DOCUMENT RESUME

ED 432 897	EF 005 580
TITLE	Vulnerability Assessment of Selected Buildings Designated as Shelters: Dominica.
INSTITUTION	Agency for International Development (IDCA), Washington, DC.; Consulting Engineers Partnership Ltd.; Organization of American States, Washington, DC.
PUB DATE	1998-00-00
NOTE	36p.; Funding by the USAID-OAS Caribbean Mitigation Project and the OAS-ECHO Project To Reduce the Vulnerability of School Buildings to Natural Disasters.
AVAILABLE FROM	Web site: http://www.oas.org/en/cdmp/document/schools/vulnasst/dom.htm
PUB TYPE	Guides - Non-Classroom (055) -- Reports - Descriptive (141) -- Tests/Questionnaires (160)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Educational Facilities Improvement; Elementary Secondary Education; Foreign Countries; *Natural Disasters; Public Schools; Questionnaires; Surveys
IDENTIFIERS	Caribbean; *Dominica; *Emergency Shelters

ABSTRACT

Educational facilities in the Caribbean often serve roles as shelters during natural hazards, but they often sustain as much damage as other buildings. This study investigated the physical vulnerability of schools located on Dominica to wind forces, torrential rain, and seismic forces in order to provide relevant local agencies with some of the input required for selection of properties for Caribbean Development Bank funding. Information tables list each school, its description and vulnerable areas, and its vulnerability ratings for wind, torrential rains, and seismic forces. Additional tables list each school followed by recommendations for improvements in order to upgrade the structure against natural hazards. Appendices provide commentary on the vulnerability of buildings to water ingress from torrential rain; and a summary of wind, rain, and seismic vulnerabilities of roof and wall envelopes. A sample of the survey instrument concludes the report. (Contains eight references.) (GR)

Vulnerability Assessment of Selected Buildings Designated as Shelters
Dominica

Organization of American States
General Secretariat
Unit for Sustainable Development and Environment

USAID-OAS Caribbean Disaster Mitigation Project
OAS-ECHO Project to Reduce the Vulnerabilityof School Buildings to Natural Disasters
1998

This report was prepared by Consulting Engineers Partnership Ltd.
Dominica and Barbados

CEP

TABLE OF CONTENTS

Hurricane Vulnerability Assessment
Seismic Vulnerability Assessment - Part I
Seismic Vulnerability Assessment - Part II

Appendix IV Technical Paper

Hassan, Ahmed F. and Sozen, Mete A., ***Seismic Vulnerability Assessment of Low-Rise Buildings in Regions with Infrequent Earthquakes,*** **ACI Structural Journal, January - February 1997**

---

1 INTRODUCTION

1.1 The Purpose of the Project

Throughout the world, including the Caribbean, natural hazards cause as much damage to educational facilities as they do to buildings of less importance. This is both regrettable and avoidable. Educational facilities deserve special attention because of their roles during the active periods of storms and also as post-disaster assets.

It is traditional for schools to be used as hurricane shelters. It goes without saying, therefore, that the damage and destruction of schools would put the sheltered population at risk during severe storms. Also, the use of school buildings for temporary housing after hurricanes would not be facilitated by damage and destruction of such schools. The longer-term problem of loss of educational facilities is arguably even more severe. If the children are not at school the parents' work is often adversely affected (in part because of "baby-sitting" problems). There is also the inevitable disruption of the pupils' education.

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.

The Caribbean Development Bank (CDB) proposes to assist its borrowing members in reducing the vulnerability of designated shelters to natural hazards. The initial screening of these designated properties is being carried out in some of the CDB member countries through the auspices of the Organization of American States (OAS) using CDMP[1] and ECHO [2] funding.

It is recognised that the suitability of properties for use as emergency shelters depends on several factors other than structural safety. Some of these factors are location, size, water storage and supply, sanitary facilities, kitchen facilities, standby power and telecommunications within the facility and externally. Most of these issues are already being addressed by other agencies. The focus of this study is on the physical vulnerability of the built facilities to wind forces, torrential rain and seismic forces. This initial screening will provide the relevant local agencies with some of the input required for selection of properties for the follow-on, CDB-funded projects.

1.2 Terms of Reference

The portions of the overall Terms of Reference (ToR) relevant to the subject of the present report are:

- Preliminary assessment and screening of properties identified by participating governments, for the purpose of classifying the properties with respect to their retrofit needs. The consultant will prepare a survey form to be applied by local engineers employed by the participating governments. The form will be applied to up to 20 properties per country. The form will contain a section on wind resistance, amended from the WIND-RITE form of IIPLR [3], and an earthquake resistance section, based on the work of Ahmed F. Hassan (ACI Journal January-February 1997).

- The consultant will prepare a work-plan for the application of the survey forms by the local engineer(s). The local engineer(s) will be assigned by each participating country to work with the consultant. The consultant will train the selected local engineers in the application of the forms and will periodically monitor the progress and quality in the application of the survey forms.
- For school properties in Dominica the investigation will establish, principally by interview and follow-up site visits:
  - what damage was suffered by the schools from Hurricanes Luis and Marilyn;
  - what type of repairs or reconstruction have taken place; and
  - what standards were used in the repairs or reconstruction related to wind and earthquakes.
- The consultant will execute a field visit to each of the participating countries. The field visit will be planned and executed with the participation of the local engineers. Prior to the field visit, the consultant will review the completed forms.
- During these field visits, the consultant will continuously articulate the issues being observed in determining vulnerability; the relative importance of various factors such as location, geometry, materials of construction, detailing; the differences between wind and earthquake vulnerability; etc. For each of the participating countries, the consultant will develop a classification (screening) of all identified properties. The classification will achieve a broad-brush appreciation for the vulnerabilities of the individual buildings to wind and earthquake events and the suitability of the properties for inclusion in a CDB retrofitting project.

As articulated above, an important objective of this project is technology transfer and the broadening of the pool of "disaster mitigation" engineers in the region. Therefore, the active involvement of local engineers (assumed to be from the relevant public works departments) is essential.

1.3 Natural Hazards in the Caribbean

The primary natural hazards facing the islands of the Caribbean are earthquakes and hurricanes. Some of the islands are also subjected to instances of volcanic activity. There are also the related hazards of tsunamis and storm surge.

Torrential rains can also, by themselves, be considered natural hazards since they often occur without the concurrent occurrence of hurricanes and sometimes result in disastrous flooding of low-lying areas. Likewise, some landslides are naturally occurring, isolated events.

1.3.1 Earthquakes

All of the Commonwealth Caribbean countries, with the exceptions of Bahamas and Guyana, lie close to the known tectonic plate boundaries. The Caribbean Plate is moving eastward with respect to the adjacent North American and South American Plates at a rate of approximately 20 millimetres per year. A moderate level of inter-plate activity is generated along these boundaries. Along the northern margin, including areas in the vicinities of Jamaica and the Virgin Islands, moderate earthquakes of shallow depth are generated. Near the plate boundaries there are also intra-plate earthquakes. In the northern Caribbean these intra-plate earthquakes are caused by internal deformation in a slab of the North American Plate. Concentrations of these earthquakes occur at depths of up to 200 kilometres.

Seismic events in the Eastern Caribbean are principally associated with a subduction zone at the junction of the Caribbean Plate and the North American Plate. The North American Plate dips from east to west beneath the Caribbean Plate along a north-south line just east of the main island arc. This leads to a moderate level of inter-plate seismicity. Superimposed on this is a pattern of intra-plate activity. There is a concentration of such activity in the Leeward Islands where the subduction of the Barracuda Rise imposes additional stresses on both the "subducted" North American Plate and the overriding Caribbean Plate. The earthquakes there are generally shallow. In the region north-west of Trinidad there is another concentration of earthquake activity where the strike of the plate boundary changes direction. These earthquakes are of intermediate depth.

Over the past forty-five years a considerable amount of research has been carried out on the seismicity of the Caribbean by the Seismic Research Unit (SRU) of the University of the West Indies (UWI). The engineering community has been requesting more and more assistance from the SRU in interpreting the fundamental research and developing "code" values for seismic forces for use in structural design. The most recent published work in this field is that of SRU's former head, Dr John Shepherd, now at Lancaster University (England).

The Pan-American Institute of Geography and History (PAIGH) is based in Mexico City. The Geophysical Commission of PAIGH is the executing agency for a major project (funded by the International Development Research Centre, Ottawa, Canada) for preparing Seismic Hazard Maps for Latin America and the Caribbean and headed by Dr. J. G. Tanner. Dr. John B. Shepherd participated in this project as the Caribbean specialist.

The final report and mapping from this project indicate that Dominica lies between the iso-acceleration lines representing 250 gals [4] and 300 gals. These are peak ground accelerations with a probability of non-exceedance of 90% in 50 years. The Caribbean Uniform Building Code (CUBiC), which is incorporated in the Dominica Building Code [5], assigns a zone factor (Z) of 0.75 to Dominica. Both of these references indicate a serious earthquake hazard for Dominica.

1.3.2 Volcanic Activity

Several of the islands of the Eastern Caribbean are volcanic in origin. The volcanoes there are considered to be either active or dormant. Dominica exhibits volcanic activity. This, however, is outside the scope of this report.

1.3.3 Tsunamis

A tsunami (or seismic sea wave or tidal wave) is a series of ocean waves generated by any large-scale, short-duration disturbance of the free surface of the ocean. The majority are related to tectonic displacements associated with earthquakes at plate boundaries. However, tsunamis can also be generated by erupting volcanoes, landslides or underwater explosions. In the open ocean, tsunamis may have wavelengths of up to several hundred miles but heights of less than 1 meter. Because this ratio is so large, tsunamis can go undetected until they approach shallow waters along a coast. Their height as they crash upon the shore mostly depends on the geometry of the submarine topography offshore, but they can be as high as 30 meters.

A tsunami travels at an average velocity of 500 to 600 kilometres per hour rising to a maximum of 800 km/h. Therefore within one hour of a major occurrence at Kick 'em Jenny (just north of Grenada), many of the islands of the Eastern Caribbean (including Dominica) will be affected. This, however, is outside the scope of this report.

1.3.4 Hurricanes

Much is not known about the storms which occurred in the Caribbean in the years before the advent of Columbus. But, of course, the European did not bring hurricanes to the Caribbean. Indeed the very name is derived from the Mayan storm god *Hunraken* and the Arawak word *hurican*, which meant the devil wind. The greatest of all recorded hurricanes occurred from 10th to 18th October 1780. Nearly 20,000 people perished as the storm hit virtually every island from Tobago in the south-east through the Windward and Leeward Islands and across to Hispaniola and Cuba. In the last 60 years in the Caribbean another 20,000 people have lost their lives because of hurricanes.

The Caribbean lies in the North Atlantic Ocean, one of the six main tropical areas of the earth where hurricanes may develop every year. Within the 111 years between 1886 and 1996, approximately 1000 tropical storms have been recorded in the North Atlantic. About half of these attained hurricane strength.

The destructive potential of a hurricane is significant due to high wind speeds and torrential rains that produce flooding and occasional storm surges with heights of several feet above normal sea level.

The pattern in recent times has been a reduction of deaths and injuries (because of better warning systems and other preparedness activities) and an increase in property damage (because of commercially-driven unsuitable building practices and locations).

The Caribbean Uniform Building Code (CUBiC), which is incorporated in the Dominica Building Code, assigns a reference pressure of 0.85 kPa [6] to Dominica. This is equivalent to a 10-minute sustained wind speed of 37.5 m/s [7] (83.8 mph) or an equivalent 3-second gust speed of 56.4 m/s (126 mph). These figures relate to a 50-year return period.

1.3.5 Torrential Rains

Although hurricanes are often accompanied by heavy rains, severe rainfall events resulting in flooding are also, and frequently, associated with troughs and tropical depressions. The risk of flooding is therefore not restricted to, nor more likely to occur, during hurricane events.

Drainage systems and structures in the Caribbean are generally designed for rainfall events having return periods of 20 years. This means that such systems are likely to become overloaded and cause some degree of flooding when rainstorms are experienced with return periods greater than 20 years. No guidance on this is provided in CUBiC. However, consideration should be given to moving this common standard to a longer return period. Intensity-duration-frequency relationships for rainfall events are required for rational engineering analysis. These are available from the Caribbean Meteorological Institute.

The damage caused by flooding depends on the type and elevation of facilities in the location. The results of flooding may range from the inconvenience of temporarily submerged driveways to the loss of equipment and finishes inside flooded buildings and consequential disruption of the functions.

Flooding has been the cause of many of the deaths and of much property damage as well. Clearly, location is critical when it comes to flood risk. Low-lying lands, river banks and lands adjacent to gullies are to be avoided if possible. If not, deliberate drainage measures must be taken. Usually this is a municipal responsibility, at least in terms of overall control, since what happens to one property can easily be affected by a neighbour's actions.

The design of external works for shelter premises would include consideration of local flooding. It would not be practical to study the overall catchment area for the design of each particular site. However, some general appraisal of the adjacent areas should be carried out as input for the design of on-site drainage structures.

1.3.6 Storm Surge

Storm surge is associated with hurricanes and consists of unusual volumes of water flowing onto shorelines. Storm surge has been responsible for much of the damage caused by hurricanes, especially in large, low-lying coastal settlements.

Storm surge is a complex phenomenon which behaves quite differently from one shoreline to another. The several main components governing their behaviour are:

Astronomical Tide:	water levels due to tidal variation;
Initial Water Level:	elevated basin-wide water levels caused by larger storms;
Pressure Deficit:	elevated water levels caused by low pressure systems;
Inland Runoff:	raised water levels in rivers and sea outfalls due to prolonged rainfall;
Current Surge:	ocean currents caused by high winds leading to the "piling up" of shallow waters;
Wave Setup:	water accumulating from continuous trains of waves on breaking on the shoreline; and
Wave Action & Runup:	effect of actual waves superimposed on the above factors.

The increase in coastal settlement has put much of our economic investment at risk from sea damage. Future rises in sea level can only make this condition more acute. Storm surge caused by hurricanes causes the most dramatic damage. Waves cause damage without accompanying surge but they are also superimposed on storm surge.

As well as causing flooding and damage to coastal structures, storm surge may also precipitate flooding further inland through the blockage of the out-falls of drainage systems.

This is outside of the scope of the present exercise.

1.3.7 Landslides

Most landslides in Caribbean islands cannot be regarded as natural hazards since they are brought about by inappropriate farming practices although triggered by natural events. Another man-induced class of landslides is road construction in mountainous areas. Often the cut embankments are too steep for stability. Often the down-slope fills are unstable.

There are, however, a few situations where nature itself produces the events. This phenomenon is outside the scope of this report.

2 INVESTIGATION PROCEDURE

2.1 Briefing

On March 23 1998, Engineers Cecil Harris CEP (Dom.) and Vivian Trotter (MCW&H) met to discuss and review the survey forms and the theory behind the seismic vulnerability survey. The information requirements for the forms were straightforward. The forms reviewed were:

- Hurricane Vulnerability Assessment - Field Survey Guide
- Seismic Vulnerability Assessment - Field Survey Guide Part I
- Seismic Vulnerability Assessment -Field Survey Guide Part II

2.2 Field Surveys

The twenty schools surveyed are all designated as emergency shelters. The list was developed by a committee consisting of Mr. Samuel L. Carrette, Local Government Commissioner; Mr. Vivian Trotter (a structural engineer from the Ministry of Communications, Works & Housing) and representatives from the Ministry of Education, Ministry of Health, Ministry of Community Development and The National Disaster Co-ordinator. The list of schools is shown at the end of this chapter.

Mr. Trotter commenced his surveys in April 1998 and completed them at the end of May 1998. Mr. Gibbs kept in touch with progress through Mr. Harris at the CEP (Dom.) office throughout this period.

2.3 Field Reviews

Following the submission of the field surveys a joint field review exercise was carried out between Messrs. Trotter and Harris at the Pichelin, Goodwill and Coulibistrie schools (seven buildings). This exercise basically confirmed the information on the Hurricane and Seismic field survey forms and clarified the surveyor approach to answering the various questions on the forms.

Final field reviews were undertaken in August 1998 by Cecil Harris and Tony Gibbs.

2.4 Desk Studies

To assist with the determination of vulnerability to hurricanes (and in accordance with the ToR) the software package WIND-RITE was utilised. WIND-RITE is a software system developed by the Wind Engineering Research Center at Texas Tech University, Lubbock, TX in conjunction with the Insurance Institute for Property Loss Reduction. This program is used to establish a relative grade for the wind resistance of buildings by assigning various vulnerability weights to: site environment, roof envelope, wall envelope, structural framing, and other secondary considerations.

A relative grade between 1 and 10 is assigned to a building during the evaluation process. A relative grade of 1 indicates that the building is highly resistant to wind-induced damage (less damage), whereas a building which receives a relative grade of 10 is highly susceptible to wind-induced damage (extensive damage). For non-engineered construction, a score of five would be considered very satisfactory.

To assist with the determination of vulnerability to earthquakes (and in accordance with the ToR) the methodology of Ahmed F. Hassan [8] was used. This methodology relies mainly on readily accessible data for an existing building such as the dimensions and arrangement of its structural elements and the floor area. Masonry walls, concrete columns and steel columns are given progressively higher weightings in determining their contributions to seismic resistance. The end result is a comparative assessment of seismic vulnerability in the form of a relative vulnerability number (RVN). The lower the RVN the more vulnerable the building is to seismic forces. A copy of Hassan's paper is provided in Appendix IV.

List of Schools Investigated

Name of School	Code Number	No. of Buildings
Giraudel Government School	DOM-GIR	1
Coulibistrie	DOM-COV	1
Morne Jaune	DOM-MJN	2
Pichelin	DOM-PCH	2
Salybia	DOM-SAL	2
Marigot	DOM-WSS	3
Bagatelle	DOM-BAG	1
Goodwill	DOM-GDL	5
San Sauveur	DOM-SSV	1
Bense	DOM-BEN	1
Paix Bouche	DOM-PBX	1
Colihaut	DOM-COL	1
Thibaud	DOM-THI	1
Vieille Case	DOM-VCS	1
Woodfordhill	DOM-WHL	3
La Plaine	DOM-LAP	1
Beotica	DOM-BOE	3
Petite Soufriere	DOM-PSF	2
Atkinson	DOM-ATK	2
Tete Morne	DOM-TMN	1
	TOTAL	35

3 RESULTS

3.1 Vulnerability to Hurricanes

3.1.1 General Observations

It would not be unreasonable for the Government to require that its new, formally designed, school buildings would have the capacity to be largely undamaged by a 50-year-return-period hurricane.

The objective stated above requires simply the application of known technology by the school's architects and engineers to:

- conceptual design (*i.e.* site selection, shape, materials, structural systems);
- analysis (*i.e.* mathematical determination of forces, stresses and deformations of the building elements); and
- detailing (*i.e.* the determination and presentation, principally through drawings, of all of the details of construction).

The next requirement is for faithful attention to be paid during construction to the details incorporated in the drawings, schedules and technical specifications for the project. Supervision and inspection are central to success in this area of execution.

The final requirement is for the property to be adequately maintained.

The above precepts seem simple enough. Yet schools are often damaged and indeed sometimes destroyed by hurricane events no worse than the "design" storm. That design storm cannot be less than (and could reasonably be greater than) the "50-year" storm. These failures come about because of the failure of the systems (or the inadequacy of the systems) set up to order the construction industry and to maintain public property.

3.1.2 Aspects of Vulnerability

The experience of recent hurricanes has demonstrated that most failures occur to roofs, windows and external doors. In a very few cases there is damage (or collapse) of walls. In even fewer cases there is foundation failure. The experience in Dominica provides confirmatory evidence of this pattern.

Roofs:

- Most of the schools have gable roofs of moderate pitch. A few have hipped ends to their roofs and a few have mono-pitch roofs. None of the roofs are optimally steep. Gable ends are favourable. Mono-pitch roofs are unfavourable and gable roofs are acceptable, provided special attention is paid to the gable-end fastening of lightweight roof sheets.
- It is well known that certain areas of roofs are much more highly stressed by wind forces than other parts. Nevertheless most of the roofs observed had constant spacing of fasteners throughout.
- The ridge fixings (without underlying spacer blocks) and the types of washers are in many cases unsatisfactory for confident resistance to wind uplift forces.

- Lightweight roof sheeting has been used for most of the schools. This sheeting is of several profiles, several thickness and several types of material. The tendency, because of commercial pressures and budgetary constraints, is for the sheeting to be somewhat thinner than is desirable.

Windows (and other openings):

- If the wind can get in, then the rain can get in. If the rain can get in, it is surprising what else can get in. Also, if the rain can get in, the use of the building as a hurricane shelter is compromised.

  The convenience of aluminium and timber louvers for everyday use is self-evident. But it must be recognised that such windows have difficulty in keeping out torrential rain driven by strong winds. Decorative (or "breeze") blocks are practical and durable. Welded wire mesh is practical but much less durable. Both of these types of openings are clearly vulnerable to the ingress of wind-driven rain.

- Flying debris usually accompanies hurricanes. Glass windows are very vulnerable to breakage if impacted by such debris. Other materials (aluminium and thin, wooden, louver blades) could also suffer damage in such circumstances.

- There was little evidence in the field surveys that the various properties were provided with "in-place" storm shutters or dedicated, prefabricated shutters in secure storerooms. Without shutters most of the buildings would be unsatisfactory shelters during severe hurricanes.

External Doors:

- Doors are much less vulnerable than windows. Their materials of fabrication are usually more robust. The main aspects of vulnerability are the hinges, the locks and the absence of bolts at the tops and bottoms of the "free" edges.

- No braces were noticed for securing doors against wind forces.

3.1.3 Summary of Wind Results

The table on the following pages summarises the conclusions of the survey with respect to wind vulnerability.

A summary showing the assessed vulnerability of the roof and wall envelopes as well as the window and door openings, is shown in Appendix II.

The WIND-RITE analysis results appear to indicate that the properties have an approximate equally high vulnerability to hurricanes. It should be noted that the WIND-RITE program will produce high vulnerabilities if the building has unprotected openings and lightweight roof sheeting. Since these vulnerable areas can be mitigated against relatively easily, it is not considered prudent to exclude a property from being considered as a shelter based on these results.

Property	Individual Building and Code Number	WINDRITE Rating	Comments	Recommendations
Atkinson	DOM-ATK-01	3.68		Repair louver windows.
	DOM-ATK-02	3.59		Repair louver windows.

Bagatelle	DOM-BAG-01	3.83		Install wooden louvers over glass windows.
Bense	DOM-BEN-01	3.39		
Boetica	DOM-BOE-01	3.68		Repair leaks to roof on Bldg. #2.
	DOM-BOE-02	3.75		Repair spalling concrete in columns & floor edges in both buildings.
Colihaut	DOM-COL-01	3.44	Galvanised cladding is extensively rusted.	Replace galvanised roof with new sheeting.
Coulibistrie	DOM-COU-01	5.83		
Giraudel	DOM-GIR-01	8.71	Result using "non-engineered" grade. Impractical design to resist wind and water ingress.	Provide shutters for open mesh windows in the front of the building. Seal skylight along stepped roof edge and install lighting to compensate.
La Plaine	DOM-LAP-01	3.79	The roof slope on buildings 2 & 3 are shallow making it susceptible to uplift forces.	
	DOM-LAP-02	4.67		Replace cladding on building #3 and increase number of fasteners on both buildings 2 & 3.
	DOM-LAP-03	6.06		
Morne Jaune	DOM-MJM-01	3.51		
	DOM-MJN-02			
Pichelin	DOM-PCH-01	3.67		
	DOM-PCH-02	3.67		Repair damaged aluminium louver windows.
Petite Soufriere	DOM-PSF-01	3.59		
Paix Bouche	DOM-PXB-01	3.57		Repair existing leaks on roof. Install additional fasteners at eaves and ridge.
Salybia	DOM-SAL-01	3.55		
	DOM-SAL-02	3.64		
San Sauveur	DOM-SSV-01	5.65		
		3.60	Improved rating when 2 feet thick wall assumed to be	

			reinforced masonry.	
Thibaud	DOM-THI-01	3.85		
Tete Morne	DOM-TMN-01	4.94		
Vieille Case	DOM-VCS-01	3.13	Result using heavy steel.	Ensure that all critical areas of roof envelope, i.e. ridge, eaves and gable ends are securely fastened.
	DOM-VCS-01A	6.06	Result using light steel.	
	DOM-VCS-02	3.13	Result using heavy steel.	
	DOM-VCS-02A	6.06	Result using light steel.	
	DOM-VCS-05	3.13	Result using heavy steel.	
Woodfordhill	DOM-WFH-01	3.94		Fix leaks in roof and repair windows in poor condition. Add additional fastener to critical roof areas.
Marigot	DOM-WSS-01	2.93	Wind loss history shows roof susceptible to damage.	Ensure that all critical roof areas (ridge, eaves and gable ends) are adequately secured.
	DOM-WSS-01A	5.05	Result using light steel.	
	DOM-WSS-02	3.33		Repair damaged louvers.
	DOM-WSS-03	3.25		
Goodwill	DOM-GDL-01	3.14	Open ventilated design provides no protection against wind and rain.	Repair all existing wooden louver windows.
	DOM-GDL-02	3.68		
	DOM-GDL-03	2.72		
	DOM-GDL-04	3.57	Wooden extension not considered.	
	DOM-GDL-05	6.58	Wooden pre-fab building.	Ensure that building is properly secured to the foundation.

3.2 Vulnerability to Torrential Rain

Torrential rains can have a significant effect both on the building and its contents.

3.2.1 Flooding

As stated earlier, flooding of low lying areas is often a natural result of torrential rains. None of the buildings investigated are located in flood prone areas. Dominica's steep terrain and absent coastal plane make such occurrences highly unlikely.

3.2.2 Water Ingress

One of the most uncomfortable and damaging aspects of a hurricane is the effect of water on sheltering persons and physical belongings. Being physically safe from flying debris, falling structure etc. is only one function of a hurricane shelter. Keeping dry is just as important to those sheltering both from a psychological and medical standpoint. The ingress of water can either be through the roof or wall envelopes. Of the buildings investigated only twenty three percent possessed wall and roof envelopes that would offer any resistance to water penetration. Roof and wall envelopes are discussed in more detail in Appendix I.

3.3 Vulnerability to Earthquakes

3.3.1 Multi-hazard Design

When compared with dealing with a single hazard, designing against multiple hazards is more than doubly difficult, especially when those hazards are wind and earthquake. Some favourable features of wind-resistant design are unfavourable for earthquake-resistant design and *vice versa* , e *.g.*:

- Heavy structures resist winds better. Light structures resist earthquakes better.
- Flexible structures attract greater wind forces. Stiff structures (generally) attract greater earthquake forces.

Both hurricanes and earthquakes impose horizontal loads on buildings. Earthquakes also impose significant vertical loads on the overall building. The vertical loading derived from wind is usually significant on parts of a building as determined by aerodynamic considerations.

However, there are many similarities in the effective design and construction of buildings to resist hurricanes and earthquakes:

- Symmetrical shapes are favourable.
- Compact shapes are favourable.
- There must be a realisation that there is a real risk that "design" forces may be exceeded. This is particularly so in the case of earthquakes where the design force is deliberately determined to be less than that expected during the anticipated life of the building. This leads to a requirement for redundancy in the structure and for "toughness" - the ability to absorb overloads without collapse.
- Connections are of paramount importance. Each critical element must be firmly connected to the adjacent elements.

3.3.2 Differences between Designing against Earthquakes and Hurricanes

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

3.3.3 Aspects of Vulnerability

Designing schools to be safe during earthquakes is a complex process requiring the involvement of specialist structural engineers. In Dominica, as in most parts of the Caribbean, the problem is compounded because of the absence of mandatory earthquake-resistant standards (See section 4.3) and the lack of a tradition of conscious engineering attention to this subject. Indeed there is no consensus that the hazard is sufficiently serious to warrant concerted action. Thus successes in the area of earthquake-resistant construction tend to be accidental. This comes about principally when the dominant design criterion overrides the demands of earthquake-resistant design.

The main problem areas are summarised below.

- Structural vulnerability was noted mainly in two-storey construction, buildings with concrete roofs and in masonry walls where the presence of reinforcement was moot. (Since concrete block walls often collapse during seismic shaking, all concrete block walls should be reinforced and tied to the adjacent structures.)
- Internal lighting fixtures and utility equipment were generally not fastened to structural elements securely enough to withstand large ground accelerations.
- Closets and heavy furniture were generally not fastened or strapped to the walls where these constituted a danger or contained valuable property.

3.3.4 Summary of Seismic Results

A summary showing the assessed seismic vulnerability of the individual building components viz. roof and walls, is shown in Appendix II.

The following table summarises the conclusions of the survey with respect to earthquake vulnerability.

Property	Individual Building and Code Number	Relative Vulnerability Number	Comments
La Plaine	DOM-LAP-O1	0.58	
	DOM-LAP-02	1.76	
	DOM-LAP-03	1.49	
Boetica	DOM-BOE-01	2.19	
	DOM-BOE-02	2.40	
Giraudel	DOM-GIR-01	3.31	
Tete Morne	DOM-TMN-01	1.39	
Pichelin	DOM-PCH-01	1.69	
	DOM-PCH-02	0.49	
Coulibistrie	DOM-COU-01	0.05	
San Sauveur	DOM-SSV-01	4.04	2' thick stone masonry walls.
Atkinson	DOM-ATK-01	2.00	
	DOM-ATK-02	1.89	
Paix Bouche	DOM-PBX-01	0.65	
Thibaud	DOM-THI-01	0.52	
Bense	DOM-BEN-01	0.66	
Colihaut	DOM-COL-01	0.62	
Bagatelle	DOM-BAG-01	1.21	
Woodfordhill	DOM-WHL-01	2.25	

Vieille Case	DOM-VCS-01	3.19	Steel framed buildings
	DOM-VCS-02	2.09	(01, 02, 03)
	DOM-VCS-03	2.83	
Salybia	DOM-SAL-O1	3.27	
	DOM-SAL-02	2.13	
Morne Jaune			
	DOM-MJN-01	0.55	
	DOM-MJN-02	2.80	
Marigot	DOM-WSS-01	1.13	
	DOM-WSS-02	0.27	
	DOM-WSS-03	0.96	
Petite Soufriere	DOM-PSF-01	2.60	
Goodwill	DOM-GDL-01	0.74	
	DOM-GDL-02	0.57	
	DOM-GDL-03	0.57	
	DOM-GDL-04	0.3	
	DOM-GDL-05	N/A	Vulnerability method not applicable to wooden buildings.

4 GENERAL ISSUES

4.1 Impact of Hurricanes on Caribbean Schools

Hurricanes David in 1979, Allen in 1980, Hugo in 1989 and Luis in 1995 caused significant damage to schools in Dominica, St. Lucia, Montserrat and Antigua respectively. The review of the damage to most of the schools showed that roof failure was the primary cause of problems, leading in some cases to complete collapse of the walls. Most of the roofs were made of wooden rafters or trusses with 26-gauge (or thinner) galvanised sheeting. Few roofs of aluminium sheeting survived. Some roofs remained partially intact but the damage to windows, doors and internal partitions was significant. Some wooden structures were completely destroyed, sometimes by falling trees and sometimes by being blown off their foundations.

In general, therefore, the response of the school buildings to hurricane forces must be judged to have been poor. It is disturbing to note that the reconstruction of many of the schools in Dominica which suffered from the recent hurricanes have been repaired in accordance with the existing design with little or no retrofitting carried out. The construction of all the new schools however, have been based on engineered concepts which would lead to better performance during future hurricanes.

4.2 Hazards versus Disasters

Disasters are often seen as unpredictable, having to do with luck and part of the risks of everyday living. Surely we have progressed beyond the stage when superstition, mythology and fatalism were the public responses to natural hazards. Hurricanes are not natural disasters, they are natural events which sometimes lead to manmade disasters. In these days of widespread technological education, sophisticated research, reliable building materials, computer-based geographical information systems and satellite-assisted warning programmes, hurricanes in the Caribbean should not lead to disasters. The one exception to this would be vulnerable agricultural crops such as bananas.

It is now evident that disasters due to natural hazards are largely preventable and soon the public will demand deliberate actions to protect communities against hazardous events.

4.3 Codes and Standards

The development and maintenance of building standards and codes is a continuing process in many countries. The mandate of national or regional professional and governmental institutions usually includes the development of building standards and the co-ordination of such activities among its various constituent members.

Dominica now has a satisfactory building code. It is understood that the Planning Department is now using the Building Code as an official document to review development applications. The government is presently reviewing a model physical planning act done for the OECS by UNDP/UNCHS with a view to incorporating these standards and having them enacted in parliament. No deadline has been set.

4.4 The Regulatory Environment

Some government agencies adopt an *ad hoc* approach to standards based, principally, on the particular individuals involved in the specific projects. In most cases the administrators tacitly assume that their designers and builders would do what is right without being told. In other cases the administrators adopt the approach of the objecting to safe design and construction, provided that these attributes do not interfere with their other aims for the projects.

Many government capital works projects are funded by international lending agencies. Typically there is reluctance on the part of these agencies to impose structural design criteria on their projects. The funding agencies leave it up to the governments and the governments leave it up to their designers and builders. This *laissez-faire* approach leads to inconsistent performance, lack of reliability and, arguably, to higher overall life-cycle costs for the built environment.

Building codes (incorporating appropriate standards) must be adopted immediately. Sufficient technical documentation exists. The fact that such documentation has deficiencies should not be an excuse for non-implementation. Codes and standards can be improved only through usage, which leads to inevitable revisions.

The system of check consultants (*bureaux de contrôle*), routinely used in French territories, is proposed. Check consultants are independent of the design consultants. It is well recognised that quality assurance is more effective where checking is done independently of creating. The system mentioned above formalises the process.

4.5 Public Awareness

During the past 100 years a total of approximately 900 tropical storms and hurricanes have been recorded over the North Atlantic area. Of these, about 50 percent were hurricanes, many in the general area of the Caribbean. With such a record, it is not surprising that everyone in this region accepts that hurricanes are a fact of life. However, the frequency of direct hits by hurricanes on any one territory is low. This has led to a considerable lack of consciousness amongst Caribbean people as to the dangerous risk to their own properties. Few believe that their island would be hit.

In the post-Columbian history of Dominica, there have been approximately 45 recorded hurricane events which have affected the island. Not all of these were direct hits by hurricane-force winds. In many cases the effects were by way of heavy seas and torrential rain. The most recent of these events were hurricanes Hugo (1989), Luis (1995) and Marilyn (1995). None of these three events produced more than minimum hurricane winds. The damage that can be expected from direct hits from such hurricanes is one or two orders of magnitude greater than what occurred in those two years. The success of school buildings during those hurricanes cannot be regarded as proof of adequacy.

4.6 Vulnerability Surveys

4.6.1 Qualitative Assessment

This is the level of assessment being carried out in the present programme. This level of evaluation does not envisage exhaustive testing of materials in place nor sophisticated computation of stresses. It does involve a careful review of all readily available data (such as drawings), an inspection of the building without destructive testing and a non-mathematical review of the data.

4.6.2 Analytical Evaluation

Facilities whose performances are deemed to be doubtful when assessed qualitatively would be subjected to an analytical evaluation. This procedure would also be used as a second stage, prior to implementation of retrofitting, in cases deemed to be self-evidently inadequate by qualitative assessment. Since analytical evaluation is a time-consuming and expensive exercise it would be appropriate to carry it out only when the funds were available for implementing the possible actions indicated by such evaluation.

It is envisaged that analytical evaluations will be undertaken for those schools selected for the CDB retrofit project.

4.7 Disaster Mitigation after the Event

In the aftermath of a disaster the focus is understandably on getting educational facilities to function again as soon as possible. Also, technical personnel and financial resources are spread very thin at such times. 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. There are examples of this in Dominica.

If such a scenario is to be avoided, very deliberate steps must be taken by the custodians of the educational 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 classrooms if the repair funding is inadequate to achieve safe standards for all of the damaged facilities; and
- 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.

4.8 Maintenance as a Tool for Mitigation

The physical condition of many Caribbean schools is poor. Windows and doors show lack of maintenance and repair. It is considered that a major effort should be taken to bring the condition of the buildings to the standard where a normal maintenance crew can be expected to deal with the routine maintenance requirements of the facility. It is considered, also, that the existing staff and maintenance budget are generally insufficient to provide for proper maintenance.

It is recommended that for public buildings with the heavy use of a school, the annual maintenance budget should amount to about 4% of the contemporary capital cost of the building and equipment, assuming that the facilities are in good condition to start with. For schools, it is estimated that the replacement cost is about US $150,000 per classroom. (This figure includes amounts for common and administrative areas as well as infrastructure.) The maintenance allocation should therefore be no less than US $6,000 per classroom per year.

The maintenance of a school, rather than being a one-time activity as is the construction of the school, is a continuous daily operation of the institution and is an important ingredient in the delivery of education.

A good maintenance system is also a good disaster mitigation system, as the review of damage caused by recent hurricanes and floods has shown. To some extent the damage to buildings was due to lack of sustained maintenance of critical items. Also, a well operated system of maintenance for buildings and equipment has the effect of being a very effective disaster mitigation measure in terms of cost and facility usage. It ensures the most economic way to keep the building and equipment in the best of form for normal use, given the original design and materials. It is essential that a maintenance plan be included in disaster mitigation plans.

It should be noted that the establishment of a secure and orderly system of archiving of construction drawings depicting the as-built condition of the final structure is an essential ingredient of the long-term maintenance schedule of any constructed facility. Because the archive will serve its purpose over the lifetime of the facility, the protection of its contents against the effects of time cannot be overlooked.

5 HURRICANES LUIS AND MARILYN IN DOMINICA

In September of 1995 Dominica was affected by two hurricanes namely Luis (September 4th & 5th) and Marilyn (September 14th). These hurricanes did not produce much structural damage to buildings but there was considerable damage to coastal roads and food crops.

5.1 Damage to Shelters

Damage to shelters as a result of these two hurricanes was minimal because they were not direct hits. Three shelters Marigot, (DOM-WSS-01), San Sauveur and Paix Bouche suffered some damage in the form of a few loosened roof sheets. Vieille Case (DOM-VCS-03) suffered severe damage as a result of the impact from the toilet block roof, which was rooted off its eave beam and dumped on the roof of this building.

No detailed records of the repairs are available. The existing school maintenance system is such that, for such miscellaneous works, a general carpenter would have carried out these repairs. It is highly unlikely that any building code standards were used.

Appendix I

Commentary on Vulnerability of Buildings to Water Ingress from Torrential Rain

Roof Envelope

The roof envelope is generally covered with corrugated steel cladding or concrete.

In the case of metal cladding, its vulnerability to water is generally dependent on:

(i) the pitted condition of the roof metal;

(ii) the adequacy of the length of laps;

(iii) the location installation and quality of the fasteners; and

(iv) the slope of the roof.

The investigation revealed that the general condition of the metal roofs reviewed in the context of parameters (i) to (iv) above is only fair.

For concrete roofs the vulnerability to water is generally dependent on:

(i) the effectiveness of the waterproofing covering (if any);

(ii) the density of the concrete;

(iii) the presence of cracks; and

(iv) the slope of the concrete.

There were no reported leaks in any of those buildings investigated with concrete roofs.

Wall Envelope

The wall envelope is the second area of possible ingress of water from torrential rain. Water penetration is much increased when accompanied by winds which not only flattens its trajectory exposing much more of the wall surface, but also increases its penetration force. The main weak links in the wall envelope are:

(i) windows

(ii) doors

(iii) vent blocks

The windows in the shelters investigated were constructed from either wood or aluminium. Twenty-five percent of the buildings have wooden louver windows, which are highly susceptible to leakage under the best of conditions. Most of the windows have missing louvers making matters worse. Aluminium louvers tend to be more watertight, but here again, all the buildings with this type of window exhibited some damage in this area due to vandalism, forced entry and/or structural defects. Approximately one third of the buildings had aluminium louvers.

Some mention should be made here of shutters. When they form part of the wall envelope, water penetration is reduced due to the nature of the surface, and the protection it offers the openings against damage from impact from flying debris. Shutters (generally wooden) are only practical in sheltered situations, such as the "corridor side" of the buildings. About a third of the shelters have wooden shutters.

Doors were all made of wood fixed in wooden frames. The doors all appeared heavy duty but generally showed shrinkage gaps between the planks of wood. A common weak point among the doors was that they did not close against a concrete lip along the bottom edge. The space thus created between the floor and the underside of the door is a worrisome leakage point.

Vent blocks are extremely common and practical alternatives to windows on the "corridor side" of classrooms and this approach is used in a quarter of the buildings. This form of wall envelope is porous by nature and provides no protection against driving wind and rain.

Appendix II

Summary of Wind, Rain and Seismic Vulnerabilities of Roof and Wall Envelopes

Property Name	**Code Number**	**Overall Structural Vulnerability**	**Roof Vulnerability**		**Wall Vulnerability**			**Vulnerable Openings**
			Wind	**Rain**	**Wind**	**Rain & Wind Ingress**	**Seismic Forces**	
La Plaine	DOM-LAP-01	X				X	X	
	DOM-LAP-02		X				X	
	DOM-LAP-03	X	X	X			X	
Morne Jaune	DOM-MJN-01	X	X			X	X	X
	DOM-MJN-02					X	X	X

Pichelin	DOM-PCH-01		X			X	X	X
	DOM-PCH-02	X	X			X	X	X
Petite Soufriere	DOM-PSF-01		X			X	X	X
Paix Bouche	DOM-PBX-01	X	X	X		X	X	X
Salybia	DOM-SAL-01					X	X	X
	DOM-SAL-02		X			X	X	X
San Sauveur	DOM-SSV-01							
Thibaud	DOM-THI-01		X	X			X	X
Tete Morne	DOM-TMN-01	X	X				X	X
Vieille Case	DOM-VCS-01		X				X	
	DOM-VCS-02		X				X	
	DOM-VCS-03		X	X			X	
Woodfordhill	DOM-WFH-01		X				X	X
Marigot	DOM-WSS-01	X	X				X	
	DOM-WSS-02	X					X	X
	DOM-WSS-03	X				X	X	X
Goodwill	DOM-GDL-01	X	X			X	X	X
	DOM-GDL-02	X	X			X	X	X
	DOM-GDL-03	X	X			X	X	X
	DOM-GDL-04						X	X
	DOM-GDL-05	N/A	X		X			X
Giraudel	DOM-GIR-01		X	X		X	X	X
Coulibistrie	DOM-COU-01	X	X				X	
Colihaut	DOM-COL-01	X	X				X	X
Boetica	DOM-BOE-01		X				X	X

	DOM-BOE-02		X	X			X	X
Bense	DOM-BEN-01	X	X				X	X
Atkinson	DOM-ATK-01		X				X	X
	DOM-ATK-02		X				X	X
Bagatelle	DOM-BAG-01	X				X	X	X

Notes :

1. The symbol "X" indicates vulnerability.
2. Walls with vent blocks are classified as vulnerable to wind and rain ingress if not provided with shutters.
3. Vulnerable openings are those windows without shutters.
4. The buildings classified as being structurally vulnerable (Overall Structural Vulnerability Column), are those building with a seismic vulnerability number less than the average (1.56) as determined by method developed by Ahmed F. Hassan.

REFERENCES

1. Caribbean Disaster Mitigation Project funded by the United States Agency for International Development (USAID) and managed by the OAS
2. European Community Humanitarian Office
3. Insurance Institute for Property Loss Reduction
4. 1000 gals is approximately equal to the acceleration due to gravity
5. This is part of the OECS Building Code project funded by the United Nations Development Programme (UNDP) through the United Nations Centre for Human Settlements (UNCHS) or Habitat.
6. kPa = kilopascals
7. metres per second
8. Seismic Vulnerability Assessment of Low-Rise Buildings in Regions with Infrequent Earthquakes by Ahmed F Hassan and Mete A Sozen, ACI Structural Journal, January-February 1997, pages 31 *et seq*

Hurricane Vulnerability Assessment

FIELD SURVEY GUIDE

Building Data

1. Name of Facility
2. Address
3. ID Number
4. Surveyor's Name
5. Survey Date
6. Year Constructed
7. Years of Major Additions or Changes
8. Was building formally engineered?
    - Yes
    - No
    - Do not know
9. Number of Storeys
10. Windstorm Loss History (Add separate sheet for additional details if necessary)

11. Surveyor's Comments (Add separate sheet for additional details if necessary)

Environment

1. Is there potential of debris from metal or wooden buildings, trees, loose material or roofing within 300 ft radius?
    - Yes
    - No
2. What is the type of surrounding terrain?
    - Coastal
    - Open field
    - Town
3. What is the type of topography?
    - Flat or gently undulating
    - Hillside or ridge
    - Promontory or cliff

Roof Envelope

1. Indicate the geometry of the roof:

   ○ Flat
   ○ Gable
   ○ Hip
   ○ Other (describe)

2. What is the primary roof support system (supported at the exterior walls)?

   ○ Reinforced concrete
   ○ Steel beam
   ○ Steel truss
   ○ Open-web steel joist
   ○ Tapered steel beam
   ○ Wood truss
   ○ Wood beam or rafter
   ○ Other (describe)

3. Is there a positive anchorage system (such as hurricane straps) connecting the roof system at the exterior walls?

   ○ Yes
   ○ No
   ○ Do not know

4. What materials are used for the roof deck?

   ○ Cast-in-place concrete slab
   ○ Precast concrete
   ○ Metal deck
   ○ Wood battens
   ○ Plywood
   ○ Wood close boarding
   ○ Other (describe)

5. What type of roof covering is used?

   ○ Built-up roof with gravel
   ○ Standing seam metal roof
   ○ Metal profiled sheets
   ○ Asbestos cement sheets
   ○ Single-ply membrane
   ○ Tile roof
   ○ Timber shingles
   ○ Asphalt shingles
   ○ Other (describe)

6. What is the age of the roof covering?

   ○ Less than 5 years
   ○ 5 to 10 years

- 11 to 15 years
- 16 to 20 years
- greater than 20 years
- Do not know

7. Are there skylights or ventilators on the roof?

   - Yes
   - No

Wall Envelope

1. What is the primary vertical load resisting system at the exterior walls?

   - Reinforced concrete
   - Steel
   - Reinforced masonry
   - Unreinforced masonry
   - Wood
   - Other (describe)

2. What is the percentage of wall area covered by glass or mesh or open blocks?

   - 0% to 5%
   - 6% to 20%
   - 21% to 60%
   - Greater than 60%

4. Are the glass or mesh or open blocks provided with permanently installed shutters?

   - Yes
   - No

4. Indicate the type of cladding (other than in 2 and 3 above) used

   - Reinforced concrete block masonry
   - Unreinforced concrete block masonry
   - Precast concrete elements
   - Stone panels
   - Metal panels
   - Wood
   - Other (describe)

6. Indicate the type of external doors in the building

   - Metal panels
   - Solid wood (incl T&G)
   - Hollow-core plywood
   - Solid-core plywood
   - Other (describe)

Other Considerations

1. Are there awnings, canopies, covered walkways or carports?

   ○ Yes
   ○ No

2. What wind code was used for the design of the building?

   ○ BNS CP28 - Code of Practice for Wind Loads for Structural Design
   ○ CUBiC Part 2 Section 2 - Structural Design Requirements, Wind Loads
   ○ BS 6399 Part 2 - Code of Practice for Wind Loads. Year?
   ○ ASCE 7 - Minimum Design Loads for Buildings and Other Structures. Year?
   ○ South Florida Building Code. Year?

3. What damage was suffered by the buildings due to Hurricanes Luis and Marilyn in 1995? (Add separate sheet for additional details if necessary)

4. What types of repairs or types of reconstruction have taken place? (Add separate sheet for additional details if necessary)

5. What standards (with reference to wind and earthquakes) were used in the repairs or reconstruction? (Add separate sheet for additional details if necessary)

6. Surveyor's comments (Add separate sheet for additional details if necessary)

Seismic Vulnerability Assessment

FIELD SURVEY GUIDE - PART 1

Name of Facility:

ID Number:

Member Information:

Member	Plan dimensions	Concrete block strength	Concrete strength	Reinforcement grade & %	Structural steel grade	Timber grade	Commen
Main foundations							
Columns							
Walls							
Beams							
Slabs							
Rafters							
Purlins							
Roofing							

Photographs:

- North elevation
- East elevation
- South elevation
- West elevation

Structural Systems (longitudinal)

- Load-bearing walls
- Braced frames
- Column and beam
- Mixed systems (describe)
- Soft storeys
- Short columns

Structural Systems (transverse)

- Load-bearing walls
- Braced frames
- Column and beam
- Mixed systems (describe)
- Soft storeys
- Short columns

School	ID number	Direction	Number of storeys	Total floor area	Column area at base (above grade)	RC wall area at base (steel columns)	Masonry wall length at base
		T					
		L					
		T					
		L					
		T					
		L					
		T					
		L					
		T					
		L					

Seismic Vulnerability Assessment

Field Survey Guide—Part 2

School

ID Number

Column dimensions													
		1T	1L	2T	2L	3T	3L	4T	4L	5T	5L	6T	6L
A	3rd storey												
	2nd storey												
	1st storey												
B	3rd storey												
	2nd storey												
	1st storey												
C	3rd storey												
	2nd storey												
	1st storey												
D	3rd storey												
	2nd storey												
	1st storey												
Wall dimensions - Longitudinal													
		1-2	1-2	2-3	2-3	3-4	3-4	4-5	4-5	5-6	5-6	6-7	6-7
		length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thick
A	3rd storey												
	2nd storey												
	1st storey												
B	3rd storey												

	2nd storey												
	1st storey												
C	3rd storey												
	2nd storey												
	1st storey												
D	3rd storey												
	2nd storey												
	1st storey												

Wall dimensions - Transverse

		1	1	2	2	3	3	4	4	5	5	6	6
		length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thick
A-B	3rd storey												
	2nd storey												
	1st storey												
B-C	3rd storey												
	2nd storey												
	1st storey												
C-D	3rd storey												
	2nd storey												
	1st storey												
D-E	3rd storey												
	2nd storey												
	1st storey												

Sketch

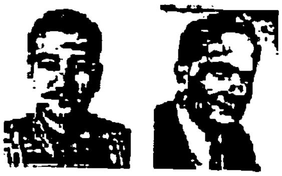
Line sketches should be provided at each floor level indicating:

- Columns
- Reinforced concrete (RC) walls and
- masonry walls.

Steel columns should be noted on the sketches and their overall dimensions stated in the table. In general, the walls should be shown only when they are continuous from floor to floor.

Seismic Vulnerability Assessment of Low-Rise Buildings in Regions with Infrequent Earthquakes

By Ahmed F. Hassan and Mete A. Sozen



Excerpt from the ACI Structural Journal. For a copy of the article in its entirety, see ACI Journal, V. 94, No. 1, January – February 1997.

This paper presents a simplified method of ranking reinforced concrete, low-rise, monolithic buildings according to their vulnerability to seismic damage. The ranking process requires only the dimensions of the structure. The process is tested using a group of buildings that suffered various levels of damage during the Erzincan earthquake of 1992. The ranking procedure reflected the observed damage satisfactorily.

Keywords: buildings; earthquake-resistant structures; earthquakes; evaluation; failure; inspection; reinforced concrete; school buildings. .

INTRODUCTION

The goal of conventional methods for evaluation of seismic vulnerability is to select buildings with a high probability of survival. This paper contains an alternative approach. A simple method is presented to help identify buildings with a high probability of severe damage.

In regions of frequent earthquake occurrence, it is proper and feasible to calibrate seismic safety assessment procedures conservatively in deference to extreme cases of damaged structures. Contradictions posed by buildings that survive earthquakes even though they would be rated hazardous by a ranking procedure calibrated exclusively on damaged structures are often ignored. As long as the number of buildings classified as hazardous is not overwhelming, this "upper-bound approach" does not stop the development of a policy for earthquake risk reduction.

In regions of infrequent earthquake occurrence where buildings with poorly delineated or weak structural systems are likely to represent a large portion of the building inventory, the upper-bound approach may actually be unconservative. If nearly all buildings are deemed hazardous, the likely policy is inaction.

In regions where earthquakes occur in intervals measured in centuries, there is a need for a simple evaluation method that focuses on selection of buildings with high vulnerability rather than those with a high probability of survival. Because seismic risk evaluation methods are based on concepts that are not all well understood, a procedure designed to identify buildings with a high probability of survival cannot be adapted conveniently to identify buildings with a high probability of failure simply by relaxing some of its requirements.

Undeniably, there is no better vehicle for identifying a vulnerable building than the considered judgment of an experienced professional. But this is an expensive vehicle, especially in regions of infrequent earthquakes. There is a need to provide reasonably objective criteria to be used for initial filtering of the building inventory. These criteria need to be at a very low level of sophistication in deference to the principle of proportionality. The required levy of calculation has to be proportional to the quality of input.

The readily accessible data for an existing building are the dimensions and arrangement of its structural elements and the floor area. The challenge is to determine whether these properties alone may be used to determine the seismic vulnerability of a building inventory at a given location.

In a paper related to damage caused by the Tokachi-Oki earthquake of 1968, Shiga, Shibata, and Takahashi presented a format (referred to as the SST Format in following text) for evaluating the seismic safety of low-rise monolithic construction in reinforced concrete. They defined the critical attribute for seismic vulnerability to be the weight of the structure divided by the sum of the cross-sectional areas of the walls and the columns.

The SST format is very attractive. The required data are easily acquired. The needed calculation is not time consuming. The result is crisp. But the application of the SST Format in general is questionable because it was derived explicitly in relation to a group of buildings with well-reinforced walls dominating lateral resistance.

Recalibrating or testing the SST format on the basis of theory or experiment is not productive because the procedure needs to be tested on the basis of responses that defy calculation and organized experiment. The procedure has to be tested against observed phenomena in a collection of buildings with dimensional and material properties based on random decisions in construction.

An opportunity for recalibrating the SST format was provided by the Erzincan earthquake of 1992. After the earthquake, the Ministry of Housing and Natural Disasters of the Turkish Republic sponsored the Middle East Technical University (METU), Ankara, to document the damage to 46 institutional building units in Erzincan. The METU team also developed floor plans of the buildings inspected. The body of information assembled by engineers from METU will be referred to at METU data.

NOTICE

REPRODUCTION BASIS