Manual for Caribbean Electric Utilities Addressing the Issue of the Mitigation of Damage Caused by Natural Hazards to Civil Works

Organization of American States
General Secretariat
Unit for Sustainable Development and Environment

USAID-OAS Caribbean Disaster Mitigation Project
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Contents

1 PREAMBLE

1.1 The Need for Special Attention to Natural Hazards

The problem of natural hazard damage mitigation should be one of conscious concern to Power Companies in the Caribbean. Consider the following:

- probabilities of occurrences of severe hurricanes, earthquakes and torrential rains are real;
- damage potential is increasing;
- insurance and reinsurance is becoming more expensive and may become difficult to obtain;
- there are few legally-enforceable civil/structural engineering design standards in the CARILEC universe;
- most standards and codes in common use do not adequately address the important question of non-structural elements;
- with appropriate design and construction techniques it is feasible to protect facilities so that they remain in operation after a natural-hazard event;
- protection costs are affordable;
- codes provide minimum standards which may not be sufficient for particular Power Company facilities.

As part of its contract with USAID/OAS-CDMP[1] to disseminate the experiences gained from the pilot project at LUCELEC[2] carried out for CARILEC (see 1.2), Consulting Engineers Partnership Ltd (CEP) was asked to prepare the present Manual which is described in section 1.3 below.

1.2 Caribbean Electric Utility Services Corporation (CARILEC)

CARILEC is an association of Caribbean electric utilities from Bermuda in the north to Guyana in the south, including utilities in French-speaking and Dutch-speaking territories. The business of the organisation, which has its offices in St Lucia, is to provide information, training, conferences and joint services to its members.

1.3 The Manual

The purpose of the Manual is to give guidelines on acceptable criteria and codes for design of structures, briefing and monitoring of consultants, performance specifications for procurement, vulnerability and maintenance of existing structures, all with special reference to the mitigation of damage due to natural hazards.

The Manual lists acceptable design criteria, codes of practice and standards that are currently available for use internationally and in the Caribbean relevant to the issue of protecting civil works against natural hazards. Thus the Manual contains performance specifications for materials and designs of new structures and buildings to mitigate the effects of natural hazards.

The Manual contains guidance to utilities on the contracting, briefing and monitoring of consultants engaged to undertake vulnerability analyses on existing facilities.

The Manual also contains information on the reduction of vulnerability of existing installations including routine and preventative maintenance and retrofitting.

1.4 In-house Resources and Outside Assistance

CARILEC member companies do not commonly use their in-house engineers to design/supply/build new civil works. Indeed, in general, the Power Companies do not usually employ in-house civil and structural engineers. Almost all new works to do with site development (roads, drainage, water supply, sewerage); buildings; machine foundations; masts and towers are contracted out to independent consultants or to design/supply/build contractors. The Manual, therefore, focuses on helping Power Companies in the contracting of outside consultants and in the procurement of civil works. There is, however, the question of existing works, equipment and services and how to reduce their vulnerability to the effects of natural hazards.

One of the important purposes of the Manual would be to guide the Power Company representative in the initial briefing of his consultants:

"If you do not take trouble at the beginning,
you will most certainly be given it before the end."
Sir Hugh Casson

The Power Company requires certain standards of reliability and performance, and its consultants and suppliers are usually capable of providing them. What is often lacking, however, is a clear articulation of those standards, performance criteria and expectations by the Power Company representative to consultants and suppliers. The Manual would facilitate communication and make it more reliable and consistent.

It is accepted that the construction industry has available to it a number of civil and structural engineers and other professionals skilled in the general fields of design and construction. However the needs of the Power Companies encompass all those general requirements and, in addition, include the special factors peculiar to the generation and distribution of electricity. These special factors need to be consciously spelt out in such a manner that there would be little room for misunderstanding on the part of consultants and suppliers.

It is rarely sufficient for a Power Company simply to employ good consultants and let them get on with the work. It is rarely sufficient for a Power Company simply to order supplies from reputable manufacturers and let them get on with delivery and installation. The briefing of consultants and the procurement of supplies requires the making of informed choices based on an appreciation of the implications of varying criteria for costs and performance.

Power Companies recognise the positive and sustained contribution they have to make to their communities. This demands that their civil and structural works perform in a reliable and predictable manner when impacted by hurricanes, floods and earthquakes. However, there is often a gap of understanding to be bridged between the Power Companies and their consultants and suppliers with respect to the performance expectations of civil works. It is in the interest of all parties that this should not happen, since electricity is a post-disaster asset of the first order and bad surprises must be minimised. This Manual should go some way towards bridging that gap.

1.5 Objectives

The objectives of the Manual include (inter alia):

- dissemination of the experience gained from previous natural disasters and from studying the vulnerability of electric utilities so as to reduce the adverse effects of future events;
- facilitating the inclusion of specific measures for the mitigation of disasters and related aspects of preparedness in the overall planning of Power Companies;
- help for senior Power Company representatives in understanding the nature and extent of the exposures to their properties posed by natural hazards;
- assistance in the reduction of the risks (within the limits imposed by economics) through informed decision making and planning;
- specific, formal, structured guidance on the briefing of consultants; the development of design criteria; the monitoring of consultants; the formulation of performance specifications for procurement of products not involving the use of consultants;
- the specific issues of vulnerability analysis of existing facilities and their retrofitting when such is indicated;
- the analysis of the vulnerability of existing works and equipment;
- the monitoring of signs of deterioration;
- the adequacy of design standards;
- when to call in a consultant to analyse vulnerability;
- the reduction of vulnerability of existing works and equipment;
- better maintenance practices and monitoring;

- setting of priorities for retrofitting;
- performance specifications for retrofitting.

The ultimate goal is to reduce the element of surprise by providing buildings, structures and civil works of predictable performance at affordable costs.

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2 GUIDANCE FOR POWER COMPANIES AND THEIR ADMINISTRATIVE OFFICERS

2.1 Role of the Power Company

2.1.1 To demand that facilities be designed, built and maintained to function during and immediately after hurricanes, earthquakes, torrential rains and other natural hazards of the levels of the agreed design events. (The technical professionals, hired as its consultants, are responsible for advising the Power Company of the hazards to which facilities will be exposed and the implications of choosing different design levels.)

2.1.2 To be responsible for the facility and to understand the implications of failure.

2.1.3 To oversee the procurement of goods and services.

2.1.4 To encourage dialogue between the administrators of the facility and its board of directors through the general manager or chief executive officer.

2.2 Archiving and Retrieval of Construction Records

2.2.1 Ensure that as-built drawings are produced for all new construction. (As-built drawings are useful for vulnerability assessments, repairs, additions, alterations and post-damage assessments.)

2.2.2 Document all repairs and replacements.

2.2.3 Duplicate as-built drawings for "working drawing" sets so that a "mint" as-built set is in the archives at all times.

2.3 Annual Reviews

2.3.1 Undertake a first, in-depth survey of the vulnerability of the facilities leading to recommendations and (if so indicated) retrofitting actions.

2.3.2 Carry out annual reviews:

2.3.2.1 Check implementation of recommendations
2.3.2.2 Identify overlooked items
2.3.2.3 Benefit from new knowledge
2.3.2.4 Identify deterioration
2.3.2.5 Review maintenance procedures

2.3.3 Consciously allow in the annual budget for the review process.

2.4 Background Reading

A useful primer on the subject of natural-hazard damage mitigation for essential facilities in the Commonwealth Caribbean is the PAHO document "MITIGATION".[3]

2.4.1 "MITIGATION" provides background information on natural hazards.

2.4.2 It provides a non-specialist's guide to design and vulnerability surveys.

2.4.3 It includes a discourse on design against multiple hazards.

2.5 Power Companies' Support for Damage Mitigation Issues

There is a need to change the fatalistic approach to disasters which, too often, accompany natural hazards. No longer can Caribbean countries tolerate extensive damage and destruction by hurricanes and earthquakes. power companies can play an important role in this campaign not only by example but also by giving support and encouragement to the efforts of others in the following related activities:

2.5.1 Code development and enforcement

2.5.2 Research into natural hazards (Reference: *Primer on Natural Hazard Management in Integrated Regional Development Planning*. OAS/USAID)

2.5.3 Continuing education programmes for construction industry practitioners

2.5.4 Natural hazard impact assessments (NHIA)

2.5.5 Liaison with donor and lending agencies on performance standards

2.5.6 Independent audits

2.6 Responsibilities

The Power Companies should discuss with their design professionals (engineers and architects) the allocation (or reallocation) of responsibilities with a view to eliminating gaps in the process, such as conscious attention to the safety of the non-structural components of the building envelope. This may well lead to a reassessment of the traditional fee structures.

2.7 Quality Assurance

The system of check consultants (*bureaux de controle*), routinely used in French territories, is proposed. Such a system is also used, with variations, in Colombia. It has indeed been used on several major projects in the Commonwealth Caribbean, principally at the instigation of catastrophe-insurance providers. It is to be recommended. Check consultants are independent of the design consultants. It is well recognised that quality assurance is more effective where checking is done independently of creating. The system mentioned above formalises the process.

2.8 General Admonition

The Power Company should endeavour to take due cognizance of its consultants' recommendations with regard to the design, construction and maintenance of facilities; particularly with regard to their proper functioning during and immediately after hurricanes, earthquakes, torrential rains and other natural hazards.

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3 SELECTING CONSULTANTS

3.1 Two Critical Characteristics

3.1.1 Precise professional performance specifications cannot be written. The interpretation of terms of reference will vary from firm to firm and, therefore, different levels of service are inevitable.

3.1.2 Successful consulting engineering services depend on a sufficient amount of time being spent by competent and knowledgeable persons in an efficient manner on the assignment. This translates into adequate compensation. Inadequate compensation eventually leads to inadequate engineering and greater life-cycle costs.

3.2 Selection Criteria

3.2.1 Qualification and experience of firms and/or principal players

3.2.2 Specific knowledge of designing against natural hazards within the design team

3.2.3 Capacity and work-load of consultants

3.2.4 Local knowledge and presence

3.2.5 Professional independence and integrity

3.2.6 Cost of services

3.3 Selection Procedures

3.3.1 Draft the terms of reference.

3.3.2 Draw up a short list of not more than four consulting engineering firms.

3.3.3 Request proposals which should contain:

- 3.3.3.1 past experience of projects of a similar nature
- 3.3.3.2 details of organisation, project control and financial control
- 3.3.3.3 size and responsibilities of staff
- 3.3.3.4 type of organisation and managerial method proposed for the execution of the work
- 3.3.3.5 quality assurance procedures
- 3.3.3.6 knowledge of local conditions and local resources
- 3.3.3.7 technical approach to the project
- 3.3.3.8 availability of resources
- 3.3.3.9 approach and commitment to technology transfer

3.3.4 Assess proposals, negotiate with the selected firm and conclude an agreement.

3.3.5 As an alternative to the competitive method outlined in items 3.3.2 to 3.3.4 the Power Company may chose to select a consultant based on first-hand knowledge and past relationships. This is often the safest approach.

4 BRIEFING AND COORDINATING CONSULTANTS

4.1 Specific Discussion on Natural Hazards and Agreement of Performance Expectations

Experience has shown that the design against natural hazards is not something that Power Companies can take for granted. At the outset the representatives of the Power Company should hold discussions with its consultants and clearly articulate the policy position of the company with respect to natural hazards and the performance expectations in the event of differing levels of severity of hurricanes, earthquakes, torrential rains and other phenomena.

4.2 Steps in the Monitoring of Consultants and Approval Stages

4.2.1 Inception report

4.2.2 Preliminary design and cost estimates

4.2.3 Review and "sign off" on agreed mitigation measures

4.2.4 Tender documents

4.2.5 Approved list of tenderers (contractors)

4.2.6 Contract award

4.2.7 Monthly reports during construction

4.2.8 Taking possession of constructed facility and the maintenance period

4.2.9 Final certification and receipt of all manuals and as-built drawings

5 DECIDING ON DESIGN CRITERIA

5.1 General

Codes of practice and specifications should be used for new construction, for alterations to existing facilities, for major maintenance and for retrofitting of existing facilities to improve levels of safety.

Very commonly consultants use the minimum standards of codes, usually because of commercial pressures. Most codes are for general construction and not specific to Power Company needs.

There is also the problem of building to unnecessarily high and expensive standards. Power Companies (in consultations with their consultants) should select, on informed and rational bases, appropriate design criteria for facilities of differing importance.

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

Codes of practice and specifications apply not only to new buildings but also to alterations and major renovations of existing buildings.

5.2 Hurricane

5.2.1 Basic wind speeds and reference pressures

Different codes and standards define and describe wind forces and speeds differently. Since CARILEC companies have to deal with different standard 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 and topography

Thus, in the commonly-used OAS/NCST/BAPE "Code of Practice for Wind Loads for Structural Design" 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 30 m above the ground in an open situation ....."*

5.2.2 Caribbean Uniform Building Code (CUBiC)

Figure 1 in Appendix II shows a map of the Caribbean region with isolines of reference velocity pressures taken from CUBiC for 50-year return periods.

Table 1 in Appendix II gives the CUBiC reference pressures (50-year return periods) along with corresponding wind velocities for different averaging periods.

5.2.3 Averaging periods

Figure 2 in Appendix II presents graphs which may be used to convert wind speeds of one averaging period to speeds of another averaging period.

5.2.4 Return period

The Power Company, in consultation with (and advice from) its consultant, should make conscious decisions with respect to desired levels of safety for different facilities. These decisions are translated into return periods. The longer the return period the greater the level of safety. Figure 3 in Appendix II presents graphs from the OAS/NCST/BAPE Code addressing this parameter.

5.3 Earthquake

5.3.1 Caribbean Uniform Building Code (CUBiC)

Table 2 in Appendix II 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).

5.3.2 Dr John Shepherd's research

Figure 4 in Appendix II shows a map of the Eastern Caribbean region with isolines of accelerations due to earthquakes based on a three-year research programme which was completed in 1994 and representing some of the latest thinking on the seismicity of the region.

It should be noted that:

- 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 3/2 rating;
- Grenada, St Lucia and St Vincent would warrant a Zone 2 rating.

Table 3 in Appendix II shows this information in comparison with the CUBiC, UBC and SEAOC factors.

5.3.4 Importance factor

Earthquakes are not amenable to statistical analysis and return periods in the same way as windstorms or rain. Nevertheless The Power Company, in consultation with its 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.

5.4 Torrential Rain

5.4.1 Lirios' curves

Intensity-duration-frequency curves have been developed for several territories in the region and may be available through the Caribbean Meteorological Institute in Barbados. A sample is given at Figure 5 in Appendix II.

5.4.2 Return period

Traditionally, quite short return periods have been selected for design rain storms. It was quite common for facilities to be designed for 1-in-20-year storms. Much damage and disruption is caused with increasing frequency by torrential rains. There needs to be a reassessment of this design criterion.

5.4.3 Changing conditions

The other factor affecting rain runoff and flooding is upstream development outside of the control of Power Companies. It is not unlikely that well-designed drainage systems prove to be inadequate some time after they have been implemented because of greater runoff than could reasonably have been anticipated at the time of design. This typically happens when land use upstream is changed due *eg* to urban expansion. Therefore it is appropriate to adopt a conservative approach to the selection of rainfall design criteria.

5.5 Storm Surge and Tsunami

5.5.1 Storm surge

This complex phenomenon is of interest for coastal sites. Computer models are available for developing storm-surge scenarios for coastlines. One such model is TAOS (The Arbiter of Storms) developed by Charles C Watson and tailored for the Caribbean under the USAID/OAS-CDMP programme.

5.5.2 Tsunami

Figure 6 in Appendix II shows a credible scenario from a likely eruption of the Kick 'em Jenny submarine volcano just north of Grenada.

5.5.3 Advice

The studies of both of these hazards are highly specialised subjects for which expert advice should be sought for all low-lying, coastal developments.

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6 REVIEWING VULNERABILITY AUDITS AND SETTING IMPLEMENTATION PRIORITIES

6.1 Vulnerability Audit

Reference should be made to the following documents for full descriptions of vulnerability audits of CARILEC companies:

6.1.1 Buildings and civil works

- Vulnerability Audit, St Lucia Electricity Services Ltd, Inception Report, September 1994, Consulting Engineers Partnership Ltd
- Vulnerability Audit, St Lucia Electricity Services Ltd, Final Report, July 1995, Consulting Engineers Partnership Ltd

6.1.2 Transmission and distribution

- Hurricane Vulnerability Assessment of the St Lucia Electricity Services Ltd's Transmission and Distribution Systems, September 1994, McLean Engineering Company Inc
- Hurricane Vulnerability and Risk Analysis of the VINLEC Transmission and Distribution System, July 1996, Applied Research Associates Inc

6.1.3 Hydroelectric installations

- Natural Hazards Vulnerability of the Dominica Hydroelectric Expansion Project, April 1995, Jerome V DeGraff

6.1.4 Hurricane damage

Useful post-disaster information and assessments can be obtained from the report:

- Case Study of the Effects of Hurricane Luis on the Buildings and other Structures of the Electricity Section of the Antigua Public Utilities Authority, February 1996, Consulting Engineers Partnership Ltd

6.2 Priorities

This issue can only be addressed with respect to a particular Power Company. Damage mitigation is best done in a phased programme so as not to disrupt the principal functions of the company. Further, damage mitigation is an ongoing exercise and not a one-time, crash programme. It ought to become an integral part of the culture of the company.

The speed with which the initial, catch-up phase proceeds depends on financial resources, the seriousness of the problem and the size of the problem. Techniques are available for assisting with the decision-making process when determining priorities. Such techniques often involve cost-benefit analyses and are increasingly interwoven with considerations of business-interruption insurance.

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7 RETROFITTING AND MAINTENANCE (OR ABANDONMENT) OF EXISTING FACILITIES

7.1 Maintenance, Repairs and Replacement as a Tool for Mitigation

7.1.1 Ensure that an adequate maintenance programme is in place. The maintenance budget should be of the order of 4% of the current value of the building/facility per annum and should address:

> 7.1.2.1 metal-work and timber-work
> 7.1.2.2 equipment for occasional use (stand-by) to be regularly tested by its periodic use
> 7.1.2.3 repairs leading to moderate improvements
> 7.1.2.4 replacements leading to significant improvements (repair v replacement is an economic issue to be addressed in this exercise)

7.1.2 Regular staff training in the use and operation of equipment

7.2 Other Issues

To maintain a good relationship with the insurance industry and to benefit from more favourable catastrophe-insurance premiums, high quality maintenance programmes should be adhered to by Power Companies.

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8 NEW PROJECTS

8.1 Construction Projects

8.1.1 Most such projects would involve outside consultants. The procedures described in Section 3 of this Manual will assist in the process of selecting those consultants. Further, the monitoring of the project (through monitoring the work of the consultants), will be informed by Section 4 of this Manual.

8.1.2 One of the most important functions of the Power Company's officers is deciding on the appropriate levels of safety for the planned facilities. This is addressed in Section 5 of this Manual.

8.2 Procurement of Equipment and Prefabricated Goods

8.2.1 Often these items are handled by the in-house staff of the Power Company. It is therefore even more important that care be taken in specifying the performance standards with respect to natural hazards when preparing tender documents.

8.2.2 There may be some occasions when it would be appropriate to employ a specialist consultant to write the clauses for natural hazard performance. It may also be possible to have general specifications covering this issue. In such a situation some care and judgement would need to be exercised to ensure applicability for each specific case.

8.3 Insurance Issues

8.3.1 The role of the insurer is ideally to provide protection to the Power Company for events beyond reasonable design levels. Insurance premiums should logically be related to:

> 8.3.1.1 the degree of quality control in place at the design phase;
> 8.3.1.2 the degree of quality control in place throughout the construction phase;
> 8.3.1.3 the degree of quality control in place during the useful life of the facility by way of adequate maintenance.

8.3.2 To achieve the best relationship with the insurer the Power Company should consider engaging in dialogue with the insurer at the initial planning stages of the project. This is certainly the approach adopted on projects destined to be insured through the Factory Mutual system which offers the most-favourable premium rates.

8.4 Detailed Engineering

Appendix III is included in this document, not for the direct use by Power Company personnel, but possibly for use by the consultants to the Power Company. It 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.

It is recommended that Appendix III be issued by Power Companies to their consultants when embarking on new projects, extensions to existing facilities and major renovations.

Footnotes

1. Caribbean Disaster Mitigation Project, funded by the United States Agency for International Development and managed by the Organization of American States

2. St. Lucia Electricity Services Ltd.

3. Mitigation: *Disaster Mitigation Guidelines for Hospitals and other Health Care Facilities in the Caribbean.* Co-authored by Mr. Tony Gibbs, Dr Jose Grases and Mr. James Williams and coordinated by Dr. Jean Luc Poncelet, PAHO 1992.

APPENDIX I: Catalogue of Resource Providers

1. The Organisation of American States (OAS)
2. Caribbean Electric Utility Services Corporation (CARILEC)
3. Caribbean Disaster Emergency Response Agency (CDERA)
4. University of the West Indies (UWI) - Faculty of Engineering and the Seismic Research Unit (SRU)
5. University of Technology, Jamaica (UTEC) and the University of Guyana (UG)
6. Council of Caribbean Engineering Organisations (CCEO) and its constituent member bodies
7. Association of Commonwealth Societies of Architects in the Caribbean (ACSAC) and its constituent member bodies

8. Consulting firms specialising in natural hazards and in designing against them
9. Individual specialists in natural hazards and in designing against them
10. Building Research Establishment, UK (BRE) and other international organisations
11. Statutory bodies and government agencies involved in science and technology
12. Pan American Health Organisation (PAHO) - Emergency Preparedness & Disaster Relief Coordination Programme
13. United States Agency for International Development (USAID) - Office for Foreign Disaster Assistance (OFDA)

APPENDIX II

Table 1: Reference Wind Velocity Pressures and Wind Speeds (50-year return period)

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	0.40	26	25	31	39

Trinidad - S	0.25	20	19	25	30
Notes	q_{ref} = pressures in kilopascals (kPa)	wind speeds in metres per second (ms^{-1})			

Table 2: Z Values and Seismic Zone Coefficients

Territory	Z Value CUBiC & UBC 85	Z Factor UBC 1988 & SEAOC 1990	Zone Number
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	0.50	0.15 - 0.2	2
Dominica	0.75	0.3	3
Grenada	0.50	0.15 - 0.2	2
Guyana (Essequibo) Guyana (rest of)	0.25 0.00	0.1	1
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	0.15 - 0.2	2
Tobago	0.50	0.15 - 0.2	2

Trinidad (NW)	0.75	0.3	3
Trinidad (rest of)	0.50	0.15 - 0.2	2

Table 3: Seismic Hazard Values for Structural Design Purposes Commonwealth Caribbean (Compiled by Tony Gibbs)

				PAIGH		PAIGH/TG		Equivalent		Cor
	CUBiC Z values 1985	Equivalent Zone Number (SEAOC 80)	Equivalent Z factor (UBC 88)	isoacceleration lines		Z factor	Zones	Zone No	Z factor	Zone
Country				max	min	1993/94	1993/94	(SEAOC 80)	(UBC 88)	(SEA 80
Anguilla				300	250	0.500	2.5	2.5	0.20	
Antigua & Barbuda	0.750	3	0.30	850	450	1.000	4	4	0.40	
Bahamas - southern				115	70					
Barbados	0.375	2	0.15	225	175	0.375	2	2	0.15	
Belize - north	0.500	2.5	0.20	200	120					
Belize - south	0.750	3	0.30	240	200					
British Virgin Islands				550	450	1.000	4	4	0.40	
Cayman Islands				160	80	0.375	2	2	0.15	
Cuba				250	80					
Dominica	0.750	3	0.30	300	250	0.500	2.5	2.5	0.20	
Dominican Republic				425	225					
Grenada	0.500	2.5	0.20	175	125	0.375	2	2	0.15	
Guyana - Essequibo	0.250	1.5	0.10	130	90					
Guyana - remainder	0.000	0	0.00	90	80					
Haiti				250	125					
Jamaica	0.750	3	0.30	260	150					
Montserrat	0.750	3	0.30	600	400	1.000	4	4	0.40	
Puerto Rico				350	240			4	0.40	

St Kitts & Nevis	0.750	3	0.30	450	300	0.750	3	3	0.30	
St Lucia	0.750	3	0.30	175	150	0.375	2	2	0.15	
St Vincent & the Grenadines	0.500	2.5	0.20	175	100	0.375	2	2	0.15	
Trinidad - NW	0.750	3	0.30	370	300	0.750	3	3	0.30	
Trinidad - remainder	0.500	2.5	0.20	370	300	0.750	3	3	0.30	
Tobago	0.500	2.5	0.20	300	270	0.500	2.5	2.5	0.20	
Turks & Caicos Islands				160	80					

Notes:

- In the Zone columns 1.5 means between 1 and 2
- In the Zone columns 2.5 means between 2 and 3
- CUBiC = Caribbean Uniform Building Code
- SEAOC = Structural Engineers Association of California
- UBC = Uniform Building Code (ICBO)
- ICBO = International Conference of Building Officials
- PAIGH = Pan American Institute of Geography and History
- PAIGH/TG = PAIGH's research (by Dr Shepherd) interpreted by Tony Gibbs

Source: *Seismic Hazard Values for Structural Design Purposes*, Commonwealth Caribbean, Compiled by Tony Gibbs (22-Jan-99)

Figure 1: Regional Map of Wind-pressure Contours (from CUBiC)

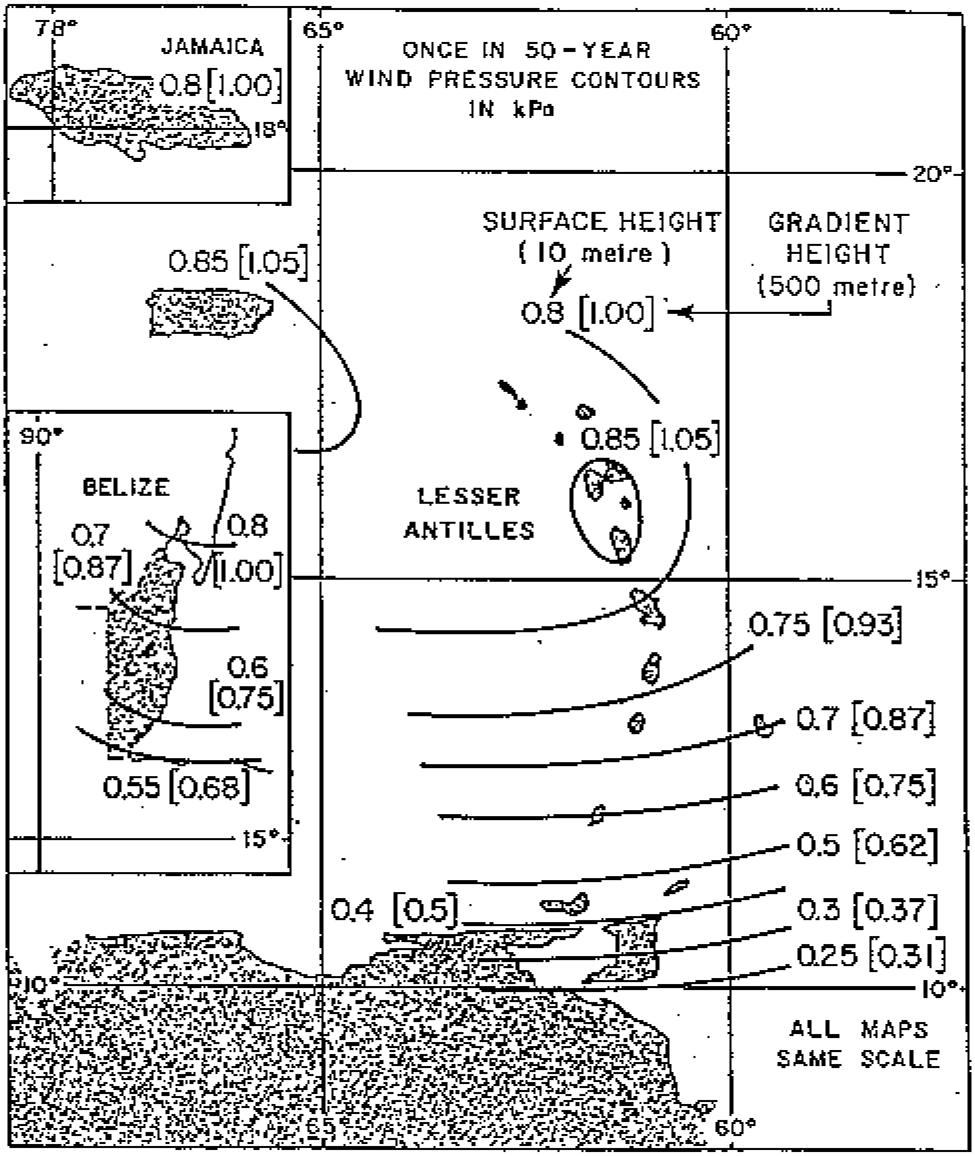
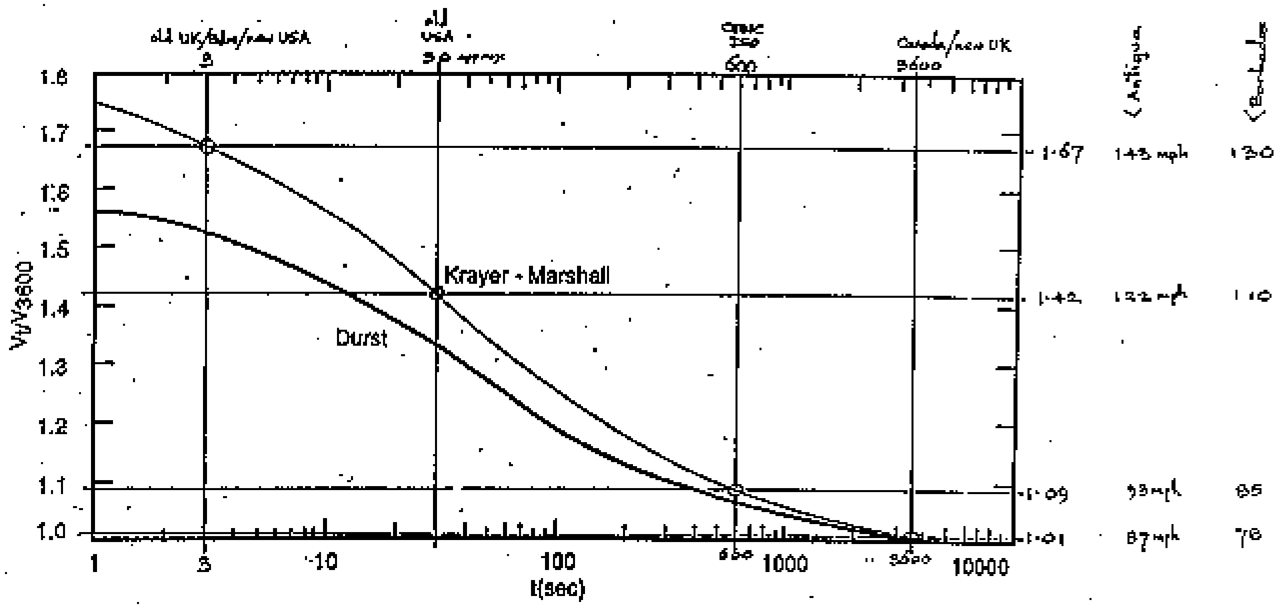


Figure A200.1 Map of Region of Application

Figure 2: Durst and Krayer-Marshall Graphs (wind-speed variation with averaging period)



Ratio of Probable Maximum Speed Averaged over *t* Seconds to Hourly Mean Speed

Source: Ref. 4

Figure 3: S_3 Factor for Return Period and Probabilities (from OAS/NCST/BAPE Code)

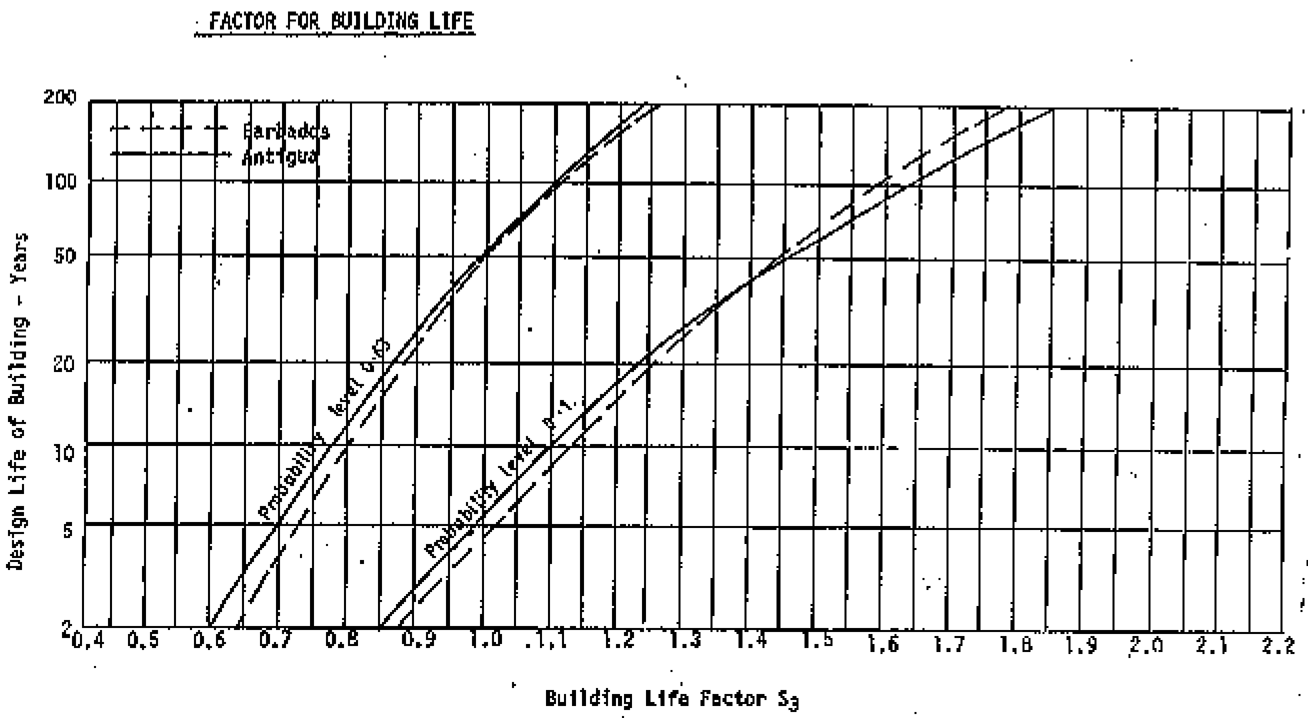


Figure 4: Isoacceleration Map of the Eastern Caribbean (from John Shepherd - PAIGH)

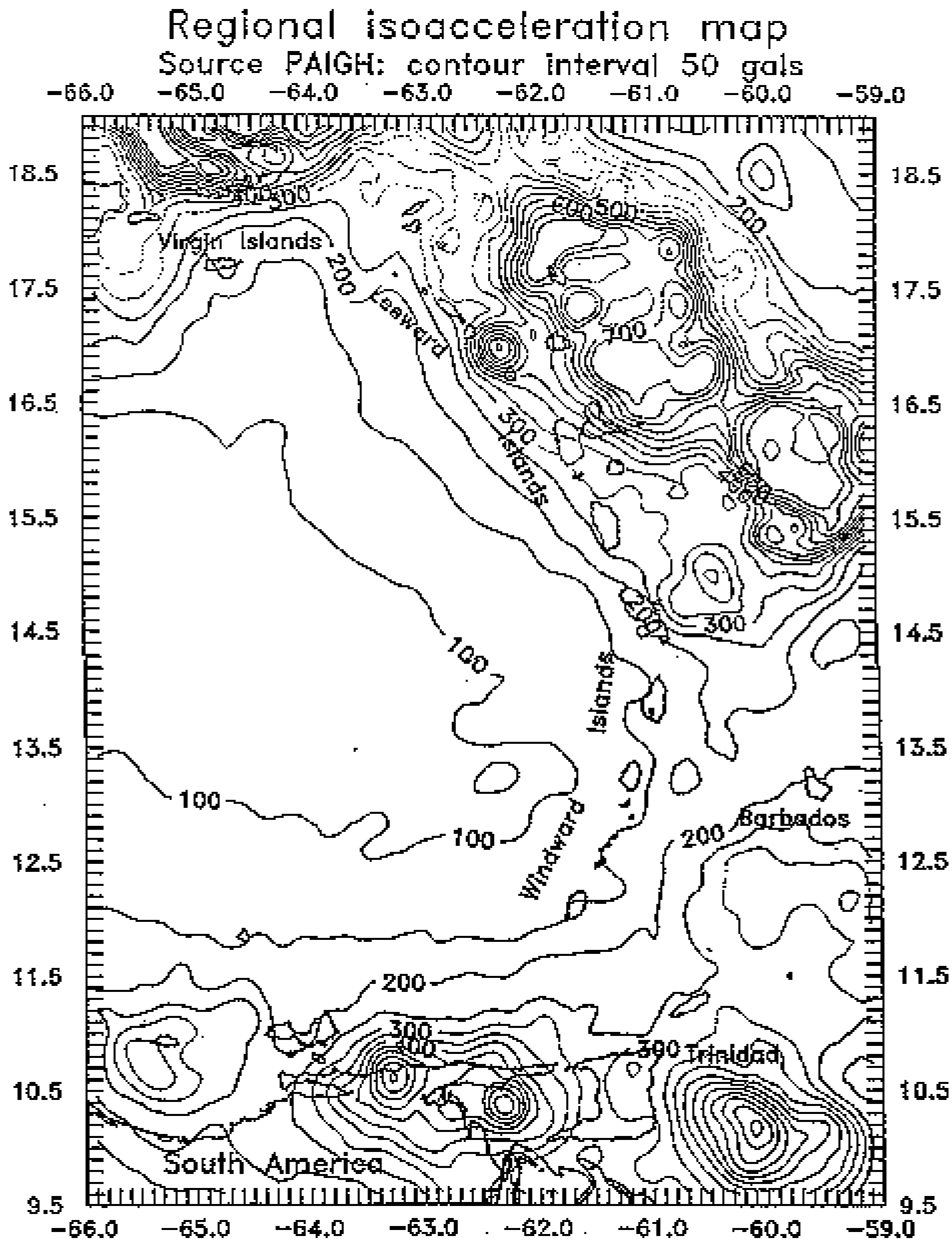


Figure 5: Rainfall-Duration-Frequency Curves for Seawell Airport, Barbados (Based on recording rain-gauge data for the period 1942-70. Station elevation = 183 feet above MSL) (from Lirios)

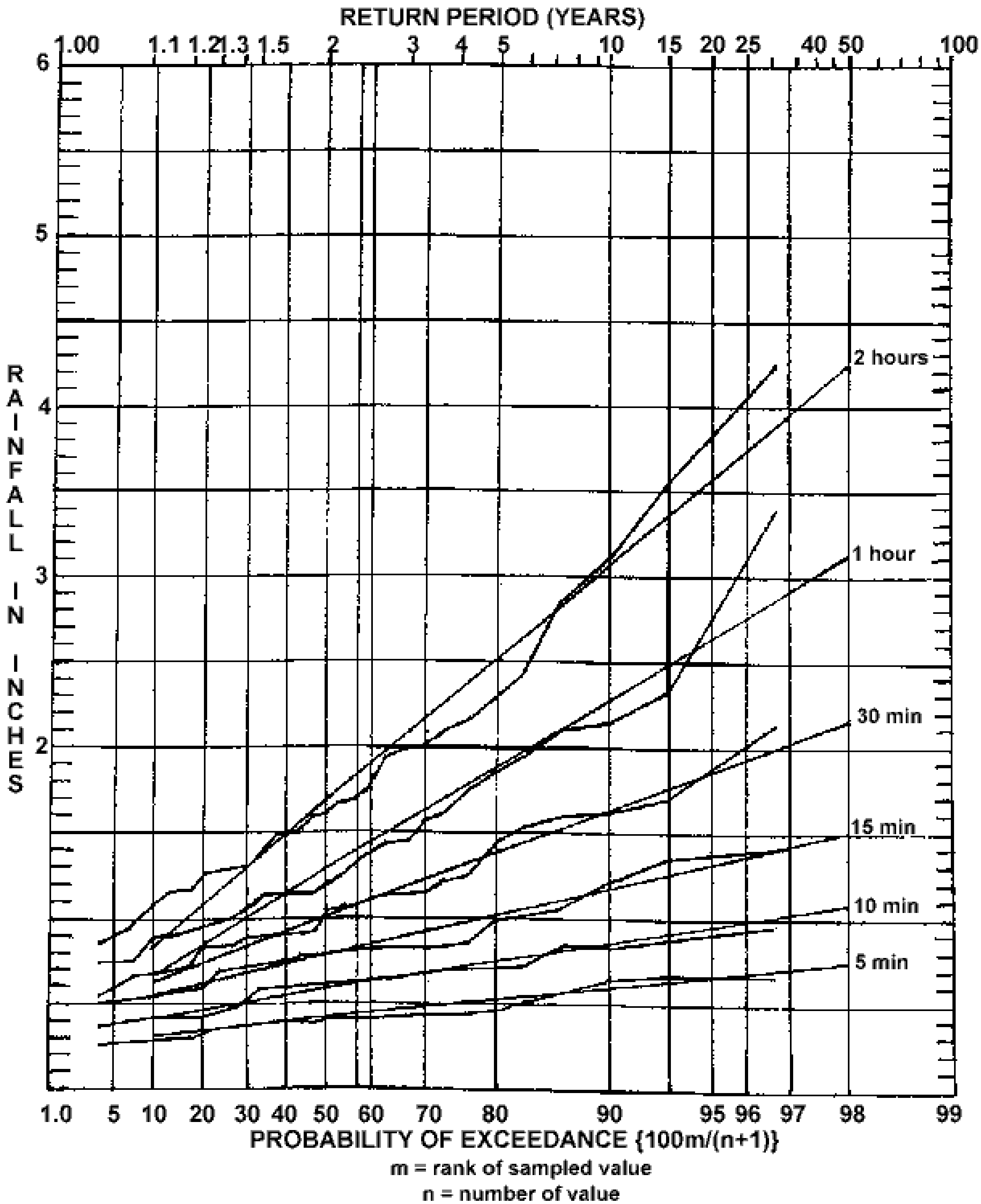
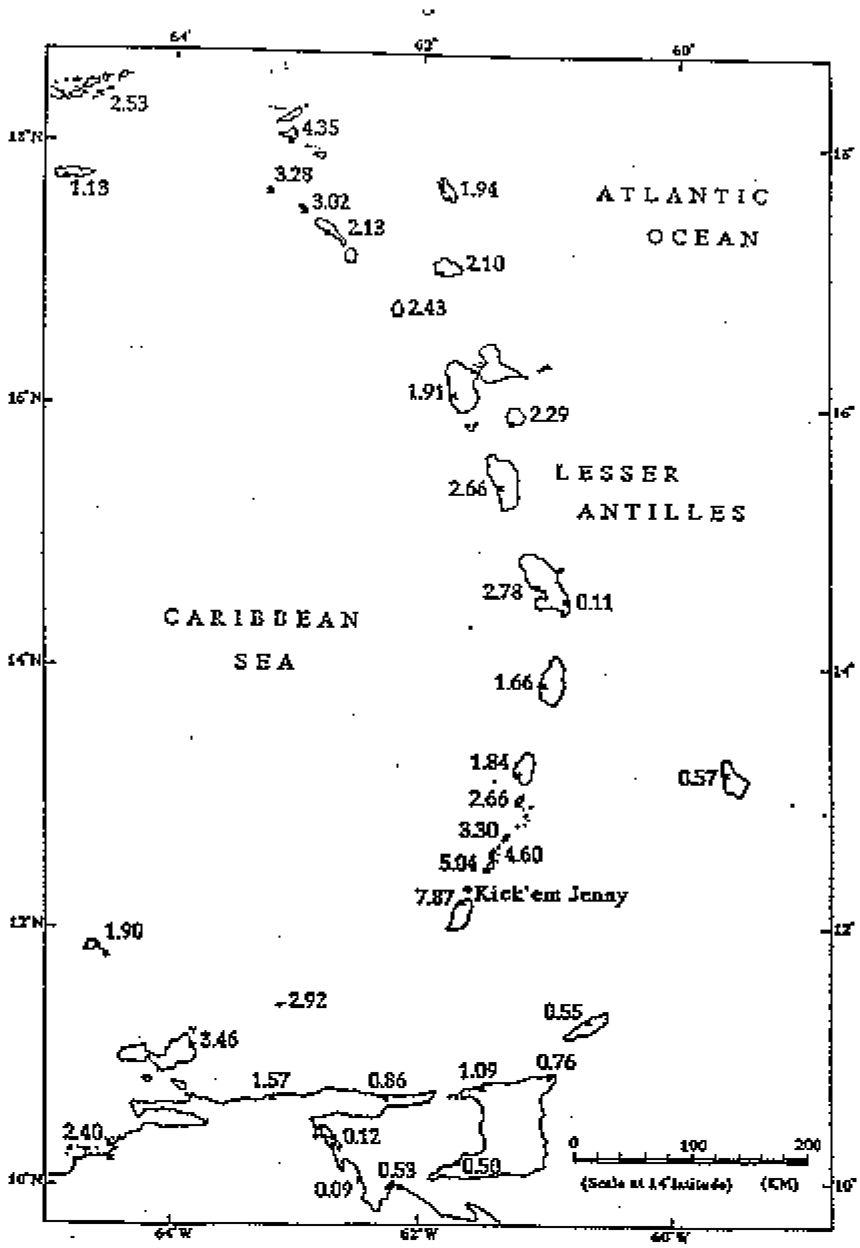


Figure 6: Tsunami Heights for Realistic Kick 'em Jenny Eruption (from Martin Smith & John Shepherd)



Final run-up values in metres for a 'realistic' scenario event at Kick'em Jenny (VEI = 3).

APPENDIX III: Check List for Designing to Counteract Earthquakes, Hurricanes and Torrential Rains

1 Seismic, Hurricane and Rain Hazards

1.1 History

- 1.1.1 Earthquake
- 1.1.2 Hurricane
- 1.1.3 Torrential rain

1.2 Geology

1.3 Tectonics

1.4 Design characteristics

- 1.4.1 Earthquake design characteristics
- 1.4.2 Hurricane design characteristics
- 1.4.3 Design characteristics for torrential rains

2 Site Conditions

2.1 Soils

- 2.1.1 Liquefaction
- 2.1.2 Seismic characteristics

2.2 Topography

- 2.2.1 Land slide
- 2.2.2 Building on slopes
- 2.2.3 Topographic effect on wind speeds
    - 2.2.3.1 Ridges
    - 2.2.3.2 Valleys
- 2.2.4 Flood prone areas
    - 2.2.4.1 Torrential rains
    - 2.2.4.2 Storm surge
    - 2.2.4.3 Tsunami

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 Power Company'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 and torrential rains

4.3 Critical areas or components of facilities

4.4 Post-yield behavior 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
5.2.3 Elevational 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 - see table of pros and cons
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 Diagrams of favourable and unfavourable shapes (see attached)

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 Ideal to establish structural breaks (create rectangular plan forms)

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 Ideal to establish structural breaks (create rectangular plan forms)

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

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

12.4 Non-structural walls and partitions

12.5 Shelving

12.6 Mechanical and electrical plant and equipment

12.6.1 Securely fastened to the structure
12.6.2 Pipework

13 Construction Quality

14 Maintenance

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