A2 Multi-hazard Design

A2.1 Contradictions and Synergies

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1 Contradictions and Synergies in Designing Against Hurricanes and Earthquakes

Designing against multiple hazards is more than doubly difficult when compared with designing against a single hazard, especially when those multiple hazards are wind and earthquake. Many favourable features of wind-resistant design are unfavourable for earthquake-resistant design and vice versa.

(1) Heavy structures resist winds better. Light structures resist earthquakes better.

(2) Flexible structures attract greater wind forces. Stiff structures (generally) attract greater earthquake forces.

Both hurricanes and earthquakes impose horizontal loads on buildings. Earthquakes also impose significant vertical loads on a building overall. The vertical loading derived from wind is usually significant on parts of a building as determined by aerodynamic considerations.

However, there are many similarities in the effective design and construction of buildings to resist hurricanes and earthquakes:

(3) Symmetrical shapes are favourable (OHPT[1]-1)

(4) Compact shapes are favourable (OHPT-2)

(5) There must be a realisation that there is a real risk that "design" forces may be exceeded. This is particularly so in the case of earthquakes where, largely for economic reasons, the design force is deliberately determined to be less than that expected during the anticipated life of the building. This leads to a requirement for redundancy in the structure and for "toughness" - the ability to absorb overloads without collapse. (OHPT-3)

(6) Connections are of paramount importance. Each critical element must be firmly connected to the adjacent elements.

There is a basic difference in the performance expectations in the event of an earthquake as opposed

[1]Overhead projector transparency

to a hurricane. A building is expected to survive its "design hurricane" with virtually no damage. Even a catastrophic hurricane should only lead to repairable damage. On the other hand the "design earthquake" is expected to cause (hopefully repairable) damage, and a catastrophic earthquake is likely to lead to a situation where the building cannot be repaired and must be demolished. In such an event success is measured by the absence of deaths and serious injuries.

The accompanying table summarises the main differences between hurricanes and earthquakes as they affect structural design.

	Wind	Earthquake Effects
(1) Source of loading	External force due to wind pressures.	Applied movements from ground vibration.
(2) Type and duration of loading	Wind storm of several hours' duration; loads fluctuate, but predominantly in one direction. (OHPT-4)	Transient cyclic loads of at most a few minutes' duration; loads change direction repeatedly.
(3) Predictability of loads	Usually good, by extrapolation from records or by analysis of site and wind patterns.	Poor; little statistical certainty of magnitude of vibrations or their effects.
(4) Influence of local soil conditions on response.	Unimportant	can be important (OHPT-5&6)
(5) Main factors affecting building response.	External shape and size of building; dynamic properties unimportant except for very slender structures.	Response governed by building dynamic properties: fundamental period, damping and mass.
(6) Normal design basis for maximum credible event.	Elastic response required.	Inelastic response permitted, but ductility must be provided; design is for a small fraction of the loads corresponding to elastic response. (OHPT-7)
(7) Design of non-structural elements. (OHPT-8)	Loading confined to external cladding.	Entire building contents shaken and must be designed appropriately.

Main Differences Between Wind and Earthquakes
From The Arup Journal

2 Quality Assurance in Design and Construction, the Human Factor

The most difficult problem to solve in the construction industry is the effective enforcement of standards. In one form or another the independent checking of design and construction is widespread in many jurisdictions. The French system is one that appears to be the most successful[2]. What sets France apart from most is the quality of their checking agencies. However, some other jurisdictions do adopt a similar approach for special facilities. In the United Kingdom all dams, tunnels and bridges are reviewed by specially-licensed, private-sector consultants. Here in the English-speaking Caribbean, the Turks & Caicos Islands have made provisions for "special inspectors" in their recently-introduced building code. A similar arrangement is being proposed for the Organisation of Eastern Caribbean States building codes.

The checking agencies in France are known as *bureaux de contrôle*. The *bureaux de contrôle* are independent firms licensed by the state. They pay well and attract, and keep, some of the best talent. They check designs and also make site visits during construction. Their involvement in projects is necessary if decennial (10-year) insurance cover is to be obtained by the building owner. Some lending agencies also demand the certification of *bureaux de contrôle*. The most remarkable characteristic of the system that it is hard to find anyone in France who disagrees with it. In Martinique and Guadeloupe the *bureaux de contrôle* are seen as being generally helpful and as having a developmental role in the construction industry. Suffice it to say that the use of *bureaux de contrôle* in Martinique and other parts of France is widespread and its beneficial effect is manifest.

But how do others see the role of *bureaux de contrôle*? Here are two quotations from Peter Rice's book "The Engineer Imagines":

> "It is no accident of time that both the La Villette and IBM projects first appeared in France where there exist the most intelligent and knowledgeable checking authorities that I have come across. The large centralized controlling offices, *bureaux de contrôle*, Socotec, Veritas, CEP and others each have at their head engineers who are equal in ability to any I have encountered in the best design offices, as Centre Pompidou amply demonstrated." - page 113
>
> "Others not so closely involved must also be asked to review the project to question the assumptions and demand explanations. .... The presence of a competent, dedicated and sceptical checking authority is also very important in this respect." - page 123

(Peter Rice, now deceased, was one of the outstanding structural engineers of the 20th Century.)

[2] See “The Impact of Bureaux de Contrôle on Damage Levels in Hurricanes” by Tony Gibbs, 1996

3 Concluding Thoughts

The extensive loss of life and property caused by hurricanes and earthquakes can be avoided by the implementation of existing technology and without great financial strain. What is required is the will to do so. Because it would require about two generations to replace the building stock in most communities, as much attention should be paid to the retrofitting of existing buildings as to the improved design and construction of new buildings[3]. At this time there are few technical constraints hindering the satisfactory design and construction of most buildings against hurricanes and earthquakes. (This is not to say that research and development should not continue.) However, there are severe cultural, socio-economic, political and bureaucratic constraints to achieving success in this field.

Education and training programmes need to have a greater emphasis placed on the specific requirements of earthquake-resistant and hurricane-resistant design. At the higher educational levels the subjects should be taught from the points of view of background studies and fundamentals. The mere teaching of code procedures is not enough.

The lack of code enactment is a serious hindrance to progress in many territories. Of course code enactment would not be enough without enforcement. Funding agencies (loans and grants), domestic mortgage institutions and insurance companies could play pivotal roles in this regard.

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[3] Reference:- “Vulnerability Assessment of Shelters in the Eastern Caribbean, Retrofitting -Terms of Reference for Consultants, Standards, Global Estimates - November 1998" - Prepared for the Organization of American States under the USAID/OAS Caribbean Disaster Mitigation Project and the OAS/ECHO School Vulnerability Reduction Programme by Tony Gibbs, Consulting Engineers Partnership Ltd

A2.2 The Process of Structural Design

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1 INTRODUCTION

1.1 The Purpose of Hazard Resistant Design

Throughout the world, including the Caribbean, natural hazards cause much damage to buildings. This is both regrettable and avoidable.

It goes without saying that the damage and destruction of buildings would put the affected population at risk during severe storms and after all severe natural-hazard events.

It is often said that safe buildings may not be affordable, especially in relatively-poor developing countries. This is a fallacy. Particularly with respect to hurricane resistance, safe buildings are not only technically feasible but also achievable at very modest cost. This thesis has been tested and confirmed on several occasions over the years.

Cost comparison studies have been carried out by a number of authors on a wide range of structures.

Ipek's analysis[4] of a single-bay, multi-storey, reinforced concrete framed structure indicated that, for typical Caribbean conditions the cost of the structure, when applying levels of earthquake forces similar to those prescribed by CUBiC, only increased by 0% to 14%. A similar study was carried out by Whitman *et al* [5] and indicated that for similar conditions the increase in the structural cost, related to the overall building cost, ranged between 2% and 5% with an additional 1% for non-structural items. In these two studies the cost increments relate to providing earthquake resistance to buildings otherwise designed for gravity loads only.

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[4] "Increase in Building Cost due to Seismic Coefficient" by M Ipek, CENTO Conference on Earthquake Hazard Minimisation, Ankara, July 1968 (overhead projector transparency, OHPT-1)

[5] "Seismic Design Analysis" by RV Whitman, JM Biggs, J Brennan, CA Cornell, R de Neufville, EH Vanmarcke; Structures Publication No 381; MIT; 1974 (OHPT-2)

In 1977 the US Department of Housing and Urban Development funded a Cost Impact Analysis[6] by Ralph W Goers & Associates (structural engineers) which determined the extra costs of earthquake and hurricane resistance for a variety of single-family dwelling houses. The incremental costs ranged from 0.24% to 2.2%.

The retrofitting cost for Victoria Hospital (St Lucia) was estimated by CEP in 1993 to be 1% of the contemporary replacement cost of the facility[7].

The retrofitting cost for Princess Margaret Hospital (Dominica) was estimated by CEP in 1980 to be 2.2% of the contemporary replacement cost of the facility[8].

The implemented retrofitting cost for most of the US$27 million worth of buildings of a major public utility in the Caribbean was less than 1% [9].

The results of all of the above-mentioned studies confirm very moderate first costs for protection against the natural hazards of earthquakes and hurricanes. Additional benefits would accrue over the life of a building, such as the reduced cost of insurance which could be set against those modest first-cost increases.

1.2 Terms of Reference

An important issue to be addressed if we are to succeed in designing and constructing buildings resistant to hurricanes and earthquakes is the preparation of suitable terms of reference for the designers. Too often this is taken for granted.

It is often not sufficient to specify appropriate standards for projects. There is also the need to ensure that the standards are being followed and are being interpreted correctly.

As an aid to addressing these problems, suggested terms of reference for consultants working on buildings are presented in this document. These terms of reference are deliberately more detailed than usual. This would facilitate a more orderly approach to the execution of the consultants' functions and also facilitate the monitoring of these functions by the clients'

[6]Part of Contract No H-2195R between US HUD Office of Policy Development and Research and the Applied Technology Council on "A Methodology for Seismic Design and Construction of Single-family Dwellings"

[7]"Vulnerability Assessment of the Victoria Hospital, Castries, St Lucia" by Consulting Engineers Partnership Ltd under contract to the Pan American Health Organization (Emergency Preparedness & Disaster Relief Programme Office in Barbados)

[8]"Study for the Retrofitting of Princess Margaret Hospital, Roseau, Dominica" by Consulting Engineers Partnership Ltd under contract to the United States Agency for International Development

[9]"Hurricane Damage Mitigation Programme for The Barbados Light & Power Co Ltd" by Consulting Engineers Partnership Ltd, 1992

representatives.

Experience shows that such an orderly approach reduces the incidence of oversights, reduces abortive work by the consultants and leads to a more efficient project overall.

2 TERMS OF REFERENCE FOR DESIGN CONSULTANTS

2.1 Briefing

The consultant will receive a brief from the client. In particular, the consultant will initiate specific discussion on natural hazards and reach agreement with the client on performance expectations for the project. The client's policy position with respect to natural hazards and the performance expectations in the event of differing levels of severity of hurricanes and earthquakes is to be clearly articulated. Decisions must be made on the appropriate levels of safety for the planned facilities. This is addressed further in Section 3 of this document.

2.2 Document Search and Interviews

The consultant will request from the client and receive all available reports related to the project and the site.

After study of the available documents the consultant will carry out interviews of the technical and other personnel of the client to supplement the information on the project obtained from the documents.

2.2.1 Inception Report

On completion of the document review and supplementary interviews the consultant will prepare an inception report including:

- the consultant's understanding and interpretation of the terms of reference;
- changes to the terms of reference since the start of the assignment;
- an appraisal of the available information and an outline of the consequential field investigations to be conducted so as to complement the information already obtained, including any special investigations which may be required;
- an outline of the programme for the remainder of the assignment.

2.3 Field Surveys and Laboratory Tests

The consultant will carry out field surveys to supplement and confirm previously-obtained information. Such field surveys may include laboratory testing of materials taken from the site.

For the assessment of foundation conditions affecting anchorage and the seismic response of facilities it will be necessary for the consultant to undertake geotechnical surveys of the site and it may be necessary to undertake geophysical surveys as well.

2.4 Preliminary Appraisals, Conceptual Design and Project Definition

The consultant will interpret the brief and prepare conceptual designs for consideration by the client.

The design, analysis and detailing of buildings to be resistant to earthquakes and hurricanes are complex processes involving many issues. As an *aide-mémoire* for detailed engineering, an Appendix is included in this document. Planners and architects usually dominate this phase of a project. It is important that they receive early advice from the engineers on the design team on the implications for the design concepts of natural hazards.

2.4.1 Design Stage I Report

On completion of the work described in 2.3 and 2.4 the consultant will prepare a Design Stage I report including:

- the design standards and codes to be used on the project;
- the agreed design criteria for the project;
- preliminary design and drawings;
- outline specification;
- procurement procedures for the construction contractors and suppliers;
- conditions of contract - general and particular;
- cost estimates;
- an outline of the programme for the remainder of the assignment.

The client will review the report and hold discussions with the consultant (which may lead to revisions) and will conclude with the formal approval of the project, as defined in the report, for implementation.

The vulnerability of a building to earthquakes and hurricanes is very often associated with the non-structural components of the building. These components rarely receive the attention they deserve from the construction industry.

In modern buildings those elements not part of the principal load-resisting system account for a high percentage of the cost. Traditionally, structural engineers are not consciously and directly involved with these elements. Architects, electrical engineers and mechanical engineers are usually responsible for them. These disciplines do not usually focus on wind and earthquake resistance. In most cases the relevant persons are by no means equipped for the task of providing wind-resistant and earthquake-resistant components. The solution of this problem may involve the reallocation of design responsibilities among the members of the design team with a commensurate reallocation of compensation.

This stage effectively defines the project. It is therefore most important that it be done thoroughly by the design team and be reviewed carefully by the client. The likelihood is that a satisfactory Design Stage I phase would lead to a successful project.

2.5 Design Stage II

The consultant will undertake the detailed design, analysis and detailing of all aspects of the works to be constructed. This phase of the project will include:

- the iterative process of analysis and refinement of the designs;
- construction details;
- technical specifications;
- bills of quantities.

2.6 The Tender Process

The consultant will undertake the following tasks:

- prequalification of contractors and suppliers;
- inviting tenders;
- pre-tender meeting with the bidders;
- answering questions from bidders during the tender period;
- opening of tenders, review and reporting on tenders.

The tender process culminates with the client's decision and the contract award by the consultant on behalf of the client.

2.7 Construction Stage

The consultant will undertake the following tasks:

- conduct a pre-construction meeting with the chosen contractor;
- undertake supervision-in-chief, provide resident supervision in appropriate circumstances and advise the client on the need for additional inspectors;
- conduct site meetings and prepare progress reports for issue to the client;
- check shop drawings and provide approvals when compliance with the contract documents is achieved;
- issue and administer variations and additions to the contract;
- certify payments to the contractor;
- issue the certificate of substantial completion;
- monitor latent defects during the maintenance period;
- deliver as-built drawings to the client.

At the end of the maintenance period the consultant will carry out a final inspection of the works and issue the final certificate for payment to the contractor.

3 STANDARDS FOR DESIGN

3.1 General

Codes of practice and standards should be used for new construction to achieve more consistent and predictable performance and to improve levels of safety.

Very commonly consultants use the minimum standards of codes, usually because of commercial pressures. Also, most codes are for general construction and not specific to the needs of critical infrastructure projects such as health-care facilities, telecommunications facilities, water and electrical facilities and national security facilities.

There is also the problem of building to unnecessarily high and expensive standards. Clients (in consultation with their consultants) should select, on informed and rational bases, appropriate design criteria for facilities of differing importance. Suggestions for buildings are made in the following sections 3.2 and 3.3 to assist in this process, but not to preempt such consultation and selection.

Clients should recognise the need to review, on an ongoing basis, the conditions of their facilities and their standards. Standards do change as knowledge increases.

3.2 Design Criteria for Wind

3.2.1 Basic Wind Speeds and Reference Pressures

Different codes and standards define and describe wind forces and speeds differently. Since Caribbean clients have to deal with different standards regimes it is important to be able to convert from one standard to another. The main parameters used in defining wind speeds are:

- averaging period
- return period
- height above ground
- upstream ground roughness
- topography

Thus, in the commonly-used OAS/NCST/BAPE "Code of Practice for Wind Loads for Structural Design"[10] 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 ....."*

3.2.2 Caribbean Uniform Building Code (CUBiC)[11]

Figure 1 at the end of this section shows a map of the Caribbean region with isolines of reference velocity pressures taken from CUBiC for 50-year return periods.

Table 1 at the end of this section gives the CUBiC reference pressures (50-year return periods) along with corresponding wind velocities for different averaging periods.

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[10]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.

[11]CUBiC Part 2 - Structural Design Requirements; Section 2 - Wind Load; 1985

3.2.3 Averaging Periods

Figure 2 at the end of this section presents graphs which may be used to convert wind speeds of one averaging period to speeds of another averaging period.

The OAS/NCST/BAPE "Code of Practice for Wind Loads for Structural Design" uses an averaging period of 3 seconds. CUBiC uses an averaging period of 10 minutes.

3.2.4 Return Period

The client, in consultation with (and advice from) its consultant, should make conscious decisions with respect to desired levels of safety for different facilities. These decisions can be translated into return periods. The longer the return period the greater the level of safety. Figure 3 at the end of this section presents graphs from the OAS/NCST/BAPE Code addressing this parameter. For most critical facilities, a return period of 100 years is the suggested minimum appropriate standard.

3.3 Design Criteria for Earthquake

Much less is known about the earthquake hazard than about the wind hazards in the Caribbean. Because of this, and because of the ongoing research in this field, there is the need for regular reviews of design criteria by the construction industry in general and consultants in particular. There may also be the justification for site-specific and project-specific studies for large or critical facilities.

For most projects, the guidance provided by existing standards and research papers would suffice. Some of these documents are listed below.

3.3.1 Caribbean Uniform Building Code (CUBiC)[12]

Table 2 at the end of this section gives the CUBiC zone factors (Z) for different locations in the region. The table also shows the corresponding values for the Uniform Building Code (USA) and the Structural Engineers Association of California (SEAOC) code.

3.3.2 PAIGH[13] Research

Figure 4 at the end of this section shows a map of the Eastern Caribbean region with isolines of accelerations due to earthquakes based on a recent research programme which was

[12]CUBiC Part 2 - Structural Design Requirements; Section 3 - Earthquake Load; 1985

[13]Instituto Panamericano de Geografía y Historia

completed *circa* 1994 and finally published in 1997[14]. It represents some of the latest thinking on the seismicity of the region.

It should be noted that, in comparison to the guidance in CUBiC:

- BVI, Antigua & Barbuda and Montserrat would warrant a Zone 4 rating (CUBiC Z = 1.00, SEAOC 1990 Z = 0.4);
- the whole of Trinidad would warrant a Zone 3 rating;
- Dominica would warrant a Zone 2+ rating;
- Grenada, St Lucia and St Vincent would warrant a Zone 2 rating.

Table 3 at the end of this section shows this information in comparison with the CUBiC, UBC and SEAOC factors.

3.3.4 Importance Factor

Earthquakes are not yet amenable to statistical analysis and to the determination of return periods in the same way as windstorms. Nevertheless the client, in consultation with the consultant, must still make conscious decisions with respect to desired levels of safety for different facilities. These decisions are translated into importance factors in codes and standards. These factors usually vary from 1.0 to 1.5. For critical facilities, an importance factor of 1.2 is the suggested minimum appropriate standard.

3.3.5 Concept

Satisfactory earthquake-resistant design requires more than the faithful following of the mathematical requirements of standards documents. Appropriate geometry or configuration of the overall building or structure and appropriate structural systems are critical for success.

3.3.6 Detailing

Good conceptual design and good analysis must be complemented by good detailing in order to achieve satisfactory performance of buildings and other facilities in earthquakes.

[14]Seismic Hazard in Latin America and the Caribbean - Final Report; Instituto Panamericano de Geografía y Historia; Volume 1 (JG Tanner, JB Shepherd); Volume 5 (JB Shepherd, JG Tanner, CM McQueen, LL Lynch); 1997

3.3.7 Moving the Goalposts

In most Caribbean islands critical facilities[15] operate in normal times with little or no spare capacity. In the aftermath of a major hurricane or earthquake the times are certainly not normal. In such circumstances it is vital that the critical facilities operate at close to optimum efficiency.

The conventional and traditional approach to earthquake-resistant design is to resist minor earthquakes without damage, to resist moderate earthquakes without structural damage (but tolerating non-structural damage) and to resist major earthquakes without collapse. In other words, emphasis is placed on saving lives, not on saving facilities. This would no longer do for critical facilities.

There are two aspects that must be addressed in the new, proposed paradigm for critical facilities - the improved performance of non-structural components and the mitigation of damage to load-bearing structures through the use of response-reducing devices.

Energy isolating and dissipating devices are no longer untried. Many successful installations have been completed in several countries. These devices protect buildings by limiting the energy entry at source (*eg* base isolation) or by providing energy-dissipating devices within the structure. By so doing it becomes feasible to move the goalposts with respect to performance expectations.

The aim is to design critical facilities so that they function with little degradation in efficiency in times of major earthquakes.

4 OTHER ISSUES

4.1 Forms and Systems and Materials

This is dealt with in more detail in Session A3.1 “Conceptual Design”.

4.2 The Influence of Available Construction Processes

This matter is dependent on the size, cost and importance of the project. Although it is sensible and conventional to utilise readily available processes in the design and construction of projects, this must not be an exclusive principle.

Such limitations would hamper the development of the construction industry. Progress can be made by introducing new methods and systems whenever the opportunity for so doing

[15] Examples are hospitals, electricity, water, telecommunications, international transport, fire service.

presents itself. Precast concrete, prestressed concrete, slip forming, pressure-injected piles are all cases of new forms of construction introduced to the Caribbean during the past five decades.

4.3 The Need to Satisfy the Contractor

Fairness in dealing with construction contractors leads to greater economy in the long run. If soils investigations are not carried out by the consultants the tenderers must cover themselves for unforseen conditions. If construction documents (drawings, schedules and technical specifications) are not complete or are delivered late, the planning of the construction is hampered. If genuine[16] "extras" are rejected by the consultants the word soon gets around to others in the industry.

4.4 The Need to Satisfy the Investor

The conscientious following of the processes described in Section 2 of this document would constitute a full service in most instances. If the design consultants receive normal fees these services should be provided. If the investor is unwilling to pay for a normal service, the consultant should advise on sensible reductions without compromising the essential integrity of the project.

[16] *ie* extras properly claimed in accordance with the conditions of contract and not overstated by the construction contractor in order to adopt a bargaining position.

Reference Wind Velocity Pressures
and
Wind Speeds
(50-year return period)
(taken from CUBiC)

Location	**q_{ref}** CUBiC	**10 min** CUBiC	**1 hr**	**1 min** (or "fastest mile")	**3 sec**
Antigua	0.82	37	35	45	56
Barbados	0.70	34	32	41	51
Belize - N Belize - S	0.78 0.55	36 30	34 29	43 37	54 45
Dominica	0.85	38	36	46	57
Grenada	0.60	32	30	38	47
Guyana	0.20	18	17	22	27
Jamaica	0.80	37	35	44	55
Montserrat	0.83	37	36	48	59
St Kitts/Nevis	0.83	37	36	48	59
St Lucia	0.76	36	34	43	57
St Vincent	0.73	35	33	42	56
Tobago	0.47	28	26	38	42
Trinidad - N Trinidad - S	0.40 0.25	26 20	25 19	31 25	39 30
Notes	q_{ref} = pressures in kilopascals (kPa)	wind speeds in metres per second (ms^{-1})			

Table 1

Z Values
(taken from CUBiC)
and Equivalent Seismic Zone Factors and Numbers

Territory	Z Value CUBiC & UBC 85	Z Factor UBC 1988 & SEAOC 1990	Zone Number SEAOC
Antigua	0.75	0.3	3
Barbados	0.375	0.15 - 0.2	2
Belize - (areas within 100km of southern border, ie including San Antonio and Punta Gorda but excluding Middlesex, Pomona and Stann Creek)	0.75	0.3	3
Belize - (rest of)	0.50	0.2	2+
Dominica	0.75	0.3	3
Grenada	0.50	0.2	2+
Guyana - (Essequibo)	0.25	0.1	1+
Guyana - (rest of)	0.00		
Jamaica	0.75	0.3	3
Montserrat	0.75	0.3	3
St Kitts/Nevis	0.75	0.3	3
St Lucia	0.75	0.3	3
St Vincent	0.50	0.2	2+
Tobago	0.50	0.2	2+
Trinidad - (NW)	0.75	0.3	3
Trinidad - (rest of)	0.50	0.2	2+

Table 2

Seismic Hazard Values for Structural Design Purposes in the Commonwealth Caribbean

(Compiled by Tony Gibbs)

Table 3

Regional Map of Wind-pressure Contours

(from CUBiC)

Figure 1

Wind-speed Variation with Averaging Period

(from Durst and Krayer-Marshall)

Figure 2

S_3 Factor for Return Period and Probabilities

(from OAS/NCST/BAPE Code)

Figure 3

Isoacceleration Map of the Eastern Caribbean

(from John Shepherd - PAIGH)

Figure 4

APPENDIX

DETAILED ENGINEERING

Check List for Designing to Counteract Natural Hazards (Earthquakes and Hurricanes)

This Appendix constitutes a comprehensive list of issues to be addressed in designing to counteract the effects of natural hazards. This is a very complex process, if done properly and thoroughly. Thus, check lists are invaluable to the exercise. For any particular project all of the items may not be relevant, but excluding items from a comprehensive list is always easier than adding relevant items to a short list.

1 Seismic and Hurricane Hazards
1.1 History
1.1.1 Earthquake
1.1.2 Hurricane

1.2 Geology

1.3 Tectonics

1.4 Design characteristics
1.4.1 Earthquake design characteristics
1.4.2 Hurricane design characteristics

2 Site Conditions
2.1 Soils
2.1.1 Liquefaction
2.1.2 Seismic characteristics

2.2 Topography
2.2.1 Landslide
2.2.2 Building on slopes
2.2.3 Topographic effect on wind speeds
2.2.3.1 Ridges
2.2.3.2 Valleys

2.3 Other Factors
2.3.1 Corrosive Environments
2.3.1.1 Coastal areas
2.3.1.2 Industrial and other chemical pollutants

3 The Client's Brief

3.1 Function

3.2 Cost

3.3 Reliability
3.3.1 Serviceability for different components of the facility
3.3.2 Safety for different components of the facility

4 Design Philosophy

4.1 Performance in moderate and frequent hazardous events
4.1.1 Protection of property
4.1.1.1 Cost of repairs should be minor

4.2 Performance in strong, rare, hazardous events
4.2.1 Saving lives
4.2.2 Repairable damage (very critical facilities in earthquake events)
4.2.3 Protection of all property in hurricanes

4.3 Critical areas or components of facilities

4.4 Post-yield behaviour of structural elements
4.4.1 Ductility
4.4.2 Energy absorption
4.4.3 Deformations

4.5 Building Envelope for Hurricanes
4.5.1 Windows, external doors and roof cladding

5 Choice of Form or Configuration

Poor design concepts can be made safe but are unlikely to perform really well in strong earthquakes

5.1 Failure modes
5.1.1 Redundancy
5.1.2 Accidental strength
5.1.3 Column capacities (and those of other vertical load-carrying elements) - New Zealand's "capacity design"
5.1.4 Designing for failure
5.1.4.1 Avoid failure in vertical, shear and compression elements
5.1.4.2 Avoid brittle failure

5.1.4.3 Avoid buckling failure
5.1.5 For hurricane forces design for repeated loads without degradation

5.2 Geometric issues
5.2.1 Simplicity and symmetry
5.2.2 Long buildings to be structurally broken (separation gaps of sufficient widths to avoid hammering in earthquakes)
5.2.3 Elevation shape
5.2.3.1 Sudden steps and setbacks to be avoided
5.2.4 Uniformity
5.2.4.1 Distribution of structural elements
5.2.4.2 Principal members to be regular
5.2.4.3 Openings in principal members to be avoided
5.2.5 Continuity
5.2.5.1 Columns and walls from roof to foundation (without offsets)
5.2.5.2 Beams free of offsets
5.2.5.3 Coaxial columns and beams
5.2.5.4 Similar widths for columns and beams
5.2.5.5 Monolithic construction
5.2.6 Stiffness and slenderness (h>4b)
5.2.6.1 Stiffness versus flexibility
5.2.6.2 Maintaining the functioning of equipment
5.2.6.3 Protecting structure, cladding, partitions, services
5.2.6.4 Resonance
5.2.7 Favourable and unfavourable shapes
5.2.7.1 Square
5.2.7.2 Round and regular polygons
5.2.7.3 Rectangular
5.2.7.3.1 Aspect ratios
5.2.7.4 **T** and **U** shaped buildings
5.2.7.4.1 Aspect ratios
5.2.7.4.2 Deep re-entrant angles
5.2.7.4.3 Establish structural breaks (create rectangular plan forms - see 5.2.2)
5.2.7.5 **H** and **Y** shaped buildings
5.2.7.5.1 Aspect ratios
5.2.7.5.2 Deep re-entrant angles
5.2.7.5.3 Establish structural breaks (create rectangular plan forms - see 5.2.2)
5.2.7.6 External access stairs
5.2.7.7 False symmetry - regular perimeter masking irregular positioning of internal elements
5.2.8 Soft storey
5.2.9 Cantilevers to be designed conservatively
5.2.10 Desirable roof shapes for hurricane resistance
5.2.10.1 Steep pitched roofs (20 - 40 degrees)

5.2.10.2 Hipped roofs are preferable
5.2.10.3 Gable roofs are an acceptable compromise
5.2.10.4 Mono-pitched roofs are undesirable
5.2.10.5 Boxed eaves recommended for overhangs exceeding 450mm
5.2.10.6 Parapets reduce wind uplift
5.2.10.7 Ridge ventilators reduce internal pressures

5.3 Distribution of horizontal load-carrying functions in proportion to vertical load-carrying functions (avoid the overturning problem)

5.4 Structural system to be agreed by design team
5.4.1 Moment-resisting frames
5.4.2 Framed tubes
5.4.3 Shear walls and braced frames
5.4.4 Mixed systems

6 Choice of Materials
6.1 Local availability

6.2 Local construction skills

6.3 Costs

6.4 Politics

6.5 Ideal properties
6.5.1 High ductility
6.5.2 High strength-to-weight ratio
6.5.3 Homogeneous
6.5.4 Ease of making connections
6.5.5 Durable

6.6 Order of preference for low-rise buildings
6.6.1 In-situ reinforced concrete
6.6.2 Steel
6.6.3 Reinforced masonry
6.6.4 Timber
6.6.5 Prestressed concrete
6.6.6 Precast concrete
6.6.7 Unreinforced masonry not recommended

6.7 Light-weight roof cladding of pitched roofs
6.7.1 Method of fixing critical to roof performance

7 Construction Considerations

7.1 Supervision

7.2 Workmanship

7.3 Ease of construction

8 Components

8.1 Base isolators and energy-absorbing devices (to be given consideration)

8.2 Foundations

8.2.1 Continuous

8.2.2 Isolated (to be avoided)

8.2.3 Piled

8.3 Movement joints

8.4 Diaphragms

8.5 Precast concrete

8.6 Welded beam-column joints for moment-resisting steel frames (to be avoided)

8.7 Shear walls and cross bracing

8.8 Hurricane straps, wall plates and connections

8.9 Joint details for roof trusses

8.10 Asbestos-cement cladding (unfavourable in hurricane situations)

9 Elements

9.1 Structure

9.2 Architecture

9.3 Equipment

9.3.1 Electrical feed to be kept clear of roof structure

9.3.2 Electrical feed to be routed underground within the property

9.4 Contents

10 Cost Considerations
10.1 Capital costs ignoring natural hazards (hypothetical, academic)

10.2 Capital costs including natural hazards

10.3 Maintenance costs

11 Analysis
11.1 Understanding the structural model

11.2 Torsional effects

11.3 Geometric changes
11.3.1 The P-delta effect

11.4 3-D analysis (required only for irregular structures)

11.5 Dynamic analysis (required only for complex structures)

11.6 Stress concentrations

11.7 Complexity of earthquake effects and inadequacies of sophisticated analytical methods

11.8 Effects of non-structural elements
11.8.1 Change in the natural period of the overall structure
11.8.2 Redistribution of lateral stiffness and, therefore, forces and stresses (this could lead to premature shear or pounding failures of the main structures and also to excessive damage to the said non-structural elements due to shear or pounding)

11.9 Soil-structure interaction
11.9.1 Critical but usually ignored or played down

12 Detailing
12.1 Compression members

12.2 Beam-column joints
12.2.1 Reinforced concrete
12.2.2 Structural steel :- all-welded construction

12.3 Reinforced-concrete frames

Inception Report

- the consultant's understanding and interpretation of the terms of reference;

- changes to the terms of reference since the start of the assignment;

- an appraisal of the available information and an outline of the consequential field investigations to be conducted so as to complement the information already obtained, including any special investigations which may be required;

- an outline of the programme for the remainder of the assignment.

Design Stage I Report

- the design standards and codes to be used on the project;
- the agreed design criteria for the project;
- preliminary design and drawings;
- outline specification;
- procurement procedures for the construction contractors and suppliers;
- conditions of contract - general and particular;
- cost estimates;
- an outline of the programme for the remainder of the assignment.