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International Conference on Disaster Mitigation in Health Facilities

Executive summary: International conference on disaster mitigation in health facilities Mexico City, 26–28 February 1996

Why a conference on disaster mitigation?

Since 1960 natural disasters in Latin America and the Caribbean have caused the death of more than 180,000 persons and approximately US$ 54 billion in property damages. The health sector has been particularly hard hit – hundreds have lost their lives when hospitals and health centers have collapsed in the most serious events, and health services interrupted when most needed.

As many as 50% of the more than 15,000 hospitals existing in the Region may be at high risk to natural disasters. A considerable number of these health facilities lack disaster mitigation programs, emergency plans or the appropriate infrastructure for resisting powerful earthquakes and hurricanes.

This need not be the case. Health facilities can take measures to reduce the structural impact of natural disasters. The additional cost of building hospitals to seismic and wind resistance standards is minimal, making the failure to enforce such standards inexcusable. Providing structural reinforcement in existing facilities is, however, much more costly.

Interventions to reduce nonstructural vulnerability – protecting equipment, medical supplies or ensuring the integrity of lifeline services, for example – can be carried out to a large extent by staff of the health facility with minimal capital investment.

Who attended?

More than 500 representatives from governments, international, regional, and nongovernmental organizations and the private sector of the Latin American and Caribbean countries met in Mexico City from 26 to 28 February 1996, at the International Conference on Disaster Mitigation in Health Care Facilities. The Conference was convened by the Pan American Health Organization, Regional Office for the Americas of the World Health Organization (PAHO/WHO), together with Mexico’s Ministry of Health, Ministry of the Interior, and Social Security Institute; the Secretariat of the International Decade for Natural Disaster Reduction (IDNDR) of the UN Department of Humanitarian Affairs; the Economic Commission for Latin America and the Caribbean (ECLAC); the General Secretariat of the Organization of American States (OAS) and the World Bank.

What was discussed?

Presentations on disaster impact, vulnerability analysis and mitigation strategies for health facilities included case studies from Chile, Colombia, Costa Rica, Eastern Caribbean Islands, Ecuador, Jamaica, and Mexico. Government delegations presented progress reports on disaster mitigation objectives and practices in their national facilities. Technical Commissions met to discuss specific disaster mitigation strategies for earthquakes and hurricanes.

A highlight of the Conference and an expression of Mexico’s commitment to making hospitals safe, was the agreement signed by the Minister of Health of Mexico, Dr. Juan Ramon de la Fuente, and Dr. George Alleyne, Director of PAHO, whereby national and international committees will recognize the efforts and achievements made by national hospitals toward realizing safety.
Outcome

Conference participants approved *Recommendations and Goals*, urging Governments and regional and international organizations to adopt policies to reduce the vulnerability of existing and planned hospitals to hurricanes and earthquakes. They also defined mitigation strategies in the design, construction, retrofitting, and maintenance of health facilities. These strategies will be presented for consideration to the political and technical decision–making levels of the health sector, bilateral and multilateral financing agencies, development planning organizations, professional schools, and other sectors, private as well as public.

A five–year plan for initiating or strengthening the disaster mitigation process in hospitals in each country was recommended. To the degree allowed by local political, economic, and organizational conditions, it was recommended that by the year 2001 all “priority” hospital structures be able to withstand moderate–to high–intensity events without suffering functional damage and without danger of collapse. It was also recommended that level of vulnerability to natural hazards and the level of preparedness be criteria for accrediting hospitals.

Arguably the most important result of the Conference was the personal commitment developed or strengthened among the participants to promote disaster mitigation strategies in new constructions and retrofitting projects. Participants requested PAHO to continue its disaster mitigation program in the areas of promotion, training and regular evaluation of achievements in countries and territories of Latin America and the Caribbean.

The Conference “Recommendations and Goals”, the reports of the technical commissions on seismic and hurricane mitigation, and other documents and case studies presented during the Conference may be requested, in Spanish or English, from: Disasters Documentation Center, P.O. Box 3745–1000, San Jose, Costa Rica; Tel: (506) 257 2141; Fax: (506) 257 2139; and http://www.paho.org; gopher://gopher.paho.org.

International conference on disaster mitigation in health facilities: Recommendations and goals

Mexico City 28 February 1996

Preface

Since 1960 natural disasters in Latin America and the Caribbean have caused the deaths of some 180,000 people and approximately US$ 54 billion in property damages. The health sector has been particularly vulnerable to these damages, so much so that hurricanes like “Gilbert” (Jamaica, 1988) and “Luis” and “Marilyn” (Antigua and Barbuda, St. Kitts and Nevis, St. Maarten, and other islands, September 1995) and the earthquakes in Mexico (1985), El Salvador (1986), and Costa Rica and Panama (1991) seriously damaged hospitals and health centers just when they were most needed to provide health services. ECLAC estimates that during the period 1985 to 1988 the health sector lost roughly US$ 1.9 billion.

In Latin America and the Caribbean there are just over 15,000 hospitals, as many as 50% of which are located in areas at high risk to natural hazards. Many of these facilities lack emergency plans and disaster mitigation programs or the appropriate infrastructure for resisting powerful earthquakes or hurricanes.

Concerned about the high risk that this situation poses to the health of the populations and economic well–being of the countries, delegates from Governments, representatives of governmental, international, regional, and nongovernmental organizations and the private and scientific sectors of the Latin American and Caribbean countries met in Mexico City from 26 to 28 February 1996 at the International Conference on Disaster Mitigation in Health Care Facilities. This Conference was convened by the Pan American Health Organization, Regional Office for the Americas of the World Health Organization (PAHO/WHO), together with the Ministries of Health and Interior of Mexico, the Social Security Institute of Mexico, the Secretariat of the International Decade for Natural Disaster Reduction of the United Nations Department of Humanitarian Affairs (IDNDR), the Economic Commission for Latin America and the Caribbean (ECLAC), the General Secretariat of the Organization of American States (OAS), and the World Bank.
The participants decided to alert the Governments and international, regional, and subregional organizations of the need to adopt regional and national policies to reduce the vulnerability of existing or planned hospitals to hurricanes and earthquakes and other hazards, with the objective of helping to protect the lives of patients and health personnel and ensuring the availability of health care services.

1. The participants of the International Conference on Disaster Mitigation in Health Care Facilities, held in Mexico City from 26 to 28 February 1996, considering that:

1.1 The definition of health adopted by the countries in the WHO Constitution is: “a complete state of physical, mental and social well-being and not merely the absence of disease” and the prevention and reduction of damage due to natural hazards form an integral part of health;

1.2 The General Assembly of the United Nations has declared the decade of 1990−1999 the International Decade for Natural Disaster Reduction (IDNDR, Resolution 44/132) and adopted the “Strategy and Plan of Action for a Safer World” at the World Conference on Natural Disaster Reduction, held in Yokohama, Japan, in May 1994;

1.3 The high number of lives lost and the economic costs produced either directly or indirectly by the inadequate measures employed to protect health care facilities against the impact of hurricanes, earthquakes, and other hazards can be avoided;

1.4 The uninterrupted operation of health care facilities in the wake of a disaster, when the need for them is greatest, is extremely important, both socially and politically;

1.5 The program for disaster mitigation in hospitals, promoted by PAHO with the generous support of the Governments of Canada and the United States, as well as the pilot project for hospital vulnerability analysis conducted by this same Organization with the backing of the European Community’s Humanitarian Office (ECHO), have been very satisfactory and necessary;

1.6 Disaster mitigation measures should be carried out at the structural level of the physical plant (location, soil conditions, design, and compliance with and application of construction standards), the nonstructural level (equipment, installations, hazardous and pharmaceutical substances, furniture), and the functional level (physical distribution and training of human resources). It is important to guarantee the integrity of lifeline services outside of the hospitals or to create basic reserves to permit hospital autonomy;

1.7 Interventions to reduce nonstructural vulnerability (protection of equipment and supplies, better securing of furniture and equipment, planning for emergencies) can be identified and carried out by the staff of the health facilities themselves with minimal economic investment;

1.8 The United States Federal Emergency Management Agency, in its publication "Seismic Considerations−Health Care Facilities" (FEMA publication No. 150) states that: "The average increase in cost of health care facilities...should be less than 1.5 percent of the construction cost of the building which, of course, is only a part of the total project costs." The cost of protecting against high winds is generally less than protecting against earthquakes.

1.9 The greatest challenge will be to provide structural reinforcement for existing health care facilities, despite the relatively high cost such corrective reinforcement measures or structural adaptations may present, as well as to fulfill the need for highly specialized professional advisory services;

1.10 Regular maintenance and inspection of health care facilities, particularly in zones at seismic or meteorological risk are of great importance;

1.11 Health care facilities form an integral part of the communities they serve, sharing hazards and many aspects of vulnerability, and disaster reduction projects and programs in communities also contribute to reducing risk in health facilities;

2. Urge all countries and institutions to:
2.1 Take into account that each country has the primary responsibility for protecting its population and infrastructure from the impact of natural disasters, as formulated in the "Strategy and Plan of Action for a Safer World", adopted at the World Conference on Natural Disaster Reduction, held in Yokohama, Japan, in May 1994;

2.2 Declare the adoption of concrete measures to mitigate the impact of natural phenomena on the physical plant, lifeline services and equipment in health care facilities as a high health, social, and economic priority, and as an integral part of disaster prevention and emergency preparedness plans;

2.3 Define guidelines, integrated plans and programs for disaster mitigation in existing hospitals and other health care facilities, as well as those in the planning phase, mustering the political will and resources necessary to prevent facilities designed to improve health from causing loss of life and injuries when natural hazards strike, and to ensure their uninterrupted operation in emergencies;

2.4 Take into account the recommendations made by the Technical Commissions on earthquakes and hurricanes during the Conference;

2.5 Review the working documents "Role of International Development Financing Agencies," "Economic Impact of Natural Disasters on Health Infrastructure," and "General Policies for Incorporating Disaster Risk Factors in Health Infrastructure Investment Projects" as technical and scientific guidelines for the formulation of this strategy and its respective work plan;

2.6 Ensure that the planning, design, construction, alteration, and maintenance of health facilities be carried out by multidisciplinary professional teams to guarantee proper investment in health facilities.

3. Recommend to the countries at risk to hurricanes and earthquakes that they continue, strengthen or initiate the disaster mitigation process in health facilities between the years 1996 and 2001, for which it will be necessary to establish an annual schedule for reaching objectives, to be determined in accordance with constraints and possibilities of local political, economic, organizational, technical and logistic conditions. The following is proposed:

3.1 Formally identify which of the existing health care facilities are of greatest priority for the study and adoption of measures to reduce the impact of hurricanes or earthquakes;

3.2 Adopt legislation and standards regulating the characteristics of the investment in order to avoid structural collapse and nonstructural damages that would affect the safety or functionality of the hospital in the event of a disaster;

3.3 Consider geological and hydrometeorological hazards as determining factors in decision-making when planning health services, and introduce disaster mitigation measures into the design and construction of new health establishments or into the remodeling and expansion of existing facilities;

3.4 Carry out structural vulnerability studies and design retrofitting for those health care facilities which have been classified as "priority" in accordance with accepted norms and procedures, given the present state of technical knowledge;

3.5 Ensure that existing hospitals in areas exposed to natural hazards meet the standards and regulations governing nonstructural safety in case of disaster;

3.6 Include measures for nonstructural mitigation against earthquakes and/or hurricanes, as appropriate, in all plans for maintenance, inspection, remodeling, and upgrading of existing hospitals;

3.7 Identify budgetary resources and have mitigation plans to protect the lives of patients and health workers in hospitals classified as "priority" and where vulnerability studies have been made.

By the end of the year 2001:
3.8 All hospital structures considered "priority" will be able to withstand moderate to high-intensity events without suffering functional damage and the maximum established probable event for their designs without danger of collapse, within the useful life defined for their location, and will protect the life and health of their occupants and maintain essential health care services;

3.9 The level of vulnerability to natural hazards, as well as the level of preparedness, will be criteria to be considered in hospital accreditation;

3.10 Assign necessary allotments to carry out measures to reduce vulnerability of health facilities within the budgets of all public and private institutions in the health sector.

4. Recommend to the regional and subregional organizations that they:

4.1 Consider the recommendations of the “International Conference on Disaster Mitigation in Health Care Facilities” in the agenda of subregional meetings of Ministers of Health and at other gatherings during 1996, so that they are adopted as policy;

4.2 Request PAHO/WHO to serve as a facilitator to promote the exchange of information and mutual support for disaster mitigation in health facilities, in the health sector, among other sectors, and regional and subregional agencies among the countries of Latin America and the Caribbean, taking advantage of the development and experience that some countries have already attained in this area;

4.3 Encourage and promote the development of training and research in universities and institutions of higher learning as a means to maintain efforts to reduce the impact of disasters on the health sector;

4.4 Strengthen the ongoing education and training of health workers in the mitigation of structural, nonstructural, and functional damage, as well as in disaster preparedness;

4.5 Follow up on schedules for disaster mitigation in health facilities in order to assist countries to comply with established goals;

4.6 Support the countries in the development and use of data banks and experts in mitigation;

4.7 Support the efforts of the countries to include risk assessment in the health sector.

5. Urge international agencies to:

5.1 Include the presentation of these Recommendations in the agenda of their respective Governing Bodies for approval;

5.2 Include risk analysis with respect to natural hazards as part of the criteria for the approval of loans or grants for hospital construction or retrofitting;

5.3 Strengthen their technical cooperation on the subject, promoting the development and dissemination of methodologies that will be utilized and the standards that will be applied when carrying out risk analyses with respect to natural hazards in both the health sector and the planning of economic development;

5.4 Support and promote the linkage between loans and grants aimed at improving structural and nonstructural safety, and the organized response of priority health care facilities.

Technical recommendations for seismic disaster mitigation in health facilities

During the Technical Commission for Seismic Mitigation convened at the International Conference for Disaster Mitigation in Health Facilities, health professionals, engineers and architects analyzed design, construction and operational aspects of new health facilities and retrofitting existing ones in terms of effective disaster mitigation measures. The recommendations made by participants aim at the formulation of hospital
mitigation plans, understanding hospital mitigation as those measures taken before a disaster occurs to reduce to a minimum human and material losses, reducing physical, organizational and functional vulnerability, to ensure that the hospital continues to function during and after a disaster.

The group recommends:

I. That it is necessary to mitigate the impact of earthquakes in health facilities through an effective reduction of structural, non-structural and functional vulnerability. These elements are described as follows:

**Structural elements:** Include all those elements that support the structure of a building (beams, columns, foundations, supporting walls, etc.).

**Non-structural elements:** Include all those elements that do not support the structure of a building and its contents, including: architectural components, electrical and water connections, mechanical equipment, ceilings, windows, laboratory and medical equipments and supplies.

**Functional and organizational aspects:** such as design of physical space (site-selection, better distribution of external and internal space, etc.), and organization (emergency plans, drills, multidisciplinary teams, etc.).

II. That mitigation concepts should be present from the moment of formulation of the project, both for new buildings and modifications of existing ones.

III. That vulnerability of a hospital should be considered from a global and multi-disciplinary perspective, focusing on design, construction and operation of the hospital.

IV. That even though the decision for implementation of disaster mitigation measures is mainly political, the technicians must provide for the decision makers, an estimation of the level of vulnerability in relation to intervention costs.

V. That countries should promote specific recommendations for the construction of safe health facilities, since current regulations do not include provisions to guarantee the functionality of the hospital after an earthquake.

That accreditation of hospitals should include vulnerability evaluation.

VII. That countries should request PAHO to continue its program on disaster mitigation in health facilities in the areas of promotion, training and regular evaluation of achievements. There is an urgent need for the experiences in several countries with mitigation projects to be compiled and disseminated in the Region.

VIII. That disaster mitigation and vulnerability reduction for health facilities should be promoted in universities and professional associations.

IX. That the design of health facilities should include seismic risk analysis, soil and site conditions and estimates of expected losses. Experience has shown that the inclusion of these factors do not increase project costs more than 5%.

X. That cost should not be the main factor when deciding upon design of new projects or reinforcement of existing facilities. The terms of reference should include technical and safety criteria.

XI. That the need for retrofitting of existing hospitals should be based on a cost/benefit analysis in relation to acceptable level of risk.

XII. That priority criteria in selecting hospitals for vulnerability reduction should include: risk level, hospital complexity and population served. The use of hospitals classified as "high risk" should be limited as long as mitigation measures are not implemented in order to protect the lives of their occupants.

XIII. That countries should try to obtain credit and grants from financial institutions, to be used in prevention and mitigation activities for health facilities.

XIV. That governments and institutions should provide funds for maintaining health facilities to avoid deterioration and consequent increase of vulnerability.
XV. That financial institutions should require countries to include minimum disaster mitigation criteria in the preparation of investment projects for health infrastructure.

Mexico City, February 27, 1996.

Recommendations resulting from technical committee meeting 2 (hurricanes)

Recommendations resulting from technical committee meeting morning session 2 (hurricanes)

27 FEB. 96

CHAIRMAN: PETER FORDE (TRINIDAD AND TOBAGO)

INTRODUCTION: A. ADAMS (JAMAICA)

RAPPORTEUR: R. HEIL (ST. MAARTEN)

The Commission has produced the following recommendations.

1. Governments should mandate the use of appropriate building codes and include special provisions for hospitals.

   An importance factor of 1.5 on design forces is to be used in the construction of health facilities in hurricane zones, as well as special inspection procedures, including strict quality control, from the design stage to completion of construction.

2. Non structural elements of the building envelope e.g., windows and cladding, are to be designed to similar levels of safety, as those applied to structural elements. In addition, all glass used should be laminated or storm shutters should be provided.

3. Each country is to form a national technical advisory group or commission to develop and advise on mitigation measures for health facilities. This group should include but is not limited to:

   a) Technical personnel involved in health care as well as maintenance departments of the Ministry of Health;

   b) Government technical and project management agencies responsible for hospitals;

   c) Representatives of professional institutions of engineers and architects.

4. The additional costs of design for increased wind–forces and new standards for non structural elements should be absorbed in project costs.

5. Where appropriate, wind and/or hydro–meteorological studies are to be conducted to support design of health facilities.

   NOTE: TECHNICAL CONSIDERATIONS ARE CONSIDERED TO BE COVERED BY CONSTRUCTION CODES TO BE SELECTED.

Recommendations resulting from technical committee meeting afternoon session 2 (hurricanes)

CHAIRMAN: AUGUSTIN COMPTON (ST. LUCIA)

INTRODUCTION: ING. TONY GIBBS (BARBADOS)

RAPPORTEUR: R. HEIL (ST. MAARTEN)

1. The commission takes the same position as voiced in point 3 of the morning's proceedings with the following additions:
a) The group or committee as meant under point 3. of this morning’s proceedings will focus on health;

b) It is to be expected that the health sector would act as a catalyst for other sectors.

2. The considerations to be taken into account in determining the order of priority of hospitals for retrofitting against hurricanes are:

- location of the hospital;
- level of hurricane hazard and history of occurrence;
- area of influence of the hospital, based on the population it serves;
- level of care it provides (local, regional, national/teaching);
- age of the hospital;
- type of construction in consideration, whether it meets hurricane hazard standards;
- degree of vulnerability;
- cost factor;
- organization for disasters (plan available?);
- training of personnel;

3. For the preparation of projects to retrofit priority hospitals subject to potential damage by hurricanes, the following requirements should be met:

- technical assistance should be obtained from specialized agencies;
- standardization of procedure manuals should be achieved to negotiate international loans;
- priority should be granted to hospital for retrofitting by financing agencies;
- national funds are to be allocated as counterpart for this purpose.

4. The formulation and drafting of invitations to tender for the design and execution of projects must clearly stipulate the need for specific expertise in the design for hurricanes and other natural hazards;

5. As the construction of a new hospital or major retrofitting are rare occurrences in any given island, it is extremely important to clearly define the organizational structure for decision-making. In the pre-construction programme, there should be two clearly defined intervals for client review, discussion and decision-making following any necessary amendments. These intervals would follow the consultant's inception report and the preliminary design submission;

6. PAHO should develop a rating and accreditation system for preparedness for hurricanes and other natural hazards, or should encourage the Health Ministries to jointly develop such a common rating. Such a system would provide goals, posts and incentives to individual hospitals to aim at, so as to further accelerate the mitigation activities.

**International conference on disaster mitigation in health facilities: Agenda**

**Site of the Conference:** Unidad de Congresos Centro Medico Nacional Siglo XXI  
**Address:** Av. Cuauhtémoc No. 330  
Col. Doctores, 06720 Mexico, D.F.  
**Telephone:** (525) 761 2725

**Sunday, 25 February**

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<tr>
<th>Time</th>
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<tbody>
<tr>
<td>14:00–20:00</td>
<td>Arrival of Participants Registration of Delegates and Observers</td>
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<td></td>
<td>Hotel Calinda–Geneve</td>
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<td></td>
<td>Calle Londres 130</td>
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<td>Col. Juárez 06600</td>
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**Monday, 26 February**

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<tr>
<td>08:00–12:00</td>
<td>Registration of Delegates and Observers (continued)</td>
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<td>Time</td>
<td>Session</td>
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<tr>
<td>09:00−10:00</td>
<td>Plenary Session</td>
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<td>Opening Ceremony (Separate Agenda)</td>
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<td>10:00−10:30</td>
<td>Break</td>
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<tr>
<td>10:30−10:40</td>
<td>Objectives of the Conference and Work Methodology (PAHO/WHO)</td>
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<td>Election of Presidents and Rapporteurs</td>
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<td>Drafting Committee</td>
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**First issue: Impact**

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<tr>
<td>10:40−11:00</td>
<td>&quot;Mitigation in the Countries of the Americas&quot;</td>
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<tr>
<td></td>
<td>Dr. Eduardo Peña Triviño, Vice−President of the Republic of Ecuador</td>
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<tr>
<td>11:00−11:20</td>
<td>&quot;Economic Impact of Disasters on the Hospitals of Latin America and the Caribbean&quot;</td>
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<td></td>
<td>Lic. Daniel Bitran ECLAC</td>
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<tr>
<td>11:20−11:40</td>
<td>Videotape</td>
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<td>11:40−12:00</td>
<td>&quot;Case study on the impact of the 1985 Mexican earthquake&quot;</td>
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<td>Drs. Felipe Cruz Vega and Carlos Rojas Enríquez</td>
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<tr>
<td>12:00−12:25</td>
<td>&quot;Case study on the impact of Hurricane Luis on the Lesser Antilles&quot;</td>
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<td>Eng. Tony Gibbs</td>
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<tr>
<td>12:25−13:00</td>
<td>Observations, questions and responses</td>
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<td>13:00−14:30</td>
<td>Lunch</td>
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**Second issue: Mitigation policies and strategies**

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<th>Time</th>
<th>Panel: &quot;Policies and Strategies&quot;</th>
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<tr>
<td>14:30−15:00</td>
<td>Moderator: Eng. Julio Kuroiwa</td>
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<tr>
<td></td>
<td>Eng. Vanessa Rosales, Structural aspects</td>
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<td>Eng. Ruben Boroschek, Non−structural aspects</td>
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<td>Dr. Raúl Morales, Organizational aspects</td>
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<tr>
<td>15:00−15:30</td>
<td>Panel: &quot;Vulnerability assessment in hospitals at risk to earthquakes.&quot;</td>
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<td>ECHO−PAHO/WHO Project</td>
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<td>Moderator: Ms. Belén Martínez Carbonell, ECHO</td>
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<td>Eng. Julieta Giraldo, Colombia</td>
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<td>Eng. Ruben Boroschek, Chile</td>
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<td>Eng. Jaime Argudo, Ecuador</td>
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<td>Eng. Jose Grases, Venezuela</td>
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<td>15:30−15:50</td>
<td>Case study: &quot;Reconstruction and Mitigation Programs in Jamaica post Hurricane Gilbert&quot;</td>
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<td>Eng. Alfrico Adams</td>
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<td>15:50−16:15</td>
<td>Break</td>
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**Third issue: Policies and financing**

<table>
<thead>
<tr>
<th>Time</th>
<th>&quot;Role of International Development Financing Agencies&quot;</th>
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<tr>
<td>16:15−17:00</td>
<td>Moderator: Dr. Daniel López Acuña</td>
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<td>Mr. Steve Bender, OAS</td>
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<td>Mr. John Bowlin, World Bank</td>
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<td>Mr. Ricardo Bermúdez, USAID/OFDA</td>
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<td>Mr. Luis Busco, Chile</td>
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<td>17:00−17:30</td>
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Case study: “Legislation on Disaster Mitigation and Construction Codes in Colombia”
Eng. Omar Darío Cardona

Case study: “Construction codes in the Caribbean (CUBiC)”
Mr. Jeremy Collymore, CDERA.

17:30–17:50 Case study: “Disaster Mitigation in Existing and New Hospitals in Costa Rica”
Eng. Miguel Cruz

17:50–18:15 Conclusions of the day, organization of the Technical Commissions and work methodology for the second day.

**Tuesday, 27 February**

09:00–13:00 Three parallel activities beginning at 9:00 a.m., as follows:

09:00–10:00 1. PLENARY:
National Program on Hospital Certification for Disaster Situations in Mexico

Dr. Hector Fernandez Varela
General Director of Standards, Supervision and Development of Health Services, Mexico

Mr. Efrén Franco Daze
General Director of Works, Conservation and Equipment of the Ministry of Health, Mexico

Reading of Agreement between Ministry of Health of Mexico and PAHO/WHO on Hospital Safety for Disaster Situations

Dr. Federico Ortiz Quezada
Director General of International Affairs of the Ministry of Health of Mexico

Signing of Agreement

Dr. Juan Ramón de la Puente
Minister of Health, Mexico

Dr. George A.O. Alleyne
Director, Pan American Health Organization, Regional Office of the World Health Organization

10:00–13:00 Country and Organization reports

09:00–13:00 2. TECHNICAL COMMISSIONS

Commission 1.
Design and construction of new facilities at risk to earthquakes.
Retrofitting of existing facilities at risk to earthquakes.

Commission 2.
Design and construction of new facilities at risk to hurricanes.
Retrofitting of existing facilities at risk to hurricanes.

10:30–13:00 3. DRAFTING COMMITTEE.

13:00–14:30 Lunch

14:30–18:00 Continuation of meetings

**Wednesday, 28 February**

09:00–12:00 Visit to National Disaster Prevention Center—CENAPRED (separate agenda)

12:00–14:00 Lunch

14:00–15:30 Plenary Session
Technical Commission Reports Discussion

15:30–18:00 Break – Optional Video session

18:00 Closing Ceremony (separate agenda)

**Thursday, 29 February**
General policies on consideration of natural disasters in proposals for investment in health infrastructure

by VANESSA ROSALES ARDON,
Advisor in Hospital Disaster Mitigation
PAHO/PED

Introduction

Statistics from recent years demonstrate that whenever a natural disaster of considerable magnitude has occurred in the Americas and the Caribbean, the health infrastructure has been significantly affected. The social and economic consequences of these damages have been amply discussed in other documents (Reference No. 1). Nevertheless, and despite the good intentions of some sectors, little or nothing is being done to learn from these experiences and take concrete action to mitigate the effects of disasters on the health infrastructure. A specific example of the fact that knowledge of natural hazards and good intentions are not enough was brought to light during the recent hurricane season in the Caribbean, when hospitals and other facilities that had already been severely damaged in the past by other, similar phenomena were destroyed or damaged even further.

Among the many reasons why disaster mitigation is still not a priority for the health sector—other than budget constraints, which are commonly evoked as an excuse—mention must be made of the lack of a standard or common language for defining what a vulnerability study should entail. Vulnerability analysis can range from a page–long study by a geologist to a 10–volume compendium prepared by a multidisciplinary team that includes geologists, engineers, planners, architects, and the like. The lack of laws or regulations requiring these kinds of study, in contrast to other countries where environmental impact assessments are carried out, contributes to the prevailing confusion. Obviously, too, the cost of such vulnerability studies varies considerably.

A proposal for investment in health infrastructure may have two objectives: the improvement or expansion of existing facilities, or the construction of a new service. The reality is that the construction of new hospitals, at least in Latin America, is not very frequent, since it commonly implies the negotiation of large–scale loans. The current trend is either toward the construction of less complex health services complexity for local levels or toward the equipping, modernization, and expansion of already–existing complex hospitals. In both cases, the ideal would be to consider the natural hazards inherent in the surroundings and potential supply restrictions in terms of water, electricity, and access, although different approaches are required in each instance. For example, if the study of that natural hazards at a specific site selected for a new hospital indicates that it is a highly dangerous area for which the prevailing design and construction standards cannot guarantee acceptable safety or operational levels in the event of natural disaster, the project may be ruled out or a more suitable site found. However, if a hospital already exists, it is considered to be immovable, and any investment made should guarantee a minimum level of safety and operations.

In any case, it must be remembered that, in either case, the national budget is seriously committed in terms of foreign debt, and therefore, such investments must be protected. Consequently, it also becomes necessary to provide the decision–making levels in the health sector with tools or terms of reference that enable them to include natural hazards and the limitations of the surroundings as important factors in considering the feasibility of investment proposals for health infrastructure and to use a standardized format that specifies the kind of information required, the criteria for analysis, the conclusions that can be reached, and the profiles required of the professionals or firm undertaking the study.

These terms of reference may also be used by international financing entities, donors, and cooperation agencies to oblige the countries to carry out risk and vulnerability studies prior to the granting of a loan for health infrastructure. In this manner they would be insuring their investment and protecting the countries from incurring greater future indebtedness out of the need to recover health services affected by a disaster.
Some of the international financing organizations are currently making significant progress in the negotiation of loans by including references in their procedures manuals to natural disasters as determinants in decision-making with regard to the feasibility of a particular project. However, the lack of a general format for requesting this information from the country soliciting the loan greatly limits its applicability, since no obligations are imposed in this respect.

The purpose of the present document, therefore, is to make a preliminary proposal on how to include natural hazards as an important factor in the feasibility of proposals for investment in health infrastructure—one that will be useful to both the grantors and the recipients of loans. The area of application is restricted to the health sector due to the degree of complexity and the social importance of the facility in question. It is assumed from the outset that most of the countries in the Region already possess or are in the process of preparing building codes that classify different buildings according to their strategic importance and consequently assign them certain minimum safety standards.

Natural hazards in project formulation

A number of documents exist that present various methodologies for the inclusion of natural hazards in the formulation of development projects (Reference No. 2)—all very valuable and applicable, with certain adjustments, to specific health sector projects and initiatives.

Generally speaking, previously compiled information must be available on the characteristics of present-day natural hazards, both within the country and specifically in the area in which there are plans to locate an infrastructure project or improve an existing facility. In most cases the scientific community possesses statistics on the incidence of disasters and their magnitude, areas of occurrence, and probable periods of recurrence. Ideally, this information is available in the form of maps, zoning plans, and even microzoning plans in the case of seismic phenomenon, which also include geological and soil dynamics information for the region or the periodicity of hurricane recurrence classified by wind velocity. Based on this knowledge, probable losses are estimated for future events. In the case of a project for new infrastructure, this is precise when it should be ascertained whether the site selected for the location of the project is the most appropriate one, or whether it would be more desirable to consider another site with a lower risk level. One determinant in making these decisions is the availability and desirability of what may be termed vital lines: access routes, drinking water and electricity supply, and communications.

Assuming that the area selected is an appropriate one for new infrastructure projects and that the degree of risk inherent in the surroundings is known with regard to existing infrastructure, the next step consists of determining the degree of compliance by the proposed design or facility with local safety standards (such as building codes and regulations). This point is critical, since a level of acceptable risk should be defined, which even involves difficulties of an ethical order. To what extent may losses be accepted? Is the aim solely to ensure the saving of lives or operation of the service in the wake of a disaster? Is it sufficient for a building to remain standing, although equipment and valuable installations are damaged? Is it sufficient for a building to remain standing only as long as it takes to evacuate its occupants? Will financial resources be available to recover losses? Are there other hospitals or health centers nearby to which both the patients and the victims of the disaster can be transferred?

From this point on, two very different paths may be taken. In the case of a project for new infrastructure (Diagram No. 1), the proposed design should be modified in keeping with these considerations and the level of acceptable risk. The project budget should be adjusted if the changes in the design are substantial. Some figures used by Federal Emergency Management Administration (FEMA) of the United States and a number of investigators ensure that the increased cost of a project that includes disaster mitigation measures does not exceed more than 3% to 5% of the total cost. However, no studies exist in this regard in the Latin American context. Logic leads to the assumption that it should not be much more expensive to erect a safe and well-constructed building than a poorly designed one, even for the short term, without giving thought to the possibility of future damages caused by disasters.

Together with the proposal for a new infrastructure project, a mechanism should be planned to ensure that the safety conditions of the building will be maintained with the passage of time. The only measure that has shown to be effective is a preventive maintenance program, whose budget is included in the hospital's regular operating funds and entrusted to the care of professionals trained in this field. There are many cases of well-located and well-constructed hospitals that nevertheless become highly vulnerable because of their deterioration over time and the lack of maintenance. This vulnerability, however, usually refers to
nonstructural aspects. Consequently, in formulating a new infrastructure project, the design of a maintenance program and its associated costs should be included. There are many examples of very modern hospitals with functional designs that have been built with loans from international financing agencies and that nevertheless have never been placed in operation because the country lacks the resources to equip and maintain them. The problem in this case is visibility: Obviously, an agency or a politician attracts greater attention from the communications media and the public by inaugurating a brand-new hospital, even though it may be empty inside, than by allocating resources for improvement of the existing hospital infrastructure.

Completion of a new hospital project from the standpoint of its construction and equipment is still not the end of the road, since its organizational and operational aspects are equally important, and are usually never considered when the project is being formulated. The specification of evacuation routes, signs and floor maps, and other elements that are part of the facility's emergency plan should be taken into account from the design stage.

In the case of existing hospitals (Diagram No. 2), after acceptable risk has been defined, the next step is selection of the most appropriate methodology for carrying out the vulnerability study. A technical discussion of the various methodologies is beyond the scope of the present document; good explanations can be found in other texts (Reference No. 3). The selection of the methodology, however, depends on the outcome expected to be obtained. Will the evaluation made be used solely to detect operating deficiencies or problems that can be easily corrected? Is the condition of the structure assumed to be adequate in terms of the previously defined level of acceptable risk? Are there serious doubts about the safety of the structure, or have they been confirmed by damage caused by previous events? Are funds available to completely remodel the building, or is it desired only to ascertain if an area is safe, in order, for example, to install new and costly equipment? If the purpose of the project is to enlarge the existing area, what will interaction will take place between the new structure and the old if a disaster occurs?

**DIAGRAM No. 1 SEQUENCE FOR VULNERABILITY ANALYSIS FOR NEW FACILITIES**

Completion of a new hospital project from the standpoint of its construction and equipment is still not the end of the road, since its organizational and operational aspects are equally important, and are usually never considered when the project is being formulated. The specification of evacuation routes, signs and floor maps, and other elements that are part of the facility's emergency plan should be taken into account from the design stage.

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Based on the responses to these and other similar questions, an appropriate methodology is selected. The methods for qualitative evaluation (for which there are many references, including many in the form of questionnaires adapted to the contexts of the countries in question, as, for example, Chile), have the advantage that the hospital employees themselves are able to perform them without professional assistance from a specialist. The disadvantage is that such diagnostics cannot be conclusive, since they contribute information only for the establishment of low-cost practical recommendations, capable of being executed only in the short term (to improve the anchoring of heavy equipment, for example). Carrying out these evaluations costs little, and in the formulation phase, these methods will be prove useful depending on the objectives of the project.

Quantitative methods of vulnerability analysis are expensive, and their application constitutes a project in itself, since specialized professional assistance is indispensable. The results derived from these kinds of study may lead to a proposal for the reinforcement or adaptation of the structure. Their use is justified, for example, if the intended investment is very large or if the fundamental purpose of the project is precisely to improve the response of the structure to natural disasters.

If the quantitative diagnosis points to the need for readjusting the structure, formulation of this new project becomes a delicate and complex process, in addition to being expensive, since the intervention should be planned in stages in order to interfere minimally with the normal operation of the hospital. The organizational aspects mentioned above with regard to a project for a new hospital (safety indications, etc.) should also be
included. Nevertheless, an additional problem exists that is often ignored, probably because of its complexity and because the solutions are not within the reach of those who formulate the project: the availability and desirability of vital lines. In the case of a new hospital, if the drinking water supply is insufficient or if it cannot be guaranteed that access routes will remain open after a disaster, there is still the possibility of selecting a more appropriate site for the construction of the new hospital. If the country negotiates a loan in order to equip with advanced technologies a hospital that is demolished every 2 years by a hurricane, for example, or whose only route of access includes an old bridge that will not withstand another earthquake, it is worth asking whether a responsible attitude would not instead be to prioritize activities or see to it that the country does not go into debt to purchase something it will inevitably lose or that will not be accessible when most needed.

The sequence of a vulnerability study for both types of investments in health infrastructure with the most adequate executing units for the required outcome is more easily visualized in the annexed diagrams (Diagrams No. 3 and 4).

**DIAGRAM No. 3**
**EXECUTION UNITS OF A VULNERABILITY ANALYSIS PROJECT**

<table>
<thead>
<tr>
<th>STRUCTURE UNIT NO. 1</th>
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<tbody>
<tr>
<td>Structural engineer</td>
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<tr>
<td>Maintenance engineer</td>
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<tr>
<td>1 +</td>
</tr>
<tr>
<td>Specialized engineer/with experience in vulnerability analysis</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>HAZARD UNIT NO. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geologist/geotechnician (earthquake)</td>
</tr>
<tr>
<td>Expert in hydrometeorology (hurricanes)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>HAZARD UNIT NO. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architect</td>
</tr>
<tr>
<td>Electrical engineer</td>
</tr>
<tr>
<td>Mechanical engineer</td>
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</tbody>
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<table>
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<tr>
<th>OPERATION UNIT NO. 4</th>
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<tbody>
<tr>
<td>Hospital Director</td>
</tr>
<tr>
<td>Emergency Chief</td>
</tr>
<tr>
<td>Security expert</td>
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<tr>
<th>URBAN SETTING UNIT NO. 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geologist/geotechnician (earthquake)</td>
</tr>
<tr>
<td>Hydrometeorology expert (hurricanes)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DECISION UNIT NO. 5</th>
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</thead>
<tbody>
<tr>
<td>High political, sectoral and governmental level</td>
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At the present time, in which the countries' priorities are geared to sectoral reform—and the health sector is not immune to these interests—all matters concerning infrastructure have been relegated to large-scale neglect. This will probably lead undermine the achievements of previous years, exemplified by evolution from an emergency-oriented approach to natural disaster management toward an emphasis on disaster prevention and mitigation. If the countries are not able to understand what they are losing, it is up to those who provide the funds for implementing projects to guide them toward topics of vital importance, for neglecting them will have a negative impact on the economy. No matter how advanced sectoral reform may be, a hospital that collapses and takes the lives of patients and physicians should continue to be the nightmare of health sector planners until a remedy is found.

**DIAGRAM No. 4**
**EXECUTION UNITS OF A VULNERABILITY ANALYSIS PROJECT**

<table>
<thead>
<tr>
<th>LEVEL OF EVALUATION</th>
<th>AVAILABLE INFORMATION</th>
<th>METHODOLOGY</th>
<th>EXECUTING UNITS</th>
<th>RESULTS</th>
<th>APPLICATION</th>
</tr>
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### Preliminary Architectural Plans
- Basic: year, construction, reforms, geometric characteristics
- Visual Questionnaire
- Not conclusive General overview
- Correcting deficiencies in function

### Quantitative Phase I
- Structural plans of facilities
- Soil studies
- Street maps, urban networks
- Microzonification/hydrometeorological maps
- Local safety requirements (codes and Tests of resistance of materials
- Collection/verification of information
- Structure model
- Selection of maximum probable event
- Analysis of surrounding conditions
- Analysis of ductility y redundancy
- Acceptable risk
- Evaluation of structural vulnerability
- Analysis of faults or deficiencies in the surroundings

### Quantitative Phase II
- Catastrophic physical–functional
- Results Phase
- Proposal of structural retrofitting
- Non-structural

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<th>Improvements</th>
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### Definition of the executing units

The very fact of formulating the contents of a risk study for a new hospital project or of a vulnerability study for an existing hospital resolves many doubts about who or what entity is able to carry out such studies. It is not necessary to regard compliance with a requirement in this area as yet another administrative obstacle in the management of a project that must therefore be complied with however possible simply to get over the hurdle, so to speak. Rather, the ideal solution is to promote awareness of this matter in which lives are at stake, in addition to the likelihood of large economic losses for those who provide the financing for the project as well as those who receive the funds.

The optimal solution would be for the financing agency to have a professional team experienced in natural disasters that adheres to clearly established procedures in keeping with the complexity and size of the project. The recipient country should be able to provide all the scientific and technical information described above and assign at least one professional expert in the subject area as part of the project’s executing unit. If the formulation of the project is the exclusive responsibility of the health sector, that is all the more reason for ensuring inclusion of the topic of natural disasters.

If the financing and donor agencies succeed in making the suggestions above compulsory, significant progress will have been made. However, the commitment should come from the countries themselves for their own benefit.

The main problem does not lie at this level. Many examples can be cited of individual institutions that, concerned about risk, wish to carry out studies of this nature for their hospitals, even though they are not planning to negotiate international loans; furthermore, precise terms of reference for this purpose do not exist at the country level. In initiating competition or bidding to contract the studies, those in charge of making the selections find that the bidders range from businesses with competent multidisciplinary professional teams that charge astronomical fees for their services to individuals who promise to complete the study within two weeks’ time at a ridiculously low cost. If the selection criterion is only the price, very little can be expected of the least expensive offer as far as technical results and applicability are concerned. Nevertheless, care should be taken to avoid the other extreme of being guided solely by complexity or sophisticated terminology in the belief that this will ensure a valid study. As previously stated, the depth of the study will depend on the objectives pursued, and common sense, combined with an internal procedures manual, should be sufficient to ensure the most appropriate choice among the bids tendered. Careful consideration of the qualifications of the
businesses participating in the bidding, or at least a data bank of experts in the field of disaster mitigation, can simplify the selection process.

If a procedures manual is authorized that clearly maps out the basic guidelines for a study of natural hazards or a diagnosis of vulnerability (a document that will be useful only for the health sector), it will be possible to attract greater attention to the subject of natural disasters and their consequences. However, supporting regulations should also exist, such as a compulsory building code, since otherwise the minimum level of safety or acceptable risk cannot be quantified. It is a matter of concern that some countries with recognized susceptibility to frequent disasters, such as earthquakes and hurricanes, lack standards adapted to their own contexts. In many cases, these standards or codes exist, but they are not mandatory or the mechanisms to ensure their observance were not created at the same time.

This leads to another concern that particularly involves hospitals and other essential buildings. Many codes classify these structures as vital and are consequently stricter regarding certain safety factors; nevertheless, they are grounded in the premise that the only thing that should be guaranteed when a catastrophic event occurs is that structural collapse should not take place, failing to take into account that functional collapse can be also serious when it concerns a hospital.

Nevertheless, if the subject of natural disasters is accorded the importance it deserves—albeit unilaterally by the health sector with respect to its facilities through the routine inclusion of the natural hazard variable as a normal component of the management of projects related to infrastructure—officialization of a procedures manual with specific terms of reference for the study of the risks associated with disasters, combined with careful selection of trained and expert consultants in the field, will produce a reaction in other sectors in the medium term. If this is further combined with the obligation of the financing and donor agencies to satisfy these requirements, the visibility the environmental sectors have already achieved in their area of concern will be realized within a short period of time. There is no unique and infallible prescription nor any universal methodology for attaining this objective. Rather, as in the matter of the building codes, each country should individualize the general guidelines prescribed and adapt them to its own context, in keeping with the magnitude and complexity of its own projects.

Experience has shown time and again what happens over and over when the lessons of nature go unheeded.

References

1. PAHO/IDNDR: A World Safe from Natural Disaster, 1994

2. OAS: Manual sobre el manejo de peligros naturales en la planificación para el desarrollo regional integrado, 1993.


Role of international development financing agencies

Prepared by:
Stephen O. Bender
Department of Regional Development and Environment Organization of American States

1 The opinions expressed are those of the author, and do not necessarily express those of the General Secretariat of the Organization of American States, nor its Member States.

INTERNATIONAL CONFERENCE ON DISASTER MITIGATION IN HEALTH FACILITIES
Mexico, 26–28 February 1996

The views expressed, the recommendations formulated; and the designations employed in this document do not necessarily reflect the current policies or opinions of the IDNDR Secretariat, the Pan American Health Organization, or of its Member States.
I. Introduction

International development financing institutions, or lending institutions as the banks prefer to be called, respond to requests from eligible developing countries for loans to finance needed social infrastructure. These institutions develop internal policies for priorities and conditions under which they will concede loans. Their objective is to assist the borrower, whether the central government, one of its dependent institutions, or a designated quasi-public or private entity, in producing and executing an acceptable loan project. Lending institutions expect a return on the loan they make.

Their specific policies may direct lending to certain sectors, population groups, or geographical areas, and on occasion these policies may have as an objective a change (albeit imposed) in the products or services to be provided by the loan. The majority of conditions negotiated during the project cycle, however, are financial or administrative (OAS, 1988).

Mitigation of natural hazard risks is rarely a specific objective of the loan as seen by the lender or the borrower. It is presumed that the financing provided will be used wisely to produce a performing loan. The institutional structure of lending institutions does not promote sensitivity to risk considerations at the earliest stage of project review (OAS, 1988). The lender usually assumes a risk-neutral stance whereby the borrower will sufficiently guarantee the loan so that whatever damage may occur to facilities built with the loan proceeds, the lender will nonetheless recover its money (OAS, 1988).

The technical and administrative uncertainties of implementing development programs tax the lending institutions sufficiently to make them cautious about complex project analysis procedures or programs that are administratively demanding. Asking an institution to consider additional policy objectives that require careful analysis and that are difficult to administer is likely to meet resistance from the project staff. The traditional caveats that donors cannot override the sovereignty of borrowing governments, that they cannot fund activities that governments do not request, and that they cannot control the implementation process are normally valid as well (OAS, 1988).

In the case of the health sector, loans are used to build needed facilities which meet sector goals. In most instances it is assumed that the facilities built will serve throughout the life of the loan and beyond. There is rarely an explicit loan objective of addressing vulnerability to natural hazards such as earthquakes, floods, volcanic eruptions, tsunami and landslides. Nor is there usually explicit mention of protecting the life of the patient from natural disasters while in the medical facility, nor of protecting the lives of the staff or visitors, nor of protecting the equipment and services offered by the facility during and after a disaster.

It is also assumed that construction of new facilities or the addition to or modification of existing facilities will withstand perceivable natural events. Even though benefit-cost studies may be prepared as part of the loan preparation process, possible loss of structures to natural events and the benefits of natural hazard vulnerability reduction measures to achieve specific levels of risk are rarely identified. No distinction is usually made between an investment sufficient to avoid structural collapse and one sufficient to avoid functional collapse.

Damage to health facilities, from large national hospital centers to neighborhood clinics, following natural events are all too common. In the last 20 years, more than 100 hospital facilities in the Americas, serving up to 12 million people, have been affected by earthquakes. Replacement costs, at current costs, are more than US $700 million (PAHO, 1993, Vol. I). What, then, is the role of lending institutions in mitigating the losses due to natural events?
II. Rationale for mitigation as part of health sector infrastructure financing

A. The need for decreasing the availability of infrastructure

The availability of health facilities in developing countries usually falls far short of the need. Following more than a decade of under-capitalization of the sector, attention is now being turned to investment, together with a change in the number, location and scope of service delivery of health facilities. In some instances, post−disaster reconstruction has prompted radical changes in the structure and function of health facilities, as is the case following the 1985 Mexico City earthquake. But often, site selection, design and construction of health facilities are subject to political pressures, and decision−making processes and project development responsibility are outside the direct control of the health sector.

B. The intersecting need of reducing existing vulnerability and new investments in the sector

Not withstanding the need for new facilities, the vast majority of health infrastructure that will carry the sector into the next century already exists. Much of the existing stock is vulnerable to natural events because of the lack of knowledge of natural hazards when the facilities were built, inadequate design and/or construction practices, or subsequent modifications to the structures and/or their uses. Few countries have identified the specific risk levels of existing facilities. And when known, budget constraints usually dictate that available funds be used for new facilities, and not for retrofitting existing ones. Available capital is often used to upgrade the technology for health care delivery housed inside existing facilities. And, in the case of hospitals, the cost of architectural and engineering design, mechanical and electrical systems, and equipment represent up to 90% of the facility's total value (PAHO, 1993, Vol. I).

C. Synergistic effects with health as an economic sector

Arguments for increased investment in the health sector are increasingly built around arguments as to the cost and benefits of reducing public and private expenditures for curative and chronic health care. Only recently has it been recognized that the loss of facilities to natural events such as minor earthquakes, which curtail delivery of services because of a functional collapse without prompting an international appeal for disaster assistance, is a significant portion of the economic losses slowing development (PAHO, 1993, Vol. I). And in only a few cases, usually based on isolated retrofit projects or post−disaster reconstruction, are benefit−cost studies undertaken to demonstrate the efficiency of building and maintaining a less vulnerable health infrastructure.

III. A comprehensive action plan

A. The loan project preparation process

Implicit in a lending institution's loan preparation process is the assumption that the resulting level of vulnerability to natural hazards is acceptable. This is reflected in (1) the lending institution's and the borrower's mutual agreement to the terms of the loan, and (2) the belief that the site selection, design, construction, maintenance and repair process will preclude anything other than acceptable levels of risk. In the vast majority of cases, it is the borrower, and the mechanisms it employs during that process, that bears the burden of defining which natural hazards (location, severity and frequency) are to be considered and the corresponding loss reduction measures to be employed.

Lending institutions do not fix acceptable risk levels for natural hazard vulnerability levels, but rather depend on the borrower to carry out best design and construction practices. These practices are defined by locally mandated codes and standards interpreted by national criteria, sometimes using national and international consulting assistance. There are few, if any incentives for the lender to undertake its own vulnerability assessment during the loan preparation process (OAS, 1988).
Natural hazard vulnerability may be treated at the policy level by a lender (see Inter-American Development Bank/GP–92–10 in Appendix A). Direct intervention by the lender in natural hazard vulnerability reduction issues, however, is often dependent on an initiative by an individual in the lending institution with the knowledge and experience to coordinate a review of applicable local standards. In some instances, specific mention of natural hazard vulnerability reduction is triggered by post–disaster reconstruction lending policy and a request by the affected country for reconstruction assistance (see The World Bank/Operational Directive 8.50: Emergency Recovery Assistance in Appendix B).

B. The loan project preparation product

The final product of the loan preparation process for a health facility includes, among other items, the plans and specifications for the facility and the process by which the facility will be developed, along with the loan dispersal requirements. Usually, this part of the loan documentation does not address natural hazard vulnerability issues. There is little reason, therefore, to assume that vulnerability reduction to natural hazards will be manifest in anything other than the use of best practices and procedures. This means it is the burden of the borrower to meet existing national requirements as determined by experience and the state of the art at hand.

C. Loan project preparation related to broader lending practices

Loan projects for health sector facilities are developed in the context of the broader objectives of the borrower and the general lending criteria of the lender. The lender may impose credit limitations, thereby forcing the borrower to maximize the amount of infrastructure to be built from the loan proceeds, as well as to promote the greatest use possible of available local expertise and experience.

The lender may meet broader lending criteria by requiring that the borrower secure insurance for the facility. Ability to secure coverage in the private insurance market may reflect acceptable natural hazard vulnerability reduction levels. Such has been the practice of the Caribbean Development Bank. Following recent major hurricanes in the region, however, insurance became unavailable for many borrowers, and mandatory insurance clauses in loan documents were waived. Often times, public buildings may not be insured at all, or insurance may not be available at a cost deemed affordable by the borrower (the central government) or the operator of the facility (the ministry of health). In other instances, insurance requirements may be waived, postponed, or foregone if the borrower demonstrates that a good faith effort was made to obtain coverage.

Lenders now insist on an environmental impact review of loan projects, and natural hazard vulnerability may be generally considered as a part of the mandated environmental impact assessments or statements (see The World Bank/Environmental Assessment Sourcebook in Appendix C and the Caribbean Development Bank/Sector Policy Paper on Environment in Appendix D). Such statements may call for an identification of risk levels, accompanied by the identification of prevalent hazards. These requirements reflect the fact that natural events and the hazards they pose are part and parcel of environmental management, and the resulting risks are among the environmental issues most amenable to assessment and mitigation action (Bender, 1990).

IV. Policy and program issues

A. The position of the health sector

Evidence shows that natural hazard vulnerability reduction must be demand oriented. In the presence of the risk neutral stance of the lender, the borrower must be risk adverse (OAS, 1988). The health sector must insist that the process and the product leading to approval of the loan project include an acceptable level of risk.
B. Policy formulation

A policy must be in place that describes the acceptable level of risk of the facility for each applicable natural hazard vulnerability issue. This policy must be a visible part of health sector policy, accepted by lending institutions.

C. Project preparation intervention points

No matter what the loan preparation process used by the lender, there are critical intervention points for including natural hazard vulnerability reduction information and analysis. As appropriate in the project identification, pre-feasibility, feasibility, engineering design and approval phases of a project, the health sector must use appropriate natural hazard assessment information, define acceptable levels of risk and make manifest the corresponding mitigation actions (OAS, 1992).

D. Priority infrastructure vulnerability areas

Given the preponderance of existing health facilities compared with what is to be built, yet recognizing the need for new facilities, the health sector supported by lenders must determine which facilities, existing or new, are priority in terms of natural hazard vulnerability reduction. For existing facilities, this means preparing detailed vulnerability inventories by facility type, location, service function, and service life related to the type, location, severity and frequency of natural hazard events. For new structures, it means defining and selecting non-structural and structural mitigation strategies which maximize efficiency while meeting minimum risk levels. In each case, a determination of the functional, non-structural and structural alterations needed to meet acceptable risk levels must be made (PAHO, 1993, Vol. I).

V. What can lending institutions do?

A. Support to the health sector

Actions on the part of the health sector should be built around four areas which merit support from lending institutions.

First, lending institutions should actively support policy development by the health sector which defines the acceptable level of facility vulnerability to natural hazards with qualitative and quantitative measures and time tables for achieving those levels for both existing and new facilities.

Second, in assisting the health sector in developing its planning capability, lending institutions should create and/or identify key decision points in the planning process where natural hazard identification, vulnerability and risk assessments, and mitigation measure selection are to be included. The decisions made at these points should be reviewed in light of the health sector’s policy statements.

Third, lending institutions should actively support the preparation and implementation of mitigation projects including retrofitting of existing structures which help the health sector meet policy guidelines on acceptable risk levels.

And, fourth, for unresolved facility vulnerability issues, lending institutions should actively support health sector actions to prepare for emergency situations in which the sector itself is a disaster victim in need of assistance.

B. Greater technical involvement with the health sector

Greater technical involvement by international lending institutions with the health sector is needed. Three elements for the lending institutions to increase their involvement are as follows (OAS, 1988).
Lenders must change their perception of natural hazard assessment and mitigation. First and foremost, technical staffs of lending institutions must implement existing requirements for natural hazard and vulnerability assessments in response to stated lending institution policy and as part of environmental assessments. More effort must be made in information system development, increasing the quality of projects identified, and building the appropriate mitigation measures into pre-investment activities. The most cost-effective approaches for lending institutions to construct a new technical context and support for the sector are:

- Focusing on priority hazards such as earthquakes and hurricanes; and
- Choosing simple and practical information collection and systems analysis of health infrastructure.

The Pan American Health Organization (PAHO) has prepared an excellent set of guides for the health sector to mitigate disasters in its facilities. These should be used by lending institution and health sector planners alike (PAHO, 1993, Vols. I–IV). The loan project preparation process and products that are most likely to appeal to the lending institutions’ own internal need to bridge the gap between stated natural hazard components of policy, environmental assessment, vulnerability reduction, and the project preparation cycle are:

- Early identification and integration of natural hazard information and mitigation issues;
- Practical and cost-effective solutions to persistent problems; and
- Commitment to implementation by the lender and borrower project staff alike.

To achieve these effective approaches and outputs, the following cooperative mechanisms should be pursued.

- Pooling of technical resources;
- Exchange of experiences among regional and international organizations; and
- Support for government health sector planning development.

Overcoming the reluctance by lending institution staff to review or incorporate natural hazard vulnerability reduction into lending project preparation must include incentives for analysis. These should include:

1. Provision of reusable information such as guidelines to meet sector policy statements;

2. Integration of natural hazard vulnerability reduction concerns into existing mechanisms such as programming missions, project identification reports, reconnaissance surveys, environmental impact statement preparation, and project appraisals;

3. Promotion of proven mitigation measures in specific types of projects (best practices);

4. Incorporation of the costs and benefits of hazard mitigation into economic appraisals; and

5. Orientation of project staff members to issues related to hazard-prone regions and traditionally vulnerable building types.

Ultimately, the concern of lending institutions to natural hazard vulnerability issues is dependent on the degree to which natural events cause losses for projects in which the lending institution assisted in the identification, preparation, funding and/or implementation. Alternatives for assigning lending institution accountability include:

- Evaluation of losses from natural hazards in the context of the lender's program area and its project design and loan preparation performance;

- Study, discussion and publication of evaluations in instances where losses have been incurred for projects that failed to consider or evaluate natural hazard mitigation measures; and

- Promotion of professional standards on the part of the design and construction professionals responsible for preparing and implementing projects that include natural hazard vulnerability management issues.
VI. Conclusion

The financing of health facilities is a unique opportunity to address sector natural hazard vulnerability reduction issues. This is so because during the preparation of the loan project, the design and construction of the facility can and should be examined in the context of prevalent hazards and the means by which acceptable levels of risk can be reached. Constraints to fully taking advantage of this opportunity are many. Health facilities are proposed and developed as site-specific structures responding to social demands, economic constraints, and changing roles for the public and private sectors, capital markets, and sector-specific lending. Health facilities are rarely developed in a broad urban/physical planning context. They are to an even lesser degree developed in the context of structural security in the face of natural hazards.

Lending institutions are generally risk neutral, but increasingly sensitive to natural hazard vulnerability issues, at least at the policy and operational directive levels, including directives related to environmental assessments. Unfortunately, for facilities, such as those in the health sector, compliance with policy and operational directives depends on individual initiative of lending institution staff with little monitoring. But without a strong policy position on the part of the health sector, accompanied by specific requests for not only lending support but also technical assistance, training and technology transfer, it is doubtful that significant improvements in mitigation will be made. With such health sector actions as incentives, lending facilities will be in a position to follow through with mandated actions, or to create the environment for such actions where none are called for at present.

References


The response capability of hospitals in seismic disasters: nonstructural aspects

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Background

In recent decades, it has become abundantly clear that hospitals are especially vulnerable to seismic events. For many communities the consequences have been disastrous. Many hospital buildings have collapsed, leaving many victims among patients and staff. The losses in economic resources and technical and professional capabilities cannot be offset in the short term, and the political and social impact can endure for decades after the event.

This situation has occurred in all the cities located in seismically active areas. Yet, the perception of disasters is greater today than ever before, perhaps because until this century, seismic events caused general damage in cities, but hospitals did not exercise roles of particular importance. With the evolution of seismology and seismic resistant engineering in the twentieth century, systems have been developed, often in the wake of great failures, that control damage and ensure a low likelihood of collapse.

The success of these developments has not had the desired impact, however. One important reason is that certain factors unrelated to safety, such as operational requirements, take precedence in the construction of health centers. In addition, the building codes normally used for hospital design and construction are the same as those used for office buildings and residences – a circumstance that ignores the different objectives that must be pursued. The basic criteria of the building code are usually the protection of life in a serious earthquake and the limitation of structural damage in areas where earthquakes are relatively frequent. The objective of a hospital, however, should not only be to survive a seismic event, but to remain in operation and be able to serve the needs of the affected community.

The repeated instances of severe damage in hospitals around the world have generated fatalism about their capacity to survive seismic events. However studies of positive and negative experiences, such as those conducted in Chile (Boroschek, et. al. 1996) and other countries, provide alternative ways of addressing the vulnerability of health facilities.

Hospitals with low vulnerability

In hospitals whose services are essential for meeting the demand generated by an earthquake, top priority should be given to maintaining an appropriate level of operational capacity and to protecting the lives of building occupants.

In addition, the high cost of the buildings and medical and other complex equipment found in hospitals should be kept to a minimum so that the system can return to normal in a reasonable amount of time.

Protecting the operations of a hospital requires consideration of both its organizational and physical aspects; the physical aspects can be broken down into structural and nonstructural elements.

The structural elements are what keeps the edifice standing. Examples include the foundations, walls, beams, and columns. Their principal function is to bear weight and shift it to the foundation.
The nonstructural elements are supported by the structural ones. They include partitions, windows, and false ceilings, and essential networks such as telecommunications, gas, water, and heating, and the contents of the building. The nonstructural elements can be classified as vital lines, architectural elements, or equipment. It is important to point out that not only should the internal elements of the structure be considered but all those that can affect hospital operations.

Economic and functional aspects of nonstructural damage in hospitals

Advances in engineering have made it possible to reduce the risk of a structure's partial or total collapse. Nevertheless, economic losses from seismic events continue to be heavy. This is mainly because the costs of the structure account for only 10% to 15% of the total cost of a hospital. The economic losses, therefore, stem from nonstructural damage and the loss and recovery of services.

Two cases illustrate this point: In the United States, in the 1971 San Fernando earthquake, an evaluation of 25 commercial buildings indicated that structural damage represented 3% of the total costs of damage; electric and mechanical damage, 7%; damage to exterior finishings, 34%; and interior finishings, 56%. An evaluation of 50 tall buildings, which were far from the epicenter and thus subjected to a low level of movement, indicated that none incurred structural damage. However, 43 suffered damage to partitions; 18 had damaged elevators; 15, broken windows; and 8, damage to the air conditioning system (FEMA 1985). In the 1985 Mexico City earthquake two major hospitals suffered equipment losses amounting to US$ 640 million.

If nonstructural vulnerability is high, the probability of a hospital being put out of commission will be high as well. A dramatic example is the Olive View Hospital that was hit by the 1971 San Fernando earthquake. Three people died on that occasion; two patients died when life support equipment failed, and another was killed when struck by a piece from the structure. All the emergency stairways collapsed, and all the ambulances were crushed by a falling ceiling. The hospital was repaired, and its structure was considerably reinforced. However, during the 1994 Northridge earthquake it was again forced to halt operations, this time because of nonstructural damage − broken water pipes in the cooling system and the fire extinguishing system, which caused flooding on several floors. Other examples include the earthquakes that struck Managua, Nicaragua in 1972 where the Baptista Hospital continued to operate until the water supply ran out. During the earthquake of July 1995, damages to the rooftop water tank of the hospital in Antofagasta left it unable to receive new patients and curtailed operations.

The list of poor responses to seismic events is a long one, but the effects of earthquakes on different hospital buildings at different times and places are similar. The disappointing responses are a function of the complexity of health facilities and the procedures and premises underlying their construction and subsequent maintenance.

The causes of nonstructural damage

A hospital is a very complex facility. Some of the characteristics that contribute to its vulnerability are presented below:

- Activities: A wide range of work is performed in hospitals, combining the functions of hotels, offices, laboratories, and storerooms under one roof. Hospitals have large staffs made up of individuals with highly diverse functions and different educational backgrounds and interests; they therefore relate and communicate in different ways as well. This is not an easy staff to organize.

- Spatial Distribution: Because of its assorted functions, a hospital needs different sections with different basic characteristics: wards, operating and recovery rooms, and rooms for intermediate and intensive care, laboratories, outpatient care, an operating theater, a laundry, a food service, sterilization facilities, thermal plant, and many others.

- Occupants: Hospitals typically have large staffs with a variety of personnel – medical, paramedical, administrative, support, patients, and visitors – around the clock. A considerable number of patients have limited mobility and some are dependent on life support systems.
• Dependency: Hospital operations are dependent on access to outside services: utilities (such as electricity, water, and communications lines) and supplies.

• Physical Plant: The physical plant of a hospital can be divided into its architectural elements, equipment (medical, support, administrative, and industrial), supplies, furniture, and distribution or communications networks. Many parts of the physical plant contain hazardous materials.

The complexity of a hospital requires the internal organization of staff and the physical adaptation of structural and nonstructural elements in order for it to meet its operational objectives during and after a seismic event. The history of structural and nonstructural damage and operational shutdowns in health facilities indicates that this complexity is not being handled appropriately.

The current construction and maintenance processes of new health centers are at the heart of the problem. Although in order to reduce the vulnerability of a hospital it is necessary to analyze the facility as a whole, it is best to analyze the structural elements first, before proceeding to nonstructural and organizational aspects.

The aspects concerning structural vulnerability are discussed more extensively in Boroschek et al. (1996a, 1996b). As for the nonstructural aspects, the evidence indicates that seismic protection is rarely carried out because the procedures involved in building a new health center fail to take it into account. A large group of professionals usually participate in this process, coordinated by a medical and administrative board and a group of architects. In practice, the specialist in seismic aspects (if indeed there is one) works only on the protection of the structural system. Nonstructural aspects are left to professionals who are not specialists in this area, and specific responsibility for equipment and furniture is virtually left to the user. Thus, a system is created in which the basic structural design is ignored in the design, selection, location, and protection of the building’s contents.

As a result, it is common to find hospital pipes crossing expansion joints between adjoining buildings, partitions between rooms without space left to accommodate movement in floors, and equipment and furniture without seismic protection.

An indication of the situation with respect to nonstructural elements in hospitals can be found in a study that assessed the physical vulnerability of the public health system in Chile (Boroschek et al., 1996a, 1996b).

Fourteen hospitals with a total of 1,245,956 m² of construction (53.6% in areas of high seismic activity and 46.4% in areas of moderate seismic activity) were evaluated in this study. In these hospitals, dating from 1930 to 1993, the inventory of critical medical equipment as of 1992 (sisal 1992) was valued at about US$ 160 million (with a distribution of 52% in areas of high seismic activity and 48% in areas of moderate seismic activity). The typical cost of new hospitals in Chile is around US$ 1,400 per square meter, with approximately 75% of this cost arising from nonstructural elements.

Despite the economic importance of nonstructural elements in the sector, 90% of all the structures evaluated had no protection for the equipment, 80% had no protection for the furniture, and 53% were vulnerable to breakage of glass and other architectural elements.

Aspects to consider in the evaluation of nonstructural vulnerability

It should be noted that in hospitals, as in other buildings, there is a close relationship between structural and nonstructural elements. For example, it is common to find architectural facades that substantially alter the anticipated structural behavior, shortening columns and creating unanticipated weaknesses in structural elements, or to find heavy machinery or water tanks on the upper floors of a structure that can substantially change the response characteristics of the system. This is why an evaluation of nonstructural vulnerability must take structural features into account, just as a structural evaluation must take nonstructural ones into account.

Nonstructural vulnerability studies must examine different complex features that are highly interrelated, so it is helpful to group them in a way that allows common methodologies to be applied. Table 1 presents some of the elements of each of these groups. This list can be modified in accordance with the characteristics of each system.
For evaluation purposes, it is necessary to consider direct seismic effects (inertial forces, velocities, displacements) and the influence or interaction of structural and nonstructural elements in each of the internal hospital systems in an earthquake.

In order to analyze nonstructural vulnerability and ascertain its relationship to the hospital's capacity to meet treatment needs, the typical activities performed in a hospital after a seismic emergency should be identified. This identification must also extend to each of the systems and subsystems within and around the hospital.

Table 2 presents a list of clinical and support services typically found in a hospital. Using this list and assigning priority to activities performed in response to an emergency will make it possible to select the services that should be analyzed in depth. Some of them are presented in Table 3 (Pacheco 1995). The evaluation of nonstructural vulnerability should consider all aspects that ultimately affect hospital operations, with special emphasis on the services identified as priorities.

In evaluating risk, it is necessary to identify equipment, systems, and hazardous elements. Each should be rated according to three main categories: risk to life, risk of loss, and risk of interruption in operations (Steward 1989). Each of these categories should be assigned indicators for its own vulnerability and for its impact on the overall vulnerability of the hospital.

In the category of risk to life it is useful to apply a hospital related criterion such as the one developed by the United States Veterans Administration (VA 1976). In this classification, dangerous elements are those that produce debilitating injuries, substantially worsen the condition of a patient, or imperil hospital personnel. Thus, a minor cut from broken glass may be considered tolerable while a fracture or more serious cut would not be. A bedridden patient cannot follow the common recommendations for self protection in seismic situations, such as hiding under furniture or strong structures to avoid getting hit by falling objects.

Evaluations of nonstructural vulnerability should involve qualitative and quantitative safety studies in each hospital and studies of the effects of earthquakes on the operations and vulnerability of the hospital as a whole. Table 4 presents the aspects to be considered in these studies.

It should be noted that this classification of nonstructural elements considers only systems that have a negligible effect on the behavior of the supporting structure. For example, equipment should have a weight no greater than 20% of the weight of the floor on which it rests or 10% of the total weight of the structure, nor should it alter the rigidity and resistance of the structure. Otherwise, the equipment should be considered in the analysis of the structure as a whole.

Architectural elements such as partitions, facades, and lights should be evaluated in terms of the functional and physical consequences of their failure. Typical failures occur as a result of the connections selected, the amount of space between elements, the fragility of the structure, and the stress they must withstand. The failure of these elements can be classified in three broad groups: damage, detachment, and changes in the response of structural and nonstructural elements.

A number of procedures can be used to evaluate the risk of these systems. These usually establish the relationship between the anticipated deformation and the inertial forces to which the architectural element will be subjected and its ability to withstand this stress. The large number and diversity of architectural elements require the formulation of very general recommendations. Thus, the rating procedures presented below will help in conducting a proper evaluation.

For the evaluation and estimate of the risk in equipment and vital lines it is useful first to classify the systems according to their importance. One of the most accepted classifications is the one established by McGavin, (McGavin 1981), which is broken down into the following five categories:

- **A) Critical:** The systems, subsystems (or equipment) needed to operate the main system or life support systems, or whose failure can directly or adversely affect the operation of another system or critical piece of equipment.

- **B) Support:** The systems, subsystems (or equipment) required to support basic functions. The unit that depends on this system can work in a limited fashion in the event of a failure.

- **C) Support:** The systems, subsystems (or equipment) required for long term hospital operations.

- **D) Support:** All portable systems and subsystems (or equipment) not included under A.
E) Miscellaneous: Miscellaneous systems, subsystems (or equipment).

Another classification is the one presented by Watabe (1989):

**Hazardous:** Equipment that can injure patients or medical personnel.

**Emergency:** Equipment that can have a critical impact on medical operations and which cannot be immediately replaced.

**Functional:** Equipment similar to that classified as "Emergency" but which can be immediately replaced.

**Chaos:** Equipment that can create confusion in the surrounding area.

Systems are usually composed of subsystems (or equipment). Their classification is therefore a composite one in which the system and each of its component subsystems are classified.

Once the systems and subsystems have been identified and classified, they must be rated for vulnerability. The possible criteria depend on factors such as:

- Function
- Demand
- Design characteristics
- Useful life
- Previous experience
- Proximity and relationship of the system to other systems.

These factors make it possible to establish how in-depth these studies should be. The procedures for rating vulnerability can be grouped in the following way:

- **Previous Experience:** Risk in isolation under current conditions is evaluated on the basis of experience with similar elements in previous seismic events. In these cases, particular care is required in evaluating the condition of equipment in terms of the seismic stress and the seismic response of the structure in which it was housed at the time of the previous event. Thus, a piece of hospital equipment located on a lower floor should not be evaluated in the same way as equipment on an upper floor. Although the same equipment may be used in both locations and the equipment on the lower floor responded well in the past, it may not necessarily do so in other locations within the structure where the movement characteristics are different.

- **Mathematical analysis:** Mathematical models should be developed that take into account the equipment, its components, and the conditions for support and attachment to the supporting structure. Static or dynamic analysis can be used depending on the complexity of the system; likewise, simple coefficients, the response spectra, linear or non-linear analyses can be applied at each point. For these types of analyses information is needed on the physical characteristics of the element or equipment (e.g., distribution of mass, rigidity, energy dissipation capacity, internal couplings, and internal elements).

- **Laboratory tests:** when there is inadequate knowledge about the physical properties of complex equipment or elements in general or when mathematical models are very limited, laboratory tests can be carried out. They may be simple (e.g., estimates of the likelihood of objects overturning or of static slippage) or complex (e.g., tests on a vibrating table or pressure frame).

- **Group of Experts:** All the above procedures should be carried out by a group of experts. However, it is useful to recognize that economic or physical constraints often will not allow these procedures to be adequately performed. In such cases, a good criterion developed by a group of experts who can apply several experiences to one particular situation may be the only alternative for estimating risk.

Once the vulnerability of a component is established, an estimate of its overall impact on the hospital in terms of operational, physical, and economic aspects should be made.

It should be remembered that damages not only have an immediate effect by limiting service delivery but also represent considerable economic losses that, in terms of typical economic constraints, undercut the ability of the health sector to recover rapidly and reestablish normal levels of service. It is not unusual to find cases in which hospitals continue to suffer the effects of an earthquake several years after its occurrence.
Acknowledgements

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References


Table 1. Nonstructural Elements to Consider in the Evaluation of Vulnerability

<table>
<thead>
<tr>
<th>ARCHITECTURAL</th>
<th>EQUIPMENT</th>
<th>VITAL LINES</th>
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</thead>
<tbody>
<tr>
<td>• Divisions and Interior partitions</td>
<td>• Medical Equipment</td>
<td>• Medical Gases</td>
</tr>
<tr>
<td>• Facades</td>
<td>• Industrial Equipment</td>
<td>• Industrial Gas</td>
</tr>
<tr>
<td>• False Ceilings</td>
<td>• Office Equipment</td>
<td>• Electricity</td>
</tr>
<tr>
<td>• Panelings</td>
<td>• Furniture</td>
<td>• Telecommunications</td>
</tr>
<tr>
<td>• Cornices</td>
<td>• Contents</td>
<td>• Vacuum</td>
</tr>
<tr>
<td>• Terraces</td>
<td>• Supplies</td>
<td>• Drinking Water</td>
</tr>
<tr>
<td>• Railings</td>
<td></td>
<td>• Industrial Water</td>
</tr>
<tr>
<td>• Chimneys</td>
<td></td>
<td>• Air Conditioning</td>
</tr>
<tr>
<td>• Overlapping surfaces</td>
<td></td>
<td>• Steam</td>
</tr>
<tr>
<td>• Glass panes</td>
<td></td>
<td>• Pipes in General</td>
</tr>
<tr>
<td>• Attachments (signs, etc.)</td>
<td></td>
<td></td>
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<tr>
<td>• Ceilings</td>
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<tr>
<td>• Antennas</td>
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Table 2. List of Clinical and Support Services

<table>
<thead>
<tr>
<th>SERVICE</th>
<th>SERVICE</th>
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<tbody>
<tr>
<td>Internal Medicine</td>
<td>Pharmacy</td>
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<tr>
<td>Pneumology</td>
<td>Food</td>
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<tr>
<td>Medicine</td>
<td>Transport</td>
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<tr>
<td>Surgery</td>
<td>Laundry</td>
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<tr>
<td>Traumatology</td>
<td>Administration</td>
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<tr>
<td>Pediatric Surgery</td>
<td>Wards</td>
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<tr>
<td>Plastic Surgery for Burn Victims</td>
<td>Miscellaneous Hospital Services</td>
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<tr>
<td>Traumatology and Orthopedics</td>
<td>Sonography</td>
</tr>
<tr>
<td>Pediatrics</td>
<td>Pathology</td>
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<tr>
<td>Obstetrics and Gynecology</td>
<td>Kinesitherapy</td>
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<tr>
<td>Intensive Care</td>
<td>Endoscopy</td>
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<tr>
<td>Dermatology</td>
<td>Polyclinic Wing</td>
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<tr>
<td>Child Neurology</td>
<td>Nuclear Medicine</td>
</tr>
<tr>
<td>Psychiatry</td>
<td>Industrial Equipment</td>
</tr>
<tr>
<td>Ophthalmology</td>
<td>Administration</td>
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<tr>
<td>Oncology</td>
<td>Neonatology</td>
</tr>
<tr>
<td>Otorhinolaryngology</td>
<td>Dialysis</td>
</tr>
<tr>
<td>Urology</td>
<td>Recovery Rooms</td>
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<tr>
<td>Adult Emergencies</td>
<td>Blood Bank</td>
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<tr>
<td>Pediatric Emergencies</td>
<td>Boilers</td>
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<tr>
<td>Laboratory</td>
<td>Water Tanks</td>
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<tr>
<td>Sterilization</td>
<td>Oxygen</td>
</tr>
<tr>
<td>Dental</td>
<td>Gas Installations</td>
</tr>
<tr>
<td>Imaging</td>
<td>Records</td>
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</table>

**Table 3. Priority Services in Seismic Emergencies**

<table>
<thead>
<tr>
<th>Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery rooms</td>
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<tr>
<td>Surgical wings</td>
</tr>
<tr>
<td>Intensive care units</td>
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<tr>
<td>Intermediate care units</td>
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<tr>
<td>Emergency</td>
</tr>
<tr>
<td>Laboratories</td>
</tr>
<tr>
<td>Blood bank</td>
</tr>
<tr>
<td>Imaging</td>
</tr>
<tr>
<td>Dialysis</td>
</tr>
<tr>
<td>Sterilization</td>
</tr>
<tr>
<td>Pharmacy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SUPPORT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storerooms</td>
</tr>
<tr>
<td>Boilers and thermal plant</td>
</tr>
<tr>
<td>Laundry</td>
</tr>
<tr>
<td>Food Service</td>
</tr>
<tr>
<td>Records</td>
</tr>
<tr>
<td>Gas Installation</td>
</tr>
<tr>
<td>Ambulances</td>
</tr>
<tr>
<td>Communications</td>
</tr>
</tbody>
</table>

**Table 4: Nonstructural Aspects to Consider in Evaluating Vulnerability**

<table>
<thead>
<tr>
<th>NONSTRUCTURAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARCHITECTURAL</td>
</tr>
<tr>
<td>Interaction</td>
</tr>
<tr>
<td>Importance</td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Coupling–Support</td>
</tr>
<tr>
<td>Resistance</td>
</tr>
<tr>
<td>Rigidity</td>
</tr>
</tbody>
</table>
Reconstruction and mitigation programs in Jamaica post hurricane Gilbert

Prepared by:
Eng. Alfrico D. Adams
Consulting Engineer

Abstract
This paper briefly describes the island's exposure to hurricanes and earthquakes, and the impact of Hurricane Gilbert, 1988, on Jamaica.

It describes the then existing disaster mitigation strategies, and identifies the major areas of damage and failure.

It lists the steps taken immediately after the hurricane, to identify the deficiencies and set new strategies for repair, retro–fitting and mitigation.

Some damage observations and roof repair guidelines are summarized.

Comparisons are made between the costs of mitigation and the cost of repairs for low buildings, and recommendations are presented for improving mitigation measures in the future.

1.0 Introduction
Hospital and health facilities play a critical role in the immediate post–disaster period for naturally occurring catastrophes, in particular, after earthquake or hurricane events.

Physical damage to these facilities affect their ability to provide for the emergency needs of their communities, at the time when their services are most needed.

Governments and relevant health–care professionals, have a duty to ensure that hospitals and clinics, not only continue to provide safe and effective facilities for the persons already under their care, but are in a position to make sudden increases in the scope and effectiveness of these facilities, during, and after disasters.

This paper describes Jamaica's experience from Hurricane Gilbert, 1988.

2.0 Jamaica's hurricane experience
Hurricanes are a constant threat to Jamaica. Year after year, tropical storms aim at the eastern arc of Caribbean islands, and appear set on a path through this arc to Jamaica.
Fortunately, few of these have actually impinged on Jamaica during the last 100 years of record. The frequency of damaging hurricanes has been low enough to ensure occurrence only once during the working life of the typical Jamaican adult. This has resulted in a rather casual attitude towards hurricane-resistant design and maintenance, by both building maintenance officials and the lay-public at large.

Our Office of Disaster Preparedness, reported after Gilbert, that the population made poor response to appeals to the public, regarding long and medium term measures for hurricanes and for Hurricane Gilbert in particular. (Ref. 1)

3.0 Jamaica's most recent hurricane: Gilbert, September, 12, 1988

3.1 Maximum wind speed

Recorded 3 second wind speeds of 127–131 miles per hour (58m/sec) (Ref.3) were fairly close to the basic wind speed of 125 miles/per hour (56m/sec) recommended for design by The National Building Code, Jamaica and The Caribbean Uniform Building Code.

3.2 Damage estimates

Hurricane Gilbert caused severe damage in almost every sector of the Jamaican economy. Total damage (loss) to the Jamaican economy with its population of 2.4 million persons was estimated at between US$1.0 and 1.5 billion.

The national damage experienced in each of the sectors or utilities mentioned below, affected the health sector significantly, e.g., the level and quality of health care and emergency response were grossly affected by damage to water supply, sewerage, electricity, communications, and transportation systems.

The Health Sector

In the health sector, 23 of the 25 hospitals and half of the 377 health centres were damaged, mainly through the loss of roofs, roofbeams, ceilings and windows. Two of the hospitals were destroyed, while eleven suffered severe damage. The cost of repairs to this damage was estimated at US$13m.

Water Supply and Sewerage

Damage was estimated at US$12m. Over 50% of the water supply and sewerage disposal facilities, suffered damage varying from minor to complete destruction. Damage included Buildings and equipment, chlorinators, tanks, intakes, and pipelines.

Of the 40% of the system which depended on electricity, only 5% had stand-by generators. This further compounded the problems.

Electricity Supply

Damage was estimated at US$63m, and power supply islandwide was reduced by some 50%. Major damage was to the transmission and distribution network, with damage to wood poles being 20% and 30% respectively, and requiring replacement of 15000 wood-poles.

Telecommunications

Damage to local and international telecommunications was estimated at US$12m, and all forms of communication were badly affected.

Roads

Secondary and tertiary roads were estimated at a total repair cost of US$14m.

3.3 Buildings generally
Apart from Community and Public buildings, it was estimated that 25% of the total housing stock was damaged. 100,000 of these were low income houses, at a repair cost of US$100 million, and 35000 were middle and upper income, at a repair cost of US$225 million.

In general, buildings designed by professionals did well. Non-engineered buildings of the light-roofed variety, e.g. medium to low cost houses and generally poorly maintained light-roofs of all types, suffered badly.

Typical lightweight systems used on the roofs of both public and private buildings were:

(a) Profiled aluminum sheeting attached to timber sheathing, or closely spaced wooden laths or on steel purling.

(b) Wood or metal shingles on timber sheathing or battens.

4.0 Jamaica's earthquake experience

Jamaica falls in an earthquake prone region near to the edge of the Caribbean tectonic Plate.

Historically, the last devastating earthquake occurred in 1907. At the time, the lack of instrumentation meant that only Modified Mercalli Scale Intensity estimates of IX were available. Since then, moderate tremors of between 5.6 and 5.4 Richter Magnitude were felt in 1957 and 1993.

Local seismologists had recommended the use of effective peak acceleration EPA of 0.3g up to the 1993 event. Since then, however, the revelation that the 1993 event originated from a potentially destructive inland fault, and not offshore as previously anticipated, (Ref.6) has prompted a recommendation to increase the EPA value from 0.3g to 0.4g. This latter value is comparable with the maximum value recommended by the Structural Engineers Association of California for San Francisco.

Local seismologists have also advised that Jamaica is overdue for a major event. Jamaica is therefore in the position of being faced with the threat of a major earthquake, but with very few of its population with first hand experience of a this.

5.0 Hurricane and earthquake disaster mitigation strategies for buildings in Jamaica

It is important to recognize that Disaster Mitigation Strategies cannot be restricted to any one sector such as the health sector. Neither can it be restricted to one aspect of that sector, e.g., the proper construction of physical plant and buildings.

The strategy for hospitals and health care facilities must fit into the strategy for national disaster mitigation; otherwise, it would very soon be abandoned. Some of these strategies are, enforcement of Building Approval Standards and Codes, continuing education in the engineering profession, and the building industry and public education, which will influence the untrained sections of the labor force.

5.1 Building approval standards and codes

All Buildings constructed within given distances of the city limits, must be approved by The Local Building Authorities. This procedure is governed by Building Act Laws, applicable to individual urban centres or to parishes.

The Building Acts include Building Regulations which form the basis of Structural Evaluation of Buildings. Unfortunately, these are allowed to become out of date, with respect to design and material technology, mainly due to the lack of resources to ensure frequent and regular revisions. As a result, Building approval officers refer to the latest readily available international standard or code to supplement local documents, in approving Building designs.

In addition, during the last 12 years, two documents have been produced in Jamaica and the Caribbean, which, although they do not carry mandatory legal status, they have provided a valuable source of reference for local authorities and design professionals. They are:
1. The National Building Code, Jamaica, 1983 (Ref.4). Published with the status of recommended guidelines by the Government of Jamaica.


These documents are now in the early and initial stages of review respectively before the issue of revised versions.

5.2 Continuing education in the local engineering profession and the building industry.

The Jamaican Institution of Engineers and the Council of Caribbean Engineering Organizations, have both gone to great pains during the last 20 years to educate local professionals on the rapid developments in design for disaster mitigation, particularly with respect to earthquakes and hurricanes.

This is essential, as these fields represent rapid changes in the academic curriculum of the engineer. There still remains the difficulty of disseminating such information to all engineers who should benefit from it.

5.3 Public education

It is recognized that trained professionals are generally engaged for the design and construction of significant buildings, but that the majority of building construction is still for housing and other small buildings. This category of buildings would not normally benefit from professional services. Various attempts have been made by the local office of Disaster Preparedness to educate the public through radio, television, and newspapers, on the essential elements of hurricane and earthquake resistance of buildings. This approach has also been extended to the print media with eye catching illustrations. (See Fig. 1)

This also helps the formal building industry, as it affects the site laborer whose training on site is normally restricted to his particular functions.

Courses have been planned and executed in conjunction with donor agencies, for small builders in both the formal and informal building sectors. Here too, the deficiency has been insufficient resources to fully saturate the public consciousness.

6.0 Reconstruction phase after hurricane Gilbert

6.1 Major causes of building damage identified.

Most damage to buildings was caused by lack of holding down capacity of the roof covering, or its secondary or primary supporting members.

Figs. 2(a) 2(d), 3 and 5, show photographs and illustrations of typical damage to roof elements. Figs 3−5 refer to hospitals. Jamaica was spared the worst excesses of total destruction of buildings by Hurricane Andrew in Florida in more recent years. The main reason for this was the Jamaican practice of using reinforced concrete masonry walls, even where roofing is light weight. This practice minimized both damage and casualties.

6.2 Post hurricane evaluation conference

Immediately after Hurricane Gilbert, the Jamaica Institution of Engineers, invited wind speed experts from Canada to join local engineers in evaluating the event and its implications for design and construction standards. Prominent among these were Mr. David E. Allen, Institute for Research in Construction, Ottawa, Canada, and Professor Allan Davenport, University of Waterloo, Canada.

An international conference was held five months after the Hurricane in February, 1989. This conference was attended by design professionals, national planning representatives, and managers of public utilities.

The conference concluded that the wind speeds recommended by the existing code, were appropriate. Later in 1989, the local Meteorological Office took a more conservative view of design wind speeds, and although
not yet incorporated in the wind code, this has influenced design professionals in their selection of design speeds between 135 and 150 mph.

6.3 Measures taken to correct and mitigate damage

(a) A Review and Revision of Building Codes

In the years following Hurricane Gilbert, the Government of Jamaica instructed the Jamaica Bureau of Standards to initiate a review of the existing local building code and standards, with a view to developing a new Building Code. This work has made slow progress, again, due to lack of resources. After much debate in committees, the review committee has acknowledged the good sense of adopting sections of the Caribbean Uniform Building Code wherever appropriate.

(b) Unofficial Decision to Avoid Aluminum Roof Sheeting

In numerous instances of damage, the use of thin gauge profiled aluminum sheeting was found to be the cause of roof failures. Sheetng often tore around fasteners sometimes leaving fasteners intact.

A consensus developed among engineers and statutory bodies, to avoid the use of aluminum sheeting as a roofing material, and if used, to ensure 22 gauge minimum thickness.

(c) Every opportunity was taken, pending revision of the Building Code, to extend the concept of Importance factor used in earthquake design to wind resistant design. This concept applies a factor to increase design forces for buildings to be used for critical post−disaster facilities, such as hospitals health centres, police stations, schools to be used as shelters, etc.

(d) Retrofitting

There is little in the way of statistics to suggest that undamaged buildings were modified ensure survival in future hurricanes. However, it was evident that damaged buildings which were repaired during the first year or 18 months tended to have modifications done, which would improve resistance to future hurricanes.

As time distanced us from the actual Hurricane experience, small buildings in the informal sector seem to drift toward the faulty designs based more on economy than hurricane resistance. It is clear that mandatory code provisions will be needed for this aspect.

7.0 Retrofitting measures for particular cases

Detailed information on the damage analysis of hospital structures has been unavailable, but the typical nature of hospital construction in pre−1988 construction, should justify the use of results of investigations on typical structures for other building applications.

The following analyses of damage and retro−fitting designs and costs, draws upon work done by The Urban Development Corporation (UDC), the Jamaican statutory body which was given the task of managing the reconstruction of the majority of the hospitals and schools damaged by Hurricane Gilbert.

Much of that information was summarized in a paper presented by John Pereira, former Deputy General Manager in charge of the Technical Services Department, UDC, to the Caribbean Disaster Mitigation Project Workshop, Trinidad, March 1995, and in presentation by others at the JIE/SCSE Seminar in 1989. As previously indicated, most of the damage was restricted to roofs.

7.1 Tabular summary of mechanism or cause of failures observed in typical roof systems

<table>
<thead>
<tr>
<th>LOCATION OF FAILURE</th>
<th>PROBABLE CAUSE OF MECHANISM OF FAILURE</th>
<th>INCIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sheeting to woodsheathing or laths</td>
<td>Tearing or rolling of sheeting. Static or fatigue (see fig. 2(a))</td>
<td>High</td>
</tr>
<tr>
<td>2. Timber Purlins/rafter connection</td>
<td>Pull out of nails (see fig. 2(a))</td>
<td>High</td>
</tr>
<tr>
<td>3. Rafter to wall plate connection</td>
<td>Poorly secured or missing strap (see fig. 5)</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Straightening of bent re−bar</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
4. Wall plate held by 13mm wall rebar Pull out of nail/screws (see fig. 2 (b) Moderate
5. Connection of sheeting to Purlin Failure of connection in uplift Occasional
6. Truss support connection Failure of dowel bars due to uplift (see fig. 3) Occasional
7. Failure of edge beam

7.2 Retrofit arrangements for damaged roofs

The following are some of the modifications made by the UDC in restoring damaged roofs.

<table>
<thead>
<tr>
<th>DETAIL PRIOR TO HURRICANE GILBERT</th>
<th>DETAIL POST–GILBERT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Various types, thickness and lengths of profiled metal sheeting</td>
<td>Use of 26 gauge minimum steel sheeting with aluminum or galvanized coating in continuous sheets</td>
</tr>
<tr>
<td>2. Purlin Connection to rafters nailed</td>
<td>Sheet metal cleats for wood to wood connections</td>
</tr>
<tr>
<td>3. Rafters/Wall Plate Connections Metal, straps omitted partially or wholly, or connection nailed</td>
<td>Metal strap or cleat fixed to each rafter preferably to concrete belt beam.</td>
</tr>
<tr>
<td>4. Timber Wall– Plate held down by 13mm hold– down bolts at 1,35m centres</td>
<td>Wall plate hold–down bolts spaced at maximum 1,05m (42in) centres.</td>
</tr>
<tr>
<td>5 Timber Purlin spacing up to 1.2m (48in).</td>
<td>Maximum spacing 900mm (36in) centres</td>
</tr>
<tr>
<td>6. Screws to sheeting spaced at one per sheet or 900mm (36in)</td>
<td>Spacing of screws at 450mm (18in) centres. Spacing halved at eaves or overhangs</td>
</tr>
<tr>
<td>7. Open eaves for overhangs up to 900mm (36in) length</td>
<td>Boxed eaves used for overhangs exceeding 450mm (18in)</td>
</tr>
</tbody>
</table>

These are consistent with this writer’s own practices, with the exception of item 6, for which the Building Code specification (See item 4) is more stringent.

7.3 Retrofit arrangements for combined earthquake and hurricane resistance

Perhaps because the only tremors in recent memory were moderate in magnitude at 5.4 to 5.6 on the Richter scale, there has been no attempt at retrofit for undamaged buildings.

On the other hand, in some cases where repair proved necessary, the opportunity was taken to improve resistance by:

(a) Introducing shear walls where possible (See Fig.4)

(b) Improving the strengths of damaged masonry walls by replacing with poured concrete, or introducing poured concrete stiffener columns.

7.4 Damage and retrofit to princess Margaret hospital

In the particular case of the Princess Margaret Hospital in Morant Bay, damage caused by Gilbert consisted of the total removal of the roof, damage to windows and doors, water damage to fittings, cupboards, work stations etc., and damage to wall finishes etc. (See Fig.3)

Subsequent to the hurricane damage, the building was vandalized and sanitary fittings etc. removed.

Retrofit consisted of:

(i) Introducing shear walls to provide earthquake lateral resistance, and to compensate from the higher earthquake forces, expected from the new concrete roof – Approximate Cost US$55,000.

(ii) Replacing the original timber roof with a concrete roof to solve the problem of wind uplift; (See Fig.4) and non–structural works such as partitioning, windows, doors, plumbing, sanitary, and electrical installation and fitting, cupboards, workstations etc., cost a further US$1.1 million
7.5 Costs of mitigation and repairs

An analysis of the added Costs in percentage terms of providing earthquake and hurricane resistant construction in Jamaica, was presented by John Pereira, and these can be rationalized and summarized as follows, for buildings of low rise (say 3–storeys). These relate to basic construction cost, excluding Mechanical and Electrical Services, fees, land and finance, and are mainly based on buildings repaired by the Urban Development Corporation, Jamaica.

These are consistent with the writer's own observations.

**TABLE 7.5 COST OF MITIGATION AND REPAIRS (AFTER PEREIRA)**

<table>
<thead>
<tr>
<th>Element or Building System</th>
<th>Cost of Mitigation as % Increase on Overall Cost of Building</th>
<th>Cost of Repair or Replacement after a Major Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquakes and Hurricanes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Bearing Wall (Reinforced concrete masonry)</td>
<td>8.0%</td>
<td>Up to 100%</td>
</tr>
<tr>
<td>2. Building Frame System (With some shear walls) 2 storey example</td>
<td>3.0%</td>
<td>Up to 100%</td>
</tr>
<tr>
<td>Hurricanes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Roof System in single storey building</td>
<td>3.0%</td>
<td>15 – 30%</td>
</tr>
</tbody>
</table>

It is evident also, that the real costs of damage may be well beyond the values in column of the table if costs, such as damage to contents, and costs of temporary relocation of occupants are included.

8.0 Recommendations for improving mitigation measures in the future

8.1 Building code design forces for health facilities

Local building codes should be reviewed and revised regularly to:

(a) Ensure ready availability of reliable design values, Examples of these are, basic wind speeds, seismicity (Zone Factors) and special provision for post–disaster facilities:

eg. An Importance factor as recommended by the National Building Code, Jamaica, and the Caribbean Uniform Building Code, or the option of extending the recurrence interval beyond 50 years for basic wind speed, as recommended by the NBCJ. For the latter, the recurrence interval should be stated in the Codes. 100 years is a recommended interval (Ref.7)

8.2 The building approval and inspection system

The Statutory building approval and inspection system, must be strengthened and made more effective for all buildings, but particularly for health facilities.

8.3 Minimum thickness of profiled metal sheeting on roofs

At Clauses 4.6.11.4 (a) and 4.8.5.1 of the National Building Code, Jamaica, minimum, sheet thicknesses are recommended as 28 British Standard gauge (0.376mm) for steel sheeting and 24 British Standard Gauge (0.559mm) for aluminum sheeting.

These should be increased to 26 gauge (0.457mm) and 22 gauge (0.711) respectively.

8.4 Improved fasteners and connections to roofing systems

Deficiency in this respect caused the most damage during Hurricane Gilbert. The National Building Code Jamaica, requires minimum 3/16" (5mm) fasteners at 9" (230mm) minimum spacing for steel sheeting and 8" (200mm) for aluminum sheeting with 1/2 " (13mm) minimum diameter washers. If this had been observed, damage would have been vastly reduced. This needs to be adhered to. All timber ridge–joints – rafter
bearings. and wall plates, should be connected by metal straps or bolts, adequately anchored to prevent uplift by wind.

It is vital also, that fasteners be spaced closer (a maximum of 150mm) at vulnerable roof edges, such as eaves, ridges, hips and gables.

8.5 Improved fasteners and connections to roofing systems

Research and Development work to counteract fatigue effects on sheeting fasteners, is currently being incorporated in the Standards Association of Australia, SAA Loading Code AS1170. Part 2: Wind Loads (Ref. 8). This work should be considered for inclusion in local codes.

Simple illustrated manuals as companion documents to the code, would be useful to the small builder in this regard, as such requirements are only stated in general terms in the code.

8.6 Vertical anchorage at beams, walls and foundations

For both Hurricanes and earthquakes, it is essential that vertical reinforcement be fully anchored from columns into foundations, and from columns into roof edge beams.

A major cause of the loss of the roof at Princess Margaret Hospital was the lack of anchorage c of the column reinforcing bars into the edge beams which supported the roof trusses. The concrete edge beams were lifted off with the roof and thrown to the ground.

8.7 Lateral bracing of lightweight framed buildings

As previously mentioned, the common practice in Jamaica of using reinforced masonry walls reduces significantly, the likelihood of lateral instability of our buildings. It is important however, to ensure that such walls are reinforced horizontally and tied together by reinforcement of junctions.

8.7 Roof Shapes and Vents

More stress should be placed in codes and public education on the advantages of tripped roof shapes.

8.8 Maintenance of Roofing Systems

Even the best designed roofing systems are prone to deterioration due to weather and wear

Eg.
(a) Fasteners become loose due to shrinkage of lumber or vibration due to previous storms.
(b) Metal sheeting will corrode especially at fasteners
(c) Fasteners and their washers may degrade
(d) Timbers may rot, or may split due to shrinkage
(e) Leakage of water may accelerate any of the above.
(f) Reinforcing bars, metal straps and holding down bolts may corrode and lose their effectiveness.

All roofing systems should be inspected at least once per year, preferably before the start of the hurricane season, and repairs done immediately.

8.9 General

Whereas all the above mentioned provisions are important for specific roofing and building systems it must be realized that it is impossible to provide detailed provisions in codes or otherwise, for the many different systems that are available.

It is important therefore to:

(a) Ensure that design forces and the principles of hurricane and earthquake resistance are clearly set out and disseminated in codes for the benefit of trained building design professionals.
(b) Maintain mandatory standards for the quality of critical building materials eg. cement, concrete, blocks, steel, timber, profiled roof sheeting, fasteners.

(c) Strengthen and maintain the Building Approval Authorities and Building inspectorates to ensure that all designs are vetted for proper design and construction.

(d) Maintain a public education campaign to improve the understanding of all members of the public, of the general principles of hurricane and earthquake effects on buildings, and the precautions to be taken, both for the building and its occupants.

Jamaica has attempted each of the above, but none to the extent required.

(e) Develop summary guidelines or specifications based on existing or revised codes, which can be used by health administrators to instruct design and construction professionals engaged by them, on the more stringent requirements for hospital design and construction. E.g. Higher values of Importance factor, and/or recurrence interval for earthquake and wind respectively.

LIST OF REFERENCES


Impact of hurricanes on health facilities

CASE STUDIES
for presentation at the International Conference on Disaster Mitigation in Health Facilities

by
Tony Gibbs
Consulting Engineers Partnership Ltd.
Barbados
0. Synopsis

Throughout the world, including the Caribbean, natural hazards cause as much damage to healthcare facilities as they do to less-important buildings. This is both regrettable and avoidable.

It is often said that safe buildings may not be affordable, especially in relatively-poor developing countries. This is a fallacy. Particularly with respect to hurricane resistance, safe buildings are not only technically feasible but also achievable at very modest cost. This thesis has been tested and confirmed on several occasions over the years. In recent times several case studies have been carried out through international agencies such as the Pan American Health Organization. Some of these studies are presented here.

Hurricane Luis struck the independent island state of Antigua & Barbuda in the north-east Caribbean on 4 and 5 September 1995. Luis was a classical, Category-4 storm, almost perfectly formed, large in extent, loaded with moisture, with a very distinct eye of 70 kilometers in diameter and a forward motion of 17 kilometers per hour. Because of its overall size and slow forward motion, the hurricane impacted on Antigua for an uncommonly long period.

The level of damage in Antigua was equivalent to two-thirds of the gross domestic product of the country. Such an event has the potential to set back the development of a small island independent state by several years. In particular, much damage was done to essential facilities in the country.

This paper focusses on the health sector. The nature and extent of the damage are described and illustrated. (It is intended that the conference presentation of this paper will be liberally illustrated with color photographs.) The causes of failures and successes are analyzed. It is shown how the failures could have been reduced to a manageable amount and, in many cases, eliminated completely with little incremental effort and cost.

Damage to buildings was mainly due to weak connections of light-weight roofing materials, impact damage to glazed openings from flying objects, inadequate fixings of windows and external doors and water damage from the torrential rains. There were also examples of catastrophic collapse of entire buildings due to unsound structural concepts. The lack of maintenance of building components contributed significantly to the damage. The actual wind speeds were not greater than should have been expected in a 1-in-50-year event. The introduction of mandatory building standards and codes would have a significant, positive impact in reducing losses in future hurricanes.

1. Introduction

One of the distressing features of natural hazard events around the world, in general, and in the Caribbean, in particular, is the damage and destruction of health-care facilities at the times when they are most needed. This vulnerability has been recognized by the Pan American Health Organization (PAHO). It is interesting that the health-care profession is in the forefront of promoting safer building standards. In the Caribbean it was the Ministers of Health of the Caribbean Community (CARICOM) that sponsored the preparation of the Caribbean Uniform Building Code (CUBiC). As part of its programme of mitigation PAHO has commissioned studies of the vulnerability of some of the health-care facilities in the Commonwealth Caribbean. A few of these exercises are introduced in the series of case studies presented in this paper. Other studies in this paper were funded by the United Nations Development Programme (UNDP) and the United States Agency for International Development (USAID). For most of the cases presented herein there are fuller reports which can be made available for further study. After the summaries of the individual case studies general observations are made on the following topics:

- Reasons for successes and failures
- Estimated losses – social and economic
- Disaster mitigation before the events
- Disaster mitigation after the events
- Costs incurred in mitigation
- Obstacles encountered in mitigation
- Lessons learned from mitigation exercise

(It is intended that the conference presentation of this paper will be liberally illustrated with color photographs.)
2. Case studies

2.1 The Princess Margaret Hospital, Dominica, 1980

The Princess Margaret Hospital (PMH) was constructed in mid−1950s, a quarter century after the proximate, major hurricane in Dominica. In the morning of 29 August 1979 the roofing of the buildings was sufficiently damaged early in the life of Hurricane David that the delivery of medical care had to be abandoned. The Royal Navy replaced the sheeting of the hospital in quick time soon after the event. This was done as an expedient measure since PMH was the only secondary health−care facility on the island.

During 1980 USAID funded a study to determine what needed to be done to the PMH premises to permit the facility to perform satisfactorily in future severe hurricanes. This study was undertaken by Consulting Engineers Partnership Ltd. (CEP) whose report to USAID was dated September 1980.

A summary of the mitigation actions recommended at the time follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Historic Cost (US$)</th>
<th>1995−equivalent Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sheeting and hurricane straps and other retrofitting actions for roofs</td>
<td>35,300</td>
<td>67,700</td>
</tr>
<tr>
<td>hurricane shutters and other door−&amp;−window retrofitting actions</td>
<td>33,400</td>
<td>64,100</td>
</tr>
<tr>
<td>retrofitting actions for water, electric and telecommunication utilities</td>
<td>55,100</td>
<td>105,700</td>
</tr>
<tr>
<td>Total</td>
<td>123,800</td>
<td>237,500</td>
</tr>
</tbody>
</table>

The total cost is equivalent to US$1,600 per bed in 1995 dollars.

The roof retrofitting was implemented with USAID funding soon after the study. The doors and windows and the utilities were not attended to at that time.

2.2 The PCDPPP studies in the Windward and Leeward Islands, 1985

During the 1980s the Pan Caribbean Disaster Preparedness and Prevention Project (PCDPPP) undertook a series of Surveys of Hurricane Shelters in the Eastern Caribbean from Grenada in the south to the British Virgin Islands in the north. In addition to the shelters, surveys were also carried out of some of the health−care facilities as part of the same programme. The funding for the health−care facilities was provided by PAHO. The studies were executed by CEP.

In each case cost estimates of the retrofitting required to achieve a reasonable level of resistance to hurricanes were prepared. A summary of these costs is given below:

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Facilities Examined</th>
<th>Total Historic Cost of Retrofitting (US$)</th>
<th>1995−equivalent Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antigua</td>
<td>4</td>
<td>234,500</td>
<td>355,700</td>
</tr>
<tr>
<td>British Virgin Islands</td>
<td>3</td>
<td>34,700</td>
<td>48,500</td>
</tr>
<tr>
<td>Dominica</td>
<td>3</td>
<td>174,100</td>
<td>264,200</td>
</tr>
<tr>
<td>St. Kitts &amp; Nevis</td>
<td>4</td>
<td>209,500</td>
<td>317,700</td>
</tr>
<tr>
<td>St. Vincent &amp; The Grenadines</td>
<td>7</td>
<td>399,300</td>
<td>605,700</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>1,052,100</td>
<td>1,591,800</td>
</tr>
</tbody>
</table>

The retrofitting costs average US$75,800 per facility or US$5.22 per person – an infinitesimally small sum.

There is little evidence that the recommendations from this series of studies were implemented.
2.3 Cornwall general hospital, Jamaica, 1988

The Cornwall General Hospital, near Montego Bay, is a well−built, modern hospital of reinforced−concrete and masonry construction. No damage was caused to the primary structures of this complex as a result of Hurricane Gilbert. However, the hospital could not function effectively during and immediately after the hurricane. This was because almost all of the windows on the upper floors were blown in or out or were otherwise broken. In addition, the solar hot−water collector panels suffered substantial losses.

The maximum incremental cost of providing laminated, impact−resistant glass for the windows and providing adequately−strong window frames and fixings would be less than 2% of the contemporary cost of the buildings.

2.4 Glendon Hospital, Montserrat, 1989

The initial news about this hospital after Hurricane Hugo was that it was completely destroyed. On approaching the building three days after the hurricane one could see little wrong with it. The structure was undamaged, none of the windows was broken, there was one cracked glass door, none of the louvered panels was broken, most of the ceiling tiles were still in position and there were patients still being cared for in the wards.

However, most of the roof sheeting had been blown off so that most of the rooms were unusable whenever it rained. Since the roof trusses and purlins were undamaged it would have been easy to replace the roof sheets within a week of the event. (That is exactly what the Royal Navy did at the electric generating station in Plymouth.) In the event, it was more than a year before any attempt was made to install a temporary cover over the roof structure. In the meanwhile a scheme was developed by CEP (with UNDP funding) to use the existing structure to carry a thin concrete roof which would be invulnerable to future Category−4 hurricanes. That scheme was not implemented.

2.5 Victoria hospital, St. Lucia, 1993

A substantial renovation project was started at Victoria Hospital in 1993. Prior to the start of construction activities PAHO funded a Vulnerability Survey (for hurricanes, torrential rains and earthquakes) which was carried out by CEP. The results of this survey included retrofitting recommendations. These are summarized below:

<table>
<thead>
<tr>
<th>Item</th>
<th>Historic Cost (US$)</th>
<th>1995−equivalent Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>structural retrofitting</td>
<td>108,100</td>
<td>109,500</td>
</tr>
<tr>
<td>non−structural retrofitting in buildings</td>
<td>63,000</td>
<td>63,800</td>
</tr>
<tr>
<td>retrofitting of power lines, telecommunications, water storage and drainage</td>
<td>101,500</td>
<td>102,800</td>
</tr>
<tr>
<td>Total</td>
<td>272,600</td>
<td>276,100</td>
</tr>
</tbody>
</table>

This cost is equivalent to US$1,400 per bed.

During the construction stage which followed the study it is understood that some of the recommendations were incorporated in the works.

2.6 Vieux Fort/Soufrière hospital, St. Lucia, 1993

A new private ward is to be added to the District Hospital for La Soufrière and Vieux Fort. The Government of St. Lucia had already prepared most of the construction documents at the time of the PAHO−sponsored Vulnerability Study. That study, carried out by CEP, not only reviewed the plans for the proposed ward but also addressed the existing premises. The main areas of the existing buildings recommended for retrofitting actions were:
• roofs
• windows and external doors
• bracing of sub-structures, particularly for earthquake resistance
• burying of on-site telecommunications and electrical cables

Actions recommended for improving the designs of the proposed private ward included:

• reviewing the geotechnical conditions
• reviewing and bracing the sub-structure elements
• tightening the specifications for wall reinforcement and roofing fixings

Although cost estimates were not prepared for these retrofitting recommendations it was clear that they would be extremely small – certainly less than 1% of the contemporary values of the buildings.

2.7 Health-care facilities in Antigua and St. Kitts, 1995

2.7.1 Antigua

There are 30 Government health-care facilities in Antigua. Of these, 10 suffered significant damage as a result of Hurricane Luis. Cost estimates were prepared by CEP, under contract to PAHO, for the repair of 8 of the damaged facilities and these are summarized below:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Cost of Repairs (in 1995 US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holberton General Hospital</td>
<td>604,300</td>
</tr>
<tr>
<td>Mental Hospital</td>
<td>177,100</td>
</tr>
<tr>
<td>Fiennes Institute</td>
<td>182,600</td>
</tr>
<tr>
<td>Bolans Clinic</td>
<td>8,700</td>
</tr>
<tr>
<td>Swetes Clinic</td>
<td>37,200</td>
</tr>
<tr>
<td>John Hughes Clinic</td>
<td>24,300</td>
</tr>
<tr>
<td>Liberta Clinic</td>
<td>10,100</td>
</tr>
<tr>
<td>Cedar Grove Clinic</td>
<td>31,300</td>
</tr>
<tr>
<td>Total</td>
<td>1,075,600</td>
</tr>
</tbody>
</table>

2.7.2 St. Kitts & Nevis

The principal healthcare facility in St. Kitts is the J N France General Hospital. It has been recognized for a long while that this facility is very vulnerable to earthquakes and hurricanes. The hospital was constructed in the early 1960s. A report dated 1992 indicated that the structure would suffer serious damage in the event of even moderate earthquakes or hurricanes. Indeed there was damage during the passage of hurricane Hugo in 1989 and again during a storm in April 1993. It has been reported that there have been 9 incidents of significant damage by wind and rain to this facility during its 3-decade life.

The damage caused by Hurricane Luis included the loss of louvre panels, 30% of the roof covering, 10% of the roof substrate and collateral water damage to the interior because of the roof damage. The standby generator could not work because of water damage and indeed the hospital was effectively knocked out during the event. The cost of damage due to Hurricane Luis is estimated at US$140,000. However, US$370,000 has been spent during 1995 on repairs and “temporary” improvements at J N France Hospital.

There are three other hospitals in St. Kitts–Nevis. The Mary Childs Hospital suffered minor damage to its roof. Pogson Hospital had some roof damage but the facility was able to function during and immediately after the storm. The Alexander Hospital in Nevis was functional.
3 Reasons for successes and failures (the Antigua case)

3.1 Conceptual design

This is the single most−important factor determining success or failure of buildings. Once again this was demonstrated during Hurricane Luis in Antigua. With respect to hurricanes, suitable design concepts are particularly important for light−weight structures − timber walls; corrugated metal and timber roofs.

Unfavorable features evident in Antigua were:

- L−shaped plans;
- mono−pitched roofs;
- shallow−pitched gable roofs;
- long overhangs at the eaves and gables;
- long overhangs continuous with the main roof;
- corner balconies.

Favorable features evident in Antigua were:

- compact plans;
- hipped roofs;
- steep−pitched gable roofs;
- short overhangs at the eaves;
- canopies discontinuous with the main roof;
- parapets.

3.2 Strength of materials and sizes of construction components

Building materials are supplied in wide ranges of strengths. For example, commonly in Antigua, the ranges of strengths (in newtons per square millimetre − Nmm$^{-2}$) of basic building materials are as indicated below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Lowest Strength</th>
<th>Highest Strength</th>
<th>Range of Strengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>timber</td>
<td>17</td>
<td>105</td>
<td>6.2</td>
</tr>
<tr>
<td>corrugated metal roofing</td>
<td>70</td>
<td>410</td>
<td>5.9</td>
</tr>
<tr>
<td>reinforcing steel</td>
<td>210</td>
<td>460</td>
<td>2.2</td>
</tr>
<tr>
<td>concrete</td>
<td>17</td>
<td>35</td>
<td>2.0</td>
</tr>
<tr>
<td>concrete blocks</td>
<td>5</td>
<td>8</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Clearly, these significant differences must be accounted for in construction. The lack of conscious appreciation of these differences can, and did, lead to failures. (It has to be said that such lack of appreciation also led to some accidental successes.)

As well as strength, brittleness is a factor determining success and failure. The best evidence of this in Antigua was the breakage of corrugated asbestos sheeting used as roofs and sidings.

The sizes of construction components are greatly controlled by strengths of materials. Everything else being equal, the stronger the material the smaller the component size needs to be. Of course, practical considerations and aesthetics also have their influences on sizes. Such influences, when benign, lead to larger−than−necessary sizes from a strength point of view. Inadequate sizing was the contributory factor in some of the observed failures, principally those associated with light−weight roofing.

3.3 Analysis

Several of the Health−care buildings are of such a small scale as would not normally warrant detailed, formal, engineering analysis. They are of domestic scale. Indeed, some of the buildings were built to be residences.
and have been leased by Government for institutional purposes.

Component sizes for small-scale domestic construction are usually determined by tradition and rules of thumb. With the rapid introduction of new materials there isn't the time to develop new traditions. With the rapid expansion of the construction industry there isn't the time to train artisans and craftsmen through apprenticeships, as was done in the past. Rules of thumb are often not known by the new practitioners.

In such an environment some analysis is indicated, even for buildings of modest size. For critical facilities, including all Health-care facilities, analysis must be used to determine or confirm the adequacy of component sizes.

The absence of a conscious engineered approach to many of the buildings was the cause of failures of some components and their connectors. A typical situation is where there is partial failure of the roof covering at gable ends which could be avoided if analysis is done which would identify higher-than-average suction forces in the damaged areas).

3.4 Detailing and connections

In the words of the famous German architect, Mies van der Rohe, "God is in the details". It is difficult to overemphasize the importance of detailing. This is the process of arranging the structural and building elements in such a way that they perform their intended functions by carrying the applied loads safely. Thus the quantity of material may be sufficient but, if the arrangement of the material is inappropriate, failure may result. Thus was evident in some instances in Antigua.

Real-estate people talk about the three most important factors being: "location, location and location". Likewise, for hurricane resistance of lightweight structures, the three important issues can almost be said to be: "connections, connections and connections". The roof sheeting must be adequately connected to the purlins. The purlins must be adequately connected to the rafters. The rafters must be adequately connected to the wall plates. The wall plates must be adequately connected to the wall studs. The wall studs must be adequately connected to the base sleepers. The base sleepers must be adequately connected to the base walls or piers. The piers must be adequately founded. This litany simply says that the wind forces must be carried from wherever they impact on the building all the way into the ground without any weak links along the load path. Hurricanes do excellent jobs of finding weak links in structures and Hurricane Luis certainly found several.

3.5 Quality control during construction

All of the good work in the planning stages can (and often does) become unstuck by faulty construction. It is generally felt that poor construction is responsible for most of the damage in hurricanes. This is not the view of the author. However, poor construction is a contributory factor in a significant minority of the failures. It can also be said that whereas poor construction can undo good design, analysis and detailing; good construction cannot make up for bad design, analysis and detailing.

Antigua's Health-care buildings had their usual share of failures due to poor quality control during construction.

3.6 Non-structural elements

Windows and external doors are the orphans of the construction industry and their acts of revenge for lack of attention can be very embarrassing. Usually engineers are not involved in the specification of these items. Usually architects are not equipped to determine the strength requirements for these items. Usually suppliers and contractors cannot be relied on to provide more than the commercial norm, which is inadequate for Category-4 hurricanes (a reasonable requirement for Health-care buildings in Antigua). There were several failures to be seen, which is not surprising. The failures were sometimes of the fixings to the walls. At other times glass was broken by flying objects. The only ways to deal with vulnerability to breakage are hurricane shutters and laminated glass. The latter approach would still lead to breakage but the weather would be
excluded during the hurricane.

Electrical systems within the Holberton Hospital compound suffered because the power distribution lines were placed overhead. (There may have been other problems as well.) Although the loss of mains power is likely during a major hurricane, the stand−by plant of the Health−care facility should be able to do its job. On−site, low−voltage, underground distribution systems are highly desirable and economical.

Water supply is a problem in normal times in Antigua. Because of that many of the Health−care facilities had water−storage tanks. However, many (or most) of them were of little practical use after Hurricane Luis. The reason were several:

- Lack of cleaning of the tank
- No means of extracting the water from the tank
- Lack of security with the resulting emptying of the tank by neighbors in need
- Leaking walls leading to insufficient water in the tank
- Roof gutters not connected to the tank

Most of the telephones in the Healthcare facilities were working within a few days of Hurricane Luis. This utility was less vulnerable than water and electricity. As with electricity, it is advisable to place telephone cables underground at least within the boundaries of Health−care facilities.

The inadequacy of storm−water drainage can lead to much damage. There was some (not a lot) of evidence of this at the Healthcare facilities. Not enough attention is paid to this aspect of design. Even where drainage is consciously engineered, design criteria are usually inadequate, especially for critical facilities, which warrant higher−than−normal standards.

3.7 Maintenance

On the television programme CNN&Company of 13 December 1995 the main topic was urban infrastructure. The problem of decaying roads, bridges, water supply systems and sewerage systems was the subject of much debate. The cost, and political unpopularity, of preventative maintenance was recognized. It was also recognized that preventative maintenance was less expensive, in the long run, than emergency repairs and reconstruction brought about by inadequate maintenance. So it can be seen that even the wealthiest of nations won't willingly spend the funds necessary for proper preventative maintenance.

The inadequacy of preventative maintenance or, in some cases, the apparent total absence of maintenance over a long period is probably the second most important cause of much of the damage to be seen in Antigua's Healthcare Buildings.

4. Estimated losses−social and economic

Where they are available, the direct costs of damage to health−care facilities due to hurricanes has been given in the case studies presented earlier in this paper. Social and economic (as opposed to financial) costs are more difficult to quantify.

Experience has shown that the loss of a country's healthcare facilities can have a traumatic effect on its population. The loss of confidence is noticeable. There is also the practical problem posed by the tourist industry, which is vital to most of these Caribbean territories. Overseas visitors, most of whom are from metropolitan countries, feel uncomfortable and insecure when visiting states which cannot deal with secondary and tertiary healthcare issues when they arise. Although the care of the local population is the most important requirement, one cannot ignore the needs of the temporary visitor.

5. Disaster mitigation before the events

Prevention is better than cure. How often have we heard that said and how difficult it is to live by that tenet.
Disaster mitigation is best practiced by integrating the process in the everyday and every−year actions of an organization. An analogy can be drawn with environmental issues. It has come to be taken for granted that impacts of our actions on the environment must be considered at all times. This applies not only to new projects but also to ongoing activities. In the same way that environmental impact assessments (EIAs) are now a routine precondition to capital works projects, so too should natural hazard impact assessments (NHIAs) be a condition precedent to all public works, especially those related to critical facilities such as healthcare buildings.

With respect to existing buildings, mitigation actions need not be regarded as expensive "crash" programmes. One approach is to integrate mitigation measures into routine maintenance, repairs and replacements. There are many components in hospitals and clinics which have shorter lives than the main structure. Such items are commonly replaced several times during the life of the main structure. They may include doors, windows and roof coverings. These are typically the most vulnerable parts of buildings in hurricanes. When the time comes to replace such items, for reasons of wear and tear, they can readily be replaced with less vulnerable products and be more−securely fixed at very small incremental costs.

This is a low−key approach to mitigation. It must not be thought, however, that life will always be so simple. Greater problems are present in many existing buildings, where the solutions are commensurately complex and costly.

6. Disaster mitigation after the events

In the aftermath of a disaster the focus is understandably on getting healthcare facilities to function again as soon as possible. Also, technical personnel and financial resources are spread very thin. This combination of factors often leads to repairs being carried out in an expedient manner without adequate attention to safety issues. Indeed, post−disaster repairs often leave the buildings even more vulnerable than they were in their pre−disaster, inadequate states.

If such a normal scenario is to be avoided, very deliberate steps must be taken by the custodians of the health−care facilities. Such actions would include:

• clear instructions (on performance criteria for natural hazards) given to engineers, architects and contractors involved in repairs and rehabilitation;

• a willingness to accept (temporarily) smaller functioning spaces or fewer beds if the repair funding is inadequate to achieve safe standards for all of the damaged facilities;

• the employment of a mitigation officer to review and monitor the designs and construction so as to ensure that the agreed performance criteria are being met.

7. Costs incurred in mitigation

If it is assumed that an existing facility is just satisfactory for a Category−2 hurricane (likely to occur once every generation in most Caribbean islands) then the cost of upgrading that facility to Category−3 standard could be stated as:

$1.00 of mitigation is equivalent to $50.00 reduction in potential losses.

If it is assumed that an existing facility is just satisfactory for a Category−3 hurricane (likely to occur once every two generations in most Caribbean islands) then the cost of upgrading that facility to Category−4 standard could be stated as:

$1.00 of mitigation is equivalent to $20.00 reduction in potential losses.
It could be argued that the appropriate standard for general hospitals in countries which only possess one such facility is a Category–5 hurricane for most Caribbean states. The cost of upgrading a Category–4 facility to Category–5 standard could be stated as:

\[
$1.00 \text{ of mitigation is equivalent to } $5.00 \text{ reduction in potential losses.}
\]

8. Obstacles encountered in mitigation

Hurricanes are low–frequency events. Damaging hurricanes in post–Columbian times in the Caribbean are summarized in the following table:

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of known, significant hurricane events since 1492</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anguilla</td>
<td>9</td>
</tr>
<tr>
<td>Antigua</td>
<td>36</td>
</tr>
<tr>
<td>Bahamas</td>
<td>72</td>
</tr>
<tr>
<td>Barbados</td>
<td>52</td>
</tr>
<tr>
<td>Barbuda</td>
<td>8</td>
</tr>
<tr>
<td>Belize</td>
<td>27</td>
</tr>
<tr>
<td>Bermuda</td>
<td>44</td>
</tr>
<tr>
<td>Virgin Islands</td>
<td>31</td>
</tr>
<tr>
<td>Cayman Islands</td>
<td>17</td>
</tr>
<tr>
<td>Cuba</td>
<td>150</td>
</tr>
<tr>
<td>Dominica</td>
<td>43</td>
</tr>
<tr>
<td>Dominican Republic</td>
<td>62</td>
</tr>
<tr>
<td>Grenada</td>
<td>10</td>
</tr>
<tr>
<td>Guadeloupe</td>
<td>49</td>
</tr>
<tr>
<td>Guyana</td>
<td>0</td>
</tr>
<tr>
<td>Haiti</td>
<td>30</td>
</tr>
<tr>
<td>Jamaica</td>
<td>65</td>
</tr>
<tr>
<td>Martinique</td>
<td>41</td>
</tr>
<tr>
<td>Montserrat</td>
<td>13</td>
</tr>
<tr>
<td>Nevis</td>
<td>24</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>94</td>
</tr>
<tr>
<td>St. Eustatius</td>
<td>16</td>
</tr>
<tr>
<td>St. Kitts</td>
<td>80</td>
</tr>
<tr>
<td>St. Lucia</td>
<td>16</td>
</tr>
<tr>
<td>Sint Maarten &amp; Saba</td>
<td>14</td>
</tr>
<tr>
<td>St. Vincent</td>
<td>9</td>
</tr>
<tr>
<td>Tobago</td>
<td>8</td>
</tr>
<tr>
<td>Trinidad</td>
<td>14</td>
</tr>
<tr>
<td>Turks and Caicos</td>
<td>13</td>
</tr>
</tbody>
</table>

Because of the long periods between hurricanes in any one community it is very difficult to persuade policy makers to give proper attention to the issue of mitigation. In the parliamentary democracies of the region, where the life of a parliament is a maximum of 5 years, the 1–in–50–year event is not considered a priority.

Also, destruction by hurricanes are commonly regarded as an "act of God" and therefore not preventable. This phrase is even enshrined in the laws of these countries and in the insurance policies of the region.
9. Lessons learned from mitigation exercises

The principal lesson to be learned from mitigation is that it is a worthwhile exercise however little may be done. Hurricanes come in a variety of strengths. The definition of a hurricane includes a minimum wind speed of 33 meters per second. That is the lower bound of the phenomenon. There is, in theory, no upper bound but wind speeds in hurricanes have not been reliably measured greater than 100 meters per second. Because the force of the wind varies as the square of its speed, the two extremes given above would produce a nine–fold difference in wind forces. The table below gives a convenient, comparative measure of the common range of hurricanes according to the Saffir–Simpson Scale:

<table>
<thead>
<tr>
<th>Hurricane Category</th>
<th>Wind Speed in meters per second</th>
<th>Wind Speed in miles per hour</th>
<th>Damage Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC1</td>
<td>33–42</td>
<td>74–95</td>
<td>Minimal</td>
</tr>
<tr>
<td>HC2</td>
<td>43–49</td>
<td>96–110</td>
<td>Moderate</td>
</tr>
<tr>
<td>HC3</td>
<td>50–58</td>
<td>111–130</td>
<td>Extensive</td>
</tr>
<tr>
<td>HC4</td>
<td>59–69</td>
<td>131–155</td>
<td>Extreme</td>
</tr>
<tr>
<td>HC5</td>
<td>&gt;69</td>
<td>&gt; 155</td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

Statistical evidence is that, everything else being equal, the more severe the hurricane the less frequent its occurrence. Therefore, improving a building from Hurricane–Category–1 (HC1) standard to HC2 standard is worthwhile, even though an HC4 standard may be the appropriate one. That is because the statistical interval between damaging events for an HC2 building is greater than the statistical interval between damaging events for an HC1 building. In other words it should not be said that, unless the "correct" standard can be achieved, nothing should be attempted. Any improvement is worthwhile.

Hospitals under the new Colombian legislation on seismic protection: Demonstrating political commitment to risk mitigation

by

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Executive summary

The most important risk mitigation activity that the Government of Colombia has undertaken in the legal sphere, since the creation of the National System for Disaster Prevention and Relief in 1988 and its regulations the following year, has been the decision to update seismic standards and propose legislation to the Congress of the Republic establishing new seismic–resistant requirements reflecting current knowledge and the state of the art.

The new law imposes more exacting requirements for the design and construction of new hospitals so that service can be maintained even in the event of strong earthquakes. It also defines the minimum scope of the technical studies required to evaluate the structural vulnerability of existing hospitals to seismic activity. Finally, the law requires that all hospitals at the secondary and tertiary levels of complexity situated in areas of intermediate or high seismic risk be evaluated within 3 years of the date the law takes effect and that they be retrofitted or reinforced within a 6–year period.

The legislation is the product of a coordinated effort among professionals in the field and legal advisers from the Ministry of the Interior and the Ministry of Economic Development. The provisions of the law reflect the
analytical expertise amassed in evaluations of the seismic vulnerability in several hospitals conducted by the Ministry of Health, the National Office for Disaster Prevention and Relief, and the Colombian Association of Seismic Engineering.

A favorable interinstitutional environment

It is well known that the United Nations General Assembly declared the 1990s the International Decade for Natural Disaster Reduction, due to the increase and severity of disasters in recent years, particularly in developing countries. A few years earlier, the Government of Colombia had sought to promote risk mitigation and incorporate disaster prevention into its economic and social planning. After 2 years of deliberation in the Congress of the Republic, legislation was passed in 1988 creating the National System for Disaster Prevention and Relief, which together with the corresponding regulatory code issued 6 months thereafter, defined the functions and responsibilities of institutions at the national, departmental, and local levels.

The system was implemented through established government agencies at each level and was designed to function under a decentralized scheme through Committees for Disaster Prevention and Relief made up of public and private sector entities at the departmental and municipal levels. The Committees work in a decentralized fashion and, according to their purview, engage in interinstitutional activities in technical and scientific areas, planning, emergency preparedness, and community participation for the purpose of helping to instill a sense of prevention in the culture and ensuring consideration of risk mitigation in the socioeconomic development of the country.

Thus, in 1988 under the guidance and coordination of the National Office for Disaster Prevention and relief, work was undertaken at each territorial level to promote disaster prevention and mitigation and strengthen emergency preparedness, creating a favorable environment that in many cases would be effective in fostering political commitment at the national, departmental, and municipal levels.

Other significant developments that have transpired since that time include: in the scientific and technical areas, significant investment in the research, drafting and proper use of maps indicating natural hazards; in planning, the incorporation of risk mitigation into a large number of development and urban zoning plans; in the area of education and citizen participation, the first curricular adaptations, broad dissemination of public information on the subject, and commitment to strengthening linkages among civic organizations; in the area of emergency preparedness, new laws that have strengthened the fire departments, and the formation of a national network of centers for stocks and supplies.

Perhaps even more important has been the passage of extensive new laws on disaster prevention and relief in different areas of development in response to the pressures of modernization; for example, organizational standards on the apportionment of geographical jurisdictions, a statute on contracting, urban reform, publicly subsidized housing, the environment, agrarian reform, health and social security, and education.

Without underestimating these achievements or the way in which the new Colombian legislation has gradually come to grips with risk reduction and emergency relief, it can be stated that the most significant development in recent years is probably the commitment of the National Government to updating national earthquake standards in terms of technology, even though the regulations are relatively recent, since the current seismic-resistant construction code dates back to 1984.2

2 This standard was widely accepted among engineers, the construction industry, and the community. The additional cost of structural compliance with the code, imposed in extreme cases in areas of high seismic hazard, never exceeded 20%, which corresponds to a maximum of 6% of the total cost of a building.

One of the main reasons that seismic regulations were amended at the national level was because of the policy decision to improve the level of safety in new and existing hospitals and to identify instances in which the design and construction of many hospitals has left them vulnerable to serious damage, which not only could interfere with services in the immediate wake of an earthquake, but would also expose hospital occupants to danger, particularly in older structures built without the benefit of any seismic-resistant standards.

The new seismic-resistant standards introduce clear changes in a broad range of areas beyond the scope of this document. However, the most innovative features concern hospital protection requirements, which may constitute a useful model for other countries in the Region.
The new seismic standard and the hospitals

As a result of earthquakes around the world over the last 10 years, new lessons on structural behavior were drawn, and the Colombian Association of Seismic Engineering (AIS) decided to amend its Standard AIS−100−83, which served as the basis for the Colombian Code of Seismic−Resistant Construction adopted by the National Government under a 1984 executive order.

The Colombian Association of Seismic Engineering is a nonprofit, nongovernmental organization where qualified engineers devote their free time to academic and technical pursuits. Therefore, in order to ensure that the standard would be revised in the shortest time possible, the National Office for Disaster Prevention and Relief chose to enter into an agreement to support AIS in this work and reimburse it for direct expenditures incurred. Following extensive public debate among the Colombian engineering community and votes and discussions held by the AIS, Standard AIS−100−95 was issued as a technical and legal foundation upon which to draft legislation that the Minister of the Interior and the Minister of Economic Development would jointly present to Congress.

One of the concerns that led the National Government to expedite a new standard was the concern in the Ministry of Health and the National Office for Disaster Prevention and Relief over the seismic response of hospital buildings. The designs of most hospitals predate the seismic−resistant standard issued in 1984. Although the most recent hospitals have somewhat stricter seismic requirements, they will not sufficiently control the damage or prevent the functional collapse caused by moderate or strong earthquakes, which unfortunately occurs, notwithstanding most seismic codes in effect around the world.

Previously, the Ministry of Health and the National Office for Disaster Prevention and Relief took advantage of documentation provided by PAHO and the support of AIS to promote the study of structural seismic vulnerability in several tertiary−level university hospitals. They were able to obtain the commitment of some departments and municipios to use their own resources in the post−design phase of retrofitting and reinforcement. Two significant gaps were detected in this process: First, there were no terms of reference to define the minimum technical scope for structural vulnerability studies or the degree of protection or safety that hospital retrofitting should provide. Second, a requirement for these types of studies and works was needed at the national level and at the level of sectional services and departmental and municipal health departments commensurate with the political, administrative, and fiscal decentralization process in the country.

Thus, the issue of a new national seismic standard created an opportunity to legislate important aspects of hospital structural safety, which will be mentioned, without the detailed technical analyses, in the following sections.

The design of new hospital buildings

For design purposes, construction codes usually establish a coefficient of importance for the buildings that are going to be constructed, normally classified in one of three usage groups (I, II, and III). Hospitals have always been part of group III, by virtue of their special importance in serving the community in emergency situations. In contrast to the 1984 norm, the new Colombian standard establishes a fourth usage group (IV), labeled Essential Buildings. This usage group has a higher coefficient of importance; thus, the design must take into account seismic forces 30% higher than those considered for the design of a conventional building (Group I). Group III buildings, which have previously included hospital buildings, will continue to be designed for seismic forces 20% higher than under the standard now in effect.

**USAGE GROUP IV** – Essential Buildings: These are community buildings that must function during and after an earthquake, whose operations are not readily transferable to alternate sites; secondary− and tertiary−level hospitals, power plants, and control points for major power lines.

**USAGE GROUP III** – Community Buildings: These buildings are necessary for services during emergencies, health protection, and personal safety, such as: fire stations, police stations, and military barracks, health facilities, and the headquarters of agencies for emergency operations.
The other groups (I and II) under the new standard remain unchanged; conventional residential and office buildings, and buildings with significant public access.

Due to the importance of maintaining a community service capability in the aftermath of a moderate or strong earthquake, the new Colombian standard requires that hospitals be designed for maximum probable seismic movement and for seismic movement at the damage threshold, which should not affect the structure of the building or the nonstructural elements the hospital needs to maintain service and operations.

**SCOPE:** The special requirements of this Chapter [in the legislation] should be employed in the design of essential buildings in Usage Group IV and of other structures so designated by the community.

**METHODOLOGY:** A determination of whether a building is operational in the aftermath of an earthquake can be made by confirming that the building remains within the range of elastic response when subjected to seismic forces equivalent to the initiation of damage or the damage threshold.

The kind of earthquake for which this verification is made is defined as one whose probability of being exceeded within a 15-year period is 80%; that is, a relatively common earthquake that should not result in damage to the building.

*Design seismic movement* should ensure that deformations and shifts of different floors in a building should not exceed – in the case of a portal frame structure – a 1.00% drift (that is, one hundredth of the floor height).³ *Seismic movement at the damage threshold* should not exceed 0.10%, which is one tenth the maximum drift allowed each floor in response to the probable maximum earthquake of design. This requirement guarantees that a moderate or strong earthquake (the severity of which is less than that of the maximum design earthquake) will not cause structural or nonstructural damage, thereby avoiding, whenever possible, the functional collapse of a building as a result of frequent seismic activity.

³ This requirement in the new standard is more strict than in the previous one, which means greater stiffness of structure in order to prevent deformations or excessive shifts that place the nonstructural elements at risk in the event of an earthquake. An economic analysis indicates that this new requirement will increase the cost of the structure by no more than 5 % in most cases.

In addition, the new Colombian standard, unlike the previous one, requires the *design of nonstructural elements*, such as facings, architectural and decorative components, water and sanitation facilities, electric installations, mechanical equipment, and special facilities. It also defines a minimum *level of performance* that these elements should meet, requiring maximum or *superior* performance in the case of hospitals.

**SUPERIOR:** This level is one in which the damage presented in nonstructural elements is minimal, and the occurrence of an earthquake does not interfere with the operation of the building.

Thus, the design force used to calculate the stability and resistance of nonstructural elements is determined by a *performance coefficient* defined in accordance with the *level of performance*, which is more exacting for hospitals.

The design of new hospital buildings in Colombia is therefore more exacting under the recently updated regulation, which takes into account important safety aspects that previous codes overlooked. New hospitals will now be better protected and safer, not only in terms of their occupants in the event of very strong earthquakes, but also in terms of their continuity of service and functionality after moderate and strong earthquakes, which commonly occur.

**Evaluation and retrofitting of existing hospitals**

In contrast to most codes – the previous Colombian standard, in particular – the new regulations include an entire chapter on the evaluation of vulnerability in standing buildings and bringing them into compliance with the new code.
SCOPE: This Chapter establishes the criteria to be followed in order to make additions, modify, or remodel the structural system of buildings designed and constructed before the current version of the Colombian Earthquake-Resistance Standards took effect.

SEISMIC VULNERABILITY ANALYSIS: The criteria presented in this Chapter can be used to verify the seismic vulnerability of existing buildings constructed before the current Standard took effect, thereby showing the comparative level of safety vis-a-vis the level that the Standard would require in a new building.

The chapter includes evaluation and design procedures, criteria for analyses and studies, considerations for modifying building heights or attached buildings, retrofitting of the structural system, and rating seismic vulnerability prior to and after retrofitting a building.

It is important to note that the structural retrofitting of a hospital building under these regulations must take into account all the aspects described in the previous paragraph, as would be required in the design and construction of a new building.

For the verification of the seismic vulnerability of hospital buildings the Standard requires greater rigor and technical expertise on the part of the assessing engineer so that state-of-the-art techniques are applied.

ESSENTIAL BUILDINGS: Verification of seismic vulnerability in essential buildings should also cover the following:

(a) Determination of basal resistance to flexure and shearing stresses of the building in its entirety in order to verify the different possible mechanisms of collapse. This verification can examine the distribution of horizontal forces in the vertical parameter either as prescribed by the method of equivalent horizontal force or through dynamic analysis.

(b) Through a well-grounded evaluation using static procedure, the verification should define the dominant mode of weakness, whether from flexure or shearing. The “R” value of the response modification coefficient that is used should be compatible with the support indicated. The sequence of degradation of stiffness and resistance should be determined and its influence on seismic vulnerability should be explicitly studied.

These specifications – a challenge to anyone not well versed in the area – make it necessary for the engineer who performs work of this nature to have special qualifications. All these cases call for an engineer of the highest professional level and tile use of the most advanced techniques available anywhere in the world, due to the enormous responsibility and costs entailed in protecting the safety of human life and the security of the type of social service provided in hospital buildings. These provisions accord the same special importance to this type of building that is accorded important engineering works such as bridges, dams, and power plants, whose social and economic costs are very high.

Thus, the new Colombian seismic standard establishes the minimum criteria and procedures for undertaking a study of structural and nonstructural seismic vulnerability. It defines terms of reference that had not previously been established, which are a source of concern, given the proliferation of simplified or rough methods that are inadequate for these purposes and that can only be used to prioritize or classify the general status of more complex buildings. Simplified evaluations, which tend to be more qualitative than quantitative, can only be used in the case of smaller buildings or unimportant structures. They may be inadequate for deciding on the significant and often substantial monetary investments for retrofitting or decreasing the vulnerability of existing buildings.

The compulsory nature of evaluation and retrofitting

In addition to the technical requirements mentioned in the previous sections, the new Colombian standard establishes by law that the existing hospitals of a higher complexity level situated in areas of high seismic hazard should be evaluated for vulnerability within a period of 3 years and retrofitted or reinforced within 6 years. Therefore, the National, departmental, and municipal governments should make allocations for these expenditures in their budgets in the coming years, and the governments should adjust for this type of investment in the future when drafting development plans at every jurisdictional level.
BRINGING ESSENTIAL BUILDINGS INTO COMPLIANCE: Standing structures, which are classified as essential buildings on the basis of their use and are situated in areas of high and intermediate seismic hazard, should be evaluated for seismic vulnerability as per the procedures established for this purpose in the regulations within a period of 3–years from the date the current law takes effect.

These buildings should be retrofitted or reinforced so they will to the level of seismic safety equivalent to that of a new building designed and constructed as per the requirements of the current law and its regulations within a period of 6–years from the date the current law takes effect.

The Ministry of Health and the National Office for Disaster Prevention and Relief can use this legal instrument throughout the country to strengthen the program to promote seismic vulnerability studies and the retrofitting and reinforcement of hospitals, when necessary. This work can be fostered by coordinating national, departmental, and in some cases, municipal activities through cofinancing and counterpart funding processes established by the Ministry of Health, the Social Investment Fund, and the National Calamities Fund in accordance with the constitutional principles of consensus, complementarily, and decentralization. Thus, while not every hospital building (of the secondary and tertiary levels of complexity in areas of high and intermediate seismic hazard) will be able to meet the 3 and 6–year deadlines prescribed by the law, the standard will still introduce progress in this area and encourage political commitment at the regional and local levels, which in Colombia are the jurisdictions responsible for this kind of enforcement. Prior to this regulation, regional and local political commitment to proceeding with the design phase for retrofitting several important hospitals had already been demonstrated in some cases. With the regulation now in effect and its promotion and dissemination duly undertaken, greater coverage and results will be achieved and will lead to greater safety and protection for the health infrastructure of the country.

Permanent advisory commission on the standard

Since the Standard will continue to evolve as technology develops, the governing law provides for an interinstitutional Permanent Advisory Commission to decide on opportune changes that can be expedited through executive order This process will enable future technical amendments to be made in the Standard without the need for new legislation – which otherwise would have required congressional passage (as did the current law).

PERMANENT ADVISORY COMMISSION A “Permanent Advisory Commission for the Administration of Seismic–Resistant Construction” of the National Government is hereby established for interpretation and application of seismic–resistant construction standards. It will operate under the Ministry of Economic Development and form part of the National System for Disaster Relief and Prevention.

UPDATING OF THE TECHNICAL AND SCIENTIFIC ASPECTS OF THE LAW: The National Government is empowered, once approval is granted by the Permanent Commission created through this Law, and Regulatory Decrees, to make amendments to the technical and scientific aspects of this law and its regulations, which are needed and are opportune for the purposes indicated therein and within its scope.

The Permanent Advisory Commission consists of the President of the Republic, the Ministers of the Interior, Development, and Transportation or their designated representatives, the Director General of INGEOMINAS, and the Presidents of the Colombian Association of Seismic Engineering (AIS), the Colombian Society of Engineers (SCA), the Colombian Society of Architects (SCA), the Colombian Association for Structural Engineering (ACIES) or their designated representatives, and a delegate elected to represent the associations of the construction industry. AIS will serve as the secretariat of the commission.

One of the most important aspects of the membership of the commission is the role of associations as representatives of organized civil society, for while they are consultative bodies of the State, they are nongovernmental organizations that have special weight in the technical determinations made under the Standard and its applications.

In view of its technical leadership, the Permanent Advisory Commission will play a fundamental role in defining the scope of vulnerability studies and designs for hospital retrofitting. It can address all questions that arise in this regard from each specific project and authorize certain partial solutions when it is demonstrated
that the desired safety levels required by the standard cannot be met, thereby exempting the designers and officials involved in this type of exceptional project from certain kinds of liability.

**PROFESSIONALS AND OFFICIALS:** Professionals who undertake or permit the undertaking of construction works in violation of the prescriptions, standards, and provisions of this law and its regulations will be in violation of the Code of Professional Ethics and can be sanctioned by the National Professional Council of Engineering and Architecture or the corresponding Professional Councils, or the body with which they are affiliated, through the suspension or cancellation of professional accreditation, as appropriate, in the manner provided for under the law without prejudice to other civil and criminal actions that may be taken.

**PARAGRAPH:** Professionals of official agencies who authorize any form of construction work in violation of the prescriptions, standards, and provisions of this law and its regulations will incur the same sanction. In addition, such officials and persons who, although lacking qualifications as engineers or architects, authorize such works will be incurring through improper conduct in grounds for sanction by suspension or dismissal, as appropriate, without prejudice to other civil or criminal actions that may be taken.

This regulation holds officials and professionals as well as private proprietors and builders responsible. They are subject to fines that may be imposed for purposes of enforcement, with the amount being determined by the number of square meters of construction in violation of the regulation and the time elapsed without the taking of corrective measures or the demolition of the construction, also without prejudice to other civil and criminal sanctions that may be appropriate due to damages, negligence, or acts of omission.

What this situation means, in effect, is that in Colombia the vulnerability study, or diagnostic, will be combined in a single phase with the design for retrofitting or reinforcement of the existing buildings because the civil and criminal liabilities for willfully ignoring the result of a seismic vulnerability analysis and failing to design solutions are very high. Only an effective showing of insufficient resources with which to perform tile retrofitting or physical adaptation (though not the design itself) would absolve from liability the officials, proprietors, or authorities involved in these types of decisions on which hang the safety of human life and the security of health care for the community in the event of a public calamity.

From the legal standpoint, failure to take the minimum precautions that technology allows constitutes a clear case of negligence. It is now clear that technological progress and the methods of predicting the consequences of natural events have transformed the concept of "force majeure," "fortuitous acts, " or "acts of God, " which cease to be absolute principles that exonerate responsibility and now become relative elements that are a function of scientific development. In the case at hand, seismic risk – that is, the potential economic and social consequences of earthquakes – does not just depend on indications of intense seismic activity at a given site (i.e., the probability of an event as determined by a study of generating mechanisms and past events, which can be calculated). Vulnerability or conditions of resistance, tile fragility of structures exposed to phenomena also come into play, and they too are subject to estimates or determinations, given the current state of knowledge.

**References**


Annex – structure of the new Colombian seismic standard

Error! The new version of the Colombian Standard of Earthquake–Resistant Construction is structured similarly to Executive Order 1400 of 1984. The law is organized by Titles, each of which concerns a given subject. The seven Titles of Executive Order 1400 of 1984 were revised and five new Titles were added. In addition, some new Chapters were introduced into existing Titles of Executive Order 1400 of 1984.

The current version is as follows:

<table>
<thead>
<tr>
<th>TITLE</th>
<th>CONTENTS</th>
<th>OBSERVATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>GENERAL EARTHQUAKE RESISTANT DESIGN AND CONSTRUCTION REQUIREMENTS</td>
<td>Amended</td>
</tr>
<tr>
<td>B</td>
<td>CHARGES</td>
<td>Amended</td>
</tr>
<tr>
<td>C</td>
<td>STRUCTURAL CONCRETE</td>
<td>Amended</td>
</tr>
<tr>
<td>D</td>
<td>STRUCTURAL MASONRY</td>
<td>Amended</td>
</tr>
<tr>
<td>E</td>
<td>ONE– AND TWO–STORY HOMES</td>
<td>Amended</td>
</tr>
<tr>
<td>F</td>
<td>METALLIC STRUCTURES</td>
<td>Amended</td>
</tr>
<tr>
<td>G</td>
<td>WOODEN STRUCTURES</td>
<td>New</td>
</tr>
<tr>
<td>H</td>
<td>GEOTECHNICAL STUDIES</td>
<td>New</td>
</tr>
<tr>
<td>I</td>
<td>TECHNICAL SUPERVISION</td>
<td>New</td>
</tr>
<tr>
<td>J</td>
<td>FIRE REQUIREMENTS</td>
<td>New</td>
</tr>
<tr>
<td>K</td>
<td>PERMANENT COMMISSION FOR THE CODE</td>
<td>New</td>
</tr>
<tr>
<td>L</td>
<td>SANCTIONS AND RESPONSIBILITIES</td>
<td>Amended</td>
</tr>
</tbody>
</table>

Impact of hurricanes on health facilities

CASE STUDIES
for presentation at the International Conference on Disaster Mitigation in Health Facilities

by
Tony Gibbs
Consulting Engineers Partnership Ltd.
Barbados

0. Synopsis

Throughout the world, including the Caribbean, natural hazards cause as much damage to healthcare facilities as they do to less–important buildings. This is both regrettable and avoidable.

It is often said that safe buildings may not be affordable, especially in relatively–poor developing countries. This is a fallacy. Particularly with respect to hurricane resistance, safe buildings are not only technically feasible but also achievable at very modest cost. This thesis has been tested and confirmed on several occasions over the years. In recent times several case studies have been carried out through international agencies such as the Pan American Health Organization. Some of these studies are presented here.

Hurricane Luis struck the independent island state of Antigua & Barbuda in the north–east Caribbean on 4 and 5 September 1995. Luis was a classical, Category–4 storm, almost perfectly formed, large in extent, loaded with moisture, with a very distinct eye of 70 kilometers in diameter and a forward motion of 17 kilometers per hour. Because of its overall size and slow forward motion, the hurricane impacted on Antigua for an uncommonly long period.

The level of damage in Antigua was equivalent to two–thirds of the gross domestic product of the country. Such an event has the potential to set back the development of a small island independent state by several years. In particular, much damage was done to essential facilities in the country.
This paper focusses on the health sector. The nature and extent of the damage are described and illustrated. (It is intended that the conference presentation of this paper will be liberally illustrated with color photographs.) The causes of failures and successes are analyzed. It is shown how the failures could have been reduced to a manageable amount and, in many cases, eliminated completely with little incremental effort and cost.

Damage to buildings was mainly due to weak connections of light-weight roofing materials, impact damage to glazed openings from flying objects, inadequate fixings of windows and external doors and water damage from the torrential rains. There were also examples of catastrophic collapse of entire buildings due to unsound structural concepts. The lack of maintenance of building components contributed significantly to the damage. The actual wind speeds were not greater than should have been expected in a 1-in-50-year event. The introduction of mandatory building standards and codes would have a significant, positive impact in reducing losses in future hurricanes.

1. Introduction

One of the distressing features of natural hazard events around the world, in general, and in the Caribbean, in particular, is the damage and destruction of health-care facilities at the times when they are most needed. This vulnerability has been recognized by the Pan American Health Organization (PAHO). It is interesting that the health-care profession is in the forefront of promoting safer building standards. In the Caribbean it was the Ministers of Health of the Caribbean Community (CARICOM) that sponsored the preparation of the Caribbean Uniform Building Code (CUBiC). As part of its programme of mitigation PAHO has commissioned studies of the vulnerability of some of the health-care facilities in the Commonwealth Caribbean. A few of these exercises are introduced in the series of case studies presented in this paper. Other studies in this paper were funded by the United Nations Development Programme (UNDP) and the United States Agency for International Development (USAID). For most of the cases presented herein there are fuller reports which can be made available for further study. After the summaries of the individual case studies general observations are made on the following topics:

- Reasons for successes and failures
- Estimated losses – social and economic
- Disaster mitigation before the events
- Disaster mitigation after the events
- Costs incurred in mitigation
- Obstacles encountered in mitigation
- Lessons learned from mitigation exercise

(It is intended that the conference presentation of this paper will be liberally illustrated with color photographs.)

2. Case studies

2.1 The Princess Margaret Hospital, Dominica, 1980

The Princess Margaret Hospital (PMH) was constructed in mid-1950s, a quarter century after the proximate, major hurricane in Dominica. In the morning of 29 August 1979 the roofing of the buildings was sufficiently damaged early in the life of Hurricane David that the delivery of medical care had to be abandoned. The Royal Navy replaced the sheeting of the hospital in quick time soon after the event. This was done as an expedient measure since PMH was the only secondary health-care facility on the island.

During 1980 USAID funded a study to determine what needed to be done to the PMH premises to permit the facility to perform satisfactorily in future severe hurricanes. This study was undertaken by Consulting Engineers Partnership Ltd. (CEP) whose report to USAID was dated September 1980.

A summary of the mitigation actions recommended at the time follows:

<table>
<thead>
<tr>
<th>Item</th>
<th>Historic Cost (US$)</th>
<th>1995-equivalent Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item 1</td>
<td>57</td>
<td></td>
</tr>
</tbody>
</table>

57
sheeting and hurricane straps and other retrofitting actions for roofs 35,300 67,700

hurricane shutters and other door-&-window retrofitting actions 33,400 64,100

retrofitting actions for water, electric and telecommunication utilities 55,100 105,700

Total 123,800 237,500

The total cost is equivalent to US$1,600 per bed in 1995 dollars.

The roof retrofitting was implemented with USAID funding soon after the study. The doors and windows and the utilities were not attended to at that time.

2.2 The PCDPPP studies in the Windward and Leeward Islands, 1985

During the 1980s the Pan Caribbean Disaster Preparedness and Prevention Project (PCDPPP) undertook a series of Surveys of Hurricane Shelters in the Eastern Caribbean from Grenada in the south to the British Virgin Islands in the north. In addition to the shelters, surveys were also carried out of some of the health-care facilities as part of the same programme. The funding for the health-care facilities was provided by PAHO. The studies were executed by CEP.

In each case cost estimates of the retrofitting required to achieve a reasonable level of resistance to hurricanes were prepared. A summary of these costs is given below:

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Facilities Examined</th>
<th>Total Historic Cost of Retrofitting (US$)</th>
<th>1995-equivalent Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antigua</td>
<td>4</td>
<td>234,500</td>
<td>355,700</td>
</tr>
<tr>
<td>British Virgin Islands</td>
<td>3</td>
<td>34,700</td>
<td>48,500</td>
</tr>
<tr>
<td>Dominica</td>
<td>3</td>
<td>174,100</td>
<td>264,200</td>
</tr>
<tr>
<td>St. Kitts &amp; Nevis</td>
<td>4</td>
<td>209,500</td>
<td>317,700</td>
</tr>
<tr>
<td>St. Vincent &amp; The Grenadines</td>
<td>7</td>
<td>399,300</td>
<td>605,700</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>1,052,100</td>
<td>1,591,800</td>
</tr>
</tbody>
</table>

The retrofitting costs average US$75,800 per facility or US$5.22 per person – an infinitesimally small sum.

There is little evidence that the recommendations from this series of studies were implemented.

2.3 Cornwall general hospital, Jamaica, 1988

The Cornwall General Hospital, near Montego Bay, is a well-built, modern hospital of reinforced-concrete and masonry construction. No damage was caused to the primary structures of this complex as a result of Hurricane Gilbert. However, the hospital could not function effectively during and immediately after the hurricane. This was because almost all of the windows on the upper floors were blown in or out or were otherwise broken. In addition, the solar hot-water collector panels suffered substantial losses.

The maximum incremental cost of providing laminated, impact-resistant glass for the windows and providing adequately-strong window frames and fixings would be less than 2% of the contemporary cost of the buildings.

2.4 Glendon Hospital, Montserrat, 1989

The initial news about this hospital after Hurricane Hugo was that it was completely destroyed. On approaching the building three days after the hurricane one could see little wrong with it. The structure was undamaged, none of the windows was broken, there was one cracked glass door, none of the louvered panels was broken, most of the ceiling tiles were still in position and there were patients still being cared for in the wards.
However, most of the roof sheeting had been blown off so that most of the rooms were unusable whenever it rained. Since the roof trusses and purlins were undamaged it would have been easy to replace the roof sheets within a week of the event. (That is exactly what the Royal Navy did at the electric generating station in Plymouth.) In the event, it was more than a year before any attempt was made to install a temporary cover over the roof structure. In the meanwhile a scheme was developed by CEP (with UNDP funding) to use the existing structure to carry a thin concrete roof which would be invulnerable to future Category−4 hurricanes. That scheme was not implemented.

2.5 Victoria hospital, St. Lucia, 1993

A substantial renovation project was started at Victoria Hospital in 1993. Prior to the start of construction activities PAHO funded a Vulnerability Survey (for hurricanes, torrential rains and earthquakes) which was carried out by CEP. The results of this survey included retrofitting recommendations. These are summarized below:

<table>
<thead>
<tr>
<th>Item</th>
<th>Historic Cost (US$)</th>
<th>1995-equivalent Cost (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>structural retrofitting</td>
<td>108,100</td>
<td>109,500</td>
</tr>
<tr>
<td>non-structural retrofitting in buildings</td>
<td>63,000</td>
<td>63,800</td>
</tr>
<tr>
<td>retrofitting of power lines, telecommunications, water storage and drainage</td>
<td>101,500</td>
<td>102,800</td>
</tr>
<tr>
<td>Total</td>
<td>272,600</td>
<td>276,100</td>
</tr>
</tbody>
</table>

This cost is equivalent to US$1,400 per bed.

During the construction stage which followed the study it is understood that some of the recommendations were incorporated in the works.

2.6 Vieux Fort/Soufrière hospital, St. Lucia, 1993

A new private ward is to be added to the District Hospital for La Soufrière and Vieux Fort. The Government of St. Lucia had already prepared most of the construction documents at the time of the PAHO-sponsored Vulnerability Study. That study, carried out by CEP, not only reviewed the plans for the proposed ward but also addressed the existing premises. The main areas of the existing buildings recommended for retrofitting actions were:

- roofs
- windows and external doors
- bracing of sub-structures, particularly for earthquake resistance
- burying of on-site telecommunications and electrical cables

Actions recommended for improving the designs of the proposed private ward included:

- reviewing the geotechnical conditions
- reviewing and bracing the sub-structure elements
- tightening the specifications for wall reinforcement and roofing fixings

Although cost estimates were not prepared for these retrofitting recommendations it was clear that they would be extremely small – certainly less than 1% of the contemporary values of the buildings.

2.7 Health-care facilities in Antigua and St. Kitts, 1995
2.7.1 Antigua

There are 30 Government health−care facilities in Antigua. Of these, 10 suffered significant damage as a result of Hurricane Luis. Cost estimates were prepared by CEP, under contract to PAHO, for the repair of 8 of the damaged facilities and these are summarized below:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Cost of Repairs (in 1995 US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holberton General Hospital</td>
<td>604,300</td>
</tr>
<tr>
<td>Mental Hospital</td>
<td>177,100</td>
</tr>
<tr>
<td>Fiennes Institute</td>
<td>182,600</td>
</tr>
<tr>
<td>Bolans Clinic</td>
<td>8,700</td>
</tr>
<tr>
<td>Swetes Clinic</td>
<td>37,200</td>
</tr>
<tr>
<td>John Hughes Clinic</td>
<td>24,300</td>
</tr>
<tr>
<td>Liberta Clinic</td>
<td>10,100</td>
</tr>
<tr>
<td>Cedar Grove Clinic</td>
<td>31,300</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,075,600</strong></td>
</tr>
</tbody>
</table>

2.7.2 St. Kitts & Nevis

The principal healthcare facility in St. Kitts is the J N France General Hospital. It has been recognized for a long while that this facility is very vulnerable to earthquakes and hurricanes. The hospital was constructed in the early 1960s. A report dated 1992 indicated that the structure would suffer serious damage in the event of even moderate earthquakes or hurricanes. Indeed there was damage during the passage of hurricane Hugo in 1989 and again during a storm in April 1993. It has been reported that there have been 9 incidents of significant damage by wind and rain to this facility during its 3−decade life.

The damage caused by Hurricane Luis included the loss of louvre panels, 30% of the roof covering, 10% of the roof substrate and collateral water damage to the interior because of the roof damage. The standby generator could not work because of water damage and indeed the hospital was effectively knocked out during the event. The cost of damage due to Hurricane Luis is estimated at US$140,000. However, US$370,000 has been spent during 1995 on repairs and "temporary" improvements at J N France Hospital.

There are three other hospitals in St. Kitts−Nevis. The Mary Childs Hospital suffered minor damage to its roof. Pogson Hospital had some roof damage but the facility was able to function during and immediately after the storm. The Alexander Hospital in Nevis was functional.

3 Reasons for successes and failures (the Antigua case)

3.1 Conceptual design

This is the single most−important factor determining success or failure of buildings. Once again this was demonstrated during Hurricane Luis in Antigua. With respect to hurricanes, suitable design concepts are particularly important for light−weight structures – timber walls; corrugated metal and timber roofs.

Unfavorable features evident in Antigua were:

- L−shaped plans;
- mono−pitched roofs;
- shallow−pitched gable roofs;
- long overhangs at the eaves and gables;
- long overhangs continuous with the main roof;
- corner balconies.

Favorable features evident in Antigua were:
• compact plans;
• hipped roofs;
• steep–pitched gable roofs;
• short overhangs at the eaves;
• canopies discontinuous with the main roof;
• parapets.

3.2 Strength of materials and sizes of construction components

Building materials are supplied in wide ranges of strengths. For example, commonly in Antigua, the ranges of strengths (in newtons per square millimetre – Nmm$^2$) of basic building materials are as indicated below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Lowest Strength</th>
<th>Highest Strength</th>
<th>Range of Strengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>timber</td>
<td>17</td>
<td>105</td>
<td>6.2</td>
</tr>
<tr>
<td>corrugated metal roofing</td>
<td>70</td>
<td>410</td>
<td>5.9</td>
</tr>
<tr>
<td>reinforcing steel</td>
<td>210</td>
<td>460</td>
<td>2.2</td>
</tr>
<tr>
<td>concrete</td>
<td>17</td>
<td>35</td>
<td>2.0</td>
</tr>
<tr>
<td>concrete blocks</td>
<td>5</td>
<td>8</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Clearly, these significant differences must be accounted for in construction. The lack of conscious appreciation of these differences can, and did, lead to failures. (It has to be said that such lack of appreciation also led to some accidental successes.)

As well as strength, brittleness is a factor determining success and failure. The best evidence of this in Antigua was the breakage of corrugated asbestos sheeting used as roofs and sidings.

The sizes of construction components are greatly controlled by strengths of materials. Everything else being equal, the stronger the material the smaller the component size needs to be. Of course, practical considerations and aesthetics also have their influences on sizes. Such influences, when benign, lead to larger–than–necessary sizes from a strength point of view. Inadequate sizing was the contributory factor in some of the observed failures, principally those associated with light–weight roofing.

3.3 Analysis

Several of the Health–care buildings are of such a small scale as would not normally warrant detailed, formal, engineering analysis. They are of domestic scale. Indeed, some of the buildings were built to be residences and have been leased by Government for institutional purposes.

Component sizes for small–scale domestic construction are usually determined by tradition and rules of thumb. With the rapid introduction of new materials there isn’t the time to develop new traditions. With the rapid expansion of the construction industry there isn’t the time to train artisans and craftsmen through apprenticeships, as was done in the past. Rules of thumb are often not known by the new practitioners.

In such an environment some analysis is indicated, even for buildings of modest size. For critical facilities, including all Health–care facilities, analysis must be used to determine or confirm the adequacy of component sizes.

The absence of a conscious engineered approach to many of the buildings was the cause of failures of some components and their connectors. A typical situation is where there is partial failure of the roof covering at gable ends which could be avoided if analysis is done which would identify higher–than–average suction forces in the damaged areas.)
3.4 Detailing and connections

In the words of the famous German architect, Mies van der Rohe, "God is in the details". It is difficult to overemphasize the importance of detailing. This is the process of arranging the structural and building elements in such a way that they perform their intended functions by carrying the applied loads safely. Thus the quantity of material may be sufficient but, if the arrangement of the material is inappropriate, failure may result. Thus was evident in some instances in Antigua.

Real-estate people talk about the three most important factors being: "location, location and location". Likewise, for hurricane resistance of lightweight structures, the three important issues can almost be said to be: "connections, connections and connections". The roof sheeting must be adequately connected to the purlins. The purlins must be adequately connected to the rafters. The rafters must be adequately connected to the wall plates. The wall plates must be adequately connected to the wall studs. The wall studs must be adequately connected to the base sleepers. The base sleepers must be adequately connected to the base walls or piers. The piers must be adequately founded. This litany simply says that the wind forces must be carried from wherever they impact on the building all the way into the ground without any weak links along the load path. Hurricanes do excellent jobs of finding weak links in structures and Hurricane Luis certainly found several.

3.5 Quality control during construction

All of the good work in the planning stages can (and often does) become unstuck by faulty construction. It is generally felt that poor construction is responsible for most of the damage in hurricanes. This is not the view of the author. However, poor construction is a contributory factor in a significant minority of the failures. It can also be said that whereas poor construction can undo good design, analysis and detailing; good construction cannot make up for bad design, analysis and detailing.

Antigua's Health-care buildings had their usual share of failures due to poor quality control during construction.

3.6 Non-structural elements

Windows and external doors are the orphans of the construction industry and their acts of revenge for lack of attention can be very embarrassing. Usually engineers are not involved in the specification of these items. Usually architects are not equipped to determine the strength requirements for these items. Usually suppliers and contractors cannot be relied on to provide more than the commercial norm, which is inadequate for Category-4 hurricanes (a reasonable requirement for Health-care buildings in Antigua). There were several failures to be seen, which is not surprising. The failures were sometimes of the fixings to the walls. At other times glass was broken by flying objects. The only ways to deal with vulnerability to breakage are hurricane shutters and laminated glass. The latter approach would still lead to breakage but the weather would be excluded during the hurricane.

Electrical systems within the Holberton Hospital compound suffered because the power distribution lines were placed overhead. (There may have been other problems as well.) Although the loss of mains power is likely during a major hurricane, the stand-by plant of the Health-care facility should be able to do its job. On-site, low-voltage, underground distribution systems are highly desirable and economical.

Water supply is a problem in normal times in Antigua. Because of that many of the Health-care facilities had water-storage tanks. However, many (or most) of them were of little practical use after Hurricane Luis. The reason were several:

- Lack of cleaning of the tank
- No means of extracting the water from the tank
- Lack of security with the resulting emptying of the tank by neighbors in need
- Leaking walls leading to insufficient water in the tank
- Roof gutters not connected to the tank

Most of the telephones in the Healthcare facilities were working within a few days of Hurricane Luis. This utility
was less vulnerable than water and electricity. As with electricity, it is advisable to place telephone cables underground at least within the boundaries of Health-care facilities.

The inadequacy of storm-water drainage can lead to much damage. There was some (not a lot) of evidence of this at the Healthcare facilities. Not enough attention is paid to this aspect of design. Even where drainage is consciously engineered, design criteria are usually inadequate, especially for critical facilities, which warrant higher-than-normal standards.

3.7 Maintenance

On the television programme CNN&Company of 13 December 1995 the main topic was urban infrastructure. The problem of decaying roads, bridges, water supply systems and sewerage systems was the subject of much debate. The cost, and political unpopularity, of preventative maintenance was recognized. It was also recognized that preventative maintenance was less expensive, in the long run, than emergency repairs and reconstruction brought about by inadequate maintenance. So it can be seen that even the wealthiest of nations won’t willingly spend the funds necessary for proper preventative maintenance.

The inadequacy of preventative maintenance or, in some cases, the apparent total absence of maintenance over a long period is probably the second most important cause of much of the damage to be seen in Antigua’s Healthcare Buildings.

4. Estimated losses—social and economic

Where they are available, the direct costs of damage to health-care facilities due to hurricanes has been given in the case studies presented earlier in this paper. Social and economic (as opposed to financial) costs are more difficult to quantify.

Experience has shown that the loss of a country’s healthcare facilities can have a traumatic effect on its population. The loss of confidence is noticeable. There is also the practical problem posed by the tourist industry, which is vital to most of these Caribbean territories. Overseas visitors, most of whom are from metropolitan countries, feel uncomfortable and insecure when visiting states which cannot deal with secondary and tertiary healthcare issues when they arise. Although the care of the local population is the most important requirement, one cannot ignore the needs of the temporary visitor.

5. Disaster mitigation before the events

Prevention is better than cure. How often have we heard that said and how difficult it is to live by that tenet.

Disaster mitigation is best practiced by integrating the process in the everyday and every-year actions of an organization. An analogy can be drawn with environmental issues. It has come to be taken for granted that impacts of our actions on the environment must be considered at all times. This applies not only to new projects but also to ongoing activities. In the same way that environmental impact assessments (EIAs) are now a routine precondition to capital works projects, so too should natural hazard impact assessments (NHIAs) be a condition precedent to all public works, especially those related to critical facilities such as healthcare buildings.

With respect to existing buildings, mitigation actions need not be regarded as expensive "crash" programmes. One approach is to integrate mitigation measures into routine maintenance, repairs and replacements. There are many components in hospitals and clinics which have shorter lives than the main structure. Such items are commonly replaced several times during the life of the main structure. They may include doors, windows and roof coverings. These are typically the most vulnerable parts of buildings in hurricanes. When the time comes to replace such items, for reasons of wear and tear, they can readily be replaced with less vulnerable products and be more–securely fixed at very small incremental costs.

This is a low-key approach to mitigation. It must not be thought, however, that life will always be so simple. Greater problems are present in many existing buildings, where the solutions are commensurately complex.
6. Disaster mitigation after the events

In the aftermath of a disaster the focus is understandably on getting healthcare facilities to function again as soon as possible. Also, technical personnel and financial resources are spread very thin. This combination of factors often leads to repairs being carried out in an expedient manner without adequate attention to safety issues. Indeed, post−disaster repairs often leave the buildings even more vulnerable than they were in their pre−disaster, inadequate states.

If such a normal scenario is to be avoided, very deliberate steps must be taken by the custodians of the health−care facilities. Such actions would include:

- clear instructions (on performance criteria for natural hazards) given to engineers, architects and contractors involved in repairs and rehabilitation;
- a willingness to accept (temporarily) smaller functioning spaces or fewer beds if the repair funding is inadequate to achieve safe standards for all of the damaged facilities;
- the employment of a mitigation officer to review and monitor the designs and construction so as to ensure that the agreed performance criteria are being met.

7. Costs incurred in mitigation

If it is assumed that an existing facility is just satisfactory for a Category−2 hurricane (likely to occur once every generation in most Caribbean islands) then the cost of upgrading that facility to Category−3 standard could be stated as:

$1.00 of mitigation is equivalent to $50.00 reduction in potential losses.

If it is assumed that an existing facility is just satisfactory for a Category−3 hurricane (likely to occur once every two generations in most Caribbean islands) then the cost of upgrading that facility to Category−4 standard could be stated as:

$1.00 of mitigation is equivalent to $20.00 reduction in potential losses.

It could be argued that the appropriate standard for general hospitals in countries which only possess one such facility is a Category−5 hurricane for most Caribbean states. The cost of upgrading a Category−4 facility to Category−5 standard could be stated as:

$1.00 of mitigation is equivalent to $5.00 reduction in potential losses.

8. Obstacles encountered in mitigation

Hurricanes are low−frequency events. Damaging hurricanes in post−Columbian times in the Caribbean are summarized in the following table:

<table>
<thead>
<tr>
<th>Country</th>
<th>Number of known, significant hurricane events since 1492</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anguilla</td>
<td>9</td>
</tr>
<tr>
<td>Antigua</td>
<td>36</td>
</tr>
<tr>
<td>Bahamas</td>
<td>72</td>
</tr>
<tr>
<td>Barbados</td>
<td>52</td>
</tr>
</tbody>
</table>
Because of the long periods between hurricanes in any one community it is very difficult to persuade policy makers to give proper attention to the issue of mitigation. In the parliamentary democracies of the region, where the life of a parliament is a maximum of 5 years, the 1−in−50−year event is not considered a priority.

Also, destruction by hurricanes are commonly regarded as an "act of God" and therefore not preventable. This phrase is even enshrined in the laws of these countries and in the insurance policies of the region.

9. Lessons learned from mitigation exercises

The principal lesson to be learned from mitigation is that it is a worthwhile exercise however little may be done. Hurricanes come in a variety of strengths. The definition of a hurricane includes a minimum wind speed of 33 meters per second. That is the lower bound of the phenomenon. There is, in theory, no upper bound but wind speeds in hurricanes have not been reliably measured greater than 100 meters per second. Because the force of the wind varies as the square of its speed, the two extremes given above would produce a nine−fold difference in wind forces. The table below gives a convenient, comparative measure of the common range of hurricanes according to the Saffir−Simpson Scale:

<table>
<thead>
<tr>
<th>Hurricane Category</th>
<th>Wind Speed in meters per second</th>
<th>Wind Speed in miles per hour</th>
<th>Damage Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC1</td>
<td>33−42</td>
<td>74−95</td>
<td>Minimal</td>
</tr>
<tr>
<td>HC2</td>
<td>43 – 49</td>
<td>96 – 110</td>
<td>Moderate</td>
</tr>
<tr>
<td>HC3</td>
<td>50 – 58</td>
<td>111 – 130</td>
<td>Extensive</td>
</tr>
<tr>
<td>HC4</td>
<td>59 – 69</td>
<td>131–155</td>
<td>Extreme</td>
</tr>
<tr>
<td>HC5</td>
<td>&gt;69</td>
<td>&gt; 15 5</td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

Statistical evidence is that, everything else being equal, the more severe the hurricane the less frequent its occurrence. Therefore, improving a building from Hurricane−Category−1 (HC1) standard to HC2 standard is worthwhile, even though an HC4 standard may be the appropriate one. That is because the statistical interval
between damaging events for an HC2 building is greater than the statistical interval between damaging events for an HC1 building. In other words it should not be said that, unless the “correct” standard can be achieved, nothing should be attempted. Any improvement is worthwhile.

Reconstruction and mitigation programs in Jamaica post hurricane Gilbert

Prepared by:
Eng. Alfrico D. Adams
Consulting Engineer

Abstract

This paper briefly describes the island’s exposure to hurricanes and earthquakes, and the impact of Hurricane Gilbert, 1988, on Jamaica.

It describes the then existing disaster mitigation strategies, and identifies the major areas of damage and failure.

It lists the steps taken immediately after the hurricane, to identify the deficiencies and set new strategies for repair, retro-fitting and mitigation.

Some damage observations and roof repair guidelines are summarized.

Comparisons are made between the costs of mitigation and the cost of repairs for low buildings, and recommendations are presented for improving mitigation measures in the future.

Prepared by:
Eng. Alfrico D. Adams
Consulting Engineer
Smada Consultants Ltd., Jamaica

1.0 Introduction

Hospital and health facilities play a critical role in the immediate post−disaster period for naturally occurring catastrophes, in particular, after earthquake or hurricane events.

Physical damage to these facilities affect their ability to provide for the emergency needs of their communities, at the time when their services are most needed.

Governments and relevant health−care professionals, have a duty to ensure that hospitals and clinics, not only continue to provide safe and effective facilities for the persons already under their care, but are in a position to make sudden increases in the scope and effectiveness of these facilities, during, and after disasters.

This paper describes Jamaica's experience from Hurricane Gilbert, 1988.

2.0 Jamaica’s hurricane experience

Hurricanes are a constant threat to Jamaica. Year after year, tropical storms aim at the eastern arc of Caribbean islands, and appear set on a path through this arc to Jamaica.

Fortunately’ few of these have actually impinged on Jamaica during the last 100 years of record. The frequency of damaging hurricanes has been low enough to ensure occurrence only once during the working life of the typical Jamaican adult. This has resulted in a rather casual attitude towards hurricane−resistant
Our Office of Disaster Preparedness, reported after Gilbert, that the population made poor response to appeals to the public, regarding long and medium term measures for hurricanes and for Hurricane Gilbert in particular. (Ref. 1)

3.0 Jamaica's most recent hurricane: Gilbert, September, 12, 1988

3.1 Maximum wind speed

Recorded 3 second wind speeds of 127–131 miles per hour (58m/sec) (Ref.3) were fairly close to the basic wind speed of 125 miles/per hour (56m/sec) recommended for design by The National Building Code, Jamaica and The Caribbean Uniform Building Code.

3.2 Damage estimates

Hurricane Gilbert caused severe damage in almost every sector of the Jamaican economy. Total damage (loss) to the Jamaican economy with its population of 2.4 million persons was estimated at between US$1.0 and 1.5 billion.

The national damage experienced in each of the sectors or utilities mentioned below, affected the health sector significantly, e.g., the level and quality of health care and emergency response were grossly affected by damage to water supply, sewerage, electricity, communications, and transportation systems.

**The Health Sector**

In the health sector, 23 of the 25 hospitals and half of the 377 health centres were damaged, mainly through the loss of roofs, roofbeams, ceilings and windows. Two of the hospitals were destroyed, while eleven suffered severe damage. The cost of repairs to this damage was estimated at US$13m.

**Water Supply and Sewerage**

Damage was estimated at US$12m. Over 50% of the water supply and sewerage disposal facilities, suffered damage varying from minor to complete destruction. Damage included Buildings and equipment, chlorinators, tanks, intakes, and pipelines.

Of the 40% of the system which depended on electricity, only 5% had stand–by generators. This further compounded the problems.

**Electricity Supply**

Damage was estimated at US$63m, and power supply islandwide was reduced by some 50%. Major damage was to the transmission and distribution network, with damage to wood poles being 20% and 30% respectively, and requiring replacement of 15000 wood–poles.

**Telecommunications**

Damage to local and international telecommunications was estimated at US$12m, and all forms of communication were badly affected.

**Roads**

Secondary and tertiary roads were estimated at a total repair cost of US$14m.

3.3 Buildings generally

Apart from Community and Public buildings, it was estimated that 25% of the total housing stock was damaged. 100,000 of these were low income houses, at a repair cost of US$100 million, and 35000 were middle and upper income, at a repair cost of US$225 million.
In general, buildings designed by professionals did well. Non-engineered buildings of the light-roofed variety, e.g. medium to low cost houses and generally poorly maintained light-roofs of all types, suffered badly.

Typical lightweight systems used on the roofs of both public and private buildings were:

(a) Profiled aluminum sheeting attached to timber sheathing, or closely spaced wooden laths or on steel purling.

(b) Wood or metal shingles on timber sheathing or battens.

4.0 Jamaica’s earthquake experience

Jamaica falls in an earthquake prone region near to the edge of the Caribbean tectonic Plate.

Historically, the last devastating earthquake occurred in 1907. At the time, the lack of instrumentation meant that only Modified Mercalli Scale Intensity estimates of IX were available. Since then, moderate tremors of between 5.6 and 5.4 Richter Magnitude were felt in 1957 and 1993.

Local seismologists had recommended the use of effective peak acceleration EPA of 0.3g up to the 1993 event. Since then, however, the revelation that the 1993 event originated from a potentially destructive inland fault, and not offshore as previously anticipated, (Ref.6) has prompted a recommendation to increase the EPA value from 0.9g to 0.4g. This latter value is comparable with the maximum value recommended by the Structural Engineers Association of California for San Francisco.

Local seismologists have also advised that Jamaica is overdue for a major event. Jamaica is therefore in the position of being faced with the threat of a major earthquake, but with very few of its population with first hand experience of a this.

5.0 Hurricane and earthquake disaster mitigation strategies for buildings in Jamaica

It is important to recognize that Disaster Mitigation Strategies cannot be restricted to any one sector such as the health sector. Neither can it be restricted to one aspect of that sector, e.g., the proper construction of physical plant and buildings.

The strategy for hospitals and health care facilities must fit into the strategy for national disaster mitigation’ otherwise, it would very soon be abandoned. Some of these strategies are, enforcement of Building Approval Standards and Codes, continuing education in the engineering profession, and the building industry and public education, which will influence the untrained sections of the labor force.

5.1 Building approval standards and codes

All Buildings constructed within given distances of the city limits, must be approved by The Local Building Authorities. This procedure is governed by Building Act Laws, applicable to individual urban centres or to parishes.

The Building Acts include Building Regulations which form the basis of Structural Evaluation of Buildings. Unfortunately, these are allowed to become out of date, with respect to design and material technology, mainly due to the lack of resources to ensure frequent and regular revisions. As a result, Building approval officers refer to the latest readily available international standard or code to supplement local documents, in approving Building designs.

In addition, during the last 12 years, two documents have been produced in Jamaica and the Caribbean, which, although they do not carry mandatory legal status, they have provided a valuable source of reference for local authorities and design professionals. They are:

1. The National Building Code, Jamaica, 1983 (Ref.4). Published with the status of recommended guidelines by the Government of Jamaica.

These documents are now in the early and initial stages of review respectively before the issue of revised versions.

5.2 Continuing education in the local engineering profession and the building industry.

The Jamaican Institution of Engineers and the Council of Caribbean Engineering Organizations, have both gone to great pains during the last 20 years to educate local professionals on the rapid developments in design for disaster mitigation, particularly with respect to earthquakes and hurricanes.

This is essential, as these fields represent rapid changes in the academic curriculum of the engineer. There still remains the difficulty of disseminating such information to all engineers who should benefit from it.

5.3 Public education

It is recognized that trained professionals are generally engaged for the design and construction of significant buildings, but that the majority of building construction is still for housing and other small buildings. This category of buildings would not normally benefit from professional services. Various attempts have been made by the local office of Disaster Preparedness to educate the public through radio, television, and newspapers, on the essential elements of hurricane and earthquake resistance of buildings. This approach has also been extended to the print media with eye catching illustrations. (See Fig. 1)

This also helps the formal building industry, as it affects the site laborer whose training on site is normally restricted to his particular functions.

Courses have been planned and executed in conjunction with donor agencies, for small builders in both the formal and informal building sectors. Here too, the deficiency has been insufficient resources to fully saturate the public consciousness.

6.0 Reconstruction phase after hurricane Gilbert

6.1 Major causes of building damage identified.

Most damage to buildings was caused by lack of holding down capacity of the roof covering, or its secondary or primary supporting members.

Figs. 2(a) 2(d), 3 and 5, show photographs and illustrations of typical damage to roof elements. Figs 3–5 refer to hospitals. Jamaica was spared the worst excesses of total destruction of buildings by Hurricane Andrew in Florida in more recent years. The main reason for this was the Jamaican practice of using reinforced concrete masonry walls, even where roofing is light weight. This practice minimized both damage and casualties.

6.2 Post hurricane evaluation conference

Immediately after Hurricane Gilbert, the Jamaica Institution of Engineers, invited wind speed experts from Canada to join local engineers in evaluating the event and its implications for design and construction standards. Prominent among these were Mr. David E. Allen, Institute for Research in Construction, Ottawa, Canada, and Professor Allan Davenport, University of Waterloo, Canada.

An international conference was held five months after the Hurricane in February, 1989. This conference was attended by design professionals, national planning representatives, and managers of public utilities.

The conference concluded that the wind speeds recommended by the existing code, were appropriate. Later in 1989, the local Meteorological Office took a more conservative view of design wind speeds, and although not yet incorporated in the wind code, this has influenced design professionals in their selection of design speeds between 135 and 150 mph.
6.3 Measures taken to correct and mitigate damage

(a) A Review and Revision of Building Codes

In the years following Hurricane Gilbert, the Government of Jamaica instructed the Jamaica Bureau of Standards to initiate a review of the existing local building code and standards, with a view to developing a new Building Code. This work has made slow progress, again, due to lack of resources. After much debate in committees, the review committee has acknowledged the good sense of adopting sections of the Caribbean Uniform Building Code wherever appropriate.

(b) Unofficial Decision to Avoid Aluminum Roof Sheeting

In numerous instances of damage, the use of thin gauge profiled aluminum sheeting was found to be the cause of roof failures. Sheeting often tore around fasteners sometimes leaving fasteners intact.

A consensus developed among engineers and statutory bodies, to avoid the use of aluminum sheeting as a roofing material, and if used, to ensure 22 gauge minimum thickness.

(c) Every opportunity was taken, pending revision of the Building Code, to extend the concept of Importance factor used in earthquake design to wind resistant design. This concept applies a factor to increase design forces for buildings to be used for critical post−disaster facilities, such as hospitals health centres, police stations, schools to be used as shelters, etc.

(d) Retrofitting

There is little in the way of statistics to suggest that undamaged buildings were modified ensure survival in future hurricanes. However, it was evident that damaged buildings which were repaired during the first year or 18 months tended to have modifications done, which would improve resistance to future hurricanes.

As time distanced us from the actual Hurricane experience, small buildings in the informal sector seem to drift toward the faulty designs based more on economy than hurricane resistance. It is clear that mandatory code provisions will be needed for this aspect.

7.0 Retrofitting measures for particular cases

Detailed information on the damage analysis of hospital structures has been unavailable, but the typical nature of hospital construction in pre−1988 construction, should justify the use of results of investigations on typical structures for other building applications.

The following analyses of damage and retro−fitting designs and costs, draws upon work done by The Urban Development Corporation (UDC), the Jamaican statutory body which was given the task of managing the reconstruction of the majority of the hospitals and schools damaged by Hurricane Gilbert.

Much of that information was summarized in a paper presented by John Pereira, former Deputy General Manager in charge of the Technical Services Department, UDC, to the Caribbean Disaster Mitigation Project Workshop, Trinidad, March 1995, and in presentation by others at the JIE/SCSE Seminar in 1989. As previously indicated, most of the damage was restricted to roofs.

7.1 Tabular summary of mechanism or cause of failures observed in typical roof systems

<table>
<thead>
<tr>
<th>LOCATION OF FAILURE</th>
<th>PROBABLE CAUSE OF MECHANISM OF FAILURE</th>
<th>INCIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sheeting to woodsheathing or laths</td>
<td>Tearing or rolling of sheeting. Static or fatigue (see fig. 2(a))</td>
<td>High</td>
</tr>
<tr>
<td>2. Timber Purlins/rafter connection</td>
<td>Pull out of nails (see fig. 2(a))</td>
<td>High</td>
</tr>
<tr>
<td>3. Rafter to wall plate connection</td>
<td>Poorly secured or missing strap (see fig. 5)</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>Straightening of bent re−bar</td>
<td>Moderate</td>
</tr>
<tr>
<td>4. Wall plate held by 13mm wall rebar</td>
<td>Pull out of nail/screws (see fig. 2 (b))</td>
<td>Moderate</td>
</tr>
</tbody>
</table>
5. Connection of sheeting to Purlin  | Failure of connection in uplift  | Occasional
6. Truss support connection  | Failure of dowel bars due to uplift (see fig. 3)  | Occasional
7. Failure of edge beam

7.2 Retrofit arrangements for damaged roofs

The following are some of the modifications made by the UDC in restoring damaged roofs.

<table>
<thead>
<tr>
<th>DETAIL PRIOR TO HURRICANE GILBERT</th>
<th>DETAIL POST−GILBERT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Various types, thickness and lengths of profiled metal sheeting</td>
<td>Use of 26 gauge minimum steel sheeting with aluminum or galvanized coating in continuous sheets</td>
</tr>
<tr>
<td>2. Purlin Connection to rafters nailed</td>
<td>Sheet metal cleats for wood to wood connections</td>
</tr>
<tr>
<td>3. Rafters/Wall Plate Connections Metal, straps omitted partially or wholly, or connection nailed</td>
<td>Metal strap or cleat fixed to each rafter preferably to concrete belt beam.</td>
</tr>
<tr>
<td>4. Timber Wall– Plate held down by 13mm hold− down bolts at 1,35m centres</td>
<td>Wall plate hold−down bolts spaced at maximum 1,05m (42in) centres.</td>
</tr>
<tr>
<td>5. Timber Purlin spacing up to 1.2m (48in).</td>
<td>Maximum spacing 900mm (36in) centres</td>
</tr>
<tr>
<td>6. Screws to sheeting spaced at one per sheet or 900mm (36in)</td>
<td>Spacing of screws at 450mm (18in) centres. Spacing halved at eaves or overhangs</td>
</tr>
<tr>
<td>7. Open eaves for overhangs up to 900mm (36in) length</td>
<td>Boxed eaves used for overhangs exceeding 450mm (18in)</td>
</tr>
</tbody>
</table>

These are consistent with this writer's own practices, with the exception of item 6, for which the Building Code specification (See item 4) is more stringent.

7.3 Retrofit arrangements for combined earthquake and hurricane resistance

Perhaps because the only tremors in recent memory were moderate in magnitude at 5.4 to 5.6 on the Richter scale, there has been no attempt at retrofit for undamaged buildings.

On the other hand, in some cases where repair proved necessary, the opportunity was taken to improve resistance by:

(a) Introducing shear walls where possible (See Fig.4)

(b) Improving the strengths of damaged masonry walls by replacing with poured concrete, or introducing poured concrete stiffener columns.

7.4 Damage and retrofit to princess Margaret hospital

In the particular case of the Princess Margaret Hospital in Morant Bay, damage caused by Gilbert consisted of the total removal of the roof, damage to windows and doors, water damage to fittings, cupboards, work stations etc., and damage to wall finishes etc. (See Fig.3)

Subsequent to the hurricane damage, the building was vandalized and sanitary fittings etc.. removed.

Retrofit consisted of:

(i) Introducing shear walls to provide earthquake lateral resistance, and to compensate from the higher earthquake forces, expected from the new concrete roof – Approximate Cost US$55,000.

(ii) Replacing the original timber roof with a concrete roof to solve the problem of wind uplift; (See Fig.4) and non–structural works such as partitioning, windows, doors, plumbing, sanitary, and electrical installation and fitting, cupboards, workstations etc., cost a further US$1. 1 million

7.5 Costs of mitigation and repairs

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An analysis of the added Costs in percentage terms of providing earthquake and hurricane resistant construction in Jamaica, was presented by John Pereira, and these can be rationalized and summarized as follows, for buildings of low rise (say 3–storeys). These relate to basic construction cost, excluding Mechanical and Electrical Services, fees, land and finance, and are mainly based on buildings repaired by the Urban Development Corporation, Jamaica.

These are consistent with the writer's own observations.

**TABLE 7.5 COST OF MITIGATION AND REPAIRS (AFTER PEREIRA)**

<table>
<thead>
<tr>
<th>Element or Building System</th>
<th>Cost of Mitigation as % Increase on Overall Cost of Building</th>
<th>Cost of Repair or Replacement after a Major Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthquakes and Hurricanes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Bearing Wall (Reinforced concrete masonry)</td>
<td>8.0%</td>
<td>Up to 100%</td>
</tr>
<tr>
<td>2. Building Frame System (With some shear walls) 2 storey example</td>
<td>3.0%</td>
<td>Up to 100%</td>
</tr>
<tr>
<td>Hurricanes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Roof System in single storey building</td>
<td>3.0%</td>
<td>15 – 30%</td>
</tr>
</tbody>
</table>

It is evident also, that the real costs of damage may be well beyond the values in column of the table if costs, such as damage to contents, and costs of temporary relocation of occupants are included.

8.0 Recommendations for improving mitigation measures in the future

8.1 Building code design forces for health facilities

Local building codes should be reviewed and revised regularly to:

(a) Ensure ready availability of reliable design values, Examples of these are, basic wind speeds, seismicity (Zone Factors) and special provision for post–disaster facilities:

   eg. An Importance factor as recommended by the National Building Code, Jamaica, and the Caribbean Uniform Building Code, or the option of extending the recurrence interval beyond 50 years for basic wind speed, as recommended by the NBCJ. For the latter, the recurrence interval should be stated in the Codes. 100 years is a recommended interval (Ref.7)

8.2 The building approval and inspection system

The Statutory building approval and inspection system, must be strengthened and made more effective for all buildings, but particularly for health facilities.

8.3 Minimum thickness of profiled metal sheeting on roofs

At Clauses 4.6.11.4 (a) and 4.8.5.1 of the National Building Code, Jamaica, minimum, sheet thicknesses are recommended as 28 British Standard gauge (0.376mm) for steel sheeting and 24 British Standard Gauge (0.559mm) for aluminum sheeting.

These should be increased to 26 gauge (0.457mm) and 22 gauge (0.711) respectively.

8.4 Improved fasteners and connections to roofing systems

Deficiency in this respect caused the most damage during Hurricane Gilbert. The National Building Code Jamaica, requires minimum 3/16" (5mm) fasteners at 9" (230mm) minimum spacing for steel sheeting and 8" (200mm) for aluminum sheeting with 1/2 " (13mm) minimum diameter washers. If this had been observed, damage would have been vastly reduced. This needs to be adhered to. All timber ridge–joints – rafter bearings. and wall plates, should be connected by metal straps or bolts, adequately anchored to prevent uplift by wind.
It is vital also, that fasteners be spaced closer (a maximum of 150mm) at vulnerable roof edges, such as eaves, ridges, hips and gables.

8.5 Improved fasteners and connections to roofing systems

Research and Development work to counteract fatigue effects on sheeting fasteners is currently being incorporated in the Standards Association of Australia, SAA Loading Code AS1170.

8.6 Vertical anchorage at beams, walls and foundations

For both Hurricanes and earthquakes, it is essential that vertical reinforcement be fully anchored from columns into foundations, and from columns into roof edge beams.

A major cause of the loss of the roof at Princess Margaret Hospital was the lack of anchorage of the column reinforcing bars into the edge beams which supported the roof trusses. The concrete edge beams were lifted off with the roof and thrown to the ground.

8.7 Lateral bracing of lightweight framed buildings

As previously mentioned, the common practice in Jamaica of using reinforced masonry walls reduces significantly, the likelihood of lateral instability of our buildings. It is important however, to ensure that such walls are reinforced horizontally and tied together by reinforcement of junctions.

8.7 Roof Shapes and Vents

More stress should be placed in codes and public education on the advantages of tripped roof shapes.

8.8 Maintenance of Roofing Systems

Even the best designed roofing systems are prone to deterioration due to weather and wear

Eg.
(a) Fasteners become loose due to shrinkage of lumber or vibration due to previous storms.
(b) Metal sheeting will corrode especially at fasteners
(c) Fasteners and their washers may degrade
(d) Timbers may rot, or may split due to shrinkage
(e) Leakage of water may accelerate any of the above.
(f) Reinforcing bars, metal straps and holding down bolts may corrode and lose their effectiveness.

All roofing systems should be inspected at least once per year, preferably before the start of the hurricane season, and repairs done immediately.

8.9 General

Whereas all the above mentioned provisions are important for specific roofing and building systems it must be realized that it is impossible to provide detailed provisions in codes or otherwise, for the many different systems that are available.

It is important therefore to:

(a) Ensure that design forces and the principles of hurricane and earthquake resistance are clearly set out and disseminated in codes for the benefit of trained building design professionals.

(b) Maintain mandatory standards for the quality of critical building materials eg. cement, concrete, blocks, steel, timber, profiled roof sheeting, fasteners.
(c) Strengthen and maintain the Building Approval Authorities and Building inspectorates to ensure that all designs are vetted for proper design and construction.

(d) Maintain a public education campaign to improve the understanding of all members of the public, of the general principles of hurricane and earthquake effects on buildings, and the precautions to be taken, both for the building and its occupants.

Jamaica has attempted each of the above, but none to the extent required.

(e) Develop summary guidelines or specifications based on existing or revised codes, which can be used by health administrators to instruct design and construction professionals engaged by them, on the more stringent requirements for hospital design and construction. E.g. Higher values of Importance factor, and/or recurrence interval for earthquake and wind respectively.

LIST OF REFERENCES


**Vulnerability study "Seismic risk and reinforcement of hospitals in Costa Rica"**

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Consultant in Structural and Seismic Engineering

**Summary**

The earthquakes experienced in Costa Rica and Central America in the 1970s and 1980s prompted the University of Costa Rica and the Costa Rican Social Security Fund to conduct studies on the vulnerability of hospitals to earthquakes. These studies, done between 1984 and 1987, led to the design of the hospital reinforcements between 1989 and 1991.
The earthquakes that struck Mexico in 1985 and El Salvador in 1986 led to the decision to reinforce hospitals in Costa Rica. Three major hospitals were reinforced by three different methods, since three different companies were contracted to do the designs. The reinforcement process was not without problems, but when the work was completed, the costs thereof were economical when compared with the value of the hospital and the losses caused by earthquakes.

During 1990 and 1991, while some of them were still being retrofitted, these hospitals were exposed to moderate to strong seismic tremors, which proved the effectiveness of the reinforcements and the basis of the structural design philosophy.

The losses resulting from these earthquakes were due to the nonstructural damage which occurred in the unreinforced parts of the buildings.

The multidisciplinary approach to this project, which included seismologists, geotechnicians, architects, structural, electro−mechanical, and urban engineers, and health professionals, was later followed as well in the design of a new hospital, taking advantage of the experience gathered in the vulnerability and reinforcement studies. Coordinated by a project manager, experts in every field analyzed seismic, structural, nonstructural, and operational hazards. The different aspects of risk were analyzed, and corrective measures were designed to reduce these risks to an acceptable minimum.

Introduction

In Costa Rica, three hospitals considered of primary importance by the Costa Rican Social Security Fund were studied and reinforced between 1985 and 1992. This study−design−reinforcement process was made possible by the participation of different sectors involved with seismic risk and hospital administration.

This paper describes the development of and the procedures followed in Costa Rica for the study of the seismic vulnerability of major hospitals and, subsequently, the process of reinforcing them. It also describes the impact of these reinforcements on the hospitals during the earthquakes of 1990 and 1991.

The experience gained by the Costa Rican Social Security Fund (CCSS) and the professionals in seismic engineering was taken advantage of and applied to the design of a new hospital. The procedure followed is also described in this paper.

Some economic and cost comparisons are presented and some recommendations and suggestions are given for initiating and improving the study−design−reinforcement process in existing hospitals and for proposing a process of earthquake−resistant design for new hospitals.

Background

During the 1970s and 1980s there was a growing interest in Costa Rica in earthquake safety as a result of the earthquakes in Managua in 1972, Tilarán in 1973, and Guatemala City in 1976. This led to the promulgation of the Costa Rican Earthquake Code in 1974 by the Federated Association of Engineers and Architects and prompted the Office of Political and Economic Planning, the National Insurance Institute, and the Federated Association of Engineers and Architects itself to hire the J.A. Blume Earthquake Engineering Center of the University of Stanford to conduct a “Study of Seismic Risk in Costa Rica.” This study is currently used in the latest version of the Earthquake Code.

In 1983 the Perez Zeledón earthquake (Costa Rica) caused severe damage to Escalante Pradilla Hospital, forcing it to cease operations during the emergency and to provide service while under repair during the following 12 months.

That same year, motivated by the damages observed in Perez Zeledón, the director of Calderón Guardia Hospital in San Jose asked the University of Costa Rica to evaluate the seismic vulnerability of its facilities. The University's School of Civil Engineering responded positively and conducted a study of the operational and nonstructural vulnerability of the Hospital.
Subsequently, in 1985, CONICIT (National Council of Research and Technology) awarded the University of Costa Rica a research grant to study the seismic vulnerability of Mexico Hospital. This was the first comprehensive study of seismic vulnerability carried out in the country, since it evaluated the different types of risk to which the hospital was exposed: structural, nonstructural, and operational. Representatives of the Pan American Health Organization’s Disaster Office encouraged university personnel to initiate this type of research since it was emerging as a new field in Latin America. That same year the Costa Rican Social Security Fund hired two structural engineering firms to carry out the structural seismic vulnerability study of Monsignor Sanabria Hospital in Puntarenas and the National Children’s Hospital in San Jose.

The earthquakes that struck Mexico in 1985 and El Salvador in 1986 prompted CCSS authorities to commission the retrofitting designs for the hospitals under study and then to begin the reinforcement process.

In addition to the favorable conditions already mentioned (the existence of the Costa Rican Earthquake Code and the Study of Seismic Risk in Costa Rica,) there were two more developments during the 1980s that promoted or furthered the vulnerability and reinforcement studies. These were the creation of the National Emergency Commission, which had the important task of preparing hospitals for disaster response, and the enactment of Executive Decree 169, which obliged State institutions to study their installations and reinforce them against seismic events.

The seismic vulnerability studies carried out in Costa Rica and in other Latin American countries led to the publication of two works on the safe design of hospital facilities. These works, published at the 6th Latin American Seminar on Seismic Engineering in Mexico City in 1990, recognize the multidisciplinary nature of safe design against natural hazards and summarize the necessary design processes for reducing vulnerability in new installations. These processes, together with recent developments, were applied to the design of a new hospital, as will be shown later on.

Vulnerability studies 1984−1986

The seismic vulnerability studies were, as has already been mentioned, initiated by the University of Costa Rica in 1984 and then continued by the CCSS in two of its hospitals.

The University of Costa Rica’s work indicated that the problem of safety is not only structural but is also related to the response of the nonstructural systems and to the operational system that the hospital has for coping with an emergency.

A vulnerability study, as a result, must evaluate these three factors. The work begins with the identification of risks. In the case of earthquakes it is necessary to identify the magnitude of the area’s strong earthquakes and the intervals at which they occur (study of seismic hazard).

Once the hazard is identified, an acceptable level of risk should be defined in order to select the magnitude of the earthquake against which safety will be measured.

The levels of performance of the structure will be measured against the severity of the earthquakes, and it can thus be determined if the structure is safe. If the structure is not safe, the entire hospital system is vulnerable; however, a safe structure does not mean that the hospital system is invulnerable.

The safety of the nonstructural system involves the electrical, mechanical, and architectural system. The routing of pipes, supports for equipment, the relative location of this equipment, etc. are aspects that should be considered since they might fail during earthquakes and put the hospital out of service. Architectural elements such as facades, ceilings, doors and windows, floors, stairs, etc. can sustain damage that would force a shutdown of service.

During an emergency the operational system of the hospital could become chaotic, thus making service impossible. The arrival and departure of ambulances, the areas for treating the injured, the location of laboratories and X−ray machines relative to the emergency room, etc., are aspects that should be evaluated in vulnerability studies.

Reducing nonstructural and operational vulnerability is usually simple and inexpensive. The reduction of structural vulnerability entails more serious intervention that is both more costly and more difficult to execute. The studies carried out in Costa Rica from 1984 to 1986 indicated the need for structural changes to hospitals
in addition to nonstructural changes and relatively few operational changes.

The definition of seismic hazard used to evaluate the hospitals was taken from the "Study of Seismic Risk in Costa Rica" mentioned earlier, and the levels of performance were defined according to the Costa Rican Earthquake Code. In the case of Mexico Hospital the review was performed not only for the strongest possible earthquake in the area but also for earthquakes of more frequent occurrence. That is, the hospitals' performance was tested for catastrophic earthquakes (MM IX) and for moderate earthquakes (MM VI–VII).

The results of the vulnerability studies were relayed to CCSS authorities, who decided to commission the reinforcement designs immediately. The vulnerability studies were clear and conclusive and indicated to the political authorities what actions should be taken to reduce the impact of seismic events.

**Design and reinforcement 1986–1992**

A building should be structurally reinforced when it has been shown that its structure is liable to suffer severe damage in a large earthquake.

Reinforcement enhances the structural safety of the building but cannot make the system totally invulnerable; it would be impossible to strengthen all the elements so that the building would survive the strongest possible earthquake unharmed.

The hospitals reinforced by the CCSS were: the National Children's Hospital, Mexico Hospital, and the Monsignor Sanabria Hospital. The characteristics of these hospitals are summarized in Table 1, which also shows the cost of reinforcement. It can be observed that the cost of retrofitting fluctuated between 70 and 80 dollars per square meter of construction, a rather narrow range despite the differences in the type of reinforcement.

**TABLE 1**

<table>
<thead>
<tr>
<th>Hospital</th>
<th>Area, m²</th>
<th># Beds</th>
<th>Year Constructed</th>
<th># floors</th>
<th>Cost of reinforcement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natl. Child.</td>
<td>16,000</td>
<td>375</td>
<td>1960</td>
<td>5</td>
<td>1,100,000</td>
</tr>
<tr>
<td>Mexico</td>
<td>30,000</td>
<td>600</td>
<td>1962</td>
<td>10</td>
<td>2,350,000</td>
</tr>
<tr>
<td>Monsignor Sanabria</td>
<td>17,000</td>
<td>289</td>
<td>1970</td>
<td>10</td>
<td>1,270,000</td>
</tr>
</tbody>
</table>

The design process, the type of reinforcement, and the construction process were very different in each of the three cases. This was because the CCSS made the three consulting firms hired for this purpose completely responsible for the reinforcement design. The CCSS did not define a reinforcement policy with regard to technical aspects; it simply requested that the structural safety of the buildings be enhanced, and this was left to the judgment of the designer.

The National Children's Hospital was retrofitted with shearing walls to support the system of flat slabs and columns that constitute its structural system. During retrofitting, which lasted 25 months, the hospital had a limited bed capacity. There were critical periods when hospitalization capacity was reduced to 30 beds owing to the lack of cooperation from staff, who could not understand why they should be working while construction work was going on.

The Mexico Hospital was retrofitted with ductile rigid frames to bolster the similar system that constituted its original structure. The masonry walls were detached from the structure in order to permit it to move freely. Figure 1 shows the original configuration of the hospital and the retrofitted configuration. Construction took 36 months, and given the process used and the configuration of the hospital, bed capacity was reduced by less than a third. However, some patients died waiting for a bed, which upset the staff and the other patients.

A problem that arose in this and the other hospitals was the delay of partial deliveries by the construction company, the theft of small items by construction workers, and the constant need for additional construction because the contract did not take into account some architectural replacements inherent in the reinforcement process. The lack of coordination between the construction company and CCSS's Department of Architecture and Engineering, on the one hand, and the hospital authorities, on the other, caused enormous scheduling problems and delays in construction.
The Hospital Monsignor Sanabria, originally constructed on the basis of ductile frames, was retrofitted with shearing walls. In this case the masonry walls were not detached as the designers did not so require.

In this case, the most serious problems in the hospital during construction were operational. The work took 34 months to complete, although the contract had originally called for completion in 12 months. There was a period of 7 months during which the operating rooms were closed and the elective surgery service was suspended. The resulting damage to and thefts from the facilities and the building's finish were considerable, and the contractor refused to replace anything since the contract did not so require.

Despite the troubles that arose during construction, the work on these hospitals was successful, and they are currently providing service without interruptions. The staff has greater confidence in the structure of the buildings, and emergency response plans are in place to cope with major earthquakes.

The nonstructural elements have been considerably improved, and the simple fact that the structure responds appropriately makes the nonstructural elements respond better also. This was demonstrated to some degree during the earthquakes that these hospitals were hit by in 1990 and 1991.

The effect of the 1990 and 1991 earthquakes on the hospitals

In 1990 and 1991 Costa Rica suffered three strong earthquakes. The Cóbano earthquake occurred near the Nicoya peninsula on 25 March 1990 with a magnitude of 6.8 on the Richter scale and a depth of 29.7 km; the Puriscal earthquake occurred on 22 December 1990 with a magnitude of 5.7 and a depth of 25 km; and the Limón earthquake occurred on 22 April 1991 with a magnitude of 7.5 and a depth of 21.5 km.

Monsignor Sanabria Hospital in Puntarenas, which was undergoing retrofitting, suffered damage during the earthquake of 25 March 1990. The intensity reported in the area was VII on the Mercali scale.

The status of construction at that time was as follows: the walls on the west side were completed up to the tenth floor, the walls on the east side to the second floor, and the walls on the north side to the sixth floor. This caused non-uniform lateral displacements owing to the asymmetry of the structure added to that date.

The damage was concentrated in the masonry walls, and there was serious damage to the pharmacy's medications and equipment. There was no damage to the principal structure. It is this author's professional opinion that the reinforcements saved the building; however, the failure to separate the walls and the non-uniform process of retrofitting were what caused the damage. Excessive damage to the walls led to the evacuation of the hospital, and its capacity was reduced to 32%. The cost of repairs, according to the National Insurance Institute, amounted to 30 million colones ($300,000). This amount, added to the wasted resources over a 5-month period, comes to almost twice the cost of the retrofitting.

This earthquake truly proved the effectiveness of retrofitting, but it also showed the major operational problems that arise if walls are damaged. This problem with the walls was not corrected, and similar problems could occur in the future.

The Mexico Hospital felt the force of the earthquakes of 22 December 1990 and 22 April 1991. The intensity of the movement in both earthquakes in that area of San Jose was estimated at VII on the Mercali scale. At the time of the earthquake on 22 December 1990 the retrofitting was 70% complete. In the southeast building, which was 100% complete, no damage whatsoever occurred. In the central building and in the operating rooms, where reinforcement had not yet begun, ceilings fell, glass broke, and walls cracked. In the northwest building, where seven of ten floors had been reinforced, ceilings fell and the walls cracked on floors 8, 9, and 10. On floor 8 there were cracked columns, indicating incipient structural damage. In this building, the walls that were not detached from the structure showed cracks both in the wall and in the surrounding structure. It is estimated that the unreinforced parts would have sustained greater damage had it not been for the predominantly north-west south-east radiation of the seismic waves.

At the time of the earthquake on 22 April 1991 the retrofitting was almost complete, and there was no structural damage of any kind. There was nonstructural damage such as that mentioned earlier, but only in the unreinforced areas.

These earthquakes were not a conclusive test of the retrofitting, but they did demonstrate both the advantages of providing reinforcement and the deficiencies of the original structure. They also partially
validated the criterion adopted for the design, which was that the buildings should withstand moderate intensity earthquakes without structural damage. The attitude of the staff towards seismic events has changed substantially, and their behavior is more rational, which prevents mass panic.

The National Children's Hospital was also jolted by the earthquakes of 22 December 1990 and 22 April 1991. By the date of the first earthquake the retrofitting was fully completed. The hospital did not suffer damage, except for some fallen objects and minor cracking in some walls. Ground movement in the area of the hospital was considered moderate (MM VI). The hospital responded in accordance with the design philosophy, since there was no damage after a moderate earthquake. Although this does not afford absolute proof, since the earthquake was smaller than the design level, the behavior of the building demonstrated the advantages of reinforcement, suggesting that the response will be satisfactory during stronger earthquakes. The behavior of the staff was excellent since they remained at their posts for the duration of the quake.

In general we can see that the reinforced buildings displayed satisfactory behavior, unlike the unreinforced buildings, which, despite having undergone earthquakes smaller than the design allowed for, revealed failures that could endanger the hospitals during more intense earthquakes. During these earthquakes the positive impact of retrofitting became clear.

Designing the new hospital at Alajuela

The earthquake−resistant design of the future Alajuela Hospital represented an opportunity to apply the new design methodologies and avoid from the design stage itself the defects exhibited by the other hospitals discussed previously. The methodology involved a multidisciplinary process that integrated the different design stages with a view to obtaining safer structures without the uncertainty that surrounds conventional designs.

The design process is summarized in Figure 2 and explained below. The study of risk begins with an assessment of seismic hazard. This study, carried out by seismologists, reviews and analyzes the systems of active faults and characterizes the seismic activity of the central region of Costa Rica with an emphasis on the City of Alajuela. Both historical and recent seismic activity is taken into account, and deficiencies are identified which by their size or proximity pose the greatest threat to the hospital. The faults in the subduction area of the Pacific Coast are also included. From this study the characteristics of the earthquakes that occur at different intervals are obtained. These characteristics, such as acceleration and maximum speed of ground movement and duration of the earthquake, among others, are then utilized in the structural calculations for the hospital.

Subsequently geotechnical engineers conduct a study of the dynamic soil characteristics to determine how much the vibration of the soil deposit itself contributes to the amplification of the seismic wave. The microseismic technique of wells and electrical resistivity reveals the mechanical qualities of the different soil layers that make up the deposit. Once the soil characteristics have been identified, a study is done of the dynamic response of the deposit using seismic recorders placed in the rock base. It was determined that on average the vibration of the soil itself amplifies the seismic wave introduced into the rock base by 65 %.

In light of the movement at the base of the building (surface of the soil deposit) a dynamic analysis of the building is then done in order to determine the forces that the seismic shock introduces into the different elements of the structure. These forces are then used to quantify the amount of reinforcement that each element needs. This design process, which is the usual process in structural engineering, does not guarantee that there will be no damage to the various parts of the structure. In the case of the New Hospital in Alajuela, its behavior was analyzed and the damage was quantified (non−linear inelastic analysis). This process utilizes the techniques of damage analysis developed by earthquake engineering over the last decade. The damage quantification procedure goes beyond the methodologies indicated in the seismic codes but is consistent with the general philosophy of these codes.

Once the movement of the building during an earthquake is determined, the effect that this movement has on the nonstructural components can be ascertained. These effects are then conveyed to the team of electro−mechanical engineers so that they can be taken into account in designing the fastenings for equipment and installations. The location of ducts and pipes is determined in light of the relative movement of the different wings of the hospital; sufficient freedom of movement is left in intersecting areas.
A study is done of the external and internal circulation of vehicles and pedestrians under emergency conditions. The flow of traffic and times of arrival at the hospital are studied from different points around the city, and suggestions for modifying the urban and interurban network are made. The internal modifications provide for a network with redundant access routes, areas for fire extinguishers, a field hospital, and a heliport, and total separation of vehicle and pedestrian flow.

A coordinated multidisciplinary procedure was followed, leading to a safe overall design that made it possible to identify the risks to which the structure would be subject, and corrective measures to reduce these risks were proposed. It is hoped, as a result, to have a safe structure capable of fulfilling its mission when so required.

Conclusions and recommendations

It has been shown that the seismic vulnerability of hospitals lies not only in structural vulnerability but also involves the operational and nonstructural parts of the hospital. The most significant damage to Costa Rican hospitals during the 1990 and 1991 earthquakes was nonstructural damage, the loss of service, and the waste of resources.

The retrofittings proved effective, and in two of the three cases discussed these reinforcements substantially reduced nonstructural damage. Retrofitting is profitable when compared to the losses suffered during earthquakes, and in addition general chaos is avoided since hospital service is maintained during the emergency.

It is recommended that orderly planning be done in coordination with all the involved sectors before construction begins. The bidding conditions should contain the necessary clauses to ensure that there are no gaps in the contractor’s responsibility. Hence, although reinforcement processes are mainly structural in nature, the corresponding architectural and electro–mechanical aspects must be included.

In the case of this new hospital, a procedure other than the conventional design was followed so as to obtain a comprehensive design and a safe structure. The multidisciplinary approach encompassed seismology and geophysics as well as architecture and operational aspects.

All of these aspects should be taken into account in designing a structure that is safe against all risk, and the authorities responsible for undertaking a community interest project should require this type of approach. An effort should be made to ensure that each stage of the design process is carried out by suitable personnel and coordinated by a project manager who will not abandon the focus on the safety of the structure, so that the latter fulfills its purpose whenever emergencies arise.

In Costa Rica the process began with basic vulnerability studies, continued with greater awareness on the part of the political authorities responsible for the health care system, and has continued with the retrofitting of existing hospitals and the incorporation of new technologies in the design of new hospitals.

Bibliography


