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Our Ref: CEP/20020

1989-11-15

Mr Rolf Stephanson
United Nations Development Programme
Jemmotts Lane
ST MICHAEL

Dear Sir,

Hugo in Montserrat

In accordance with your instructions my colleague (Herbert Browne) and I have undertaken reconnaissance visits to the island of Montserrat following the passage of Hurricane Hugo. We now report on those visits and on those other matters listed in the terms of reference.

Hugo was an uncommonly severe hurricane and its impact on Montserrat was devastating. This was so in spite of the building practices there being good by Caribbean standards. Notwithstanding the above statements, there were noticeable successes in Montserrat - principally among buildings of traditional design.

The reconstruction effort should be preceded and accompanied by educational programmes at all levels and by the widespread (if not mandatory) use of the Caribbean Uniform Building Code and other companion guides to good practice.

Considerable assistance was provided to Mr Browne and myself by Messrs Franklin McDonald, Ken Sparks, Reuben Meade and Alwyn Wason, and by you and the members of your staff. We with to acknowledge this assistance.

It is my hope that this exercise will assist you in your post-disaster programmes for Montserrat.

Yours sincerely,

Tony Gibbs

TABLE OF CONTENTS

PREFACE

Every year tropical cyclones develop within the six main tropical regions of the earth. The North Atlantic is one of those regions where Montserrat and the other Caribbean Islands are located.

Tropical cyclones are formed by an organised system of revolving winds which develop over warm tropical waters. The system derives the energy from the latent heat of condensation of water vapour from the sea. A water temperature of at least 26 degrees C is required, which must be maintained for several days in order that the system may sustain itself.

The classification of tropical cyclones is based on the average speed of the system. If the wind speed is below 18 metres per second (m/s) or 40 miles per hour (mph), the system is a tropical depression. Tropical storms have wind speeds between 18 and 32 m/s (40 and 72 mph) and hurricanes are cyclones with wind speeds above 32 m/s (72 mph).

The diameter of a mature hurricane may be anything from 150 to 1000 kilometres (95 to 625 miles), with sustained wind speeds often exceeding 52 m/s (115 mph) with still higher gusts nearer the centre.

Montserrat is one of the Leeward Islands and lies 27 miles south-west of Antigua at 16 degrees 45 minutes N and 62 degrees 10 minutes W. The area of the island is 39 square miles, which supports a population of about 12 500. Montserrat is of volcanic origin with rugged mountainous terrain. There are three main mountain ridges, the highest rising to 3 000 feet above sea level.

During the period 1886 to 1986, fifty tropical cyclones have passed within a 100-kilometre (62-mile) radius of Montserrat. The chart Annex A5-I shows the tropical cyclones which have passed within 100 km of Montserrat in this period, while Annex A5-II gives a listing of these cyclones. The annual occurrence rate is 0.5; if this trend continues then one tropical cyclone may be expected to pass within a 100 kilometres of Montserrat every 2 years.

Hurricane Hugo hit Montserrat in the early hours of Sunday September 17, 1989, and continued to batter the island for the next twelve hours.

The logs for the hurricane which were compiled by the Meteorological Department at Grantley Adams Airport in Barbados, show that on September 17th, wind speeds were in the 140 mph region. According to "The Hugo News", the official newsletter of the Montserrat Hurricane Relief Effort, the lowest barometric pressure recorded was 28.25

inches of mercury, which is about 1.5 inches lower than normal.

Initial reports from radio stations stated that more than 90% of the houses in Montserrat had been damaged and the majority of the population homeless.

On September 22, the United Nations Development Programme engaged Eng Tony Gibbs and Eng Herbert Browne to undertake a mission to Montserrat to examine and report on the damage which occurred during the passage of Hurricane Hugo.

SECTION 1

INTRODUCTION AND SUMMARY RECOMMENDATIONS

1.1 Terms of Reference

Mr Tony Gibbs and Mr Herbert Browne, Structural Engineers of Consulting Engineers Partnership Ltd of Barbados were engaged by the United Nations Development Programme to examine the damage to Montserrat caused by Hurricane Hugo, and to advise on the principles of hurricane-resistant design that should be adopted by Montserrat. The Terms of Reference of the assignment are as follows:

(1) Examine the damage to structures on Montserrat caused by Hurricane Hugo.

(2) Assess the extent to which design, workmanship, material and lack of maintaining contributed to this damage.

(3) Consult with and advise the Public Works, Housing Authorities and Construction Section on principles of systems through which more hurricane resistance can be achieved in the reconstruction and repair programme.

(4) Provide a report supported by photographic materials and slides including recommendations for improvements in hurricane-resistant structures.

Visits to Montserrat

1.2 The Consultants visited Montserrat on September 21st. - four days after the hurricane -, and returned on September 26th to 30th. During the visits discussions were held with a number of residents of the island to gain "first hand" impressions of the impact of the hurricane. Specific discussions were held with Mr Ken Sparkes, the Director of Public Works, who assisted the Consultants wherever possible in the circumstances, and with Mr Rueben Meade, Director of Development Planning.

The visits were timed to allow the Consultants to observe the damage before major reconstruction takes place; but care was taken not to interfere with efforts of the Government and people of Montserrat to provide minimum protection and covering to houses and Government buildings that sustained roof damage. Photographs were taken and slides developed. These slides are available for presentation.

The Damage

1.3 The Consultants did not estimate the value of the buildings and structures damaged or the cost of reconstruction, but the total cost of damage to the infrastructure, buildings and agriculture could be well in excess of EC $450 million (US $170 million). Section 2 of this report assesses the type of damage sustained, and Section 3 examines the damage in terms of the design and condition of the structures. In general however there has been severe damage to the majority of the housing stock, major infrastructure such as the port, and important buildings. Fortunately the main hospital and the power station, while suffering loss of its roof covering were still operative, as was the Government House and parts of the Government headquarters building.

1.4 An index of the level of destruction caused by a natural or man-made disaster may be obtained from the insurance industry. A major event is described as one in which companies are called to settle claims which represent 25% of the insured value of the buildings and 50% of the insured value of the contents. The insurance industry has reported that Montserrat is in a 40/80 situation. The Consultants' examinations showed that much less than 90% of the housing stock has been "destroyed", as was reported in the press.

1.5 The long-term effect of the loss of valuable infrastructure such as the port, electricity and telephone lines and poles, and the disruption to the agriculture and tourism industries has not been assessed by the Consultant, but in examining the reconstruction measures to be recommended, account should be taken of the importance of the buildings and infrastructure to the economy of the State. The degree to which hurricane-resistant construction should be implemented must be a function of the perceived importance of the buildings and infrastructure to the community.

Summary Recommendations

1.6 The following are recommendations of design and construction procedures to be followed in the supply of new buildings and for the improvements to be made to existing structures to provide hurricane-resistant construction:

(1) All buildings and structures must be designed in accordance with the Caribbean Uniform Building Code (CUBiC), and should preferably have the shape and form which would provide low vulnerability to hurricane forces (See Section 3). New roofs should preferably be hipped with pitches of 20 to 35 degrees.

(2) Small buildings - houses and small "dry goods" shops should be constructed in accordance with documents such as the Turks and Caicos Building Guidelines or in accordance with the principles shown in the Barbados Homebuilders Guide. This is not inconsistent with CUBiC.

(3) Corrugated galvanised or aluminium roof sheeting must be installed in accordance with the Guidelines and must be properly maintained. Rusted galvanised roof sheets are very vulnerable.

(4) Roof sheets and metal cladding where used should not be less than 24 gauge (0.5 mm) for galvanised steel and 20 gauge (0.9 mm) for aluminium. These materials are satisfactory if properly used, but because of their inherent vulnerability, it is not recommended that they be used for vital facilities. Concrete roofs properly constructed have low vulnerability to hurricane winds but the design of buildings with such roofs must take into account the seismic risk in earthquake areas such as Montserrat.

(5) Electricity and telephone poles must be designed to withstand hurricane force winds and with conscious attention being paid to topographic effects* and the relative importance of different parts of the system. Maintenance of line plant must be rigorous, and it is recommended that consideration should be given to the introduction of prestressed concrete poles for main transmission lines. The use of such poles will reduce maintenance of the poles.

(Note: * Maps can readily be produced to assist in this exercise.)

(6) All communication masts must be designed to withstand wind forces appropriate for critical facilities. The failure of these masts seriously affects the internal and external communications of the country and the sub-region. Care should also be taken in the design of the foundations and the anchorages. There should be planned inspection of the masts to ensure that corrosion has not affected the fixings and hence increasing the vulnerability of the structures.

(7) Care must be taken to ensure that the design and construction of the "important" buildings such as health facilities, police stations, public utilities plant and facilities, and Government administrative buildings are undertaken with conscious regard to the need of the buildings to resist hurricane wind forces. Existing public buildings must be properly maintained so as reduce the vulnerability of the structures.

Wherever possible light gauge roof sheeting should be replaced by heavier gauge sheeting and fixed in accordance with the principles shown in the Building Guidelines.

(8) The Government of Montserrat should pass into law the mandatory use of the Caribbean Uniform Building Code for the design and construction of buildings. It may be necessary to provide the Government with the appropriate technical assistance to ensure that the legal instrument is prepared expeditiously. It may be possible within the existing planning laws to ensure the use of the Code by administrative directive. In any event no programme of reconstruction should be started without the regulatory planning instruments in place, and without an adequate complement of Building Inspectors.

(9) Guidelines for the design and construction of telephone and electricity lines and poles should be developed for the Caribbean area, where problems of terrain with associated landslides, corrosion, wood rot and hurricanes are prevalent.

(10) A formally-structured education programme for all members of the building fraternity should be put in place immediately. This programme should not be viewed or implemented as a "one-off", short-term course, but as a continuing training opportunity forming an integral part of the tertiary education process.

SECTION 2

EXAMINATION OF DAMAGE TO STRUCTURES

2.1 The annotated photographs at Annex A1 show the typical damages incurred to housing, public utility systems, Government buildings, schools, the main hospital and other buildings such as churches. It was considered that in view of the limited time available for this survey, photographs of typical failures (and successes) would be the most appropriate way of fulfilling the requirements of item 2 of the terms of reference and of explaining the nature of the problems noted.

2.2 In general it was found that the quality of construction in Montserrat is at least as good as that in any other Caribbean Commonwealth country. However, because of the severity of the hurricane, Montserrat was more heavily damaged than Jamaica by Hurricane Gilbert in 1988 or Dominica by Hurricane David in 1979. Major damage was incurred to housing, both low-cost and high-cost, and to the telephone and electricity supply system. The structure of the wharf of the main port which was constructed of a reinforced concrete deck on piles was completely destroyed by the high seas. No vestige of the structure remains above sea level. It is therefore difficult to deduce the cause of the collapse without an examination of the design and the failed structure. However the special concrete sections which were used to protect the shoreline withstood the force of the waves.

2.3. The path of Hurricane Hugo through the Windward and Leeward Islands is shown at Annex A8. The meterological data available demonstrates that Hurricane Hugo was fundamentally an extraordinary hurricane in its severity. Information from the meteorologist at VC Bird International Airport, Antigua places the eye of the hurricane just 13 kilometers south of Plymouth. This means that the entire wall of the hurricane where the wind speeds are maximum was exactly over Plymouth.

2.4 The winds which affected Plymouth were from the south east and arrived undisturbed by any land mass (which would tend to absorb some of the energy and reduce the wind velocity), and were therefore as severe as could be generated by a hurricane. Preliminary calculations of the wind speed which must have led to the failure of the metal fixings used in the roof of the hospital indicate that very short period gusts of up to 240 mph could have occurred. If this is so, withstanding the hurricane winds of this magnitude required building systems of special design, properly maintained.

2.5 Studies carried out at the Boundary Layer Wind Tunnel Laboratory of the University of Western Ontario, Canada, have demonstrated that the wind speeds are accelerated by an upward slope of the terrain. The studies were carried out using a model of Nevis, and the volcanic topography of Montserrat would provide the wind acceleration observed in the laboratory studies referred to.

2.6 The combination of the following events produced the extraordinary high winds which attacked Montserrat:

a) A fundamentally strong hurricane

b) The position oof the eye relative to Plymouth, the centre of greatest population

c) Undisturbed passage of the on-coming wind

d) The mountainous topography

This combination resulted in high wind velocities and consequent destruction of houses and infrastructure in Plymouth and the surrounding areas.

Building Failures

2.7 Generally building failures were consistent with those which had been observed after previous hurricanes. These included widespread loss of corrugated metal sheeting, loss of asphalt shingles, loss of the roof structure, blown out windows and doors, and collapsed timber and concrete blockwall buildings. It is interesting to note that some buildings constructed in the traditional manner did not collapse, but this may be due in part to the traditional shape of the roof (hipped roofs of steep pitch) and the building shape (generally compact in plan).

2.8 The most significant single unusual phenomenon which was noticed in the examination of the roof failures was the longitudinal failure of timber rafters. This type of failure was not noticed in Jamaica (1988) nor in Dominica (1979) and might have been induced by the prevalent method of fixing rafters in the concrete lintels with a holding-down longitudinal bar threaded through the mid-height of the rafter. This can be clearly seen in many of the photographs in Annex A1.

2.9 Though there was widespread damage in Montserrat, the causes of most of the damage are identifiable and the damage can be avoided or mitigated by careful design based on a technical awareness of the forces to be withstood. There is empirical evidence that hurricane proof buildings can be designed and constructed in the Caribbean and the fact that some of the buildings in Montserrat escaped without major damage is testimony to this.

Public Utilities

2.10 many of the communication masts failed, which severely hindered communications when they were most urgently needed. It was clear that most of these masts were not designed to cope with even a moderate hurricane, and therefore stood no chance in an uncommon hurricane such as Hugo. These masts, including the foundations and anchorages must be properly designed and constructed to withstand the extreme hurricane forces.

2.11 The line plant of the telephone and electricity systems failed almost completely. This was also the case in Dominica and in Jamaica in those parishes hit by the hurricane. It is difficult to ensure stability of the system in the difficult terrain, especially in circumstances where long spans have to be used over deep valleys. However, because of the importance of the system to the recovery of the country after a natural disaster, efforts should be made to design and construct the system to prevent failure of major items such as transmission towers, buildings housing power and telephone plants, and satellite dishes.

2.12 The Consultants did not have time to examine the pole systems to determine whether the poles were in sound condition before the hurricane, but experience has shown that very often there are rotted poles in the system and these poles fail very quickly adding to the vulnerability of the other poles in the system. It is recommended that in areas of vulnerability to hurricanes special efforts be taken to inspect poles regularly and to replace poles immediately it is known that rot has invaded the pole. It is further recommended that for major transmission lines consideration be given to the use of prestressed concrete poles.

2.13 It appears that there has been no design standard for line plant developed specifically for the Caribbean. It is recommended that a design study be made of the appropriate systems to be used in areas of vulnerability to hurricanes, earthquakes, corrosion, wood rot and termite infestation. Account should also be taken of the effects of topography on hurricane force winds, and the system developed accordingly.

Public Buildings

2.14 Except for the police station at Salem which was constructed of concrete frame with a concrete roof, all of the public buildings suffered damage in varying degrees. The Government House in Plymouth lost only the new addition - an office - while the main building, constructed over one hundred years ago was relatively unscathed. The photograph of this building shows clearly one of the reasons for the lack of damage, and that is its very traditional construction with high pitched short span shingled roofs.

2.15 There is no standard construction principle used for public buildings. Some of the buildings as can be seen on the photographs were of inadequate construction and probably failed at relatively low hurricane wind speed. In most buildings also, the maintenance was lacking and failure may have occurred due to the failure of critical parts of the buildings.

2.16 The Glendon Hospital lost most of its roof sheeting through failure of the roof fixings. In this case the examination showed that the fixings which appeared to be well designed metal bolts, failed by straightening of the hooks, by failure of the plastic washers, and/or by tension failure of the bolts themselves. These modes of failure can be seen in the annotated photograph at Annex A1. Corrosion of metal rivets contributed to the loss of the fascia panels. However, it was obvious that the wind forces were excessive and the flat sheeted roof and fascia panels vulnerable. Fortunately, the ceiling of this building remained relatively in place (25% of the ceiling was lost) and the hospital was still functioning. As can be seen on the photograph, the windows and doors of the building are intact. A separate detailed report has been prepared on the rehabilitation of the hospital roof.

2.17 As occurred in Dominica during the impact of hurricane David many school buildings were badly damaged. Experience has shown that the maintenance of school buildings is usually very inadequate. In metal framed buildings, as with the "Maple Leaf" schools constructed in about 1968, corrosion of the metal frame and metal roof members is a significant factor leading to failure under the impact of high winds. It must be noted also, that the normal shape of the school buildings - relatively narrow and long - combined with relatively flat roof pitches with gable ends, lead to high vulnerability under hurricane conditions.

2.18 Where maintenance of the structure, windows and doors, and roof covering is lacking, the probability of survival under attack from a hurricane is very low. For this reason it is suggested that it may not be appropriate to consider school buildings as hurricane shelters unless special efforts are taken in the design, construction and continuing maintenance of these buildings so that safety can be assured.

SECTION 3

ASSESSMENT OF THE EXTENT TO WHICH DESIGN, WORKMANSHIP, MATERIAL AND LACK OF MAINTENANCE CONTRIBUTED TO DAMAGE.

Design and Construction

3.1 As indicated in Section 2, and as shown in the Barbados Homebuilders Guide, the design of many of the buildings does not conform to the basic buiding standards developed for low vulnerability construction. Some of these standards are:

a) the optimum plan shape of the building - a square building is less vulnerable than an oblong one, an oblong one less vulnerable than an L-shaped one etc.

b) the materials of construction - light weight construction such as in a timber framed building, is more susceptible to damage than heavy construction of concrete. But the vulnerability of heavy construction to earthquake damage must be considered.

c) the construction of the roof - a lightweight roof of timber framing with roof pitches of less than 20 degree is vulnerable. A gable-ended roof is more vulnerable than a hipped roof. Large overhangs are to be avoided. Roof coverings of corrugated galvanised steel or aluminium sheets must be of at least 24 guage for galvanised steel and 20 guage for aluminium sheeting and the sheets must be securely anchored to purlins at frequent intervals as shown in the Building Guidelines. Concrete roofs are inherently less vulnerable under high winds than light weight roofs,but as Montserrat is in an active seismic zone, concrete roofs should be used with careful attention being paid to the supporting structures.

d) the construction of the walls - walls either of timber or concrete blocks not securely fixed to the columns, plates and cills are vulnerable to wind suction and pressures.

e) windows and doors - these must be strongly built and capable of being firmly locked. Hurricane shutters should be incorporated into the design of more buildings.

3.2 It appears from the examination of the damage that many of the principles outlined above were not followed and compensating strengthening was not incorporated, with the result that extensive damage occurred to buildings which might otherwise have escaped serious damage. It is probable that because of the severity of the hurricane that major damage to many facilities was unavoidable, but the photographs of the buildings that have escaped damage show that adherence to the principles outlined above will mitigate the damage.

Maintenance

3.3 The maintenance of buildings and structures is not generally given high priority in the Caribbean, and it is evident that in some of the buildings examined inadequate maintenance has contributed to the failure. It should be noted that the failure of a structure under conditions such as those induced by Hurricane Hugo is progressive although rapid. The weakest link will fail first, throwing more load on other parts of the structure which than fail progressively. Hence while there was no time to undertake a detailed examination of all of the buildings and structures that failed, the examination of some of the systems (eg the fascia of the Glendon Hospital) showed that the structure may have been saved or at least the damage reduced significantly if the corroded fixings had been detected and replaced with new fixings.

3.4 Precise determination of the place lack of maintenance has taken in the failure spectrum of the transmission towers (or the port wharf) can only be made after a detailed examination of the structures, the design plans and some tests of the materials on the ground. However visual examination of failed towers in Dominica showed that rusted anchorages were one of the causes of failure of the towers.

3.5 It is recommended that because tramsmission and communication towers are of vital importance to the community, and should be operative during and immediately after a storm, a regimen of inspection be instituted and protective painting of the towers made routine. All fixings should be examined and special attention must be given to the anchorages.

3.6 The Caribbean Development Bank has provided funds for the maintenance of school buildings and health facilities which were constructed with funds provided by the Bank. It appears however, that perhaps because of pressure to provide additional facilities the maintenance of these buildings is still inadequate. Where the design of the buildings do not provide inherently "safe" construction the poor maintenance which is unfortunately a normal condition adds to the vulnerability of the structures and accelerates failure under extreme wind forces.

3.7 It is recommended that in future funds provided by international financing agencies for the construction of important facilities include the appropriate element of annual maintenance for at least twenty years. This would not appreciably increase the financing costs of the buildings, especially as it is a normal practice for the Governments to request and receive additional funding for rehabilitation of buildings that should have been adequately maintained throughout their assumed lives.

SECTION 4

ADVICE ON THE PRINCIPLES OF DESIGN AND CONSTRUCTION

4.1 Relevant documents developed as design and construction guide and codes for Caribbean environmental conditions are:

a) Codes

- Caribbean Uniform Building Code (CUBiC)
- Bahamas Building Code
- Jamaica National Building Code
- Turks and Caicos Islands Building Code
- Draft Cayman Islands Building Code

b) Guidelines

- Barbados Homebuilders Guide to Hurricane-Resistant Design
- Building Guidelines prepared by the Pan Caribbean Disaster Preparedness and Prevention Project (PCDPPP)
- Turks and Caicos Building Guidelines

In addition there are illustrated booklets developed for small builders such as:

- "Hurricanes and Houses", published by the Construction Resource and Development Centre, Kingston, Jamaica
- "How to build a small house", a construction manual developed by UNCHS/UNDP for small builders in the Turks and Caicos Islands.

All of the documents mentioned are based on experiences in the Caribbean, and concentrate on the problems of resistant to hurricane. earthquakes, and corrosion which affect the life and stability of the buildings. It would be useful to produce a customised document for Montserrat based on the information already available and based on the specific building practices of Montserrat.

4.2 In addition to these documents there must be the relevant legislation to ensure that the principles of design and construction outlined in the documents are adhered to. The Turks and Caicos Islands has drafted specific legislation which addresses this problem, and the Planning and Development Authority which issues building permits has made the use of the Guidelines and the Code mandatory for building in the Turks and Caicos Islands.

4.3 Inspection is an important aspect of regulatory control. The PCDPPP has organised two summer training courses for building inspectors of the Commonwealth Caribbean, and these courses are intended to provide the building inspectors with the tools needed to ensure that buildings are being constructed in accordance with the relevant codes and guidelines.

4.4 The examination of the damage which occurred to new buildings in Montserrat showed that the design of critical items of construction was not in accordance with the Guidelines and therefore would probably not have been approved for construction if there was the necessary legislation and inspection of the plans had been carried out in accordance with the normal legislative requirement.

4.5 The Consultants were informed that the Director of Public Works has been given copies of the Turks and Caicos Islands Building Code and Guidelines, and that the Government of Montserrat (Ministry of Health) has copies of the CUBiC Code. The Public Works Department also sent representatives to the seminar organised by the PCDPPP in 1984 to develop the Building Guidelines, and subsequent discussions with the Public Works Department indicated that the Guidelines as prepared by PCDPPP were satisfactory and would be used by the Public Works and other Government Agencies engaged in building.

4.6 It is recommended that efforts be taken to ensure that the CUBiC Code and the PCDPPP Guidelines are used. It is possible that the existing planning law may allow the Director of Planning (or the Minister) to impose reasonable conditions for the design and construction of buildings when issuing a building permit. If this can be done within the existing laws the use of the Code and Guidelines can be put in force immediately. In any event it is recommended that no permanent rebuilding (this does not include emergency repairs) be undertaken unless the relevant Code is used.

4.7 It is recommended that:

a) The Government of Montserrat take the necessary steps to make the use of the CUBiC code mandatory.

b) An adequate number of inspectors be employed to ensure compliance with the Code and Guidelines, and the necessary institutional supporting framework developed.

c) A programme of education for builders, home owners and building technicians be initiated.

d) All new building applications must be carefully monitored to ensure that the design of the buildings and materials of construction are adequate to resist hurricane force winds and earthquakes.

4.8 It is recognised that there were failures of both old and new buildings, but as stated in Section 2 old buildings did survive the hurricane in perhaps greater proportion than did newer buildings. There is no doubt the traditional building shapes would contribute to their lower vulnerability. The challenge is to provide mechanisms to ensure that the new buildings which may be inherently vulnerable have reduced vulnerability. This can be accomplished only after a detailed examination of each building, and it is recommended that this be carried out for important buildings. On the basis of the examinations proposals for remedial retro-fitting can be developed and costed. A phased programme for this work can also be developed.The need for decisive action appears to be urgent.