Tornado Damage Documentation – Using the EF-Scale

Central Florida
Sumter County, Lake County, Volusia County
February 2, 2007

PhotoCredit: National Weather Service

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FOREWORD

In 1971, Dr. T. Theodore Fujita introduced a research paper titled, *Proposed Characterization of Tornadoes and Hurricanes by Area and Intensity*. The paper categorized tornadoes by intensity and area, with a scale divided into six categories:

- F0 (Gale)
- F1 (Weak)
- F2 (Strong)
- F3 (Severe)
- F4 (Devastating)
- F5 (Incredible)

Dr. Fujita's goals in his research in developing the F-Scale were:

- Categorize each tornado by its intensity and its area
- Associate wind speed ranges with each category of tornado

However, over the years, the F-Scale has revealed weaknesses and misuses:

- It is subjective based on cursory description of damage
- No recognition in difference in construction
- Difficult to apply with no Damage Indicators (differentiation between construction types)
- Based on the worst damage
- Overestimates wind speeds greater than F3
- Too reliant on associated wind speeds
- Oversimplification of the damage
- Did not recognize weak structures

To address these issues and shortcomings of the F-Scale, research engineers from the Wind Science and Engineering Research Center, along with over forty professionals from the engineering and meteorological communities, participated in a forum and expert elicitations to develop the *Enhance Fujita Scale (EF-Scale)*. With a directive to continue to support and maintain the original tornado database, the EF-Scale offers the following improvements:

- Enhance description of damage with examples and photos, including structures and vegetation
- Assign wind speed estimates based on level of damage
- EF Scale assignment on more than one structure, if available
- Develop a PC-based expert system
- Develop training materials
- Maintain current tornado database
- Require surveys to include data related to path width, basis for damage assignment, latitude/longitude of the path, and survey team names and hours spent in survey

The EF-Scale utilizes 28 Damage Indicators (DI), and with each Indicator, are Degrees of Damage (DOD) that are associated with an expected estimate of wind speed; a lower boundary of wind speed; and an upper boundary of wind speed that could produce the observed damage. Photographs are included in the EF-Scale to assist the investigator.[1]

The EF-Scale was implemented in February 2007, and the storms of February 2, 2007, that struck Central Florida were the first to be surveyed under the new system.

Acknowledgements: Thanks are due to Kishor C. Mehta, P.E., Ph.D., Wind Science and Engineering Research Center (WISE), Professor rtd., for his technical review; and Ms. Tanya Brown, IGERT Fellow (NSF Grant #0221688), Ph.D. Candidate, for her field assistance and her contributions to this report.

Opinions expressed in this report are solely those of the senior author and not necessarily those of the Wind Science and Engineering Research Center, Texas Tech University or the National Science Foundation.

Authors' Biographical Information

Larry J. Tanner, P.E.

Larry Tanner has over 25 years of experience as a Professional Engineer and Register Architect in the design and construction industry and is currently an adjunct instructor and a research associate in the Wind Science and Engineering Research Center (WISE) and manager of the WISE Debris Impact Test Facility. His fields of research include storm protection utilizing above ground in-residence shelters and building performance during extreme storms. His storm investigations and documentation include the following:

- Spencer, South Dakota tornado in 1998
- Oklahoma and Kansas 1998 tornadoes (member of FEMA MAT Team)
- Tuscaloosa, Alabama 2000 tornado
- Happy, Texas 2002 tornado
- Ohio 2002 tornadoes
- Southwest Missouri and Oklahoma City tornadoes, 2003
- Hurricane Ivan, Pensacola, Florida in September, 2004
- Hurricane Katrina, 2005 (member of FEMA MAT Team)
- Evansville, Indiana 2005 Tornado
- Florida Tornados, 2007
- The Super Tuesday Outbreak - Tennessee tornadoes, 2008

His work further includes collaboration with FEMA in the writing of FEMA 320, *"Taking Shelter from the Storm,"* FEMA 361, *"Design and Construction Guidance for Community Shelters,"* and FEMA 342, *"Building Performance Assessment Report of Midwest Tornadoes of May 3, 1999;"* co-authorship of *"FEMA Publication 549, Hurricane Katrina in the Gulf Coast, Observations, recommendations, and Technical Guidance;*" and co-authorship of the 2008 updates to FEMA 320 and FEMA 361.

Tanya Brown

Tanya Brown's interest in severe weather began at an early age, when her father's home was destroyed by a tornado. She earned her BS degree in Atmospheric Science in 2004 and her MS degree in Water Resources Science in 2006 from the University of Kansas. Her MS research focused on the relationship between radar-estimated rainfall and rainfall collected from rain gages in flood-prone areas. She is currently pursuing a PhD in Wind Science and Engineering from Texas Tech University with a research emphasis on damage assessment from multiple natural hazards.

ABSTRACT

In the early morning hours of February 2, 2007, Sumter County, Lake County and Volusia County of Central Florida experienced several strong thunderstorms, one of which spawned three tornadoes. Two of these three tornadoes were responsible for the deaths of twenty people in Lake County. Investigations were conducted in The Villages - Sumter County, the communities of Lady Lake and Bear Lake - Lake County, and the cities of DeLand and New Smyrna – Volusia County to determine the performance of structures and materials during these storms. These were the first tornadoes surveyed by the National Weather Service (NWS) and storm investigators using the new Enhanced Fujita Scale. The first tornado, classified as an EF-3 with a wind speed range of 136-165 mph, first struck the community of The Villages. These homes were constructed to current Florida Hurricane Standards, and though performing reasonably according to the Scale, several construction flaws in the methods of construction led to some catastrophic results. This tornado continued into the City of Lady Lake destroying the Lady Lake Church of God (a metal building system) and striking two mobile home parks, killing seven. The second tornado, also rated and EF-3, struck the Lake Mack area killing 13 as they slept in their mobile homes. Site-built homes were moderately damaged, whereas single-wide and double-wide mobile homes suffered severe-to-total destruction. The third tornado, an EF-1 with 86-109 winds, struck homes and schools in the New Smyrna Beach area producing roof damage. Through the use of the new Enhance Fujita Scale, the researchers were able to associate wind speeds to each area of damage based upon the new Damage Indicators and related Degrees of Damage.

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1.0 Storm Report

At 3:08 AM EST, on February 2, 2007, the first of three tornadoes, **Figure 1-1**, touched down in Sumter County, Florida, which is located in central Florida, approximately 60 miles north of Orlando. This tornado traveled next to The Villages, a prominent retirement community located in Sumter County, just east of the Lake County border. The tornado continued traveling ENE to Lady Lake, in Lake County, where 7 people were killed as they slept in their mobile homes. The tornado path length was approximately 15 miles long. The National Weather Service (NWS) classified this tornado as an EF-3 on the new Enhanced Fujita Scale, implemented on February 1, 2007, just one day before the storm.[2] The maximum wind gust speeds for an EF-3 tornado range from 136mph to 165 mph. A second tornado, **Figure 1-2**, touched down at 3:37 AM EST, near Lake Mack in Lake County, where 13 people were killed. The tornado continued moving ENE into Volusia County, where it struck Hontoon Island, DeLand, and crossed over Interstate 4, flipping tractor trailers before dissipating. This tornado left a 22 mile long path of destruction and was rated as a high end EF-3, with gusts approaching 165 mph. By the time it had moved into DeLand, the tornado had weakened to an EF-2, with wind gusts in the range of 111-135 mph. A third weaker and smaller tornado, **Figure 1-3**, touched down just east of Interstate 95 in New Smyrna in Volusia County at 4:22 AM EST. This tornado crossed Ponce Inlet before moving and dissipating in the Atlantic. This third tornado was rated EF-1, with wind gusts in the range of 86-110 mph.

All three tornadoes were spawned from the same supercell thunderstorm traveling across central Florida that night. These supercell thunderstorms were caused by a strong cold front advancing across Florida.[2] The air mass in place was very warm and moist, with surface temperatures in the upper 60’s and lower 70’s, and dew point temperatures just a few degrees less.[3] According to the 00Z Feb. 2, upper air sounding launched from Tampa, FL, the middle part of the atmosphere, near the 500 hPa level, was quite dry with dew point depressions of more than $20^{o}C$. A warm, moist surface, and a dry middle layer, provided favorable conditions for the development of severe, convective weather. At this time, the Convective Available Potential Energy (CAPE) measured from the Tampa sounding was 163 J/kg, but 12 hours later, the 12Z sounding showed CAPE values of 980 J/kg, meaning the atmosphere was marginally unstable.[4] The presence of atmospheric instability, a warm moist surface, a dry layer in the middle atmosphere, and an approaching cold front to provide lift, led to a deadly combination which helped to generate and fuel the supercell thunderstorms that spawned the three tornadoes.

The damage documentation of the destruction produced by the three tornadoes was evaluated using the newly adopted *Enhanced Fujita Scale* that associates the construction type and building types of 28 Damage Indicators (DI). Each DI has numerous Degrees of Damage (DOD), with each DOD in each DI category given an expected estimate of wind speed, a lower bound of wind speed and an upper bound of wind speed.[5] **Figures 1-4 through 1-6** were extracted from the NWS training session *Lesson 1: Introducing the Enhanced Fujita Scale.*[6] **Figure 1-4** tabulates the 28 Damage Indicators; **Figure 1-5** shows an example of Degrees of Damage for a Single Family Residence; and **Figure 1-6** correlates the EF Scale wind speeds with the original Fujita Scale speeds. This report does not contain all types of construction, nor does it contain examples of all degrees of damage. However, this storm report will provide additional Damage Indicators which can be included in the EF Scale Report. Building types [Damage Indicators (DI)] and associated levels of damage [Degree of Damage (DOD)] are used in this report and are identified in the EF Scale Report.[5]

Figure 1-1. Tornado 1 Track - Sumter County to Lake County, Florida[2]

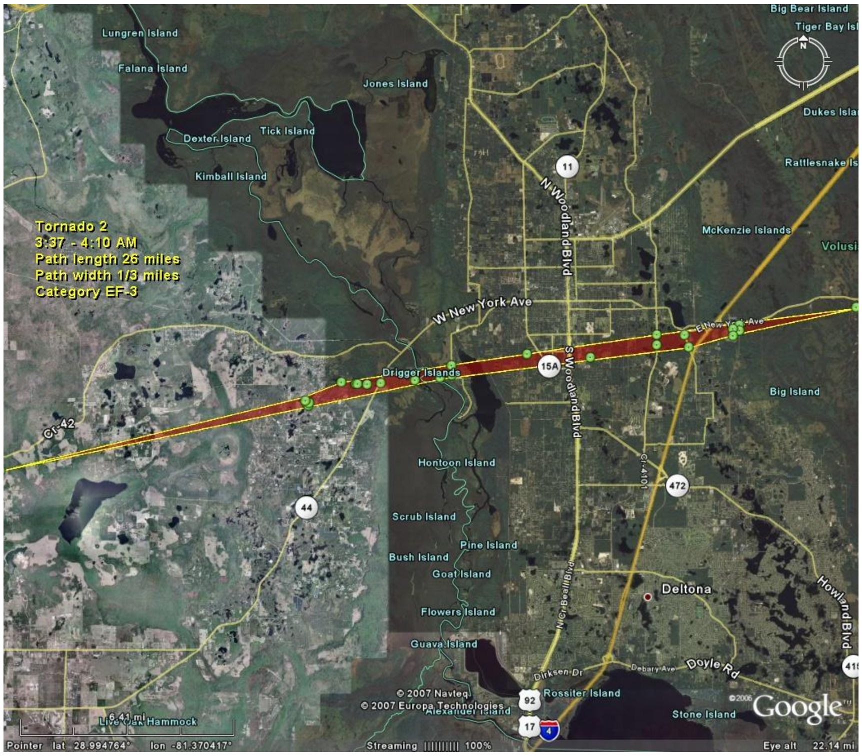

Figure 1-2. Tornado 2 Track - Lake County, Florida[2]

Figure 1-3. Tornado 3 Track - Volusia County, Florida[2]

28 Damage Indicators for EF-Scale

DI No.	Damage Indicator (DI)	*Use*
1	Small Barns or Farm Outbuildings (SBO)	*Residential*
2	One – Two-Family Residences (FR12)	
3	Manufactured Home – Single Wide (MHSW)	
4	Manufactured Home – Double Wide (MHDW)	
5	Apartments, Condos, Townhouses [3 stories or less] (ACT)	
6	Motel (M)	*Commercial & Retail Structures*
7	Masonry Apartment or Motel Building (MAM)	
8	Small Retail Building [Fast Food Restaurant] (SRB)	
9	Small Professional Building [Doctor's Office, Branch Bank] (SPB)	
10	Strip Mall (SM)	
11	Large Shopping Mall (LSM)	
12	Large, Isolated Retail Building [K-Mart, WalMart] (LIRB)	
13	Automobile Showroom (ASR)	
14	Automobile Service Building (ASB)	
15	Elementary School [single Story; Interior or Exterior Hallways] (ES)	*Schools*
16	Junior or Senior High School (JHSH)	
17	Low-Rise building [1-4 Stories] (LRB)	*Professional Buildings*
18	Mid-Rise building [5-20 Stories] (MRB)	
19	High-Rise Building [More than 20 Stories] (HRB)	
20	Institutional Building [Hospital, Government or University] (IB)	
21	Metal Building Systems (MBS)	*Metal Buildings & Canopies*
22	Service Station Canopy (SSC)	
23	Warehouse Building [Tilt-up Walls, or Heavy Timber Const] (WHB)	
24	Transmission Line Towers (TLT)	*Towers/Poles*
25	Free-Standing Towers (FST)	
26	Free-Standing Light Poles, Luminary Poles, Flag Poles (FSP)	
27	Trees: Hardwood (TH)	*Vegetation*
28	Trees: Softwood (TS)	

Figure 1-4. EF Scale 28 Damage Indicators.[6]

DOD to Wind Speed to EF-Scale

DOD	Damage Description – Framed House	EXP	LB	UB
1	Threshold of visible damage	63	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward or outward; failure of porch of carport	97	81	116
5	Entire house shifts of foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed except small interior rooms	152	127	178
9	All walls collapsed	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	162	220

Expected wind 97 mph

Figure 1-5. EF Scale Degree of Damage Single Family Residence (FR12) Example.[6]

F-Scale Converted to EF-Scale

F Scale	Wind Speed	EF-Scale	Wind Speed
F0	45-78	EF0	65-85
F1	79-117	EF1	86-109
F2	118-161	EF2	110-137
F3	162-209	EF3	138-167
F4	210-261	EF4	168-199
F5	262-317	EF5	200-234

Wind speeds in mph, 3-second gust

Figure 1-6. F-Scale to EF-Scale Conversion Table.[6]

2.0 The Villages Retirement Community Survey

Three main areas of interest were surveyed in The Villages in Sumter County—the Village of Poinciana, the Village of Sabal Chase, and the Village of Mallory Square. **Figure 2-1** shows a map of the areas investigated. As it moved through the Villages, the first tornado followed a straight path, moving ENE, but based on the damage pattern, the tornado vortex appeared to be bouncing, meaning, it was on the ground at some points, and above the ground at other points. It is believed that the tornado skipped across the Jacaranda Golf Course and first made contact with homes in this area at the intersection of Kyrle Terrace and Bailey Trail. It then moved through the Village of Poinciana, across the Allamanda Golf Course and the Liberty Park Eagle Preserve into the Village of Sable Chase, and finally toward the Coconut Cove Recreation Center in the Village of Mallory Square before continuing into Lake County.

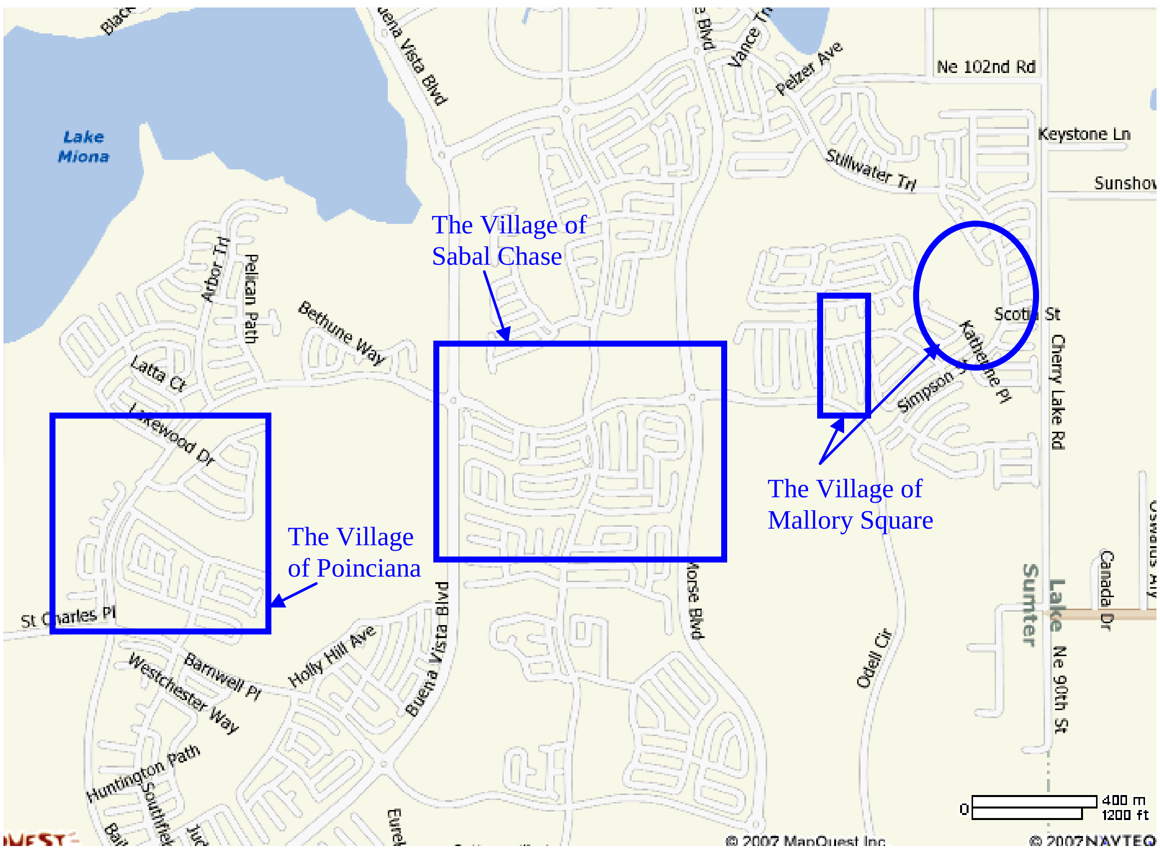

Figure 2-1. Map of the areas investigated in The Villages.

2.1 Damage Documented in The Villages

The homes investigated in The Villages are single-family, site built homes (FR12) less than five years old. Most are light wood frames, with varying envelopes of brick, exterior insulation finish system (EIFS), vinyl siding, or fiber-reinforced concrete siding. The framing systems varied from complete wood stick-built, to a hybrid of wood and light gage metal stud wall systems. Most roof structures were wood stick frame, but some homes had engineered light metal trusses. Some homes observed were constructed with an envelope of unreinforced concrete masonry units (CMU) with wood stick-frame roof structure and interior walls. Most homes had hurricane-strength garage doors, and many had hurricane resistant roof-to-wall connectors. The damage in The Villages for single family residences varied from DOD 3 to DOD 8. In general, those homes which were not directly under the influence of the tornado vortex faired very well, with mostly cosmetic damage, and roofing material loss. However, those homes located directly under the influence of the vortex had significant structural damage, roofing and wall collapse; and some were considered a total loss (DOD 10).

2.1.1 Damage in the Village of Poinciana

Figure 2-2 shows a closer map of the area investigated in the Village of Poinciana. **Figures 2-3** through **2-9** show the damage in Mount Pleasant Villas, in the Village of Poinciana. **Figures 2-3** & **2-4** were taken on Clinton Ct. The shown homes were on the windward side of the storm and suffered garage door failure and roof failure (DOD 6) from the resulting internal pressurization of the garages. Further evidence of garage pressurization is shown in **Figures 2-5 & 2-6** which show the non-loadbearing garage gable endwall blown to the ground. This phenomenon was observed numerous times throughout the Villages. The degree of damage along Clinton Ct. varied from DOD 2 to a DOD 6 with Expected Winds (EXP) in the range of 79 mph to 122 mph. The path width along Clinton Ct. was estimated to be about 150 feet. The home shown in **Figure 2-4**, which is adjacent to those homes shown in **Figure 2-3,** was moderately damaged (DOD 2)and illustrates the narrow width of the storm.

Figure 2-7 is a view looking west down Edisto Ln. It shows the collapse of garage walls and roofs, and varying degrees of roof damage with as much as DOD6. The tornado vortex passed directly over the four homes in this figure. The damaged homes shown in **Figure 2-7** were located on the north side of the storm path with their garages facing away from the windward pressures. However, all of the damaged homes had windows in the garages which were near the windward winds and were compromised by wind pressure and debris. The garages were internally pressurized and producing failure of the roof and decking, and the garage doors were blown outward. **Figure 2-8** illustrates the windward pressure on the garage wall and the broken glazing that produced the internal pressures that led to wall separation from the concrete slab and separation of the roof structure. **Figure 2-9** shows the wooden frame of the house splintered away from the anchoring bolts holding the wall to the concrete slab foundation. **Figure 2-10** depicts a garage door bulging outwards which is a clear indication of internal pressurization. The tornado vortex passed directly over this area, but it is hypothesized that the damage to the homes varied because the vortex was quite narrow and bouncing, making momentary contact with the ground. Most of the observed damage on Edisto Ln. was assessed at DOD 2-6, with EXP winds of 79-122 mph.

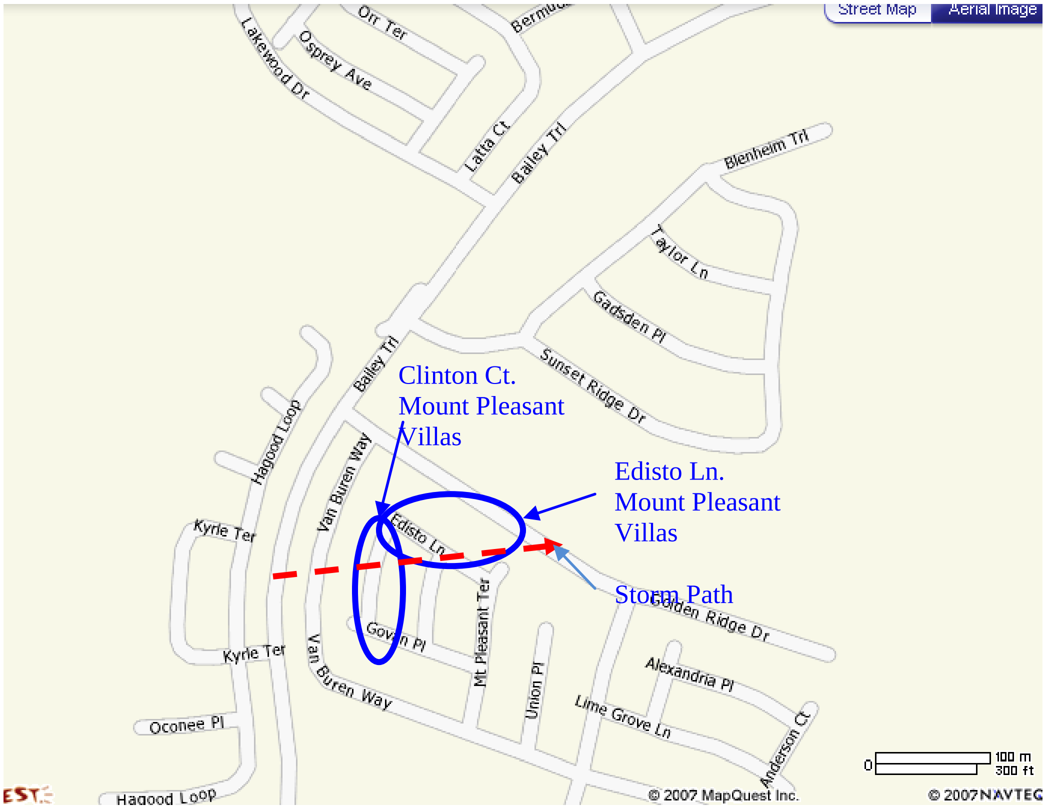

Figure 2-2. Map of area investigated in the Village of Poinciana.

Figure 2-3. DOD 4 Damage along Clinton Ct., in Mount Pleasant Villas in the Village of Poinciana, The Villages, FL.

Figure 2-4. Moderately (DOD 2) Damaged Home along Clinton Ct., in Mount Pleasant Villas in the Village of Poinciana, The Villages, FL.

Figure 2-5. Garage Wall blown out on Clinton Ct. Home (DOD 4), in Mount Pleasant Villas in the Village of Poinciana, The Villages, FL.

Figure 2-6. Damage along Clinton Ct., in Mount Pleasant Villas in the Village of Poinciana, The Villages, FL.

Figure 2-7. DOD 6 Damage along Edisto Ln., in Mount Pleasant Villas in the Village of Poinciana, The Villages, FL.

Figure 2-8. DOD 6 Damage along Edisto Ln., in Mount Pleasant Villas in the Village of Poinciana, The Villages, FL.

Figure 2-9. Damage along Edisto Ln., in Mount Pleasant Villas in the Village of Poinciana, The Villages, FL.

Figure 2-10. DOD 4 Damage along Edisto Ln., in Mount Pleasant Villas in the Village of Poinciana, The Villages, FL.

2.1.2 Damage in the Village of Sabal Chase

Figure 2-11 is a map of the area investigated in the Village of Sabal Chase. **Figure 2-12** is a further depiction of internal pressurization. The garage door in this Carlton Villas' home faced the storm. The mechanisms of failure started with the garage door and proceeded to the loss of the leeward and gable end wall.

Numerous types of residential construction were observed in the Villages, ranging from full wood stick-frame to CMU with wood trusses to a hybrid of wood stick-frame and light steel studs and trusses. **Figures 2-13 - 2-15** show the damage to an unreinforced concrete masonry (CMU) and wood truss home at 1632 Jardin Ct. in the Village of Sabal Chase. In **Figure 2-13**, a large outdoor kitchen and patio with a large overhanging roof is the source of roof failure for most of the home. **Figure 2-14** shows a large section of the center part of the roof missing which was destroyed from the inside by internal pressurization of the home. **Figure 2-15** shows most of the main roof system at the front of the house that had been blown off. This home had proper roof construction, but the patio with its large roof and open sidewalls was the catalyst that led to pressurization of the entire roof structure. There is currently no damage indicator within the *Enhanced Fujita Scale* for residential construction utilizing CMU walls and wood stick-frame roof structure. Considering that most of the walls were left standing and that most of the roof structure had been removed by the storm, a DOD 6 with EXP winds of 122 mph was assessed to this home.

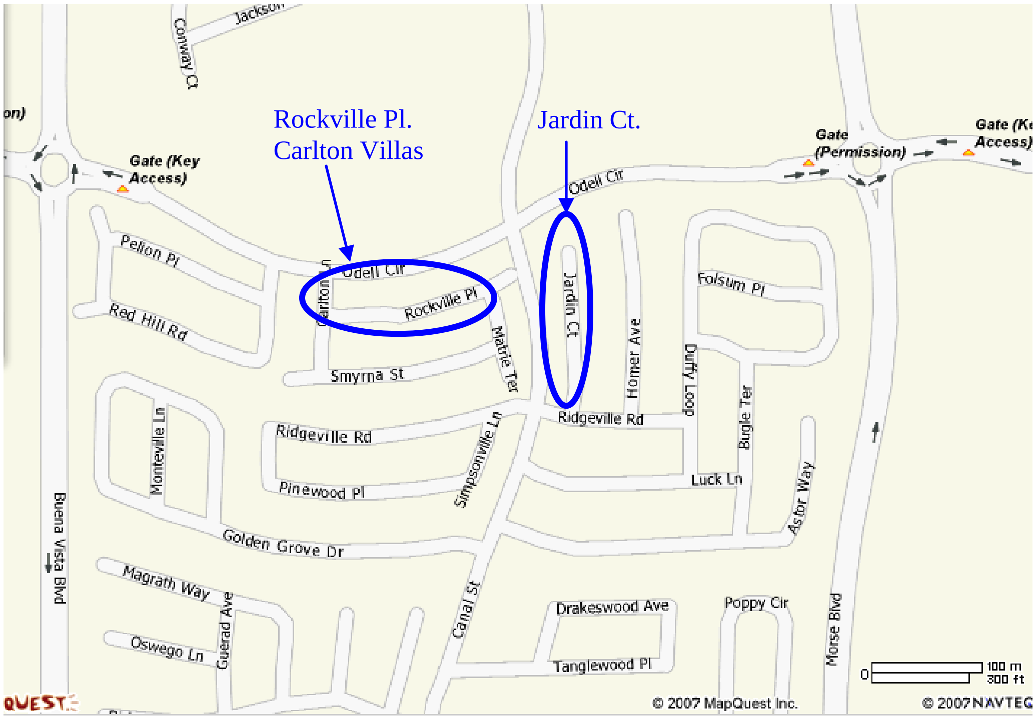

Figure 2-11. Map of area investigated in the Village of Sabal Chase.

Figure 2-12. DOD 4 Damage to a home on Rockville Pl., in Carlton Villas in the Village of Sabal Chase, The Villages, FL.

Figure 2-13. DOD 6 Damage to a home on Jardin Ct., in the Village of Sabal Chase, The Villages, FL.

Figure 2-14. DOD 6 Damage to a home on Jardin Ct., in the Village of Sabal Chase, The Villages, FL.

Figure 2-15. DOD 6 Damage to a home on Jardin Ct., in the Village of Sabal Chase, The Villages, FL.

2.1.3 Damage in the Village of Mallory Square

From the Village of Sable Chase, the tornado proceeded to strike The Coconut Cove Recreation Center and homes located in the Village of Mallory Square, refer to the map in **Figure 2-16**. The Coconut Cove Recreation Center was constructed of CMU and clad with vinyl siding with a wood stick-built roof. This structure suffered damage to siding materials, roofing, and decking materials, see **Figures 2-17 & 18**. Though the recreation center is in excess of 5,000 sf, its CMU load bearing walls and wood roof truss structure appears to be best described as a Small Professional Building (SPB) by the EF Scale document. The recreation center lost over 20% of its roofing materials, some decking, window and skylight glazing, and suffered missile damage to the vinyl cladding. It is believed that this center did not receive a direct hit by the storm vortex, and a DOD 3 was assigned based upon them observed damage and an EXP wind of 89 mph.

Across the street from the recreation center is a residence at 1459 Ft. Lawn Loop. This home shown in **Figures 2-19 - 2-22** suffered the worst damage in the entire Villages community. It is believed that the vortex was on the ground after leveling the Coconut Cove Tennis Center, **Figure 23**, and struck the first structure in its direct path, 1459 Ft. Lawn Loop. The storm struck the southwest corner of the home, pushed in the wall corner and pressurized the soffits and back porch area. The internal pressures coupled with the storm uplift pressures produced near complete removal of the roof structure and collapse of most of the walls. This damage was classified as a DOD 9 with expected winds of 152 mph producing the damage.

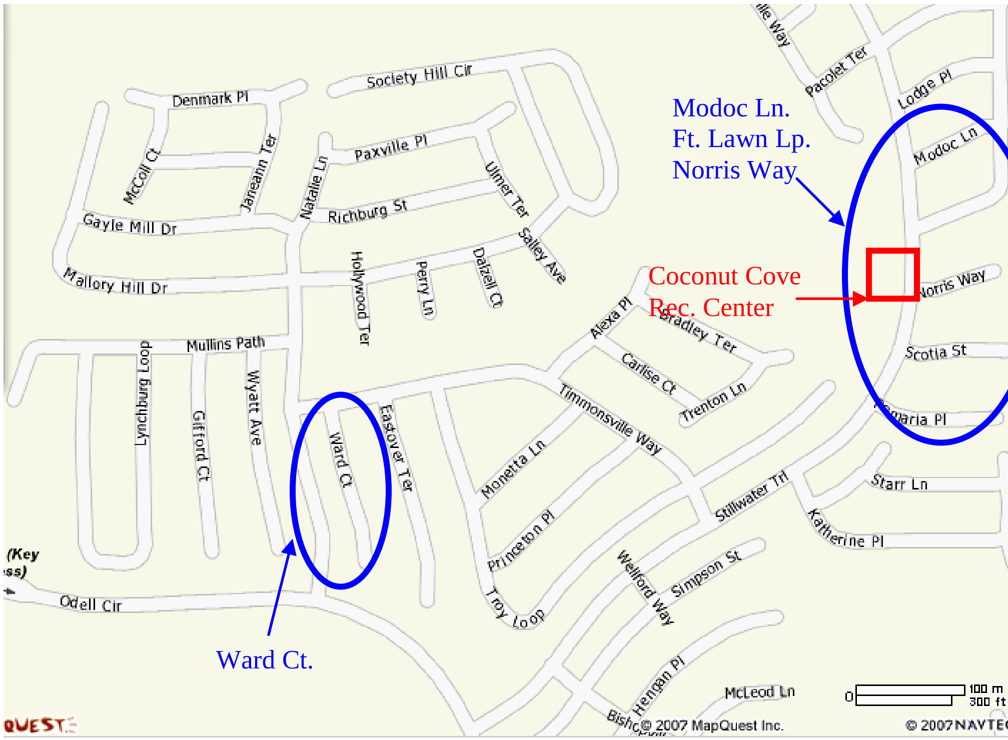

Figure 2-16. Map of area investigated in the Village of Mallory Square.

Figure 2-17. DOD 3 Damage to the leeward face of the Coconut Cove Recreation Center(SPB), in the Village of Mallory Square, The Villages, FL.

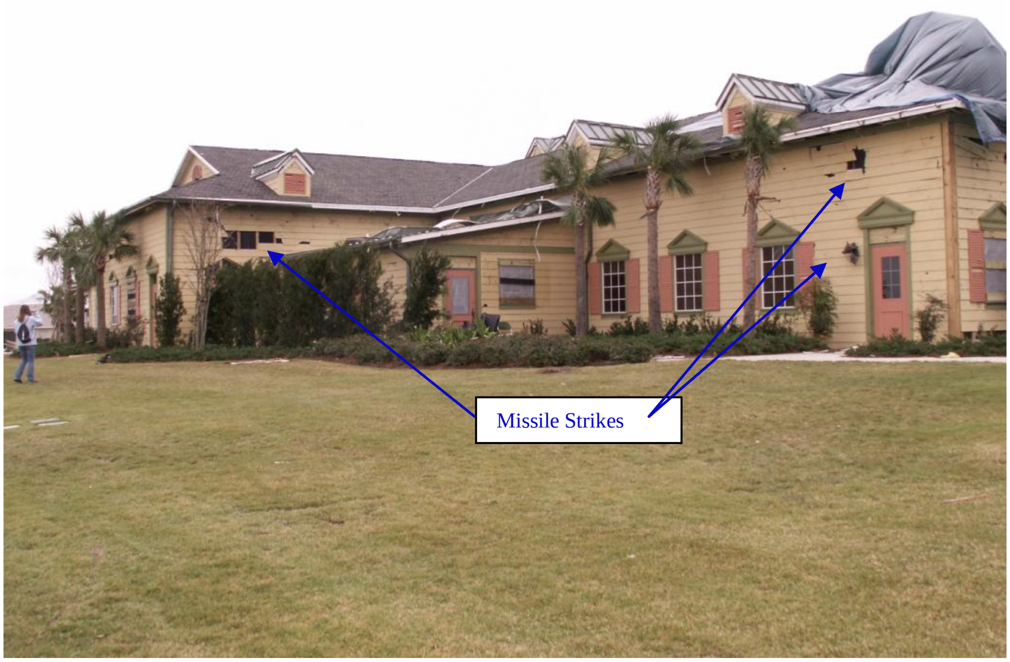

Figure 2-18. DOD 3 Damage to the windward face of the Coconut Cove Recreation Center (SPB) in the Village of Mallory Square, The Villages, FL.

Figure 2-19. DOD 9 Damage to a home on Ft. Lawn Lp., in the Village of Mallory Square, The Villages, FL.

Figure 2-20. DOD 9 Damage to a home on Ft. Lawn Lp., in the Village of Mallory Square, The Villages, FL.

Figure 2-21. DOD 9 Damage to a home on Ft. Lawn Lp., in the Village of Mallory Square, The Villages, FL.

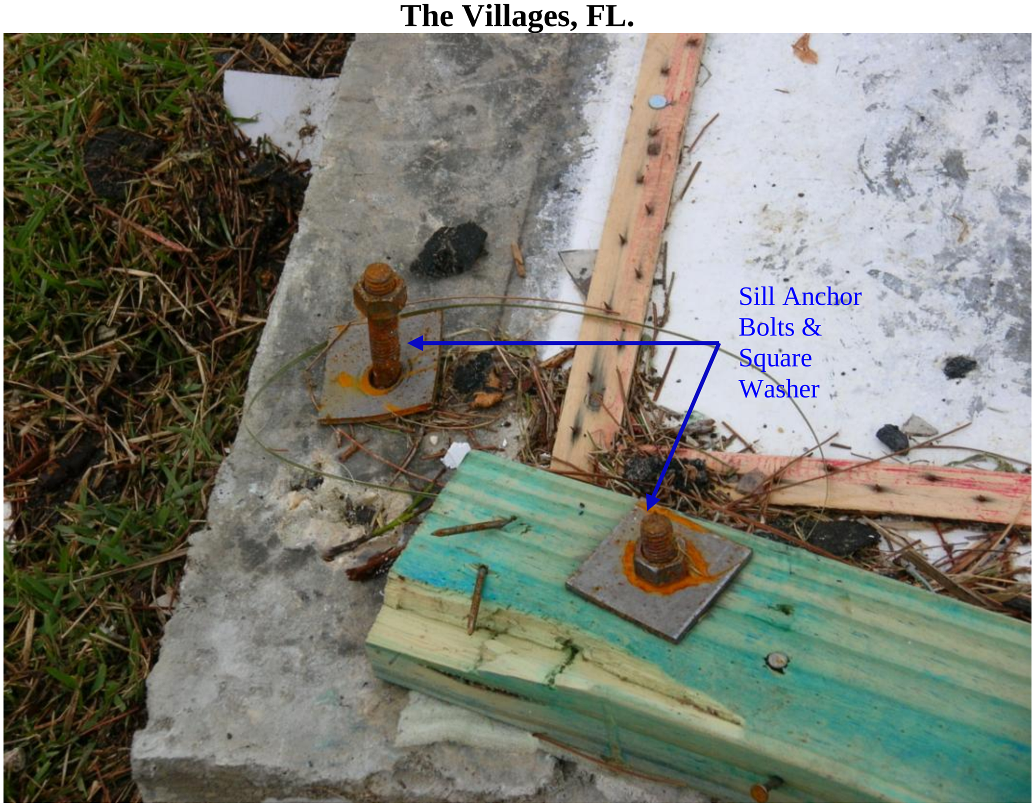

Figure 2-22. Damage to a home on Ft. Lawn Lp., in the Village of Mallory Square, The Villages, FL.

Figure 2-23. Damage to Coconut Cove Tennis Center across from Ft. Lawn Loop., in the Village of Mallory Square, The Villages, FL.

A myriad of residential building construction types was observed in the Mallory Square Village. They included traditional wood frame walls and roof structure; wood stick frame homes with steel stud interior partition walls, **Figure 2-24**; and exterior metal studs with steel stud trusses, **Figures 2-25 & 2-26**. The performance of the exterior metal stud walls appeared to be inferior to that of the wood stud walls. However, the steel stud trusses remained connected and performed similar to their wood counterparts. The Degrees of Damage for these construction hybrids were assessed at DOD 4-6 with expected winds of 97-122 mph.

Figure 2-24. DOD 6 Gable End Failure with Steel Stud Interior Partitions, Village of Mallory Square, The Villages, FL.

Figure 2-25. DOD 6 Gable End Failure to Metal Stud & Steel Truss Home, in the Village of Mallory Square, The Villages, FL.

Figure 2-26. DOD 4 Gable End Failure to Metal Stud & Steel Truss Home, in the Village of Mallory Square, The Villages, FL.

2.2 Debris Impacts in The Villages

There were many instances of missiles impacting the structures in The Villages. Most missiles were construction materials from other homes and buildings. **Figure 2-27** shows pine tree needles embedded in the sheathing of a home's wall. **Figure 2-28** shows a missile impacting the roof structure, and puncturing the room below. **Figure 2-29** shows a missile embedded in an exterior wall at 296 Norris Way. The missile measured 30" outside the exterior wall. The second part of the figure shows the same missile protruding through the exterior wall and into the bathroom of the home. The dimension measured inside the home was 3'-10." Considering a wall thickness of approximately 5", the missile would have been approximately 6'-9" long. **Figure 2-30** was taken in the same home and shows an asphalt shingle puncturing an interior wall. The inset figure is taken while standing in the doorway and shows the shingle protruding on both sides of the wall. **Figure 2-31** shows a piece of a sheet metal vent pipe penetrating the exterior wall sheathing of a home on Norris Way. Though no perforations of CMU walls were observed, numerous CMU homes received extensive impacts, as seen in **Figures 2-32 & 2-33**. The largest missile impact occurred at a home in The Village of Mallory Square and is shown in F**igures 2-34 & 2-35**. It is believed that possibly a large piece of a neighbor's roof truss produced the gaping hole.

Figure 2-27 Pine needle missile impacts on a home on Norris Way, in the Village of Mallory Square, The Villages, FL.

Figure 2-28. Missile impacts a home on Norris Way, in the Village of Mallory Square, The Villages, FL.

Figure 2-29. Missile impacts a home on Norris Way, in the Village of Mallory Square, The Villages, FL.

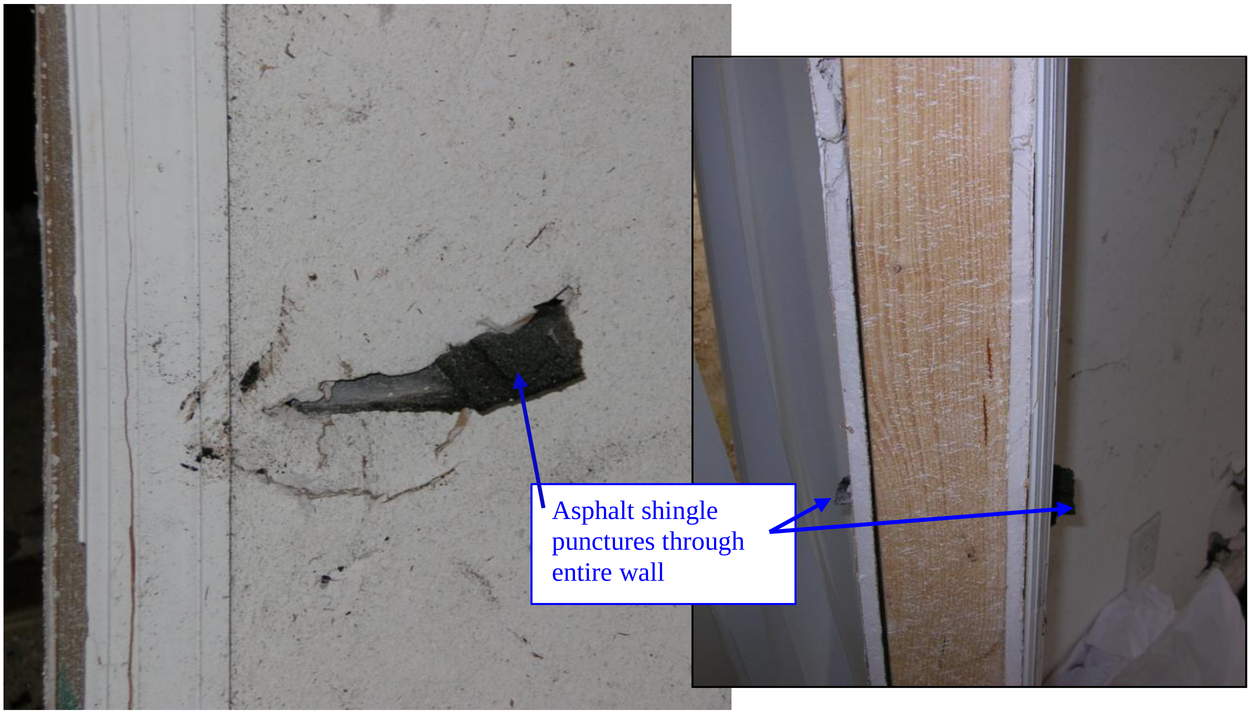

Figure 2-30. Missile impacts an interior wall at a home on Norris Way, in the Village of Mallory Square, The Villages, FL.

Figure 2-31. Sheet metal vent pipe missile impact on a home on Norris Way, in the Village of Mallory Square, The Villages, FL.

Figure 2-32. Missile impact on a CMU home on Ward Ct., in the Village of Mallory Square, The Villages, FL.

Figure 2-33. Missile impacts on a CMU home on Jardin Ct. in the Village of Sabal Chase, The Villages, FL.

Figure 2-34. Large Missile Impact on a home in the Village of Mallory Square, The Villages, FL.

Figure 2-35. Large Missile Impact on a home in the Village of Mallory Square, The Villages, FL.

3.0 Performance of Windstorm Mitigation Construction

Most of the homes damaged in The Villages by the tornado on February 2, 2007, were less than five years old. Though The Villages lies east of the Florida High Wind and Debris line of 120 mph, most of the construction observed employed numerous wind mitigating installations. CMU wall construction is a standard in the High Wind & Debris Region of Florida. Though some CMU homes were observed and documented, this type of construction was basically relegated to the commercial facilities in The Villages. Other methods of wind mitigation that were observed included numerous types of hurricane straps and hurricane impact resistant windows and overhead doors. Double top wall plates were usually strapped at 32-in. on center and truss-to-wall clips were normally installed at every truss, **Figures 3-1 & 3-2**. However, truss clips and wall straps routinely failed as the roofs and walls were removed by the storm, **Figures 3-3 & 3-4**. Roof structural elements were torn from joist hangers, **Figure 3-5**, and walls were separated from floor sill plates, **Figures 3-6 & 3-7**. Building wall corners and wall "T's" (perpendicular connection between a wall and abutting partition) routinely failed, as seen in **Figures 3-8 & 3-9.** Wall corners and T's appeared to be not laced into adjacent walls, which would account for the numerous gable endwall and corner failures. **Figures 3-10 & 3-11**, extracted from the *Architectural Graphic Standards for Residential Construction,* illustrates the traditional method of constructing exterior wall corners and interior partition connections.[7]

Figure 3-1. Typical Wall Strapping, The Villages, FL.

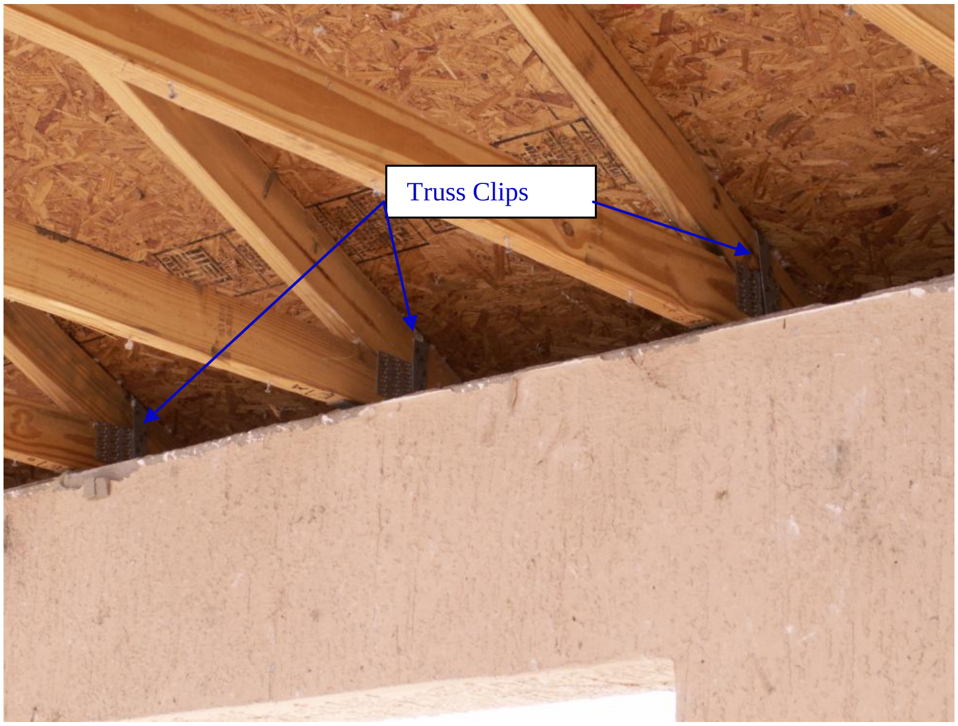

Figure 3-2. Typical Truss Strapping at CMU Wall, The Villages, FL.

Figure 3-3. Failed Truss Strapping at Wood Frame Wall, The Villages, FL.

Figure 3-4. Failed Truss Strapping at CMU Wall, The Villages, FL.

Figure 3-5. Structure Ripped from Joist Hangers, The Villages, FL.

Figure 3-6. Simpson Square Washer and Titan Concrete Anchor, The Villages, FL.

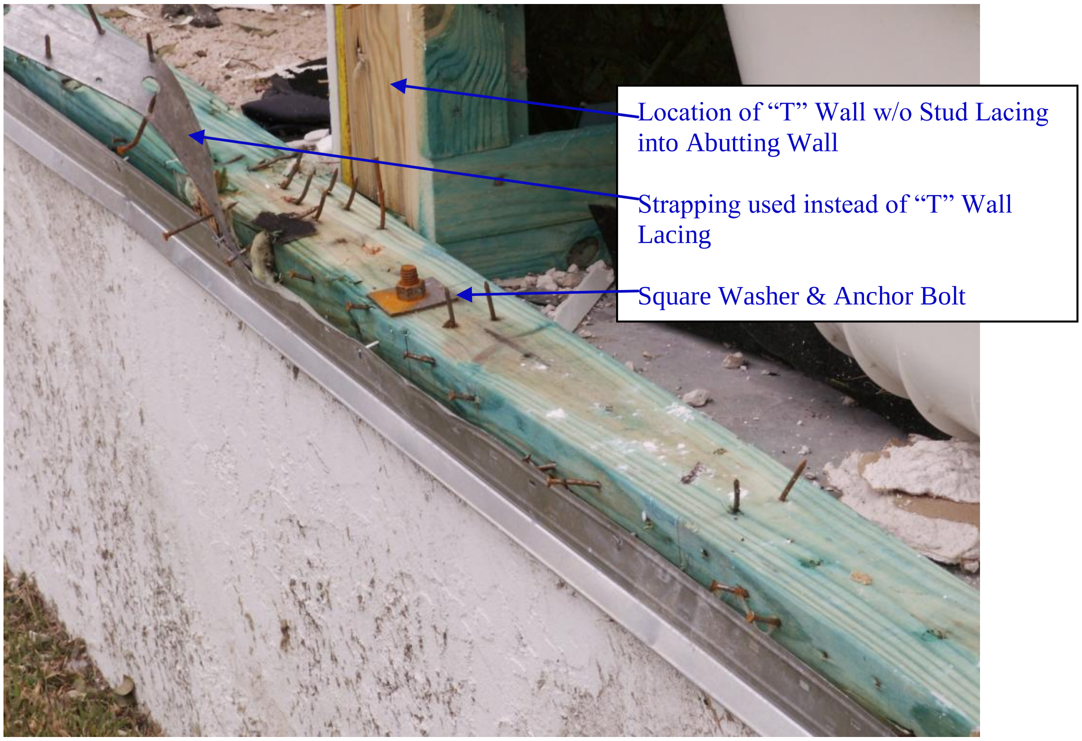

Figure 3-7. Failed “T” Wall Connection, The Villages, FL.

Figure 3-8. Wall Separation at “T” Wall, The Villages, FL.

Figure 3-9. Wall Separation at "T" Wall, The Villages, FL.

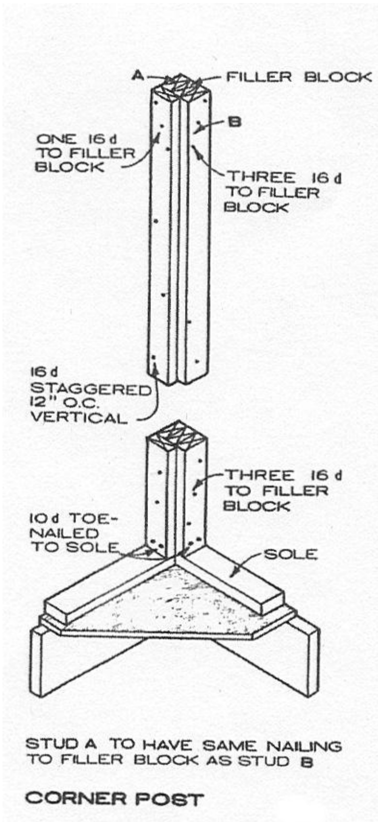

Figure 3-10. Traditional Const - Wall Corner.[7]

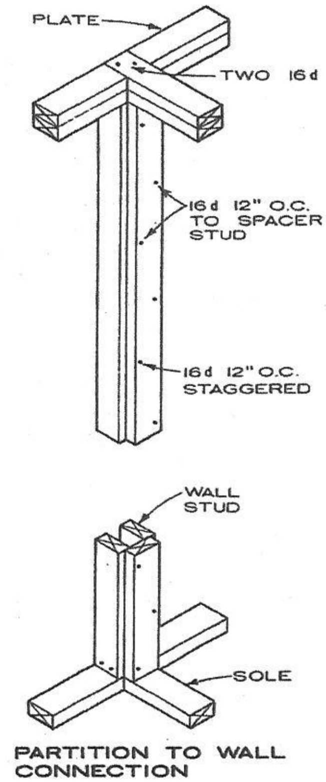

Figure 3-11. Traditional Const. - Wall & Partition Connection.[7]

Other wind mitigation installations included hurricane impact resistant windows, glass block glazing, and impact resistant overhead doors. Previous storm investigations have revealed that double (insulated) glazing and hurricane tested windows perform well in hurricane events and offer some resistance on the periphery of tornadoes. The typical mode of failure is the sacrificing of the outer glazing sheet, with the inner sheet remaining in place, as seen in **Figure 3-12**. Glass block, though not resistant to large missile impacts, provides reasonable protection from smaller missiles, see **Figure 3-13**. Garage overhead door (OHD) failures from impacts and wind pressures are routinely a major mechanism in failure of buildings. Recommendations for OHD structural improvements date back to the Federal Emergency Management Agency (FEMA) Building Performance Assessment Report of the Midwest Tornadoes of May 3, 1999.[8] Most of the OHD's investigated in The Villages were strengthened to these guidelines and were rated for hurricane wind and impact resistance and performed well in this tornadic event. **Figure 3-14** is a home in the Village of Poinciana that shows an OHD that was impacted by multiple missiles. The OHD door in **Figure 3-15**, which was removed from its garage to allow access to vehicles trapped inside the garage, illustrates the door's massiveness.

Figure 3-12. Impact Resistant Window Glazing, The Villages, FL.

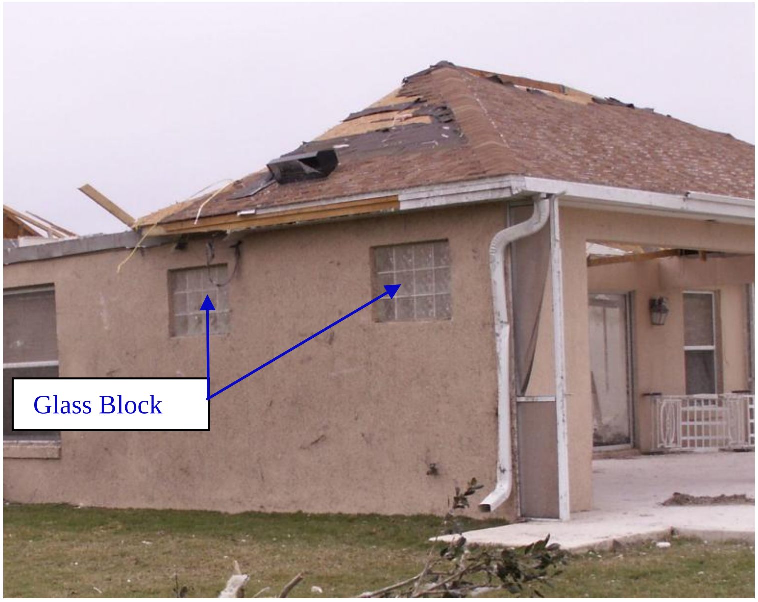

Figure 3-13. Glass Block Glazing, the Village of Sable Chase, The Villages, FL.

Figure 3-14. Impacted OHD, the Village of Mallory Square, The Villages, FL.

Figure 3-15. Impact Resistant OHD, the Village of Mallory Square, The Villages, FL.

4.0 Lady Lake Survey

The town of Lady Lake was hit by the same tornado as that which devastated The Villages just to the west. There were three main areas of investigation in Lady Lake in Lake County. The Lady Lake Church of God was severely damaged, as was Sunshine Mobile Home Park, where three people were killed, and Lady Lake Mobile Home Park, where one person was killed. Three additional deaths were attributed to this storm which occurred in mobile homes not located in parks. **Figure 4-1** shows a map of the locations investigated in Lady Lake. The tornado continued its ENE track from The Villages and traveled into Lady Lake before dissipating.

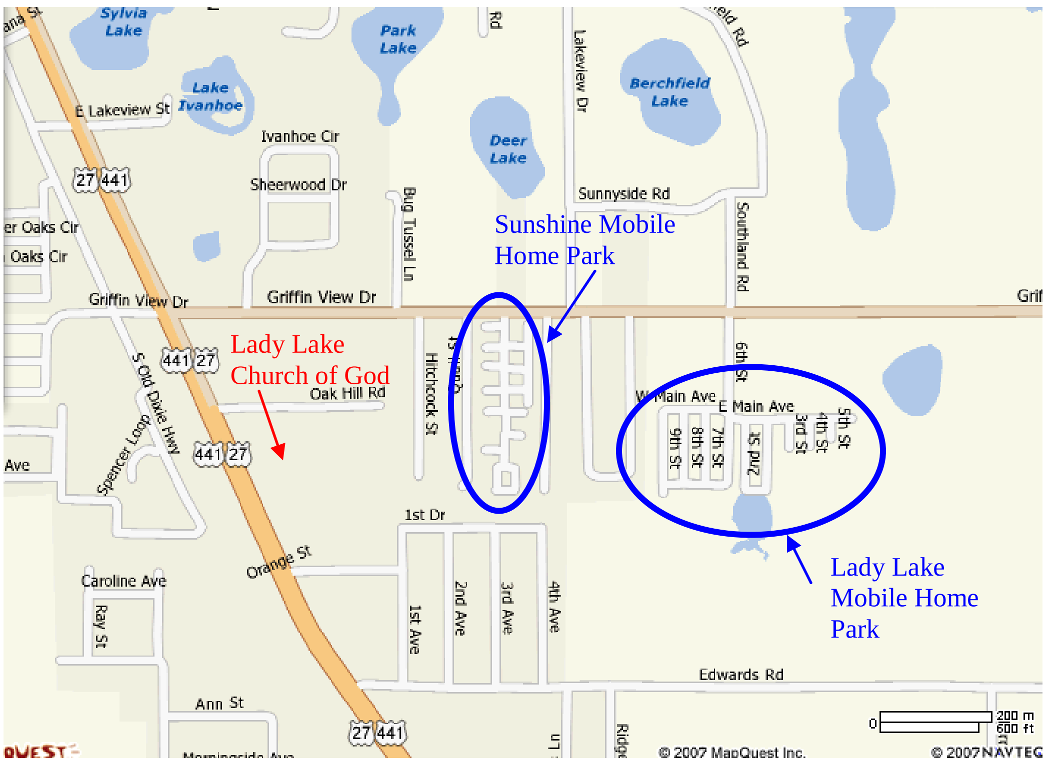

Figure 4-1. Map of area investigated in Lady Lake, FL.

4.1 Damage Documented at the Lady Lake Church of God

The Lady Lake Church of God had served as a shelter for many years, and per the church pastor, had been designed to withstand 150 mph winds. The church was a pre-engineered metal building system (MBS) built in 1976. The sanctuary structure was a high-bay with knee bents spaced at 25-ft. on center that rose approximately 25-ft. at the ridgeline. The light gage broken metal siding and roofing were attached to “Z” purlins bolted to each bent. The attached educational building was a lower MBS structure, 10-ft. tall at the eves, and was constructed similarly to the sanctuary, but with straight columns and mono-sloped roof beams. **Figure 4-2** shows the complete destruction of the church. **Figure 4-3 & 4-4** taken on the north side of the sanctuary depicts the knee bents collapsed toward the center of the building. **Figure 4-5** pictures a typical bent base connection to the foundation which consisted of two 1-in. diameter bolts. The educational wing of the church is pictured in **Figure 4-6**. The Lady Lake Church of God was totally demolished, and was assessed a DOD 8 after experiencing expected winds of 157 mph.

Figure 4-2. (MBS) DOD 8, Lady Lake Church of God view from US HWY 27 (West Elevation), Lady Lake, FL.

Figure 4-3. (MBS) DOD 8, Lady Lake Church of God side view (North Elevation), Lady Lake, FL.

Figure 4-4. (MBS) DOD 8, Lady Lake Church of God, typical failed Frame Bent, Lady Lake, FL.

Figure 4-5. (MBS) DOD 8, Lady Lake Church of God view from US HWY 27 (West Elevation), Lady Lake, FL.

Figure 4-6. (MBS) DOD 8, Educational Building Damage at the Lady Lake Church of God, Lady Lake, FL.

4.2 Damage Documented in Sunshine Mobile Home Park

A large portion of the damage in Sunshine Mobile Home Park was caused by falling trees, but there were many instances where the wind alone caused much of the damage, **Figure 4-7**. This mobile home park consisted of mostly older units, built in the 70's and 80's. Because the homes were pre-1994, tie-downs were sparse or widely spaced. Many of the tie-downs were rusted near the ground, and failed along the rusted sections, **Figure 4-8**. In addition, many of the anchors were not securely anchored in the ground due to the loose sandy soil, **Figure 4-9**. The degrees of damage (DOD) observed in the Sunshine Mobile Home Park ranged from DOD 2-8 for DI MHSW. Expected winds producing this damage would have ranged from 74-118 mph.

Figure 4-7. Typical tree damage to homes in Sunshine Mobile Home Park, Lady Lake, FL.

Figure 4-8. A rusted and snapped tiedown in Sunshine Mobile Home Park, Lady Lake, FL.

Figure 4-9. Improperly installed anchor that has moved in the sandy soil, Sunshine Mobile Home Park, Lady Lake, FL.

4.3 Damage Documented in Lady Lake Mobile Home Park

The damage in Lady Lake Mobile Home Park was very similar to that observed in Sunshine Mobile Home Park. Fallen trees crushed many homes, and all the homes were pre-1994 construction, and their tie-down provisions and installation did not meet the current Florida Building Code. The tie-downs were widely spaced and connected with poorly installed anchors for sandy soil. Many tie-downs were loose and offered little resistance to the home translation due to the wind forces, while others failed due to rusting. Similar to Sunshine Mobile Home Park, no longitudinal straps were observed across the ends of the units. **Figure 4-10** pictures a home which has rolled on its top because the tie-down straps failed. **Figure 4-11** shows a snapped undercarriage strap, with the buckle still attached. **Figure 4-12** shows a home shifted off its CMU pier foundation; however the translation was restrained by the over-the-top anchoring straps. **Figure 4-13** depicts a home that shifted more than 3' from its original position. The inset picture shows the tie-down strap nearly pulled from its anchor. Mobile homes single wide (MHSW) were routinely observed that had their over-the-top tie-down straps not installed and still in their factory wraps, as illustrated in **Figure 4-14**. The damage observed in the Lady Lake mobile homes ranged from a DOD 3-7 with an estimated wind speed range of 87-109 mph.

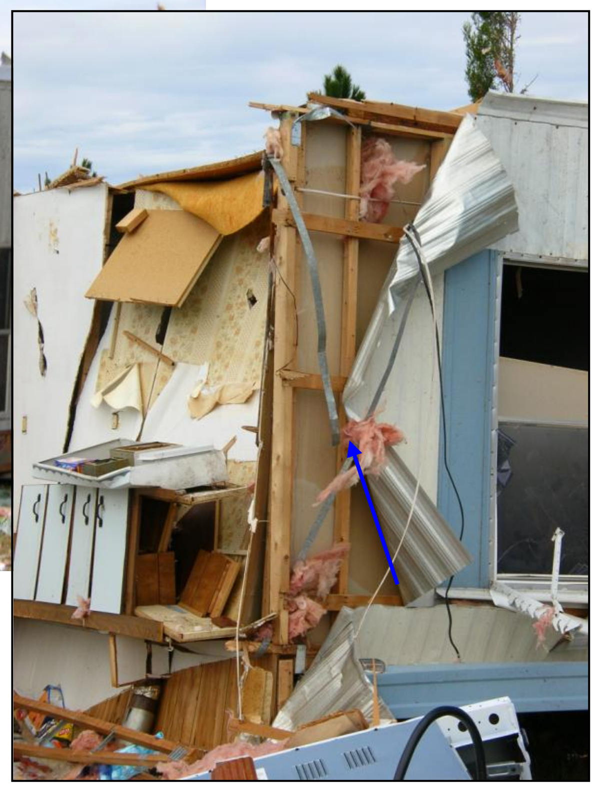

Figure 4-10. DOD 5 MHSW rolled over when Anchoring straps snapped in Lady Lake Mobile Home Park, Lady Lake, FL.

Figure 4-11. An undercarriage strap snapped at a MHSW in Lady Lake Mobile Home Park, Lady Lake, FL.

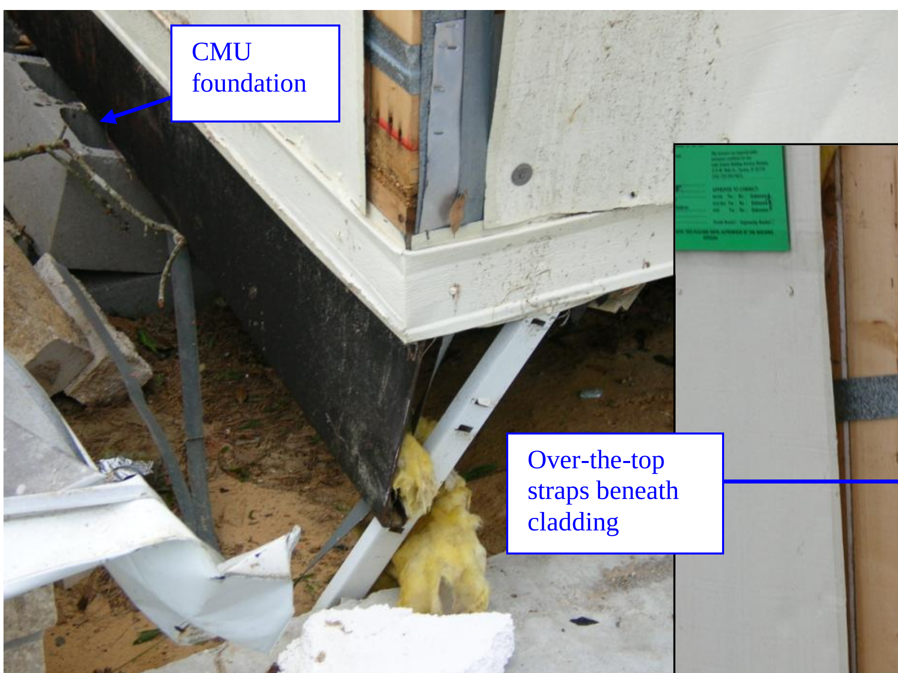

Figure 4-12. A MHSW home with over-the-top straps is shifted off its CMU foundation, but still held in place, in Lady Lake Mobile Home Park, Lady Lake, FL.

Figure 4-13. A MHSW home with tie-down straps is shifted off CMU piers by more than 3', in Lady Lake Mobile Home Park, Lady Lake, FL.

Figure 4-14. A rolled up strap not being used at a MHSW home in Lady Lake Mobile Home Park, Lady Lake, FL.

4.4 Damage Documented Between Sunshine and Lady Lake Mobile Home Parks

Situated just between Sunshine Mobile Home Park and Lady Lake Mobile Home Park, were two streets lined with homes constructed of concrete masonry units. Even though the vortex passed directly over these homes, the damage was limited to roof damage, siding damage, and other cosmetic damages. **Figure 4-15** shows homes where the only visible damage is roofing and roof decking materials. The observed damage was assessed to be a maximum of DOD 4, with expected winds of 97 mph. This area, along with the Sunshine and Lady Lake Mobile Home Parks, saw similar wind speeds, but the performance of the CMU homes on permanent foundations was noticeably better than the tied-down manufactured homes.

Figure 4-15. DOD 4 Damage to CMU homes between Sunshine Mobile Home Park, and Lady Lake Mobile Home Park is limited to roof damage.

5.0 Lake Mack Survey

The community of Paisley in northern Lake County is west of the intersection of Highways 42 and 44 near Lake Mack. Thirteen people were killed in this deadliest tornado of the night. The area investigated in Lake Mack is shown on the map in **Figure 5-1**. The NWS listed this tornado as an upper end EF-3 storm (138-167 mph). This tornado traveled from Lake Mack, across Highway 44 and into Volusia County, where it devastated Hontoon Island, and also caused damage to portions of the City of DeLand before dissipating.

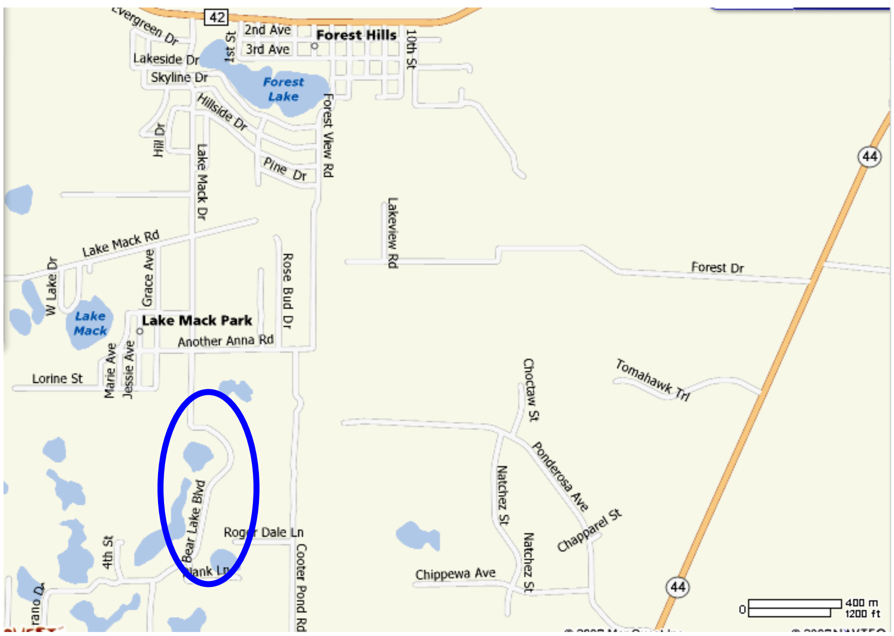

Figure 5-1. Map of area investigated in Lake Mack, FL.

5.1 Damage Documented in Lake Mack

Like the two previous mobile home parks, the homes in the Lake Mack area (Bear Lake) were generally older mobile homes and were not constructed to “high windstorm standards.” Some had over-the-top tie-downs, most of which were not properly deployed and maintained. **Figures 5-2 through 5-4** show a double-wide home (MHDW) which performed reasonably well. The owner had tightened the straps at the beginning of the previous hurricane season, and though the house suffered extensive damage and was assessed as a DOD 6, the occupants survived with no injuries, and most of the contents of the building survived with little damage. This home had a proper number and spacing of the undercarriage straps and over the top straps, which held the undercarriage, floor and walls securely in place. However, the roof was lifted off most of the unit. The average spacing of the undercarriage straps was approximately 6’, and there were longitudinal straps at the corners of the ends of the double wide unit. The MHDW pictured in **Figure 5-5** had adequate frame straps with no over the top straps. Though the frame straps performed well and were still attached to both sides of the home, the structure still blew away with only the floor diaphragm remaining. The MHSW unit shown in **Figures 5-6 & 5-7** had both frame and over-the-top straps, but the unit structure still failed, leaving only the floor and undercarriage. Based upon the expected wind speeds for each DI, the expected wind speed range of 93-113 mph appears reasonable.

Figure 5-2. DOD 6 MHDW Home, Bear Lake, Lake County, FL.

Figure 5-3. DOD 6 MHDW Home, Bear Lake, Lake County, FL.

Figure 5-4. DOD 6 MHDW Home, rear elevation, Bear Lake, Lake County, FL.

Figure 5-5. DOD 9 MHDW Home with Frame Straps and Over the Top Straps, Bear Lake, FL.

Figure 5-6. DOD 6 MHSW home with over-the-top straps attached at both sides of the home, which blew out from under the straps in Bear Lake, FL.

Figure 5-7. DOD 6 MHSW home with over-the-top straps attached at both sides of the home, which blew out from under the straps in Bear Lake, FL.

6.0 Damage Documented in Volusia County

The third tornado formed in the Florida morning of February 2, 2007, and first touched down in eastern Volusia County striking the town of Deland. It then weakened as it reached the intracoastal waterway in New Smyrna Beach. The NWS rated this storm at its peak intensity as an EF-1 with wind speeds of 86-109 mph. Most of the damage to site-built, residential structures in Deland was relegated to roofing and cladding materials (DOD 3), **Figure 6-1**. DOD 2 roof damage was observed at the Deland Middle School portable classrooms and at the Florida Technical College, Deland, **Figures 6-2 & 6-3**. The most extensive damage investigated in Deland was in the Hawthorne Hills Mobile Home Park. This damage was similar to that observed in Sunshine and the Lady Lake Mobile Home Parks and ranged from tree fall damage to DOD 4-6, **Figures 6-4 & 6-5**. By the time the storm reached the outskirts of New Smyrna, **Figures 6-7 & 6-8**, damage was random and isolated to roofing and cladding, DOD 4-6. Based upon the degrees of damage for each damage indicator, the expected wind speed for the New Smyrna area would have been 79-105 mph.

Figure 6-1. DOD 2 Residential Damage, Deland, Volusia County, FL.

Figure 6-2. DOD 2 Middle School Roof Damage, Deland, Volusia County, FL.

Figure 6-3. DOD 2 Roof Damage, Florida Technical College, Deland, Volusia County, FL.

Figure 6-4. DOD 6 MHSW Damage, Hawthorne MH Park, Deland, Volusia County, FL.

Figure 6-5. DOD 4 MHSW Damage, Hawthorne MH Park, Deland, Volusia County, FL.

Figure 6-6. DOD 4 Residential Damage, New Smyrna , Volusia County, FL.

Figure 6-7. DOD 2 Residential Damage, New Smyrna, Volusia County, FL.

7.0 SUMMARY AND CONCLUSIONS

In the early morning hours of February 2, 2007, Sumter County, Lake County and Volusia County of Central Florida experienced several strong thunderstorms, one of which spawned three tornadoes. Two of these three tornadoes were responsible for the deaths of twenty people in Lake County. Investigations were conducted in The Villages - Sumter County, the communities of Lady Lake and Bear Lake - Lake County, and the cities of DeLand and New Smyrna – Volusia County to determine the performance of structures and materials during these storms. These were the first tornadoes surveyed by the NWS and storm investigators using the new Enhanced Fujita Scale. There were several key findings:

1. The first tornado was classified as an EF-3 with wind speeds of 136-165 mph. The primary Damage Indicator (DI) was One Family Residences (FR12) with an observed Degree of Damage (DOD) for a majority of the structures in the range of 3-8, with a single DOD 10 demolished structure. The homes in The Villages were site-built and were less than five years old. Their construction type varied from total wood frame; CMU with wood frame roofs; to a hybrid of wood frame and light gage metal construction. Most of the homes investigated were constructed utilizing current hurricane mitigation methods and products. These included steel straps, roof clips, hurricane glazing, and hurricane-rated overhead doors. Those homes not directly under the storm vortex suffered small amounts of roofing, decking and cladding damage. In addition to these damages, those homes near or under the vortex further suffered loss of roof structure, garage doors and walls. Two mechanisms of failure were noted relating to the severely damaged homes: (a) These homes subjected to the higher speed winds, lost glazing and garage doors, became internally pressurized which produced subsequent failure of large portions of the building structure and walls; (b) Most homes observed were not constructed with traditional frame wall "T's" and building corners which contributed to extensive loss of whole wall sections.

2. The Lady Lake Church of God was a light gage metal building system (MBS) reportedly engineered to withstand 150 mph winds. The church had been used for years as a designated shelter from high wind events. Based upon previous storm investigations, MBS routinely suffer progressive failure beginning at low wind speeds with the loss of the light gage metal skin. Although the structure may have ultimately seen winds of 150 mph, based upon this field observation, it is believed that catastrophic failure (DOD 9) probably began at a much lower speed, probably 115-120 mph.

3. All of the mobile homes investigated were pre-1994 hurricane standard units that included both single-wide (MHSW) and double-wind homes (MHDW). The observed degrees of damage varied from DOD 2-6 for the MHSW to DOD 6-9 for the MHDW. The expected winds producing these levels of damage would have ranged from 74-118 mph. Many did not have tie-downs; had too few tie-downs; had too wide of spacing for the tie-downs; did not use the tie-downs in place; or had poorly maintained tie-downs which were loose or rusted. Only one home was observed with frame ties, over the top ties and longitudinal ties. This home still experienced damage due to the wide spacing of the over the top ties and the resulting roof loss and unit horizontal displacement. Although members of this investigative team did not observe any post-1994 manufactured housing, a FEMA Mitigation Assessment Team did investigate some units damaged by these storms and determined their level of performance to be improved over those observed by this team.[9]

Because this storm occurred in the middle of the night, many people were unprepared and unaware that a deadly storm was approaching. Although the National Weather Service issued tornado warnings with sufficient time for people to take cover, most people were not watching television or listening to the radio due to the late hour. In a situation like this, tornado warning sirens would have proven to be useful. People with NOAA weather radios would also have heard the warning and been able to take cover. Furthermore, had the people known of the approaching storms, there was no appropriate location for them to seek shelter. The Lady Lake Church of God was a designated shelter, but it did not survive the storm, and anyone who had gone there to seek shelter would have been severely injured. The State of Florida is a favorable climate for the development of severe weather due to the abundance of warm, moist air; and many tornadoes are spawned from the numerous hurricanes that affect the region annually. The science of wind engineering has made vast improvements over the years in understanding the effects of wind forces on buildings. Industry has met many of these needs in providing products that help mitigate the damages. However, catastrophic failures continue, in large part, due to loss of building connections or lack of attention for making proper connections. The manufactured housing industry post-1994 homes offer reasonable code wind resistance when the homes are properly internally connected and installed (tied and anchored). Architects, engineers, contractors, manufacturers, and installers must be vigilant in improving building designs, construction, and installations that provide a dependable level of wind resistance and safety.

Storm investigations are difficult, at best. The lives of the people affected are shattered by the loss of loved ones, homes, and prized possessions. The data is important for the development of information which can be used to better mitigate the losses. Dr. Fujita's F-Scale provided a methodology to quantify the damage and the destructive forces of the wind. The Enhanced Fujita Scale further provides tools to identify different types and qualities of construction using the Damage Indicators and associated wind speeds based on Degrees of Damage unique to the construction types.

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