Mitigation of Losses due to Earthquakes with Particular Reference to the Cost Impact of Introducing CUBiC-based Building Codes in the Eastern Caribbean

by

Tony Gibbs

IX International Seminar on Earthquake Prognostics

San José, Costa Rica

19th-23rd September 1994

MITIGATION OF LOSSES DUE TO EARTHQUAKES WITH PARTICULAR REFERENCE TO THE COST IMPACT OF INTRODUCING CUBiC-BASED BUILDING CODES IN THE EASTERN CARIBBEAN

by

Tony Gibbs

Director of Consulting Engineers Partnership Limited

Trinidad, Grenada, St Vincent, Barbados, Dominica, St Kitts (Caribbean)

Godalming, Bristol (England)

1 Seismicity

Seismic events in the Eastern Caribbean are principally associated with a subduction zone at the junction of the Caribbean plate and the Americas plate. The Caribbean plate is moving eastward relative to the Americas plate at a rate of about 20mm per year. The Americas plate dips from east to west beneath the Caribbean plate along a north-south line just east of the main island arc. This leads to a moderate level of inter-plate seismicity. Superimposed on this is a pattern of intra-plate activity. There is a concentration of such activity in the Leeward Islands where the subduction of the Barracuda Rise imposes additional stresses on both the "subducted" Atlantic plate and the overriding Caribbean plate. The earthquakes there are generally shallow. In the region north-west of Trinidad there is another concentration of earthquake activity where the strike of the plate boundary changes direction. These earthquakes are of intermediate depth (Figures 1, 2 and 3).

Over the past forty years a considerable amount of research has been carried out on the seismicity of the Eastern Caribbean by the Seismic Research Unit (SRU) of the University of the West Indies (UWI). The maximum historical intensities (Modified Mercalli Scale) of earthquakes in the Eastern Caribbean, as reported by Dr John Shepherd when he was head of the SRU, were:

Antigua, St Kitts-Nevis, Dominica	IX
Montserrat, St Lucia, Grenada, Trinidad	VIII
St Vincent, Barbados	VII

Some of these figures are one degree lower than those in Dr Robson's 1964 catalogue. (Dr Robson was the first head of SRU.)

During the past twenty-five years the engineering community has been requesting more and more assistance from the SRU in interpreting the fundamental research and developing "code" values for seismic forces for use in structural design. The most recent work in this field is that of Dr John Shepherd, now at Lancaster University. Figure 4 shows a Regional Isoacceleration Map for the Eastern Caribbean. This indicates that the region can be crudely divided into three sub regions:

(a) an area of very severe exposure in the north
(b) an area of moderately severe exposure in the south
(c) an area of moderate exposure in the middle

2 Earthquake-Resistant Engineering

In previous generations there was little conscious engineered attention to earthquake-resistant design in the Eastern Caribbean. Much more attention had been paid to designing against hurricane-force winds. This led to the general practice of assuming that buildings satisfactory for hurricanes would also perform satisfactorily against the other lateral forces such as earthquakes. This, of course, was a serious misconception. One of the major differences between designing against earthquakes and hurricanes has to do with performance expectations and, therefore, detailing. Conventional earthquake-resistant design uses forces which are much smaller than those which could occur in the expected event. Therefore the structure will yield (go beyond its elastic range). Detailing for toughness and ductility is of paramount importance. With hurricane-resistant design it is expected that the structure will remain elastic when impacted by the expected event.

Over the past three decades there has been a gradual improvement in the engineered approaches to earthquake-resistant design. In the mid-sixties *avant garde* engineers were beginning to apply simple formulae relating the lateral earthquake force to the mass of the structure. By the end of the sixties a few engineers were beginning to use the techniques, similar to those in California at the time, leading to a triangular distribution of lateral forces for multi-storey structures. The acknowledgements of the influence of different structural systems came soon after. The first attempts at dynamic analysis of more complex structures were made early in the seventies. The first major building in the Eastern Caribbean to be subjected to "full" dynamic analysis and to be designed and detailed as a ductile moment-resisting space frame in reinforced concrete was the 15-storey Holiday Inn in Port-of-Spain, Trinidad. The construction of this building was completed early in 1974. The main thrust since then has been the broadening of earthquake-resistant design techniques to a wider audience and to a greater range of projects.

The advent of low-cost personal computers and software has facilitated and encouraged the wider application of three-dimensional analyses and dynamic analyses to structures.

At present, however, there are still many significant structures which are not subjected to conscious earthquake-resistant design techniques.

3 Government Attitudes

Currently there are no laws or regulations requiring any structures in the majority of Eastern Caribbean states to be designed and built to be resistant to any specified level of seismic activity. Some government agencies adopt an *ad hoc* approach to the issue based principally on the personalities involved in any particular project.

In most cases the administrators subconsciously assume that their engineers would do what is right without being told. In other cases, the administrators would adopt the approach of not objecting to earthquake-resistant design provided it did not interfere with their other aims for the project. The most important of these aims is low capital cost. Although this is understandable, there is much misunderstanding about the cost of providing earthquake resistance (and the potential cost of having structures which do not possess earthquake resistance).

Many government capital works projects are funded by international lending agencies - the Caribbean Development Bank, the World Bank, the Inter-American Development Bank, the European Investment Bank, etc. Typically the funding agency refuses to impose earthquake-resistant design criteria on a project. The funding agency leaves it up to the government who leaves it up to the engineer. Funding agencies and clients need to be consciously involved in decisions relating to the performance expectations of capital works.

4 Engineering Attitudes

In the Eastern Caribbean each island territory would have a different attitude and approach to earthquake-resistant design. Within any particular territory each firm or design group may have a different approach to the subject. Within any one design group each designer may have a different approach. Lastly, a particular engineer may adopt quite different attitudes and criteria from one project to another without any objective technical basis for so doing. Expediency is the order of the day. This lack of consistency is costly to the communities and is part of the reason for the unfavourable rating given to the region by the catastrophy insurance industry.

The engineering profession is very vulnerable to pressures from clients, architects and funding agencies. Pragmatism often encourages the engineer to turn a blind eye to important earthquake-resistant issues. Many engineers pretend that the problem doesn't exist in the hope that by so doing it would disappear.

There are noticeable exceptions to that attitude however. There are a few engineers who have been prepared to become unpopular by making a considerable effort to improve the engineering approach to earthquake-resistant design. One of the penalties paid by such engineers is a greatly increased design effort for no additional fee. Indeed design costs, not construction costs, are the most important financial effect of introducing proper earthquake-resistant procedures to the building industry in the region.

5 Code Development

In 1968 an informal meeting of a few senior engineers from different territories in the Commonwealth Caribbean was held in Guyana. The purpose was to discuss matters of mutual interest to the profession. Out of that meeting came the Council of Caribbean Engineering Organisations (CCEO).

Two of the functions of the CCEO were the development of building codes and the co-ordination of such activities among the various constituent bodies of the CCEO. In 1969 the CCEO requested the Association of Professional Engineers of Trinidad & Tobago (APETT) to prepare a Code of Practice for Earthquake-Resistant Design on behalf of CCEO for use throughout the Commonwealth Caribbean. The authors of the Report, which was issued in 1970, were David Key (consulting engineer), Desmond Imbert (lecturer at the University of the West Indies) and John Tomblin (head of the Seismic Research Unit).

Essentially, the recommendation at that time was for designs to be carried out generally in accordance with the 1968 edition of the "Recommended Lateral Force Requirements" of the Structural Engineers Association of California (SEAOC).

Regional seminars were held in Jamaica in 1970, 1973 and 1974 with the aim of developing and finalizing the Code. In 1972 APETT had issued a draft of such a Code.

Significant changes were made to the SEAOC Code in 1975 and this led to considerable re-thinking of the position in the Caribbean.

A major conference was held in Trinidad in January 1978 devoted entirely to the seismicity of the Caribbean region and earthquake-resistant practices. Following that conference CCEO set up a committee to prepare interim guidelines for use by engineers pending the re-writing and publishing of the Code. The members of that committee were Myron Chin (UWI), Arun Buch, Alfrico Adams, Tony Gibbs and Maurice St Rose (four consulting engineers). The committee issued its report in July 1978.

A major exercise was mounted in the eighties to prepare a total building code for the Commonwealth Caribbean. The first phase of the Caribbean Uniform Building Code project (CUBiC) was completed in 1986. That year, those sections of CUBiC dealing with structural design requirements were completed and accepted by the Council of Health Ministers of the Caribbean Community (CARICOM). Funding for this exercise came from the United States Agency for International Development, the Caribbean Development Bank, the Council of Caribbean Engineering Organisations and the Caribbean Community Secretariat. The management of the CUBiC project was undertaken by Myron Chin, Alfrico Adams, Tony Gibbs and Alwyn Wason (development consultant). Specialist consultants for the seismic code provisions were Principia Mechanica of London.

The philosophy and structure of the seismic code were not dissimilar to those of the California "Blue Book" - "Recommended Lateral Force Requirements" of the Structural Engineers Association of California (SEAOC). The zone factors recommended for the Eastern Caribbean in the CUBiC document are:

Zone 3	Z = 0.75	Antigua-Barbuda
		St Kitts-Nevis
		Montserrat
		Dominica
		St Lucia
		North-west Trinidad
Zone 3/2	Z = 0.50	St Vincent
		Grenada
		the rest of Trinidad
		Tobago
Zone 2	Z = 0.375	Barbados

The recent work done by Dr John Shepherd was referred to in the early part of this paper. Based on these studies, if the separate island states were to be put in zones as defined by the Caribbean Uniform Building Code (CUBiC) the listing would probably be as follows (with the CUBiC Z-factors shown in parentheses for comparison):

Zone 4	Z = 1.00	British Virgin Islands
		Antigua-Barbuda (cf 0.75)
		Montserrat (cf 0.75)
Zone 3	Z = 0.75	St Kitts-Nevis (cf 0.75)
		Trinidad (cf 0.75 and 0.50)
Zone 3/2	Z = 0.50	Anguilla
		Dominica (cf 0.75)

		Tobago (cf 0.50)
Zone 2	Z = 0.375	St Lucia (cf 0.75) St Vincent (cf 0.50) Barbados (cf 0.375) Grenada (cf 0.50)

It can be seen that there are several changes to the earlier 1985/86 CUBiC thinking. Clearly there is a need for continuing debate of and research into the seismic hazard and revision of engineering recommendations. In the meanwhile a conservative approach is indicated.

6 Cost Impact

With the introduction and formal adoption of the CUBiC approach to earthquake-resistant design, a significant change in strategy among engineers and architects is envisaged. At present much effort is spent in debating the need for earthquake-resistant design. Since there is no commitment and no official regulation to provide against seismic forces, they tend to be ignored at the conceptual design stage. This leads to the majority of buildings being of inappropriate shape and structural configuration for earthquake resistance. The engineer is then left with the task of making an inappropriate design safe - an expensive exercise. Thus the major benefit of an officially-sanctioned CUBiC would be (or should be) to revolutionize the conceptual design of buildings to make them more in keeping with the demands of aseismicity. Continuing education of practicing professionals (engineers and architects) would go hand in hand with the introduction of an officially-sanctioned CUBiC. Economy in earthquake-resistant structures would be achieved through greater effort in design by more knowledgeable professionals. More money may need to be allocated to design so as to reduce the overall cost of capital works projects.

Cost comparison studies have been carried out by a number of authors on a wide range of structures. Notwithstanding the differences between earthquake-resistant design and hurricane-resistant design, in assessing the cost impact of earthquake-resistant design in the Eastern Caribbean, the benchmark would usually be a building satisfactory for hurricane-force winds. In other words, how much more would it cost to make a building, which is safe for hurricanes, earthquake-resistant? David Key's analysis of the 11-storey TATIL building in Trinidad produced the following results based on the full construction cost (the building was originally designed for a SEAOC Z-factor of 0.75):

(a) Saving if re-designed with no seismic requirement but for Trinidad wind loading (basic wind speed of 40 m/s) - 2.9%.

(b) Saving if re-designed with no seismic requirements but for Barbados wind loading (basic wind speed of 55 m/s) - 1.8%.

Ipek's analysis of a single-bay, multi-storey, reinforced concrete framed structure is shown in Figure 5 with typical Eastern Caribbean conditions superimposed. A similar study was carried out by Whitman et al and is presented in Figure 6. In these two studies the cost increments relate to buildings designed for gravity loads only.

The intention with respect to CUBiC was to have a period of trial use during which the Code would have been "calibrated" and compared with previous practice. It was envisaged that some of the comparative exercises would be carried out in a controlled manner so as to obtain reliable and representative figures for cost impact. The results of such exercises should produce interesting reading. It may be that the current Caribbean Disaster Mitigation Project (CDMP) provides an excellent opportunity and vehicle for carrying out these calibration exercises. CDMP is funded by USAID and managed by the Organisation of American States (OAS).

7 The Way Forward

What is needed now is a period of intense lobbying, public awareness campaigning and education of the whole building industry.

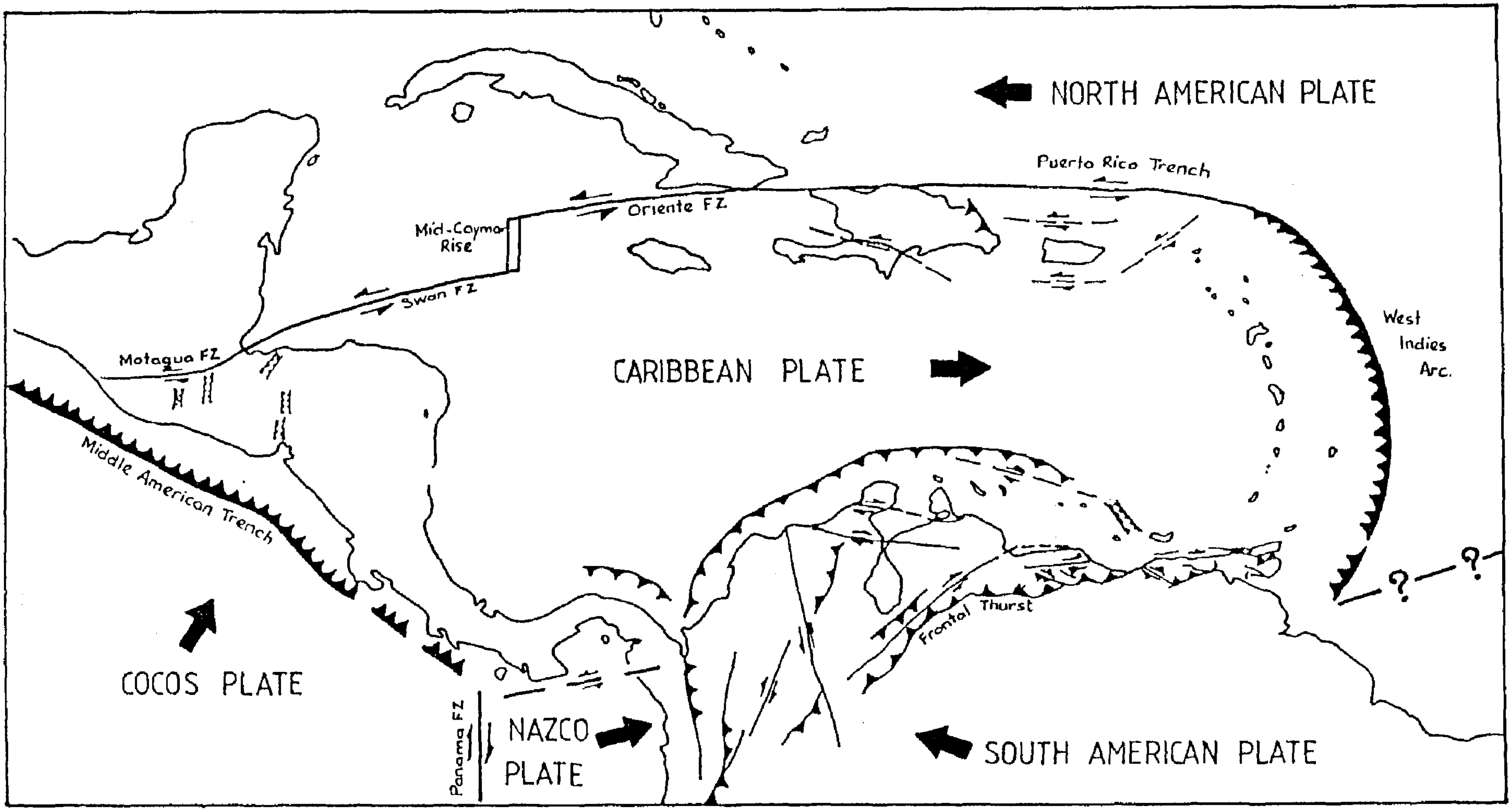
The lobbying is required to persuade government agencies, other regulatory bodies and funding agencies to require that established seismic design criteria be incorporated into the programmes of all public and major private development projects. This is the minimum area that should be addressed.

Public awareness campaigns should be undertaken to facilitate the implementation of earthquake-resistant design regulations. An uncooperative public would make effective progress difficult if not impossible.

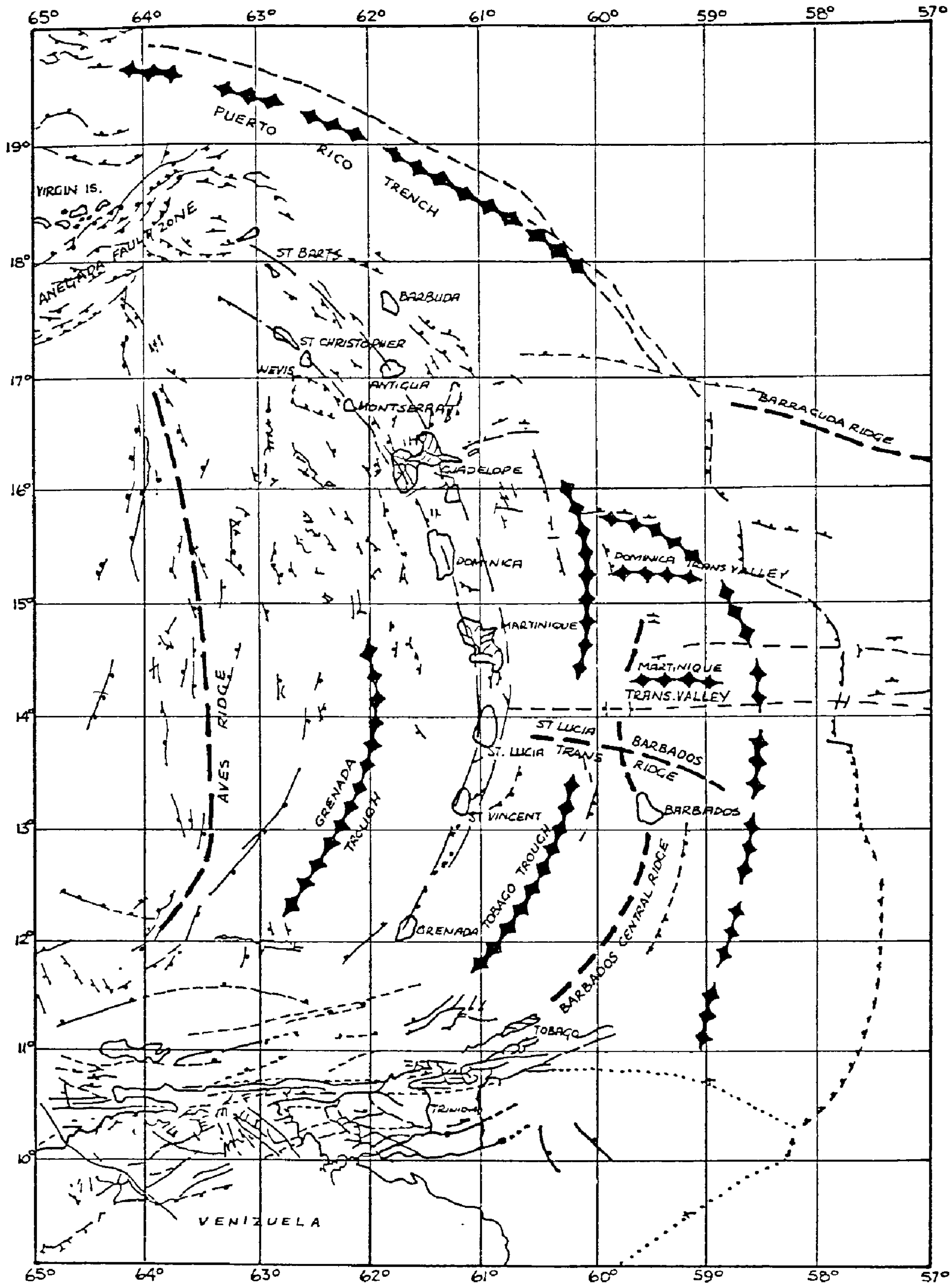
The majority of engineers, architects and builders are still in need of a lot of formal education in the field of earthquake-resistant design. From 1969 to 1990 the CCEO did an admirable job in fostering continuing education programmes in conjunction with the University of the West Indies. The CCEO has been dormant since then. The UWI has continued its efforts, principally through its regular programmes. However, a new thrust of increased intensity is now required.

The current crisis in the catastrophy insurance industry provides a window of opportunity. Catastrophy insurance (earthquakes and hurricanes, principally) has become scarce and expensive. In this environment a degree of self insurance is an option but not one which can be taken lightly. Contingent on this approach is the need for more predictable performance of facilities. This demands better information on the hazards, better designs and better construction.

Bearing in mind that most of the buildings to be used over the next thirty years in the Eastern Caribbean have already been constructed, a programme of damage mitigation through retrofitting is strongly recommended. It would take about one generation execute such a programme but, in terms of the history of the Caribbean, that is not a long time.

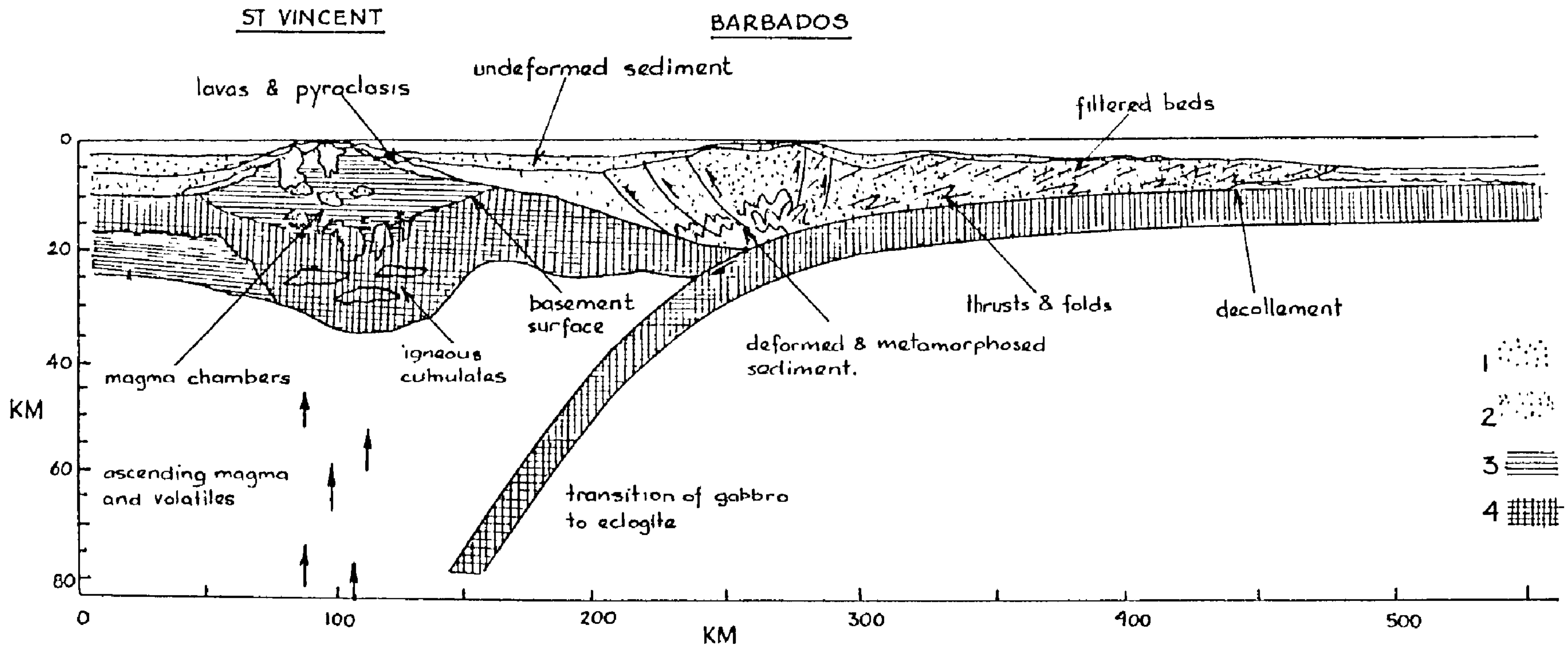


Tectonic Setting of the Caribbean
(after Molnar and Sykes, 1969)
Figure 1



Main Features of Eastern Caribbean
(based on compilation by JE Case and TA Holcomb USN00
and from Peter and Westbrook, 1976)

Figure 2

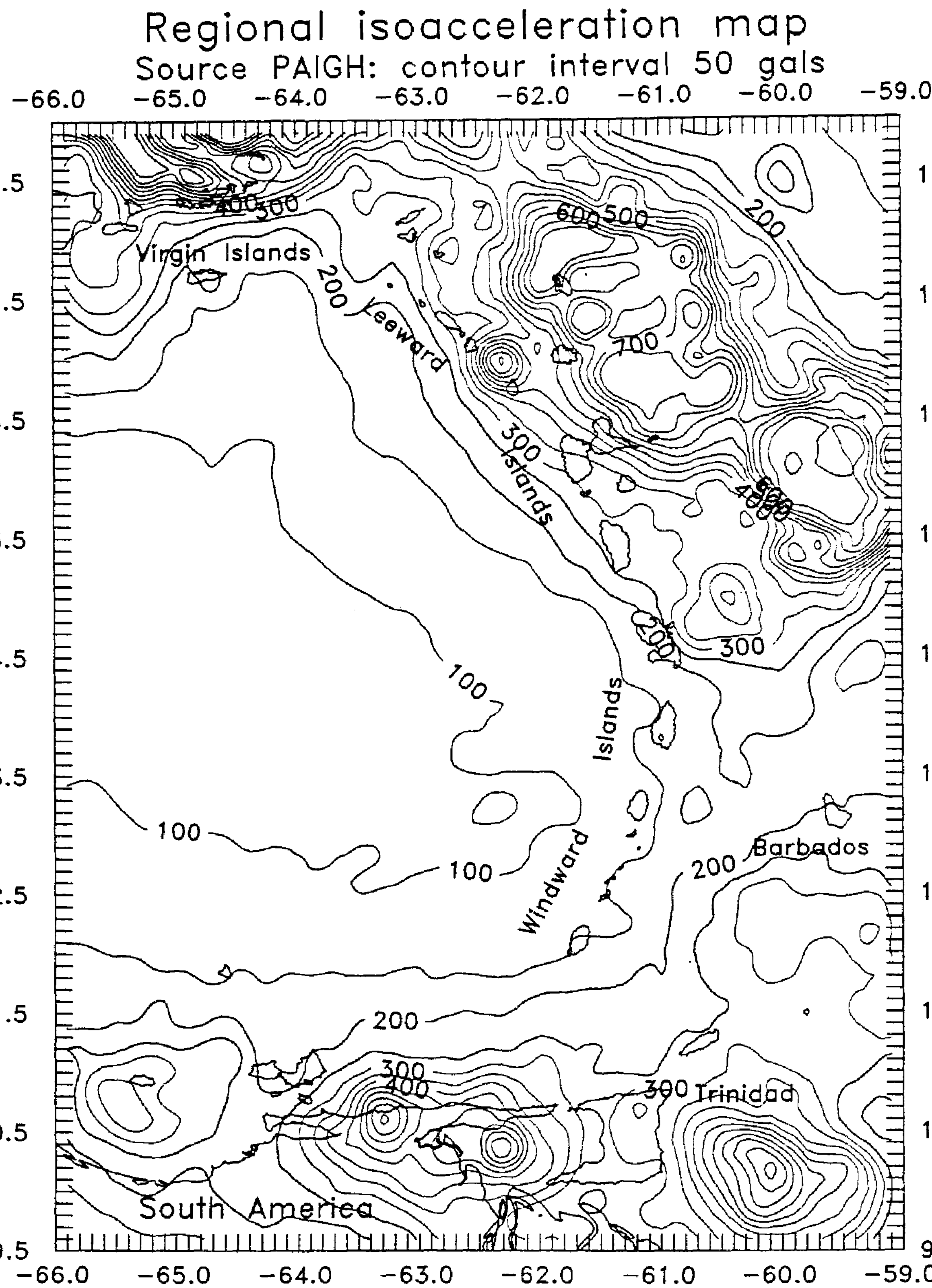


Diagrammatic cross-section of the Eastern Caribbean island arc illustrating the structure and the processes acting on it. 1. Undeformed sediment. 2. Deformed and/or consolidated sediment. 3. Igneous crust produced by the volcanic arc. 4. Main oceanic crustal layer and lower crust of arc. Vertical exaggeration 2:1.

Structure in Region of Barbados

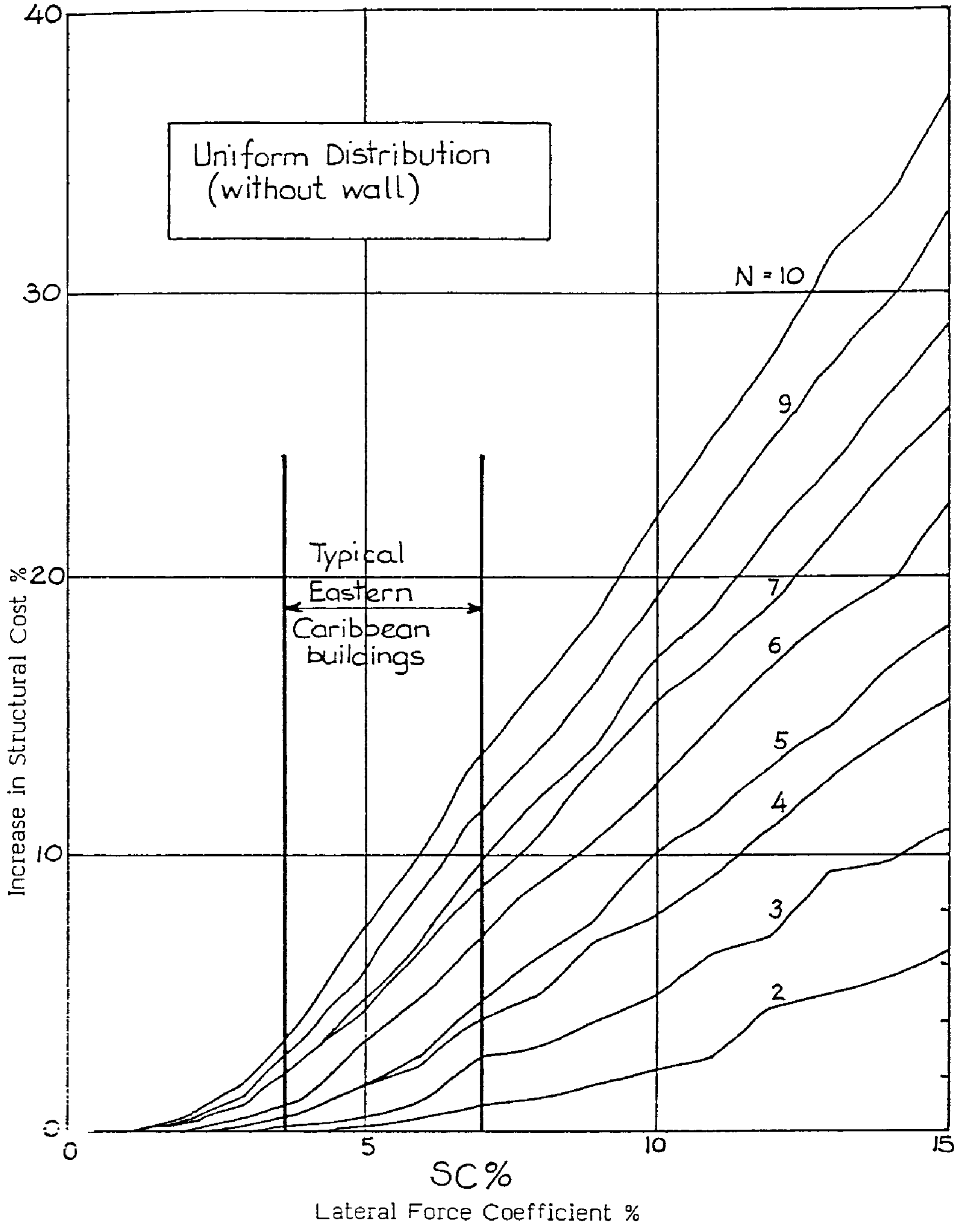
(Westbrook, 1970)

Figure 3



Regional isoacceleration map
Source PAIGH: contour interval 50 gals
-66.0
-65.0
-64.0
-63.0
-62.0
-61.0
-60.0
-59.0
18.5
17.5
16.5
15.5
14.5
13.5
12.5
11.5
10.5
9.5
Virgin Islands
Leeward
Islands
Windward
Islands
Barbados
Trinidad
South America
100
200
300
400
500
600
700

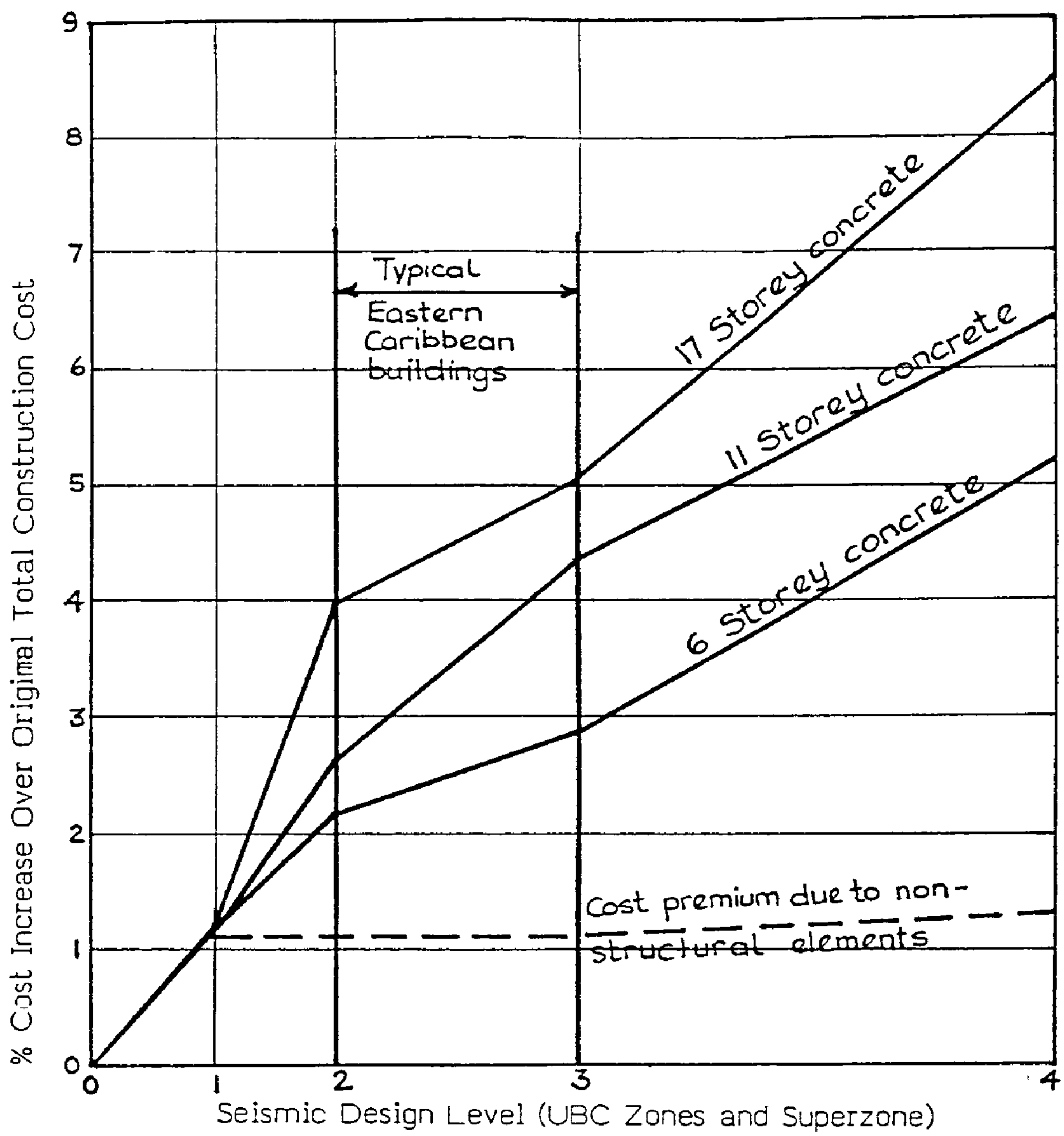
Figure 4



Cost Impact of Earthquake-Resistant Design

(Ipek)

Figure 5



Effect on Cost of a Seismic Design
of Typical Concrete Apartment Buildings
(after Whitman et al)

Figure 6

REFERENCES

Chin, M: Buch, A: Adams, A: Gibbs, T: St Rose, M (1978) - *Report of Seismic Code Committee.*

Chin, M; Adams, A; Gibbs, T; Wason, A (1986) - *Caribbean Uniform Building Code (CUBiC), Part 2, Section 3, Earthquake Load.*

Key, D; Tomblin, J; Imbert, D (1972) - *Draft Code of Practice for the Design of Earthquake-Resistant Structures.*

Key, D; Tomblin, J; Imbert, D - APETT (1972) - *Preliminary Report on the Design of Earthquake-Resistant Structures.*

Key, D (1978) - *Earthquake-Resistant Structures in the Caribbean: Design Practice, Costs and Problems.*

Shepherd, J (1983) - *Seismicity of the Greater and Lesser Antilles.*

Shepherd, J - PAIGH (1993) - *Regional Isoacceleration Maps.*