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ABSTRACT

Dozens of natural disaster shelters (mostly schools) in five Caribbean islands were assessed as to their vulnerability and the needed retrofitting to upgrade them. This report provides retrofit consultants with terms of reference and building design criteria for withstanding various natural disasters, as well as estimated global costs of various retrofitting needs of those properties deemed to be vulnerable to natural hazards. Information to help in decision making on the appropriate levels of safety for the planned facilities is also provided. Appendices provide checklists for vulnerability surveys of non-structural components for hurricanes and earthquakes; and a checklist for designing facilities to help mitigate the effects from earthquakes, hurricanes, and torrential rains. (GR)

USAID

Organization of American States

E C H O

Vulnerability Assessment of Shelters in the Eastern Caribbean Retrofitting Terms of Reference for Consultants Standards Global Estimates

Organization of American States General Secretariat

Unit for Sustainable Development and Environment

USAID-OAS Caribbean Disaster Mitigation Project

OAS-ECHO Project to Reduce the Vulnerabilityof School Buildings to Natural Disasters

October 1998

This report was prepared by
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CEP

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1 INTRODUCTION

1.1 The Purpose of the Project

Throughout the world, including the Caribbean, natural hazards cause as much damage to educational facilities as they do to buildings of less importance. This is both regrettable and avoidable. Educational facilities deserve special attention because of their roles during the active periods of storms and also as post-disaster assets.

It is traditional for schools to be used as hurricane shelters. It goes without saying, therefore, that the damage and destruction of schools would put the sheltered population at risk during severe storms. Also, the use of school buildings for temporary housing after hurricanes would not be facilitated by damage and destruction of such schools. The longer-term problem of loss of educational facilities is arguably even more severe. If the children are not at school the parents' work is often adversely affected (in part because of "baby-sitting" problems). There is also the inevitable disruption of the pupils' educations.

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.

The Caribbean Development Bank (CDB) proposes to assist its borrowing members in reducing the vulnerability of designated shelters to natural hazards. The initial screening of these designated properties has been carried out in participating CDB member countries through the auspices of the Organisation of American States (OAS) using CDMP and ECHO funding.

It is recognised that the suitability of properties for use as emergency shelters depends on several factors other than structural safety. Some of these factors are location, size, water storage and supply, sanitary facilities, kitchen facilities, standby power and telecommunications within the facility and externally. Most of these issues are already being addressed by other agencies. The focus of this document is on the physical vulnerability of the built facilities to wind forces, seismic forces and torrential rain.

1.2 Terms of Reference

The portions of the overall Terms of Reference (ToR) relevant to the subjects of the present document are:

- Development of terms of reference for the consultants who will be contracted for the retrofit work, including the detailed investigations that will be required under the CDB-funded projects
- Determination of standards for retrofitting and for new construction
- Global cost estimates for retrofitting

1.3 Issues Addressed in other Reports under this Assignment

Five separate country reports have been issued for Anguilla, Antigua & Barbuda, Dominica, Grenada and St Kitts & Nevis. These reports covered the vulnerability surveys of shelters in the five countries. The issues addressed were:

- Preliminary assessment and screening of properties identified by participating governments for the purpose of classifying the properties with respect to their retrofit needs
- The preparation of survey forms to be applied by local engineers employed by the participating

governments

The forms were to be applied to up to 20 properties per country. The forms contained a section on wind resistance, amended from the WIND-RITE form of IIPLR, and an earthquake resistance section, based on the work of Ahmed F Hassan (ACI Journal January-February 1997).

- The consultant prepared a workplan for the application of the survey forms by the local engineers or other technical personnel. These local personnel were assigned by each participating country to work with the consultant. The consultant trained the selected local personnel in the application of the forms and periodically monitored the progress and quality in the application of the survey forms.
- For school properties in Antigua & Barbuda, Dominica and St Kitts & Nevis the investigation was to establish, principally by interview and follow-up site visits:
    - what damage was suffered by the schools from Hurricanes Luis and Marilyn;
    - what type of repairs or reconstruction have taken place;
    - what standards were used in the repairs or reconstruction related to wind and earthquakes.
- The consultant carried out field visits in each of the participating countries. The field visits were planned and executed with the participation of the local personnel. Prior to the field visits, the consultant reviewed the completed forms.
- During these field visits, the consultant continuously articulated the issues being observed in determining vulnerability; the relative importance of various factors such as location, geometry, materials of construction, detailing; the differences between wind and earthquake vulnerability; *etc.* For each of the participating countries the consultant developed a classification (screening) of all identified properties. The classification achieved a broad-brush appreciation for the vulnerabilities of the individual buildings to wind and earthquake events and the suitability of the properties for inclusion in a CDB retrofitting project.

As articulated above, an important objective of this project is technology transfer and the broadening of the pool of "disaster mitigation" engineers in the region. Therefore, the active involvement of local personnel was essential. To further this goal it is intended to hold a workshop for the participants in the surveys to review the methodology and the results of the country exercises.

1.4 An Issue not Addressed in the Terms of Reference

While examining the dozens of shelters (most of which were schools) in the 5 Eastern Caribbean states it became evident that little or no attention is paid to architectural design issues in the narrow sense of the term. Eastern Caribbean children spend 6 hours a day, 5 days a week, 40 weeks a year for 10 years in the environments of their schools. Those environments influence their thinking and their perceptions of what is worthwhile. The schools which Eastern Caribbean students are doomed to study in and gaze upon are on the whole without quality.

The single-minded pragmatism of those responsible for capital works projects needs to be tempered if spiritual quality is to be introduced into the built surroundings of the education sector.

The goal in education is excellence. There should be a similar goal for educational premises. The intention is to produce successful projects. To be successful a project must be well designed. How could this be measured? Decades ago Ove Arup proposed the following amendment to Vitruvius' simple formula:

$$\mathbf{E} = \frac{\mathbf{C+XC+D}}{\mathbf{P+SP}}$$

where **E** stands for efficiency or excellence; **C** is commodity; **XC** represents commodity in excess of that required, but still of some value; **D** stands for delight, the artistic quality; **P** is the financial price and **SP** is the social price. It is very difficult to put values on **XC**, **D** and **SP** but an effort must be made to do so. Certainly planning and investment decisions must take account of these issues. To achieve high values of **E** better designs are required, not only better accounting.

Furthermore, **XC** and **D** can be provided at little or no additional construction cost. What would certainly be required is considerably greater design effort, and that could have a cost implication.

The issues to be addressed include not only utility and the confining of spaces but also:

- form and mass;
- scale and proportion;
- the exploiting of the natural textures and colours of the materials of construction;
- applied colour (including black and white);
- harmony and contrast;
- the use of natural lighting and ventilation;
- sensitive detailing.

As the subregion moves towards safer schools (and other shelters) the opportunity must not be lost to improve the overall quality of the built environment.

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2 TERMS OF REFERENCE FOR RETROFIT 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, earthquakes, torrential rains and other phenomena 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, as-built drawings, technical specifications and laboratory test results of materials used in the construction of the existing facilities.

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 existing facilities 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

In cases where the as-built documentation is inadequate for the assessment of the facilities 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 built facilities.

For the assessment of storm-water drainage provisions it may be necessary for the consultant to undertake topographic surveys of the site.

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

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. As *aides-mémoire* Appendices I and II are included in this document addressing this issue.

2.4 Analyses of Existing Buildings and Project Definition

The consultant will undertake structural analyses of the existing buildings to determine their degrees of vulnerability to hurricanes and earthquakes. These analyses will also lead to proposals for the strengthening of the buildings and the reduction of other vulnerable aspects of the facilities.

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 Appendix III is included in this document.

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:

- 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 developed, for implementation.

2.5 Design Stage II

The consultant will undertake the detailed design, analysis and detailing of retrofitting actions. This involves:

- 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 a clerks of works;
- 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.

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3 STANDARDS FOR RETROFITTING

3.1 General

Codes of practice and standards should be used for new construction, for alterations to existing facilities, for major maintenance and for retrofitting of existing facilities to achieve more consistent performance and 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.

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.

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

3.2 Design Criteria for Hurricanes

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" 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)

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.

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.

3.3 Design Criteria for Earthquake

Much less is known about the earthquake hazard than about the wind and rainfall 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)

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 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 completed *circa* 1994 and finally published in 1997. 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 or rain. 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.

3.3.5 Concept

Satisfactory earthquake-resistant design requires more than the faithful following of the mathematical requirements of standards documents. Appropriate geometry 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.

3.4 Design Criteria for Torrential Rain

3.4.1 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 at the end of this section.

3.4.2 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.

3.4.3 Changing Conditions

The other factor affecting rain runoff and flooding is upstream development, usually outside of the control of the client for a particular facility. 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.

3.5 Design Criteria for Storm Surge and Tsunami

3.5.1 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. This model is now operational at the Caribbean Meteorological Institute in Barbados.

3.5.2 Tsunami

Figure 6 at the end of this section shows a credible scenario from a likely eruption of the Kick 'em Jenny submarine volcano just north of Grenada. It is not commonly remembered that the great Lisbon (Portugal) earthquake of 1755 generated a significant tsunami in Barbados and in the 19th century many lives were lost in the (now) US Virgin Islands due to a tsunami generated by a nearby earthquake.

3.5.3 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.

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	0.78	36	34	43	54
Belize - S	0.55	30	29	37	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 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

Country	CUBiC Z-values 1985	equivalent Zone No (SEAOC 88)	equivalent Z-factor (UBC 88)	PAIGH max	PAIGH min	PAIGH/TG Z-factors 1993/94	Zones 1993/94	equivalent Zone No (SEAOC 88)	equivalent Z-factor (UBC 88)	proposed by TG Zone No. (SEAOC 88)	consequent Z-factor (UBC 88)
Anguilla				300	250	0.500	2.5	2.5	0.20	3	0.3
Antigua & Barbuda	0.750	3	0.30	450	450	1.000	4	4	0.40	4	0.4
Bahamas											
Barbados	0.375	2	0.15	225	175	0.375	2	2	0.15	3	0.3
Belize - north	0.500	2.5	0.20	200	120					2	0.2
Belize - south	0.750	3	0.30	240	200					3	0.3
British Virgin Islands				550	450	1.000	4	4	0.40	4	0.4
Cayman Islands				140	80	0.375	2	2	0.15	2	0.2
Dominica	0.750	3	0.30	300	250	0.500	2.5	2.5	0.20	3	0.3
Grenada	0.500	2.5	0.20	175	125	0.375	2	2	0.15	3	[illegible]
Guyana - Essequibo	0.250	1.5	0.10								
Guyana - remainder	0.000	0	0.00								
Jamaica	0.750	3	0.30	200	160					2	0.2
Montserrat	0.750	3	0.30	600	400	1.000	4	4	0.40	4	0.4
St Kitts & Nevis	0.750	3	0.30	450	300	0.750	3	3	0.30	4	0.4
St Lucia	0.750	3	0.30	175	150	0.375	2	2	0.15	2	0.2
St Vincent & the Grenadines	0.500	2.5	0.20	175	100	0.375	2	2	0.15	2	0.2
Trinidad - NW	0.750	3	0.30	350	250	0.750	3	3	0.30	4	0.4
Trinidad - remainder	0.500	2.5	0.20	400	250	0.750	3	3	0.30	4	0.4
Tobago	0.500	2.5	0.20	300	250	0.500	2.5	2.5	0.20	3	0.3
Turks & Caicos Islands				160	80					2	0.2

Notes:
In the Zone column 1.5 means between 1 and 2
In the Zone column 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 results (by Dr Shepherd) interpreted by Tony Gibbs

Seismic Hazard Values for Structural Design Purposes
Commonwealth Caribbean
Compiled by Tony Gibbs
31-Aug-98

Regional Map of Wind-pressure Contours

(from CUBiC)

Figure 1

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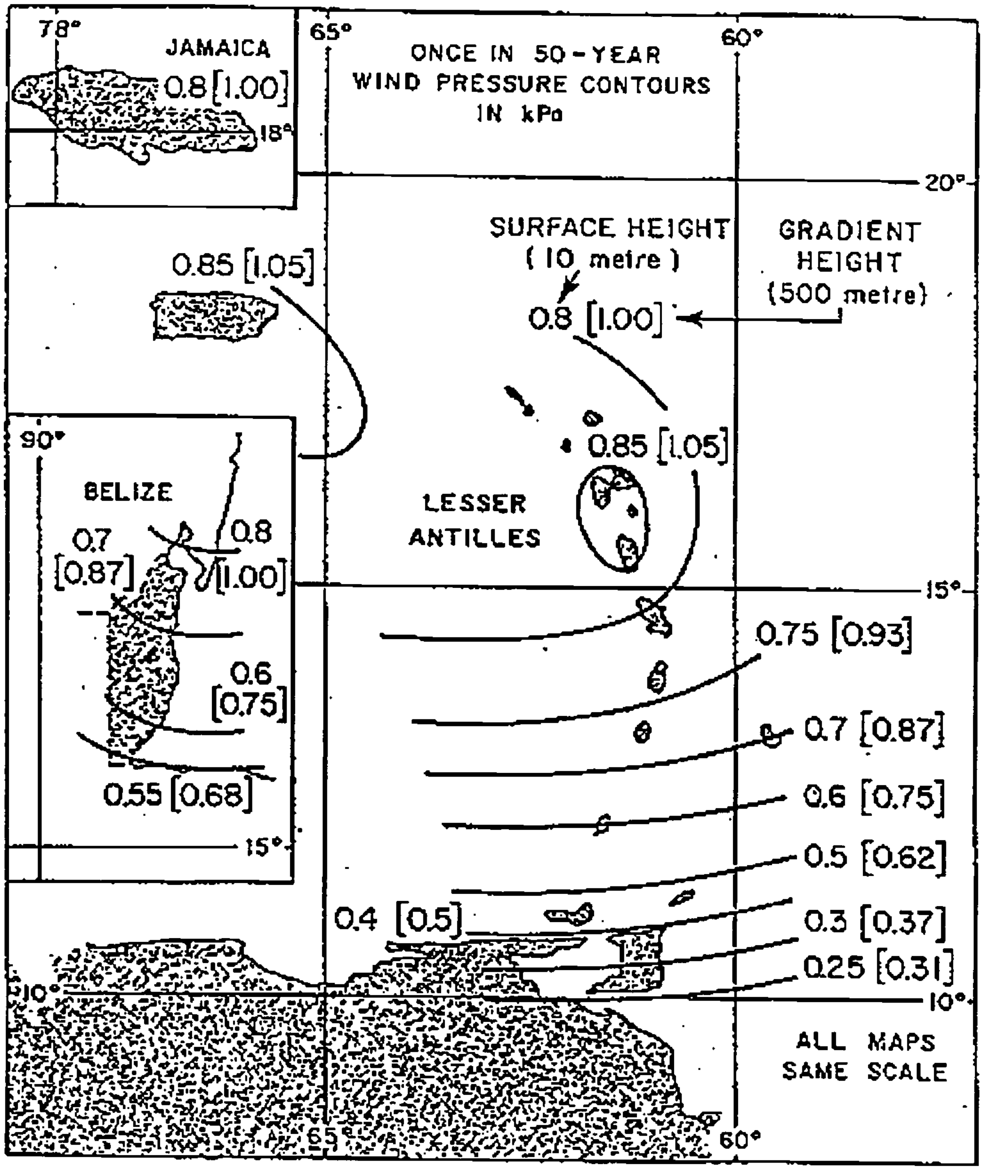
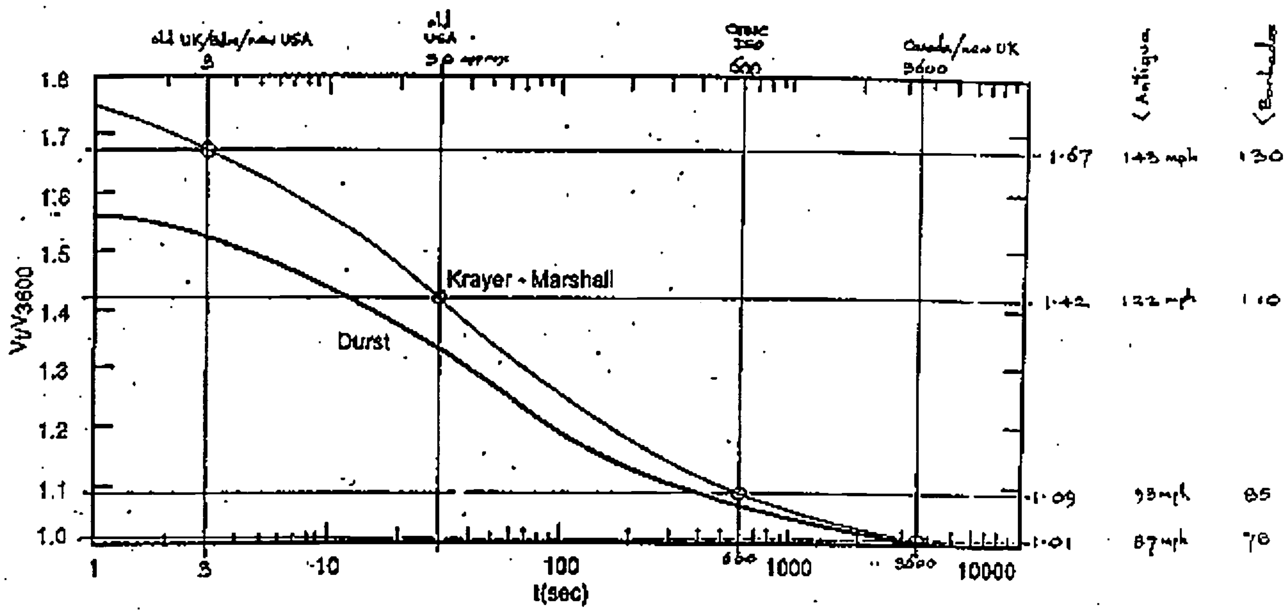


Figure A200.1 Map of Region of Application

Wind-speed Variation with Averaging Period

(from Durst and Krayer-Marshall)

Figure 2



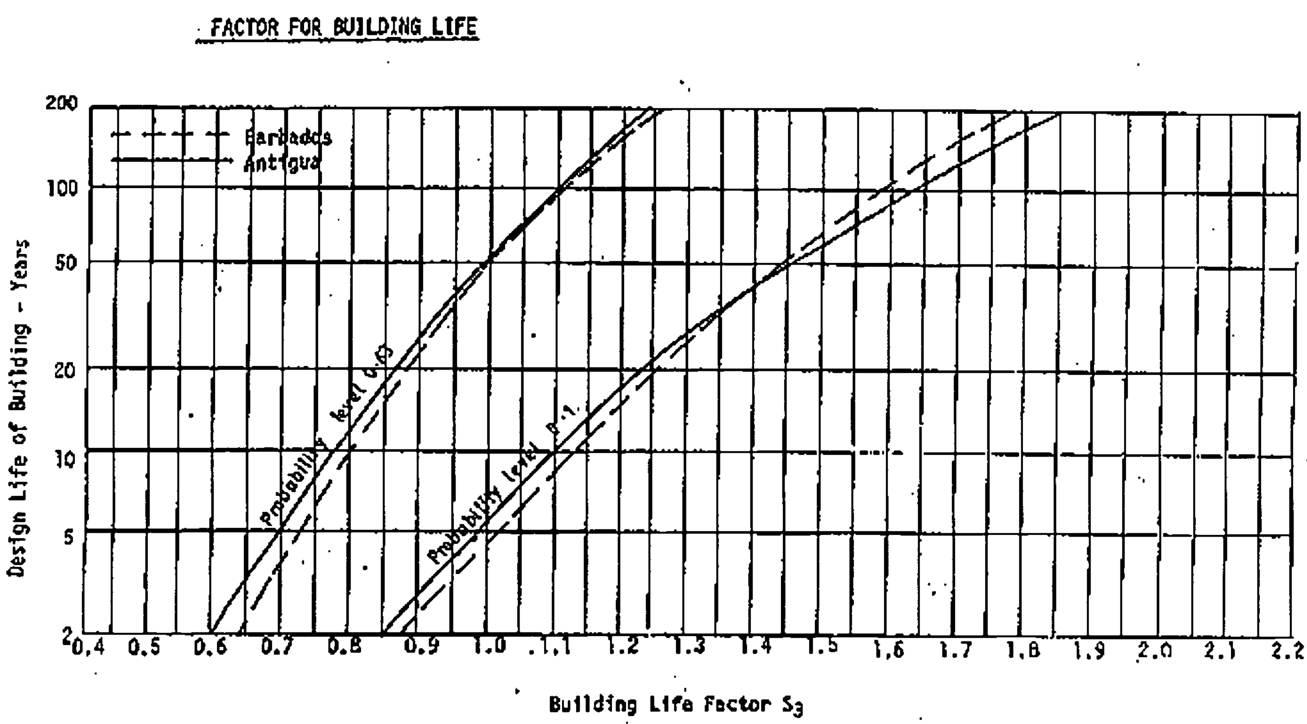
Ratio of Probable Maximum Speed Averaged over *t* Seconds to Hourly Mean Speed

Source: Ref. 4

S_3 Factor for Return Period and Probabilities

(from OAS/NCST/BAPE Code)

Figure 3



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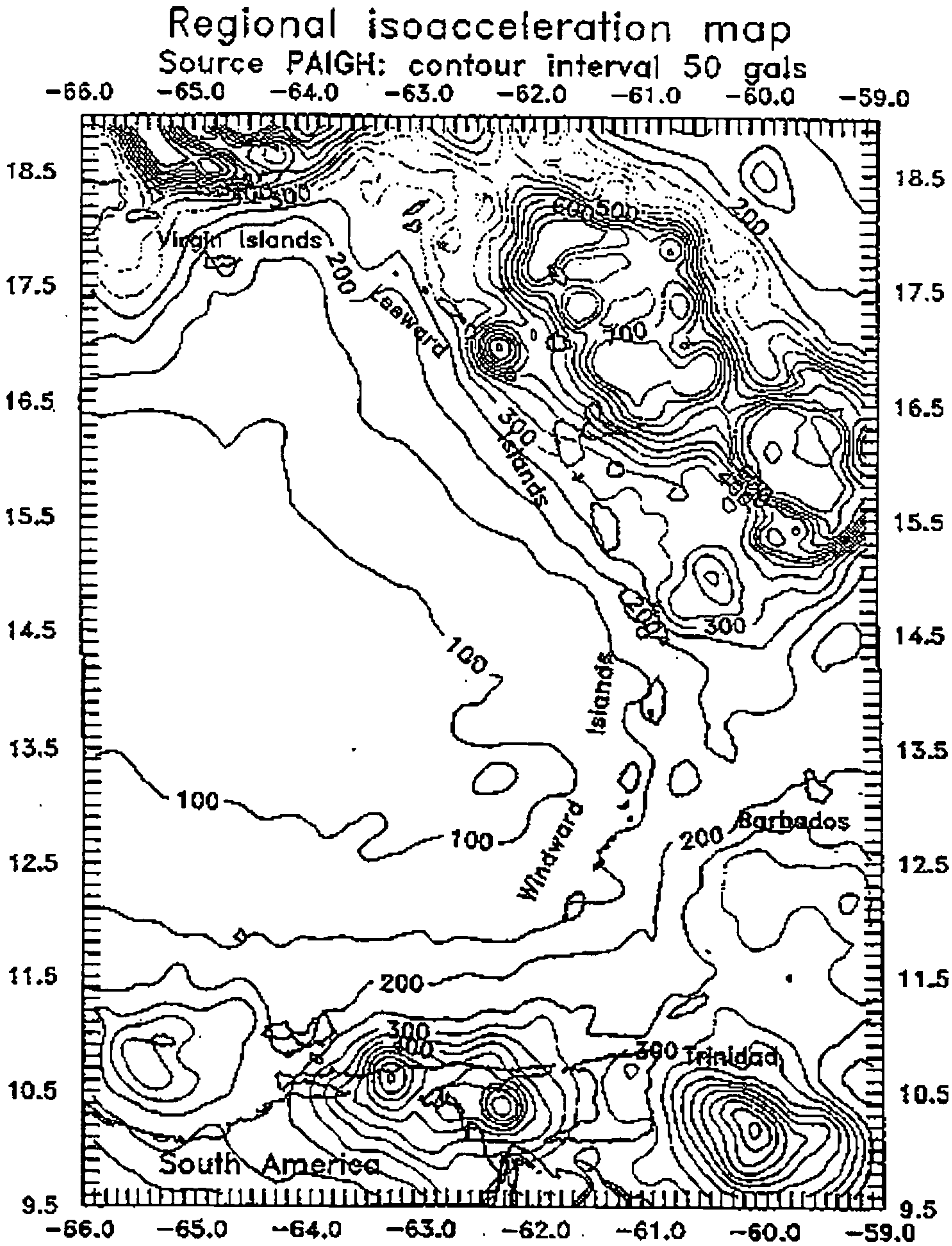
Isoacceleration Map of the Eastern Caribbean

(from John Shepherd - PAIGH)

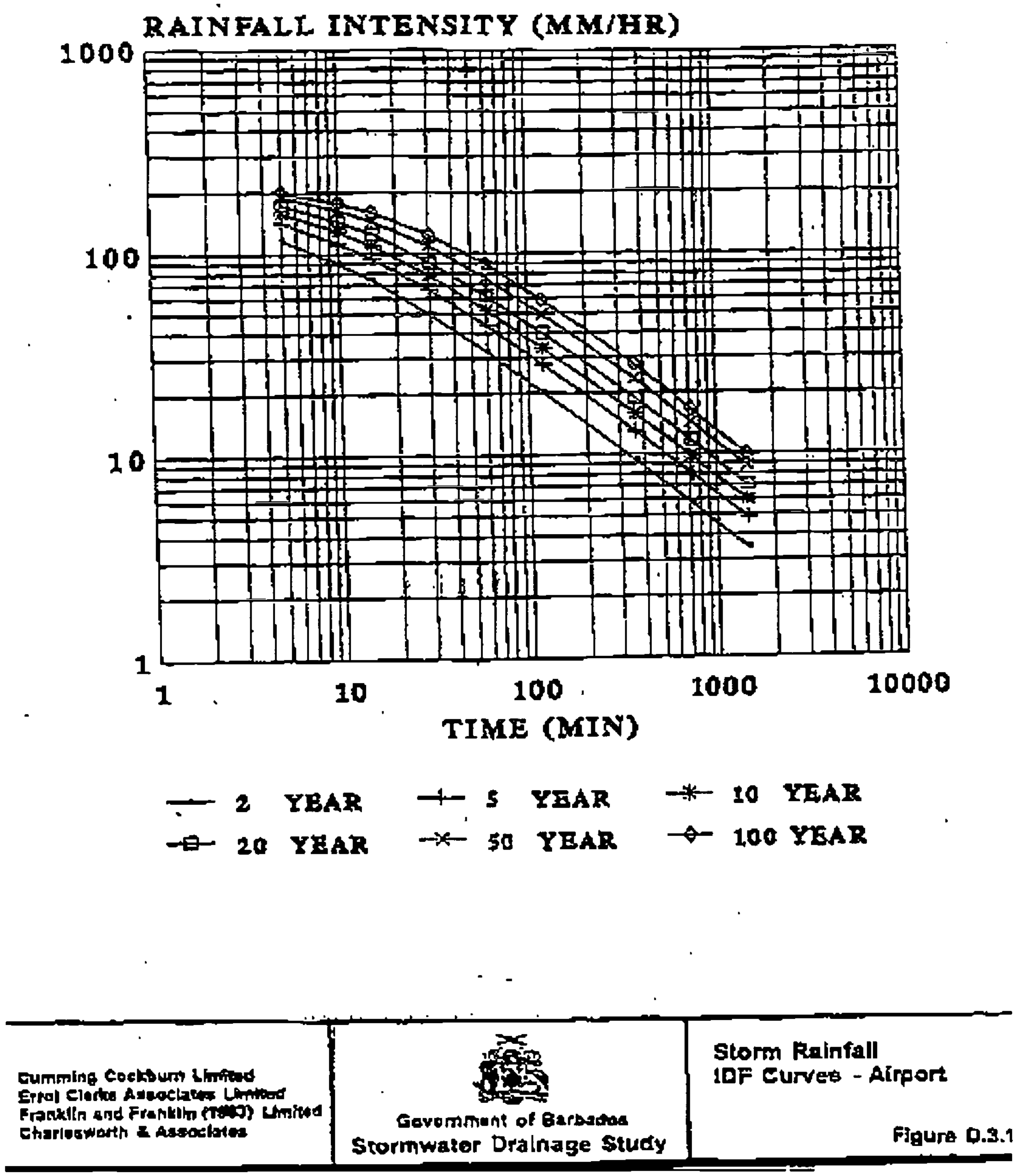
Figure 4



Rainfall Intensity

(Government of Barbados, Stormwater Drainage Study, 1983)

Figure 5



Tsunami Heights for Realistic Kick 'em Jenny Eruption
(from Martin Smith & John Shepherd - 1992 VEI = volcanic explosive index)
Figure 6

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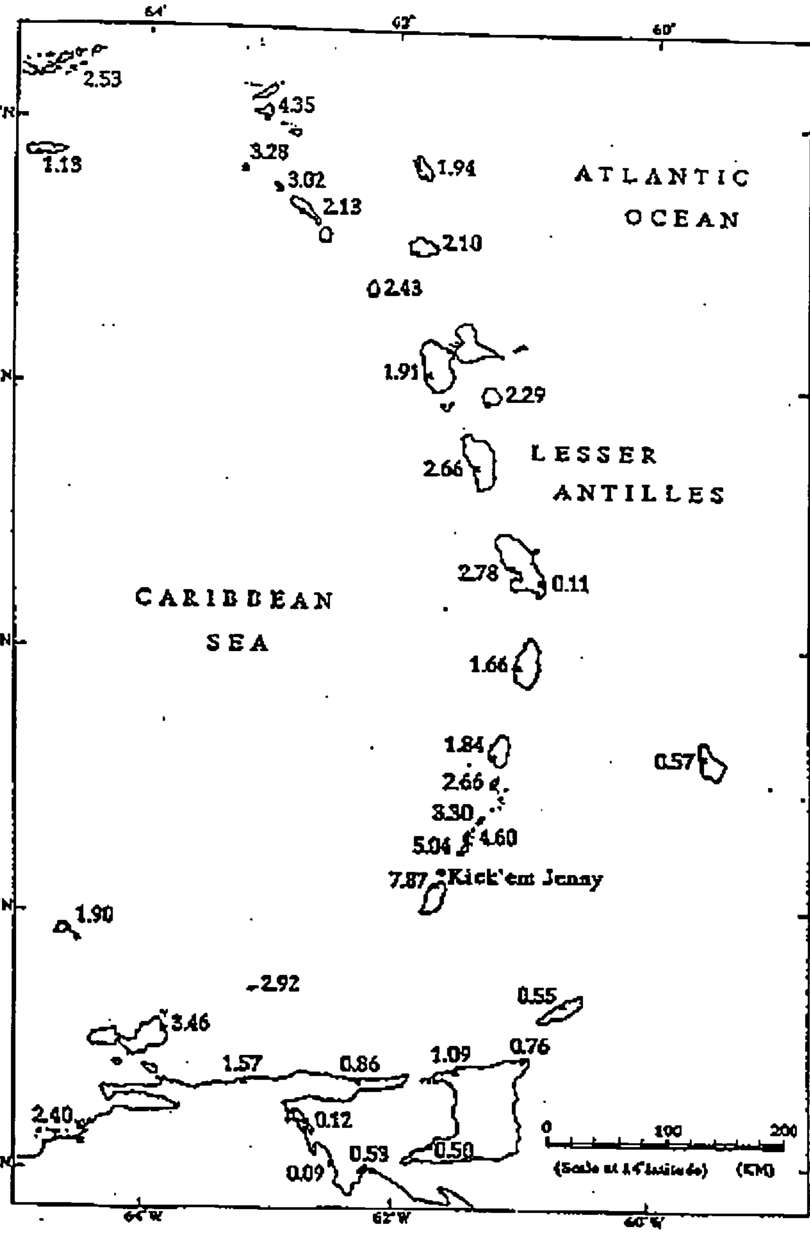

Final run-up values in metres for a 'realistic' scenario event at Kick'em Jenny (VEI = 3).

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4 GLOBAL COST ESTIMATES FOR RETROFITTING

4.1 General

The vulnerability surveys reported on in the five country documents referred to in section 1.2 of this document were preliminary screenings of the properties. The level of accuracy of those exercises was not great. Those findings can best be characterised as broad-brush comparative assessments. This section provides similarly approximate estimates of the costs of various aspects of retrofitting of those properties deemed to be vulnerable to natural hazards.

For convenience of use, all retrofit estimates are related to the floor area of shelters, assumed to be single-storey buildings. The estimates may then be adjusted for particular cases of buildings greater than one storey.

4.2 Roofing

Vulnerability to hurricanes occurs principally with lightweight roofs. In the shelters which were examined, these roofs were covered with corrugated metal sheeting in the main. Corrugated asbestos sheeting can also be found as roofing for shelters.

The chosen material for retrofitting or replacement of roofing is 24-gauge, corrugated, galvanised, steel sheeting. The profile is assumed to be "industrial" or trapezoidal and not arc-tangent. This profile would permit valley fasteners used in conjunction with 20-mm washers. (Ridge fasteners require cyclone washers and under-ridge spacers for equivalent strength. Such a system is reliable but more expensive than the proposed system.)

In computing the estimate related to floor area, the assumption was made that the roof area is 35% greater than the floor area.

The estimate for replacing the entire roof sheeting is EC$11.75 per square foot of floor area.

If the roof sheeting is satisfactory and all that is required is additional (or better) fasteners, then the estimate for the fasteners and their installation would be EC$2.75 per square foot of floor area.

4.3 Windows

The protection of all windows and other openings (such as breeze blocks and mesh-protected openings) is to be provided by plywood hurricane shutters. Other approaches would include the installation of proprietary shutter systems and the replacement of glazed windows with laminated glass systems tested to South Florida Building Code standards. Both of these satisfactory alternatives would be more costly than the plywood shutters.

It is assumed that plywood shutters (made of 20-mm form plywood and painted for increased life) would be specifically fabricated and marked to match all windows and other openings. They would then be kept in storage and installed at least once each year, in advance of the hurricane season, as a trial run and to ensure that all components are in good condition.

The shutters are intended to be secured to the walls surrounding the openings with stainless steel bolts. The bolts will be fixed permanently into the walls and matching washers and nuts will be provided. Alternatively, female sockets can be cast into the walls to be flush with the wall surface with the bolts being the movable part of the securing device.

The shutters will provide protection against wind, flying debris and rain. Such protection can never be guaranteed to be 100% effective but will greatly improve the security of the shelters.

The estimate for providing shutters for all windows and other openings is EC$6.50 per square foot of floor area. Window area is assumed to be 33% of floor area.

If shutters exist but their adequacy is in doubt, then an estimate of EC$1.00 per square foot of floor area could be used for upgrading the shutters.

4.4 External Doors

It is assumed that the doors are, themselves, sufficiently strong to withstand the wind forces and flying debris. The common problem with external doors is the inadequacy of the hinges and latches.

Two approaches are suggested. It is often possible to provide adequate security simply by installing bolts at the free corners of doors. If this is not sufficient then braces could be the answer. This latter approach is estimated here.

Two braces will be provided for each door. The braces will be of timber (painted for durability) and secured to the adjacent walls with stainless steel bolts. The bolts will be fixed permanently into the walls and matching washers and nuts will be provided. Alternatively, female sockets can be cast into the walls to be flush with the wall surface with the bolts being the movable part of the securing device.

The estimate for providing braces for all external doors is EC$1.50 per square foot of floor area. It is assumed that there would be one door for each room (average area of a room taken as 400 square feet).

4.5 Walls

Unless walls are reinforced and restrained by frames (or other walls at angles to the subject walls) they are liable to failure in earthquakes. There are also several documented cases of unreinforced walls failing in hurricanes. It is easy to prove that such failures could happen.

The amount and disposition of reinforcement in masonry walls can be determined by non-destructive testing. Such testing was outside of the scope of the preliminary screening carried out for this study. However, such testing is envisaged for the further studies which would be required for the retrofit implementation project.

The method proposed for strengthening masonry walls, assumed to be inadequately reinforced, is to employ the ferro-cement technique. This is external reinforcing of the walls. Galvanised reinforcing mesh is intermittently fixed to both faces of the wall and mortar is applied to form reinforced skins on both faces of the wall. This technique has been tested at laboratories in Mexico and the Caribbean.

The estimate for providing this form of strengthening is EC$11.25 per square foot of floor area. It is assumed that wall area is about 80% of floor area.

4.6 Structural Frames

Frames would normally consist of beams and columns. Catastrophic failure of frames would generally be associated with failure of columns. Indeed good earthquake resistant design would aim for yielding ("failure") of the beams with the columns remaining elastic.

Strengthening of steel columns can readily be achieved by welding on plates to the existing columns.

Strengthening of concrete columns can be achieved by reinforcing them externally in various ways. The method with the potential of adding the most strength to existing columns is jacketing. This involves enclosing the concrete column with a steel jacket. This method is frequently used for the columns supporting elevated roads. It is, however, expensive and probably unnecessary for most buildings. Partial jacketing has been used successfully for building columns. This involves steel angles placed at the corners of columns and connected to one another with steel straps, sometimes in triangulated patterns.

The estimate for providing column strengthening is EC$4.00 per square foot of floor area.

4.7 Timber Roof Framing

The estimate for adding hurricane straps to purlin/rafter junctions is EC$2.25 per square foot of floor area.

The estimate for adding hurricane straps to rafter/wall junctions is EC$1.50 per square foot of floor area.

If it is necessary to replace the entire timber roof framing along with all hurricane straps, then the estimate would be EC$15.75 per square foot of floor area.

4.8 External Works

This cannot be reasonably estimated because of the vast variations in conditions. Nor can such costs be related to the floor areas of shelters.

4.9 Using Cost Factors to Determine Cost Estimates

The following table can be used to determine cost estimates for retrofitting. When inspecting buildings using the survey form, the inspector should make a determination regarding the structural and non-structural elements listed in the table. Based on that determination, he/she should assign a vulnerability factor for each element based on a scale of 0-1.0. A vulnerability factor of zero would indicate no vulnerability while a vulnerability factor of 1.0 would indicate that the element needs complete rehabilitation. The formula to determine retrofit cost is simple: For each structural and non-structural element, multiply the total floor area of the building in square feet by the vulnerability factor and the cost estimate per square foot of floor space. Retrofit costs for each element can be added to determine the retrofit cost for the entire facility. The following table provides an example. A spreadsheet version of this table is also available (Microsoft Excel version 3).

Shelter Name: Forest Primary School			
Total area in Square Feet: 3500			
square footage X vulnerability factor X cost in EC$ = retrofit estimate			
Item	**Vulnerability Factor**	**Cost per sqft. in EC$**	**Retrofit estimate EC$**
Roofing			
sheets	0.3	$11.75	$12,337.50
fasteners	0.1	$2.75	$962.50
Windows			$0.00
shutters	1	$6.50	$22,750.00
upgrade	1	$1.00	$3,500.00
Doors	0.3	$1.50	$1,575.00
Walls	0	$11.25	$0.00
Frames	0	$4.00	$0.00
Roof Frames			$0.00
purlin/rafter	0.2	$2.25	$1,575.00
rafter/wall	0	$1.50	$0.00
complete	0	$15.75	$0.00
External Works			
Total			$42,700.00

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Appendices

APPENDIX I

EARTHQUAKES

Check List for Vulnerability Surveys of Non-structural Components for Earthquakes

ITEM	YES	NO	NOTES
Electricity			
Generator a Is the emergency generator adequately secured?			
Batteries a Are the batteries securely attached to the battery rack? b Is the rack cross-braced in both directions? c Does the battery rack have bolts secured to a concrete pad?			
Diesel Fuel Tank a Is the tank securely attached to the supports? b Are the tank supports cross-braced in both directions? c Is the bracing attached with anchor bolts secured to a concrete pad?			
Fuel Lines and Other Pipes a Are these lines and pipes attached with flexible connections? b Are they able to accommodate relative movement across joints?			
Transformers, Controls, Switchgear a Are these items properly attached to the floor or wall?			
Bus Ducts and Cables			

a Are these able to distort at their connections to equipment without rupture? b Are they able to accommodate relative movement across joints? c Are they laterally braced?			
Fire Fighting			
Smoke Detectors and Alarms a Are they properly mounted? b Are the control system and fire doors securely anchored?			
Fire Extinguishers and Hose-reel Cabinets a Are the cabinets securely mounted? b Are the extinguishers secured with quick-release straps?			
Emergency Water Tank a Is it securely anchored to its supports? b Are the supports braced in both directions? c Are the supports or braces anchored to a concrete foundation?			
Propane Tanks			
The Tank a Is it securely anchored to its supports? b Are the supports braced in both directions? c Are the supports or braces anchored to a concrete foundation?			
Shut-off Valve a Does the system have an automatic, earthquake-triggered shut-off valve? b If manual, is a wrench stored close by?			
Supply Pipes a Are they able to accommodate relative movement across joints and at the tank? b Are they laterally braced?			

Plumbing			
Water Heaters and Boilers a Are they securely anchored to the floor or wall? b Does the gas line have a flexible connection to the heater or boiler to accommodate movement?			
Pumps a Are they anchored or are they mounted on vibration isolation springs with seismic lateral restraints?			
Hot and Cold-water Pipes and Wastewater Pipes a Are the pipes laterally braced at reasonable intervals? b Do they have flexible connections to boilers and tanks? c Can they accommodate movement across joints? d Are "free" pipe penetrations through walls large enough to for seismic movement? e Are they free of asbestos insulation (which can be broken in an earthquake)?			
Solar Panels a Are they securely anchored to the roof?			
Elevators			
Cab a Is it properly attached to the guide rails? b Is there an alarm system for emergencies?			
Cables, Counterweights, Rails a Are cables protected against misalignment during an earthquake? b Are counterweights properly attached to guide rails? c Are guide rails properly attached to the building structure?			
Motors and Control Cabinets a Are these anchored?			

Air Conditioning			
Chillers, Fans, Blowers, Filters, Air Compressors a Are they anchored or are they mounted on vibration isolation springs with seismic lateral restraints?			
Wall-mounted Units a Are they securely mounted?			
Ducts a Are they laterally braced? b Can they accommodate movement at locations where they cross separation joints?			
Diffusers a Are the grills anchored to the ducts or to the ceiling grid or to the wall? b Are hanging diffusers adequately supported?			
Non-structural Walls and Partitions			
Concrete Block, Brick, Clay Block a Are they reinforced vertically and/or horizontally? b Are they detailed to allow sliding at the top and movement at the sides? c Are they restrained at the top and the sides against falling?			
Stud-wall and Other Lightweight Walls a Are partial-height partitions braced at their top edges? b If they support shelving or cabinets, are they securely attached to the structure of the building?			
Ceilings and Lights			
Ceilings a Do the suspended ceilings have diagonal bracing wires? b For plaster ceilings is the wire mesh or wood lath securely attached to the structure above?			

Lighting a Do light fixtures (*eg* lay-in fluorescent fixtures) have supports independent of the ceiling grid? b Do pendant fixtures have safety restraints (*eg* cables) to limit sway? c Are emergency lights mounted to prevent them falling off shelf supports?			
Doors and Windows			
Doors a If exit doors are heavy metal fire doors that might jam in an earthquake, is there a crowbar or sledge hammer readily available to facilitate emergency opening? b Do automatic doors have manual overrides? c What directions do the doors swing?			
Windows a Is it known whether the glazing has been designed to accommodate lateral movement? b Do large windows, door transoms and skylights have safety glass?			
Appendages and Sundries			
Parapets, Veneer and Decoration a Are parapets reinforced and braced? b Do veneers and decorative elements have positive anchorage to the building?			
Fences and Garden Walls a Is it known whether these were designed by an architect or engineer to resist lateral forces? b Are masonry walls reinforced vertically and rigidly fixed to their bases?			
Signs and Sculptures a Are signs adequately anchored? b Are heavy and/or tall sculptures anchored to prevent overturning?			
Clay and Concrete Roof Tiles			

a Are such tiles secured to the roof with individual fixings for each tile?			
Movable Equipment			
Communications a Is radio equipment restrained from sliding off shelves? b Are telephones placed away from edges of desks and counters? c Are elevated loud speakers and CCTV anchored to the structure?			
Computers a Is vital computer information backed up regularly and stored off site? b Is heavy computer equipment with a height-to-width ratio greater than 2 anchored or braced? c Are desktop items prevented from sliding off tables? d Are access floors braced diagonally or do they have seismically-certified pedestals?			
Storage of Records and Supplies a Are shelving units anchored to walls? b Are shelves fitted with edge restraints or cords to prevent items from falling? c Are heavier items located on the lower shelves? d Do filing cabinet drawers latch securely? e Are heavily-loaded racks braced in both directions? f Are fragile or valuable items restrained from tipping over? g Are chemical supplies secured or stored in "egg crate" containers?			
Hazardous Items a Are gas cylinders tightly secured with chains at top and bottom (or otherwise)? b Are the chains anchored to walls? c Are chemicals stored in accordance with manufacturers recommendations? d Are cabinets for hazardous materials given special attention with respect to anchoring?			

Furniture a Are heavy potted plants restrained from falling or located away from beds? b Are beds and tables and equipment with wheels provided with locks or other restraints to prevent them rolling unintentionally?			

APPENDIX II

HURRICANES

Check List for Vulnerability Surveys of Non-structural Components for Hurricanes

ITEM	YES	NO	NOTES
Roofs			
Light-weight coverings a Check the gauge of corrugated sheeting b Check the type and quality of corrugated sheeting c Are there valley fasteners? d Are ridge fasteners supplemented by spacer blocks under the ridges? e Check the fastener spacings for interior areas and for perimeter areas (for 15% of the roof dimension along eaves, gables and ridges) f Are asphalt shingles fixed in accordance with manufacturer's recommendations for hurricane areas? g Are asphalt shingles laid on waterproofing felt on top of ¾-inch (or greater) plywood sheets which in turn are fastened by screws or annular nails to supporting timber rafters? h Are wooden shingles individually fixed to close boarding which in turn is fastened by screws or annular nails to supporting timber rafters? NB i In all cases the methods of fixing must, at least, comply with the manufacturers' recommendations for severe hurricane locations ii If battens are used, the fastening of the battens to the close boarding must be at least as strong as the fastening of the covering to the battens			
Other coverings a Are slates individually fixed to close boarding? b Are concrete or clay tiles individually fixed to close			

boarding? NB i In all cases the methods of fixing must, at least, comply with the manufacturers' recommendations for severe hurricane locations ii If battens are used, the fastening of the battens to the close boarding must be at least as strong as the fastening of the covering to the battens			
Windows			
Are they made of laminated glass fixed to frames with structural silicon and able to resist, without breaching, the impact of flying objects such as an 8-foot long 2-inch by 4-inch piece of timber moving at 35 miles per hour (similar to the requirements of Dade, Broward and Palm Beach Counties of Florida)? **or**			
are they protected by pre-installed or pre-fabricated shutters which are made of at least ¾-inch timber or otherwise able to resist without breaching the impact of flying objects such as an 8-foot long 2-inch by 4-inch piece of timber moving at 35 miles per hour?			
Are they made of timber or aluminium louvres with provisions for excluding the rain during storm conditions?			
The windows or shutters must be secured to the walls, slabs, beams or columns near all corners of each panel or in accordance with the manufacturers' recommendations for severe hurricane locations			
Doors			
Glass Sliding Doors a Are they made of laminated glass fixed to frames with structural silicon and able to resist without breaching the impact of flying objects such as an 8-foot long 2-inch by 4-inch piece of timber moving at 35 miles per hour? **or** b are they protected by pre-installed or pre-fabricated shutters which are made of at least ¾-inch timber or otherwise able to resist without breaching the impact of flying objects such as an 8-foot long 2-inch by 4-inch piece of timber moving at 35 miles per hour? c Do the moving frames have a certificate from the supplier indicating compliance with the requirements for the appropriate intensity of hurricanes, including both strength			

and deflexions? d Are the fixed perimeter frames secured to the walls, slabs, beams or columns by bolting or in accordance with the manufacturers' recommendations for severe hurricane locations? e Are the tracks of the top and bottom rails deep enough to prevent the moving doors from being dislodged in severe hurricanes? (The manufacturer's advice should be sought.)			
Roller Shutter (or Overhead) Doors a Do these have certificates from the suppliers indicating compliance with the requirements for the appropriate level of hurricanes, including both strength and deflexions? b Are the fixed perimeter frames secured to the walls, slabs, beams or columns by bolting or in accordance with the manufacturers' recommendations for severe hurricane locations? c Are the side tracks deep enough to prevent the moving doors from being dislodged in severe hurricanes unless some other mechanism is employed to prevent such an occurrence? (The manufacturer's advice should be sought.)			
Other Doors a Are timber doors solid core or made up from solid timber members? b Is each door leaf fixed by hinges or bolts in at least four locations adjacent to all corners?			
Other Apertures a Is protection from wind and rain provided by pre-installed or pre-fabricated shutters which are made of at least ¾-inch timber or otherwise able to resist without breaching the impact of flying objects such as an 8-foot long 2-inch by 4-inch piece of timber moving at 35 miles per hour? b Are the shutters secured to the walls, slabs, beams or columns near all corners of each panel or in accordance with the manufacturers' recommendations for severe hurricane locations?			
Solar Water Heaters and Air-conditioners			

Do these have certificates from the suppliers indicating compliance with the requirements for the appropriate intensity of hurricanes for both manufacture and installation?			

APPENDIX III

DETAILED ENGINEERING

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

Appendix III 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, 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 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

2.2.4 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 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 and torrential rains

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

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

14.1 Refer to Appendix A.3 (Maintenance as a Tool for Mitigation) from "Disaster Preparedness Manual for Caribbean Schools" by Consulting Engineers Partnership Ltd, November 1996 under contract to the Caribbean Disaster Emergency Response Agency.

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