



Structural Vulnerability Assessment for St. Kitts and Nevis

Post-Georges Disaster Mitigation Project in Antigua & Barbuda and St. Kitts & Nevis

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1.0 EXECUTIVE SUMMARY

As a part of the Post George Mitigation Project aTotal of 94 Government buildings in St Kitts and Nevis were subjected to a structural vulnerability assessment with regard to the hurricane and earthquake hazard. Vulnerability to flooding, storm surge and landslide damage was also identified.

The assessments were made not on the basis of rigorous analysis but rather on vulnerability assessment models previously developed. These models give rough comparisons of the vulnerability of buildings in the same general area.

The study shows up the need for a structured and well-funded approach to regular maintenance of public buildings. Too many of them are less than well kept. The state of disrepair of the class of building called “steel-framed” was most noticeable.

Four of the buildings surveyed were said to be designated emergency shelters. In general, they were found to be either not sufficiently strong or to be operationally deficient in that they did not have the necessary facilities to support the targeted function.

The vulnerability of each building was catalogued and recommendations for retrofitting work to be undertaken were given along with estimated costs. The most frequently observed vulnerability of the buildings was related to the absence of storm shutters to protect the windows.

TheTotal price tag of the retrofitting recommendations is EC \$5,400,000.

Recommendations for improving the standard of hazard resistant design and construction on the two islands are included in this report.

2.0 INTRODUCTION

The islands of St Kitts and Nevis are located in the northern corner of the Caribbean chain at Latitude 17°25’30” N, Longitude 62°52’00” W and Latitude 17°05’00” N, Longitude 62°31’00” W, respectively.

The islands are of volcanic origin – there is a dormant volcano on each island. Habitation is mostly along the islands’ coastal strips which are to a large extent low-lying and sloping gently at first then quite steeply up to the mountains at the center. Parts of these coastal areas are subject to flooding due to storm surge and tsunamis. But the whole landmass of the islands (104 square miles) is even more susceptible to the hazards of earthquake and hurricane.

The Earthquake Hazard

St Kitts and Nevis lie in the zone of highest seismic risk in the Eastern Caribbean where large, shallow earthquakes may be expected due to under-thrusting of the Barracuda Ridge below the Caribbean plate.

Information from Robson's Catalogue indicates that the islands experienced major earthquakes in 1690, 1843 and 1950 which caused major damage. Intensities on the Modified Mercalli Scale were IX, IX and VIII respectively. (See Figure 3a)

The Hurricane Hazard

The islands also lie in the path of North Atlantic hurricanes which every year between June and November sweep through the Caribbean Sea packing devastating winds and torrential rains.

For many years, these islands were said to have a ten percent chance, in any period of 50 years, of experiencing hurricane winds with speeds higher than 120 miles per hour (averaged over 3 seconds). (Caribbean Council of Engineering Organizations). With the introduction of the St Kitts and Nevis Building Code in the last year or so that wind speed has been moved up to 145 miles per hour. This is roughly equivalent to a wind speed of 119 miles per hour when averaged over 60 seconds and represents a shift from a category 2 to a category 3 hurricane on the modified Saffir-Simpson Scale. (See Figure 3b)

In 1928, the islands were struck by a major hurricane. Between 1929 and 1988 the environment was relatively calm. But from 1989 to 1999 six (6) major hurricanes have affected the islands causing severe damage to buildings.

By far the most damage occurred to roofs. The most frequent type of failure observed was the stripping away of the roofing. This included corrugated metal sheeting, asphalt shingles and built-up roofing. Less frequently, the roof failure included loss of the roof decking and the rafters themselves. Typically, the rafter failure occurred at the wall anchorage. Nails and hurricane clips were pulled out. Another kind of rafter failure was also observed. In this case the rafter split along a line through the hole drilled to insert the anchor rod (see Appendix I). The top portion of the rafter was blown away leaving the bottom portion securely in place.

Open verandahs were shown to be very vulnerable. Many of them were demolished. Steel-framed buildings also suffered roof damage. Corrugated metal roof sheets were dislodged and in some cases purlins and rafter overhangs were buckled. Some of these failures occurred because the buildings were poorly maintained. Members were corroded and had lost considerable strength.

Windows were also shown to be weak points in the building envelope. Many let in large amounts of water even if they were not blown out or otherwise damaged by windborne debris.

The Structural Vulnerability Assessment of government buildings in St Kitts and Nevis, as a component of the Post Georges Disaster Mitigation Project, is intended to be a mechanism through which the buildings are examined to identify weaknesses in form, material, construction detailing or maintenance procedures which could contribute to loss in a hazard event.

Once such weaknesses are uncovered, recommendations are made for strengthening the structures and approximate costs are assessed.

The hope is that a phased retrofitting plan will be implemented to address this problem.

3.0 The Task

A total of 92 buildings were identified for the survey, 47 in St Kitts and 45 in Nevis.

These included small essential facilities, such as health centers and police outposts, hospitals, fire stations, primary schools, libraries, broadcasting studios and government ministry buildings. Among these were five (5) buildings (four in Nevis, one in St Kitts) which were identified as Designated Emergency Shelters.

The buildings were mostly single storey structures, though there were several two-storey ones and three of them were three storeys high. They were typically of concrete and concrete block construction. Some of the older buildings were constructed of unreinforced stone masonry. Pre-engineered, steel-framed buildings were also represented. Some of these carried concrete block wall cladding. Others were clad with metal and still others with a synthetic fibreboard. Roofs were mostly of the light, timber-framed type clad with corrugated metal panels.

A listing of the buildings and their geographic positions is shown at Appendix II.

Each building site was inspected to assess vulnerability to natural hazards such as flooding, landslides, storm surge, hurricane wind and wind blown objects.

For each building, significant data were collected such as age, materials of construction, roof geometry, and structural action.

Building features known to increase or decrease vulnerability to the wind hazard were noted – roof overhangs, open verandahs, rafter-to-wall connection, soffits, and window protection.

The condition of the buildings was also noted.

For each building, its distance from the coast and its elevation above mean sea level were recorded.

Building data collected are shown at Appendix V.

A separate survey of each building was carried out to collect additional information which would allow assessment of vulnerability to damage due to earthquake. This additional information typically included plan dimensions of the buildings and cross-sectional areas of walls and columns.

The five (5) buildings or building complexes identified as Emergency Shelters were further studied to determine their suitability for use as such. Holding capacity and availability of support facilities such as water closets, lavatories, showers, kitchens, potable water storage and delivery systems, electricity-generating equipment were examined, with a view to determining whether each facility should be

- A. declared safe for use during and after a hazard event
- B. declared suitable for use after a hazard event, if serviceable
- C. declared unsuitable for use as an Emergency Shelter

These findings are discussed at Section 7 below.

The assessment of seismic vulnerability was limited to damage due to ground shaking. Damage due to the dramatic effects of liquefaction was not considered. According to records in Robson's Catalogue, liquefaction occurred in Nevis during the 1690 event but there is no record of such occurrences in St Kitts. Assessment of vulnerability to this particular phenomenon which sometimes results from earthquake activity is beyond the scope of this project.

4.0 METHODOLOGY

Assessment Models

Earthquake

Vulnerability to damage due to earthquake was assessed using the procedure developed by A F Hassan and M A Sozen of Purdue University. This procedure is explained in detail in a paper titled "Seismic Vulnerability Assessment of Low-Rise Buildings in Regions with Infrequent Earthquakes" which was published in the Structural Journal of the American Concrete Institute in January, 1997.

It provides a rough comparison of vulnerability to earthquake damage among buildings in the same general area by calculating column indices and wall indices. These indices are ratios of column cross sectional area and wall cross sectional area in each orthogonal direction, to Total floor area. Column and wall indices are then plotted against each other to give a level of vulnerability. For the purposes of this study the plot shown at Figure 4 was constructed. A plot in Zone 5 was considered to indicate high vulnerability (low column and wall indices) while a plot in Zone 1 or Zone 2 was considered to indicate low vulnerability (high column and wall indices). Moderate vulnerability was assigned to buildings which plotted in Zones 3 and 4.

The assessment method was developed for nominally reinforced concrete buildings with unreinforced masonry walls. Equations are not included for modeling reinforced masonry, structural steel columns and their typical portal frame action. Similarly, the method does not allow for modeling the effect of the in-plane wall bracing ordinarily found in steel-framed buildings. In these cases the model gave results which suggested unrealistically low resistance to earthquake.

It was therefore necessary to make adjustments to the model based on the ratios of elastic moduli of concrete and the other materials – reinforced masonry, structural steel, wood. Steel and wood sections were transformed to equivalent concrete sections. This also meant that masonry walls were assigned a strength 3.3 times higher than unreinforced masonry. Further, because the newer engineered buildings were considered to have been detailed in accordance with modern codes for earthquake resistant design reinforced concrete columns in such buildings were assigned twice the strength of older ones. Steel bracing in sidewalls was modeled as reinforced concrete wall.

The method was calibrated against two buildings known to have low vulnerability to earthquake damage. In each case the assessment showed good correlation with designed strength.

Earthquake vulnerability rankings are shown at Appendix III.

Wind

It was intended that vulnerability to the wind hazard be assessed using the WINDRITE computer software owned by the Insurance Institute for Property Loss Reduction.

However, it was found that this software is no longer recommended for use in studies of this nature. The WINDRITE data collection system was therefore used, in part, in compiling notes during the field investigation phase of the work but this software was not used for weighting and manipulating the information to produce a vulnerability ranking.

Instead, vulnerability was determined based on the following building characteristics.

1. poor condition of building generally
2. poor condition of metal roof sheeting
3. roofed with common asphalt shingles or built-up roofing
4. open verandahs
5. roof overhangs exceeding 2 feet where there are no soffits
6. timber rafters anchored with a rod through a hole drilled through them
7. unbraced side walls (steel-framed buildings)
8. unprotected windows

The characteristics were not weighted.

High vulnerability was assigned to buildings exhibiting three or more of the listed characteristics, moderate vulnerability was assigned to buildings exhibiting two of the characteristics and low vulnerability was assigned if the building exhibited not more than one of the listed characteristics.

Since both of the islands are small (69 square miles, 35 square miles), are situated very close to each other (2 miles across the channel) and the buildings are all located on gently sloping ground relatively near to the coast it was felt that variations in exposure and topography are small. These parameters would not therefore be the dominant ones pointing to greater or lesser vulnerability of the buildings.

Wind vulnerability rankings are shown at Appendix III.

Record Drawings and Codes

For the most part the information used in carrying out the vulnerability assessments was collected during on-site surveys of the buildings. Drawings were very seldom available for study.

On-site surveys did not include breaking into ceiling cavities to view rafter-to-wall connections or breaking walls to determine reinforcing details.

Likewise, information about codes used for design purposes was hard to come by.

Holding Capacity of Shelters

Neither the National Emergency Management Agency (NEMA) in St Kitts nor the Office of Disaster Preparedness in Nevis currently list the number of persons which the various emergency shelters are intended to accommodate.

In order to test the adequacy of support facilities at each shelter an estimate was made of the probable maximum number of people who could be accommodated in reasonable comfort. No particular allowance was made for privacy.

Four of the five shelters assessed under this project were located in schools. Half of the Total floor area was therefore earmarked for storage of school furniture and emergency food supplies, for kitchen and bathroom facilities and for daytime interaction between family members. The remaining area was allotted on the basis of fifty-five (55) square feet per person.

Recommendations for construction of additional cooking, bathing and toilet facilities were based on the shelter capacities derived in this way and the provisions of the St Kitts and Nevis Building Code regarding maximum number of persons per fixture.

Stand-by Electricity Generating Capacity

Recommendations for the rating of the generator to be installed at each of the shelters reviewed was based on an allowance of 0.002 KVA per square foot of Total floor area. This would allow for powering lights water pumps and refrigeration equipment but not electric stoves or air-conditioning which put a high demand on the generator.

5.0 FINDINGS

A review of the survey indicates that taken as a group the public buildings in St Kitts and in Nevis are fairly resistant to damage due to the natural hazards of earthquake and hurricane.

As a general observation it could be said that much more attention should be given to regular maintenance of the buildings. More than anything else a hard look needs to be taken at the institutional arrangements now in place for identifying, authorizing, funding and delivering the required maintenance actions.

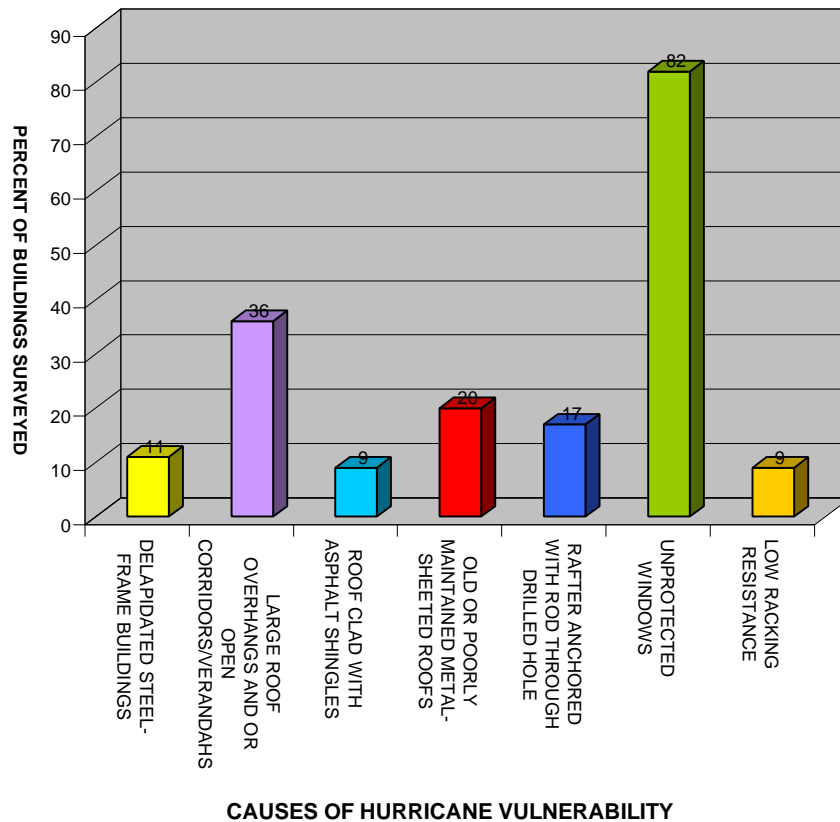
The deficiency most often observed was lack of protection for windows and equipment access openings in walls. 81 percent of buildings surveyed fell into this category.

In making recommendations for installing storm shutters for the protection of windows it was considered that all types of windows, not only those with glass panels, needed such protection. Metal louvre windows are also vulnerable. Even when they are not smashed by the impact of debris they will let in large amounts of wind driven rain.

The most severe deficiency encountered was the poor state of repair of the class of building called “pre-engineered steel-framed structure”. The deficiency was particularly severe where this type of structure also had walls of “cement fibreboard” as opposed to concrete block. The percentage of buildings falling into this category was small (21 percent).

Other notable points of vulnerability were open, roofed corridors where the main roof continues across the exterior wall to form the roof of the corridor (18 percent of the buildings) roof clad with ordinary asphalt shingles which are not rated for installation in high wind areas and buildings with rafters anchored by means of a steel rod passed through a hole drilled in the rafter - a detail which is no longer recommended (10 percent of the buildings).

The Bar Chart below shows the distribution of wind vulnerabilities among the buildings surveyed.



In general, the buildings surveyed showed satisfactory resistance to earthquake. Higher vulnerabilities were noted for masonry or steel-framed buildings with soft interior bracing walls.

The survey of the buildings identified as emergency shelters revealed that as a general rule these buildings do not have a sufficient number of the necessary facilities such as bathroom and kitchens to support this function.

A detailed review of the assessment of each building is given at Appendix IV along with a description of recommended retrofit actions and associated costs.

6.0 COSTING

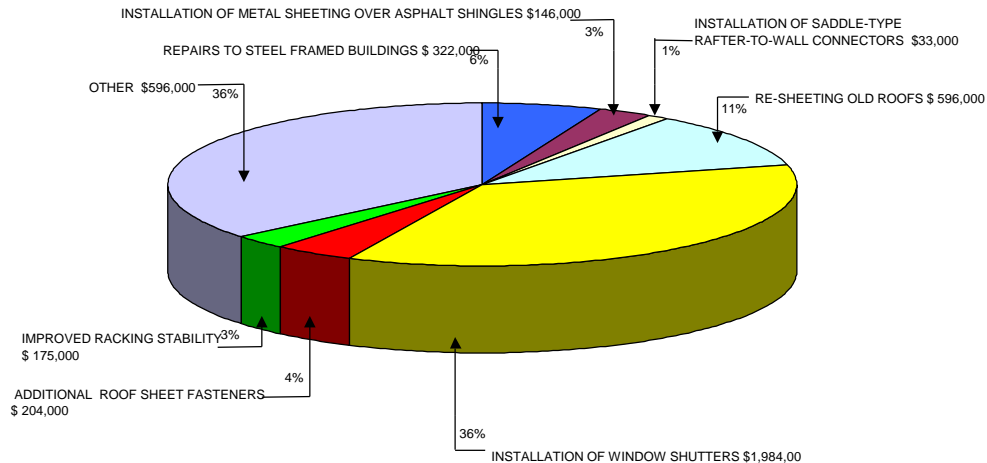
For the most part the estimated costs for implementing the various retrofitting recommendations were worked up from the unit rates shown at Appendix VI.

Some of these rates were adopted from the work previously done by Tony Gibbs, titled *Retrofitting Terms of Reference for Consultants - Standards, Global Estimate*. Where rates were developed by the Consultant, "duty free" pricing was assumed.

For ease of use, and as far as was practical, unit rates were reduced to dollars per square foot of floor area.

The total estimated cost of the recommended retrofitting work is EC \$5,400,000.

The distribution of this amount among the different categories of retrofit action is shown graphically below.



RETROFITTING COST BY CATEGORY
AS A PERCENT OF TOTAL COST (EC \$)

7.0 GENERAL RECOMMENDATIONS

Construction

For new and retrofit work, sheets should be fastened to the roof with galvanized screws instead of nails since screws provide increased holding power. The screws should be complete with neoprene washers and should be driven into the flat troughs of the sheets. Tape sealant should be used at side laps and end laps.

Where the popular 8/3 corrugated sheets are used the screws should be driven into the tops of the corrugations. The screws must therefore be longer to allow for the space between the top of the corrugation and the roof support member. Ideally, this type of sheet should be attached with a special washer which has a head shaped to match this curved surface more closely. Given the widespread use of this sheet it is recommended that sources of supply for this washer be identified and the washer specified for general use.

In many instances the main roof continues beyond the exterior wall to form the roof of verandah or open-sided corridor. As a mitigative measure consideration might be given to adding soffits below the roof sheets in these areas as opposed to either separating the two roofs or providing more closely spaced roof sheet fasteners.

The same idea might be extended to treat roof overhangs. In all situations, however, the strength of the rafter installation should be sufficient to resist the increased wind pressures which will occur at these locations on the roof.

Material Specifications

Roof sheet material should be 24 gauge galvanized steel with an additional protective coating such as PVF2. Aluminium sheets should be avoided. They must be held down at much closer intervals and in this ocean environment are subject to corrosion - called white rust.

Particular attention should be given to the specifications for procurement of pre-engineered steel buildings. These structures are competitively priced and they can be erected relatively rapidly. However, they are plagued by corrosion problems.

All standard weight steel sections which are exposed to the weather should be hot-dip galvanized with standard coating thickness. Light gauge members, whether exposed or not, should be hot-dip galvanized with extra heavy coating thickness.

The minimum thickness of material in structural sections should be 18 gauge and the minimum thickness of wall panels, trim and flashing should be 24 gauge.

These measures will go a long way toward preventing rapid deterioration of the members in this type of building.

Even the galvanized coating breaks down after about ten years of exposure. An economic analysis should be undertaken to determine whether it would make good sense to specify one of the weathering steels for use in exposed locations in these buildings. This material is quite expensive but it generates a protective coating when exposed to the weather and seals the

surface. No maintenance is required and the useful life might be sufficiently long to justify the high first cost.

Training

Continued training sessions for building designers and constructors in the techniques of hazard resistant design and construction should be an important component of the hazard mitigation process.

8.0 RECOMMENDATIONS FOR EMERGENCY SHELTERS

Criteria

Emergency Shelters are categorized as Essential Facilities. Such facilities are expected to survive a hazard event intact so as to be capable of providing logistical support to the nation's response to the event. Their function is to provide temporary housing for citizens whose homes were rendered uninhabitable and who could not be accommodated at the homes of relatives, friends or neighbours.

Shelters should therefore be of robust construction which is resistant to earthquake and hurricane damage; be located in areas which are not prone to flooding either by rain water runoff or by ocean waves; be located within easy reach of the residential areas which they are intended to serve; have adequate support facilities such as toilets and baths, potable water storage, kitchen and independent electricity generating equipment; be such that their use as a shelter for an extended period of time does not put a strain on the community because the facility cannot perform an important function customarily assigned to it in normal times.

Existing Buildings

These buildings should be well-maintained and should have been subjected to hazard mitigation audits and necessary retrofitting action.

This would include attention to important typical detail such as type of roofing material and method of fixing to the roof structure, length of roof overhangs, method by which rafters are fixed to supporting walls. Attention should also be given to the need to protect windows with storm shutters where the windows are not of the new impact-resistant type, to ensure that windows of all types are properly fastened into the walls and that doors can be braced or bolted from the inside.

These measures would go a long way toward reducing the chance that roof and wall envelopes would be breached by hurricane winds.

The hazard mitigation audit should also focus on the buildings' resistance to earthquake.

In general, buildings constructed of any of the usual materials would be acceptable. But since the resistance to induced lateral forces is crucial, shape and form are very important.

It is known that regular shapes will be more resistant to damage than irregular shapes (see Figure 1); that cross walls which brace exterior walls at frequent intervals are important (see Figure 2); that exterior walls which have a large percentage of openings (as for windows and doors) must be stabilized by the frame action of reinforced concrete beams and columns or by the x-bracing used in light steel-framed buildings. Further, it should be checked that all concrete and concrete block walls, whether interior or exterior, are reinforced. It would also be important to ensure that where two-storey buildings are being considered the lower storey is at least as well braced and buttressed by walls and frames as the one above.

Buildings sites which are located within the storm surge zone (say, less than 12 feet above Mean Sea Level) or are located in areas which historically flood in periods of heavy rains should be avoided as far as possible.

School buildings should be selected only as a last resort since it is always desirable to get students back into class as rapidly as possible after a hazard event and this is not consistent with use of the building for housing displaced persons.

New Shelters

When new structures are to be built as emergency shelters all of the considerations noted above should be taken into account. In addition, the forces which the structures are to be designed to resist should be stipulated in the designers' briefs in each case since the level of security required might be above that minimum which is prescribed in the Building Code.

Further, once a potential site has been identified, the foundation soils should be examined to a depth of at least 50 feet. This examination should include a check on whether the soils on the site are potentially liquifiable.

EARTHQUAKE INTENSITY

FIGURE 3a

| APPROXIMATE MAXIMUM INTENSITY | MODIFIED MERCALLI SCALE |
|-------------------------------------|--|
| I | Not felt. Marginal and long period effects of large earthquakes. |
| II | Felt by persons at rest, on upper floors, or favourably placed. |
| III | Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognised as an earthquake. |
| Minor VI | Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickbacks, books, etc., off shelves. Pictures off walls. Weak plaster and Masonry D cracked. |
| Damaging VII | Difficult to stand. Noticed by drivers of motorcars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks, fall of plaster, loose bricks, stones, tiles. Some cracks in masonry C. Small slides and caving in along sand or gravel banks. Concrete irrigation ditches damaged. |
| Destructive | General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. Frame structures, if not bolted, shifted off foundations. Underground pipes broken. Conspicuous cracks on ground. |
| X | Most masonry and frame structures destroyed with their foundations. Some well built wooden structures and bridges destroyed. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. |
| Major XII | Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air. |
| Great | |

SAFFIR/SIMPSON SCALE
(with wind speeds)

FIGURE 3b

| Hurricane | mph Basic Wind Speed (1-minute avrg) | Damage |
|------------|---|--------------|
| Category 1 | 74-95 | Minimal |
| Category 2 | 96-110 | Moderate |
| Category 3 | 111-130 | Extensive |
| Category 4 | 131-155 | Extreme |
| Category 5 | >155 | Catastrophic |