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Lessons from Hurricane Andrew

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At dawn on 26 August 1992 Hurricane Andrew made its first landfall on the Louisiana coast at Point Aufer Island. This category four storm had already caused 16,000 M$ of insured losses [Ref.1] in southern Florida before it hit a rural region of southern Louisiana near Morgan City, 115 km west of New Orleans. The winds caused by Hurricane Andrew effected the built environment of coastal Louisiana in various ways that depended on the level of designer input and the construction quality control. A variety of commercial buildings, dwellings and engineered structures were examined by a United States National Science Foundation funded disaster team and a summary of their findings is presented here; along with some useful design suggestions for hurricane or cyclone-prone areas.

Introduction

In the Florida area Hurricane Andrew made 250,000 people homeless, put 86,000 people out of work and caused an estimated damage of 25,000 M$ [Ref.2] which includes the insured loss of 16,000 M$ noted above. When passing over the Bahamas, Florida and Louisiana Hurricane Andrew also caused 62 excess deaths as of 07 September 1992 [Ref.2]. When the storm devastated parts of southern Florida (see Figure 1) the one-minute mean velocities, at a 20 m elevation, reached 67 m/s as reported by the United States National Weather Service (Figure 2). The lowest central pressure recorded was 922 hPa (Figure 2) and there have only been two other storms in the United States, this century, with a lower landfall central pressure. They were the Labor Day Storm in 1935 (892 hPa) and Hurricane Camille in 1969 (909 hPa).

The wind speeds in Hurricane Andrew were only more severe than a 50-year design storm (i.e. a recurrence interval of 50 years) for one small portion of the Florida coast at Biscayne Bay [Refs.3 and 4] near the Burger King International Corporate Headquarters. A storm surge of 5.1 m in this area was the largest recorded for Hurricane Andrew. The bulk of the wind-effected area experienced less than the 50-year design wind. The level of damage was far higher than might be expected for buildings that were designed correctly and that had been inspected adequately. This brings into question the design, construction and inspection processes in Florida. A very similar scenario occurred with Hurricane Elena on the United States' Gulf Coast [Ref.5] and Cyclone Tracy in northern Australia [Ref.6].

It is important to note that the concept of a recurrence interval is a probabilistic one. There is a 64% chance of experiencing at least one such storm in 50 years, a 26% chance of at least two and an 8% chance of at least three storms in this time period [Ref.7]. Thus the recurrence interval terminology may be somewhat misleading. There is actually about a one in twelve chance of at least three storms with wind speeds equal to or greater than the 50-year design speed occurring within the 50 year period!

After causing the Florida damage noted in Table 1, Hurricane Andrew travelled west over the Gulf of Mexico, then turned north and struck the Louisiana coast between New Orleans and Lafayette. The worst damage occurred in St. Mary's Parish in the towns of Morgan City, Berwick, Patterson, Bayou Vista, Franklin and Jeanerette. By this time Hurricane Andrew had been downgraded to a category three storm on the Saffir/Simpson hurricane scale. This rural region of Louisiana has sugar cane as the principal crop and the damage to this valuable resource was about 200 M$. The total damage cost in Louisiana was estimated at about 1000 M$. The major cities of Lafayette, Baton Rouge and New Orleans were all in the periphery of the storm and suffered principally tree and sign damage. The eye passed to the west of Morgan City and Berwick (Figures 1 and 3), and since northern hemisphere hurricanes rotate in an anti-clockwise sense, these towns experienced the highest winds resulting from the superposition of the rotational and translational surface wind speeds [Ref.8]. One severe tornado was spawned by the hurricane in Louisi-

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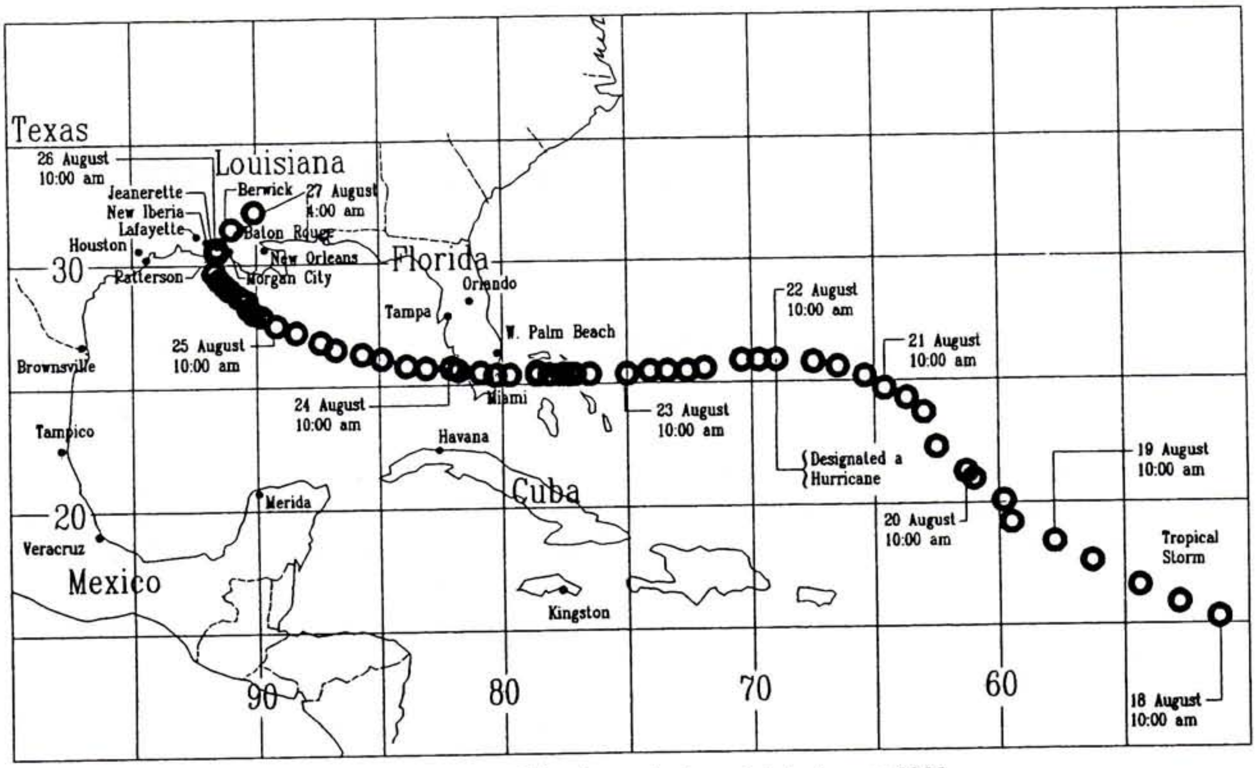

Figure 1. Path of Hurricane Andrew in late August 1992.

ana and caused damage over a 12 km long track. The principal focus of this discussion is damage in the Louisiana region since the wind speeds were somewhat less than in southern Florida and, thus, the failure mechanisms were in many cases more easily discerned.

Fortunately, a major storm surge did not accompany Hurricane Andrew in Louisiana. The coastal region was protected by the extensive, largely unpopulated bayou system. Consequently the damage to structures generally resulted from wind and windborne debris. One result of the wind induced failures was the extensive rain damage inside buildings. Rain damage after roof failure was a huge source of loss in Florida too. Smith [Ref.9] claims that 90% of roof coverings in the southern Florida storm path experienced severe damage and;

"Loss of roof coverings and the subsequent water infiltration damage will undoubtedly be the major cause of property damage inflicted by Hurricane Andrew."

Commercial Structures

Commercial buildings usually have some level of professional design input and so they are expected to perform well The structural systems were generally adequate to the task, bu the cladding often failed in a manner which resulted ir significant water damage or total roof loss. Some commercia buildings did survive with very little damage. The Soutl Central Bell building and 100 m high telecommunicatioı tower in Morgan City had no damage to the structure o satellite dishes. Similarly the Morgan City Hospital receive only very minor cladding damage, which did not impact on th building's important post-disaster function.

Table 1.

Housing Damage Estimates from Southern Florida and Louisiana

Damage	**Homes**		**Apartments**		**Mobile Homes**	
Location	FL	LA	FL	LA	FL	LA
Totally Destroyed	8,373	1,085	10,719	38	8,974	2,178
Major Damage	37,245	4, 494	13,995	290	1,100	1,764
Minor Damage	40,362	12,331	13,889	509	519	2,237
Fraction of Damage Dwellings Habitable	47%	69%	36%	61%	5%	36%

Sources: Florida State Governor's Office, the United States Federal Emergency Managment Agency, the United States Weather Service and the American Red Cross.

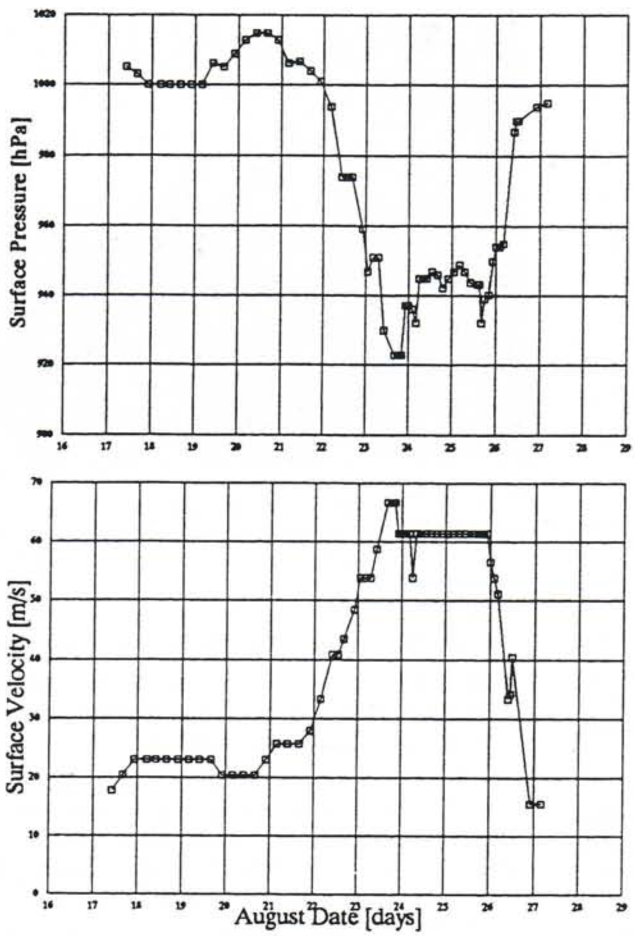

Figure 2: One-minute mean surface wind speeds and surface central pressures of Hurricane Andrew estimated from aircraft dropsondes (Source: United States National Weather Service).

In contrast most of the free-standing, petrol station canopies generally lost their cladding, but the structures were intact. There was one exception at New Iberia on Highway 90. This Exxon canopy kept its cladding in place, but the resulting loads completely destroyed the structure. This is an interesting ethical dilemma for the designer to consider. Should one design the cladding to be removed by the wind and so maintain the structure (thereby contributing to the windborne debris) or keep the cladding intact and run the risk of yielding the structural system?

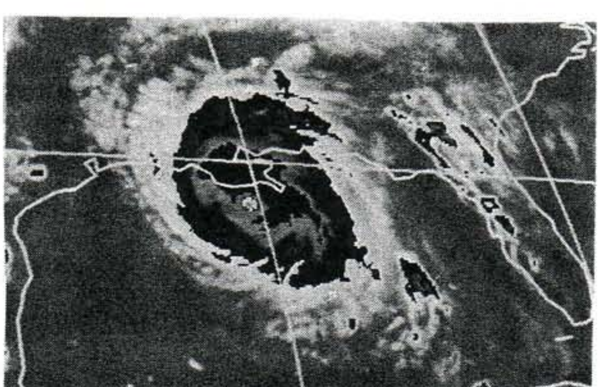

Figure 3: Photo of Hurricane Andrew crossing the Louisiana coast taken from the Geostationary Observation Environmental Satellite (GOES). Courtesy of Dr. Ray Zehr of the United States' National Oceanic and Atmospheric Administration (NOAA).

Figure 4: Delchamps Supermarket in Patterson, on Highway 90, lost most of its cladding on the front of the building creating large internal pressures.

Figure 5: Unreinforced blockwork wall blown out when the front facade failed on the Patterson Delchamps Supermarket.

The Delchamps Supermarket at Patterson (Figure 4) lost much of its entrance facade. This precipitated the loss of much of the roof sheeting and the structural failure of an unreinforced blockwork wall at the rear of the building due to an increase in internal pressure (Figure 5). The failure of unreinforced, unfilled concrete blockwork walls via this mechanism was common in the commercial buildings of coastal Louisiana.

The loss of sheet cladding material on many low-rise building roofs was often caused by an inadequate fastening of the wall/roof edge flashing. The wind moving up the face of the windward wall was able to penetrate under the edge flashing; allowing much larger pressures to develop under the leading edge roof sheeting. Frequently the flashing was deformed from its initial vertical position, at the top of the wall, to a horizontal orientation by the wind. A secondary consequence of this was that driving rain was then able to get into the ceiling space, even if the roof sheeting was not lifted off.

Infrastructure

The extent of hardship associated with a disaster such as Hurricane Andrew may be ameliorated somewhat by the maintenance of basic services (power, water, sewage etc.). The extensive damage to the power poles in the storm path meant that many residences were without electricity for several weeks. The Patterson State Bank in Figure 6 was apparently quite undamaged by the passage of Andrew; one of the many commercial buildings that performed well. However, the utility poles in the foreground are typical of the thousands that fell all over this coastal region of Louisiana. Advocating the additional expense of underground power may seem more reasonable when faced with this level of infrastructure repair. One consequence of the lack of power was that the water treatment plants were off line and so safe drinking water had to be imported into the area.

One disturbing feature of the investigation was the poor performance of many buildings, such as schools, which have a post-disaster function. Two schools (Berwick and Patterson High Schools), both of the same design, lost portions of the gymnasium roof while hundreds of people were sheltering inside. In the Jeanerette Senior High School the gymnasium was crowded with local residents when the single-ply membrane over the roof decking failed and removed the six mid-roof stormwater drain inlets. The resulting deluge saturated the interior of the entire school, even though the roof structure survived intact. The single ply membrane was only glued to the poly-urethane insulation at about one metre grid spacing over the roof. The failure also lifted all the air-conditioning plant off the roof.

Other aspects of infrastructure damage in Louisiana are worth noting. Debris blocked many roads for several days after the storm and restricted the infusion of emergency services. In addition, much of the organic debris was washed into streams and lakes, causing an oxygen depletion which resulted massive numbers of dead fish and other marine life.

Homes and Dwellings

The damage to homes ranged from none to total destruction, with neighbouring homes often performing quite differently (Figure 7). The level of architectural and engineering design input is typically minimal and so the owner must rely on the integrity of the builder and his adherence to the Louisiana building codes. The construction quality and the adequacy of inspection varied widely; resulting in the disparity of destruction.

Some older homes weathered Andrew quite well, but this observation must be tempered by the Darwinian philosophy of "natural selection". The older, better built homes have seen several severe storms and so have survived. Whereas the older, weaker dwellings have long since been destroyed by storms in the past.

The Collins Square Apartments (Jeanerette) in Figure 8 became seriously water damaged when the gable roof end failed. Frequently the structural integrity of the gable roof was compromised, but the equivalent hip roof survived. In fact, Figure 7 shows just such a comparison. The hip roof on the right was largely unscathed, while the gable roof in the centre suffered severe roof damage. Given similar construction quality the hip roof seems to weather the storm better for two reasons:

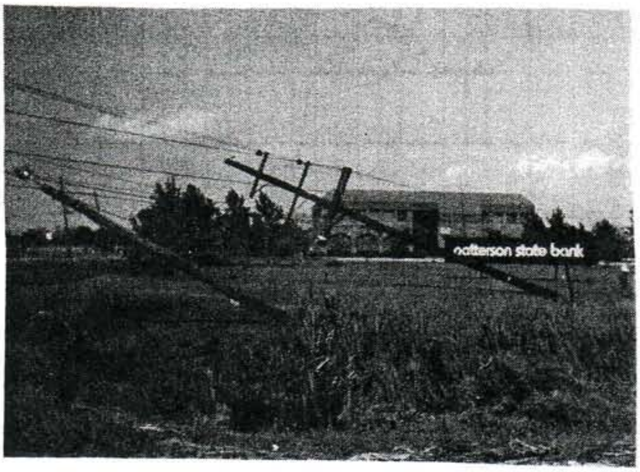

Figure 6: The Patterson State Bank was apparenlty undamaged by gusts of up to 56m/s, but thousands of power poles were laid over around the whole region.

(i) The shape offers less obstruction to the wind and so the uplift pressures are generally less [Ref.10] *and*

(ii) The complexity of the carpentry in the three-slope intersection of a hip roof produces added strength and increases the redundancy to resist wind loads.

The failure of individual shingle and tile elements was common. Figure 9 shows the asphalt shingles selectively removed by the ridge vortex formed in the strong wind [Refs.7 and 11]. Larger, well-fixed sheeting elements such as steel decking generally performed better in high winds than individual shingles or tiles. This is because the peak wind loads are area averaged on the steel-deck roof and hence may be reduced due to the lack of load correlation over the bigger roof element area [Ref.7]. This reduced peak load correlation is augmented by the greater number of load paths available to the large sheeting elements.

The practice of fixing asphalt roof shingles (common roofing material in North America) with a staple gun instead of the traditional large-head nail appears to produce some problems. The stapled shingles failed more frequently than their nailed counterparts. The reason for this may be two-fold. It is possible that the easier procedure of using a staple gun may

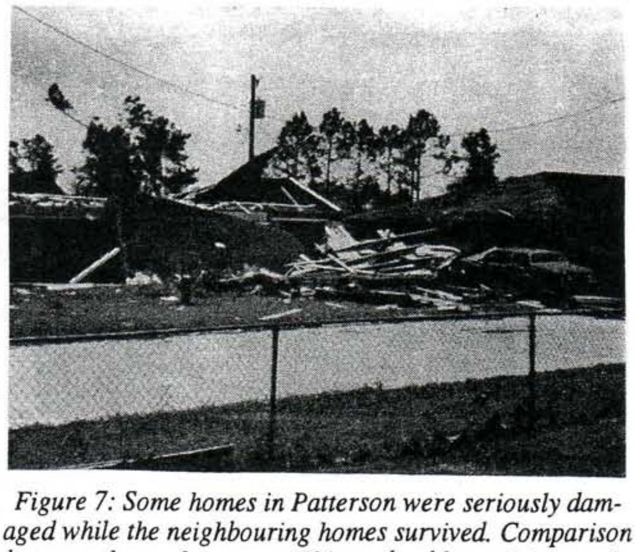

Figure 7: Some homes in Patterson were seriously damaged while the neighbouring homes survived. Comparison between the performance of hip and gable roofs is seen in this photograph.

Figure 8: Gable roof failure at the Collins Square apartment complex, Jeanerette LA.

result in a weaker fixing on to the roof surface. Some specific research is required to confirm this suggestion. The second reason, which was very obvious to all observers, was that the staples were rarely oriented along the shingle seam. Frequently they were at an angle or even running up the roof slope. This installation procedure allows the shingle to tear more easily along the staple. A large-head nail does not have this installation concern because of its radial symmetry.

Clay and concrete tiles are held down, in this region of North America, by either wire ties onto wooden purlins or by a mortar pad on a plywood decking. Hurricane Andrew revealed that this latter procedure is very susceptible to human error. The pads of mortar were frequently too small and, since the tiles were being walked on during installation, the bonding to the tile was often non-existent. The result was a cascading tile failure with broken pieces dislodging others downwind. It should be noted, however, that the mortar did bond better to the clay tiles than the concrete tiles [Ref.12]

The substrate on which the shingle and tile roofs were built was generally a 19 mm plywood board [Ref.12]. However, some builders used the cheaper, compressed particle board for this purpose. The particle board did not perform well when saturated by the heavy rain; particularly when the weather protection afforded by the shingles or tiles was gone. The roofs constructed with plywood generally did better, and particle board is now outlawed by the building codes in the southern Florida.

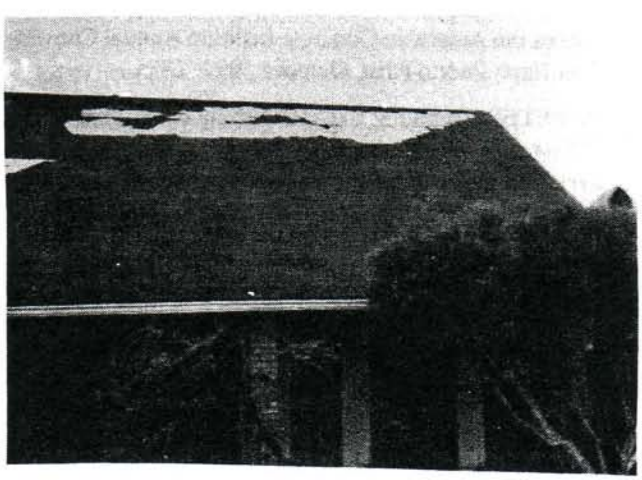

Figure 9: Flow over a roof caused by the ridge vortex. This selectively removed the asphalt shingles from a home in Ledoux Circuit, Patterson, LA.

Mobile Homes

A common type of low-cost housing in Louisiana is the mobile home (also called a manufactured home in North America). They are built in a factory environment (with the potential for better quality control) and shipped to the owners site for semi-permanent installation. These designs generally have far less redundancy than conventional homes, and when some structural component fails the rest of the building usually follows (see Table 1). In fact, it was uncommon to see a mobile home only partially damaged by the wind. They were usually found either relatively unscathed or totally destroyed. One example at Shady Grove , Patterson, is in Figure 10 where the dwelling was rolled over twice and completely destroyed.

A common mechanism for this failure is an inadequate method of holding the building down. One popular technique is to use soil augers attached to galvanized, 25 mm wide straps that wrap over the roof of the mobile home from side to side and attach to the frame. In this design one must account for the reduced soil strength when it is saturated by the heavy rains that accompany a cyclone or hurricane. During the inspection of mobile home parks in Patterson and Bayou Vista the galvanized straps were often seen broken by fatigue failure [Ref.13] and occasionally the auger ground anchors were pulled out of the saturated soil. The clean, new ground anchors in Figure 11 were found where the mobile home in Figure 10 used to be. The owner had obviously procrastinated on the installation of ground anchors just one week-end too long.

Figure 10: Mobile home park at Shady Grove, Patterson LA.

Conclusions

During the authors' visit to the devastated areas of Louisiana a variety of design or construction faults were readily apparent. The following comments and recommendations result from frequent observations of the same type of failure and the perceived causal mechanisms.

* Better building inspection is required in general, and particular attention needs to be paid to structures with a post-disaster or refugee function such as schools.

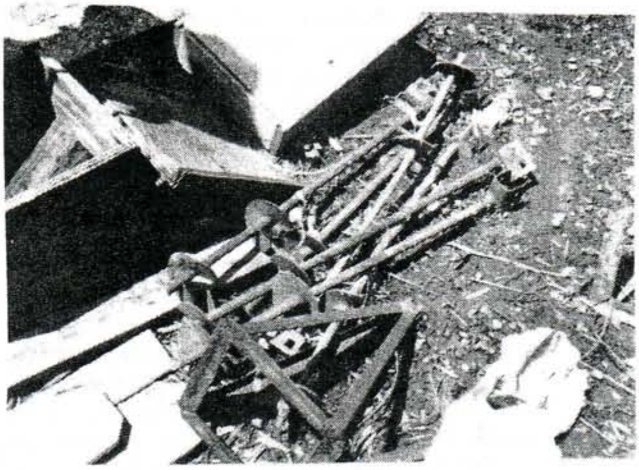

Figure 11: Uninstalled anchors that were found tossed beneath the mobile home in Figure 10.

* Hip roofs generally fared better than the equivalent gable design.
* Unreinforced masonry and blockwork frequently blew out when the house had been exposed to a large internal pressure after a window was broken (usually by debris).
* The use of well-designed storm shutters to curtail missile damage to windows and doors would decrease the likelihood of wall damage or total roof loss (Figure 12) via the mechanism of large increases in the internal pressure.
* Large roofing elements, such as rolled steel decking, generally performed better than the small component built up roofs using tiles or shingles.
* Better detailing and fixing of wall/roof edge flashing is required. Frequently the vertical part of the edge flashing was deformed to a horizontal position by the wind; exposing the interior to wind-driven water damage. Some research of design concepts may be of value.
* The unwise practice of toe-nailing roof trusses to the walls was common. This contributed to the failure in Figure 12. The lessons learned in Cyclone Tracy [Ref.6], such as cyclone rods, triple-grips and straps, need to be applied to other hurricane-prone areas.
* Perhaps the insurance industry may now be motivated to develop a rating scale (conceptually similar to that used for fire) to fiscally encourage owners and builders to design more with wind in mind.

Finally, the following quotation was written in 1926 after a hurricane hit southern Florida. One is tempted to muse about the degree of change in the intervening seventy years.

"Well-built structures weathered the hurricane except for minor damage such as broken windows and displaced roofing and shingles, while those of substandard construction were generally wrecked. A large percentage of the concrete block structures were demolished; absence of interlock and the use of poor mortar were the weak points. The older frame houses generally withstood the storm, but many of the small frame buildings, erected during the boom period, with little regard for proper bracing, were blown to bits early in the storm." [Ref.14]

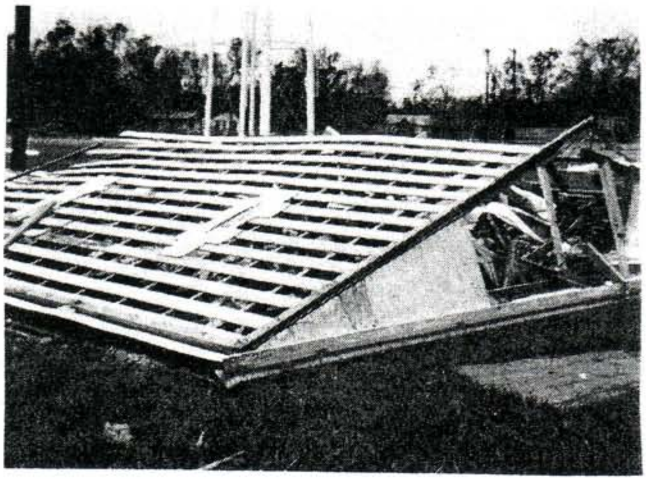

Figure 12: Roof was lifted off the Hattie A. Watts Elementary School in Patterson, LA.

Acknowledgements

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References

1.R. KORMAN, D. KOHN and S.W. SETZER: Unnatural Disaster. *Engineering News Record*, McGraw-Hill, 01 February 1993,pp 26-30.

2.E. RAPPAPORT: *Preliminary Report (updated 02 March 1993) on Hurricane Andrew, 16-28 August 1992. United States National Hurricane Center*, Florida 1993.

3.T.A. REINHOLD, P.J.VICKERY and M.D. POWELL: *Wind Speeds In Hurricane Andrew: Myths and Reality*, Proceedings of the American Concrete Institute Annual Convention, San Juan, Puerto Rica, October 1992, 18 pp.

4.J.A. PETERKA and S. SHAHID: *New Gust Wind Speed Map (Task 6). Report for the Technical Assessment and Advisory Council*, CSU/TTU Cooperative Project on Wind Engineering, Fort Collins, Colorado, USA, September 1992. p 64.

5.COMMITTEE ON NATURAL DISASTERS: *Hurricane Elena, Gulf Coast. August 29 to September 02, 1985. Volume 2, Division of Natural Hazard Mitigation, United States National Research Council*, Washington 1991, 121 pp.

6.G.R. WALKER and J.E. MINOR: *Cyclone Tracy in Retrospect: A Review of its Impact on the Australian Community*. Proceedings of the Fifth International Conference on Wind Engineering, Colorado State University, Fort Collins, Colorado, USA, July 1979, pp 1327-1337.

7.L.S. COCHRAN: *Wind-Tunnel Modelling of Low-Rise Structures*. PhD Dissertation, Colorado State University, Fort Collins, Colorado, USA, December 1992, 509 pp.

8.R.A. PIELKE: *The Hurricane*. Routledge Press, 1990.

9.T.L. SMITH: Hurricane Andrew, A Preliminary Assessment. *Professional Roofing Magazine*, United States, September 1992, p58.

10.D. MEECHAM, D. SURRY, and A.G. DAVENPORT: *Wind Action on Hip and Gable Roofs*, Proceedings of the Second Asia Pacific Symposium on Wind Engineering, Beijing, China, June 1989, pp 501-508.

11.L.S. COCHRAN: Low Rise Architectural Aerodynamics: The Texas Tech Experimental Building. *Architectural Science Review*, Volume 35, Number 4, December 1992, pp 135-142.

12.E.L. KEITH and J.D. ROSE: *Hurricane Andrew. Structural Performance of Buildings in Southern Florida (August 24, 1992). American Plywood Association Report T92-21*, Tacoma, Washington 1992, 68 pp.

13.E.D. JANCAUSKAS, G.R. WALKER, and M. MAHENDRAN: *Fatigue Characteristic of Wind Loads on Roof Cladding*, Proceedings of the Second Asia Pacific Symposium on Wind Engineering, Beijing, China, June 1989, pp 576-583.

14.G.R. SOLOMON: Damage and Reconstruction at Fort Lauderdale. *Engineering News Record*, McGraw-Hill, Volume 97, Number 16, 14 October 1926,pp 627-628.