. At this level, details should be derived which are less susceptible to failure from stress reversals. Likewise elements, or indeed structures, which suffer from aerodynamic instabilities, should either be avoided or carefully engineered.

Simple Design Codes

The simplified Australian Code limits its use to buildings less than 15m high or 1000 square metres in area, and hence embraces 'non-engineered' structures. Indeed its intention was to provide simple rules for traditional housing. Design wind pressures are given for roofs and walls and for internal pressures which combine a basic 'dynamic' pressure with appropriate pressure coefficients A simplified treatment of terrain and topography is provided enabling designers non-conversant with wind engineering to be able to design relatively easily.

The Caribbean Uniform Building Code also attempts to provide a simple treatment, but here the Code is based on the ISO wind document[11] and includes greater complexity in the treatment of wind structure and response. An appendix in the Code sets down the basic wind speeds converted into pressure, for each of the Caribbean locations, but no guidance is provided for what safety factors should be used; although the ratio of 1000 year return to 50 year return wind pressures are given, as discussed previously, again inferring the need for higher safety factors in tropical cyclone regions.

It is reported that this Code has not found wide acceptance in the Caribbean despite being available for some considerable time. The Barbados Association of Professional Engineers developed a wind loading code in 1970 based on the UK wind code CP3 Chapter V Part 2.[12] It has subsequently been revised and adapted as a Barbados National Standard, and is widely used in the Caribbean

Design Guidance

The 'deemed to satisfy' rules that were proposed above for non-engineered buildings would need to be developed in the light of the knowledge gained in the design of engineered structures in temperate climates and be produced in the form of guidance documents, clearly and unambiguously presented Such design guides would not require local expertise of wind behaviour for their application as they would comprise the distillation of that expertise. They would encompass the relevant local building techniques and materials to provide appropriate design guidance. They would need to consider acceptable configurations making due allowance, for example, for the use of the building. Acceptable details to prevent possible fatigue damage would be provided without the need for assessment by calculation The guides would also need to ensure overall stability of the building with particular emphasis on continuity of connections between principal components and the provision of appropriate foundations.

Guidance would need to be given to ensure any attachments to buildings such as signs, aerials, shutters, etc , were equally robust; injury or damage from wind-borne objects must be prevented as far as possible.

Additional rules, for the local authority, could be established which would define zones where buildings would be particularly susceptible to wind damage. Consideration in such zones could be given to providing 'wind shelter' if this were practicable. Consideration would also need to be given to establishing zones where buildings would not be allowed if there were the possibility of flooding in the aftermath of the storm.

Whilst this paper does not attempt to provide proposals it is envisaged that they would therefore comprise three types of rules:

a. Zoning rules for the local authority charged with decisions on building applications. These would set down zones where non-engineered buildings would not be allowed (such as on the crests of steep hills whose height were at least equal to that of the buildings, immediately on the shore line, or in steep sided valleys where wind tunnelling was known to occur). Zones where simple design rules could be used, could be defined covering all but the most onerous of the above sites. The most severe zones would then require all structures to be designed in such areas to be fully engineered.

b. Preferred configuration rules, which would provide some relaxation of the requirement for the use of codes; examples would be in the use of pitched roofs of 30° to 40° slopes; of the use of hipped roofs rather than gabled ends; of buildings with limited openings and provision for keeping these closed in stormy conditions, such as by shutters. (This clearly would rely on the occupier and may be difficult to impose.) Free standing walls would need to have return ends and preferred configurations for eave details could be provided.

c. Guidance on acceptable details could be provided, as has been described by Mayo[1] and by Eaton in this seminar.[13] These would include roof joist, rafter and panel connections for example and could be developed for the specific form of construction in current use in the area.

Conclusions

As outlined above, procedures are available to quantify the parameters needed to produce Codes of Practice for areas subject to tropical storms. For non-engineered traditional structures design guidance should be developed based on wind engineering expertise to derive appropriate configurations, use of components and acceptable details to minimise the risk of wind damage. Such Guidance would seem more likely to provide safer housing and shelter than the application, and possible misapplication, of design codes. Guidance could also be produced for use by the local Authority in deciding zones where structures could be built and zones where engineering advice would be required

For fully engineered structures existing codes can be used, but care has to be exercised in obtaining the most reliable basic wind data for the site area, and in adapting the safety factors to be used in design to achieve the required reliability Consideration should be given to providing increased security, through higher safety factors, for those structures which are considered essential to withstand the extreme storm for use in disaster relief

For 'intermediate' structures simplified codes are being produced to provide a more consistent reliability of structures, without undue economic penalty

References

1. Mayo A., *Cyclone resistant houses for developing countries.* Building Research Establishment, 1988

2. Walker G. R., 'A simplified wind loading code for small buildings in tropical cyclone prone areas'. *J.W.E.I A,* 30, 1988.

3. *Caribbean Uniform Building Code· Part 2* 'Structural Design Requirements Section 2: Wind Load'. Caribbean Community Secretarial, Georgetown Guyana, 1989

4 Cook N. J., *Designers Guide to wind loading of building structures,* Part 1. Butterworths, 1995.

5 British Standards Institution, BS 6399 Part 2: *Code of Practice for wind loads* (in final draft).

6. Collier C. G. et. al Extreme surface wind in mid-latitude climates, J Wind Eng & Ind Aero (in press).

7. Georgiou P. N., 'Design wind speeds in tropical-cyclone prone regions'. *Report BLWT* -2-1985 University of Western Ontario, 1985.

8. *Eurocode 1* Part 2.4: Wind Actions (in final draft for publication as ENV-1-2-4).

9. British Standards Institution, *BS 8100* Part 1, 1980 and *BS 8100* Part 4, 1995 'Code of Practice for towers and masts'.

10.Wyatt T. A., 'Risk Analysis· Tropical and Temperate Climates Contrasted'. *Windstorm: Coming to terms with mankind's worst natural hazard.* Submitted to Royal Academy of Engineering.

11.*ISO/TC98/SC3/WG2/N129·* 'Wind Actions on Structures'.

12 British Standards Institution, *CP3* Chapter V Part 2: 'Wind Loads', 1972

13 Eaton K., Vulnerability of tropical housing – lessons for the future. *Windstorm: Coming to terms with mankind's worst natural hazard* Submitted to Royal Academy of Engineering