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Natural Disaster Reduction through Structural Quality

Réduction des catastrophes naturelles grâce à une meilleure qualifé des structures

Verringerung von Naturgefahren durch bessere Bauqualität

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SUMMARY

The paper discusses the role the structural engineer can play in reducing natural disasters. The paper examines the strategies for disaster reduction and the obstacles that must be faced. The paper suggests that the control of quality must be a high priority in hazard resistant construction and suggests ways how this might be improved.

RÉSUMÉ

Cet article présente le rôle que peut jouer l'ingénieur civil dans la réduction des catastrophes naturelles et il examine les stratégies à envisager et les obstacles à surmonter pour y parvenir. Il envisage de donner un rôle prioritaire au contrôle de la qualité des constructions devant résister aux risques envisagés et il suggère des moyens pour l'atteindre.

ZUSAMMENFASSUNG

Es wird die Frage nach dem Beitrag des konstruktiv tätigen Bauingenieurs bei der Linderung von Naturkatastrophen aufgeworfen, nach Strategien des Vorgehens und zu erwartenden Hindernissen. Der Verfasser vertritt die These, dass der Qualitätssicherung beim Bau widerstandsfähiger Tragwerke hohe Priorität zukommen muss, und schlägt Wege zu deren Verbesserung vor.

THE PROSPECTS OF NATURAL DISASTER REDUCTION THROUGH IMPROVEMENTS OF STRUCTURAL QUALITY

1.0 INTRODUCTION

Over the past 20 years the costs of natural disasters have escalated significantly. The number of catastrophes, as defined by the reinsurance industry, has nearly quadrupled. The World Bank has similar estimates for the increase in the costs of post-disaster reconstruction. The losses to smaller nations are often well in excess of their GNP and their development is seriously impeded.

It is these concerns and the needless waste involved which has inspired the declaration of the 1990's as the International Decade for Natural Disaster Reduction. The goal of the Decade is to reduce the losses of life and property from disasters due to various natural hazards including earthquakes, wind storms, tsunamis, floods, landslides, volcanic eruptions, wild fires, grasshopper and locust infestation.

Natural disasters are not a new problem and in fact are as old as the hills. Human history and mythology is steeped in the dread of catastrophes as far back as biblical times. At some times in our history, peoples' responses have been fatalistic and disasters regarded as "Acts of God". In some quarters this is still the case. But fortunately this is not the only view. While the natural events themselves may be inevitable and will continue, the disasters which result must be regarded largely as "Acts of Mankind" or more exactly, the failure of mankind to take prudent action when collectively in possession of the knowledge to do so. We are, indeed, "masters of our destiny".

In our progress to civilization, the concern for natural disasters and the development of counter-measures has been a powerful and persistent incentive. In fact it has been contended that the capacity to deal with natural disasters has been and is a critical measure of the advancement of our civilization. To come through a severe natural disaster is a test of the technical capacity to mitigate the disaster, the social capacity to take appropriate humanitarian action as a community, and the political capacity to prepare for the emergency and maintain law and order at a time when there is panic and confusion.

These capacities are still a critical test of our own civilization. It is appropriate that it was the United Nations that passed the international resolution expressing our collective international intent to reduce natural disasters. It is not the intent, however, that the United Nations will take on the task by itself. It could not, the task is too great.

The task must be accomplished first through individual countries developing a national plan of action, and the internal institutions for emergency preparedness and disaster planning; second, through collective bilateral and multilateral action, and third through the involvement of various sectors of society which have a stake in the outcome and ability to influence events. This last group includes the engineering profession, scientists, and technologist; the financial community, involving investors and insurers; as well as industry,and many important non-governmental organizations involved with emergency preparedness,

It is important to find where the weaknesses are in the way that we do things at present, find out what more can be done, and make changes. This is the challenge.

At present, the increasing threat of natural disasters, in spite of our increased knowledge is ominous. It is due to several causes. First, the increase in population and increase in size and numbers of large cities. This increases the "target area" for the disasters to strike. Second, because of the increasing scarcity of land, settlement is occuring on land such as coastal regions and floodplains, which are more vulnerable to natural disasters; and third because of the increasing cost and complexity of the infra-structure of modern life.

We are steadily becoming more vulnerable. The nature of the vulnerability is different in different countries. In India and Bangladesh, threatened by cyclones in the Bay of Bengal, there is the tragic threat to human life and the destruction of a fragile economy. In Tokyo or San Francisco, threatened by major earthquakes, there is not only a threat to life but also a different kind of danger from the economic shock wave which may follow as the insurance companies sell stocks to pay claims reaching, perhaps, many tens of billions of dollars.

Civil engineers, and in particular structural engineers, have a vitally important contribution to make in reducing these natural diasters. The evidence is that a major cause of earthquake and windstorm disasters is structural failure; the other major cause being inundation by the storm surge accompanying tropical cyclones, coastal erosion and river flooding. The skills and knowledge of civil engineers are key to the prevention of both these causes of disaster. Their skills are needed in the prevention of these disasters and reconstruction after the disaster has struck

There are indications that much more can be done.

This paper first discusses the general approaches to disaster mitigation and the role played by civil engineers. We illustrate the evolution of a natural disaster by considering the structural damage due to recent hurricanes in the Caribbean. We conclude with some suggestions for tasks for structural engineers to consider.

2.0 DISASTER MITIGATION: THE MAIN LINES OF DEFENCE

To appreciate the potential civil engineering role, it is worth considering the three main lines of defence in mitigating disasters - prevention, reduction of the impact, and recovery.

TABLE 1. MEASURES FOR DISASTER MITIGATION
***** major, ** significant, * minor**

First Line of Denfence: Prevention		Civil Engineering Involvement
Hazard risk assessment	***	Estimation of extreme winds, seismicity and floods;
Planning	**	definition of hazard prone areas;
Prevention	***	design of hazard resistant construction; inspection and maintenance; geotechnical site evaluation of slopes; shore protection and flood prediction.
Second Line of Defence: Reduction of Impact		
Emergency preparedness		
Warnings	*	Flood, landslide warnings;
Dissemination		
Evacuation		
Shelter	*	Evaluation of safety an design of shelters;
Search and Rescue		
Third Line of Defence: Recovery		
Relief (food, medical and other aid)		
Post-disaster assistance	**	Re-establishing utilities; evaluation of damaged buildings and other facilities;
Reconstruction	***	Redesign, restoration and rehabilitation of damaged buildings and other facilities

The first line of defence is prevention. This involves assessing of the risk of the hazard occurring; planning and siting of settlements so that the effect of the hazard is minimized; and construction of buildings, structures, and protective works (sea walls, dykes, etc.) which are hazard resistant.

The second line of defence is reducing the impact of the hazard. This includes the development of warning systems, the dissemination of the warnings to the public, evacuation and shelter, as well as search and rescue.

The third of defence is recovery. This embraces relief operations, post disaster assistance and ultimately reconstruction.

Clearly, the measures higher in the disaster-recovery cycle have greater leverage in reducing the potential disaster. However the humanitarian response following a disaster is such that more resources are usually given to measures lower down the list. The purpose of the International Decade for Natural Disaster Reduction is to reverse this trend, by putting greater emphasis on prevention, without jeopardizing relief and reconstruction.

Civil engineers and structural engineers have an important role in most phases of these defences but particularly in the prevention phase and the reconstruction. Table 1 indicates the degree of involvement.

3.0 HURRICANE GILBERT

The transformation of a natural hazard into a natural disaster is apparent from the following example of hurricane Gilbert. This storm was described as the "hurricane of the century" and was the most severe storm to strike Jamaica since Hurricane Charlie in 1954. The losses were over $2.2 B, in excess of the annual GDP of the island.

Sustained wind speeds at 10 m height near the coast were estimated to be about 40 m/s with gusts up to about 60 m/s, similar to the "design speeds" in the codes for Jamaica. All regions of the island were affected. The influence of terrain roughness and topography would have modified these approach wind speeds at the coast where they would be higher on hill crests and lower in the lee of hills.

The damage (and its consequences) can be summarized as follows.

Roughly 130,000 or 25% of the houses suffered significant damage. These ranged from simple "chattel" houses, housing estates built through government agencies, and the larger more expensive houses particularly those on the hill crests surrounding Kingston. Without roofs, water damage from the torrential rains crippled the capacity of families to recover. Damage was mainly to roofing.

Significant damage was reported to ten hospitals. This left the community without the facilities to treat those injured in the storm, and they faced afterwards the replacement of the structure, supplies and costly medical equipment.

Schools, and churches and other buildings designated and used a refuges, were badly damaged even when people were sheltering in them. 500 of the 580 schools in the island were damaged or destroyed.

Other essential structures destroyed included communication towers and buildings. Early in the storm, the roof of the main international telephone exchange was damaged, the switching equipment drenched, and communications overseas were cut off. This confused reporting of conditions and delayed the despatch of relief and supplies.

Internally, communications were cut by the failure of the 300 ft. tower on St. Catherines Peak carrying the main microwave repeaters for the island. Towers at the police headquarters in Kingston, and the military base at Newcastle were destroyed interfering with the essential military and police communications. Towers at most radio and television stations on the island were also damaged, preventing broadcast of warnings and bulletins.

The Mona Campus of the University of the West Indies lost roofs from the Administration buildings, the Law school, the Performing Arts Centre and the student residence. The losses included the Law and various library collections, valuable research results and a long delay in the academic year.

Utilities, such as power and water were interrupted for many days - weeks inland. Although the main high voltage distribution network on the island, carried on steel towers survived intact, 50% of the wooden utility poles were destroyed both by wind and fallen trees and branches. Water supply was interrupted in many regions, in one instance due to the collapse of a roof over a reservoir.

There was extensive damage to industrial buildings throughout the island. Principally these were older buildings but there were numerous examples of newer buildings as well. The loss of these structures had a direct impact on the productivity of the economy and jeopardised the income of the workers.

The tourist industry, the island's largest foreign currency earner, was seriously affected. Photographs in the foreign press of hotels without their roofs caused vacationers to switch their bookings.

Although damage to larger office buildings in down town Kingston was relatively light, there was extensive glass breakage, and water damage was consequently serious. One insurance company lost the records on its policyholders.

Losses to agriculture contributed significantly to the measure of the disaster. As well as very heavy crop damage - to bananas, citrus, sugar, coffee and coconut palms, there was widespread damage to storage sheds, and chicken houses (the occupants of which were decimated). Jamaicans who were accustomed to being self reliant for food, were suddenly dependent on imports.

The heavy rainfall which accompanied the storm washed out roads and bridges and once again compromised the efforts at relief and slowed down recovery.

The following conclusions can be made on the disaster due to hurricane Gilbert.

- The disaster was primarily due to the failure of buildings and disruptions in its aftermath.
- The intensity of the storm itself closely matched the design wind considered in the standards prepared for use in Jamaica (CUBIC and Jamaican Building Code). If buildings had been designed to withstand these winds with the appropriate safety factors, and built accordingly, very little damage might have occurred.
- The marginal costs of building to these standards would have been nominal.
- Most of the building failures appeared to be the result of inadequate quality control.
- There was evidently a lack of guidance and appropriate standards for roofing. This applied in particular to the thicknesses and fasteners needed for aluminium and galvanized steel sheet, and the use of adequate attachment of the rafters to the walls.

On the positive side there were examples of the proper functioning of well built structures.

- Most block masonry walls were reinforced. This prevented wall collapse even after the roof had gone and reduced fatalities. The practice was learnt in part over 50 years ago following a severe earthquake.
- "Hurricane straps" used to hold down the roof rafters to walls worked well when used.
- Traditional style, steep hipped roofs, with short eves, planting beneath the sheeting performed noticeably better than flat, gabled roofs, with lattice and corrugated sheeting.

- A significant number of pre-engineered metal buildings erected throughout the island performed without significant damage. They were designed and built to the standards; the trades erecting the buildings were trained and inspection was thorough.

Other important factors which help the recovery included:

- excellent advanced weather warnings, giving time to bring in supplies and board up windows;

- relatively high insurance coverage (about 99% reinsured in hard currency) allowing early financing of repairs and;

- generous supply of foreign aid and funds for reconstruction.

The capability of buildings and structures to survive is also a key determinant in the severity of a earthquake disaster. This latter was illustrated in two earthquakes of comparable intensity at the site - Armenia and Loma Prieta. The loss of life, which was tens of thousands in the former case versus a little more than a hundred in the latter, reflected the general use of modern building codes in the design of structures in San Francisco.

The paramount question is how hazard resistant construction can be achieved more widely?

4.0 SOME OBSTACLES

To consider the obstacles to hazard resistant construction it is necessary to recognize that the construction process is awkward and often involves a number of people with separate responsibilities and influence on the outcome. They include the owner who will take responsibility for the use and maintenance of the structure once it is designed and built; the investor (owner, government, bank or aid agency) who wishes to see a return on his investment; the insurer, who protects the investor by insuring the structure against natural disaster; the design professional who contracts with the owner to design the structure; the contractor who builds it; the materials suppliers; and finally a government regulatory body that sets standards, prescribes a code of practice and inspects the construction for compliance with the code.

In most countries the "construction industry" tends to have a loosely knit, fragmented structure, particularly in developing countries.

Skills and trades are sometimes migrant, poorly trained and inexperienced in some "newer" technologies. Experienced job site superintendents are hard to find, preferring to "retire" to more regular occupations instead of the "roller-coaster" of the construction industry cycles. Unlike the manufacturing industry, construction deals mostly with "one off" products, and instead of the controlled environment of a factory, contends with variable site and weather conditions.

Bidding practices are competitive and financial risks are high. There are incentives to cut corners and disincentives to careful inspection of workmanship.

Regulatory practices concerning disaster resistant construction have important deficiencies in most jurisdictions. In developing countries codes and standards pose problems. Often they are hard to get, reflect conditions in countries which are quite remote, and are unenforced. Loading and materials standards are sometimes mismatched. "New" technologies (roofing materials, for example, introduced for economic reasons to replace "traditional" approaches) are sometimes marketed without adequate technical information.

Many countries in which disasters occur are poorer countries. Owners may be very short of funds and resources and may not be particularly concerned about a threat which last occurred a generation ago. This short term perspective also prevails amongst more sophisticated owners and investors. There are hopeful signs that this is changing.

In many communities the perception of disasters is accompanied by a fatalism which inhibits special efforts to confront the hazard; there may be gaps in understanding about what can be done.

When funds are stretched to the limit, maintenance becomes a low priority. A recent practice in some UNDP construction projects to incorporate a special maintenance fund in the initial capital grant may be a useful approach. At the same time there has been a reluctance for aid agencies to interfere in decisions which are considered to be prerogative of the country receiving the aid. Their influence on hazard resistance has similarly been restrained.

While the owner and investor protect their investment through insurance, local insurance companies usually reinsure the bulk of their disaster coverage overseas. This spreads the risk of these infrequent events and provides for hard currency payments when and if the losses arise. Because of this indirect relationship between the insured party and the reinsurer, the latter has very little direct knowledge of any structure or its hazard resistance. The local insurer, carrying a small fraction of the risk, tends to lump the risk with other hazards such as fire.

Historically the insurance industry has had a strong influence on the standards of marine safety, with shipping and off-shore oil construction. However the influence of insurance in improving the disaster resistance of on-shore construction has been slight. Proposals for premium incentives for disaster rated construction are however now under study. This is timely in view of recent bad disaster insurance experience (a fivefold increase in the number of "catastrophic" events in the past twenty years) and the reluctance of reinsurance companies to provide coverage.

5.0 WHAT STRUCTURAL ENGINEERS CAN DO?

The following are a number of actions which the structural engineering profession is particularly well qualified to take.

5.1 Risk Assessment

a. Develop regional risk maps. Risk mapping should give the magnitude of key structural loads such as earthquake peak ground acceleration and maximum wind speed (or velocity pressure), for specific levels of annual risk. Such procedures are now established for most important structural loads. In some cases the basic meteorological or other geophysical data may be lacking. In these cases synthetic methods may be assumed to estimate the data that is lacking. One example of the latter is the "Monte Carlo" simulation of hurricane winds.

b. Develop maps of local site hazards and allow for these hazards in assessing the loads. These include soft soils which selectively amplify certain frequency bands in the earthquake shock spectrum at bedrock; land subject to flooding; and topography which causes "speed-up" of the wind, near hill crests.

c. In particular 'balanced risk' approaches to safety for strategically important structures such as hospitals, major bridges, etc. should be encouraged. In this the risk levels of the design loads are chosen so that the marginal costs of increasing the resistance of the structure are balanced by the decrease in the expected costs of failure.

5.2 Siting and planning

Use this information on hazard risks in the siting of structures and settlements. The information of risks should if possible be integrated into the assessment of insurance risks.

5.3 Hazard Resistant Construction

A major reason for the failure to achieve adequate hazard resistant construction has been found to be inadequte quality control in the construction process. Hazard resistant construction should therefore be thought of as part of the overall approach to quality control in the industry. The steps that should be taken to assist in achieving this are:

a. Within selected jurisdictions, investigate the quality control measures available to the construction industry together with a critique of their effectiveness. The study should address such issues as materials supply and distribution, design and specification processes, construction, training, regulation and inspection. These questions should be asked at the level of the housing owner/builder, design and/or construction by national companies and international companies. The enquiry should evaluate the influence on the quality of construction of insurance, financial institutions, aid agencies, government, industry as well as the public.

b. As a result of this investigation recommendations for action should be developed which will improve hazard resistance as part of a total quality approach to construction. The following interlocking objectives should be part of this broader approach to hazard resistance:

- to improve the awareness of industry, the public and government of the value of hazard resistant construction and its proper maintenance;
- to improve the performance of new and existing structures providing essential services during a disaster; and
- to improve the job quality in construction; and
- to improve the productivity and profitability of the construction industry.

c. Increase the awareness of the importance of hazard resistant construction in key sectors of society which can influence the quality of the construction process. Within the scope of these objectives, several initiatives might be productive.

- Make the aid agencies, banking and insurance industries aware of the importance of hazard resistance and study ways for their direct involvement in the quality assurance process;
- Make various industries - the tourist and manufacturing industries in particular - aware of the cost-benefit advantage of hazard resistant construction so that they will act as pace setters in encouraging other sectors to follow.

- Make government aware of the importance of ensuring the serviceability of essential service buildings and structures during and after the disaster. Ensure that such buildings reflect a "balanced risk" approach to safety in which the safety factor reflects the uncertainties and the strategic importance of the building.

- Consider the appointment of a "hazard resistance auditor" to verify and assist with hazard resistant construction. This person would be available to government in certifying public buildings for hazard resistance, the insurance companies and to individual investors.

d. A number of technical issues deserve detailed study. The following is a selction:

- Adaptation of traditional designs which functioned well to current techniques. One example is the use of hip roofs. These roofs are traditional in some areas and can carry over 50% more wind load than a gable roof with the same amount of material.

- The strengthening of old buildings through the use of "strong materials" and other means.

- The development of procedures and criteria for the assessment of the hazard resistance of existing buildings and structures, including the certification of disaster shelters.

- Incentive mechanisms for use by the insurance industry to raise the hazard resistance of construction.

- Approaches for industry to include disaster resistance of buildings as part of the overall plant safety.

- The development of user friendly codes and standards which foster the use of both new and traditional methods.

- Establishment of better plans for reconstruction which avoid the repetition of previous defects.

- Expansion of the engineering study of collective disasters, involving many structures, as opposed to the more usual concern for individual structures.

To achieve a significant reduction in natural disasters in accordance with the IDNDR, civil engineers should be prepared to take a leadership role particularly in improving hazard resistant construction as well as the protection against floods and landslides.

A Total Quality Control approach should be taken to the construction industry in order to improve the effectiveness of the industry and the delivery of hazard resistant construction.