A.- NATURAL THREATS IN THE AREA

A.1.- INTRODUCTION

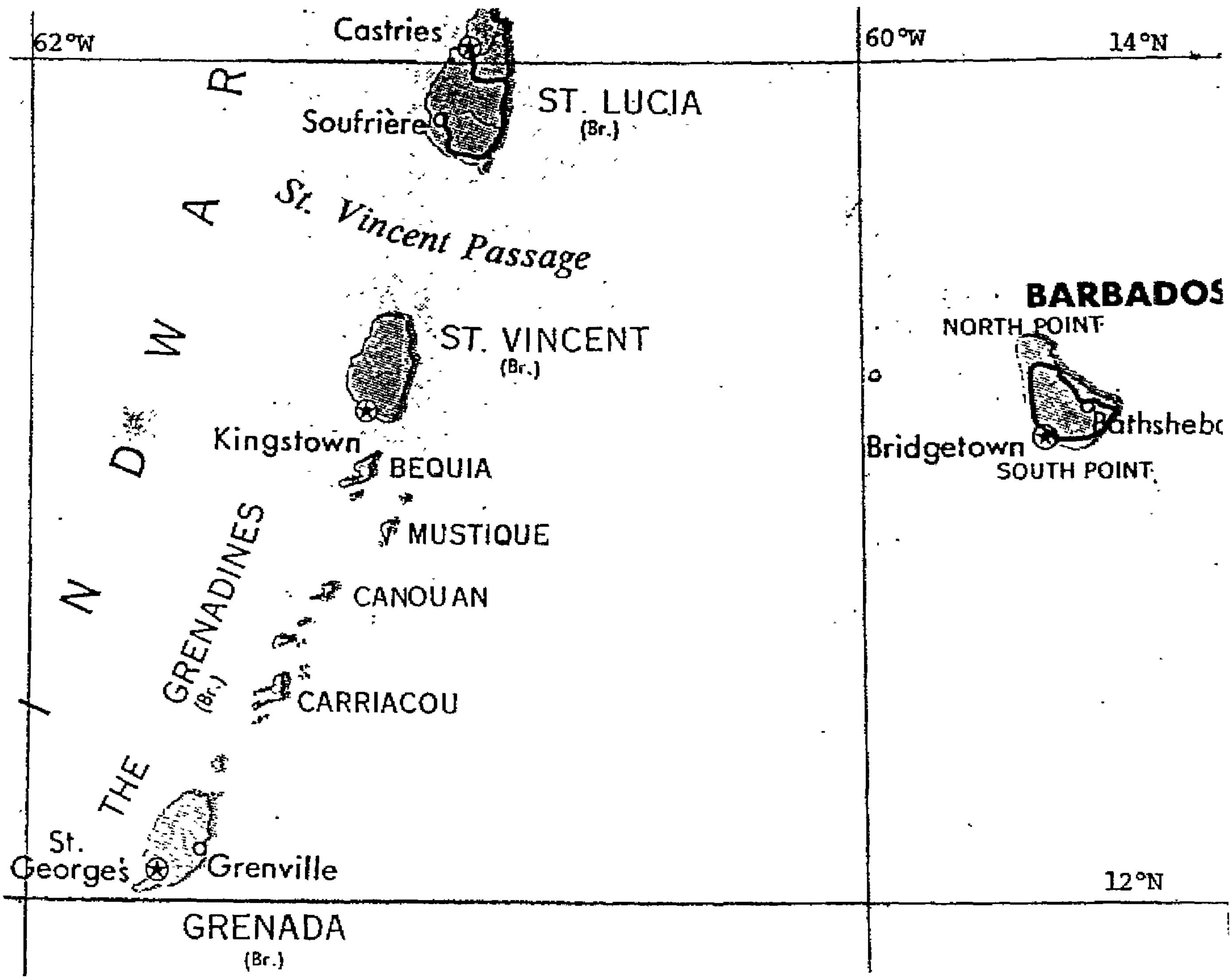
Saint Vincent is an island that is part of the Caribbean country known as Saint Vincent and the Grenadines, incorporated to the British Comunity of nations. Its name was probably given by Christopher Columbus, who discovered it on January 22nd, 1498, on Saint Vincent's day.

With a surface of 345 Km^2, it is located at about 61° 15'W - 13° 15'N, 35 Km South-SouthWest of Saint Lucia and 160 Km to the West of Barbados (See Map A.1). Essentially it is a volcanic island; a mountain range crosses it from North to South.

The highest elevation is that of La Soufriere Volcano (1.230 m), located towards the Northern extreme of the island, from which violent eruptions are known to have happened in historical times (see Section A.4). At the same time there is a written record of damages due to hurricanes and earthquakes, which are studied in Sections A.2 and A.3 of this Report. Particularly, in the descriptions about the island it stands out that the country's economy was greatly affected by the volcanic eruption of 1902 and by the hurricane of 1898.

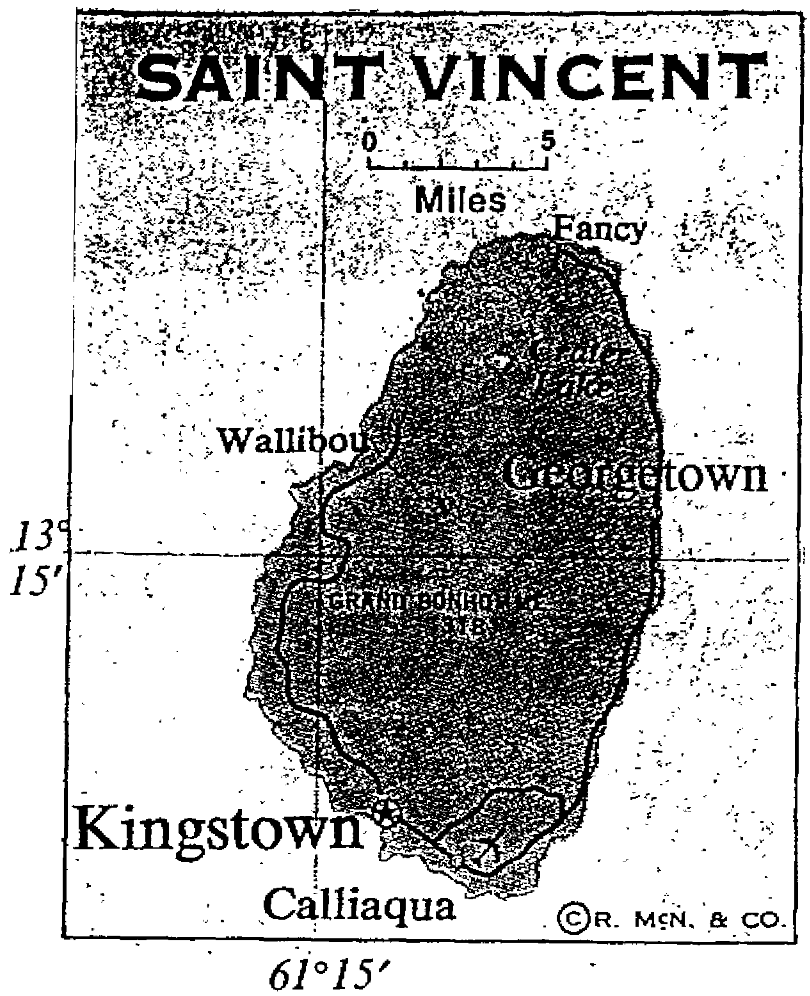
The average annual precipitation varies between 1300 mm in the coast, to about 2 or 3 times more in the central mountains.

By 1987, the population of Saint Vincent and the Grenadines mounted to 112.000 inhabitants, with an average density of about 290 inhabitants/Km^2 in the island of Saint Vincent, predominantly rural (~74%), settled in zones close to the coast.



MAP A.1 **LOCATION OF THE ISLAND OF SAINT VINCENT AND THE GRENADINES IN THE EASTERN CARIBBEAN**

Kingstown, located leewards, to the South-West of Saint Vincent, is the capital city with a population -for 1984- of 18.400 inhabitants; at the present time the number is around 30.000 inhabitants. In the opposite side of the island, windwards, there is Georgetown (see Map A.2).



MAP A.2 ISLAND OF SAINT VINCENT

The medical attention services in Saint Vincent and the Grenadines are under the administration of the Health Ministry, divided in 9 medical districts: 7 in the island of Saint Vincent and 2 in the Grenadines, with a total of 50 doctors at the services of the State.

By 1986 the country had 1 doctor per 440 inhabitants and a total of 350 hospital beds (1 bed per 309 inhabitants).

The Kingstown hospital is the only installation with the capability to offer acute attention and in it a total of 38 doctors operate. Five centres of minor health, with a total of 60 beds, operate in rural areas in which minor surgery and the stabilization of patients is practised.

A.2.- SEISMIC THREAT

A.2.1.- ANTECEDENTS

The island of Saint Vincent has been affected in historical times by close and distant quakes over which written record has remained (Robson, 1964; Grases 1971 and 1990). In Table A.1 a list of the most important known quakes is retained, which occured in the past two centuries (XIX and XX), with a brief description on the effects and Mercalli Intensity in the island of Saint Vincent; the information on some of them extends to the neighbouring islands, synthesized in isoseismal maps collected in Grases (1990) (see Figure A.1 to A.6).

TABLE A.1

MOST IMPORTANT EARTHQUAKES THAT HAVE AFFECTED SAINT VINCENT DURING THE XIX AND XX CENTURIES

DATE	MAGNITUDE MS	EPICENTRAL COORDENADAS		OBSERVATIONS AND MERCALLI INTENSITY IN SAINT VINCENT (S.V.)
		N (1)	W (1)	
1834-11-25	--	--	--	Masonry buildings damaged. Cracking of the Court House walls, S.V., intensity VII-VIII.
1839-01-11	7,5-7,8	14,9	60,6	According to damage distribution (see Figure A.1), intensity VII at S.V.
1843-02-08	~ 8	--	--	Strong quake near Antigua; inetnsity V at Kingstown.
1844-01-19	--	--	--	Epicentral area towards Grenada; strongly felt at Kingstown (V).
1844-08-30	7,0	13,0	61,0	Walls of some of the Kingstown buildings cracked. Chimneys and old buildings collapsed. Intensity VII.
1888-01-10	7,5	11,5	62,0	Intermediate focal depth; damage light in S.V. Intensity V (see Figure A.2).
1906-02-16	7,0	14,2	60,5	Strongly felt and damages in Saint Lucia. ¿Damage in S.V.? Intensity V, (see Figure A.3).
1928-09-27	6,5	12,0	60,0	Barbados shaken by strong quake. Intensity at S.V., V-VI (see Figure A.4).
1946-05-21	7,0	14,8	60,46	Similar pattern as 1839, though with smaller magnitude. Intensity VI (see Figure A.5).
1953-03-19	7,5	14,1	61,21	Similar pattern to 1906 with deeper focus towards the west; with larger magnitude, the given intensity at S.V. is VII (see Figure A.6).

(1) For XIX century events, magnitudes and epicentral coordinates are based on microseismic data.

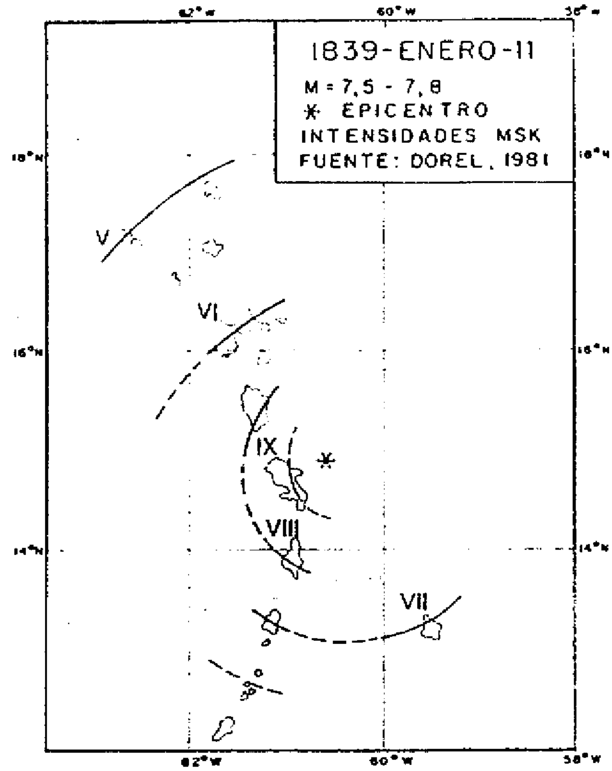


FIGURE A.1 EARTHQUAKE OF JANUARY-11-1839

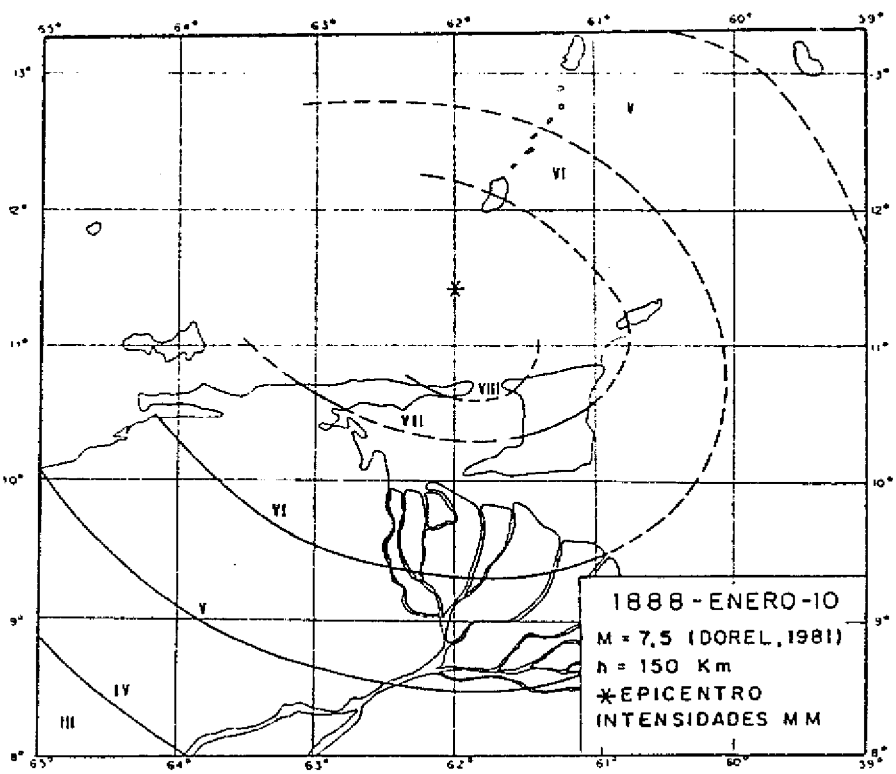


FIGURE A.2 EARTHQUAKE OF JANUARY-10-1888

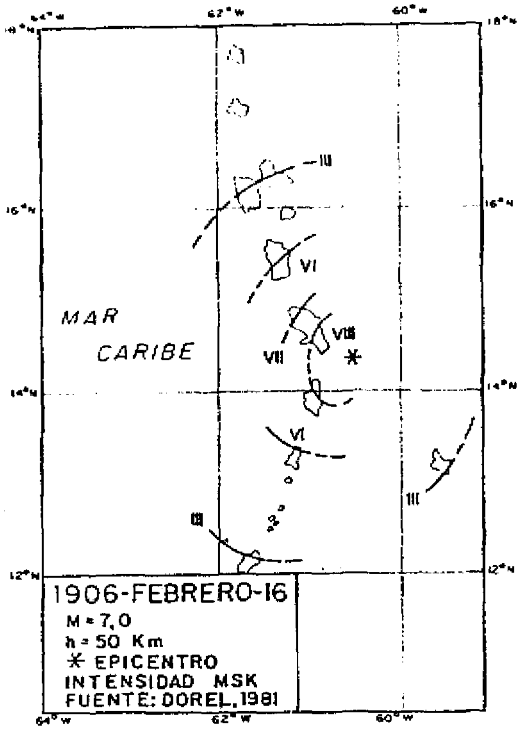


FIGURE A.3 EARTHQUAKE OF FEBRUARY-16-1906

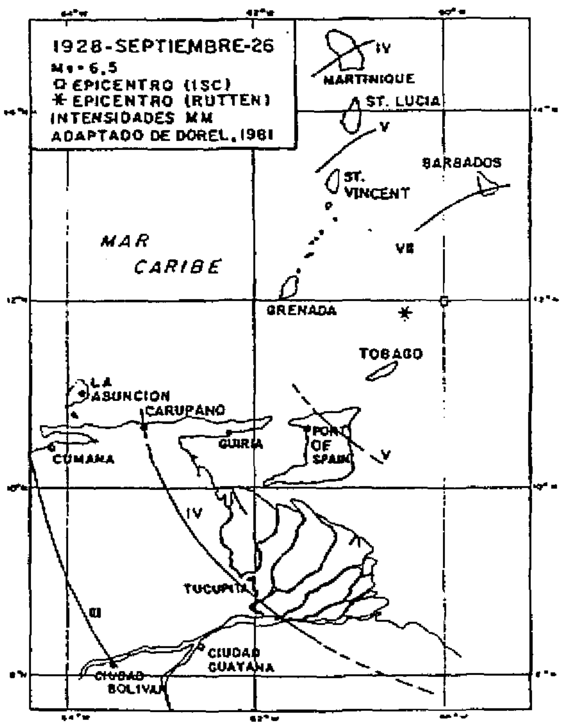


FIGURE A.4 EARTHQUAKE OF SEPTEMBER-29-1928

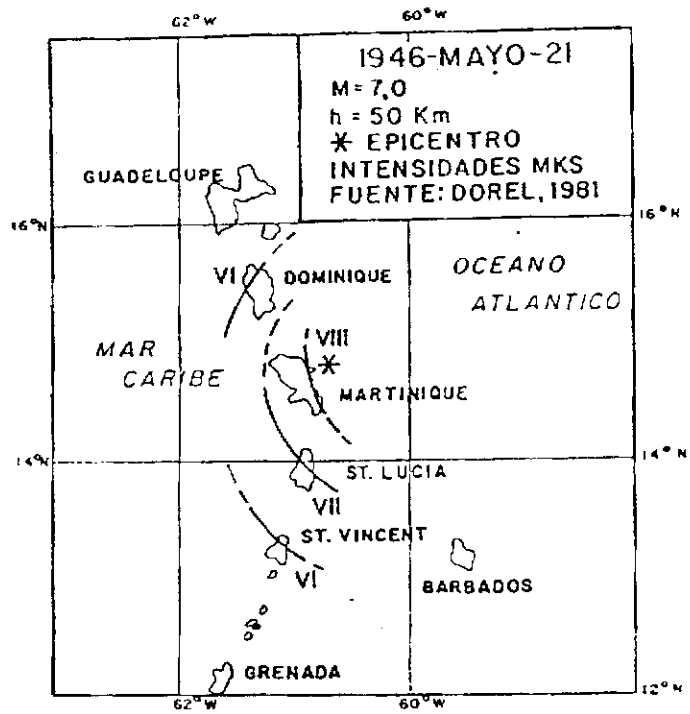


FIGURE A.5 EARTHQUAKE OF MAY-21-1946

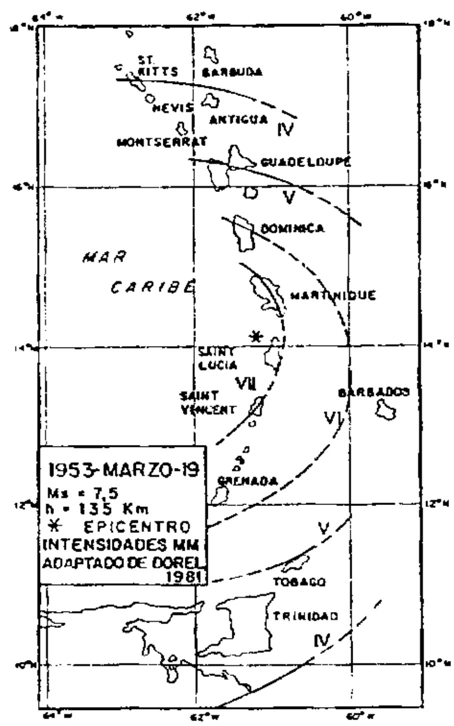


FIGURE A.6 EARTHQUAKE OF MARCH-19-1953

The maximum Mercalli intensities recorded in the given period, are in the range of Grade VII to Grade VIII, with an important contribution to the hazard by the great quakes that occured towards the seismogenic zones located to the North of the island arc (see earthquakes of 1839 and 1953). The mean frequency of those of greater intensity is of about 1 century.

Although the information of Table A.1 can not be considered exhaustive, it is the best on hand. From this table it is concluded that extreme quakes of intensities VIII should be considered possible with mean return periods exceeding a century

A.2.2.- SEISMIC HAZARD STUDIES

Specific studies of seismic hazard for the Kingstown area are not readily available. The closest area for which results of modern studies of seismic hazard have been published, is for the Roseau Dam (Saint Lucia Island) located at 13,91° N - 61,00° W, which is about 80 Km north from Kingstown. In that study (Aspinall et al. 1994) present the results of the hazard in terms of the annual probabilities of exceedence of: (a) maximum ground accelerations (PGA), equivalent to (Ao), and (b) maximum ground velocities (PGV), equivalent to (Vo). The (PGA) and (PGV) distribuitions are reproduced in Figure A.7.

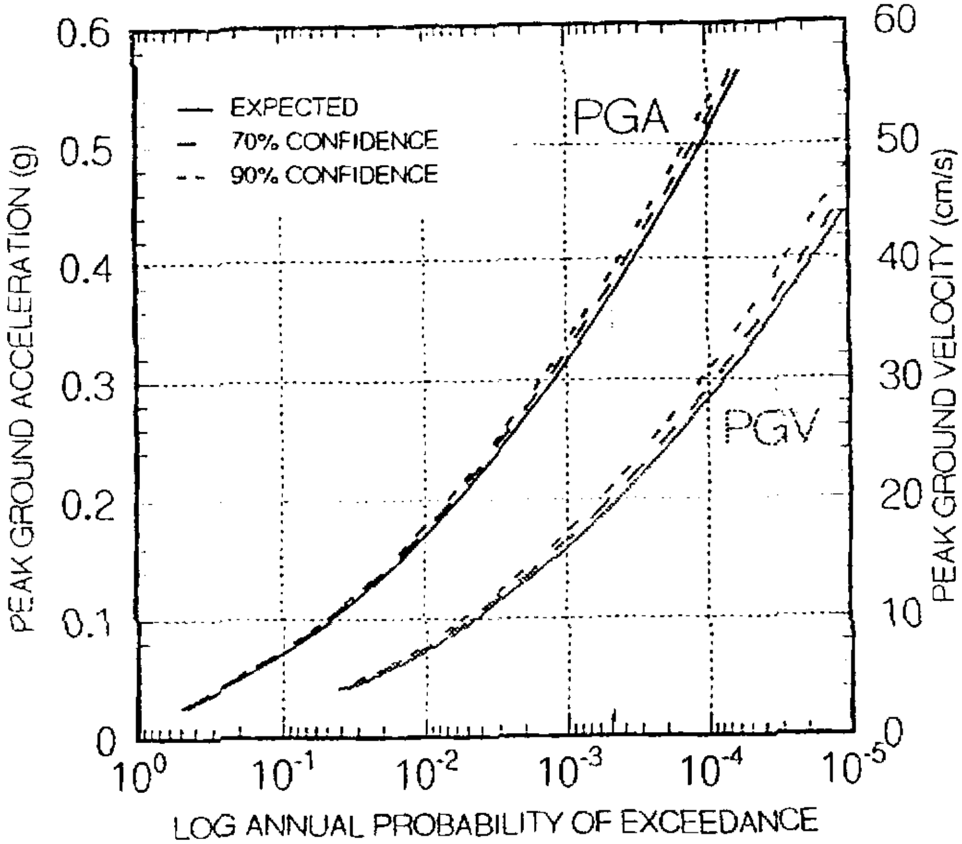


FIGURE A.7 **RESULTS OF ASPINALL ET AL (1994) FOR ROSEAU DAM, IN TERMS OF THE ANNUAL PROBABILITIES OF EXCEEDENCE OF PEAK GROUND ACCELERATIONS AND VELOCITIES**

It is important to note about the quoted report, that at levels of probability of 2×10^{-3}, the contribution to the risk of the northern subduction zone (maximum Richter magnitudes M_u of up to 8,7) is predominant (60% of the total). For movements with greater return periods, around those demanded in the verification of new health care installations, that percentage can be even greater taking into consideration: (i) the shape of the used attenuation laws and

(ii) that, in the modelled seismogenic zones, the M_u Magnitudes are smaller: 7,6 and 6 for the overthrusting and southern subduction zones, respectively.

In Table A.2 the expected values of Ao and Vo are reproduced for the Roseau Dam given by Aspinall et al (1994); also the infered values for Ao in Kingstown, partially backed-up by sensibility studies presented in Table 3 of the already quoted Aspinall report.

TABLE A.2

MAXIMUM GROUND MOVEMENT VALUES FOR THE INDICATED EXCEEDENCE PROBABILITY LEVELS

EXCEEDENCE PROBABILITY LEVEL	LOCATION OF ROSEAU DAM		KINGSTOWN
	Ao (g)	Vo (cm/seg)	Ao (g)
2×10^{-3}	0,27	12,9	0,20-0,23
10^{-3}	0,31	15,8	0,24-0,28
5×10^{-4}	0,37	19,2	0,30-0,34

The results of a study done by Shepherd for the the Panamerican Institute of Geography and History (IPGH) between 1991 and 1993 are presented in Figure A.8. In them the isoacceleration curves for intervals of 50 gals and average return periods of 500 years are given (Giesecke, personal communication).

Regional isoacceleration map

Source PAIGH: contour interval 50 gals

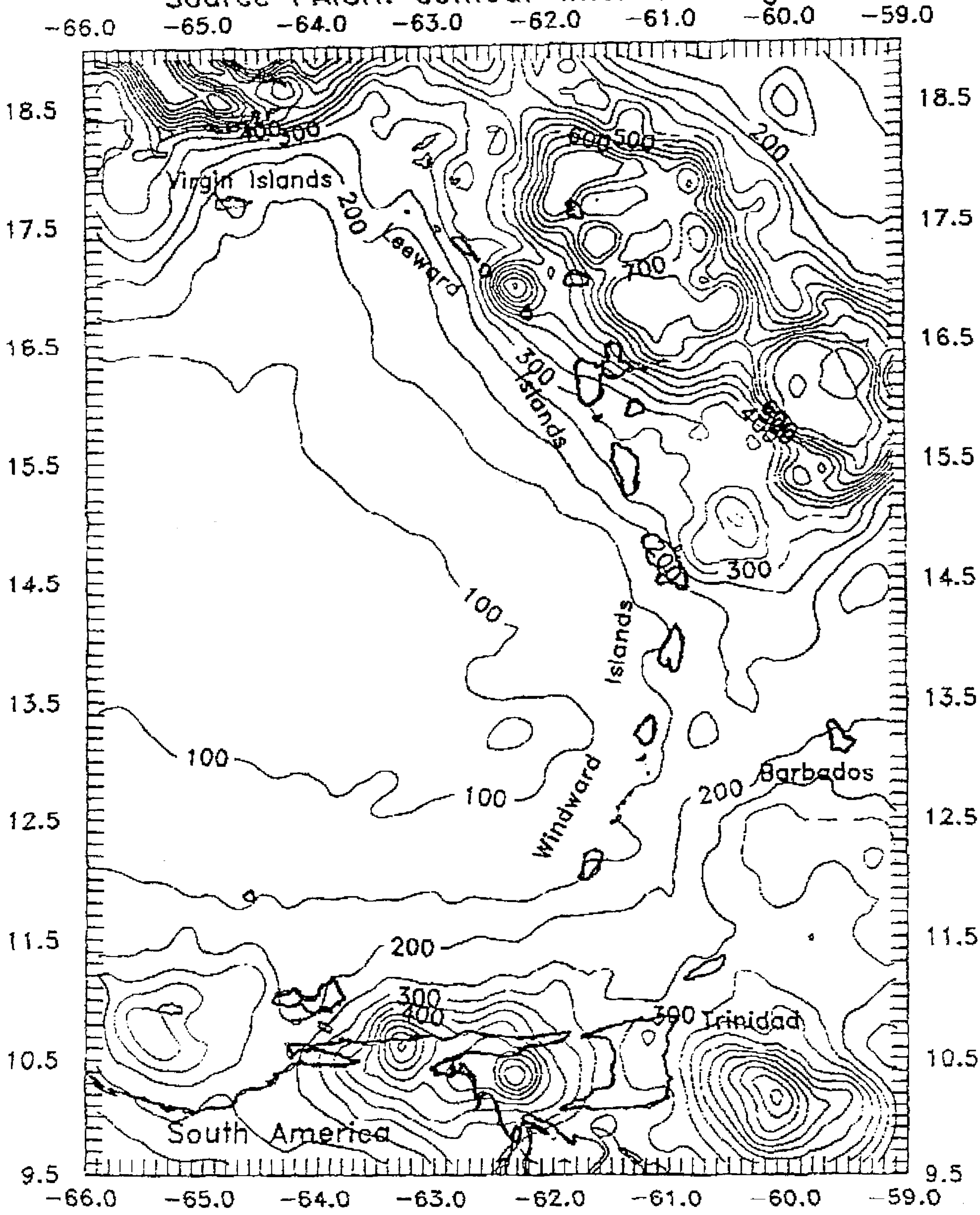


FIGURE A.8 MAP ELABORATED FOR IPGH BY J. SHEPHERD (SOURCE: GIBBS, PERSONAL COMMUNICATION)

For the Kingstown region, Saint Vincent, the values given out from the map are of about 140 gal (0,15g).

A.2.3.- CUBIC SPECIFICATIONS (1985)

In Part 2, Section 3, of the available Caribbean Uniform Building Code (CUBIC) -1985 edition- structural requirements for seismic actions are established. This normative body adopted as reference, is essentially based: "... on SEAOC but with appropriate sections from UBC, ATC and New Zealand codes", all of which have suffered modifications throughout the last decade.

The expresions (1) and (2) given by CUBIC for the static method, are the same as CUBIC's (11) and (12) to characterize the spectral ordinates. The period dependency is $(T)^{-0,5}$ and the dependency with the importance of the building is: I = 1.5, for hospitals.

Its dependency of the site is given by the two following parameters:

Z: Factor related to the site seismicity and equal to 0,50 for Saint Vincent (Table 2.305.1) / it should be beared in mind that in the actual 1994 UBC, for Z = 1.00, Ao = 0.40g/.

S: Coefficient that takes into consideration the local soil conditions; for a competent soil the adopted lower limit of Ts, is equal to 0.5 sec.

As far as the structural system, Table 2.305.2 gives the values of K for each structural system. In this way, for example, for a wooden building of limited ductility (K = 1.2), the minimum coefficient, considered at yield level (ultimate states), has the shape of Figure A.9.

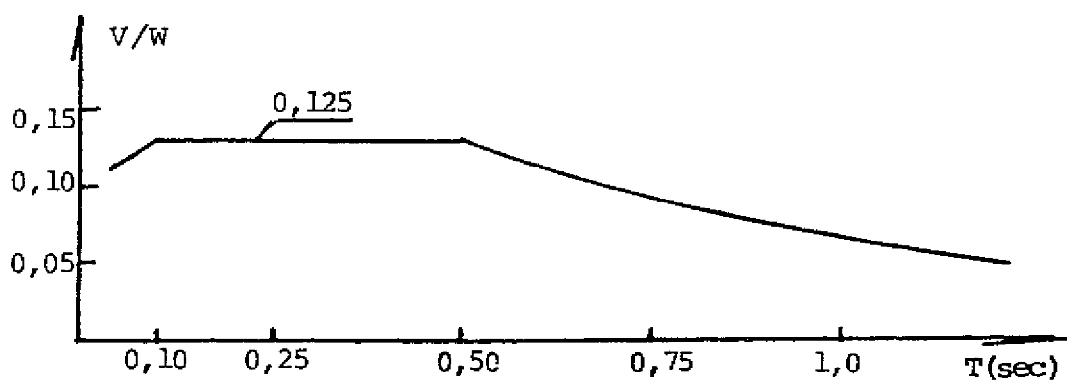


FIGURE A.9 **ORDINATES OF THE DESIGN COEFFICIENT OF V/W ESTABLISHED BY CUBIC (1985) FOR HEALTH CARE INSTALLATIONS IN THE AREA OF KINGSTOWN (COMPETENT SOILS, STRUCTURES OF LIMITED DUCTILITY)**

For periods greater than 0.1 sec approximately, the ordinates of Figure A.9 have a shape close to the ones that could be expected for structures with high damping (~10%) with a magnification factor of about 2.0 and ductility factors of about 3.0. They are:

$$Ao = \frac{0{,}126 \times 3{,}00}{2{,}00} = 0{,}19g$$

this value being close enough to the one given in Table A.2 which is associated to a return period of 500 years suitable for service installations.

A.2.4.- VERIFICATION REQUIREMENTS

Based on the previous Section, the reference requirements in Kingstown for wooden-type hospital installations, of limited ductility, are reasonably described by the spectrum of Figure A.9. For reinforced concrete buildings, the values will have to be adjusted according to the damping and ductility of each case.

In those cases where mass or rigidity irregularities are not present, the Equivalent Static Method of Section 2.305 can be applied according to CUBIC's Section 2.304.

A.3.- EXTREME WINDS THREAT

A.3.1.- ANTECEDENTS

It is a known fact that the Eastern Caribbean is under the threat of frequent hurricane-type winds (Figure A.10). Annually, from the approximately 100 tropical depressions or potential hurricanes, only about 10 reach to be tropical storms and about six reach the level of hurricane.

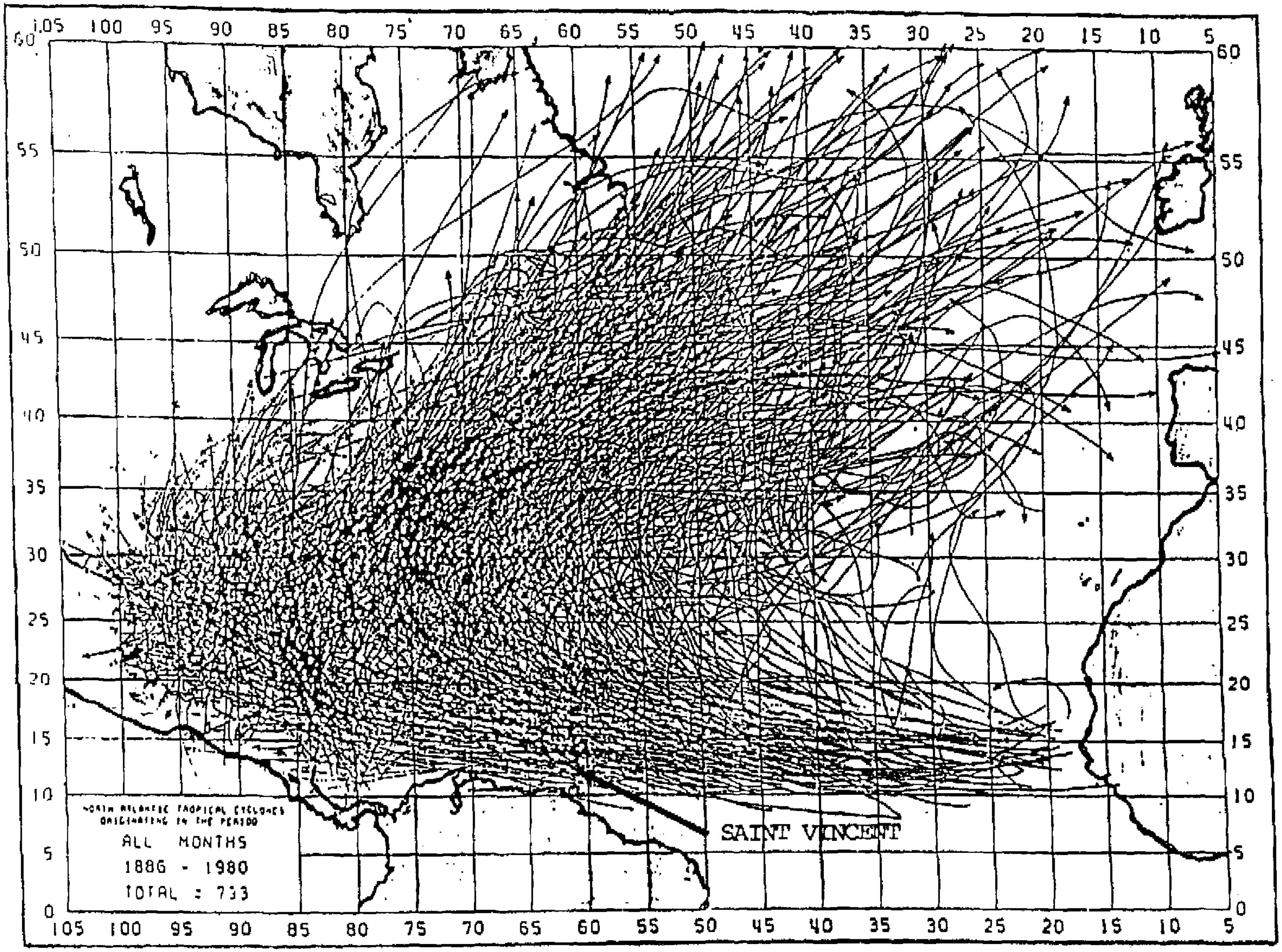


FIGURE A.10 COURSE OF 793 TROPICAL CYCLONES, THAT REACHED AT LEAST THE LEVEL OF TROPICAL STORM, DURING THE PERIOD 1886-1980 (NATIONAL HURRICANE CENTER, MIAMI)

During the period 1955-1988, the latitudes between Saint Lucia and Grenada have been the centre of 7 tropical storms that reached the level of hurricane (Table A.3)

TABLE A.3

TROPICAL STORMS QUALIFIED AS HURRICANES (WINDS EXCEEDING 118 km/hour) BETWEEN SAINT LUCIA TO THE NORTH AND GRENADA TO THE SOUTH; PERIOD 1955-1988

YEAR	NAME	AFFECTED AREA	KNOWN EFFECTS
1955	Janet	Barbados	57 victims 122 victims
1960	Abby	Saint Lucia	--
1963	Edith	Saint Lucia	10 victims; losses of 3,5 million US$.
	Flora	Grenada	6 victims
1980	Allen	Saint Lucia Saint Vincent	9 victims; 70.000 affected; losses of 88 million US$. 20.000 affected; losses of 16,3 million US$.
1987	Emily	Saint Vincent	200 affected; losses up to 5 million US$.
1988	Gilbert	Saint Lucia	A tropical depression, caused flooding and slides

A.3.2.- CHARACTERIZATION

One of the principal limitations in the characterization of extreme winds, comes from the turbulent nature of the air flow and measurement problems.

Hence the adoption as velocity values of the average in 10 minutes, the average in 1 hour, or others, has to be carefully decided. These distributions of "maximum velocities" are the basis for the probabilistic decision-making; its transformation into dynamic pressures, including the effects of short-term gusts, is solved in the codes through suitable coefficients.

The refference pressures (q_{ref}), are proportional to the square of the velocity; they vary from one zone to another according to what is shown in the Map of CUBIC's Figure A200.1 which is reproduced here.

Samples of different areas of the planet reveal that the distribution of annual maxima is adjusted to Gumbel cumulative distribution function Type 1, with characteristic values α and $\tilde{v}$:

$$F_V(v) = \exp\left\{-\exp\left[-\alpha\left(v-\tilde{v}\right)\right]\right\}$$

In Figure A.11 distributions corresponding to different locations are compared; the ranges of extreme wind velocities established in the Venezuelan and the State of Florida (USA) Codes (Grases 1996) are pointed out. The distributions corresponding to: Dominica, Saint Vincent, Northern Trinidad and Guyana, have been infered from the data established in the CUBIC Code.

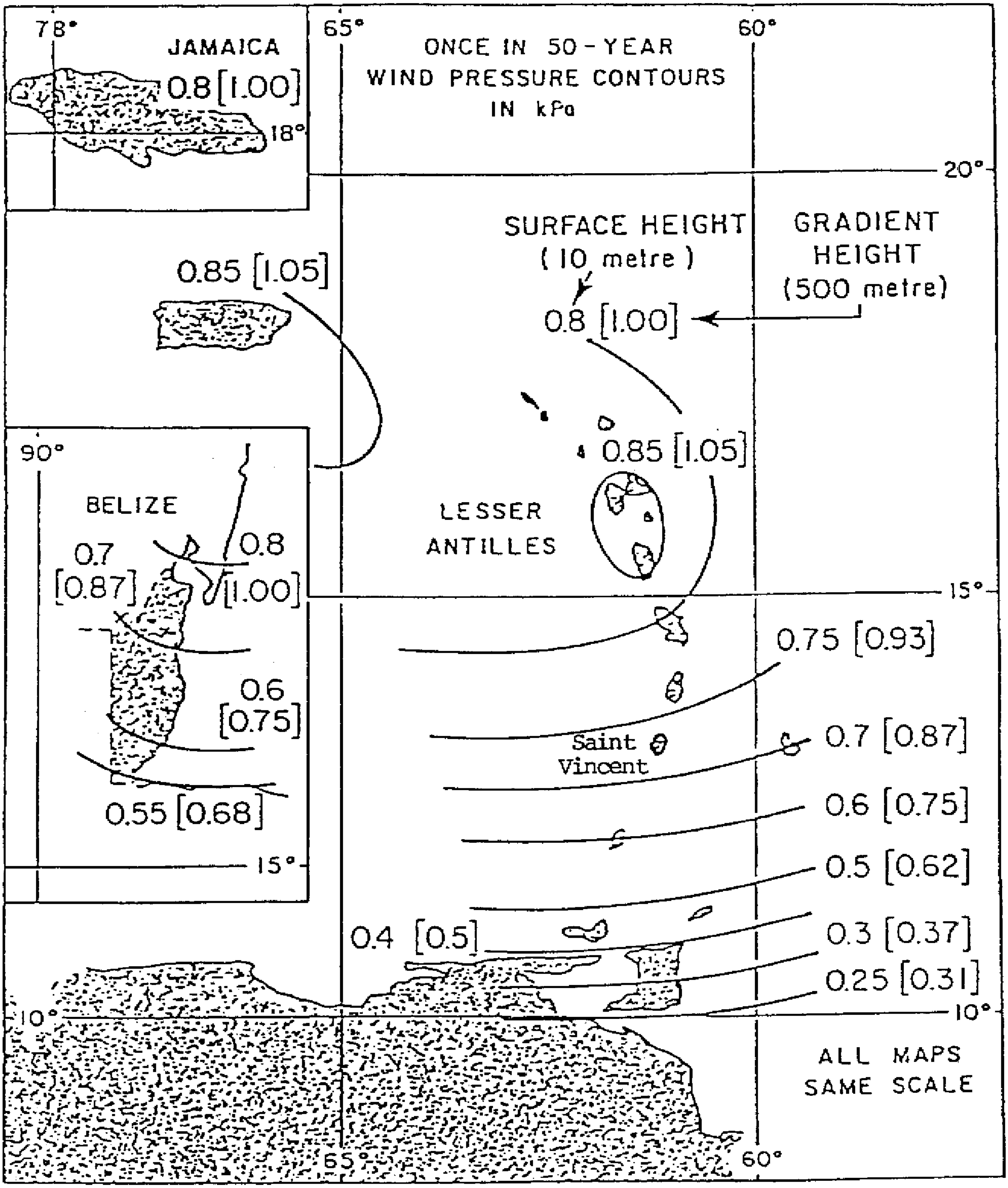


FIGURE A200.1 MAP OF REGION OF APPLICATION (CUBIC, 1986)

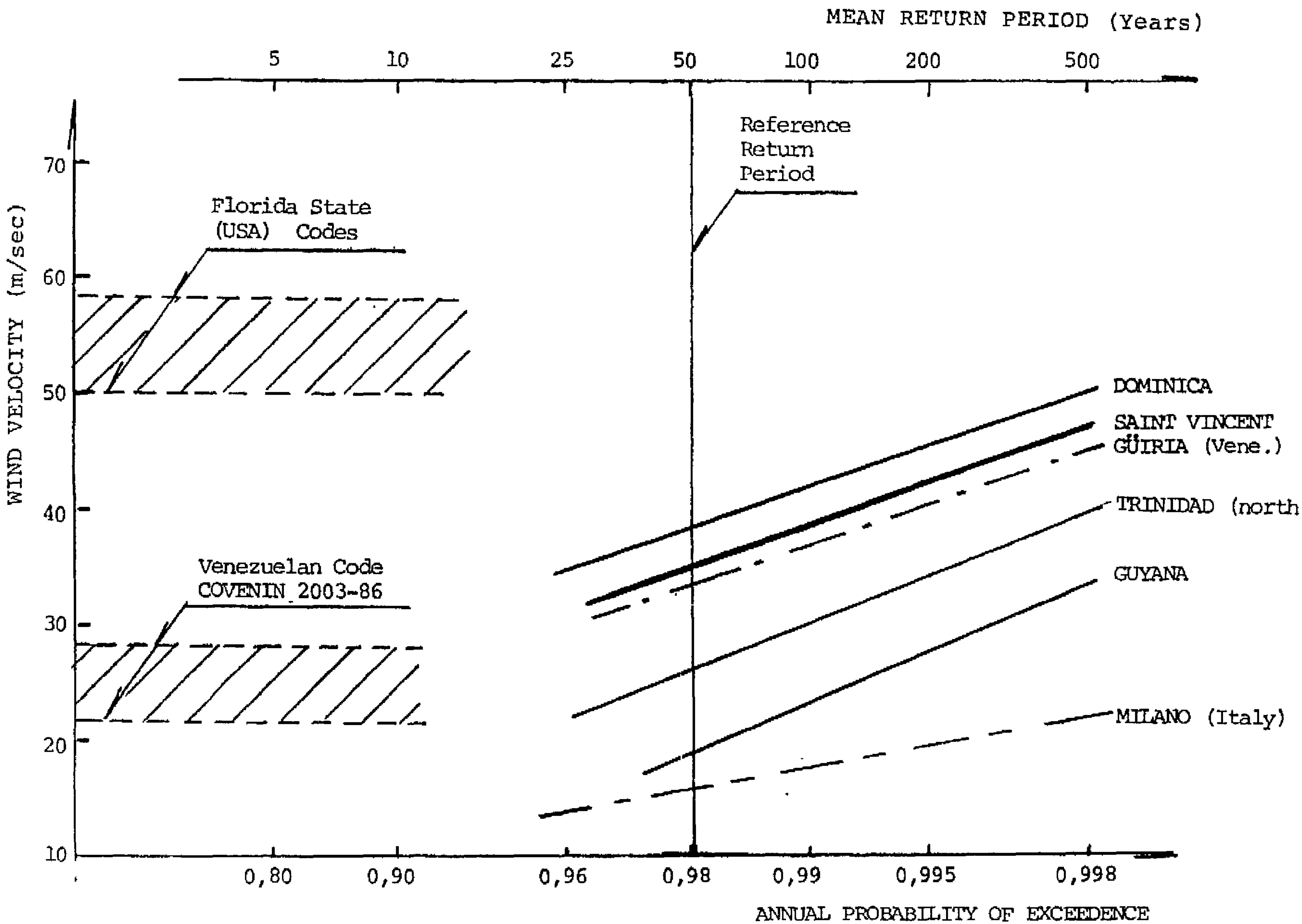


FIGURE A.11 CUMULATIVE DISTRIBUTION FUNCTIONS OF WIND SPEEDS AND DESIGN RANGES ACCORDING TO DIFFERENT CODES (GRASES, 1996)

A.3.3 SPECIFICATIONS TO BE USED

According to the Caribbean Uniform Building Code (CUBIC, 1986) specifications Part 2, Section 2, "Wind Load", the force per unit area W , in kPa (102 Kg/m^2), is:

$$W = (q_{ref}) \times (C_{exp}) \times (C_{shp}) \times (C_{dyn})$$

where:

W: Equivalent static wind force, normal to the surface of the structure or element; internal and external wind forces should be incorporated.

q_{ref}: $q = \frac{1}{2} \rho v^2$ where ρ is the air density $\left(1{,}2 \frac{kg}{m^3} \times \frac{1}{g}\right)$. The value of q_{ref} is given in Figure A200.1, with 0,73 for Saint Vincent (it is equal to V_{ref} = 35,0 m/sec, 10 minutes average measured at a hight of 10 meters, on flat ground).

C_{exp}: Takes into consideration the variability of the pressure by velocity due to: hight over the ground, roughness of the ground and topography of the sorrounding zones. If the simplified method is used, CUBIC's Appendix 1 gives values for this coefficient, in Table A103.1. For coastal zones, multiply by 1,3; hence for Kingstown the corresponding value would be:

$$C_{exp} = 1,1 \times 1,3 = 1,43 \quad \text{up to a hight of 15 m}$$

C_{shp}: Coefficient of aerodynamic shape, nondimensional; represents the (superficial aerodynamic pressure)/(pressure due to the reference velocity). Structures with enclosures will be submited to internal pressures determined by the dimensions and distributions of the openings. This requires combining the internal and external pressures. If the simplified method of Appendix 1 is used, it should be combined directly with C_{dyn}.

C_{dyn}: Factor of dynamic response that takes into consideration the following wind actions: pressure fluctuation due to random gusts that act in short periods; fluctuating pressures due to building's excitation and wind path. If the simplified Estatic Method of CUBIC's Appendix 1 is used, the wind load combined in external and internal surfaces should be based in the combined factor:

$$(C_{shp}\, C_{dyn.})_{comb} = (C_{shp}\, C_{dyn.})_{ext} - (C_{shp}\, C_{dyn})_{int}$$

For buildings with roofs extended in gable-ends, the product of the external factors for the different parts of the building are those of Figure A104.1. The corresponding internal factors are given in CUBIC's Table A104.1.

CUBIC's simplified method is applicable for the design of exterior surfaces. It could also be used for the principal structural system, as long as: (a) the building does not exceed 15m in height; (b) the building is not located close to the top of a hill or promontory; (c) the displacements caused by wind action, calculated with this method, don't exceed 1/500 of the hight of the structure or of the relevant span. All these conditions apply in the buildings of the Saint Vincent hospital, including the latter based on considerations of height and stiffness of resisting members.

The previous formulation could be put in the form of:

$$W = 0{,}061\ (C_{exp})\ (C_{shp})\ (C_{dyn})\ (V^2) \qquad (kg/m^2)$$

with (V) in (m/sec).

This is similar to the equivalent equation (6.1), of the 1986 Venezuelan Code: Wind Actions (COVENIN 2003-89), The Venezuelan Code is essentially coincident with the North-American Standard ANSI A58.1, the value of W being:

$$W = 0{,}063\ (K_s)\ (C_p)\ (G_h)\ (\alpha)\ (V^2) \qquad (kg/m^2)$$

with (V) reduced to (m/sec).

The specification of both Codes follow similar principels. In both (V) has the same meaning and is measured in the same way; (G_h) and its equivalent (C_{dyn}) (gust factors) have similar values; (C_p) and its equivalent (C_{shp}) (form factors) also have comparable values; (α) is the eolic importance factor that for hospitals in the COVENIN Code, equals 1,15 and is not incorporated in CUBIC. The more pronounced differences are observed in the exposition coefficients (K_z in COVENIN and Cexp in CUBIC) that, for the conditions of the Kingstown hospital, the heights of interest and for the application of the Simplified Method, is found at the rate of 2 to 1, CUBIC being the greater; besides, in the COVENIN Code the coefficient K_z increases with the height following a parabolic distribution, closer to the real one, as opposed to the rectangular used by CUBIC.

In both Codes the internal pressures are taken into consideration. The influence of the area of openings is incorporated in the COVENIN Code with the concept of permeability, which is the fraction of the opening area in a surface refered to its total area.

Having seen the previous reasons, it was decided to use the COVENIN 2003-89 verification methods, respecting the wind velocities established in CUBIC for the Saint Vincent region.

A.4.- VOLCANISM

Towards the North of the island, at about 22 Km from Kingstown, the La Soufriere volcano is found (13,30º N - 61,18º W) (see Map A.2), which apparently generated an important explosion at the begining of the XVIII century (1718) covering the whole island with ashes.

In the literature about this volcano the activity of 1812 is described as important. Münchener (1988) gives April 1812 as the eruption date and, according to that source, it would have caused 1.600 victims.

In May 1902, a series of eruptions devastated the whole northern region of the island; the piroclastic impacts had an extension of about 77 Km^2 approximately (about 4 to 6 Km from the volcano) and, along with the flow of material from the foot of the mountain, it caused around 1.500 victims. Simkin et al (1981) show destructions in farm land and mud slides, although it only reports 1 victim.

1979 appears as the date of the last eruption (OEA, 1993), associating itself to fatalities, property losses and a volcanic index of explosivity 4 (OEA, 1993). The population was evacuated during 1 month as a preventive measure. Witnesses in Kingstown (Browne, 1996) remember the falling of ashes up to one inch in the urban zone of the capital city.