WOOD STRUCTURES SURVIVE HURRICANE CAMILLE'S WINDS

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ABSTRACT

About four times a year hurricanes strike the Atlantic or Gulf Coasts of the United States, taking a toll of many lives and causing millions of dollars of damage. To improve the performance of wood structures in future hurricanes through greater knowledge of structural behavior, structural damage along the Gulf Coast of Mississippi was surveyed after Hurricane Camille hit this area the night of August 17, 1969. It was reported to be the most intense hurricane ever to enter the United States mainland, with winds up to 190 miles per hour and waves 20 feet high.

Wood-frame structures not damaged by wave action or flooding exhibited remarkable resistance to the high winds, while more ridgid masonry construction was totally destroyed. Wind damage was generally less to hip roofs than to gable roofs. the few cases of severe wind damage to wood-frame houses were the result of poor nailing practices, indicating that sound construction practices could greatly reduce the damage.

Mobile homes in unprotected areas were generally overturned and became complete losses. Much of this damage could have been avoided by adequately anchoring the mobile homes to an economical wood-post foundation.

Conventional construction of any type was not adequate to resist the severe wave action along the coast; however, pole-type foundations with the buildings elevated above ground level would have greatly reduced property damage from wave action and from flooding further inland.

Information and illustrations on many types of construction are given to demonstrate that wood structures properly constructed do have high resistance to hurricane forces.

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INTRODUCTION

The Forest Service has long been interested in the effects of hurricanes on wood structures, and in methods of improving these structures for greater resistance to hurricanes.[1,2,3] To add to knowledge of wood structure performance, two Forest Service engineers surveyed the damage caused when Hurricane Camille hit the Gulf Coast of Mississippi and Louisiana the night of August 17, 1969. This report presents observations of wood structure performance that should be helpful to those concerned with erection of buildings in hurricane areas.

Hurricanes are large, violent tropical disturbances with winds rotating about a low-pressure center. Because of their great size, they are among the most feared and most destructive storms on earth, although tornadoes are more violent. A mature hurricane has a diameter from 60 to 1,000 miles. Wind velocities are above 75 miles per hour. Other features of hurricanes are:

1. Counterclockwise rotation north of the equator, with winds spiraling inward and upward.
2. Heavy cloudiness and precipitation.
3. A central "eye" with occasionally cloudless skies, light winds, fair weather, and no rain.
4. spiraling bands of clouds radiating out from the center like the arms of a pinwheel.

About four hurricanes per year enter the United States mainland.

Hurricanes are unpredictable. They frequently change their course in an irregular manner. The number of tornadoes associated with individual hurricanes may vary greatly, making each hurricane unique. since much of the destruction of well-constructed buildings in hurricanes, attributed to wind and exclusive of wave action, may be

*Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[1]Anderson, L.O., and Smith, W.R., Houses Can Resist Hurricanes. U.S. Forest Serv. Res. Pap. FPL 33 1965, Forest Prod. Lab., Madison, Wis.

[2]McDonald, John K. Homes for Hurricane Country. Forest & People. Third Quarter, 1967.

[3]Smith, W. R. Building Homes to Withstand Hurricane Damage. Forest Prod. J. 11(4): 176. 1960.

caused by the hurricane-spawned tornadoes, wind velocity alone is not an adequate measure of hurricane severity. Other variables also influence the way each hurricane may affect buildings and other structures. These include:

1. The magnitude of hurricane-driven tides and resultant waves.
2. Tree cover.
3. Soil type.
4. Elevation of the land.
5. Density of buildings in the affected area.

Wind velocity readings may tend to be misleading, since they are localized measurements, usually made in open areas, and at different altitudes than those of actual buildings. Trees and other physical features may significantly affect wind velocities on any given building site. For these reasons, the authors stress that the observations reported do not necessarily apply to all hurricanes, or all locations in the present hurricane damage area. The conclusions reached by the authors, after observing the damage wrought by Hurricane Camile, apply specifically only to that hurricane. However, there is enough similarity in damage caused by hurricanes so that this report will have value in predicting future hurricane damage, and can result in better building design for hurricane areas. Such knowledge should help to avoid much of the damage which has occurred year after year. apparently, few changes in building design and precautionary measures based on previous studies and experience have been used in the Gulf Coast area.

HURRICANE CAMILLE

Hurricane Camille was reported to be the most intense hurricane ever to enter the United States mainland. Rain and waves driven by winds estimated by the New Orleans Weather Bureau at 150 to 190 miles per hour hit the Gulf Coast east of New Orleans between Biloxi and Waveland, Miss. (fig. 1) at 10 p.m. the night of August 17, 1969, continuing to pound the coast until about 4 a.m. on August 18. Tides up to 20 feet high almost completely destroyed costal structures. the hurricane then traveled inland northwesterly, gradually losing its fury. At Hattiesburg, Miss., 73 miles north of Gulfport, the wind still reached a velocity of 100 miles per hour during the hurricane (fig. 2). Severe hurricane damage from high winds extended inland over an area about 40 miles wide and 80 miles long in Mississippi and Louisiana. Torrential rains and tornadoes spawned by the hurricane caused additional damage in a much larger area, ultimately resulting in heavy rains and floods in parts of Virginia.

WAVE ACTION

The most severe damage from the storm was caused by wave action along the waterfront. On the Biloxi, Miss., coastline, and along the entire coast from Biloxi to Waveland, there was almost total destruction in an area extending about 1 block back from the waterfront. This was the area of heavy wave action which resulted in washing boats, barges, cargo, pallets, and debris considerable distances inland.

Large apartment buildings, restaurants, and shops were completely destroyed and the debris was washed inland. The few structures that remained were completely gutted (fig. 3). Where the buildings were not directly on the waterfront, the first floor framing frequently remained in place supporting the relatively undamaged second floor (fig. 4). The seaward end of one well-built apartment house was destroyed by wave action, while the rest of the building remained intact (fig. 5). These buildings were built directly on the ground instead of on piers as one might expect along shorelines in the hurricane zone.

FLOODING

Flooding in the low areas slightly inland was a major cause of damage (fig. 6). The wave action backed water into the streams and drainage ditches so that water from the heavy rains could not drain. The contents of many homes were completely destroyed by water even though the house remained intact, Waterr about 6 feet deep passed through some of these houses, but apparently washed in gradually, without actual wave force.

FALLEN TREES

Although there was a great deal of tree damage throughout the hurricane area, the heavy tree cover may have greatly reduced direct wind damage to buildings. Buildings in unprotected areas were there was a clear sweep of wind generally sustained more damage, and in such

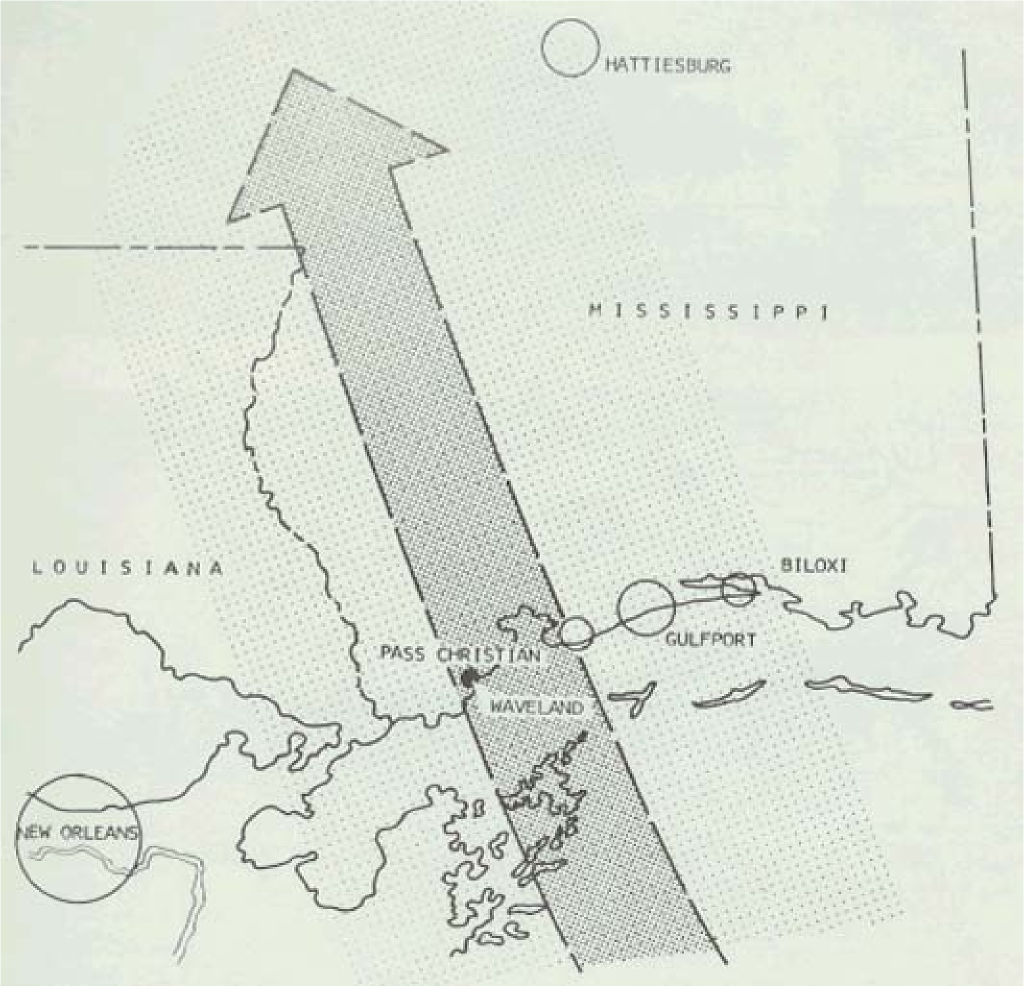


Figure I.--Path of Hurricane Camille. M I37 078

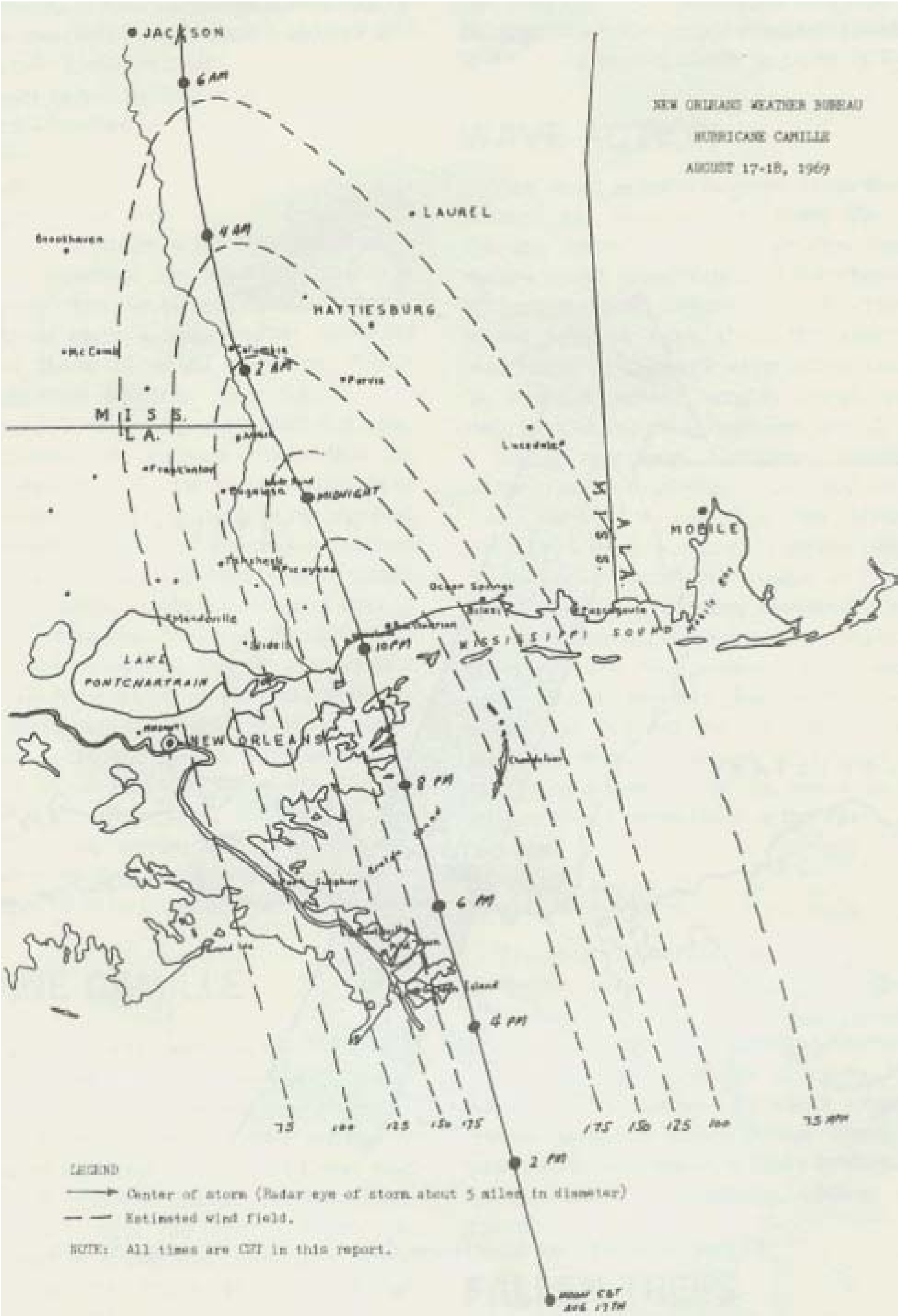


Figure 2.––New Orleans Weather Bureau report, August 17-18, 1969.

Figure 3.--Waves, water, and wind completely destroyed buildings along the Coast and gutted the few that remained standing.

MI 36996-A2-4
MI 36996-A3-18

Figure 4.--First floor framing supporting undamaged second floor. M I37 083

Figure 5.––Seawardend of this building took fulI force of wave; the rest of the structure remained intact.

M I37 084

Figure 6.--Houses in low inland area severely damaged by a combination of wind and water.

MI 36925-I8

Figure 7.--Most observations of fallen trees indicated that buildings were spared or lightly damaged.

MI 36996-A3-2I
MI 36996-A3-9
MI 36996-A3-I4
MI 36996-A3-8

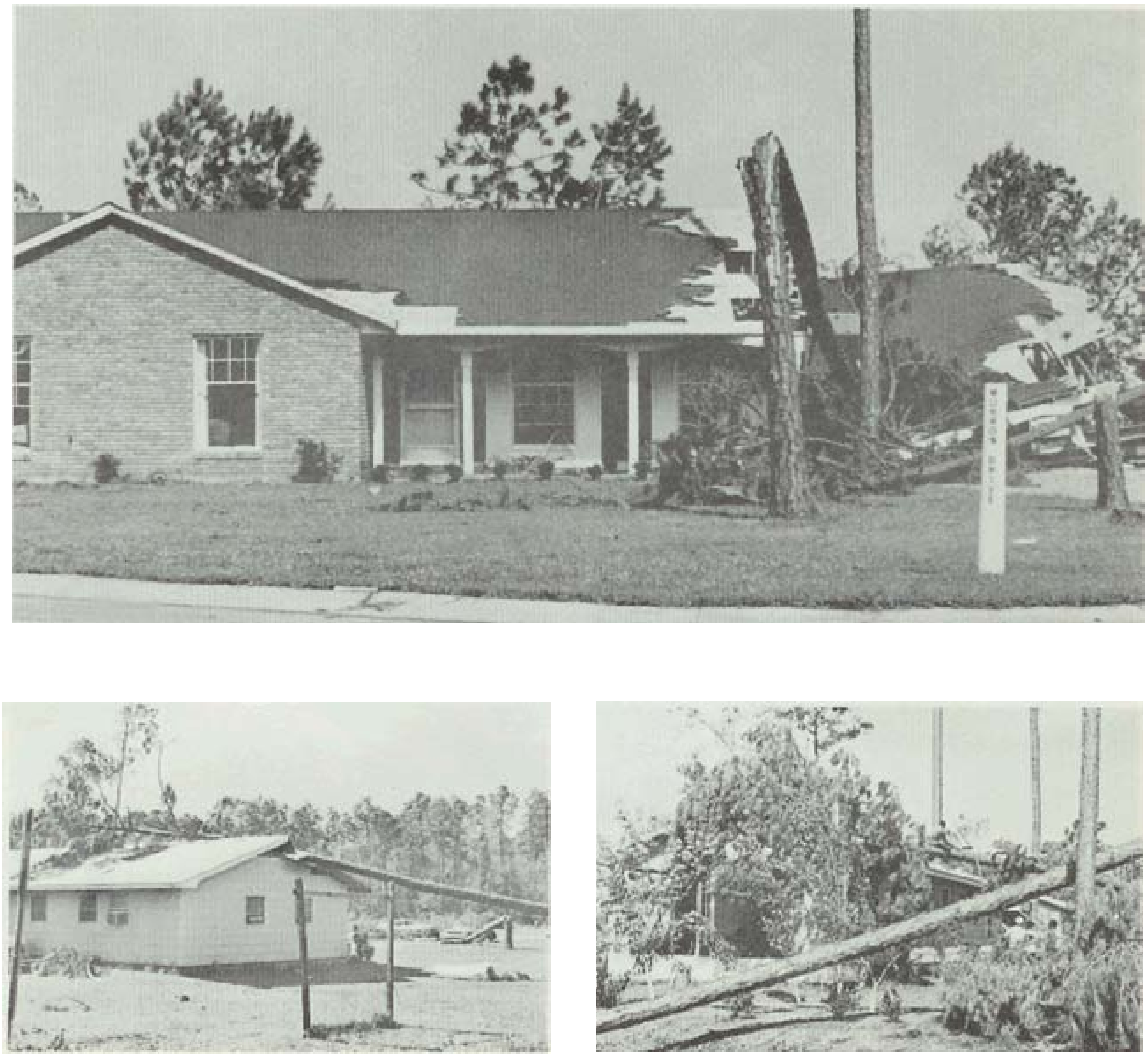
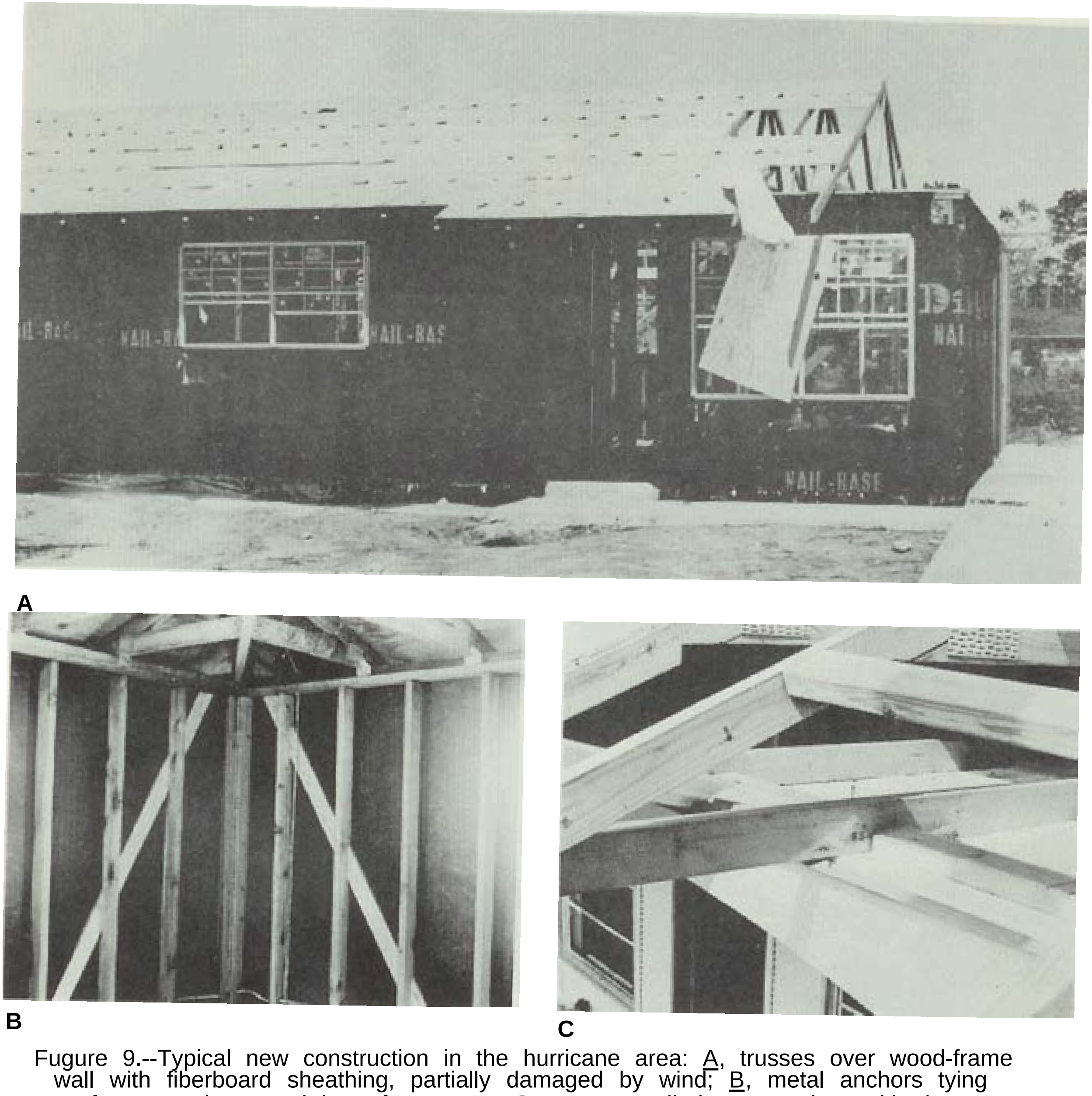


Figure 8.--Fallentrees that hit houses directly over a garage or carport opening did the greatest damage. Houses supported many trees without collapsing.

MI 36996-AI-II
MI 36996-A3-I
MI 36996-A3-I0



A

B

C

Fugure 9.--Typical new construction in the hurricane area: A, trusses over wood-frame wall with fiberboard sheathing, partially damaged by wind; B, metal anchors tying roof to top plate used in a few cases; C, trusses nailed to top plate with three sixteenpenny nails.

MI 36996-A3-I
MI 36996-A3-3
MI 36996-AI-I4

Figure 10.--A large wood-frame-house in Pass Christian that had very little damage.
MI 369965-AI-4

Figure II.--Older house that was located in Pass Christian near the center of the storm, yet came through the storm with little damage.
MI 36996-AI-6
MI 36996-AI-8

Figure I2.--Gable-end house with greater damage than nearby house with hip roof.
MI 36996-I6

Figure 13.--This roof blown completely off the house had neither collar beams nor proper nailing of rafters to joists. MI 36925-28

MI 36925-27

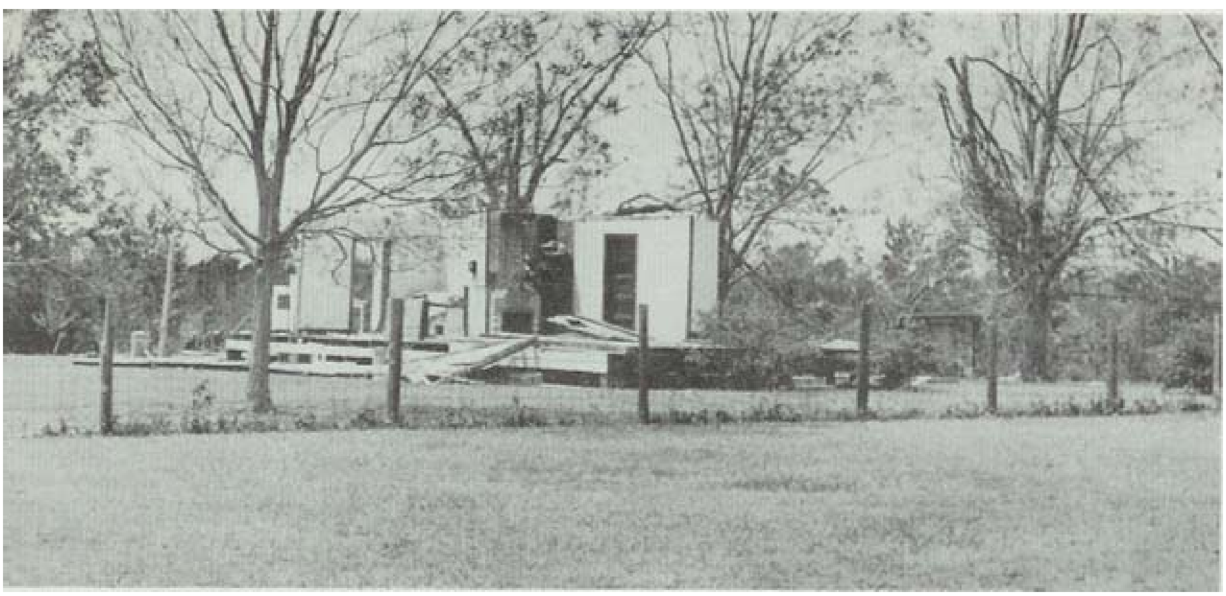


Figure 14.--Exploded house, with damage apparently caused by a hurricane-spawned tornado. MI 36925-22

Figure 15.--Concrete block and brick masonry completely destroyed.

MI 36925-8
MI 36925-20
MI 36996-A2-I

A

B

Figure 16.--Wind damage in unprotected rural area. A, concrete-block restaurant destroyed; B, wood-frame house across the road from restaurant was not seriously damaged.

MI 36925-23
MI 36925-24

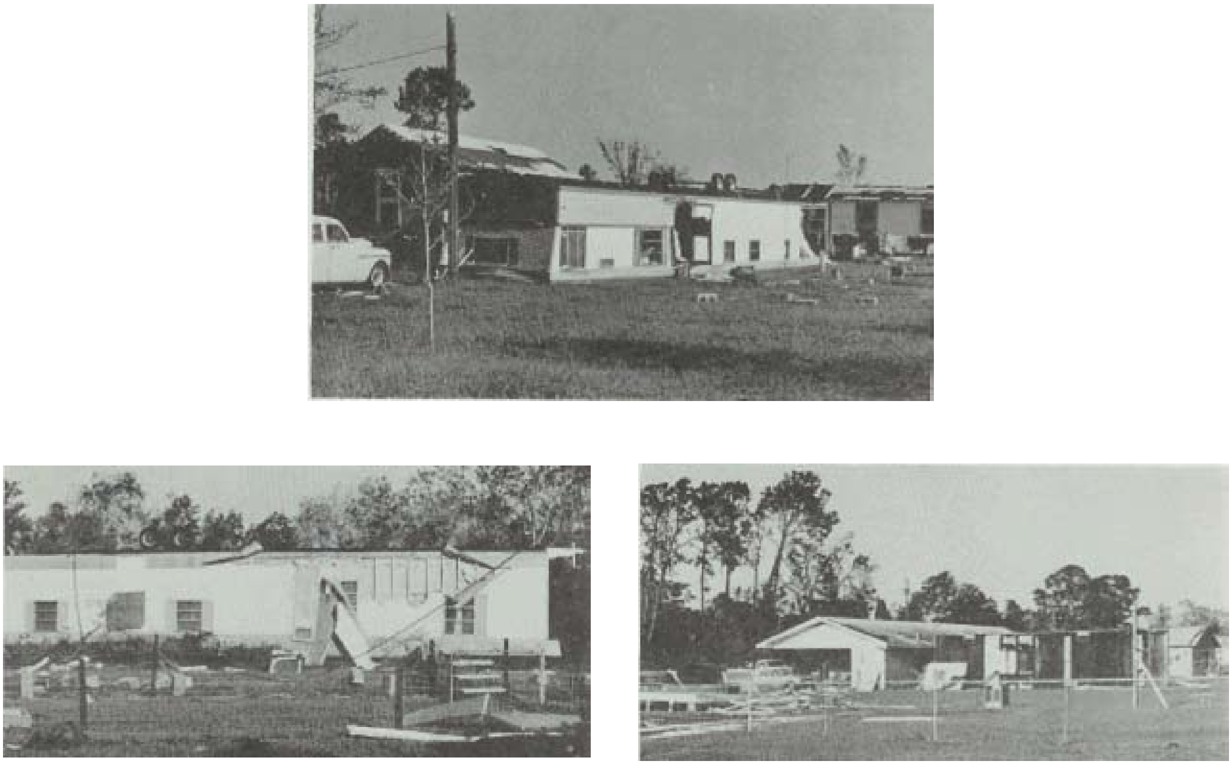


Figure 17.--Mobile homes overturned in areas where wood-frame houses were not seriously damaged. MI 36996-A2-13 MI 36996-AI-I MI 36996-A2-7

Figure 18.--Mobile home in unprotected area completely destroyed. Along a mile of country road, five homes were observed in this condition. MI 36925-30

Figure 19.--Mobile home with heavy ropes tying It down to pipes driven into the ground. Two adjacent mobile homes were a total loss. MI 36996-A2-I2

areas mobile homes were overturned. In most instances we observed, the fallen trees spared buildings (fig. 7), but a few did considerable damage (fig. 8).

DIRECT WIND DAMAGE

Where there was no damage from water and fallen trees, wood-frame buildings withstood the 150- to 190-mile-per-hour winds exceptionally well. In the same areas, concrete block and brick masonry walls were often blown in and mobile homes were overturned.

Small Wood-Frame Buildings

Typical new residential construction in the Gulf area is concrete slab and wood frame with roof trusses (fig. 9). Fiberboard sheathing is used with let-in 1- by 4-inch diagonal bracing at each corner. The soleplate is usually nailed to the concrete slab with hardened nails at 4 feet on center. Roof trusses are toenailed with three sixteenpenny nails at each bearing point. In one case, a metal anchor was used to tie the truss to the top plate (fig. 9,B), buty this practice did not appear to be common in the area observed. The roof is usually asphalt shingles over 3/8- or 1/2-inch plywood sheathing. siding is often a combination of wood siding and brick veneer.

Residential construction observed in the Gulf area is very similar to that used in many other parts of the country. No special construction methods were noted which might be considered necessary in hurricane zones. Buildings in Gulfport, Miss., are built to meet the requirements in the Southern Standard Building Code and are designed for 125-mile-per-hour winds.

In some housing subdivisions located on higher ground, there was little damage. In Pass Christian, which was one of the hardest hit communities, there were many houses that stood like fortresses in this badly damages area (fig. 10). One home in Pass Christian that showed no evidence of special hurricane construction, for example, suffered very little damage (fig. 11). The plywood-shuttered windows saved this house from window breakage and much interior damage.

The shape of the roof and size of roof overhang seemed to be a major factor in the extent of damage. In many subdivisions, it was possible to view several blocks of houses witgh alternative types of roof construction. In every case, there was much less damage to the hip roofs than to the gable roofs. shingles and even some roof sheathing were frequently blown off the gable ends of houses when neighboring houses with hip roofs had little or no damage (fig. 12).

In rural areas 10 to 20 miles north of Gulfport there were a few isolated buildings that were completely destroyed by wind. These buildings had little protection from trees and other buildings which could account for greater wind damage. However, even in these exposed locations, houses that were nearly destroyed were found to be of substandard construction. One house that had severe damage was built without sheathing (fig. 13). Joints in the drop siding occurred at wall intersections. The walls of a corner room may have collapsed to cause the roof to leave the house; however, if the rafters had been properly nailed to the joists and tied together with collar beams, the house probably would have suffered only minor damage. Examination of the rafters showed they were toenailed to the top plate, but no more than one nail was used in securing a rafter to a joist where recommended practice is to use five tenpenny nails.

The only wood-frame house of the thousands observed in the hurricane area that was completely destroyed by the effect of wind alone appeared to be exploded (fig. 14). Since this type of destruction is usually associated with tornadoes, it is probable that a tornado spawned by the hurricane struck the house. Even though the walls and roof were gone, the floor and partitions did not move from the brick pier foundation. Other houses int he same area were not badly damaged.

Masonry Construction

In the hurricane area from Biloxi to Pass Christian were high winds and some flooding, but no direct wave action, was involved, there were many unreinforced concrete block and brick masonry buildings which were completely destroyed by the wind (fig. 15). Others in more protected locations were undamaged. Typical destruction was apparently due to masonry walls failing under vibrations and wind pressures, usually followed by roof structures separating and either collapsing or blowing away some distances. Some roofs with truss construction remained intact even though one supporting wall collapsed. One concrete block restaurant about 20 miles inland was completely destroyed, while a wood-frame house across the toad had only shingle damage and damage from debris from the concrete block restaurant (fig. 16).

Mobile Homes

Most mobile homes in unprotected areas were overturned and appeared to be nearly complete losses, whereas wood-frame houses in the same areas suffered only minor damage (fig. 17). Although mobile home damage was widespread, many mobile home courts located throughout the hurricane area had only minor damage. Where the courts were well screened by woods, and homes were quite close together, damage was usually only from falling trees. Apparently, wind must get a good clear shot at a mobile home before it will turn over. In a rural area about 15 miles inland, the isolated mobile home sitting on hilltops all were destroyed (fig. 18). In Gulfport there was one mobile home which had been tied down with ropes, and it withstood the storm, although mobile homes nearly were overturned (fig. 19).

It was not possible to judge how well mobile homes would have withstood damage if they had been rigidly attached to the ground. It would seem that a simple post foundation system of pressure-treated wood for mobile homes, to which the mobile home was firmly attached, would prevent a great deal of damage in hurricane zones.

SUMMARY

Well-built conventional wood-frame construction performed exceptionally well in Hurricane Camille, except when subjected to severe wave action. Wood-frame homes, in particular, exhibited remarkable resistance to the high winds. Apparently conventional construction whose components are well attached to each other is adequate to resist the wind forces in hurricane zones.

However, conventional construction of any type on solid foundations is not adequate to resist the severe tide and wave actions along coastlines during hurricanes. Much of the damage to the coastal buildings done by Hurricane Camille would probably have been avoided if high pier-type foundations had been used to reduce the force of water directly on the buildings. This type of foundation would also have greatly reduced property damage from flooding further inland.

Damage to wood-frame homes from wind appeared to be less for those homes with hip roofs than with gable-end roofs. Most hip roofs that were observed lost fewer shingles and did not have the roof sheathing and rake damage common to houses with gable-type roofs.

Mobile homes were treated badly by Hurricane Camille, as they were by previous hurricanes. Mobile homes overturned by the wind were generally complete losses. Buildings of lightweight construction, as mobile homes, should be adequately anchored in hurricane or high wind zones. We believe that much of the wind damage to mobile homes could be avoided by anchoring them to an economical wood pier-type foundation.

As our Nation grows, people expect and need more from their forests--more wood; more water, fish and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U.S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

* Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.

* Participating with all State forestry agancies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.

* Managing and protecting the 187-million acre National Forest System.

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; adn by cooperating with all States and with private citizens in thier efforts to achieve better management, protection, and use of forest resources.

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