6.2.2.1. Low rise house types

(1) **Type 1R** - Wooden, stud-wall, one story construction on a concrete foundation, with a poorly-attached wooden-framed flat or pitched roof with tin covering. Generally have one to three bedrooms with one bath and seven to eight foot ceilings. Windows are aluminum louver, glass louver, or glass pane. (Plate 1)

(2) **Type 2R** - Wooden, stud-wall, one story construction or modular construction on cement block pilings, with a poorly-attached wooden-framed flat or pitched roof with tin covering. Generally have one to three bedrooms with one bath and seven to eight foot ceilings. Windows are aluminum louver, glass louver, or glass pane. (Plate 1)

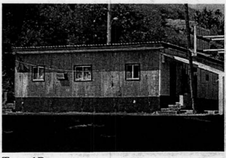
(3) **Type 3R** - Modular metal-sided, stud-wall, single story construction, with a well-attached wooden-framed flat or pitched roof with tin covering or precast waffle concrete panels. Generally have one to three bedrooms with one bath and seven to eight foot ceilings. Windows are usually glass pane, but may be glass, aluminum, or wooden louvers on older structures. (Plate 1)

(4) **Type 4R** - Hollow block or concrete-filled block with small gauge rebar, single story construction, with a well attached wooden-framed flat or pitched roof with tin covering. Generally have two to four bedrooms, with one bath and eight foot ceilings. Windows are aluminum, glass, or wooden louver, or glass pane. (Plate 1)

(5) **Type 5R** - Concrete-filled block with heavy gauge rebar or steel-reinforced concrete, single story construction, with a well-attached wooden-framed roof with tin covering. Generally have two to four bedrooms with one to two baths and eight foot ceilings. Windows are usually glass pane, but may be glass, aluminum, or wooden louvers on older structures (Plate 1)

(6) **Type 6R** - Steel-reinforced concrete, single story construction. with a flat steel-reinforced concrete roof. Generally have one to three bedrooms with one bath and eight foot ceilings. Single family, duplex, triplex or fourplex. Windows are aluminum, glass, or wooden louver, or glass pane. Typically 700-1500 square feet per unit. (Plate 1)

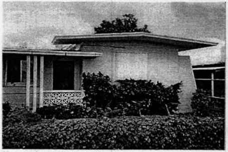
Plate 1. Residential


Type 1R


Type 2R


Type 3R


Type 4R or 5R


Type 6R (with shutters)


Type 6R (without shutters)

(7) Type 7R - Steel-reinforced concrete, single story construction, with a flat or pitched concrete roof, frequently with ceramic tile. Generally have two to four bedrooms with one to two baths and 8-10 foot ceilings. Typically 1200-2500 square feet. Windows are usually glass pane. (Plate 2)

(8) Type 8R - Custom-designed steel-reinforced concrete, one to three story construction, with a flat or pitched concrete roof, often with ceramic tile. Generally have three to six bedrooms with two to four baths and may have vaulted ceilings. Frequently have extensive (over-sized) glazing and pane glass windows. Typically 2000-5000 square feet. (Plate 2)

6.2.2.2. Low, mid and high rise apartment and condominium types

(1) Type 9R - Steel-reinforced concrete, two to three story construction, with a flat concrete roof, sometimes faced with decorative tile. Generally have one to three bedrooms with one to two baths and eight foot ceilings. Stairwells are external (exposed or partially exposed). Windows are aluminum louver, glass louver, or glass pane. Glass sliding doors are common. (Plate 2)

(2) Type 10R - Steel beam and steel-reinforced concrete construction, mid and high rise (4 to 15 stories), with an elevator core and internal stairwells. Generally have one to four bedrooms with one to three baths and eight to ten foot ceilings, frequently with balconies. May have extensive glazing, pane glass windows, and glass sliding doors. (Plate 2)

6.2.2.3. Miscellaneous structures

(1) Type 11R - Generally poorly constructed wooden and/or sheet metal shack-like structures, with poorly attached or unattached foundations. May or may not have light-weight windows and wooden doors. May or may not have indoor plumbing. (Plate 2)

(2) Type 12R - Mobile homes and containers converted into homes; containers usually have windows. Raised on block pillars, with or without skirting. Usually tied down with cables. (Plate 2)

Plate 2. Residential


Type 7R


Type 8R


Type 9R


Type 10R


Type 11R


Type 12R

6.2.3. Commercial Structure Types

6.2.3.1. Non-hotel type structures

Low rise commercial buildings on Guam are generally one to three story, steel reinforced concrete structures or rectangular sheet metal structures. While most of the one and two story concrete buildings have concrete roofs, a few still have wooden-framed roofs covered with tin. Most of the sheet metal buildings use steel beam frames and supports. Of these, some are ribbed with heavy-gauge steel, while others use 2 X 4 wooden studs or light-weight metal studs/ribs between the major framing supports. The weight/gauge of the steel siding and framing varies from building to building.

Mid-rise and high-rise types are of steel beam and steel-reinforced concrete construction, with an elevator core and internal stairwells. The largest of these buildings are hotels, which are discussed separately. The types of commercial structures, including low rise, mid rise, and high rise types, are shown below.

(1) Type 1C – Wood sided or modular metal-sided, stud-wall, single story construction, with a poorly-attached wooden-framed flat or pitched roof with tin covering. Generally have seven to eight foot ceilings. Primarily used for storage or small stores. (Plate 3)

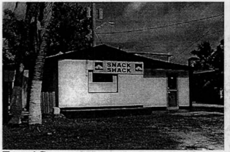
(2) Type 2C - Hollow block or concrete-filled hollow block with small-gauge rebar, single story construction, with a well-attached wooden-framed flat or pitched roof with tin covering. Generally have eight to ten foot ceilings. Often windowless or with small glass panes. Doors are usually wood and singular. Commonly small stores, lounges, massage parlors, or auto repair shops. (Plate 3)

(3) Type 3C - Concrete-filled block (with heavy-gauge rebar) or steel-reinforced concrete, single story construction, with a well-attached wooden-framed roof with metal panel covering or pre-cast waffle concrete panels. Generally have eight to ten foot ceilings. Windows are usually glass panes or plate glass. Doors are usually single or double swinging types. Commonly small stores (e.g., video shops, mom-and-pop stores). (Plate 3)

(4) Type 4C - Steel-reinforced concrete, single story construction, with a flat or pitched concrete roof, often with decorative ceramic tile. Generally have ten to twelve foot ceilings. Windows and doors are usually plate glass. Commonly small stores (e.g., video stores, dress shops, mom-and-pop stores) and restaurants. (Plate 3)

(5) Type 5C - Sheet metal exteriors with steel beam frames and supports, and ribbed with small gauge steel, aluminum, or 2X4 wooden studs between the major framing supports. The weight/gauge of the steel siding and framing is generally lighter weight and smaller gauge. Frequently used as warehouses or automotive shops, hardware stores; many contain wide sliding or roll-up type doors. May have one or more lower walls made of hollow block or concrete-filled block. (Plate 3)

Plate 3. Commercial



Type 1C


Type 2C


Type 3C


Type 4C


Type 5C


Type 5C

(6) Type 6C - Sheet metal exteriors with steel beam frames and supports. and ribbed with steel studs or steel lattice between the major framing supports. The weight/gauge of the steel siding and framing is generally heavier weight and larger gauge. Frequently used as warehouses, grocery stores, or automotive shops; contain well-attached wide sliding doors, roll-up sliding doors, and/or double plate glass doors (Plate 4)

(7) Type 7C - Steel-reinforced concrete, two to three story construction, with a flat concrete roof, sometimes faced with decorative tile. Generally have ten to twelve foot ceilings and exterior entrances to each office. Often have extensive glazing and double plate glass swinging type doors. Stairwells are external (exposed or partially exposed). (Plate 4)

(8) Type 8C - Steel-reinforced concrete, one to three story construction, with a flat or pitched concrete roof, sometimes faced with decorative tile. Generally have ten to twelve foot ceilings and interior entrances to offices. Stairwells in multi-story buildings are internal. Buildings usually have extensive glazing. May contain a small elevator. These include office centers, fast food restaurants, medical centers, small churches, service stations, and small shopping centers. (Plate 4)

(9) Type 9C - Steel beam and steel-reinforced concrete, one to three story construction, with a flat concrete or synthetic roof. Generally have 12-25 foot ceilings, numerous partitioned/walled areas inside, and large atriums or courtyards. Stairwells in multi-story buildings are internal, and escalators and elevators are common. Buildings usually have large multi-door entrances and large, well-attached sliding or roll-up doors Windows are few or non-existent. These include large shopping centers/malls, large warehouses (old FISC warehouses), theaters, and large churches. (Plates 4 and 5)

Plate 4. Commercial

Type 6C

Type 7C

Type 7C

Type 8C

Type 8C

Type 9C

(10) Type 10C - Steel beam and steel-reinforced concrete construction, mid and high rise (4 to 20 stories), with one or more elevator cores and internal stairwells. Generally have ten to twenty foot ceilings, with a few main entrances and interior entrances to individual offices. Usually have extensive glazing. Examples are the main Bank of Guam Building, ITC Building, GCIC Building, and Pacific News Building. (Plate 5)

6.2.3.2. Hotel type structures

Hotels on Guam run the gambit from small, economical one story types to very large high rise luxury types. The largest hotels (Outrigger, Hilton, Hyatt) have around 600 rooms and the tallest (Pacific Islands Club) has a tower of 32 stories (with a 26-story tower under construction). Most of the low rise hotels are steel-reinforced concrete with concrete roofs, while the mid rise and high rise structures are of steel beam and steel-reinforced concrete construction. Hotel types are listed below.

(1) Type 1H - Concrete-filled block or steel-reinforced concrete, one- or two-story construction, with a flat or pitched concrete roof, often with decorative ceramic tile. Generally have eight to ten foot ceilings, outside entrances to each room, and exterior stair wells. Windows are usually small and may be louvered or pane glass types. (Plate 5)

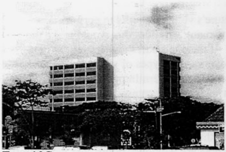
(2) Type 2H - Steel-reinforced concrete, two to six story construction, with a flat concrete roof, sometimes faced with decorative tile. Generally have ten to twelve foot ceilings and inside or outside entrances to each room. Stairwells are external (exposed or partially exposed) or internal. (Plate 5)

(3) Type 3H - Steel beam and steel-reinforced concrete construction, mid and high rise (5 to 32 stories), with one or more elevator cores and internal stairwells. Generally have large lobby areas, ten to twenty foot ceilings, with a few main entrances, and interior entrances to individual rooms. Usually contain many restaurants and shops. (Plate 5)

Plate 5. Commercial and Hotel


Type 9C


Type 10C


Type 10C


Type 1H


Type 2H


Type 3H

6.2.4. Governmental Structure Types

Governmental buildings run the gambit from poorly constructed sheds to large one-of-a-kind structures such as power plants and air terminals. The large one-of-a-kind structures are covered under the Transportation Assessment and the Infrastructure Assessment. The government has a great deal of residential properties at Tiyan and at the University of Guam that have been converted for office and educational use. These are primarily Type 6R. Many barracks type buildings from the old Naval Air Station at Tiyan have been converted to office use. These are primarily Type 7C. The government also has many offices and warehouses of Types 5C and 6C.

6.2.5. Methods of Determining Structural Vulnerability

6.2.5.1 General

While one popular method to determine a structure's vulnerability is to perform engineering studies of the structure, there are too many variables that would make the results questionable for every similar structure. If there is a sufficient amount of data, then an evaluation of the historical performance of various types of structures to various intensities of winds is a valid and desirable approach for determining vulnerability. The large historical data available for Guam affords such an opportunity. The Final FEMA Report on Typhoon Paka (FEMA 1998g), which surveyed damage to structures and the electrical power distribution system, was also an excellent source of information. Data from other tropical areas can be used to augment the local data to a certain extent. With steel-reinforced concrete structures, the weak points are windows, doors, and peripherally attached equipment (e. g., air conditioners, vents, etc.). If well-engineered storm shutters are employed, the limiting factor in protecting the integrity of the structure's envelope or skin is the strength of the storm shutters.

6.2.5.2. Saffir-Simpson Tropical Cyclone Scale

The Saffir-Simpson Tropical Cyclone Scale (STCS—pronounced "sticks") discussed in Chapter 5 describes the levels of damage with respect to tropical cyclone Category. This allows a classification to within 10-15 miles per hour at the low end of the Scale and to 20-30 miles per hour at the higher end of the Scale. The STCS is shown in detail in Appendix C. For structures on Guam, it is not necessary to use Tropical Storm Category A. Little structural damage occurs from weak tropical storm-force winds (TS A).

Table 6.1. Saffir-Simpson Tropical Cyclone Scale (STCS) typhoon categories, the corresponding sustained wind and gust speed ranges, and expected elevated water levels in bays and over reefs.

Ty Category	Sustained (mph)	Gusts (mph)	Description of Damage Level	Storm Surge Bays/Reefs (ft)
1	74-95	95-120	Weak	4-6 / 2-3
2	96-110	121-139	Moderate	6-8 / 3-5
3	111-130	140-165	Strong	8-12 / 5-8
4	131-155	166-197	Extreme	12-18 / 8-12
5	156-194	198-246	Catastrophic	18-30+ / 12-20+

although agriculture is susceptible to damage from these winds. Only the weakest structures are susceptible to damage from TS B Category winds. Thus, most structures on Guam are not vulnerable to winds until they reach typhoon intensity. The STCS Typhoon Categories are listed in Table 6.1.

6.3. EXPOSURE CONSIDERATIONS

Guam is a relatively small island with a relatively low elevation. Its coastal areas are subject to the maximum over-water winds. Its inland areas are subject to some frictional reduction of the winds due to increased surface roughness. They are also subject to local accelerations due to interactions with bluffs, valleys, and mountains/hills. Urban areas are also subject to frictional reduction of the wind, but winds also accelerate between buildings, especially massive concrete buildings and high rise buildings. Buildings, trees, and mountains may also block structures from the full force of the winds. The effects of these interactions between the wind and the terrain change with small changes in wind direction, and it is not feasible to predict these small changes in wind direction. In many cases it is not possible to measure it. Thus, for Guam, the maximum winds over the island will be treated the same as the maximum winds over water.

Much of the structural damage is due to the effects of wind gusts. The potential peak gust over water and over Guam's small land area are similar, if not the same. The lulls are likely lower over land, and thus the wind-induced pressure forces are likely somewhat higher over land than over water. **All things considered, the over-water wind speed should be representative of the over land wind speed.**

6.4. MODES OF FAILURE

6.4.1. Wooden structures

The predominant mode of failure for wooden structures is through uplift of the roof. This generally works in concert with the failure of doors and /or windows, which allows the wind to penetrate the structure's envelop. The wind then imposes an upward force on the roof from the inside of the structure. This, coupled with the lift (suction) imposed by the wind flow across the roof, can cause the roof structure to break away from the anchoring walls.

Most of Guam's houses with wooden roofs are attached with galvanized-steel connectors and straps. This practice has been promulgated by FEMA as a mitigation measure due to the frequency of typhoons affecting Guam and the recurrent roof failures. This construction can hold up to Typhoon Category 4 winds, if the structure envelop is not pierced or the construction has not deteriorated. There are several factors that can affect the capacity of a roof to resist being separated from the supporting structure (uplift resistance capability). These are listed in Table 6.2.

Once part or all of the roof separates from the supporting walls, the exterior and interior walls are susceptible to toppling. Steel-reinforced structures are not susceptible to toppling walls, although single hollow block walls or partitions held in place only with concrete or small size rebar can be blown down when winds reach Typhoon Category 3.

Other important modes of failure for wooden structures are:

1. Failure of doors and windows -- The failure of doors and windows occurs due to wind-induced pressure forces and airborne debris. These losses are critical as they allow the wind to breach the structure skin or envelop. This changes the internal pressure and forces the roof upward from the inside of the structure. It also allows extensive water incursion.

a. Windows -- In wooden houses, the window frames are frequently the weakest part of the structure. The windows sweat and water gathers on the frame, making it susceptible to rot. Window frames are also a favorite area for termites to attack. Window frames need to be periodically inspected and changed as necessary.

Older wooden houses are usually not retrofitted with new window and frame materials, even though there are many new window materials that are resistant to wind-blown missiles. Storm shutters can protect the windows and prevent failure. The most common type of "storm shutter" used on wooden structures is nailed up 4 X 8 plywood sheets. This is sufficient for weaker typhoons (Typhoon Category 1 and Typhoon Category 2), but it begins to fail when winds reach Typhoon Category 3 values.

b. Doors -- Doors are also weak areas in the structure envelop. Door frames are a favorite location for termite activity and they weaken with time. Most doors open inward, and thus, only the door latch holds the door in place against the force of the wind. Dead bolt locks help to improve the strength of the door. While inward opening doors are preferred in residences, outward opening doors are considerably stronger With the outward opening door, the door frame, in addition to the latches, brace the door against the force of the wind.

Table 6.2. Factors that affect the capacity of a roof to resist being separated from the supporting structure (uplift resistance capability).

FACTOR	COMMENTS
Overhang length	Increased length increases uplift
Corrosion of connectors	3-25 years depending on exposure and the type of steel and covering and maintenance
Termite infestation	5-25 years depending on treatment, maintenance
Rotted wood	5-25 years depending on treatment, maintenance
Split or damaged wood	Occurs at initial construction
Incorrectly applied connectors	Occurs at initial construction
Increased distance between rafters and trusses	Reduces number of anchoring connections holding roof to walls

2. Failure of roof materials - The primary factors affecting roof failure are shown in Table 6.2.

3. Collapse of gable walls above the 8 foot basic wall -- This can occur before or after the loss of the roof. This wall is usually minimally load bearing, and more poorly constructed than the load bearing lower walls.

4. Lighter structures can be blown off of block or concrete pier foundations or off of slab-on-grade foundations where the structure is not attached. Some people have converted shipping containers to houses. These are susceptible to being blown over unless they are properly tied down.

6.4.2. Sheet metal structures

The corrosion weakens the screws and rivets used to hold the sheet metal together. The wrenching effects of recurrent strong wind events causes the metal joints to develop gaps. Expansion and contraction due to heating and cooling also tends to deteriorate the flush fit between adjoining sheet metal panels. Once the wind can get under the sheet metal skin, serious damage to the skin and even the iron framing can occur during strong winds.

There are common design problems with sheet metal structures that often lead to damage during high wind events. These are:

(1) weaknesses associated with sliding and roll-up doors installed in metal structures;

(2) weaknesses at the interfaces between the roof and the building sides;

(3) studs are often too light weight or too far apart, allowing the force of the wind to buckle-in the sheet metal walls; and,

(4) building walls are installed in panels instead of single sheets. Ideally the wall structure would be a single piece of metal without joints except at the corners.

6.4.3. Concrete structures

The major vulnerability of steel-reinforced concrete structures comes from flooding and internal wind damage that occurs when windows and/or doors fail, breaching the structure envelop. Hurricane shutters can reduce flood damage considerably. **Shutters are the most important mitigation measure that can be taken for a concrete structure.** Engineered storm shutters, especially the accordion type, will endure winds up to Typhoon Category 5. **The current 10% insurance credit for engineered shutters for concrete structures is insufficient as an incentive to obtain shutters.** A 20-25% credit might convince more people to install engineered shutters. Structural damage to steel-reinforced concrete structures may occur in Typhoon Category 5 winds, where large and heavy projectiles can damage even the concrete.

There are actions that can be taken to strengthen the doors and windows of concrete structures.

a. windows -- Many window failures are due to failure of the frame. Many frames lack sufficient strength and begin to twist in strong winds, causing the glass panels to twist. Some frames also fail because they are not sufficiently attached to the walls.

There have been many improvements in frames and in glass strength. Glass that can withstand a 2 X 4 traveling at 100 mph is now available. Florida has adopted glass strength requirements for its building codes (H. Saffir, personal communication). This stronger glass is also more resistant to bending due to the force of the wind and pressure forces induced by strong wind gusts.

b. doors -- Most doors open inward, and thus, only the door latch holds the door in place against the force of the wind. Dead bolt locks can help to improve the strength of the door. While inward opening doors are aesthetically preferred in residences, outward opening doors are considerably stronger. With the outward opening door, the door frame in addition to the latches brace the door against the force of the wind and pressure forces induced by wind gusts. Storm shutters are also available for doors and afford considerable protection from wind-blown missiles.

Another common failure on Guam occurs with glass sliding doors. When winds reach strong Typhoon Category 3, wind gusts can create pressures sufficient to lift even heavy glass sliding doors off of the track. Once the door is off the track, the wind blows it inward, and the wind and rain enter the structure. To prevent this failure, mechanisms need to be installed to anchor the sliding doors to the walls or the floor. Typhoon shutters can also help prevent damage to the doors.

6.5. VULNERABILITY DETERMINATION

The vulnerability of the various residential (R) structure types is summarized in Table 6.3 and that of various commercial (C) structure types is summarized in Table 6.4. Commercial structures are separated into hotel (H) and non-hotel (C) types. Structures with wood and tin roofs and those with sheet metal siding are divided into "old" and "new". Old refers to those older than 10 years without good maintenance and those older than 20 years with good maintenance. Conversely, new refers to structures 10 years old or less without good maintenance and those 20 years old or less that have been maintained well.

Fully concrete structures are evaluated according to whether or not they have commercially-made metal storm shutters for windows and doors. WS refers to structures with commercially-made metal storm shutters and WOS refers to structures without the shutters.

Table 6.3. The vulnerability of residential buildings to tropical cyclone wind damage based on historical data and the Saffir-Simpson Tropical Cyclone Scale, where tropical cyclone sustained wind intensity is given in terms of Tropical Cyclone Category and in miles per hour (mph). WS refers to structures with commercially-made metal storm shutters for windows and doors, and WOS refers to structures without commercially-made metal storm shutters.

[illegible]	[illegible]						
	TS B	TY 1	TY 2	TY 3	Wk-Mod TY 4	Str TY 4-Wk TY 5	Mod-Str TY 5
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1R Old 1R New	Minor	Moderate Minor	Major Moderate	Extensive Major	Extensive Extensive	Extensive Extensive	Extensive Extensive
2R Old 2R New	Minor	Moderate Minor	Major Moderate	Extensive Major	Extensive Extensive	Extensive Extensive	Extensive Extensive
3R Old 3R New	Minor	Moderate Minor	Major Moderate	Extensive Major	Extensive Extensive	Extensive Extensive	Extensive Extensive
4R Old 4R New		Minor	Moderate Minor	Major Moderate	Major Major	Major Major	Extensive Extensive
5R Old 5R New		Minor	Moderate Minor	Major Moderate	Major Major	Major Major	Major Major
6R WS 6R WOS			Minor	Minor Moderate	Moderate Major	Major Major	Major Major
7R WS 7R WOS				Minor	Minor Moderate	Moderate Major	Major Major
8R WS 8R WOS				Minor	Minor Moderate	Moderate Major	Major Major
9R WS 9R WOS				Minor	Minor Moderate	Moderate Major	Major Major
10R WS 10R WOS				Minor	Minor Moderate	Moderate Major	Major Major
11R Old 11R New	Moderate Minor	Major Moderate	Extensive Major	Extensive	Extensive Extensive	Extensive Extensive	Extensive Extensive

Table 6.4. The vulnerability of hotel and non-hotel type commercial buildings to wind damage based on historical data, the Saffir-Simpson Tropical Cyclone Scale, and engineering wind load information. WS refers to structures with commercially made metal storm shutters for windows and doors and WOS refers to structures without commercially made metal storm shutters. "Main" refers to primary concrete structure and "Aux" refers to auxillary attached buildings made of sheet metal or with metal roofs.

[illegible]	[illegible]						
	TS B	TY 1	TY 2	TY 3	Wk-Mod TY 4	Str TY 4- Wk TY 5	Mod-Str TY 5
[illegible]	[illegible]	[illegible]	96-110	[illegible]	[illegible]	[illegible]	[illegible]
1C Old	Minor	Moderate	Major	Extensive	Extensive	Extensive	Extensive
1C New		Minor	Moderate	Major	Extensive	Extensive	Extensive
2C Old		Minor	Moderate	Major	Major	Major	Extensive
2C New			Minor	Moderate	Major	Major	Extensive
3C Old		Minor	Moderate	Major	Extensive	Major	Major
3C New			Minor	Moderate	Major	Major	Major
4C WS				Minor	Minor	Moderate	Major
4C WOS					Moderate	Major	Major
5C Old		Minor	Moderate	Major	Extensive	Extensive	Extensive
5C New			Minor	Moderate	Major	Extensive	Extensive
6C Old			Minor	Moderate	Major	Extensive	Extensive
6C New				Minor	Moderate	Major	Extensive
7C WS				Minor	Minor	Moderate	Major
7C WOS					Moderate	Major	Major
8C WS				Minor	Minor	Moderate	Major
8C WOS				Minor	Moderate	Major	Major
9C Main				Minor	Minor	Moderate	Major
9C Aux				Minor	Moderate	Major	Extensive
10C WS				Minor	Minor	Moderate	Major
10C WOS				Minor	Moderate	Major	Major
[illegible]							
1H WS				Minor	Minor	Moderate	Major
1H WOS				Minor	Moderate	Major	Major
2H WS				Minor	Minor	Moderate	Major
2H WOS				Minor	Moderate	Major	Major
3H WS				Minor	Minor	Moderate	Major
3H WOS				Minor	Moderate	Major	Major

There are four levels of damage that are addressed These include:

(1) minor - generally constrained to water leakage around doors and windows, and superficial exterior damage including minor roof damage, resulting in wet floors, rugs, and some spotty damage to ceiling tiles and walls;

(2) moderate - generally involves some glass breakage and significant damage to some portion of the roof, resulting in significant water damage to the ceilings and walls of interior structure;

(3) major - generally involves major window and door breakage, and nearly total loss of the roof, resulting in water damage to the entire contents of the structure and the need for partial structure reconstruction;

(4) extensive - involves total loss of roof and collapse of walls, resulting in "total" destruction of the structure and its contents, and the need for total reconstruction of the structure.

6.6. COST ANALYSIS

The cost analysis at this time can only be estimated, but it can likely be estimated to within 25 %. The Guam Bureau of Planning has compiled a data base of all of the structures on Guam. The information in that data base can be applied to a formula to more closely estimate the damage from a given storm. The formula simply multiplies the number of structures of a given type with the average cost per structure of damage associated with a given wind speed (Category). The number and type of structures can be determined from the Bureau of Planning structures data base. Once the formula is applied to the residential, commercial, and hotel structures, an estimate of the private sector building losses is available. Building losses for the government sector (GS) and the US Air Force (AF) and Navy (NAV) sectors can be determined from historical damage data to come up with a total estimate of building damage from a given intensity of typhoon. The total building cost (TBC) for a tropical cyclone of a given Category ($_{TC}$) is determined from:

$$TBC_{TC} = TCR_{TC} + TCC_{TC} + TCH_{TC} + TBCGS_{TC} + TBCAF_{TC} + TBCNAV_{TC}$$

6.7. GUAM BUREAU OF PLANNING STRUCTURES DATABASE

The Guam Bureau of Planning has just completed an extensive survey of the Island's buildings, and they have put it into a comprehensive data base. From this data, the total number of structures on Guam was 31,666. A break down of these structures by village is shown in Table 6.5. For cost estimates for various structures with respect to various tropical cyclone intensity categories, see Appendix E.

Table 6.5. Breakdown of the total number of structures on Guam by village based on the new Bureau of Planning structures data base.

Village	Number of Structures	Ranking
Agana Heights	880	11
Agat	1,113	9
Asan/Maina	436	18
Barrigada	1,746	5
Chalan Pago/Ordot	1,399	7
Dededo	6,373	1
Hagåtña	489	16
Inarajan	656	14
Mangilao	3,369	3
Merizo	497	15
Mongmong/Toto/Maite	1,629	6
Piti	444	17
Santa Rita	973	10
Sinajana	766	12
Talofofo	721	13
Tamuning/Tumon	5,539	2
Umatac	203	19
Yigo	3,049	4
Yona	1,384	8
TOTAL	[illegible]	

7. VULNERABILITY ASSESSMENT OF THE AIRPORT, SEAPORT, AND HIGHWAY SYSTEM

7.1. SCOPE

Typical hurricane vulnerability transportation assessments concentrate on the evacuation of people from vulnerable areas to less vulnerable areas (USACE 1995a, 1995b). That is to say that they address coastal/near coastal evacuation times, coastal/near coastal evacuation routes, and coastal/near coastal evacuation methods. On Guam, coastal/near coastal evacuation is not as serious or time-consuming a problem as in most other areas, especially continental ones with highly vulnerable populations. Most people on Guam that need to evacuate can reach designated shelters in less than 15 minutes. Evacuation, generally requires moving only a few families to shelters at higher elevations, and higher elevations are available only a few hundred yards inland. Even with a rapid rise in water level, there is usually sufficient time for evacuation, unless one waits until the core of hurricane-force winds arrives. Thus, there is little requirement for driving long distances on traffic-choked, low-lying evacuation routes. **On Guam, the storm surge and coastal inundation threat is not as serious as the threat of destructive winds. The costs of storm surge/inundation damage on Guam has historically been less than 10 percent of the cost of damage from wind.**

Since Guam is extremely isolated, it is totally dependent on on-island resources for its initial recovery. Initial recovery efforts depend on vehicular access to affected areas in order to provide relief to affected people and to restore vital services. Outside assistance may take up to a few days, and its arrival is dependent on the operation of the civilian and military airports and seaports. The survivability of these facilities is paramount. In addition, restoration of water, power and communications depends on the level of survival of the infrastructure, maintenance equipment, and stored spare materials.

For these reasons, the scope of the transportation vulnerability assessment for Guam concentrates on the survivability of the airport, seaport, and island highway system as opposed to the evacuation of people.

7.2. METHODOLOGY

The airfields are located on high plateaus and are thus primarily vulnerable to the wind, debris, and flood hazards. In a secondary manner, the airports are vulnerable to wind shear, mechanical turbulence, and sea salt deposition. The latter is more a long term problem rather than an immediate one, unless salt water gets directly into electrical wiring and equipment. In this case, merely drying the equipment will probably not restore it, and repairs can be very expensive, if they are at all possible. This vulnerability assessment uses engineering design and historical performance information to determine the vulnerability of the facilities. The Saffir-Simpson Tropical Cyclone Scale is then used to classify the levels of damage according to tropical cyclone intensity category and wind speed.

The seaports are highly vulnerable to winds, storm surge, coastal inundation, high seas, some hazardous surf, and flooding from the sea and from torrential rains. They are also highly vulnerable to sea salt deposition, erosion, and pollution. Seaport vulnerabilities are based on the assumption that the event occurs at high tide. The vulnerabilities are determined from past studies, engineering design specifications, and historical performance information. The Saffir-Simpson Tropical Cyclone Scale (see Chapter 5 and Appendix C) is again used to classify the levels of damage according to tropical cyclone category and wind speed.

7.3. AIRPORT FACILITIES

7.3.1. General Information

Airport facilities include the A. B. Won Pat International Air Terminal (subsequently referred to as the Guam International Airport (GIA) and, to a lesser extent, Andersen Air Force Base (AAFB). GIA, located in the center of the Island at Tiyan, is considered the primary facility and will receive the majority of the assessment. However, AAFB, located at the northeast end of the Island, is very important as the primary air facility for receiving relief materials brought in by military and military-contracted aircraft.

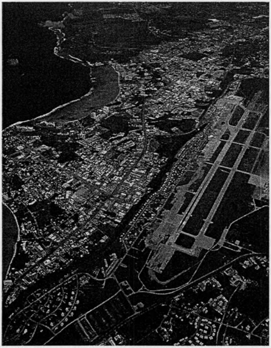


Figure 7.1. Guam International Airport and runway complex. (Courtesy: GIAA)

7.3.2. Guam International Airport (GIA)

Guam International Airport Authority (GIAA) is an autonomous agency of the Government of Guam. The Air Terminal Manager and his staff oversee four divisions, which include Operations, Properties & Facilities, Airport Police, and Aircraft Rescue Fire Fighting. GIA is a 24-hour, single runway operation with a large, modern air terminal and state-of-the-art navigation aids (Figure 7.1). It is capable of handling the largest wide body aircraft. Currently, there are 35 daily departures and 36 daily arrivals, and a total of 37, 786 air operations per year. Passenger volume is approximately 1.662 million passengers per year (20 January 1999 memo from Andrew Murphy). The airfield is surrounded with an eight-foot chain-link fence that plays a major role in restraining debris from entering the runway, taxiways, and ramps. The Guam Air Traffic and Approach Control Facility (CERAP) is located at AAFB, with the radars located atop Mount Santa Rosa in northeast Guam. These radars, the microwave antennas used to transmit the data, and the airport navigation aids are vulnerable to damage by strong winds (medium-strong Typhoon Category 3 and higher) and flying debris. The Air Traffic Control system, airport navigation aids, and airport lighting all are served with emergency power from back-up generators.

The terminal building is a massive, steel-reinforced concrete structure of 770,000 square feet with a large multi-story central lobby with large sections of plate glass windows and automatic sliding and swinging plate glass doors (Figure 7.2). The terminal contains

Figure 7.2. Guam International Air Terminal from runway side showing jet ways.

large retail shopping areas, eateries, moving walkways, and technologically advanced baggage processing systems. The terminal was designed to meet or exceed the 155 mph wind-loading requirement. There are 18 gates, most with passenger loading bridges. **The passenger loading bridges, the plate glass windows, and the glass sliding doors of the terminal building are all susceptible to damage from strong winds (weak Typhoon Category 4 and stronger) and from flying debris blown by typhoons of moderate to strong Category 3 and stronger winds.** Normal power is supplied to the terminal from Guam Power Authority sources, but back-up generators are available for up to 9 megawatts of emergency power.

There are three hangers providing a total hanger space of 68,360 square feet and more than 103,000 square feet of office and shop space. The hanger space is sufficient to house about 150 general aviation aircraft (19 Jan 99 memo from Victor J. Cruz). The hangers are steel-reinforced concrete with pre-engineered metal roofing. With permission of the lessees, the hangers are available to house civil aviation and commuter aircraft. Larger jet aircraft are usually evacuated to other locations when Typhoon Category 1 or stronger winds are predicted. The doors and the windows of the hangers are vulnerable to damage when winds reach strong Typhoon Category 3 or stronger intensity. A sheet metal maintenance building is vulnerable to damage from winds of Typhoon Category 4 or stronger.

During Typhoon Paka, the western Tiyan area was exposed to sustained winds of about 130-135 mph (weak Typhoon Category 4 winds). Damages to the terminal building amounted to about $1.425 million while damage to non-terminal facilities was on the order of $1.492 million. Nearly half of the terminal costs ($699,355) were for damages to the passenger loading bridges. Other Tiyan facilities had damages amounting to $1.56 million. (18 Feb 98 memo from Ivan C. Quinata). The old part of the terminal was being remodeled for connection to the new terminal. Damage to the construction site (old terminal) was $1.227 million. The most serious GIAA facility damages from Typhoon Paka and the estimated costs are shown in Table 7.1.

Table 7.1. Summary of major damages at selected Guam International Airport Authority (GIAA) facilities and estimated costs. (Source: **Guam International Airport Authority**)

Facility	Representative Types of Damage	Estimated Costs
New Terminal Bldg.	Ramp lights, automatic sliding doors, water infiltration, security cameras, window sealants	$725, 859
Passenger Loading Bridges	Power units, aircraft hoods, water infiltration	$699,355
Commuter Terminal	Air conditioning ducts, doors, electrical wiring	$264,377
Aircraft Maintenance Bldg.	Cracks in roof, insulation, flood lights, fans	$260,082
Parameter Fencing	Chain link fencing blown down	$542,967
Runway Guidance Signs	Blown away	$106,651
Nosedock Hanger Bldg.	Roof vent units, insulation, glass doors	$267,982
Hangers	Metal roofs, metal roll-up doors, AC units	$201,973
Cargo Buildings	Metal roll-up doors, doors, AC ducts, ceiling tiles	$161,747