3.0 INVESTIGATION PROCEDURE

3.1 General

There are 11 main buildings on the hospital compound. A list of these buildings, their floor area, type of construction, age and general condition is presented in Appendix B along with a site location plan.

Six layout drawings (reproduced in Appendix C) for the L-Block and Baron Wing were obtained from the St Lucian Ministry of Planning, Personnel, Establishment and Training (MPPET). However, they only provide a limited amount of information on the actual structure. Consequently, most of the information obtained was gathered through on-site observations and discussions with hospital personnel and the designers of the L-Block refurbishment project.

3.2 Desk Studies

3.2.1 Earthquake-Resistant Design

There are a number of guidelines which can be followed to ensure that buildings and ancillary items offer the best possible resistance to earthquakes. Although deviation from the following rules will not necessarily result in an unsafe structure, the basic principles are well-grounded. Ideally, buildings should be:

(i) Symmetrical

(ii) Not too elongated in plan (length:width ratio <3)

(iii) Continuous and monolithic, with a uniform strength distribution.

(iv) Designed so that vertical members will remain intact after horizontal members have failed.

(v) Designed so that columns and walls are continuous from foundations to roof.

Features such as projecting towers, abrupt changes in section of structural elements and offset columns/beams should be avoided. Adjacent buildings should be constructed with at least 100mm gaps between them to allow for movement and to prevent battering.

Non-structural items such as infill panels, windows, doors, suspended ceilings, services and fixtures also require careful consideration. Inappropriate detailing of stiff, infill panels could lead to premature failure of surrounding structural elements and/or the panel itself.

Similarly, windows and door frames should ideally be separated from the structure to lessen the chance of damage to the glass or jamming of doors. In the case of services, excessive displacements could result in damage to pipes or other critical utility lines. Where possible, flexible joints should be used.

Most of the buildings on the site contain one or other of the inherent weaknesses mentioned above. Most prevalent among the reinforced-concrete-frame structures are the presence of potentially damaging infill panels in combination with relatively slender columns. (See photos #5 & 8).

3.2.2 Hurricane-Resistant Design

Although there have been instances of block walls being blown over in hurricanes, adequately reinforced and tied panels usually perform well. Lightweight roof structures are generally the cause of greater concern. The provision of hurricane straps and adequate holding-down details is a must and sheeting of 24 gauge or greater thickness is desirable. The loss of a few roof sheets is not usually costly in terms of replacement, however, collateral damage to equipment and fittings inside the building by wind and rain can be substantial.

The close-boarding in evidence under the corrugated galvanized sheets on the buildings of the L-Block and Baron Wing provide a useful second line of defence in the event that the roof sheeting is lost. Paediatrics, the former Nurses Home and most of the Administration and Laboratory buildings are concrete roofed and should therefore be reasonably safe from the effects of high winds. The roof sheeting on all the other buildings, with the exception of the asbestos-roofed Chest Wing, is in very poor condition. Many of the sheets are corroded and lack adequate fixings (see photos #10, 29 & 44). On the older buildings, holding-down details to prevent wind uplift of the main timber structures are noticeably absent (see photo #24).

3.3 Site Inspections

Three visits were made to the site. On the 14th of January 1993, Mr Tony Gibbs visited the site accompanied by Dr Sterling Mungal and Mr Cosmos Andrews. On May 21st a second visit was undertaken, this time in the company of Engs Cromwell Goodridge and Lyndell Gordon and Mr Humphrey Inglis. During the third site visit on the 22nd and 23rd of July 1993, a number of photographs were taken by Engs Tony Gibbs and Stephen Sandiford (Eng Goodridge was again in attendance on this trip). These photos are included in Appendix D.

Inspections were limited to the superstructure and its ancillary fixtures, and to equipment vital to the maintenance of hospital operations. No specific examination of foundations has been undertaken; in the absence of structural plans this would require much more intensive site investigation. It should be realized, however, that the type and condition of the foundations and the characteristics of the underlying soil will have a significant influence on the effects of earthquakes on the buildings.

3.4 Buildings

Comments on individual buildings are contained in the following sub-sections.

3.4.1 Paediatric & X-Ray Wing

This is a 3-storey, concrete-framed building with infill blockwork panels constructed about 30 years ago. The roof is an SB slab - a proprietary system composed of hollow clay blocks, reinforcing bars and concrete. It is likely that the floors are of similar construction. Several of the reinforced concrete members show signs of deterioration in the form of cracking which could lead to spalling. There are also cracks along the edges of infill panels and along the soffit of the roof ring beam. The east face of the building is composed primarily of large areas of glass with thin metal louvres (see photos #3 & 4). There is a similar arrangement on the west face.

The relatively small columns and concrete frame elements are not likely to provide adequate resistance to earthquake loads. This inability will be further exacerbated by the observed general deterioration of the reinforced concrete members. Furthermore, the glass panes (unless the frames are specifically designed and detailed) could be damaged by the in-plane shear forces generated during an earthquake. These panes are also vulnerable to the impact of flying debris during a windstorm. The loss of these glass panels would expose the upper two storeys to the elements.

The corrugated roof sheeting covering the SB roof has a very shallow pitch and is likely to be lost during a hurricane. The SB roofing system is notoriously prone to spontaneous minor failures where pieces of individual bricks may fall from the ceiling. Under earthquake loads this is likely to be magnified to catastrophic effect.

It is understood that this building is to be replaced during Phase II of the refurbishment project.

3.4.2 The L-Block

The so called L-Block is a predominantly single-storey building with some two-storey sections on the eastern and northern faces. It is constructed primarily of stone masonry with newer additions of reinforced concrete and blockwork. The stone masonry is some 100 years old but, paradoxically, exhibits less severe deterioration than some parts of the newer annexes. The columns, beams and floors on the northern side of the buildings show extensive signs of poor construction - honeycombing, inadequate cover to reinforcement and consequent corrosion of reinforcement and spalling of concrete are evident. It was also apparent that at least one of the newer columns has insufficient shear reinforcement (see photo #17.)

The older parts of the block are timber-floored in fair to poor condition with signs of termite infestation. According to Eng Cromwell Goodridge, the consulting engineer working on the refurbishment on behalf of the Government, these floors are to be replaced by reinforced concrete slabs. This is good, as the new slabs will act as reliable diaphragms and so improve the lateral force distribution, and hence the earthquake resistance, of the structure.

Although unreinforced masonry is inherently vulnerable to earthquakes, the system of many intersecting walls results in correspondingly low stresses. On the other hand, the overall L-shape of the building and the presence of the assorted infill sections are inherent weaknesses.

The roof structure throughout the block is composed primarily of light-weight, corrugated, roof sheeting fixed to timber close-boarding using twisted galvanized nails at 9-in to 12-in centres. These elements are supported by 2"x4" rafters at 2-ft centres. In most cases, the rafters are in part indirectly supported by timber trusses at 12-ft centres bearing on the walls. Although this is adequate for gravity loads, it was not clear what method (if any) had been used for securing the trusses against wind uplift. Some walls displayed diagonal and vertical cracks at the truss junction (see photo #14). It was speculated that these may have occurred during Hurricane Allen.

The verandah along the western and southern sides of the building has a separate canopy roof at a shallower slope than the main roof. Again, there was no sign of a positive holding-down fixing. Typical sketches of the timber roof structure are included in Appendix E.

Further investigation - by breaking out a section of the wall around the ends of the lower chords of the trusses - is recommended to confirm whether holding-down fixings are present and adequate for the interior trusses. In any event, a reinforced concrete ring beam should be provided at eaves level to tie the load-bearing walls together and so improve both earthquake and hurricane resistance.

In order to obtain a reliable assessment of the vulnerability of the existing timber roof structure, an analysis of the roof was performed using a once-in-100-year wind in accordance with the BNSI/BAPE/NCST/OAS Code of Practice: "Wind Loads for Structural Design". A summary of the calculations is included in Appendix E.

3.4.3 The Baron Wing

This wing is a rectangular 3-storey, stone-masonry structure linked to the L-block via a permanent reinforced concrete bridge. The interior floors are all timber - and will remain so after refurbishment - while the existing exterior verandah floor is concrete. The hipped roof structure is similar to that in the L-block with corrugated galvanised sheets on close-boarding on timber rafters. There is a separate timber canopy over the gallery at second floor level.

This building is currently only used as a storage area, however, plans call for its renovation and use as staff accommodation and amenities. To this end several repairs will need to be effected.

As a new timber floor will be used on the interior, the concrete balconies will therefore serve an important function: acting as stiff horizontal diaphragms tieing the walls together and distributing the lateral loads due to earthquakes. However, the eastern sides of both of the balconies currently exhibit serious cracking at midspan (see photo #22). These cracks must be chased out and repaired. In the event that during repair the slabs are not found to contain sufficient reinforcing steel, then they should be demolished and replaced by new, adequately-reinforced, concrete slabs.

The timber roof over the upper balcony does not have adequate provision for resisting uplift (see photo #24). These details will need to be revised during renovations.

3.4.4 Former Nurses Home

This L-shaped, split-level building currently houses nephrology, cardiology and an STD unit, as well as some nurses quarters. It is of reinforced concrete construction with blockwork infill panels, concrete floor and roof slabs. The building has 5-storey and 3-storey wings around a 6-storey core which houses the stairwell. Generally it is in good condition and appears to have been consciously designed and well constructed. However there are several features which make it vulnerable to earthquakes. These are:

(i) The L-shape.

(ii) The open area of the cafeteria (in the middle storey of the smaller wing) which forms a "soft" storey in comparison to the stiffer upper storey.

(iii) The varying heights and stiffnesses of the 3 ,5 , and 6-storey blocks.

(iv) The accidental stiffening effects of partial infill panels which could lead to additional loads on the relatively slender concrete columns.

The uppermost storey of the stairwell houses water tanks. Inaccessible from inside the building, this area is reached via an outer stair from the adjacent roof. There is a large opening on the west face of this storey which could lead to excessive wind pressures on the walls at this level during a hurricane. It is understood that the water tanks will eventually be moved to another location on the compound.

3.4.5 Administration & Laboratory Buildings

These buildings, like Paediatrics and the former Nurses Quarters, are again relatively slender reinforced concrete frames with blockwork infill panels and are about 3 storeys high.

A part of the Administration building is roofed in timber (close-boarding covered by asphalt shingles on 2"x4" rafters), the remainder is a concrete slab. The timber-roofed section, which is a public waiting area, is open on one side and there are also openings in the stairwell leading to the offices. The buildings are connected by a link corridor at the rear of the Administration building (see photos #7 & 8).

The 9-in-square reinforced concrete columns on the Laboratory building do not appear to be of sufficient size to provide adequate ductility during an earthquake. The slender corridor linking the two buildings is also a weak point in the structure. Where hurricane resistance is concerned, the metal and glass louvred windows in evidence on both buildings (and on several other buildings on the compound) are very vulnerable in hurricanes, while the opening at the ground floor level of the Administration block places additional pressure on the timber canopy and threatens the security of the hospital pharmacy beyond.

3.4.6 Former Doctor's Residence

Currently in use as a geriatric nursing home, this building has combinations of blockwork and timber walls with either reinforced concrete or timber floors. It is supported on concrete columns on its northern side and walls elsewhere. The generally steep-sided intersecting gable roofs are covered by corrugated galvanized sheeting which is, most likely, supported on timber rafters. It was not possible to see the actual structure of the roof during the site visit.

There has been deterioration of the concrete in some of the supporting columns as evidenced by cracking near the bases. There is no effective tieing of the timber and blockwork sections of the building. This is a liability.

3.4.7 Boiler House & Standby Generator Building

These are two small buildings on the west edge of the site. The structures are of concrete frame and infill-block-panel construction with timber-framed roofs supporting corrugated metal sheets. Both buildings are vulnerable to hurricanes and earthquakes.

In the case of the standby generator building, the presence of the large doorway in the north wall substantially reduces the relative stiffnesses of the ends of the structure and therefore makes it more susceptible to earthquake damage.

The concrete floor of the boiler house is supported on a masonry retaining wall along its west side and reinforced concrete columns elsewhere. As with other concrete structures on the site, the columns show signs of cracking; in one case the concrete has fallen away exposing a rusting section of rebar (see photo #30). The combination of an elevated, top-heavy, main structure (containing the boilers) supported on slender columns is seismically unfavourable. The inverted pendulum effect could cause large seismic forces which could lead to the premature failure of the already damaged lower columns.

The boiler house roof is not adequately fixed to the walls and the corrugated sheeting leaks. The door opening on the generator building provides easy access for wind-driven rain and also leads to greater wind pressures on the walls than for a completely enclosed building.

3.4.8 Kitchen

The kitchen is a long, single-storey, masonry structure with concrete floor and a timber-framed, gable-ended roof. The roof structure, like most of the older buildings, is composed of corrugated roof sheeting on close boarding on 2"x4" rafters at 2-ft centres. There are several doors along the eastern side of the buildings which will need to be more effectively secured in the event of a hurricane. The roof sheeting is badly rusted.

3.4.9 The Chest Wing

Located on the east side of the compound, this split-level, 2-storey reinforced concrete framed structure is in relatively good condition. The separate monopitch roofs with overhangs are, however, not a good shape for hurricane resistance. As on other buildings, the partial infill panels may lead to increased damage to the concrete frame in an earthquake.

3.5 Services and Utilities

The maintenance of a reliable supply of power and water and a functioning communication system are important factors in the operation of the hospital during a hurricane and immediately after a hurricane or earthquake. The effective disposal of sewage also requires careful consideration in order to minimize the likelihood of outbreaks of disease following disasters. The provision of internal backup supplies of power and water will not only ensure continuity of hospital operations, but will also decrease dependence, and lighten the burden on, public utilities after a disaster.

3.5.1 Electrical Power

Most of the electrical power is carried through the compound via suspended wires supported by poles and walls (see photo #33). Unless very high voltages are required - when it might be expensive to provide the necessary insulation - it would be advisable to bury all electrical services within the site to decrease their vulnerability in hurricanes.

The standby generator (see photo #32) is inadequate for the present needs of the hospital and is to be upgraded. The generator is currently housed in a small building on the western side of the site which is highly vulnerable to both hurricanes and, to a lesser extent, earthquakes (see section 3.4). The generator should be housed in a more secure building. It should be located away from critical areas of the hospital where noise and vibration could affect operations but should also be easily accessible during, as well as after, any hazardous event. The equipment should preferably be anchored directly to the structure. Currently this is not the case. Where vibration isolators are necessary, they should be designed to contain the effects of seismic displacement.

3.5.2 Water

The hospital has its own water tank. It is not known whether the current storage capacity is adequate. It is apparent that the structure is not in the best of condition (see photo #35). In the event of a break in the public water supply the water tank may be required to supply the needs of the hospital for an extended period of time. Appropriate, regular maintenance should be performed to ensure that both the tank and attendant pumps are functioning.

3.5.3 Boilers

The boilers are not anchored to the floor of the building in which they are housed (see also sub-section 3.4.6). This makes them more vulnerable to earthquakes. The pipe carrying hot water to the wards and operating theatre is hung from the roof trusses inside the building and suspended from metal poles on the outside. As the roof is not secure against wind uplift, neither will the pipe be. Although suspending the external pipework is good for earthquakes, it also makes it more susceptible to damage during a windstorm. Flexible joints should be considered for this and all other pipework to minimize the likelihood of damage due to excessive differential movement during seismic events.

3.5.4 Sewerage and Solid Waste Disposal

The existing sewerage does not function effectively. It is somewhat dilapidated, and prone to blockages and occasional overflows (see photo #36). Given the dangerous waste (syringes, blood) which is generated by hospitals on a daily basis, the provision of appropriate sewage and solid waste disposal facilities is critical. Ideally, the hospital should have its own in-house systems for dealing specifically with medical waste. In addition, the existing system of septic tanks, pipes and wells will need to be upgraded so that "regular" sewage can be more effectively handled. Most of the system is in very poor condition.

3.5.5 Miscellaneous Items

Damage during an earthquake is not limited to structures. Significant disruption can also occur through damage to seemingly minor fittings. Photographs #37 and #38 indicate areas which also require attention. Potentially hazardous supplies or equipment should be secured by fixing to the structure and should be stored away from critical facilities. Shelving (as in the pharmacy) and cupboards should be securely fixed to the walls. Shelves should be provided with lips to prevent items from sliding off.

3.6 Communications

The maintenance of effective communication links during and after a disaster will allow the hospital to make more effective use of its resources. This not only refers to telecommunications, but also to the physical links between buildings on the hospital compound. It has already been stated that the hospital is composed of many individual buildings. Most of the covered walkways connecting buildings within the compound eg see photo #34, are either exposed to the elements (which would make it difficult to use them during a hurricane) or inappropriately constructed (which could lead to the link being severed during a storm or earthquake). It is desirable that these bridges be protected to ensure that they will remain functional.

The protection of utility wires by burying them has already been mentioned. This can of course be extended to telecommunications lines. If the facility does not already exist, then the installation of an intercom network for communications between buildings should also be considered. The hospital should also have an external wireless communications link from the Administration building to the local Emergency Operations Centre (EOC).

3.7 External Works

Access to the hospital from Castries is via a narrow winding road further restricted by the presence of parked vehicles. Clearly, the provision of a reasonably direct and free route should be a priority. Parking facilities in the hospital itself are inadequate.

As the site is located on a hillside, extensive flooding is not likely to be a major problem. However, drainage works could be improved in many areas to better handle stormwater flows and prevent overloading downstream drains.

The two main stormwater outfalls on the east and west of the compound are not clearly defined, this is especially apparent for the western outfall. Neither of these drains are screened to prevent debris and waste from clogging the flow (see photos #40 & 42). As mentioned earlier, flooding of the site is not likely to be a problem, however the presence of large areas of swampy ground or stagnant water near the hospital is not desirable.

Drainage inside the compound is handled by a system of pipes and shallow concrete drains (like that in front of the kitchen in photo #41). However, many of these need maintenance or repairs - downpipes are missing, eaves guttering broken, and most of the existing concrete gutters are not large enough to contain heavy flows. The area in front of the Chest Wing is one instance where the lack of a clearly defined drainage path produced a small area of localized flooding near the entrance to the building during a moderate downpour (photo #39). Overall, the drainage system is in fair to poor condition.

4.0 CONCLUSIONS & RECOMMENDATIONS

4.1 General

The hospital facilities are generally in poor condition. There is widespread evidence of inadequate maintenance and many of the structures are likely to suffer significant damage during a severe earthquake or hurricane. Some buildings and ancillary fixtures will require remedial work to ensure adequate security, others should be replaced.

The refurbishment of the L-Block is an opportunity to correct some of the deficiencies in the existing structure. The use of new concrete floor slabs is a significant enhancement.

Generally, remedial work can be divided into short-, medium-, and long-term objectives.

4.2 Short-Term

The immediate goals would be:

(i) Installation of appropriate hurricane straps and fixings for timber roof structures, (holding-down bolts should be given careful attention).

(ii) Rusting corrugated metal sheets should be replaced with newer sheeting of at least 24 gauge thickness.

(iii) Fixings for roof sheeting should be of the cyclone washer type as used on the new maternity wing.

(iv) Further investigation and repair/replacement of the balcony slabs on the Baron Wing.

(v) A reinforced concrete ring beam should be installed at eaves level in the L-Block. This would not only improve the uplift resistance of the roof, but would also improve the ability of the entire structure to resist lateral loads.

4.3 Medium-Term

More medium-term in nature would be the following:

(vi) The demolition of the following buildings:

1. All derelict structures on the site (see photo #44).
2. The Boiler House
3. The Standby Generator building

The equipment currently housed in these buildings should be transferred to more secure areas.

(vii) Walkways connecting buildings should be permanent structures protected from the elements. The concrete link between the Baron Wing and the L-Block, and that joining the Laboratory and Administration buildings, should be detached at one or both ends and constructed with an appropriate joint to allow for earthquake movements.

(viii) Communications and utility lines should be placed underground.

(ix) Existing pipework should be replaced by pipes with bends and flexible joints.

(x) Protection in the form of shutters should be provided for all windows. External doors should be secured by bolts.

(xi) A regular maintenance programme should be created to oversee drainage and sewerage works and general cleaning of the compound.

(xii) An external wireless link to the local EOC to be installed.

(xiii) Regular weekly testing of backup facilities such as the water tank and the standby generator should be instituted. This could be done as part of an overall emergency preparedness programme.

4.4 Long-Term

In the long-term:

(xiv) The existing sewerage and waste disposal system should be upgraded. The hospital should be provided with its own treatment and disposal plants.

(xv) The Paediatrics wing should be demolished. It is understood that this is to be undertaken in Phase II of the refurbishment plan.

5.0* COST ESTIMATES

Order-of-magnitude cost estimates are provided for the extra-over work necessary for securing the buildings and facilities in the event of earthquakes, hurricanes and torrential rains. It is assumed that the existing structures are adequately designed and constructed for gravity loads. In some cases it is not feasible to execute satisfactory refitting. In such cases (marked * in the accompanying table 2) the cost estimates relate to temporary protection pending demolition and rebuilding.

The estimates are separated between structure and non-structure. Non-structure includes plumbing, electrical works, mechanical plant, windows, doors, ceilings and decorative finishes. Structure is loosely defined here to include all loadbearing elements as well as non-loadbearing walls and roof coverings.

The costs for internal structural items relate solely to earthquake resistance.

Generally the estimates are conservative in view of the limited time available for this study.

All costs are given in Eastern Caribbean dollars.
(EC $2.70 = US$1.00; EC$1.00 = US$0.37)

	Building/ Facility		Structure	Non-structure
1.	L-Block		$ 60,000	$ 39,000
2.	Baron Wing		$ 30,000	$ 16,000
3.	Paediatrics	*	$ 12,000	$ 20,000
4.	Chest Wing		$ 40,000	$ 20,000
5.	Former Doctor's Residence	*	$ 3,000	$ 4,000
6.	Former Nurses Quarters	*	$ 80,000	$ 20,000
7.	Boiler House	*	$ 1,000	$ 2,000
8.	Generator Bldg	*	$ 1,000	$ 1,000
9.	Administration		$ 30,000	$ 30,000
10.	Laboratory		$ 15,000	$ 15,000
11.	Kitchen		$ 20,000	$ 3,000
12.	Water Tank		$ 1,000	$ 3,000
13.	Standby Generator		-	NA
14.	Boilers		-	NA
15.	Utility Lines		-	$100,000
16.	Drainage		$ 30,000	-
17.	Telecommunications		-	$140,000
	Sub-Totals		$323,000	$413,000
	Overall Total			**EC$736,000**

NA = Estimate not available

Table 2