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12 POSSIBLE MITIGATION STRATEGIES FOR HURRICANES AND EARTHQUAKES IN THE CARIBBEAN

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ABSTRACT

The Caribbean is affected by geological, climatic and environmental hazards such as earthquakes, volcanic eruptions, landslides, tropical cyclones, floods, drought, environmental pollution and deforestation. However, historically, the damage caused by earthquakes has not been as great as that caused by hurricanes and floods. In this paper therefore, possible mitigation strategies for reducing losses from hurricanes and earthquakes in the Caribbean are discussed with particular reference to the Caribbean Uniform Building Code (CUBiC) provisions for wind and earthquake loads. A brief review of these provisions is presented and it is emphasised that there is an urgent need to enforce compliance with the requirements of CUBiC and to encourage higher standards of construction quality throughout the Caribbean. Other factors affecting effective mitigation strategies are outlined and the economics and practicalities of mitigation are discussed against the background of the attitudes of the Caribbean peoples at risk and the nature of Caribbean political administrations. The paper concludes that successful mitigation strategies must involve the close collaboration between the local community and the government agencies and must contain a mixture of immediately visible improvements and of less visible but long-term sustainable benefits. In this regard the paper recommends the urgent completion of Part 5 of CUBiC which deals with the construction of Small Buildings.

INTRODUCTION

Of the various hazards that the islands of the Caribbean are exposed to, the most potentially damaging are hurricanes and earthquakes and Tomblin (1992) has given a comparison of historical losses due to these types of disasters in the West Indies. In the period 1722-1990 hurricanes have claimed some 42,626 lives and earthquakes have caused about 16,000 fatalities in 8 major events over the period 1691-1946. Other hazards such as landslides, floods, drought, environmental pollution and deforestation have caused relatively minor losses in the recent past.

In this paper therefore, possible mitigation strategies for reducing losses from hurricanes and earthquakes in the Caribbean are discussed with particular reference to the Caribbean Uniform Building Code (CUBiC) provisions for wind and earthquake loads. A brief review of these provisions is presented and it is emphasised that there is an urgent need to enforce compliance with the requirements of CUBiC and to encourage higher standards of construction quality throughout the Caribbean. Other factors affecting effective mitigation strategies are outlined and the economics and practicalities of mitigation are discussed against the background of the attitudes of the Caribbean peoples at risk and the nature of Caribbean political administrations. The paper concludes that successful mitigation must involve the close collaboration between the local community and the government agencies and must contain a mixture of immediately visible improvements and of less visible long-term sustainable benefits. In this regard the paper recommends the urgent completion of Part 5 of CUBiC which deals with the construction of Small Buildings.

BRIEF REVIEW OF CUBiC PROVISIONS FOR WIND AND EARTHQUAKE LOADS

It is instructive to first of all briefly trace the development of the CUBiC project with particular reference to the wind and earthquake loads provisions.

Development of Wind Load Provisions in the Caribbean

In August 1970 the Barbados Association of Professional Engineers (BAPE) (1970) produced a draft code of practice entitled Wind Loads for Structural Design for use in the Caribbean Region. This code was based largely on the then Draft British Standard Code of Practice CP3:Chap.V:Part 2 Wind Loads but with much of the meteorological data rewritten to be appropriate to the Caribbean region. Since then it was accepted by the Council of Caribbean Engineering Organisations (CCEO) and had been used extensively throughout the region. However the need for a revised edition was felt and in November 1981 a second edition was produced. Extensive use was made of the BS CP3:Chap.V:Part 2: Wind Loads (1972) in order to provide the extended range of pressure and force coefficients. The appendix on the dynamic response of buildings to wind loads was based on the Draft American National Standard ANSI A58.1 - Minimum Design Loads for Buildings and other Structures (1980) with additional information from Supplement No. 4 of the National Building Code of Canada (1970)

CUBiC Wind Load Provisions

In 1983 the Caribbean Uniform Building Code (CUBiC) project was undertaken and the opportunity was taken by the Short Term Consultant, Professor A. Davenport of Canada to adapt a document which had been prepared for the International Standards Organisation (ISO), Technical Committee 98, Working Group 2 on Wind Loads. It was recognised that international standards had an important role to play as the world moved towards being a global village and the CUBiC wind load provisions were characterised by the following desirable attributes of an international standard:

- The objectives of the standard should be clearly identified together with the factors which influence the behaviour and affect the safety of the structure.
- The standard should recognise that there may be several adequate methods for design and should therefore not be dogmatic about the approach adopted but rather to suggest where possible equivalences of different approaches taken in different codes.

Thus, the CUBiC wind load provisions consist of a basic document and five technical appendices. The basic document sets out the various actions of the wind which should be considered and the general requirements of the standard. The first of the appendices describes a Simplified Design Procedure which it is intended should meet the needs of the majority of structures. The remaining four appendices contain technical information on the four principal factors determining the wind loading viz:-

(i) The wind climate.

(ii) The influence of terrain and exposure.

(iii) The aerodynamic characteristics.

(iv) The dynamic effects of wind.

The wind climate was evaluated from an extensive study of hurricanes in the Caribbean carried out by Davenport *et al* (1985). The influence of exposure includes the effects of terrain roughness and height above ground as well as the speed up over hills. The aerodynamic coefficients have been obtained principally from those appearing in the National Building Code of Canada (1985) parts of which were adapted from the Swiss Norma. Included also are the results of turbulent boundary layer flow wind tunnel tests on low buildings as well as high structures. The dynamic effects include treatment of the action of wind gusts as well as excitation on slender structures by vortex shedding and instability. Both the resonant amplification and background excitation are considered.

Wind Force Per Unit Area

The Wind Force, per unit area is, in principle, determined from a relationship of the general form:

$$w = (q_{ref})\,(C_{exp})\,(C_{shp})\,(C_{dyn})$$

where w = Wind force per unit area

q_{ref} = Reference velocity pressure which corresponds to the mean velocity pressure over open terrain at an equivalent elevation of 10 m, averaged over a period of approximately 10 minutes and with a recurrence interval (return period) of once-in-50-years.

C_{exp} = Exposure Factor which accounts for the variability of velocity pressure at the site of the structure due to:

(a) the height above ground level

(b) the roughness of the terrain; and

(c) the undulating terrain, the shape and slope of the ground contours

C_{shp} = Aerodynamic shape factor which is the ratio of an aerodynamic pressure on the surface of the structure to a velocity pressure.

C_{dyn} = Dynamic Response Factor which accounts for the following actions of the wind:

(a) fluctuating pressures due to random wind gusts acting for an interval of time shorter than that specified in the averaging time for the reference velocity pressure and acting over all or part of the surface area of the structure;

(b) fluctuating pressures in the wake of the structure (vortex shedding forces) producing resultant forces acting transversely as well as torsionally and longitudinally; and

(c) fluctuating pressures induced by the motion of the structure.

The Reference Wind Velocity Pressures for the various islands of the Caribbean are given in Table 1 and the once-in-50-year Wind Pressure Contours are given in Figure 1.

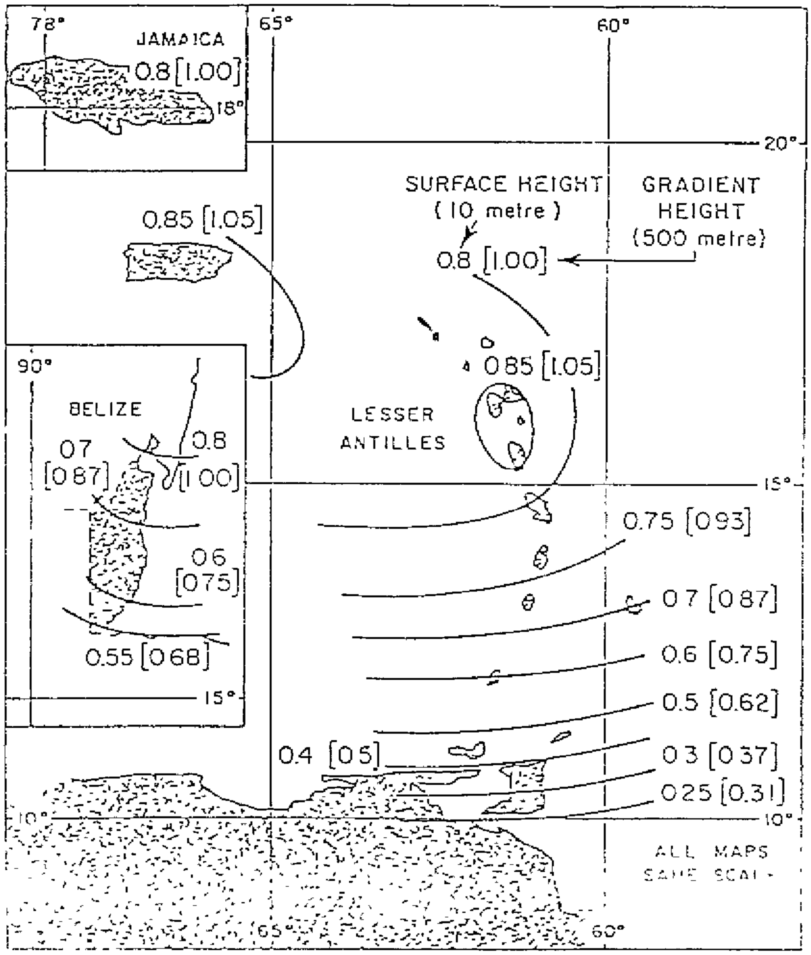

Fig. 1. Once-in-50-year Wind Pressure Contours in kPa

Table 1
Reference Wind Velocity Pressures for Caribbean

Location	q_{ref}*	Wind Pressure kPa q_{10}	q_{100}	Wind Speed m/sec V_{ref}+
Guyana	0.20	0.05*	0.35	18.0
Trinidad - South	0.25*	0.05*	0.40	20.0
- North	0.40	0.10*	0.60	25.5
Tobago	0.47	0.15	0.65	28.0
Grenada	0.60	0.25	0.80	31.5
Barbados	0 70	0.30	0.90	34.2
St. Vincent	0.73	0.35	0.93	35.0
St. Lucia	0.76	0.36	0.95	35.5
Dominica	0 85	0.42	1.06	37.5
Montserrat	0.83	0.40	1.07	37.2
Antigua	0 82	0.39	1.05	37.0
St. Kitts-Nevis	0.83	0.38	1.07	37.2
Jamaica	0.80	0.40	1.00	36 5
Belize - North	0.78	0.38	1.00	36.0
- South	0.55	0.26	0.70	30.5

*It is recommended that 0.25 kPa be taken as a minimal value.
+Calculated from $V_{ref} = \sqrt{2q_{ref}/0.0012}$

Earthquake Provisions of CUBiC (1985)

The earthquake provisions of CUBiC (1985) contain recommendations on:

(i) Method of analysis
(ii) Equivalent static force analysis
(iii) Dynamic analysis
(iv) Distribution of lateral forces
(v) Overturning
(vi) Deformation due to earthquake loads
(vii) Lateral force on elements of structure
(viii) Design principles

Of fundamental importance in the Equivalent Static Force Analysis is the choice of the Zonal Factor, Z.

Seismic Zoning Coefficient – Z

It is not economic to design a structure to perform elastically to the worst expected earthquakes. Design philosophy ideally should be based on the following principles:

(a) Structures are provided with sufficient strength andstiffness to resist moderate earthquakes so that the frequency of occurrence of damage is acceptably low.

(b) Structures are provided with sufficient strength and stiffness to ensure that the probability of collapse in a severe earthquake is acceptably low.

These principles dictate an evaluation of risk associated with structures in a seismic environment. It follows from this that the seismic zoning coefficient should be determined from considerations of seismic risk.

To evaluate appropriate seismic zoning coefficients for the Caribbean countries, the first step would be to develop seismic risk maps for the entire region. Zoning coefficients can then be determined by drawing contours of equal risk. This approach has been adopted in the ATC (1984) provisional code, NBCC (1990) and the Uniform Building Code (UBC) codes. In these codes, risk was determined on the basis of the effective peak acceleration and effective peak velocity. Peak ground acceleration was used in UBC (1991).

Seismic risk calculations have been carried out for some Caribbean countries. These include Trinidad and Tobago (Shepherd and Aspinall, 1983) and Jamaica

(Shepherd and Aspinall, 1980). It is recommended that these calculations be extended to include all of the Caribbean countries so as to establish a common and justified basis for determining seismic zoning coefficients.

A paper by Faccioli et al (1983) recommended zoning coefficients along the lines of the Uniform Building Code in the Caribbean territories. They recognised the need for seismic risk evaluations in determining zoning coefficients but concluded that more research and data were needed before such calculations can be undertaken. In the event, Faccioli et al (1983) recommended zoning values based on maximum historical intensities.

The paper by Faccioli et al (1983) is very concise and does not present a discussion of the zonal recommendations. It should be feasible to assemble an appropriate working document which records the authors and other local researchers accrued knowledge and insights. Such knowledge will be needed in the future as a basis for considering revised or new methods of determining parameters for seismic design. For example, deriving peak effective acceleration for engineering design purposes might be considered appropriate for relieving some of the difficulties engendered by the variability of ground acceleration values as recorded by the seismologists. The step can only be considered if the original data is fully documented as to its quality and shortcomings.

There are some misgivings when maximum historical intensities are used as the basis for determining zonal coefficients. Maximum intensities or magnitudes do not by themselves define the risk from earthquakes. There are other important factors like frequency of occurrence, attenuation laws, etc which should be taken into account in defining such risk.

Although Faccioli et al (1983) state that the historical intensity records are influenced by volcanic earthquakes, such earthquakes can produce localised high intensities and frequently occur in swarms which can number many tens or hundreds of shocks. Thus there is a need to undertake research studies to determine the significance of such swarms as a hazard and as a basis for the recommendations given by Faccioli et al (1983) to be improved upon.

Table 2 summarises the Z-values as proposed by the various committees and researchers since 1978 for use in the Caribbean region in comparison with those recommended by the Short Term Consultant (STC), Principia Mechanica Limited of London, UK and those adopted in CUBiC. It is of interest to note that the STC recommended that the approach suggested by Faccioli et al (1983) could be used until such research studies have been carried out. The STC further recommended that St. Lucia should be upgraded to Zone 3 and Barbados to Zone 2.

Suggested Changes in CUBiC Earthquake Load Provisions

Since the publication of the CUBiC earthquake load provisions in 1985, substantial advances have been made in improving seismic codes and there is now greater collaboration between seismologists, geotechnical engineers and structural engineers. Thus, Chin and Pantazopoulou (1994) have made the following recommendations:

- The CUBiC provisions for earthquake loads need to be revised and updated to bring it in line with modern seismic codes such as the NBCC (1990).
- There is an urgent need to analyse the earthquake data in the Caribbean in order to arrive at a single design parameter based on acceleration. In addition, the contribution of the overstrength of some structural systems need to be taken into account in the reduction factors.
- Most failures in structures subjected to earthquake loads can be attributed to poor detailing especially at beam and column connections and it is therefore recommended that in a revised CUBiC, there should be a section on proper detailing for good aseismic behaviour.

In addition there is an urgent need to enforce compliance with the requirements of CUBiC for both wind and earthquake loads and it is strongly recommended that urgent attention should be given by the various standards bodies to complete Part 5 of CUBiC which deals with the construction of Small Buildings. Berke and Werger (1991) have also made, *inter alia*, similar recommendations for Antigua and St. Kitts and Nevis following the damage done by Hurricane Hugo in 1989 and it is of interest to quote their specific recommendation as follows:

> *"Review existing building codes and compliance procedures for adequacy in relation to hurricane forces to assure safety. This step requires the updating of the Caribbean Uniform Building Code, (CUBiC) particularly for small buildings, and the hiring of additional inspection staff. Such staff, however, should not be viewed as enforcers of the code, but as extension specialists who act as promoters and trainers of appropriate building construction practices. Further the code should not be viewed as regulations, but as a guide for providing sound construction practices."*

Table 2
Z-Values for Use in CUBiC

Territory	Post 1978 Conf. Seismic Code Committee	Z-Values Recommended 1983 Seminar Faccioli, Taylor & Shepherd	(STC) Principia Mechania	Adopted in CUBiC
Jamaica	.75/1/0	.75	.75	.75
Leeward Islands				
Antigua	.75/1.0	.75	.75	.75
St. Kitts/Nevis	.75/1.0	.75	.75	.75
Montserrat	.75/1.0	.75	.75	.75
Windward Islands				
Dominica	.5	.75	.375	.75
St. Lucia	.5	.5	.75	.75
St. Vincent	.5	.5	.375	.5
Barbados	.5	.25	.375	.375
Grenada	.5	.5	.75	.5
North Trinidad	.75	.75	.75	.75
South Trinidad	.75	.5	.375	.5
Tobago	.75	.5	.37	.5
Guyana - Essequibo	–	–	–	.25
Rest of Guyana	–	–	–	.00
Belize				
Region within 100 km of Southern Border i.e including San Antonio and Punta Gorda but excluding Middlesex, Pomona and Stann Creek				
Rest of Belize				

Footnote: Z is a numerical zonal coefficient related to the seismicity of the region.

OTHER FACTORS INFLUENCING EFFECTIVE MITIGATION STRATEGIES

The upgrading of CUBiC however is only one part of the overall process of disaster management and it is absolutely necessary to develop realistic disaster mitigation plans at the national, regional and local levels and to be successful there must be close collaboration between the local community and the government agencies.

Kunar (1995) in a case study of hazard mitigation in Jamaica looked at the experience of Jamaica in developing and implementing a disaster mitigation programme to reduce the impact of hurricanes and earthquakes and the recent experiences with Hurricane Gilbert in 1988 and the Woodford Earthquake in 1993 highlighted some of the strengths and weaknesses in the disaster mitigation programme which Kunar summarised as follows:

- *Despite a great effort in the development of appropriate building codes, the dissemination of this information and the necessary training of designers, architects and construction contractors is insufficient. More financial resources should be made available for organisations like Construction Resources and Development Centre (CRDC) in the informal sector and the Jamaica Institution of Engineers (JIE) in the formal sector for training and education. Design guidelines and principles that can be understood by the design and construction industry are needed to supplement the building codes.*
- *Design codes need to be improved following the findings of surveys following the two events. The*

recommendations of Allen (1989), specifically with regard to the development of minimum standards for the anchorage of roof structures and roofing to be incorporated into the National Building Code of Jamaica (NBCJ), should be considered. In the seismic code, further research into the seismic hazard is needed to define the seismic zonation for Jamaica, especially following new information derived from the Woodford earthquake.

- *The system for building control and site inspections needs to be strengthened. Adequate resources and training are needed to ensure that standards are applied properly.*
- *The disaster prevention procedures should be expanded to include guidance and principles for retrofit and maintenance especially for buildings and facilities required for post-disaster operations. The main lesson from the damage caused by Hurricane Gilbert is that a great deal of the damage could have been avoided by relatively low cost retrofit measures and a good maintenance programme.*

The lessons learnt from the Jamaica experience can be very valuable in helping other Caribbean islands to identify where the limited human and financial resources need to be applied in order to derive maximum benefits from their disaster mitigation programmes against the background of the attitudes of the Caribbean peoples and the politicians.

CONCLUDING REMARKS

Based on the foregoing it is appropriate to bring together the main points outlined in the paper and to make the following concluding remarks:

1. Each Caribbean island needs to identify its own hazards, vulnerability and risk and must develop realistic disaster mitigation plans at the regional, national and local levels and make them known throughout the local community and governmental agencies.
2. There is an urgent need for the completion of Part 5 of CUBiC which deals with the construction of Small Buildings and for the enforcement of compliance with the requirements of CUBiC.
3. A great deal of damage to non-engineered structures could be avoided by the introduction of low cost retrofit measures and good maintenance of buildings and effective training programmes at all levels.

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