Mitigation: Disaster Mitigation Guidelines for Hospitals and Other Health Care Facilities in the Caribbean

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Pan American Health Organization

***Regional Office of the* World Health Organization**

A CONTRIBUTION TO THE INTERNATIONAL DECADE FOR NATURAL DISASTER REDUCTION

On the cover:

Hurricane Gilbert in September 1988 was classified as one of the most severe hurricanes of this century. Hardest hit was Jamaica, where nine of the island's 26 hospitals were severely damaged and three health centers totally destroyed. Shown here, the Princess Margaret Hospital sustained extensive damage, and patients were evacuated.

Photo: Carlos Gaggero/PAHO/WHO

EMERGENCY PREPAREDNESS AND DISASTER RELIEF

COORDINATION PROGRAM

PAN AMERICAN HEALTH ORGANIZATION

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This document represents a collaborative effort of engineers and health sector administrators. PAHO wishes to acknowledge the following persons, whose technical input resulted in the valuable publication: Mr. Tony Gibbs, Director of Consulting Engineers Partnership, Ltd. in Barbados; Mr. José Grases, Director of Coral '83, an engineering consulting firm in Caracas, Venezuela; and Mr. James Williams, retired Director of the Queen Elizabeth Hospital in Barbados. Dr. Jean Luc Poncelet, the Pan American Health Organization's Subregional Disaster Adviser for the Caribbean coordinated the preparation of this publication.

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PREFACE

The Commonwealth Caribbean Countries are at risk to many natural hazards including hurricanes and earthquakes. Within the last few years, they have been subjected to two major hurricanes that have caused severe damage to health care facilities. Particularly devastating was the damage done to hospitals throughout Jamaica by hurricane Gilbert in 1988, and to the main hospital in Montserrat by hurricane Hugo in 1989.

The costs of restoration of these facilities have already run into millions of United States dollars, at a time when almost all of these countries are experiencing adverse economic pressures, and when some have already entered economic structural adjustment arrangements with the International Monetary Fund. Many governments are finding it extremely difficult to meet their budgeted recurrent expenditures, and except for Trinidad and Tobago, are becoming increasingly dependent on tourism as their principal source of income and the main prop for their economies.

On the other hand, funds are being received for major capital projects in the service sectors of governments, mainly by grants and loans from international agencies. In particular, funding for capital projects for the restoration, retrofitting and expansion of hospitals is being made available to many of these countries either by the Inter–American Development Bank or the European Economic Community.

A major consideration when executing these capital projects must be to ensure that any construction and retrofitting of facilities be done in such a way that they not only achieve their primary health objectives, but also minimize adverse impact on the future earnings and recurrent expenditures of governments. This can only be accomplished by utilizing design and construction techniques which will make the facilities adequately resistant to damage by any type of hazard, and which can be cost−effectively and affordably maintained and managed.

Only within the last decade has systematic consideration being given in the Commonwealth Caribbean Countries to designing and constructing health care facilities to withstand the impact of natural hazards. Among them, hurricanes and earthquakes have been particularly destructive during historical times.

It is difficult to design buildings to withstand the dynamic actions due to both high winds and strong ground shaking because the effects of their respective forces on building structures are markedly different. There are, however, well established cost−effective design and construction techniques that are available for reducing property losses due to these hazards. Appropriate standards are contained in the Caribbean Uniform Building Code which is currently called CUBiC. This code was formally accepted by the Caribbean Council of Ministers of Health in 1988, but is not yet mandatory in any of these countries.

This booklet is consistent with the philosophy and aims of CUBiC. It identifies and explains in layman's terms the characteristics to be considered in the design and construction of buildings in order to effectively resist both hurricanes and earthquakes, and highlights critical and cost−effective factors in order to reduce the vulnerability. It is intended to help health and hospital administrators, as well as construction and maintenance personnel, to understand design and construction requirements in order to adequately mitigate the hazards of hurricanes and earthquakes threatening health care facilities. It also provides them with a basic knowledge to communicate sensibly, viligantly and purposefully with the architects, engineers, and contractors involved in the construction, restoration, and retrofitting of their facilities.

SUMMARY OF RECOMMENDATIONS

1. The CUBiC code for building construction should be made mandatory in all Commonwealth Caribbean Countries.

2. Health service administrators and construction and maintenance personnel should have at least a basic knowledge of the engineering requirements for hazard−resistant construction.

3. Vulnerability analyses should be carried out on all health service buildings.

4. Performance specifications should be part of purchasing procedures for critical hospital equipment.

5. Hospital disaster preparedness plans should be revised where necessary to include response procedures for earthquakes, and should also include vulnerability analysis as part of the requirements for retrofitting of the facility.

6. Disaster response exercises should be mandatory for hospitals and should be held at least once a year.

7. Countries without hazard evaluations in respect of earthquakes, hurricanes, and floods should seek to obtain this information as soon as possible for use in the vulnerability analyses.

8. Hospitals should keep available in safe custody updated architectural and engineering drawings of their buildings.

CHAPTER 1: SCOPE AND OBJECTIVES

1.1 Introduction

This booklet has been prepared for non−engineers, such as building owners, health care officials, managers, and maintenance personnel. Its twofold purpose is to inform those officials involved in the planning, operation and management of health care facilities of the potential magnitude of the impact caused by natural hazards, and to provide a useful tool to assist them in the risk mitigation of existing facilities and in the reliable design of new constructions.

It deals specifically with the potential problems that may be generated by hurricanes, earthquakes and floods, which are the natural hazards to which the Commonwealth Caribbean Countries are primarily at risk, and the measures that may be taken to mitigate these hazards. Consideration is given to the special requirements of health care facilities so that they may be designed to remain functional during and immediately after hurricanes, floods and earthquakes, and in particular, to ensure that any damage should be limited in order to preclude evacuation of hospital buildings, although disruption of some of the functions may be unavoidable.

The intent is to explain in simple terms the problems created by these hazards and to point the way towards countermeasures to be considered in coping with these problems. The enforcement of engineering design codes, such as CUBiC[1] is the first basic step in order to reach that objective.

[1] Caribbean Uniform Building Code (CUBiC), Caribbean Community Secretariat, Georgetown, Guyana 1985.

A summary of recommendations and a checklist are included as Annexes to serve as an aide−memoire for quick and easy reference by the busy health care executive.

It is important to stress that the contents of this document represent a simplified version of very technical and scientific knowledge, and that there are many areas where the appropriate expertise needs to be enlisted. It is expected that the guidelines given for hazard mitigation will be used wisely and that expert advice will be obtained when necessary.

1.2 Objectives

This booklet is intended to:

1. Provide decision−makers and managers in the Health Sector with a tool for administering the design, construction, and retrofitting of health care facilities.

2. Identify priorities in the construction and retrofitting of buildings in the health sector, taking into account the financial constraints and the relationship between the intensity and frequency of natural hazards.

3. Increase awareness and provide a means for the identification of vulnerable situations in existing facilities.

4. Facilitate communication between technical and non−technical parties involved in designing and constructing new facilities as well as reducing the vulnerability of existing ones.

CHAPTER 2: THE NATURE OF NATURAL HAZARDS IN COMMONWEALTH CARIBBEAN COUNTRIES

2.1 Introduction

There is a widely held expectation that health care facilities are prepared to deal with emergency situations. The impact of past earthquakes and hurricanes has proven that hospitals and health care installations may be vulnerable and therefore rendered unable to respond.

During the last two decades more than one hundred hospitals in the Americas have reported severe disruption, if not total collapse, as a consequence of earthquakes. For instance, during the San Fernando, California, earthquake of 9th February 1971, four hospitals were damaged so severely that they were no longer operational just when they were most needed. Furthermore, the majority of deaths caused by that earthquake occurred in two of the hospitals which collapsed. It was an ironic feature of that earthquake that the most hazardous place to be in San Fernando was in a hospital!

In the Caribbean, hurricanes have caused severe damage to hospitals in Dominica, Jamaica, Montserrat, and St. Kitts. In Jamaica, some hospital buildings had to be evacuated because of damage by hurricane Gilbert in 1988.

There are indeed many similar examples worldwide in respect of earthquakes, hurricanes, and floods.

2.2 General Definitions

At the outset, some basic concepts and information are necessary in order to better understand the contents of this booklet.

Hazard

A hazard is a phenomenon which, when it manifests itself in a given area over a specific period of time, has the potential for severe social disruption, trauma, property damage and loss.

The potential impact of a hazard is normally expressed in terms of its magnitude or intensity, which are expressed as a probability function over a specified time period according to hazard type.

Hazard functions can be derived for different sites if there are sufficient relevant records going back over a significant period of time. For example, if we analyze the known history of earthquake occurrences in the Eastern Caribbean countries, and we measure their size in terms of the intensities given by the Modified Mercalli Intensity Scale, we will find that not all countries are under the same seismic hazards.

Vulnerability

Vulnerability is a measure of the intrinsic susceptibility of structures, contents and processes to fail once they are exposed to potentially damaging natural phenomena.

Vulnerability is generally expressed as the degree of expected damage or loss, given in a certain scale, as a function of hazard intensity.

Risk

Risk is a measure of the probability of expected loss for a given hazardous event.

Structural Elements

The portions of a building that support it and resist gravity, earthquakes, hurricane winds and other type of loads are said to be the structural elements.

The structural elements of buildings include columns (pillars), beams (girders and joists), floor or roof sheeting, slabs or decking, load bearing walls and foundations.

Non−structural Elements

The non−structural elements of a building include every part of it and all of its contents with the exception of the structure.

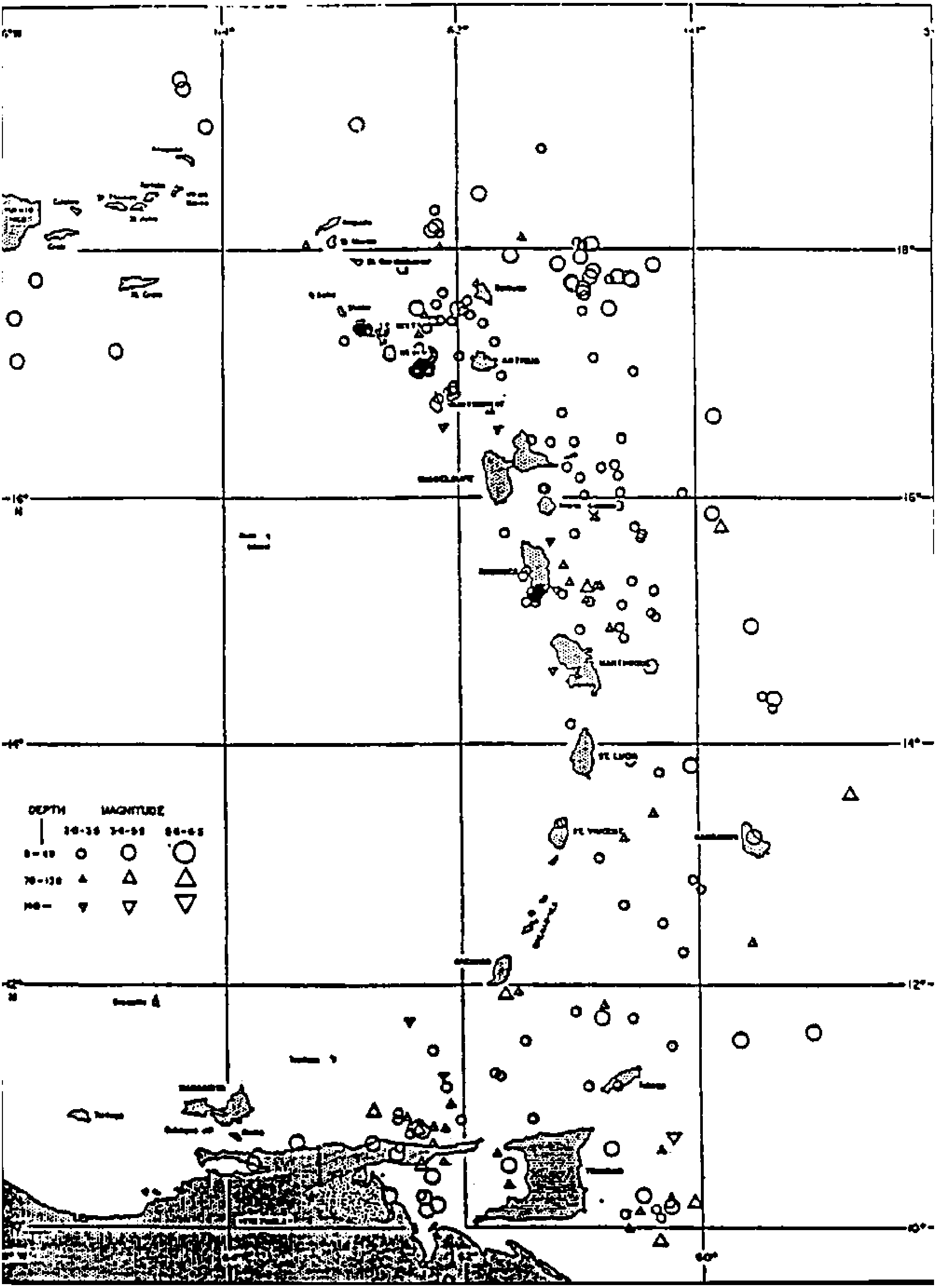
Common non−structural items include ceilings, windows, laboratory equipment, inventory stored on shelves, computers, electrical equipment, furnishings and light fittings.

2.3 Earthquakes

Definition and Measurement

Earthquake. An earthquake is a sudden motion or trembling of the ground produced by the abrupt displacement of rock masses. Most earthquakes result from the movement of one rock mass past another in response to tectonic forces.

The focus is the point where the earthquake's motion starts, and the epicenter is the point on the earth's surface that is directly above the focus. Figures 2.1 and 2.2 show maps of Eastern Caribbean earthquake epicenters for the periods January to June and July to December 1989 respectively.



DEPTH
MAGNITUDE
18°
16°
14°
12°
10°
60°

Figure 2.1 Eastern Caribbean Earthquake Epicenters, January – June 1989

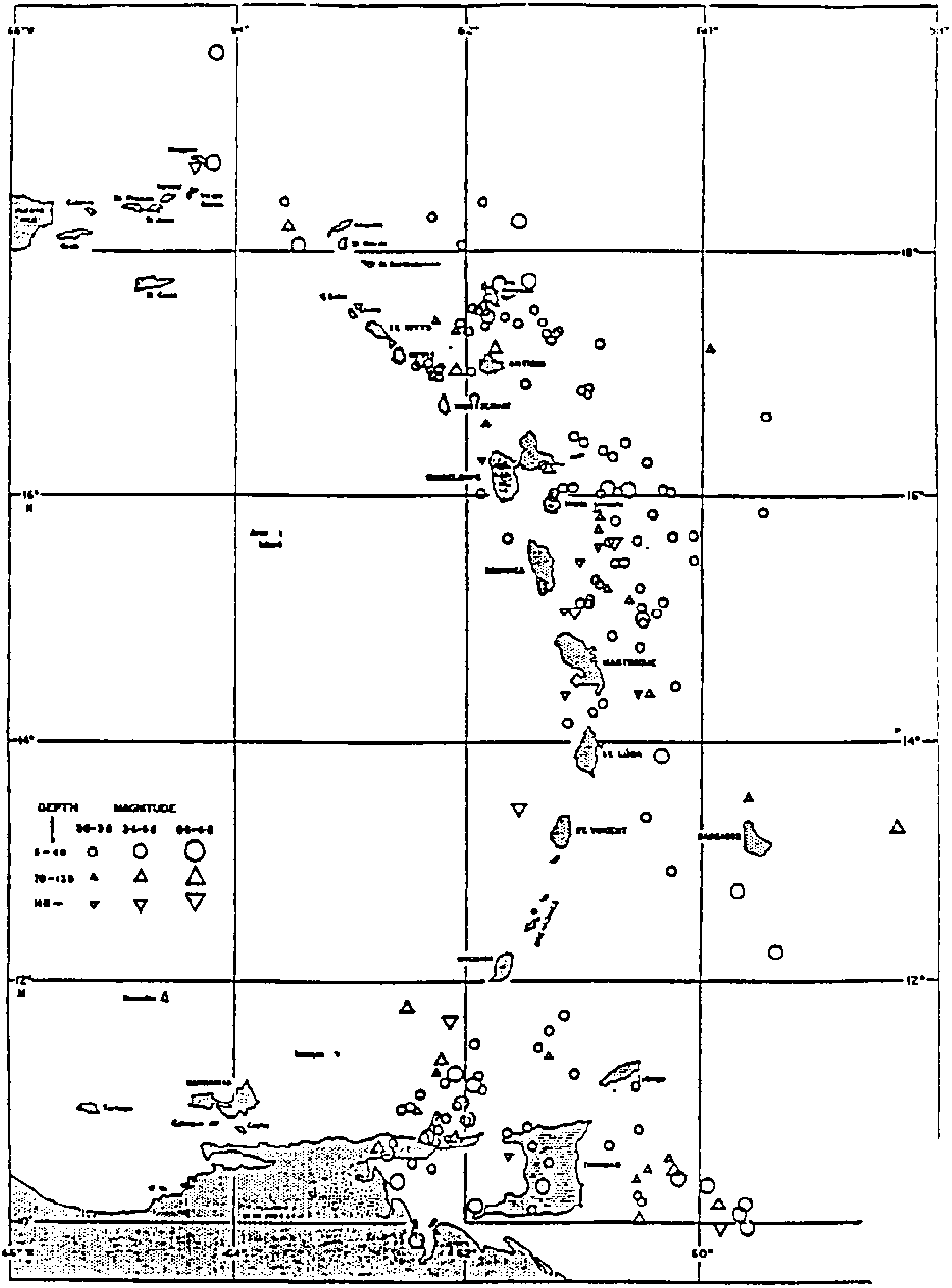


Figure 2.2 Eastern Caribbean Earthquake Epicenters, July – December 1989

Earthquake Magnitude. Earthquake magnitude is a measure of the strength of an earthquake as calculated from records of the event made on a calibrated seismograph.

In 1935, Charles Richter first defined local magnitude, and the Richter scale is commonly used today to describe an earthquake's magnitude.

Earthquake Intensity. In contrast, earthquake intensity is a measure of the effects of an earthquake at a particular place.

It is determined from observations of the earthquake's effects on people, structures and the earth's surface. Among the many existing scales, the Modified Mercalli Intensity Scale of 12 degrees, symbolized as MM, is frequently used (see Annex 1).

Table 2.1 lists some of the strongest earthquakes that have affected the Larger and Lesser Antilles. The given degree of MM intensity is representative of the most affected inhabited area. The name of the island is stated even if the intensity only occurred in specific sites of that island.

Based on the known effects of past events, mean return periods of the expected MM intensity are given in Table 2.2. The values given must be properly interpreted. When it is said that in Barbados the mean return period of intensity grade VII lies between 50 and 70 years, it means that according to available data, the expected number of years between occurrences of that intensity ranges from 50 to 70 years, although it can be shorter or longer.

Figures 2.3 and 2.4 show maps of two of the reported earthquakes. The impact of these events has shown that the local effects of earthquakes can have an enormous range in both space and time. This was clearly demonstrated by the 1766 earthquake (Figure 2.3), centered in northeast Venezuela, which generated aftershocks for 14 months and caused severe damage in West Trinidad and in areas as far as Encaramada on the Orinoco River. Figure 2.4 shows the wide area affected by the 1843 earthquake in the Caribbean. Centered in the northeastern Caribbean, heavy damage was done in Antigua (40 killed and the sinking of English Harbour), Montserrat (16 killed), Guadeloupe, Dominica, St. Kitts; landslides, liquefaction and permanent settlements occurred.

Table 2.1 List of Destructive Earthquakes in the Larger and Lesser Antilles (Caribbean)

DATE	MAGNITUDE	COUNTRY	MM INTENSITY
1690, Apr. 5	7.5 – 8.0	St. Kitts, Antigua	VIII
1692, Jun. 7	–––	Jamaica	IX
1701, Nov. 9	–––	Hispaniola	VII
1751, Oct. 18	–––	Hispaniola	VIII – IX
1766, Jun. 11	–––	Cuba	IX
1766, Oct. 21	7.9	Trinidad	VIII
1770, Jun. 03	–––	Hispaniola	VIII
1810, Oct.	–––	Cuba	VII – VIII
1824, Apr. 20	–––	St. Thomas	VIII
1827, Nov. 30	–––	Guadeloupe, Martinique	VII
1839, Jan. 11	7.5 – 7.8	Martinique	IX
1842, May 7	7	Hispaniola	IX
1843, Feb. 8	7.8 – 8	St. Kitts, Montserrat, Antigua, Guadeloupe, Martinique	IX
1844, Apr. 16	–––	Puerto Rico	VII
1844, Aug. 30	7	St. Vincent	VII
1851, May 16	7	Guadeloupe	VII
1852, Aug. 20	–––	Cuba	IX
1867, Nov. 18	7.5	St. Croix, Virgin Islands	IX
1875, Dec. 8	–––	Puerto Rico	VII – VIII
1880, Jan. 22	–––	Cuba	VIII
1887, Sep. 23	–––	Hispaniola	VIII

1888, Jan. 10	7.5	Grenada	VII
		Trinidad	VII – VIII
1897, Apr. 29	7	Guadeloupe	VII
1904, June	–––	Hispaniola	VII – VIII
1906, Feb. 16	7	Martinique, St. Lucia	VII – VIII
1907, Jan. 14	7	Jamaica	IX
1918, Feb. 24	6.2	Trinidad	VII – VIII
1918, Oct. 11	7.5	Puerto Rico	IX
1928, Sep. 26	6.5	Barbados, Tobago	VI – VII
1932, Feb. 3	6.7	Cuba	VIII
1939, Aug. 14	–––	Cuba	VII
1945, Dec. 23	6.5	Trinidad	VII
1946, May 21	7	Martinique	VII – VIII
1946, Aug. 4	8.1	Hispaniola	IX
1953, Mar. 19	7.5	St. Lucia, St. Vincent	VII
1957, Mar. 1	6.5	Jamaica	VIII
1968, Sep. 20	6.9	Trinidad	VII
1974, Oct. 8	7.5	Antigua, Barbuda	VIII
1976, Feb. 19	5.7	Cuba	VII – VIII

Table 2.2 Mean Return Periods of Modified Mercalli Intensity in Years

	MODIFIED MERCALLI INTENSITY		
	VII	VIII	IX
Any site in one of the Larger Antilles (Cuba, Hispaniola)	<10	25–35	90–110
Given site in one of the Larger Antilles	<10–15	35–45	140–160
In the Leeward Islands Area	<10	25–35	70–90
In any of the Antilles Windward Volcanic Islands	~10	30–40	120–130
Barbados	50–70	170–200	700–900*

* Not observed in historical times

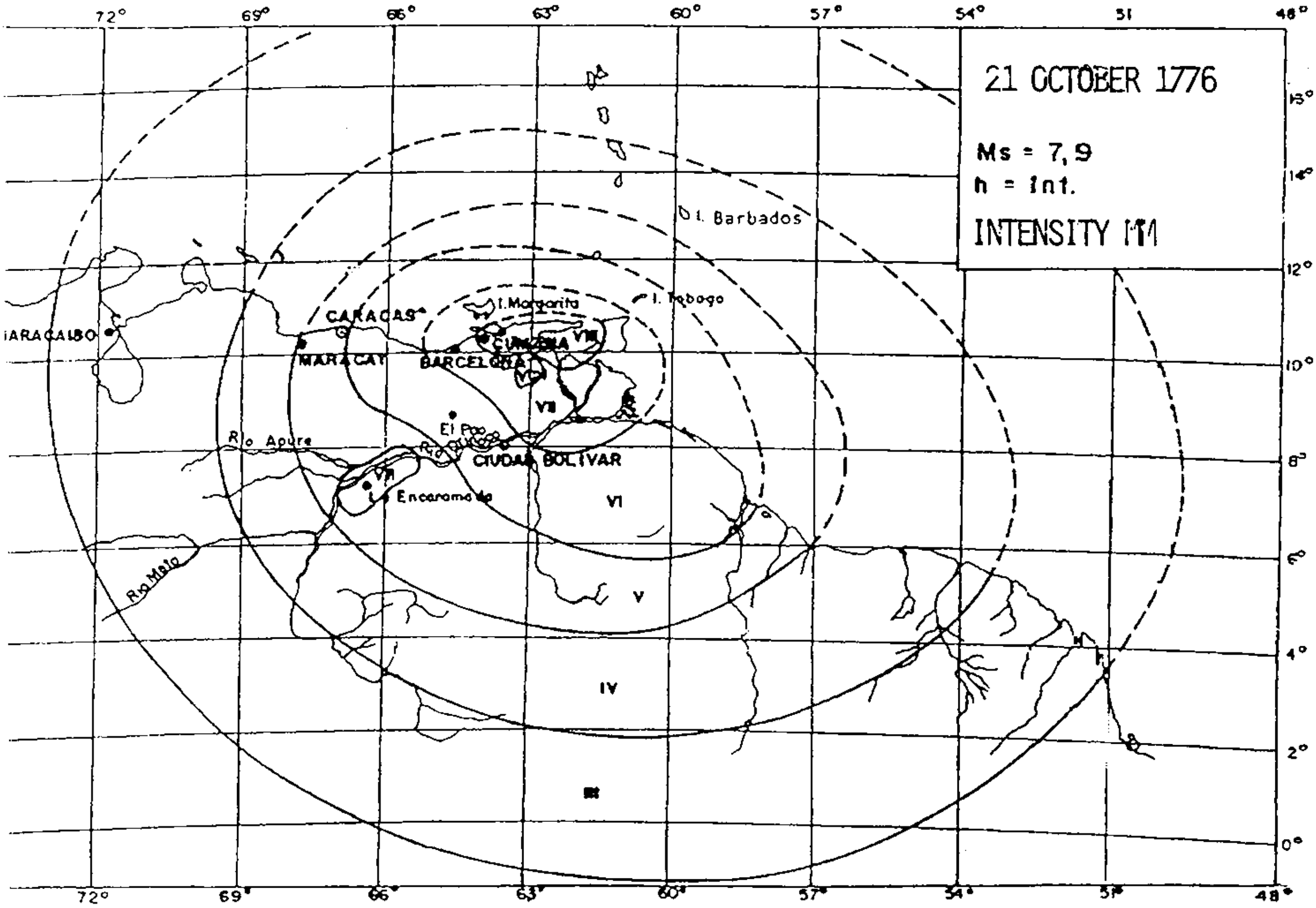

21 OCTOBER 1776
Ms = 7,9
h = Int.
INTENSITY MM
I. Barbados
I. Margarita
I. Tobago
CARACAS
MARACAY
BARCELONA
CUMANA
El Pao
CIUDAD BOLIVAR
Rio Apure
Encaramada
Rio Meta
VIII
VII
VI
V
IV
III
72°
69°
66°
63°
60°
57°
54°
51
48°
12°
10°
8°
6°
4°
2°
0°

Figure 2.3

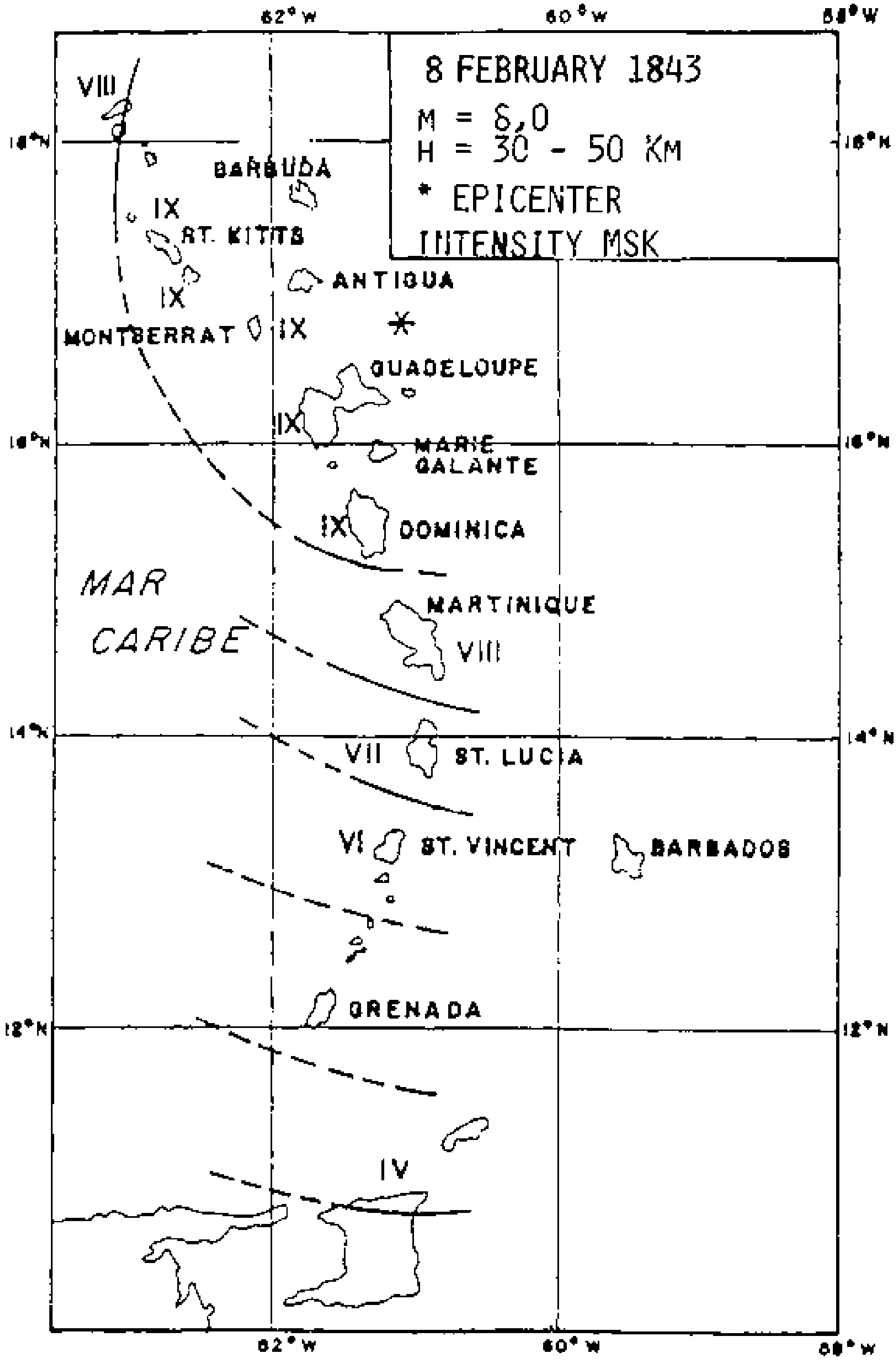


Figure 2.4

SOURCE: DOREL, 1981

Earthquake Hazards

Earthquake hazards can be categorized as either direct hazards or indirect hazards.

Direct Hazards

- Ground shaking;
- Differential ground settlement;
- Soil liquefaction;
- Immediate landslides or mud slides, ground lurching and avalanches;
- Permanent ground displacement along faults;
- Floods from tsunamis or seiches.

Indirect Hazards

- Dam failures;
- Pollution from damage to industrial plants;
- Delayed landslides.

Most of the damage due to earthquakes is the result of strong ground shaking. For large magnitude events, trembling has been felt over more than 5 million sq. km (1.93 sq. miles). As a consequence, engineering decisions are normally taken on the basis of ground shaking evaluations, expressed in terms of expected maximum ground accelerations.

Site Risks

Some common site risks are:

(i) *Slope Risks* – Slope instability, triggered by strong shaking may cause landslides. Rocks or boulders can roll considerable distances.

(ii) *Natural Dams* – Landslides in irregular topographic areas may create natural dams which may collapse when they are filled. Field inspections are therefore necessary to avoid potentially catastrophic avalanches after strong seismic shaking.

(iii) *Volcanic Activity* – Earthquakes may be associated with potential volcanic activity and may occasionally be considered as precursory phenomena. Precautions should therefore be taken against explosive eruptions which are normally followed by ash falls and/or pyroclastic flows, volcanic lava or mud flows, and volcanic gases.

2.4 Volcanoes

Table 2.3 shows the active volcanoes in the Caribbean region, and their associated hazards and periodicity over the last 10,000 years. Within recent times, Mt. Soufriere in St. Vincent has been the most active of these volcanoes. Although the return period of these volcanoes may be exceedingly long, it is well advised not to locate any permanent health care facilities within their immediate vicinity.

The environs of volcanoes tend to be endowed with extremely fertile soil and are therefore attractive areas for population settlement. In these cases, the use of low cost chattel buildings is highly recommended to accommodate local health care resources for the delivery of health services to these populations.

Site selection must take into account local volcanic hazards. In order to minimize catastropic effects such as the one in St. Pierre, Martinique in 1902, roof design must take into consideration thick ash coverage.

2.5 Hurricanes

Definitions

The Caribbean region is located in the North Atlantic Ocean, one of the six main tropical areas where cyclones may develop each year.

Country, Volcano, Periodicity (1)	Location		Date Last Eruption (2)	Effects		Volcanic Hazards						Volcano Mt. (11)	Comments
	Latitude	Longitude		Fatl (3)	Prop (4)	Expl (5)	Pryo (6)	PhEx (7)	Lava (8)	Mdfl (9)	VEZ (10)		
WEST INDIES													
Saba (Caribbean)													
The Mountain	17.63N	063.23N	Holocene										
St. Eustatius													
The Quill	17.48N	062.95N	Holocene										
St. Kitts and Nevis						x		x					
Mount Misery (St. Kitts)	17.37N	062.80W	1843?										
Nevis Peak (Nevis)	17.15N	062.58W	Holocene										
Montserrat													
Soufriere Hills	16.72N	062.18W	Holocene			x							
Guadeloupe													
Soufriere de la Guadeloupe	16.05W	061.67W	1976			x	x	x		x	1-3		
Dominica													
Morne au Diable	15.62N	061.45W	Holocene										
Morne Diablotins	15.50N	061.42W	Holocene										
Microtrin	15.33N	061.33W	1880					x			3		
Morne Patates	15.22N	061.37W	Holocene										
Martinique													
Montagne Pelee	14.82N	061.17W	1929	x	x	x	x	x	x	x	3-4		
St. Lucia								x			1		
Qualibou (Soufriere)	13.83N	061.05W	1776										
St. Vincent													
Soufriere	13.33N	061.78W	1979	x	x	x	x	x	x	x	0-4		
Grenada													
Kick-em-Jenny (submarine)	12.30	061.63	1777								0		

Table 2.3 List of Active Volcanoes in the Caribbean

Cyclone. The term "cyclone" refers to all classes of storms with low atmospheric pressure at the centre. Cyclones are formed when an organized system of revolving winds, clockwise in the Southern Hemisphere, anti–clockwise in the Northern Hemisphere, develops over tropical waters.

Cyclones are classified on the basis of the average speed of the wind near the centre of the system as follows:

Wind Speed	Classification
Up to 61 km/hr (39 mph) 61 km/hr (40 mph) – 115 km/hr (73 mph)	Tropical Depression Tropical Storm
Greater than 115 km/hr (73 mph)	Hurricane

Hurricane. A hurricane is a low pressure, large scale weather system which derives its energy from the latent heat of condensation of water vapor over warm tropical seas. In order to develop, a hurricane requires a sea temperature of at least 26°C maintained for several days and a large expanse of sea surface (about 400 km or 250 miles in diameter). A mature hurricane may have a diameter ranging from 150 to 1000 km (93 to 621 miles) with sustained wind speeds often exceeding 187 km/hr (116 mph) near the centre with still higher gusts.

A unique feature of a hurricane is the eye. The system of revolving winds does not converge to a point, but becomes tangential to the wall of the eye at a radius of 8 to 12 km (5 to 7.5 miles) from the geometric centre of the hurricane. There is therefore very little wind in the eye, and as it passes over a point on the earth's surface, there is a dramatic reverse in the wind direction at that point. The eye provides a convenient frame of reference for the system, and can be tracked with radar, aircraft or satellite.

Classification

The Saffir/Simpson scale is often used to categorize hurricanes based on their wind speed and damage potential. The following five categories of hurricanes are recognized:

Category	Wind Speed (Fastest Mile)		Damage
	km/hr	mph	
HC1	119 – 151	74 – 95	Minimal
HC2	152 – 176	96 – 110	Moderate
HC3	177 – 209	111 – 130	Extensive
HC4	210 – 248	131 – 155	Extreme
HC5	>248	>155	Catastrophic

The destructive potential of a hurricane is significant due to the high wind speeds, accompanying torrential rains which produce flooding, and storm surges along the coastline.

Caribbean Experience

The occurrence of cyclones in the Caribbean has been widely documented over the last five hundred years. It is estimated that over 4000 tropical storms have occurred in the Caribbean region during that time. Of these, about 50 percent fell under the wind speed classification for hurricanes. This amounts to an average of 4 hurricanes within the region every year.

Some significant post–Columbus hurricane events are listed in Table 2.4. The greatest of all hurricanes occurred from October 10th to 16th 1780. Nearly 20,000 people perished as the storm hit virtually every island from Tobago in the southeast through the Leeward Islands and across to Hispaniola. The death toll was 4,500 in Barbados, 9,000 in Martinique, and 4,500 in St. Eustatius.

Analyses of the available data using sophisticated data – processing techniques on the computer allow the frequency and intensity of regional hurricanes to be presented in various useful ways. This information is also used, together with extensive meteorological statistics, to help predict the occurrence and intensity of future hurricanes.

Although the general direction in which a hurricane may travel can be predicted with a fair amount of accuracy, their tracks can be tortuous as shown in Figure 2.5. It shows the hurricane activity in the Atlantic and Caribbean for 1955 which was a relatively active year; 12 tropical storms occurred, 9 of which developed into hurricanes.

Table 2.4 Some Significant Post–Columbus Hurricane Events in the Caribbean

YEAR	HURRICANE	DEATHS	HISTORIC COSTS (US$)/DAMAGE
1509			Santo Domingo destroyed
1667			St. Kitts mostly destroyed
1768			4000 houses destroyed in Havana, Cuba
1772			Extensive damage in Dominica, Antigua, Montserrat, Nevis, St. Kitts, The Virgin Islands, Puerto Rico
1780–Oct 3			Savanna–la–Mar, Jamaica destroyed
1780–Oct 10–16	Great Hurricane	Nearly 20,000	Severe damage in every island from Tobago to Hispaniola
1825	Santa Ana		7000 houses destroyed in Puerto Rico
1831		1500	$7.5 million damage in Barbados
1912			Jamaica struck

1926			Cuba struck
1928			Guadeloupe, St. Kitts, Montserrat, Virgin Islands and Puerto Rico struck
1930	San Zenon	2000	$15,000 damage in the Dominican Republic
1933			Trinidad struck
1935			Bimini Islands, Bahamas struck
1951			Jamaica struck
1955	Janet		Barbados and Grenada struck
1961			Belize struck
1963	Flora	>7000	US$625 million in damage to Tobago, Grenada, Dominican Republic, Haiti, Jamaica, Cuba, Bahamas
1979	David		Extensive damage in Dominica and the Dominican Republic. Over 200,000 homeless, and damage over US$1 billion
1980	Allen		St. Lucia and Dominica struck
1988	Gilbert		Extensive damage in Jamaica
1989	Hugo	82	Extensive damage in Montserrat and South Carolina, U.S.A. Total damage over US$ 10 billion

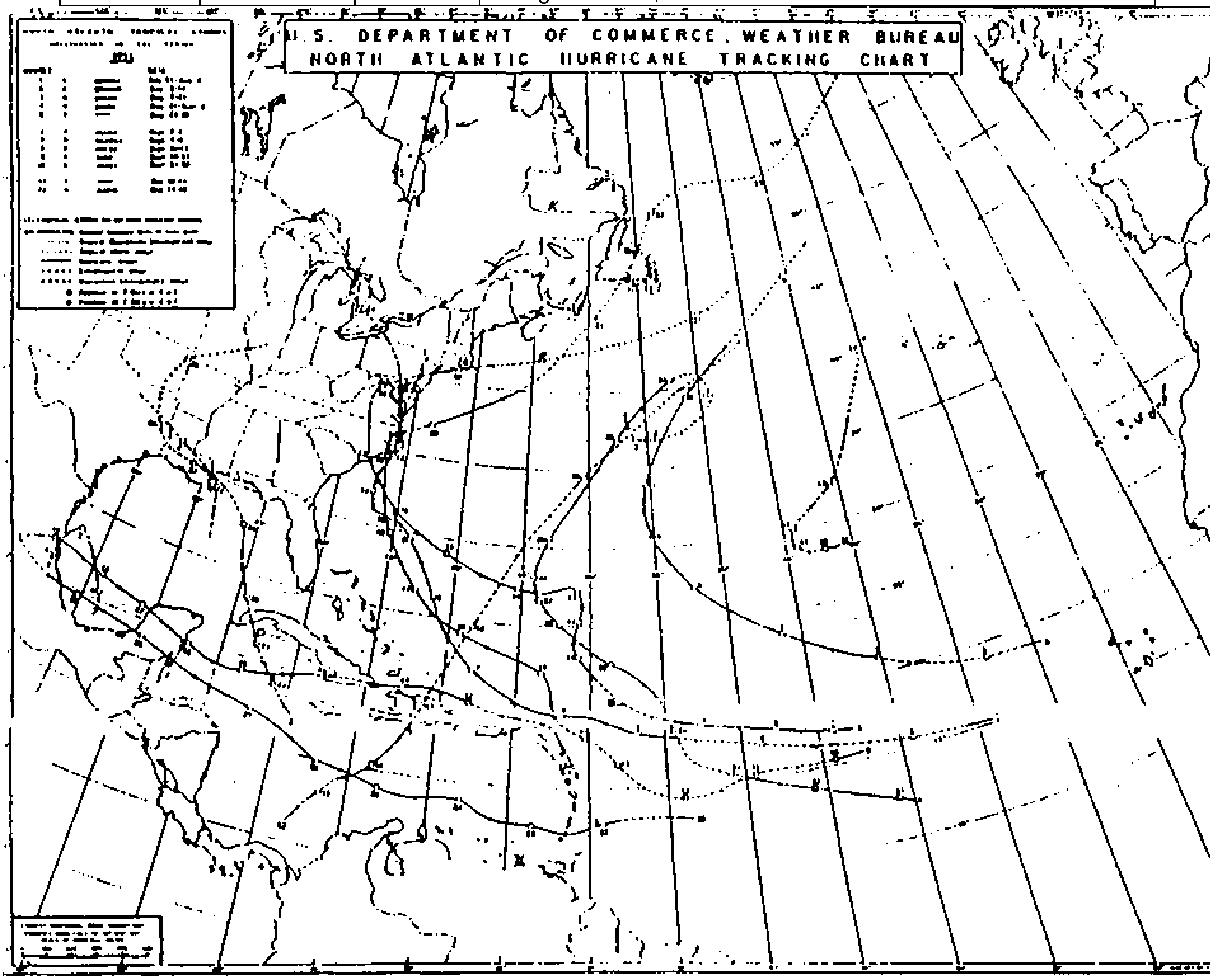


Figure 2.5 Hurricane Tracks can be Tortuous

2.6 Floods

Rainfall

Although rainfall in the Caribbean is characterized by short duration and high intensity, rainfall events of long uninterrupted duration, usually of low intensity, do occur. Most of the severe storms occur during the period known as the hurricane season (from June to October); however, many of them are not associated with hurricanes, but rather with tropical depressions or tropical waves. Rainfall intensity in the Caribbean usually increases with elevation for any given island. Intensities are also higher closer to the equator.

Records from recording rain gauges are available from Grantley Adams International Airport in Barbados from 1942, and from some other of the islands (Jamaica, Trinidad and Tobago, St.Lucia) from 1963 onwards. Some of the island states do not yet have recording rain gauges. These records are necessary for the compilation of rainfall–intensity–duration frequency maps. Typical rainfall isohyets for Barbados are given in Figure 2.7.

Flooding

Flooding can be caused either by short duration, high intensity events where the drainage facilities are inadequate to cope with the rate of runoff, or by long duration, low to moderate intensity events where the substrata becomes saturated, and most of the rainfall results in runoff.

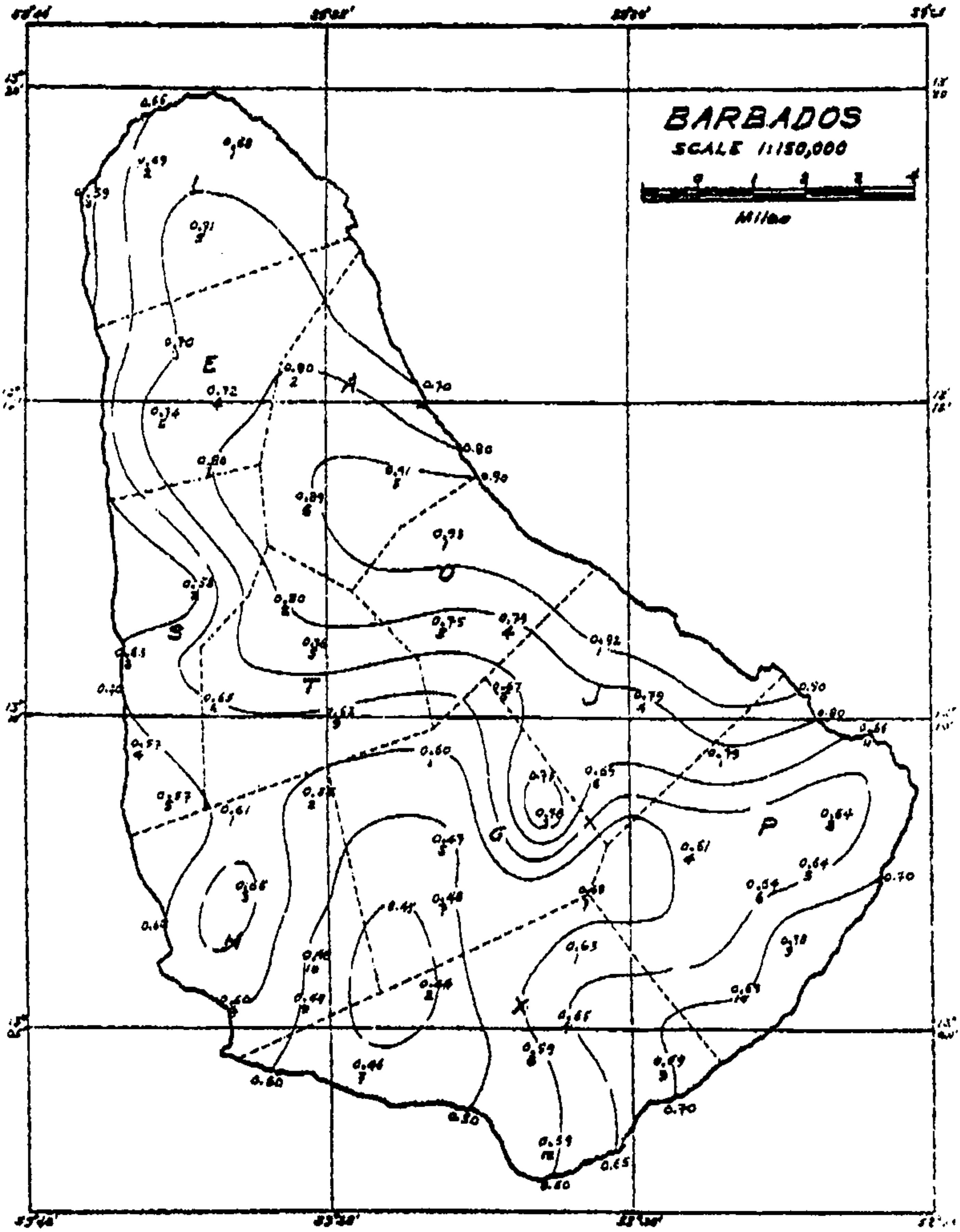


Figure 2.6 Rainfall Isohyets for Barbados

CHAPTER 3: THE CRITICAL NATURE OF HEALTH CARE FACILITIES IN DISASTER MITIGATION

3.1 Relative Importance of Health Care Facilities

Most of the health services in the Commonwealth Caribbean Countries are provided by hospitals and health centres which are owned and operated by Governments. Hospitals normally provide emergency medical care, and secondary or tertiary medical care or both, whereas health centres deliver public health services and some basic primary medical care. Health centres are called polyclinics in Barbados.

Of the health care facilities, the acute care hospital plays by far the most significant and pivotal role in disaster mitigation because of its primary function in treating injuries and disease.

The psychiatric and geriatric hospitals play a relatively minor role except where there is damage to their facilities, or there is a significant enough adverse psychological impact on individuals in the affected population to warrant their involvement.

The primary role of health centres is one of surveillance, even though historical evidence has shown that outbreaks of communicable diseases following natural disasters have been the exception rather than the rule.[2]

[2] PAHO Disaster Report No. 2, Jan. 1983. ***Report on Disasters and Emergency Preparedness for Jamaica, St. Vincent and Dominica***

Some health centres are also equipped to treat persons with minor injuries, and this is extremely useful in relieving congestion at the acute care hospitals.

3.2 Hospitals

Special Considerations

Hospitals require special consideration in the mitigation of natural hazards because of the following factors:

(i) their occupancy characteristics;

(ii) their continuing role during disaster situations in the preservation of life and good health, especially in the diagnosis and treatment of injuries and disease;

(iii) the social costs of their immobilization, and the economic costs of restoration in the case of damage.

Occupancy Characteristics

Hospitals may at anytime have a population of resident patients, transient patients, staff and visitors. This has three major implications for disaster preparedness planning:

(i) Treatment of patients has to continue during a hazardous event: Provision must be made for staff and support services to be readily available at all times.

(ii) The safety and security of all occupants must be assured: A vulnerability analysis needs to be done, and if necessary, the facility must be appropriately retrofitted to recognized standards of design and construction. There are cost-effective methods for doing this, and elsewhere in this booklet appropriate guidance is given.

(iii) It may become necessary at anytime during a hazardous event to evacuate ambulant and non–ambulant patients: This problem may be exacerbated if the hazardous event is of sudden onset and occurs at a time when the hospital is full of visitors who, for the most part, will be unfamiliar with the evacuation procedures.

Visitors in this case could be a serious problem since in the Commonwealth Caribbean, visiting patients is a popular cultural practice, and the number of visitors at peak periods on weekends may be at least double the number of patients in residence.

The majority of hospitals have a bed complement of between 100 and 300 over a range of 30 to 1000 beds. Evacuation plans should therefore be made with the relevant figures in mind.

The Role of the Hospital in Disaster Situations

An acute care hospital is expected to continue to treat patients and also deal with the anticipated increase in injuries during a disaster. To do so, staff must be in place and know how to respond. Also, the building and its contents must remain in a serviceable condition throughout the disaster episode since in Commonwealth Caribbean hospitals, almost all of the industrial type activities which support the clinical functions are hospital based.

Most hospital authorities recognize these facts and have developed formal plans for disaster mitigation (Table 3.1). However, all of these plans are deficient in the provision of alternative arrangements in the case of severe damage and immobilization of the facility. It would appear that little or no attention has been given to this problem. This is indeed very alarming since many of these countries are small and isolated, and in some cases are served by only one hospital. Damage to that hospital would be a major crisis for that country if no alternative arrangements were in place.

Systematic and easy mobilization of staff, equipment and supplies in a safe and secure environment is of paramount importance for an effective disaster response. This emphasizes the critical nature and interdependency of processes, buildings and contents. Deficiencies in any one of these elements of the hospital's functional system could induce a crisis in that institution.

Table 3.1 Status of Disaster Preparedness – Caribbean Region based on information provided in 1991 by the Health Disaster Coordinators

COUNTRY	HEALTH SECTOR DISASTER MANAGEMENT PLANS	HEALTH SECTOR DISTRICT PLANS ADEQUATE	HOSPITAL PLANS REVISION	DRILL	IDNDR NATIONAL COMMITTEE ACTIVE	HEALTH SECTOR COORDINATOR PART–TIME FULL–TIME	WORKING BUDGET NO = NO BUDGET NS = NO SPECIFIC BUDGET YES = SPECIFIC BUDGET
Anguilla	Weak	Weak	Irregular	No	No	P	NO
Antigua & Barbuda	Some	Fair	Irregular	Irregular	Under Disc. & MOH	P	NS
Aruba	Weak	Weak	Irregular	No	No	P	NS
Bahamas	Some	Some	Annual	Irregular	Under Disc. and MOH	P	NS
Barbados	Fair	Some	Irregular	Irregular	Under Disc. and MOH	P	NO
Belize	Weak	Some	Irregular	Irregular	Under Disc. and MOH	P	NS
Bermuda	Good	Some	Annual	Irregular	No	P	NS
British Virgin Is.	Some	Some	Irregular	Some and	Under Disc. and MOH	P	NS

				Irregular			
Cayman Is.	Fair	Weak	Irregular	Irregular	Under Disc.	P	YES
Cuba	Good	Good	Annual	Irregular	Yes & MOH	P	YES
Dominica	Good	Fair	Annual	Irregular	Yes & MOH	P	NS
Dominican Republic	Fair	Some	Some and Irregular	Some and Irregular	Yes & MOH	P	NS
French Guiana	Good	Weak	Irregular	No	No	P	NS
Grenada	Some	Some	Irregular	Irregular	Yes & MOH	P	NO
Guadeloupe	Good	Some	Irregular	No	No	P	NS
Guyana	Weak	Some	No	No	No	P	NS
Haiti	Weak	None	No	No	Yes & MOH	P	NS
Jamaica	Good	Weak	Some	Partial	Yes + MOH	P	NS
Martinique	Good	Some	Annual	No	No	P	NS
Montserrat	Good	Some	Annual	Irregular	In Process	P	NS
Curaçao	Yes	Some	Unknown	Yes & No	No	P	?
Bonaire	Yes	–	Unknown	No	No	P	?
Saba	Yes	Yes	Yes	Yes	Yes	P	?
St. Eustatius	Yes	Yes	Yes	No	No	P	?
St. Maarten	Yes	Yes	Yes	Yes & No	No	P	NS
Puerto Rico	Fair	Weak	Irregular	Irregular	No	P	NO
Saint Lucia	Some	Some	Irregular	Irregular	No	P	NS
St. Kitts/Nevis	Fair	Weak	Irregular	Irregular	No	P	–
St. Vincent and the Grenadines	Fair	Fair	Annual	No	No	P	NS
Suriname	Weak	Weak	No	No	No	–	NO
Trinidad and Tobago	Fair	Fair	Some and Irregular	Partial	Yes + MOH	P	NS
Turks and Caicos	Some	Fair	Irregular	Irregular	No	P	NO
U.S. Virgin Islands	Yes	Yes	Annual	Yes	No	P	NS

Processes. Processes are concerned essentially with the mobilization of people, equipment and supplies. The arrangements in this regard include provision for the establishment of a Committee dedicated to the task of formulating measures for the mitigation of disaster.

The terms of reference of a disaster preparedness committee invariably includes the formulation of a formal disaster preparedness plan, dissemination of its contents among staff in order to create an awareness and knowledge of the plan, staff training in the execution of the plan, and drills and exercises to evaluate the appropriateness of the plan for the types of hazards envisaged. Plans are reviewed at frequent intervals.

Buildings. Plans should include alternative arrangements in the event of serious damage to the hospital facility. The effects of hurricanes David, Gilbert and Hugo on hospitals in the affected countries have clearly demonstrated that this is a serious deficiency in planning which needs urgent attention.

Experience has also shown that in the design and construction of buildings, consideration must be given to the safety, security and preservation of certain critical areas of the hospital such as the emergency department, the diagnostic facilities, the operating theaters, the pharmacy, the medical and food stores, and the utility backup services.

In the past, emphasis in hospital design was placed almost solely on provision of an optimum allocation of space, configured in such a way as to facilitate inter−related departmental functions and activities.

Because of the low cost of design and construction, many of the older hospitals were built as residential cottage type buildings, and although this type of structure is highly resistant to damage by hurricanes and earthquakes, many of them were immobilized during hurricane Gilbert because of destruction of their open and fragile interconnecting walkways.

The high rise hospital, in spite of newer techniques in design and construction, also proved vulnerable because of defects in its non−structural components.

Both types of structures failed because of simple faults in the design which could have been corrected at a marginal additional cost during construction or by retrofitting.

Building Contents. The contents of a building are likely to cause more problems with earthquakes than with hurricanes. Much damage can be avoided by simple and inexpensive means such as securing shelving to walls, and siting plant and equipment in strategic and secure positions.

Regular inspections and proper maintenance of these items should also ensure that they are always serviceable and in good shape.

Economic and Social Costs

In the Commonwealth Caribbean Countries, health care is generally regarded as a right of the individual and of the whole community. As such, most of the health care facilities are owned and operated by governments, and financed through general revenues generated mainly by taxation. Public health services are provided free of charge, and personal health services are provided at little or no charge at all. Very little direct revenues (less than 10% of the health budget) accrue to governments from the operation of these services, even though recurrent expenditures are high. The recurrent expenditures on health in these countries account for about 5 to 15% of the national budget, with 40% of the health budget being spent on hospital services.

Since health institutions rely heavily on the economic capacity of governments to fund them, their survival will ultimately depend upon the state of the economies of governments.

Any adverse impact on the economy of a country will affect its capacity to provide health services, and because of the importance and high capital cost of the acute care hospital, any severe damage to such a facility may not only affect the human productive capacity of that country, but would erode the public finances because of the cost of its restoration.

Impact of Hurricanes. Hurricanes are particularly dangerous because they occur frequently and cover large surface areas in their tracks. This makes the individual islands exceedingly vulnerable because of their small size and fragile economies.

The destruction caused in recent times by hurricanes Gilbert and Hugo to housing stock, buildings, (including hospitals), and crops is ample testimony to this. For example, in Jamaica, the largest of the Commonwealth Caribbean Countries, 95% of all health care facilities suffered damage due to hurricane Gilbert. The cost of emergency repairs alone was estimated at US$13 million with 55% spent on secondary health care facilities.[3] The cost of restoring these facilities has exacerbated the already flagging economy of this country. Even though grants and loan funds are available for this purpose, spending capital funds on physical structures in the service sectors of the Commonwealth Caribbean invariably increases recurrent expenditures and produces no additional revenue.[4]

[3] PAHO Disaster Report No. 5 − ***Hurricane Gilbert in Jamaica****,* Sep. 1988.

[4] Winston Cox − ***National Problems in Financing the Health and Social Sectors****.* Paper read at Caribbean Centre for Development Administration Workshop on Health Care Financing, Jan. 1985.

Capital Investments.

Within recent times, much capital funds have been invested in hospital expansion and retrofitting, despite the fact that this capital is non−revenue generating, and will create an additional burden on governments in meeting the recurrent expenditures to run these facilities properly. This makes it all the more critical to make sure that these investments in social programmes in a time of economic stringency are secure and not subject to the vagaries of natural hazards.

Tourism. The case for designing and constructing new facilities and retrofitting existing ones to recognized engineering standards is further strengthened by recent shifts in these countries to a tourism−based economy. An observable trend indicates that older wealthy tourists are vacationing in countries where there is an availability of quality health services. In addition, there is evidence that a fast−growing component of the tourist market includes visitors for educational and health purposes.[5]

[5] Alister McIntyre − ***Developing Tourism.*** *Caribbean Affairs,* Vol. 1, No. 1, Jan.−Mar. 1988.

Within the last two decades, tourism has become the industry that is making an increasingly significant contribution to the economies of most of these island states. In some cases, it is the major source of foreign exchange earnings and the main support of economic growth.

It is a promising notion that the health care plant in the Commonwealth Caribbean can make a significant contribution to the economies of these countries through tourism. This is all the more reason for new health care facilities to be designed and for constructed to withstand natural hazards, and existing ones to be similarly retrofitted so that this promise may be fulfilled.

CHAPTER 4: DESIGN CONSIDERATIONS FOR NATURAL HAZARDS

4.1 General Considerations

Health care facilities present special characteristics of occupancy, complexity, critical supplies, hazardous items, dependency on utilities, and continuous interaction with the external environment. Too often, the admittedly infrequent cases of natural disasters are ignored in the planning and design of hospitals and related facilities − even in regions such as California where the risks are so well known. It is possible to accurately predict what may actually happen to an installation as a consequence of a hurricane, flood, earthquake or volcanic eruption, but given the variety of simultaneous activities which go on in a hospital, it is necessary to carefully analyze possible scenarios in order to avoid chaotic disruption.

An unsafe structure results in structural damage or collapse. If collapse occurs, there is a major disaster and the hospital becomes a liability rather than a community resource. Major damage will result in evacuation and loss of service for an unknown time.

4.2 Earthquakes

Seismic Design Requirements

Although this document is not intended as an engineering design manual, several problems of building design should be recognized by the health care facility owner, administrator, planner, architect or engineer as factors that may substantially increase the earthquake risk to their building, existing or new.

Seismic Hazard Evaluation. Proper seismic hazard evaluation, including local soil conditions, is of paramount importance. Although this is a general earthquake resistant design requirement, cases where this has been overlooked have led to catastrophic situations.

This means that the extent of damage to a building depends as much on its strength and the type of soil supporting it, as on the intensity and characteristics of the ground motion itself. Inadequate attention to foundation may give rise to differential settlements of footings. For instance, in extreme cases where liquefaction occurs, the building may suffer tilting, cracking and eventually non−repairable damage, leading to a total loss. Settlements are also likely to occur if isolated footings of columns are sitting on different soil types. The same can be said if mixed foundations are used in the same building.

Seismic Performance Requirements

Design of new health care facilities in accordance with CUBiC is intended to ensure an acceptable level of safety. It is nevertheless recognized that for a large earthquake with a low probability of occurrence of intervals of several centuries, there may be some structural and non−structural damage, but life threatening collapse is improbable. This accepted risk criterion stems from the fact that it is not practical or economical to obtain absolute safety from any natural or man−made hazard.

Nevertheless, the fulfillment of code prescriptions does not necessarily protect against many non−structural hazards.

Health care facility owners should also consider how to implement additional seismic performance requirements to protect the occupants and contents of their buildings. The basic strategy for reducing non−structural damage involves precautions in accordance with up−to−date requirements similar to CUBIC.

The following are suggested as seismic performance goals for health care facilities:

(i) The expected damage after an intense earthquake should be repairable and non−life threatening.

(ii) Patients, staff, and visitors should be protected during an earthquake.

(iii) Emergency utility systems in the facility should remain operational after the earthquake.

(iv) Occupants, and rescue and emergency workers should be able to circulate safely inside the facility.

These goals are intended to ensure that the facility will be available for its planned disaster response role after an earthquake.

Although some of these problems are addressed in seismic design building codes and performance requirements, their solutions reside more so in the designer's understanding of the reported seismic response than in the specific code provisions. The problems are essentially concerned with site selection, building configuration, the non−structural elements, building ties, and non−structural issues.

Site Selection

For many years it has been known that local soil conditions have a definite influence on the characteristics of ground motions. Compacted hard rock−type grounds are likely to be accelerated with high frequency ground motions, in contrast to soft unconsolidated thick deposits where shaking tends to have longer period motions. More recently, it has been determined that topographic irregularities can significantly amplify the expected motions relative to flat terrain, and the topography of the basins which contain soil deposits may play an important role in the characteristics of ground motion.

Siting on top or close to active faults, or in tsunamic prone areas must be definitely avoided. Site studies prior to the design and construction of a new facility are more than justified and, in fact, are normal procedures in the evaluation of the seismic vulnerability of existing installations.

Building Configuration

Engineers and architects have learnt that an important feature in the expected building performance is the regularity and symmetry in the overall shape of the building. All other things being equal, a box−shaped building is inherently less vulnerable than an L−shaped, a U−shaped building, a building with wings, or those with a tower rising from a lower structure. An irregular shaped building may twist as it shakes, thus increasing the damage.

It can therefore be concluded that:

(i) simple rectangular buildings are the most desirable, the length being not more than about three times the width;

(ii) symmetrical buildings in plan and elevation are better than asymmetrical ones. Possible irregularities should be examined in both horizontal and vertical planes.

Effects of Non−structural Elements. These components not only suffer damage; they may, in fact, cause it. What this means is that certain non−structural elements may interact with the structure, somehow changing the expected dynamic response during the earthquake. This must be carefully evaluated in order to avoid unfavorable interaction.

Building Ties. Experience of past earthquakes has revealed that a frequent cause of distress has its origins in inadequate connections which tie the building or parts of its appurtenances together. Occasionally this can be due to lack of maintenance in corrosion prone areas. Particular attention should be given to the connections of precast facade elements.

Non−structural Issues

Beyond the mandated requirements of a code, the discipline to conform to a code such as CUBiC requires a rational approach to design that focuses attention on a number of issues, normally overlooked, that can be avoided by rather inexpensive means.

For example, shelves that store medical supplies should be fixed to the walls to prevent them from overturning, or the containers from falling during intense shaking. Such reduction of non−structural vulnerability may very well be the difference between a structurally safe, but useless, facility and a functional, operational installation in a post earthquake emergency phase.

4.3 Hurricanes

Design Criteria

Some health care facilities, and within them certain departments, will be more important than others in the aftermath of a natural disaster. For example, acute care hospitals play a more critical role than health centres, and buildings which house life supporting equipment will require much greater levels of security than, say, those which house laundry facilities.

It is also worth noting that, with regard to intensity, each hurricane is an open−ended phenomenon. That is to say, **there is no such thing as a maximum wind speed for all hurricanes.** It follows, therefore, that one cannot economically design against the occurrence of every conceivable hurricane. When consultants are commissioned to provide designs for health care facilities, it is essential that the brief specify both the criticality of the component hospital units and the wind design criteria to be employed.

The Saffir/Simpson categorization of hurricanes was set out in Chapter 2 of this booklet. The probability of the occurrence of a hurricane of particular intensity decreases with an increase in the category number. In other words, a category 5 hurricane (catastrophic damage potential) is less likely to occur in any year than a Category 1 hurricane (minimal damage potential). In Figure 4.1, the building life factor, S_3, is plotted against the design life of the building for Antigua and Barbados at two probability levels. The S_3 factor is one of those used in the calculation of the design wind speed. It can be seen from the graph that the S_3 factor increases with the design life of the building for the probability of a particular wind speed being exceeded in any year.

The specification of design wind speeds must be done in relation to a particular averaging period over which the wind is measured. Typical averaging periods are 1 hour (Canadian Code), 10 minutes (Caribbean Uniform Building Code), 3 seconds (Barbados Association of Professional Engineers Wind Code) and fastest mile (USA Code).

The following table lists the equivalent wind speeds for a 120 mph wind expressed for each averaging speed and shows clearly the need to specify the averaging speed:

Averaging Period	Wind Speed			
1 hour (Canada)	120	113	91	79
10 minutes (CUBiC)	127	120	96	84
Fastest mile (USA)	158	149	120	105
3 second (BAPE)	181	171	137	120

Designers often allow for security against Categories 2 and 3 hurricanes. It is advisable, though, that the most critical facilities be designed for categories 4 and 5 hurricanes. Hurricane Hugo in 1989 was a category 4 hurricane and Gilbert in 1988 was category 5.

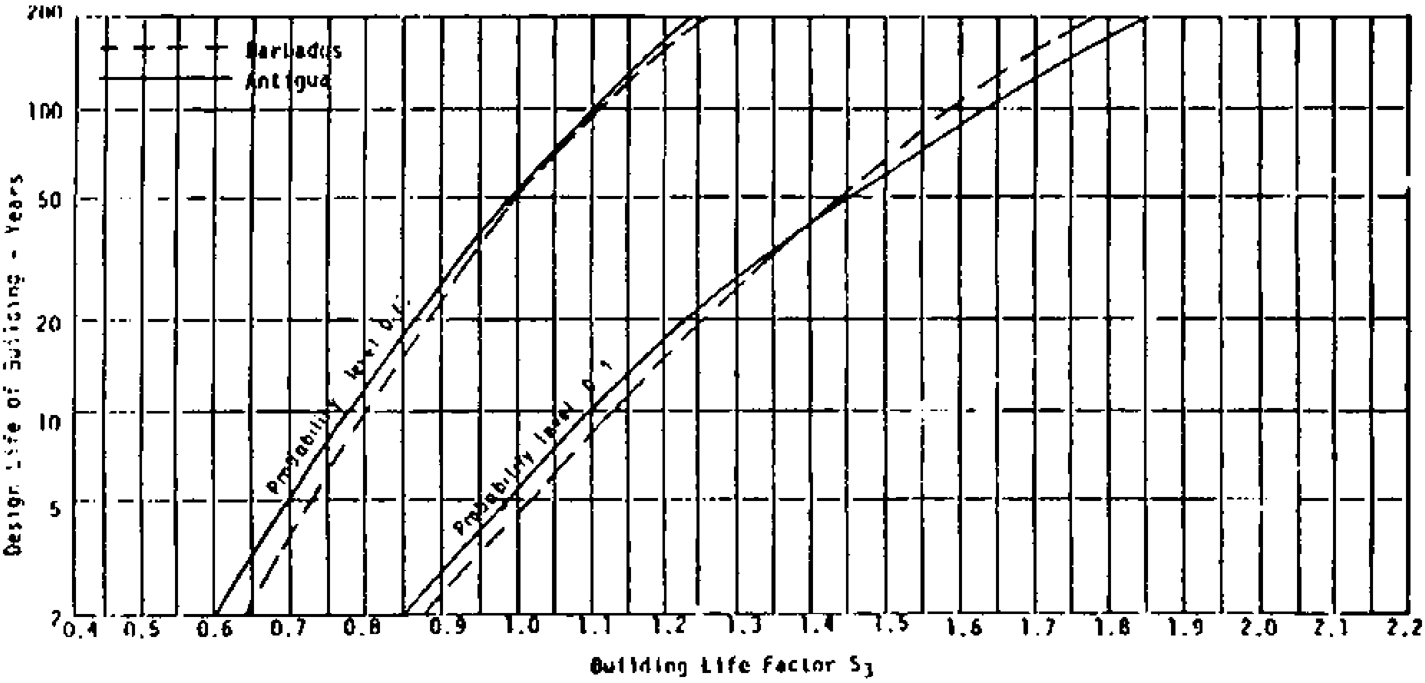


Figure 4.1 Factor for Building Life

The determination of design criteria for health care facilities requires an initial assessment of their importance by health care managers, followed by the careful selection of design values in conjunction with the consultant.

The initial architectural brief prepared for the design of new health care facilities provides the best opportunity for health care managers to influence the safety of the completed structures with regard to natural hazards including hurricane force winds. Besides selecting the basic wind speed to be used in the design, other issues to be considered include the siting of facilities, building shape, and type of structure. These issues are addressed below.

Siting of Facilities

The intensity of hurricane force winds is modified by the topography of the surrounding area. Some examples are:

(i) Gently sloped valleys which act as funnels for the wind and accelerate its speed;

(ii) Very exposed hill crests where acceleration of the wind is known to occur;

(iii) Deep, steep sided, enclosed valleys which provide shelter from the wind;

(iv) Heavy surrounding afforestation which provides windbreaks. Account must therefore be taken of the effects of the surrounding topography when siting and designing structures.

Building Shape

Dome and polygonal shapes present fewer sharp edges to modify adversely the flow of wind over the building. This leads to fewer areas of localized high wind suction and consequently an improvement in security.

Most buildings, however, are rectangular in plan. Length to width ratios of 3:1 or less are favorable with the most efficient plan ratio for wind resistance being 1:1, which is a square. There is increasing vulnerability with ratios above 3:1.

L–shaped plan forms are also more vulnerable than square ones. An increase in pressure occurs when the wind channels into the junction between the two wings. In general, buildings which are asymmetrical in plan or elevation are more vulnerable than symmetrically shaped buildings to the lateral loads which winds generate.

Where lightweight roofs are employed on buildings, the shape of the roof will be the major factor in its proneness to hurricane damage.

Lightweight Roofs

One of the most important elements of a building is its roof, the loss of which will result in much damage to the contents. The performance of roofs under wind loads is influenced by the materials used for construction. The best security against high winds is provided by reinforced concrete roofs. Reinforced concrete slabs offer the best protection.

Throughout the Caribbean, lightweight roofs are commonly used for both private homes and public buildings. These are generally constructed of corrugated metal sheeting on timber battens and rafters. Alternatively, the sheets, shingles, or other cladding are supported on timber closeboarding on rafters.

In some cases, steel rafters and purlins are used. However, because of their relatively reduced strength compared to reinforced concrete, lightweight roofs are inherently unsafe.

Listed below there are several measures which may be taken to improve the security of such roofs.

(1) Choice of roof shape. The order of preference for shapes is:

(i) hipped (i.e. sloped on 4 sides),
(ii) steep pitched gable;
(iii) shallow pitched gable;
(iv) monopitch;
(v) flat.

Experience has shown that pitches between 20° and 40° provide the best wind resistance.

(2) The use of heavier gauge sheeting, 0.5 mm minimum thickness for steel and 0.9 mm minimum thickness for aluminum. The thicker the sheeting, the less likely for it to fail under fatigue loading or pull through. Asbestos sheets are not recommended since these are brittle and more likely to suffer impact damage from airborne debris.

(3) The use of a closeboarded timber deck. This provides a second line of defence. The cladding then serves as waterproofing and its loss does not immediately lead to the failure of the roof structure.

(4) Screw fixings are less likely than nailed fixings to pull out under uplift forces and are preferred. A closer spacing of the fixings should be provided in higher suction zones adjacent to the eaves, gable ends and ridges. Fixings should be installed in the valleys of the corrugations as this will reduce the opportunity for flexure of the sheets and fatigue failure under the cyclical suctions generated by hurricane winds.

However, especially for sinusoidal sheet profiles, this may sometimes lead to leaking. If fixings are made to the ridges of corrugations, then spacer blocks should be placed between the sheets and the purlins.

(5) The use of short or no overhangs. If shading is required over windows and doors, separate canopies should be used. Failure of these would not endanger the roof.

(6) The provision of parapets to reduce uplift at the edges.

(7) The inclusion of ridge ventilators to reduce the internal pressure on the roof and walls.

Windows, Doors and Walls

Window and door openings are the next most vulnerable areas. Glass windows are particularly vulnerable and should be protected by using storm shutters. Where feasible, shutters should be fixed permanently to the building. This will ensure that they are always available and will eliminate the need for storage. Shutters may be made from timber, plywood or tongue and groove. Manufactured aluminum shutters are easy to install and are readily available in some countries.

External doors should be of robust construction and kept in good repair. It is not sufficient to rely on standard bolts to secure doors and large windows. The high pressures and suctions generated during a hurricane may cause bolts and hinges to fail at their fixings. It is recommended that braces be used to strengthen doors and window shutters. These braces may be secured in slots in the wall on either side of the opening or in brackets bolted to the wall.

The recent major hurricanes in the Caribbean have demonstrated that concrete blockwalls may be blown down by hurricane winds. Adequate reinforcement is therefore required for blockwalls.

Building Connections

It is imperative that all of the components of a building be securely interconnected. A well constructed roof will not stay in place during a hurricane if it is not attached to the rest of the building. The use of bolts and metal straps is recommended for connections. For timber to concrete connections, the bolts should be well anchored in the concrete members.

Summary

In summary, there are many measures which may be incorporated into the design of new health care facilities in order to ensure safety under hurricane conditions. Close communication should be maintained with the consultants during the design phase and a detailed scheme prepared with security against hurricane damage foremost in mind.

4.4 Floods

Design of Drainage Systems

In designing stormwater drainage systems for health care facilities, the level of design must be based on the relative importance of the facility. This relative importance can be determined by health care professionals.

Ordinary drainage facilities in the Caribbean are normally designed to accommodate runoff from storms having return periods of up to 20 years. However, on two occasions during the past twenty one years, in October 1970 and December 1977 respectively, Barbados experienced rainfall events that were estimated to have return periods in excess of 50 years.[6]

[6] Barbados Water Resources Study, 1977–78.

Flood control systems for essential facilities such as health care facilities must have a higher level of design than non–essential facilities.

The following guidelines should therefore be used in arriving at criteria for the design of drainage systems:

(i) Pavements, especially vehicular accesses, should be free of excess stormwater in all floods having return periods up to 50 years.

(ii) There should be no ingress of water to main buildings in any event as a result of flooding.

(iii) Alternative travel paths for stormwater should be provided in case of blockage.

The time of concentration of the drainage basin, that is, the times used as the duration for the rainfall event, is small for such facilities, usually less than 10 minutes.

Rainfall intensity can increase significantly for small changes in duration for short duration events. As an example, in Bridgetown, Barbados, the intensity of a 15 minute storm having a return period of 25 years is 5.32 inches/hour, while the 10 minute storm having the same return period is 5.94 inches/hour, an increase of 12 percent. It is therefore critical that the storm duration is calculated accurately.

Since rainfall data from recording rain gauges are scarce for most of the region and totally lacking for many islands, recourse must be made to extrapolating existing data to arrive at values for higher return periods than available. In islands where there are no recording rain gauges, the records of the non–recording gauges can be used to arrive at rainfall intensity–duration–frequency curves by employing existing curves from a station in another island.

Siting of Facilities

Health care facilities located near water courses, such as valleys, or flood plains are more susceptible to flooding than are those located on high ground or away from watercourses.

Conditions upstream of the facility influence the runoff to the facility. For example, dense vegetation reduces the peak rate of runoff by increasing interception of rainfall and by increasing the time of concentration whereas heavily developed areas increase the overall runoff as well as reduce the time of concentration, thereby increasing the runoff rate.

Facilities sited on high elevations are likely to have smaller catchment areas.

Subsoil Conditions. The type of subsoil conditions and ground cover as well as the method of stormwater disposal influence the volumes of runoff. For instance, in Barbados the coral limestone that lies just below the topsoil is very porous and fissured. This results in high absorption rates and also lends itself to subsoil disposal using suckwells.

In some of the other islands that are of volcanic formation, the soil is almost impervious and disposal must be by surface flow, usually in closed or open conduits, and eventually to natural watercourses or the sea.

Drainage Systems. The type of drainage system chosen has a significant effect on the overall performance of the system. Closed systems using pipes or box drains are more susceptible to blockage and are more difficult to maintain. On the other hand, earth swales and channels incorporated into the landscaping are easy to construct and maintain, and are also less costly and aesthetically pleasing. This type of system should therefore be considered whenever possible.

Maintenance of System. No flood control system can function effectively unless it is adequately maintained on a regular basis. Probably the single biggest cause of flooding of built facilities in the Caribbean is partially or totally blocked drainage systems or watercourses.

In designing drainage systems for health care facilities, engineers and designers should choose the system that meets all the previous requirements and is the easiest to maintain in both the short and long term.

CHAPTER 5: DESIGNING NEW HEALTH CARE FACILITIES FOR MULTIPLE HAZARDS

5.1 Conceptual Design

Conceptual design involves a series of decisions among which are:

(i) the siting of the building;
(ii) geometry or shape or configuration of the building;
(iii) the structural system;
(iv) the construction materials.

So basic are these issues that they must be addressed at the earliest stages in the development of a project. All parties should be involved at this stage – client, architect, engineers and builders. Unfortunately, the present organization of the construction industry makes it difficult for builders to be involved in design development. This places a greater obligation on architects and engineers to better understand the construction process, and be conscious of the implications of their design decisions on costs and facility of construction. Costs are affected by relative ease of construction, availability of materials, equipment and labor, and time for construction.

In some countries, the responsibility for monitoring costs is given to a separate discipline – the quantity surveyor. It would be better if the knowledge of costs resided in the minds of the designers. To take this argument to its logical conclusion, it would be better if there was one person (the conceptual designer) with the necessary expertise in architecture, engineering, cost estimating and construction. Such a person used to be the Master Builder. Arup described this notion succinctly: "Civilization is built on Specialization. Specialization may destroy Civilization."

5.2 The Design Process

When engineers become involved in design, they take out their calculators too quickly. True design precedes detailed calculation. To be sure, some calculation is required in the process of design, but the principal calculations can only be done after the bulk of the design has been done. Mathematics is then a tool for refining the design and for determining the details of construction. This is not to downplay the importance of structural analysis and detailing. It is more so to emphasize the proper chronology of these functions.

The building life cycle is as follows:

(1) Design (i.e. conceptual design)
(2) Analysis
(3) Detailing
(4) Construction and Inspection
(5) Maintenance
(6) Demolition.

Each function is affected by each other stage in the cycle, but this is not at variance with the order of precedence given above. Good analysis cannot make up completely for bad design, and good construction can certainly not correct bad detailing.

5.3 Comparison of Design Features for Multiple Hazards

Designing against multiple hazards is more than doubly difficult, especially when those hazards are wind and earthquake. Many favorable features of wind−resistant design are unfavorable for earthquake−resistant design and vice versa:

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

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

Both hurricanes and earthquakes impose horizontal loads on buildings. Earthquakes also impose significant vertical loads on a building overall. The vertical loading derived from wind is usually significant on those parts of a building which show certain aerodynamic characteristics.

There are however some similarities in the effective design and construction of buildings to resist hurricanes and earthquakes:

(i) Symmetrical shapes are favorable.

(ii) Compact shapes are favorable.

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

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

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

Table 5.1 summarizes the main differences between hurricanes and earthquakes as they affect structural design.

Table 5.1 Main differences between wind and earthquakes

	WIND	EARTHQUAKE EFFECTS
(1) Source of loading	External force due to wind pressures	Applied movements from ground vibration
(2) Type and duration of loading	Wind storm of several hours' duration; loads fluctuate, but predominantly in one direction	Transient cyclic loads of at most a few minutes' duration; loads change direction repeatedly
(3) Predictability of loads	Usually good, by extrapolation from records or by analysis of site and wind patterns	Poor; little statistical certainty of magnitude of vibrations or their effects
(4) Influence of local soil conditions on response	Unimportant	Can be important
(5) Main factors affecting building response	External shape and size of building; dynamic properties unimportant except for very slender structures	Response governed by building dynamic properties: fundamental period, damping and mass

(6) Normal design basis for maximum credible event	Elastic response required	Inelastic response permitted, but ductility must be provided; design is for a small fraction of the loads corresponding to elastic response
(7) Design of non−structural elements	Loading confined to external cladding	Entire building contents shaken and must be designed appropriately

5.4 Implementation Guidelines

Structural configuration is the single most important factor in determining the performance of buildings subjected to earthquakes and hurricanes. The following recommendations are proposed and are particularly appropriate for **non−engineered** construction and for **minimum−cost** construction:

(1) Limit the height of buildings to two stories.

(2) Use lightweight floors and roofs to reduce risks in earthquakes. Ensure that they are securely fastened to the walls to improve their performance in hurricanes. Alternatively, if concrete roofs are used as a hurricane−resistant strategy, ensure that the vertical elements (walls and columns) are conservatively built to carry the significant horizontal loads from earthquakes.

(3) The shape of the building should be, as far as possible, symmetrical. This symmetry also applies to the arrangement of partitions and openings. This would lead to a more balanced distribution of forces in the structure.

(4) Provide sufficient distance between openings to avoid narrow and slender piers. Keep the openings moderate in width to avoid long−span lintels.

(5) Link the heads of all walls together by providing a continuous collar or ring beam at floor and roof levels.

(6) Lightweight roofs should be not less steep than 20 degrees to improve their wind resistance. As a general rule, the steeper the better up to about 40 degrees.

(7) To improve their wind resistance lightweight roofs should have a hipped shape (sloping in four directions) rather than a gable shape (sloping in two directions) or a monopitch shape.

(8) To improve their wind resistance, lightweight roofs should have minimum overhangs at the eaves. In fact it would be better to have no overhangs and to introduce a parapet. The need to shade windows and doors from sun and rain may be met by separate canopies.

(9) The incorporation of ridge ventilators would reduce internal pressures and help retain lightweight roofs in a hurricane.

Clearly, the above recommendations are very restrictive indeed. But to vary significantly from them would require the conscious involvement of engineers to achieve safe construction. Today's technology permits almost anything to be done. In fact, it could be said that advances in technology are responsible for much bad design. Technology and the availability of funds permit badly designed buildings to be made safe. The aim is not to restrict design, but to sensitize people to those factors requiring caution.

5.5 Implementation Constraints

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

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

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

5.6 Procurement, Installation and Maintenance of Equipment

Not much attention has been given in the past to the procurement, installation, and maintenance of equipment in hazard mitigation, although there is ample evidence that this is an important factor, and simple, effective, and inexpensive measures can be taken at an early stage of construction or retrofitting to prevent costly damage at a later stage.

Where equipment will be exposed to the elements, it is important that, to the extent possible, they should be protected against damage by hurricanes. Apart from ensuring the security of the plant itself, damage is prevented to adjacent structures from collapse of the plant or resulting airborne debris.

In earthquake prone areas, the specifications for and siting of utility installations are particularly important and must take into account subsoil conditions. Also, plant and equipment should be securely mounted and fixed to their foundations.

When ordering equipment, either directly or through a consultant, the design criteria for wind loads and earthquakes must be defined and specified in the tender document in relation to a particular code of practice.

Once equipment and fixings have been designed to withstand the specified criteria and have been delivered to site, it will next be necessary to ensure that installation is carried out in accordance with the manufacturer's instructions. Supervision of installation will be important.

Finally, there must be ongoing checks and timely maintenance of the fixings to equipment. Particular attention should be paid to the prevention of the corrosion of fixings. Whenever necessary, fixings should be replaced with no lesser specifications than those originally installed. The development of a maintenance manual is perhaps the best way to ensure that the above procedures are followed.

CHAPTER 6: RETROFITTING OF HEALTH CARE FACILITIES FOR MULTIPLE HAZARDS

6.1 Introduction

In the Commonwealth Caribbean, there already exists much of the complement of health care facilities required to meet foreseeable needs. The use of most of these facilities is envisaged for some time to come.

It is likely that several of the existing facilities are vulnerable in varying degrees to damage from seismic forces or hurricane force winds. However, the opportunity exists to effect improvements to them. The implementation of relatively inexpensive measures has already realized significant improvements in the security of structures. For greatest benefit, the retrofitting of existing facilities should be undertaken in a systematic way.

Many existing buildings do not meet the current technical requirements. This means that their vulnerability to natural hazards may be so high that their associated risk largely exceeds currently accepted levels. Remedial actions based on scientific knowledge must therefore be taken in order to reduce risk and assure adequate performance. This retrofitting must be consistent with existing engineering requirements and in the case of the Commonwealth Caribbean countries, CUBiC requirements should be adopted.

6.2 Evaluation of Vulnerability

General Considerations

Those responsible for health care facilities need to investigate the local vulnerability to hurricanes, earthquakes and flood actions in order to get precise estimations of the degrees of hazard. Once this is done, they will have the proper information in order to decide how much risk they are willing to accept.

In many cases, a non−engineer can at least make a preliminary assessment of the approximate degree of risk by use of the information presented here and by keeping in mind two basic questions as each non−structural item is considered:

(1) would anyone get hurt by this item in an earthquake or a hurricane?
(2) would interruptions and outages be a serious problem?

This will produce a preliminary list of items for a more detailed consideration. At this stage of planning, it is better to be conservative and overestimate vulnerabilities than to be too optimistic. An example is given in Table 6.1 to show how this information can be summarized in respect of earthquakes. A general sample form is also shown at Annex 2 that can be used to highlight the critical factors for hurricanes and earthquakes.

There are basically two types of elements to be evaluated within this intrinsic aspect of disaster mitigation: the building with its contents, and the infrastructure.

Facility: XYZ OFFICE Assumed Intensity: Severe

PRIORITY	NONSTRUCTURAL ITEM	LOCATION	QUANTITY	VULNERABILITY			ESTIMATED RETROFIT COST, EACH ITEM	ESTIMATED RETROFIT COST, SUBTOTAL	NOTES
				✚	$				
4	air conditioner	roof	1	mod	25-75%	mod	$100	$100	sits on springs; no seismic restraints
5	suspended ceiling	throughout	5000 sq. ft	mod	100%	mod	$.20/sq. ft	$1,000	no diagonal wires
1	water heater	utility room	1	high	100 %	high	$50	$50	gas fired; no flexible pipe; no anchorage
3	tall shelving	employee storage	40 lin. ft	high	100	low*	$200	$200	* low because contents not essential; unanchored; 8 ft high
6	freestanding partitions	secretarial stations	20 @ 6 ft	low	0-5%	low	0	0	stable layout (returns)
2	fluorescent lights	offices and lobby	50	high	25-100%	mod	$1,500	$1,500	fixtures just rest loosely on ceiling grid
							TOTAL	$2,850	

✚ LIFE SAFETY HAZARD $ % OF REPLACEMENT VALUE DAMAGED POST-EARTHQUAKE OUTAGE

Table 6.1 Illustration of Blank Form

Buildings and Contents

To identify the elements at risk, firstly identify the prevalent types of construction; secondly analyze – the strength and stability of the building elements and joints; and thirdly evaluate vulnerability of equipment and installations.

Structure. Common building types in the Caribbean are reinforced concrete buildings, brick masonry buildings with light roofing, and wooden buildings with light roofing. Specialized engineering efforts are required in order to properly evaluate structural vulnerability.

Non–structural Elements. The non–structural elements include exterior non–loadbearing walls, infill walls, interior partition systems, windows, ceiling systems, elevators, mechanical equipment, electrical and lighting systems, and the contents of the building.

Non–structural damage has been more frequently than not the cause of heavy losses, particularly in earthquakes. Damage to non–structural components may be severe, even if the building structure remains essentially intact.

Cost implications may also be heavy, given that the building structure only represents 15% to 20% of the cost of the building. Therefore, the more vulnerable the non–structural elements are to earthquake and hurricane actions, the higher will be the risk to the occupants and the larger will be the expected losses.

The disruption may be aggravated by the fact that earthquake and hurricane–resistant design codes do not usually have formal provisions governing the design of mechanical and electrical systems. Experience has shown that secondary effects from non–structural damage may also exacerbate the situation. For example, ceiling planks or wall finishes that fall on corridors or stairs will hamper traffic, and fires, explosions and spilled chemicals will be hazardous to life. Also, damage to utility systems may make the modern hospital virtually useless because it depends on these systems for its ability to function properly.

Much of the contents of a health care facility are essential to its operation. Items from costly equipment to patient records cabinets are all needed immediately after an earthquake or hurricane. Normal building codes do not cover such items, therefore protective measures must be undertaken by building management and by occupants.

Observed incidents in past earthquakes may illustrate the types of problems to be considered:

(i) overturning of slender and loose oxygen and flammable gas bottles, with uncontrolled leakage creating a highly dangerous situation;

(ii) overturning of the back–up generator due to rusted and weakened anchorage to its foundation, causing interruption of the emergency power supply and creating a hazard that could lead to a fire;

(iii) total or partial overturning and oil spilling of high voltage transformers also causing interruption of the emergency power supply and creating hazard that could lead to a fire;

(iv) shifting of the telephone control console, causing a temporary interruption of the ability to communicate with the hospital;

(v) overturning of storage racks and falling of bottles from cabinets, resulting in the spillage of contents and the loss of necessary medications and drugs;

(vi) falling of laboratory equipment and breaking of costly instrumentation such as microscopes and computer consoles;

(vii) elevator counterweights and cables becoming entangled.

There are also many problems associated with hurricanes to consider, such as the destruction of roofs and windows with consequential damage to equipment, furniture and records by wind and water.

The building content vulnerability can be greatly reduced. Specific measures for earthquakes have been proposed and implemented by FEMA.[7] They are of paramount importance in order to assure the safe egress from a damaged health care facility, particularly since the typical layout of the building may be unfamiliar and confusing to visitors, and lights may be out because of damage to the electrical system. Since elevators should not be used even if they work, the only way down would be by stairways. In earthquakes, these may be crumbled with debris because, being a rigid element between stories, they attract large forces and are therefore likely to be damaged. Doors may be jammed by the shaking of the building and may make egress difficult.

[7] Federal Reserve Management Agency. Earthquake Hazard Reduction Series 35 FEMA 150, 1987: ***Seismic Considerations: Health Care Facilities.***

It must be emphasized that even if the non−structural damage prevents normal operation of the facility, the building may still be in a good enough condition to be used for providing essential emergency services. It is therefore important and necessary that in such situations, an immediate structural inspection be done by trained professionals.

Many of the problems that are outlined in this manual stem from lack of attention to expected actions from natural hazards. Even though designs of buildings which are in accord with modern codes, such as CUBiC, cannot guarantee lack of damage, they will ensure a basic level of safety that is difficult to obtain in any other way. Codes establish minimum requirements that can be increased according to the importance of the facility.

Infrastructure

The infrastructure includes the physical external resources on which the hospital depends, such as the communication, water supply, sewage, energy and information systems of the facility. The impact of natural hazards on these resources is briefly discussed:

Telecommunications. Telephone exchanges and overhead lines can be seriously damaged by natural hazards; underground lines are not susceptible to hurricanes, and are usually well insulated and flexible enough to resist damage by floods and earthquakes.

Water Supplies. The main water supply system normally consists of pumping stations, water treatment plants and underground pipelines. It may suffer disruption due to pumping failures or, more often, due to piping breakages. This is a good reason for hospitals to have reserve tanks. Tanks should be incorporated in the daily supply system in order to ensure that the water is in good condition whenever an emergency occurs.

Power Supply. A power supply system consists of generators, high tension lines and sub−stations etc. Installations on the ground are among the most vulnerable parts of the system. Transformers and porcelain equipment are weak points of the system, since their failures by damage may start fires. Poles carrying overhead lines are particularly vulnerable to high winds. These are good reasons why health care facilities should have serviceable back−up generators which can be put into use at any moment. A good practice is to test them once a week. Precautions must also be taken to ensure that they are properly anchored to their foundations.

Sewage System. If storm drainage is combined with domestic effluent, vulnerability may be high during floods. In an earthquake, the vulnerability of open−air channels will be lower than that of underground high−pressure systems. The vulnerability of underground systems can be decreased by the use of flexible joints. Detailed analysis of site conditions is necessary in earthquake prone areas.

Gas and Oil Supplies. During earthquakes, the vulnerability of oil/gas pipelines depends on their strength and flexibility. High flexibility of the pipes may prevent breakdown in a moderate earthquake; differential settlement can be compensated for, and ground displacement will not necessarily lead to a breakdown. Special attention must be directed to connections to the buildings, and special design criteria are necessary in such cases.

6.3 Implementation Strategies

Physical Considerations

How should upgrading be implemented? The answer depends upon the nature of the physical conditions in the facility and also the characteristics of the organization.

For example, in simple terms, the retrofitting program of the Veterans Administration (VA) hospitals has followed a self−help implementation with the collaboration of consultant experts.[8] Firstly, a vulnerability analysis was conducted to review the facilities and assess the site hazards, secondly specific actions were established, and finally cost estimates were prepared.

> [8] Veterans Administration: ***Study* to *Establish Seismic Protection Provisions for Furniture, Equipment and Supplies for VA Hospitals.*** Office of Construction, Washington, D.C., Feb. 1980.

A vulnerability analysis would commence with a visual survey of the facilities and the preparation of a preliminary evaluation report. A typical form for use in this regard is presented at Annex 2.

This overview would identify areas which require attention. The report would then be discussed by the consultants and the facility authorities with a view to setting priorities and timetables for carrying out further work.

Once the retrofitting programme has been designed, further surveys and analyses would be conducted on the individual areas identified for upgrading.

It is generally possible to divide the resulting recommendations into two categories:

> (1) Those that can easily be implemented in the short term: Provide storm shutters to windows and braces to doors, install additional fixings to roof sheets, bolt down the external plant, relocate important stores to more secure buildings if currently housed in vulnerable buildings. These works can usually be undertaken by the facility's own maintenance staff or by small contractors.
>
> (2) Those requiring additional specialist advice, significant capital, extensive modifications or new construction for implementation in the medium to long term.

In the VA example, decisions have ranged from building demolition and substitution to minor interventions. In many cases, implementation has been the responsibility of maintenance staff. Major advantages for involving maintenance personnel derive from their knowledge of the site and their availability for periodic monitoring of the measures adopted. Indeed, upgrading existing buildings and structures can be coordinated to good advantage with routine repairs and maintenance. For example, existing nail fixings to roof sheets can be conveniently replaced with screw fixings when the sheets are being replaced at the end of their life span. Also, in the routine replacement of roof sheets, a thicker gauge could be used.

Cost Considerations

The additional cost necessary to make a building resistant to hurricanes, earthquakes and floods can be considered to be a kind of insurance. Comparative studies have demonstrated that the increased cost associated with a fully "Code resistant building" compared to the cost of a building where the code has been ignored, may range between 1 to 4% of the cost of the building. If the cost of hospital equipment is included, the percentage would be much lower, since equipment costs can be as high as 50% of building costs.

If the problem is now analyzed in terms of the cost to protect a given piece of equipment, the differences will also be striking. For instance, the difference between disruption of electricity in a hospital due to severe damage to a US$50,000 emergency power generator and continuous service may lie in the installation of seismic snubbers or restraints for an additional US$250.

Cost estimates can only be considered as rough guides, since it is not possible to account for all of the specific differences in construction conditions found in buildings, or to allow for the variation in costs between different contractors. The cost of each of the items on the list of requirements must be added together to produce an estimated total retrofit cost for the entire facility. Normally, if non–structural protection measures are taken into account early in design, the cost will be less.

ANNEXES

Annex 1. Definition of Modified Mercalli Intensity Scale

I. Not felt. Marginal and long period effects of large earthquakes.

II. Felt by persons at rest, on upper floors, or favorably placed.

III. Felt Indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.

IV. Hanging objects swing. Vibration like passing of heavy trucks or sensation of a jolt like a heavy ball striking the walls. Standing cars rock. Crockery clashes. In the upper range of IV, wooden walls and frames creak.

V. Felt outdoors. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.

VI. Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture overturned. Weak plaster, Masonry D[1] cracked. Small bells ring (church and school). Trees, bushes shaken visibly or heard to rustle.

> [1] Masonry definitions from C.F. Richter's 1958 book, *Elementary Seismology* (W.H. Freeman and Company, San Francisco, California), are as follows: Masonry A–good workmanship, mortar, and design; reinforced, especially laterally; bound together by using steel, concrete, etc.; designed to resist lateral forces. Masonry B––good workmanship and mortar; reinforced but not designed in detail to resist lateral forces. Masonry C––ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners but not reinforced or designed against horizontal forces. Masonry D––weak materials such as adobe, poor mortar, low standards or workmanship; weak horizontally.

VII. Difficult to stand. Noticed by drivers. Hanging objects quiver. Furniture broken. Damage to Masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices also unbraced parapets and architectural ornaments. Some cracks in Masonry C. Waves on ponds, water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

VIII. Steering of cars affected. Damage to Masonry C: partial collapse. Some damage to Masonry B; none to Masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.

IX. General panic. Masonry D destroyed; Masonry C heavily damaged, sometimes with complete collapse; Masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted down, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in the ground. In alluviated areas, sand and mud ejected, earthquake fountains and sand craters.

X. Most masonry and frame structures destroyed with their foundations. Some well–built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.

XI. Rails bent greatly. Underground pipelines completely out of service.

XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown in the air.

Annex 2. Sample Form for Vulnerability Analysis

BUILDING____

GEOMETRY ____

Stories ___________ Height __________ meters

Maximum Plan Dimensions – meters

	Length	**Width**	**Area**
Ground Floor			
First Floor			
Second Floor			
Total Area			
Approximate Age			

DESCRIPTION OF BUILDING

Indicate condition in box **G** – good **F** – fair **P** – poor

FRAME

Reinforced Concrete	**Structural Steel**	**Timber**	**Loadbearing Walls**	**Other** (Specify)

FLOORS

	Reinforced Concrete	**Structural Steel**	**Timber**	**Loadbearing Walls**	**Other** (Specify)
Ground					
First					
Second					

	Column size mm	**Beam size d×d mm**	**Slab depth mm**	**Slab span m**
Ground				
First				
Second				

ROOF

Indicate condition in box **G** – good **F** – fair **P** – poor

	Reinforced concrete	**Timber**	**Steel**	**Aluminum**	**Other**	**Size d×d**
Primary mbr						
Secondary mbr						
Cladding						

* or cladding thickness units millimeters

	Hip	**Gable**	**Monipith**	**Flat**	**Other** (specify)

Shape					

	0–12	13–25	26–35	>35
Slope				

	Eaves m	Gable end m
Roof overhang		

Fixings	Type	Spacing	Valley	Ridge	Condition
Primary to building					
Secondary to primary					
Cladding to secondary					

WALLS

Condition	Stone masonry	Concrete block	Timber	Other (specify)
Exterior				
Interior				
Thickness				

WINDOWS

Size d×b	Number	Material	Condition	Shutters		Condition
				Fitted	Reqd.	

Shutters required are to be

Inside hung	Outside hung	One leaf	Two Leaves	Number

DOORS

Size d×b (meters)	No.	Material	Condition	Hinges*	Bolts*	Braces	
						Fitted	Reqd.

* Indicate **Y** – yes **N** – no for bolts and hinges of adequate strength and numbers in good condition

SITE DESCRIPTION

	Plain	Ridge	Valley	Peak	Coastal
Location					
	Other (specify)				

	High	Moderate	Low	Comments
Rood Risk				
Risk of falling trees or utility poles				

Annex 3. Checklist

** High priority for seismic evaluation

(1) Heavy ceiling−located objects: light fixtures, ducts, pipes, suspended planks

(2) Large windows and glass divisions

(3) TV sets, speakers or the like located above 4 or 5 feet off the ground, stability of tall file cabinets, storage racks or shelves, medicines and drugs stored in tall storage shelving, especially if they contain hazardous materials

(4) Emergency power generator anchorages, batteries racks if any, main computer and communication systems

(5) Gas cylinder tanks, elevated water storage tanks

(6) Large electrical equipment and transformers

(7) Computer units and other desk top office equipment

(8) Mechanical room equipment

(9) Exterior ornament such as concrete cladding, signs, or any prefabricated appendages such as parapets

(10) Gas supply and piping

** Lesser priority for seismic evaluation

(11) Fire extinguishers
(12) File cabinets
(13) Elevators
(14) Partitions
(15) Lightweight packed or heavy objects stored less than 4 or 5 feet off the ground
(16) Furniture
(17) Gas systems leading to heaters
(18) Lightweight ceilings
(19) Air conditioning equipment, generally on top of building, air conditioning distribution
(20) Water piping (cold, steam, etc.)

Hurricanes and Floods

(21) Design of buildings
(22) Location of buildings and accesses for proneness to flooding
(23) Building shape
(24) Type of roofs. For lightweight roofs, shape, cladding, fixings etc.
(25) Walls and openings in walls e.g doors, windows, decorative blocks
(26) Building connections
(27) Opportunities for retrofitting
(28) Condition of buildings and drainage system

REFERENCES

1. Caribbean Uniform Building Code (CUBiC), Caribbean Community Secretariat, Georgetown, Guyana, 1985.

2. PAHO Disaster Report No. 2 Jan. 1983 – "Report on Disasters and Emergency Preparedness for Jamaica, St. Vincent and Dominica".

3. PAHO Disaster Report No. 5 – "Hurricane Gilbert in Jamaica: Sept 1988".

4. Paper read at CARICAD Workshop on Health Care Financing, Jan 1985. Winston Cox: "National Problems in Financing the Health and Social Sectors"

5. Alister McIntyre: "Developing Tourism" – Caribbean Affairs Vol 1 No.1 Jan–March 1988.

6. Barbados Water Resources Study, 1977–78.

7. Federal Reserve Management Agency Earthquakes Hazard Reduction Series 35 FEMA 150, 1987 – "Seismic Considerations: Health Care Facilities".

8. Veterans Administration: "Study to Establish Seismic Protection Provisions for Furniture, Equipment and Supplies for VA Hospitals" – Office of Construction, Washington D.C., Feb 1980.

RECOMMENDED READING

1. Federal Emergency Management Agency – "Seismic Considerations: Health Care Facilities". Earthquake Hazards Reduction Series 35 FEMA 150, Washington, D.C**.** 1987

2. PAHO Scientific Publication No. 443, 1983: "Health Services Organization in the Event of Disaster".

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