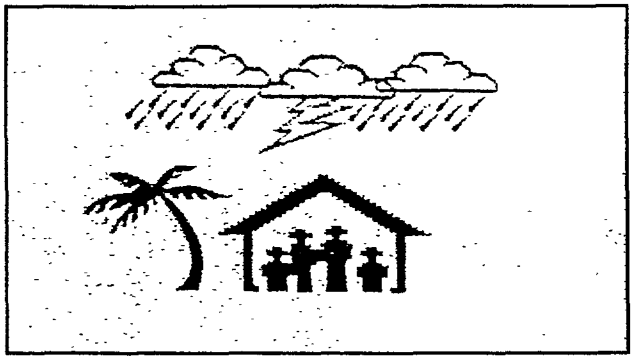
USAID/OAS Caribbean Disaster Mitigation Project



Cost and Benefits of Disaster Mitigation in the Construction Industry

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COST AND BENEFITS OF DISASTER MITIGATION IN THE CONSTRUCTION INDUSTRY

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ABSTRACT

This paper outlines some of the causes of failure observed in the losses incurred by the passage of Hurricane Gilbert over the island of Jamaica in 1988. It also presents the observations made from the effects of the Woodford (Jamaica) earthquake of January 13, 1993 on buildings in Kingston (M.M. Intensity VII).

From the lessons learnt by these observations, and the Code requirements of the National Building Code of Jamaica, the paper seeks to present the cost of including mitigation measures at the design/construction stage of the development of a building.

The benefits of designing and constructing hurricane and earthquake resistant buildings is also outlined by an indication of the relative losses which could occur from the effects of these two natural phenomena.

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OBSERVATIONS OF CONSTRUCTION FACTORS INFLUENCING DISASTER VULNERABILITY

Wind Loading

Hurricane Gilbert's passage across Jamaica clearly established, from it's effects on the islands building stock, that roof design factors largely control building damage caused by hurricane force winds. Although other building components, such as windows and wall elements, were damaged, such damage was secondary to the losses sustained from the destruction of light-weight roof structures.

Several causes of roof failure were observed. In fact, observations revealed that almost every element of the typical roof structure had failed in one instance or another. *Table 1* outlines the typical failures noted and the incidence of such failures.

Failure	**Probable Cause**	**Incidence**
Hold-down bolts to wall plate	Pull-out of bolts	low
Wall plate held by 13mm wall re-bar	Straightening of bent re-bar	moderate
Rafter to wall-plate connection	Poorly secured or missing strap	high
Truss support connection	Failure of connection in uplift	occasional
Timber purling to rafter connection	Pull-out of nails	high
Connection of sheeting to purling	Pull-out of nails/screws	moderate
Connection of sheeting to sarking	Tearing or rolling of sheeting	high

Table 1: Failures Observed in Typical Roof Structures[2]

The failures outlined in *Table 1* were caused primarily as a result of the inadequacy of the connections to transfer the forces being applied. However, secondary effects such materials failure - splitting of timber, tearing of sheeting (especially aluminum) and, inadequate maintenance - significantly, rotting of timber members, were noted to have contributed to the occurrence of failures.

Although hurricane damage to buildings in Jamaica was estimated by the insurance industry at somewhere between US$400-$600M, the cost of damage from a future event could be substantially reduced by the application of a few sound practices in roof construction and simple retrofit applications to existing facilities. In particular the lesson to be learnt is that roof specifications should not be left to the whims of the Contractor or the Supplier, but must be adequately detailed or specified by the Engineer within the construction drawings.

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[2] Based on damage caused by Hurricane Gilbert in Jamaica (1988)

Earthquake Loading

The impact of earthquake generated lateral loads on buildings are likely to be non-uniform since there are many variables which influence a structures seismic resistance. However, much knowledge has been gained from the investigation of the cause of damage to buildings caused by major earthquakes over the last forty years. Such observations have established structural elements which, if detailed correctly, will minimise the impact of earthquake loads and the extent of damage.

The recent magnitude 5.4 earthquake, which occurred on the 13th January, 1993 near Woodford (16km north of Kingston) in Jamaica, caused some damage at M.M. Intensity VII in Kingston. The earthquake, which was determined to have a focal depth of 18km, has highlighted the effect of earthquake forces on some structural elements. At these moderate levels of intensity, damage to structures just begins to occur, and therefore those elements which form the "weak link" of the structure will fail, or begin to show signs of failure. *Table 2* looks at some of these "weak links" which lead to damage.

Failure (Intensity VII)	**Probable Cause**	**Incidence**
Shear damage to columns	a) Restriction of column height with insufficient shear reinforcement	low
	b) Torsion induced by unequal column heights	low
Shear cracks in load bearing block walls	Absence of longitudinal re-bars or inadequately filled block pockets	low
Shear cracks in block walls acting as shear-walls	As above, also the poor location and choice of window openings	low

Table 2: Factors Causing Damage at Moderate Levels of Intensity[3]

It was clear that damage occurred in elements which exhibited a lack of ductility. Where it would not be possible to isolate such elements from the force path, then, in order to improve it's seismic resistance, it would be necessary to either increase the element's ductility or it's strength (or both).

Of particular note was the impact of inadequate shear reinforcement in short columns. Such columns were either "designed" as short columns or inadvertently behaved as short columns due to the restraining action of adjoining block walls. In cases such as these, it is best to alter the building at the design stage, so as to remove the potential "short column effect". This requires careful review of the architectural drawings, including elevations, by the design Engineer and a willingness by the design team to modify elements which present undue hazards.

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[3] As observed from damage caused by the Woodford Jamaica Earthquake (1993)

The willingness of the design team to modify their designs, and therein minimise vulnerability, has not, in the writers opinion, been forthcoming. Designs continue to be implemented with configurations obviously unsuited to earthquake risk reduction. The solution lies in a wider understanding of the risk factors by all involved in the design process (the "carrot"), and a move by the Insurance Industry to apply a premium penalty to poorly configured or designed buildings (the "stick").

THE COSTS OF MITIGATION MEASURES

Improved Wind Resistance

The evidence afforded by Hurricane Gilbert has lead to an improved understanding of those changes in roof detailing would be likely to withstand hurricane winds and those that did not. *Table 3* compares some of the techniques which did not work consistently with those that have been the accepted replacement methodology[4].

Prior to 1988	**Post Hurricane Gilbert**
Variability in type, thickness and length of roof sheeting	Use of 26 Gauge *Alusteel* or *Galvalume* sheeting (unspliced where possible)
Wall-plate held by hold-down bolts at 1350mm centres	Wall-plate hold-down bolts at 1050mm centres
Timber purling spacing up to 1200mm	Maximum spacing of timber purlings 900mm
Straps to rafters either omitted or at every other rafter	Hurricane twisted strap to every rafter
Retaining screws to sheeting at 900 spacing (or sheet width) by 1200mm	Retaining screws to sheeting at 450mm spacing (or one-half sheet width) by 900mm, reduced at overhangs or hips to 450mm
Open eaves up to 900mm	Boxed eaves where roof overhang exceeds 450mm

Table 3: ***Typical Pre and Post Hurricane Gilbert Roof Specifications***

The effect of the new specifications on the cost of construction has been determined to be very minimal if boxed eaves are not required (ie. roof overhang not exceeding 450mm). The cost of incorporating these more stringent specifications amounts to an additional 0.6% percent on the cost of the roof structure (*alusteel* or *galvalume* sheeting used in both cases).

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[4] UDC, Hurricane Gilbert Reconstruction

If the comparison is made with *zinc* sheeting, the increased cost of the roof structure is in the order of 5.0%. For a single story building, where the roof accounts for 13% - 15% of the total cost of the building, the increase in cost on the overall structure ranges from a low of 0.3% to a high of 3.0% (dependent on the roof cladding). The inclusion of boxed eaves would increase the preceding range. However for multistory buildings, the ratio of roof cost to total building cost would fall (~7% for two story), and consequently the percentage increase in overall cost would be further reduced.

Improved Earthquake Resistance

The improvement of the earthquake resistance of a building is not as distinct as that of the improvement of a building's wind resistance. Improved earthquake resistance can be had, without increased expenditure, by the selection of a symmetrical plan form for the building which minimises possible torsional rotation. The following check-list, *Table 4*, for the design and construction stage of any building, would be likely to improve it's earthquake resistance. For institutional buildings, the Client (Government Agency with responsibility) should include this as a part of the design brief for the project team and sign off on each item prior to implementation.

Design Stage	*Responsibility*
◆ Building plan to be regular and symmetrical if possible	Architect
◆ Cantilever balconies to be minimal in width (overhang) and not to be relied on for sole access	Architect
◆ Structural form to be agreed early in the design process	Architect/Engineer[1]
◆ All windows, door openings and stair/elevator locations to be carefully reviewed vis-à-vis their impact on the seismic resistance on structural elements (columns etc.)	Architect/Engineer
◆ All mechanical and electrical services to be reviewed prior to final designs.	Engineers- M&E and Structural
◆ Structure to have ample redundancy in lateral load carrying elements	Engineer
Construction Stage	*Responsibility*
• Closely monitor construction to ensure placement of reinforcement in accordance with the drawings	Engineer/Clerk-of-Works
• Test concrete blocks from each delivery to the site	Engineer
• Test concrete poured on site (cube strength) and inspect for consistency and workability (slump)	Clerk-of-Works
• Mechanically vibrate all structural concrete	Clerk-of-Works
• Variations to partition walls or openings, (which can affect structural performance), to be agreed by the Engineer	Architect/Engineer

***Table 4*: Check-List to Achieve Improved Earthquake Resistance**

The National Building Code of Jamaica (1983), under Section 4.1.3: *Earthquake Loads*, requires that structures are designed to meet the requirements of the latest revision of the recommended lateral force requirements of the Structural Engineers Association of California, commonly referred to as the SEAOC Code. This code sets the **minimum criteria** required to satisfy the **protection of life** at a level of shaking that relates to an M.M. Intensity of VIII to IX.

The SEAOC Code does not set out to protect the structure from damage at high intensities, nor does it purport to set an upper bound for design, although many engineers are of the belief that it does. Commentary to the SEAOC Code clearly states that the protection of life is reasonably provided, but not with complete assurance. The code is expected to ensure that buildings:

- resist minor earthquakes without damage;
- resist moderate earthquakes without structural damage, but with some non-structural damage;
- resist major earthquakes (Magnitude 6-7 at a distance of 24km) without collapse, but with some structural as well as non-structural damage.

If structures are built to meet the standards set by the SEAOC Code and hence the local (Jamaica) building code, then, the construction costs associated with such designs (which are earthquake resistant) are the minimum to be expected. It follows therefore that there should be little if any additional cost in order to comply with the building code in the construction of earthquake resistant buildings. In practice this is not always the case. But it does establish the difficulty in determining some specific additional cost, or percentage increase, for the inputs required to meet earthquake resistant designs if these are already a requirement of the building code.

Many buildings are designed by applying the SEAOC Code to establish the lateral forces that the building, or it's constituent frames, would be subjected to at different story heights. This data is then used to design the beams and columns or shear wall elements to carry the expected earthquake lateral loads. At this point, many project teams then consider the matter of earthquake resistance complete. However, it is in the detailing of individual elements of the structure, to ensure ductility or isolation, that the true impact of earthquake resistance is made manifest.

It is useful to outline the way in which the SEAOC Code addresses the **design force level** to be applied to a building. This is the total lateral load applied to the building which is then distributed to the resisting elements in proportion to their respective "stiffness" or "rigidity". This force is not the actual force to which the building may be subjected, but has in fact been shown, (from strong motion records of earthquakes), to be considerably reduced.

The formula used to determine lateral loads is

Total design base shear, $$V = \frac{Z\,I\,C}{R_w} . W$$

where,
Z = the seismic zone factor (varies in different islands)
I = the importance factor (of the building)
C = a function of the soil characteristics and the period of vibration of the building (max. 2.75 for any soil/structure)
W = total dead load of the building
R_w = numerical coefficient dependent on structural type

Once the site location is established, the value of Z I C is usually fixed for buildings under four floors. For example in Zone 4, that of highest seismic influence, ($Z = 0.4$); a standard occupancy building, ($I = 1.0$) and the maximum value of C, ($C = 2.75$ - applicable to most buildings under four stories), the value of $Z\,I\,C = 1.10$.

Since there is only a small change in the total dead load of the building, W, with the choice of different lateral load resisting systems, it becomes the factor $\mathbf{R_w}$ that significantly influences the design lateral forces used. The $\mathbf{R_w}$ factor embodies the difference in stiffness or rigidity of a shear wall compared to a special (ductile) moment resisting concrete space frame. Some typical values of R_w are set out below:-

A. Bearing Wall Systems	i) Concrete or Masonry Shear Walls	$R_w = 6$
B. Building Frame System	i) Concrete or Masonry Shear Walls	$R_w = 8$
C. Moment Resisting Frame System	i) Special Moment Resisting Space Frames (SMRSF[5])	$R_w = 12$

Note: For Seismic Zones 3 and 4, only SMRSF are permitted where frames are the sole lateral load carrying element.

It therefore follows that a building designed with Shear Walls as the lateral load carrying elements may be designed for up to **twice** the lateral load as one utilising SMRS frame elements, which relies on frame ductility to assist energy dissipation. It also is important to note that framed structures will deflect to a greater extent than those with shear walls. Therefore, any non-structural element, such as partition walls, which prevents this deformation, will itself be subject to damage and, more importantly, could alter the design behaviour of the frames.

The design team must therefore be very clear about the structural model chosen for a building and should be knowledgeable about it's expected behaviour.

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[5] SMRSF is a moment resisting space frame specially detaied to provide **ductile behaviour**

Cost of Earthquake Resistant Construction

The cost of earthquake resistant construction can primarily be said to be the cost of achieving ductility. Since concrete is not a ductile material, it's ductility is achieved by the addition of reinforcement. The three structural types outlined in the preceding section can be considered.

Bearing Wall Systems. Bearing wall systems are most frequently used for dwellings and apartment buildings up to four stories. The structure resists lateral loads by the distribution of shear forces within the load bearing walls. In such cases it is ideal to identify those walls which will be specifically detailed to carry the lateral loads. *Table 5* provides a comparison of load bearing walls specially reinforced to resist lateral loads and other walls.

The cost per square meter for the additional reinforcement, concrete and finishes (inclusive of labour) is in the order of US$10. This represents an increase of 25% over the cost of a typical block wall.

Typical Block Wall	**Wall Reinforced to Resist Lateral Load**
Vertical bars: 12mm @ 400mm	Vertical bars: 12mm @ 200 or 400mm*
Horizontal bars: optional	Horizontal bars: 10mm @ 600 or 400mm
150mm blocks (Class A)	150 or 200mm blocks* (Class A)
Alternate pockets filled with 2,000 psi conc.	All pockets filled with 2,000 psi concrete
Concrete stiffener if wall exceed 3.6m in length	Concrete Stiffener at ends to anchor longitudinal reinforcement

*Note: The spacing of the bars and the thickness of the blocks would depend on the shear force applied to a specific wall element. The permissible shear stress for Class A blocks is 35 psi.

Table 5: Comparison of Typical Block Wall to Wall Reinforced to Resist Lateral Loads

Although this may appear high, the overall cost of construction for a typical three story building, allowing for thirty five percent (35%) of the load bearing walls to be specially reinforced to resist lateral loads, is increased by only 0.8%, (based on an average construction cost of US$625 per square metre).

Building Frame Systems. These systems are suited to buildings where larger spans are desired, such as an office and hospital building. The system utilises a frame, beams and columns, to carry the vertical (dead) loads of the building, while relying upon shear walls (usually reinforced concrete) to resist lateral loads. The system is a desirable one since it has been shown to minimise drift (sway) and consequently impacts to a lesser extent on the building's contents. One limitation is the necessity to accommodate shear walls within the architectural and services plans in such a way as to minimise torsion.

The cost of shear walls are usually additive to the cost of the building, except where they can be substituted for other walls or external glazing. However, their use minimises the rigorous design, construction and inspection standards placed on SMRS Frames and also presents a more rigid structure, a desirable feature for the protection of building contents.

An estimate of cost was made for a two story building of 1,420 square metres. The additional cost for shear walls would increase the building cost by about 3.0%. If the development cost of the building is considered (total costs including M & E services, fees, land and finance), the increase would be less than 2.0%.

Moment Resisting Frame Systems. Moment resisting frame systems are usually best suited to buildings which require flexible space utilisation and "clean" facades. The SEAOC Code requires that in areas of Zone 3 and 4 that frames required to resist lateral loads be designed as Special Moment Resisting Space Frames (SRMSF). The ductility requirements of these frames exceed that of normal frames and the standards applied to construction are more rigorous.

Section 3G2, of the SEAOC Code requires that *"a specially qualified inspector under the supervision of the person responsible for the structural design shall provide continuous inspection of the placement of the reinforcement and the concrete and shall submit a certificate indicating compliance with the plans and specifications"*. The construction of buildings with frame resisting elements will therefore require great care and attention, at both the design and construction stages of their development.

The cost, in material terms, is usually less than that associated with shear walls since their is often no need to increase the size of the members (which uses additional concrete) to enable the frames to carry earthquake generated moments in addition to the moments imposed by "dead and live" loads. It is usually columns which may require re-sizing, and the additional concrete required is a fraction of that required for shear walls. However, there is usually a significant increase in the cost of reinforcement, both to carry the earthquake induced moments (main bars) and to provide ductility (links).

THE BENEFITS OF DISASTER MITIGATION

The benefits of disaster mitigation as achieved through improved structural resistance of buildings applies equally to both the threats presented by Hurricanes and Earthquakes. The evidence from the aftermath of Hurricane Gilbert in Jamaica shows that the "benefit" of a secure roof was not only related to the replacement cost of the roof element of the building, but also encompassed the consequential loss to the contents of the building, and the relocation costs of moving to and renting alternative accommodation until repairs were accomplished. *Figures 1 and 2* show the impact of hurricane devastation.

The cost increase associated with both hurricane and earthquake mitigation at the construction stage, range from less than one percent (1%) of construction cost for load bearing wall systems to a high in the order of three percent (3%) for building frame systems using reinforced concrete shear walls.

The loss of the roof of a building may represent up to 15% (single story) of the replacement cost of the building. When it is considered that consequential losses, such as water damage to the contents and finishes (paint-work), can easily represent another 15% of the cost of the building, the repair/replacement cost of total roof loss is likely to be in the order of 30% of the replacement cost of a single story building. This does not include the relocation cost for the occupants, which relate to the annual rental rates of a building (usually 5% - 10% of its current value), for the duration of the repairs. The benefit of having a roof detailed to successfully resist hurricane wind loads therefore far outweigh the small initial cost to upgrade the fixing details and roof cladding to ensure adequate performance. *Figures 3 and 4* show damage as a result of the 1993 Woodford (Jamaica) earthquake.

For earthquake incurred damage the prediction of the loss likely to be incurred is perhaps not as well defined as that of the loss of a roof. Earthquake damage can range from minor damage to non-structural elements which often does not exceed 2% of the value of the building to more major damage of structural elements which will require the relocation of the occupants while repairs are carried out. In the extreme, the total loss of the building, leading to it's demolition, may occur. Damage can therefore range from less than 2% to more than 100%, giving consideration to consequential losses. The cost of including earthquake resistant features into a buildings design, usually less than 3% of the initial construction costs, is therefore likely to prove of significant financial benefit to the owners in improved physical performance of the building.

The benefit to the occupants of the building are equally important in ensuring the preservation of life. It is not usual to place a financial value on the "peace of mind" of the occupants nor the personal and financial losses incurred from injury or loss of life. However, this is an important consideration to the macro-economic frame-work of a country. The prevention of dislocation to businesses and individuals will impact on the time taken for the countries economy to return to normal. The effects of the recent Kobe earthquake in Japan is a clear example. In a small island state, the economic dislocation has a more far-reaching impact on a countries economic performance.

CARIBBEAN DISASTER MITIGATION PROJECT

The Caribbean Disaster Mitigation Project (CDMP) is a coordinated effort to promote the adoption of natural disaster mitigation and preparedness practices by both the public and private sectors in the Caribbean region through a series of activities carried out over a five-year period. The CDMP is funded by the **USAID Office of Foreign Disaster Assistance (OFDA)** and implemented by the **Organization of American States/Unit of Sustainable Development and Environment (OAS/USDE)** for the **USAID Regional Housing & Urban Development Office in the Caribbean (RHUDO/CAR)**.

The CDMP provides a framework for collaboration with the Caribbean region to establish sustainable public and private sector mechanisms for natural disaster mitigation that will measurably lessen loss of life, reduce the potential for physical and economic damage, and shorten the disaster recovery period over the long term. Project activities vary according to location, contents and implementation strategy, but all contribute to attainment of the overall CDMP goal: a more disaster-resistant environment for the people who live, work and invest in this hazard-prone region.

Project activities include: 1) natural hazard risk audits for electrical utilities and other infrastructure systems and key lifeline facilities; 2) hazard mapping to support improved planning and location of physical development; 3) assisting the insurance industry in improving risk management for insured property; 4) assisting countries to adopt improved building standards and practices and training of builders, architects and artisans in their use; 5) stimulating community-based disaster preparedness and mitigation efforts with support of the private sector, and, 6) post disaster mitigation planning and program design.

The Project is being implemented in Caribbean countries where USAID has active assistance programs, i.e. the Dominican Republic, the Eastern Caribbean countries which are served by the Caribbean Office of Regional Assistance (CORA) of USAID, Haiti, Belize, and Jamaica. The entire region is to benefit from the project through an active dissemination of project information and methods.

The CDMP will build on past and ongoing regional initiatives in disaster preparedness and mitigation, and will promote technology transfer and institutional capacity building through direct involvement of professional associations, bankers, builders, insurance companies and reinsurers, NGO's, PVO's, community groups and government organizations in project activities.

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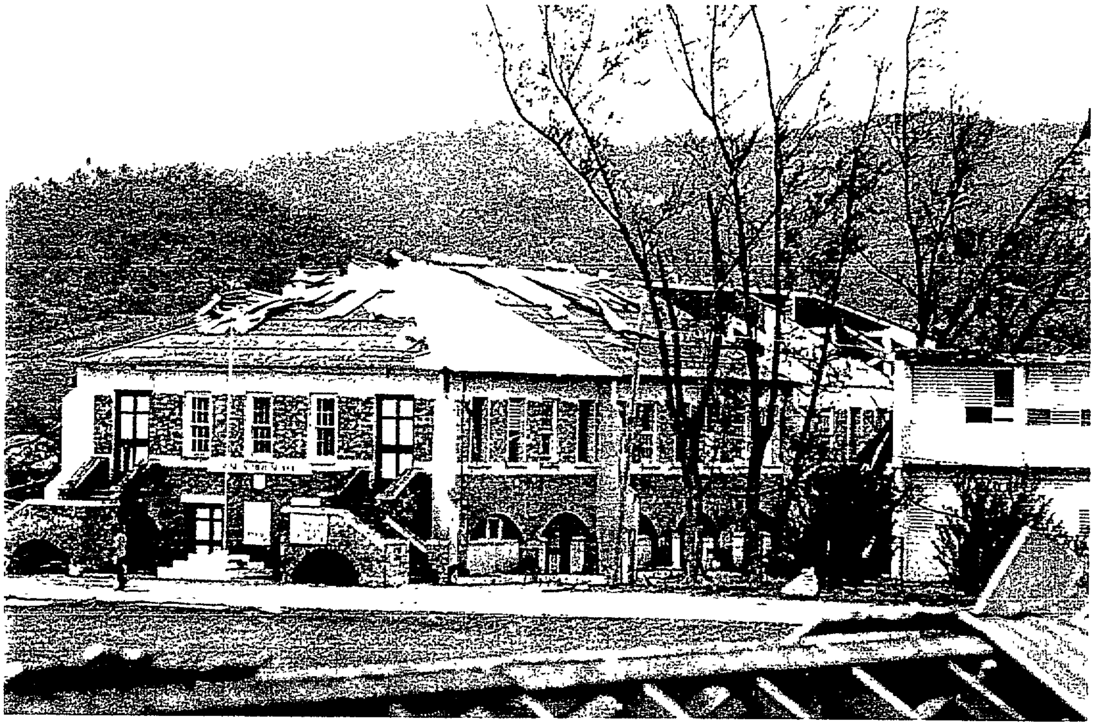

Figure 2: Hurricane Gilbert (1988) - Damage to Roof of Classroom Block at Ruseas High School in Lucea (N.Coast, Jamaica)

Photograph [illegible]

Figure 3: Interior Damage to Male Ward of the Noel Homes Hospital Caused by Loss of Roof Sheeting - Hurricane Gilbert (1988)

Photograph [illegible]

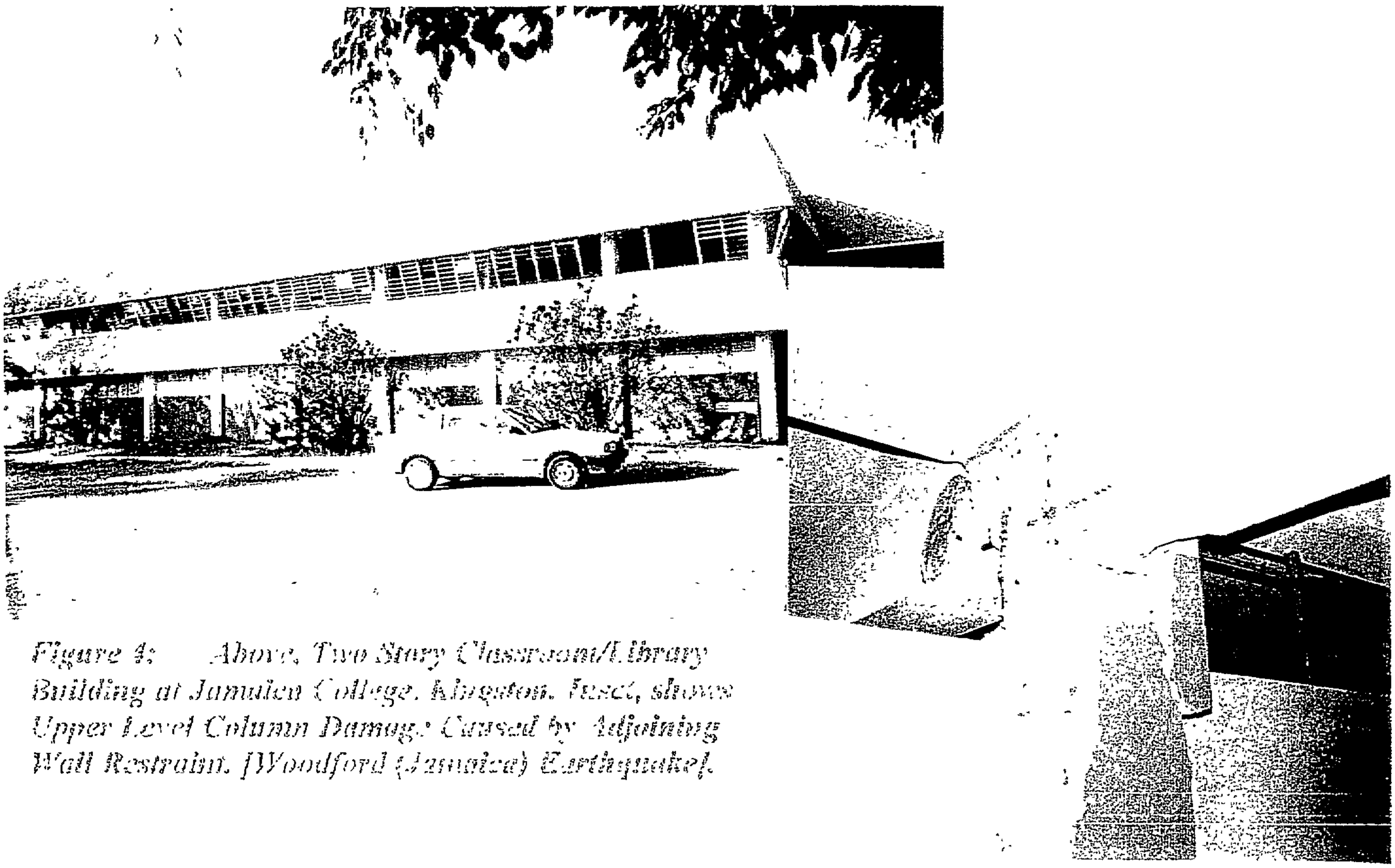

Figure 4: Above, Two Story Classroom/Library Building at Jamaica College, Kingston. Inset, shows Upper Level Column Damage Caused by Adjoining Wall Restraint. [Woodford (Jamaica) Earthquake].

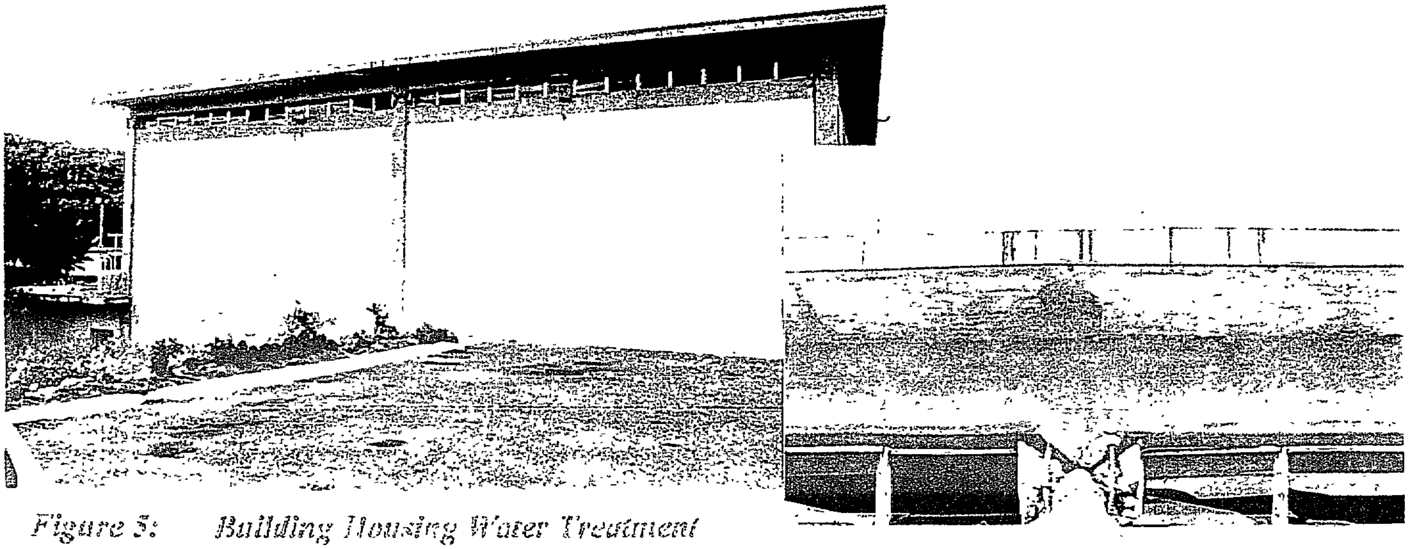

Figure 5: Building Housing Water Treatment Plant in Kingston. Walls on Exterior Restrain Columns and Cause "Short Column" Effect. Inset Shows Damage to Centre Column. [Woodford (Jamaica) Earthquake.