A Strategy for Retrofitting Critical Structures in Reducing Earthquake and Hurricane Risks

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Abstract

With three of the most severe hurricanes of this century visiting the Caribbean in the last five years (Gilbert, Hugo and Andrew), leaving in their wake billions of dollars in damage, scores of lives lost and thousands homeless, one lesson seems to have been well learnt and documented. Today every Caribbean island, without exception, has put in place at least a rudimentary disaster preparedness programme. Over the last three years, programmes aimed at sensitization and education of the public have met with reasonable success. Community groups, service clubs, voluntary organizations such as the Red Cross, St. John's Ambulance Brigade, the Scouts and Girl Guides have all been very active. In some cases detailed, national disaster plans have been developed. We must now begin to take the next step. The retrofitting of critical public buildings such as schools, churches, meeting halls and hospitals must now be put at the top of a priority listing. These structures often serve as emergency shelters and we must do all in our power to ensure not only that they remain safe and functional during the disaster but that they stand a very good chance of surviving any disaster. But we must note that by virtue of the large numbers of persons who congregate in these buildings at any one time the risk of catastrophic loss of life must be reduced to a minimum.

The schools must be targeted for retrofitting since large numbers of students occupy them between 8:00 a.m. and 4:00 p.m., on week days and with the increased use of the school facilities for shift classes together with regular evening classes and community and social events the risk is therefore great. Many of the primary schools are more than thirty-five years old, constructed of composite timber and masonry and had not been designed with any building code in mind. The denominational schools are often poorly maintained because of shortage of funds. A typical hospital complex usually consists of several buildings, many of which are more than forty years old and like the schools most likely would not have been designed in accordance with any seismic or wind code. Not only would these buildings be always filled beyond capacity, with today's shortage of hospital space, but they often represent questionable structural integrity compromised by age, decay and termites as well as increased vulnerability due to the existence of several non-engineered extensions. The present picture urgently calls for a strategy to reduce risk. These buildings must be identified, inspected and a preliminary structural analysis carried out to determine the extent of remedial and critical retrofitting needed. Then a systematic implementation of corrective work must be undertaken based upon a priority listing related to the level of anticipated risk.

This task must be urgently undertaken throughout the Caribbean if we are to reduce the present level of risk.

Introduction

There is a local saying which goes, "when your neighbour's house is on fire throw water on your own". This saying perfectly captures what disaster prevention, preparedness and mitigation programmes seek to accomplish. When Gilbert destroyed part of Jamaica in 1988 one would have thought that this would have catalyzed us here in Trinidad and Tobago "to put our money where our mouth is" and establish a serious disaster prevention, preparedness and mitigation plan. Hugo was to wreak havoc in the Caribbean in 1989, devastating Montserrat, parts of the U.S. Virgin Islands and Antigua. Total estimated losses in excess of US$5 billion. The response from the other Caribbean islands coupled with international assistance lead to the formation in 1991 of the Caribbean Disaster Emergency Response Agency (CDERA) located in Barbados, established by an inter-governmental agreement among member states of the Caribbean Community (CARICOM) and the setting up of a coordinating body of Defence Force personnel from the different island states. While these two mechanisms are laudable, the commitment of Caribbean states to disaster preparedness leaves much to be desired. Funding for research and training is but a trickle. Physical systems have been slow in coming as the regional vulnerability continues to loom large in the face of inadequate defence.

The television brought home to us a very graphic real-time view of the devastation of Charleston, South Carolina, 1990. Again we were spared no detail of the destruction brought by Andrew to the Miami area in 1992. More recently, the television has allowed us to virtually witness, in a blow by blow fashion, the destruction in even the more far flung areas such as the recent (September 1993) earthquake in India, just outside the city of Bombay. Here, more than twenty thousand lives were lost, entombed in the rubble from unreinforced stone and clay brick walled and roofed homes. Only a month ago, we witnessed the sustained flooding and consequent destruction in the Mississippi and Missouri Valley. Here, losses were of the order of billions of dollars as was the case the year before from hurricane Andrew. A few months ago, when Bret passed between Trinidad and Tobago, there was quite a bit of flooding experienced and approximately five million dollars ($1M US) was lost in agricultural crops alone. But this same tropical storm was to cause serious landsliding in the neighbouring Republic of Venezuela which resulted in the loss of more than one hundred lives. Can we say honestly that Caribbean states have done enough in putting in place the necessary disaster management systems? Admittedly, each territory will now have a rudimentary disaster plan and would have appointed at least one person with responsibility for implementing it. But this is the very problem. In most cases, the states have not sought to house their disaster agency adequately. In many cases the agency is staffed by only one person or even by several part time staff who retain their full responsibilities in other departments of government. No meaningful budget allocation is made and therefore no recruiting or training can take place. The necessary public training which all agree is urgent and absolutely necessary remains an unfulfilled request to a bureaucracy stymied by economic contraction, rising unemployment, foreign exchange problems and debt repayment rescheduling. In that climate, understandably, disaster management is not at the top of the priority listing.

Sometimes one is moved to think that if possibly we were to be bashed more severely by a hurricane or an earthquake then and only then will we be shaken from our present state of inertia and complacency. One does not dare to express this view aloud for fear that this would diminish any sense of danger and urgency that may already have been kindled. Those who warn and call for preparation have long been dismissed for spreading panic and like the Greek Princess Cassandra prophesying only evil. There is also the fear that too much call for preparation against disaster may numb the senses and generate public distrust and apathy.

Even as we talk it is being said that the deaths in Bombay could have been avoided. Unreinforced stone and clay brick walls and roofs have been responsible for similar deaths in Cairo, Egypt, in Turkey and in Armenia. Much of the destruction in Miami in the wake of Andrew (in excess of US$16 billion (Leggert, 1993)) could have been prevented if buildings were constructed in conformity to the existing building code, if roofs were tied down and if walls were reinforced or bolted to the ground beams. The loss of life and property in Venezuela was not as a result of the force of the winds but from the subsequent landsliding due to the heavy rains. Some of this destruction could have been prevented by a combination of good construction techniques, adequate foundation construction and drainage but above all more intelligent planning and location of our buildings. The same is true of the destruction of the barrios around the city of Caracas in the wake of the 1967 earthquake. Some have argued that reckless encroachment on the river by built communities and attempts to straighten the river were the principal causes of the devastation along the Mississippi and Missouri Rivers during the 1993 floods.

Even if we continue to debate the extent of the impact of mitigation and prevention strategies we must admit that in many cases much of the destruction and loss of lives could have been avoided.

This belief that we can prevent or minimize the effects of natural disasters is the driving force behind disaster plans and disaster management. This paper seeks to pursue this end in respect of presenting a strategy for retrofitting critical structures in an attempt to reduce earthquake and hurricane risk.

Developing the Strategy

The first task in developing the strategy is based upon the recognition that there exists many structures whose structural integrity is not only critical to the survival of the community but to the preservation of the quality of life. These structures must survive the onslaught of the disaster. In some cases they are needed to be fully functional during the disaster to protect the persons who may be occupying them. In other situations they may be housing vital utilities which must continue to function during the recovery period. We must therefore identify these critical structures.

Identification of Critical Structures

We must first focus on structures where large numbers of persons congregate. These include schools, churches, community halls, government offices, hospitals, recreational buildings and high and medium rise residential and office blocks. A disaster striking suddenly could find thousands of easy prey. The California experience of 1989 would suggest that we should include elevated roadways in the list. The preparation of such a listing is the first stage. This list should include as well elevated water retaining structures, silos and observation towers. To exhaustively deal with this concept of critical structures or structures which are exposed to high level risk, we must consider the factors that can create this unacceptable level of risk. The following factors would guide such a listing:

i) Structures which, if their roof or wall elements were to fail, would pose serious danger to occupants.

ii) Structures which, if their foundation were to fail, would pose serious danger to occupants.

iii) Structures which pose serious risk to other surrounding structures, should they fail, such as water tanks on elevated areas (hillsides or embankments), dams, electrical pylons, chimneys, etc.

iv) Structures which pose serious risk to their occupants and to surrounding structures because of the presence of either stored explosives, flammables, radioactive material, toxic or hazardous chemicals.

v) Structures which, should they fail, would deny other surrounding structures of vital support or protection such as retaining walls, coffer dams, underground tanks, tunnels.

vi) Essential utilities such as power plants, telecommunication towers, television dishes, and antennae, water treatment and water pumping facilities and waste water treatment facilities.

vii) Structures which are identified as disaster relief centres, hospitals and health facilities.

viii) Structures which may be extremely critical to the national economy such as a fuel pipe line, an airport tower, a jetty, a loading crane, etc.

ix) Historic buildings and monuments.

This listing or classification is not intended to be all-inclusive, but seeks to present the start of the more detailed task of ranking.

The Ranking of Critical Structures

It is obvious that all these cannot be accorded the same importance, neither do they pose the same inherent risk. In an environment of limited economic surplus one is further constrained to focus attention unequally.

How do we rank or classify? Arguably, if we assume an anthropocentric stance, we may place the highest priority on buildings which house the greatest number of persons such as schools, churches, meeting halls, high rise offices or residential blocks, auditoriums and hospitals. In this case, loss of life can be catastrophic. Nevertheless, one can argue with equal conviction that structures that are key links in the economic well-being of a country, should they be destroyed, cause even greater human suffering and death even though over longer time horizon and hence may be less spectacular. In this latter group we can include an electrical power plant upon which the nation's economic strength depends. What of a grain silo or an oil refinery in an oil-based economy, or the long term losses due to a dam failure? What this tells us is that it is not an easy task to classify the pain and suffering a community endures when ravaged by this or that natural catastrophe.

The buildings which must survive the disaster such as shelters must be given the highest classification, say, level I(a) Buildings, while structures which could produce an unacceptably high loss of life may be classified level I(b). Buildings that are critical to economic recovery but are not an absolute, immediate priority can be classified level II. Next in importance are structures of economic importance but not of an absolutely critical nature. These can be classified level III, while all other structures can be classified level IV.

After establishing the detailed boundaries of each classification and having made an inventory of all buildings and structures, the next task must be to carry out a detailed investigation of the classification levels I(a) and I(b) structures. This must be our focus.

Guidelines to Inspection of Critical Structures

Ideally one should conduct a preliminary inspection of the identified structure and its environs, the investigator should seek to establish the following:

(i) Maximum number of persons who occupy the structure at any given time.

(ii) The nature of structural integrity of the structure, age, state of decay, deterioration or cracking, loss of support.

(iii) What elements appear most unstable or requiring attention e.g. roof, walls etc.

(iv) Indicate what elements or aspects are in need of more detailed investigation.

It must be remembered that this is a preliminary investigation which seeks to establish if and where unacceptable risk exists. It therefore should guide us in selecting those structures where a more indepth investigation is necessary. One is therefore seeking to discover and identify areas of vulnerability whether they occur in the foundation, the superstructure or the roof elements. We are to be reminded that a structure may be vulnerable to seismic activity, storms, flooding or landsliding or a combination of these. A structural element may cause vulnerability to seismic activity and not to tropical storms. We must specify the nature of the risks to which the structure's stability and integrity may be particularly vulnerable.

There is need for the development of a checklist to facilitate even this preliminary investigation. Checklists have been developed to assist in implementing structures after seismic activity or storms but one can understand why it is infinitely more difficult to develop one to inspect buildings before a disaster has struck. We must be reminded that you will have to inspect buildings of a wide range of design types and structures that in the extreme may have been built more than one hundred years ago. Even this preliminary inspection should be done by a structural engineer familiar with the construction of wooden buildings, wood and masonry composite, reinforced concrete and structural steel construction. Often a single building may present all these framing structures as a direct consequence of non-engineered repeated repairs or additions. In the Caribbean, particularly in Trinidad and Tobago, we will find unreinforced load bearing walls of clay blocks or stone masonry. These are particularly vulnerable in the first instance to seismic activity but a wall collapse may occur after winds have dislodged the roof element and hence a major proportion of the horizontal bracing of the structure. Decaying wood members or termite infested roofs or wooden framing are a common occurrence. The check list should therefore focus on the following:

(i) The state of the foundation.
(ii) The state of the walls e.g. existence of cracks.
(iii) The state of the roof element including the connection of roof to wall.
(iv) The existence of elevated water tanks and their condition.
(v) Proximity to other buildings that may be damaged if the structure in question does collapse.
(vi) Proximity to large trees that could trigger collapse.

Gibbs (1991) suggests the following steps:

"1. List those buildings and facilities which are important.

2. Carry out qualitative assessments of the facilities listed in 1. This would establish which facilities are obviously satisfactory and those which are obviously not satisfactory.

3. Carry out analytical evaluation of all the other (i.e. doubtful) facilities listed in 1.

4. Embark on a programme of reduction or removal of hazards where these are shown to exist. Such a programme would follow a priority listing of facilities requiring improvement."

Gibbs recommended the use of cost-benefit analyses as a tool in developing and implementing a hazard reduction programme. On the question of qualitative evaluation, he suggested that the investigation does not involve "exhaustive testing or sophisticated computation". Nevertheless he cautioned that "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 analysis of the data". But, "it requires the exponent to have a greater degree of knowledge about the effect of natural hazards on facilities and a greater maturity of engineering judgement than any of the other functions in this programme".

A more rigorous structural analysis should be carried out for the structures that pose greatest risk and for which the structural integrity is doubtful. This analysis should be carried out as part of the more detailed and specific analysis of critical structures. The next stage does depend on availability of funds to implement the remedial retrofitting. Design will have to be executed before instituting any of the work.

Preparing for Retrofitting

It may be necessary to remove entirely the building or structure from service or use in order to be able to effect retrofitting. This might in itself prove very difficult and costly to provide temporary alternative accommodation. In less extreme cases sections of the structure or building may be isolated thereby not taking the entire facility out of service. This, nevertheless, does pose some problems in respect of security and safety of users. During the very process of retrofitting, one has to be ever mindful of the possibilities of instability and hence collapse. Retrofitting often is time consuming since it is done within given physical restraints. Often the work, like renovation, rehabilitation and refurbishment is labour intensive. The question of safety of workers is very important even more so than in the case of new constructing.

Non-destructive testing of elements will prove very useful but engineering judgement will be invaluable. This would suggest that the preliminary and detailed inspection must be carried out by a specialist or expert team including an experienced structural engineer familiar with failure modes of structures. He will be best equipped to detect incipient failure.

In many cases no drawing of initial design will be available. The investigating engineer will then have to attempt to retro-design and the function of the retrofitting will be to bring the existing structure up to the level of the retro-design capacity. Retrofitting is not simply replacing decayed or deteriorated members or removing dislodged bricks. We must be reminded that retrofitting aims at making a structure structurally adequate for its present or future use. This may mean that the structure was not designed or constructed initially to meet the effects of natural disasters or they were designed then based upon the best known information and theory but today both data and theory require more structural provisions. Yet again when carrying out repairs it may become obvious that the structural integrity of a structure in respect of the internal structure or endoskeleton may have deteriorated. Entire members may not be able to be fully replaced but must be augmented by supplementary strengthening.

As a direct consequence of renovation, rehabilitation or refurbishment a structure may have been loaded with air conditioning equipment, water storage tanks at an elevated level or on the roof, increased storage of filing cabinets or equipment at elevated floors. These new uses and additions would usually increase the risk of damage due to seismic forces and may require retrofitting and strengthening.

We must be reminded that in implementing retrofitting works just as with demolition, renovation, rehabilitation and refurbishment the investigator must be clear to differentiate structural weaknesses or damage from non-structural damage. But he must also be alert to the introduction of greater structural instability while effecting the change or additions. Severe structural damage and even collapse have accompanied these works at the peril of the workers carrying out the works or to adjoining structures.

Implementing a Strategy

In developing a national strategy for retrofitting critical structures it must be premised upon the fact that there will be limited available funding. Again, while structures behave differently under the effects of earthquakes and tropical storms, this would make one structure more vulnerable to the one rather than the other. Nevertheless, a combination of economics and other non-engineering factors will make it necessary for us to consider one approach to cover both investigation and the actual retrofitting.

To commence the investigation phase it would be best to begin with a pilot study. An area could be selected which would include a building described as category I(a) and I(b) and would present the full range structural types. This pilot study would lead to a kind of check list to facilitate a more speedy assessment at the preliminary stage. This would allow more time to be spent on the really critical structures which pose the greatest risk.

The actual pilot study can be carried out in the following stages:

Stage I
Define the area using county or ward maps. Identify and list structures in the area of study. Select a number of structures representing the different kinds.

Stage II
Visit the structures and use visual observation, interviews of occupants and users, photographs.

Stage III
Evaluate data and do preliminary risk assessment.

Stage IV
Refine the inspection check list so that subsequent preliminary investigations can be carried out more efficiently.

Stage V
Execute detailed investigation, testing and analysis needed to carry out subsequent retro-design and recommendations.

At the end of the pilot study the next task would be the implementing of a similar investigation at the level of county or ward.

The author suggests that a pilot study could be carried out as a research project supervised by a university staff using final year civil engineering students or young graduate students. Yet again it could be carried out through collaboration between engineering staff within the Ministry of Works or some other appropriately trained engineering staff and the department of civil engineering staff.

Lessons drawn from the experience can be used within the Ministry of Housing, the National Housing Authority, the Ministry of Health, the Ministry of Works, Drainage and Infrastructure and the Ministry responsible for local governments.

While a standardized approach will yield untold benefits it would be more effective to have the exercise executed by groups of trained personnel working in collaboration with the local government bodies. Ideally, there should be some type of disaster prevention inspectorate that would periodically review the level of safety of these public buildings. This paper does not seek to address the question of inspection of private structures but those which large numbers of persons frequent should raise concern. But we may wish as well to consider compulsory investigation of private schools, cinemas and halls. We should also consider the question of periodic reinvestigation, say every ten years.

Conclusions

i) There should be a deliberate move to list and identify the buildings and structures that are to be included in the classification of critical structures.

ii) A ranking system must be developed to determine which structures pose the greatest risk and should therefore be retrofitted first.

iii) There must be a pilot study to guide the preliminary and later the full or detailed investigation of all the structures at risk.

iv) We have to address the legislative and financial implications of such a programme of retrofitting.

v) The exercise must be placed clearly within the organizational framework with the provision of the necessary finance and authority to ensure completion and success.

We must also remember "who doh hear does feel"

References

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