OBSERVATIONS OF DAMAGE TO HOUSES BY HIGH WINDS, WAVES, AND FLOODS AND SOME CONSTRUCTION PRECAUTIONS

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In Cooperation with the University of Wisconsin
OBSERVATIONS OF DAMAGE TO HOUSES BY HIGH WINDS, WAVES, AND FLOODS AND SOME CONSTRUCTION PRECAUTIONS

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Introduction

Hurricanes, tornadoes, and floods annually take a destructive toll of homes and other buildings in the United States that mounts into the millions of dollars. Forest Service observations extending over many years indicate that poorly constructed buildings, regardless of the material used, are the principal source of loss in storm areas (figs. 1 and 2).

Few parts of the United States are immune to one or another of these eruptions. Tornadoes strike the Great Plains and the Middle West almost every season of the year. Hurricanes lash the Gulf and Atlantic coasts periodically with both wind and water. Floods occur in many river basins during early spring or periods of prolonged heavy rainfall.

Inspection of houses in the wake of hurricanes, other severe wind storms, and floods has afforded a dramatic means of observing both structural strong points and weaknesses. While it is probable that no type of construction can be expected to be immune to the full force of a tornado, investigation has shown that much damage inflicted by severe storms could be prevented or at least minimized by employing the known basic principles of good construction.
Figure 1. -- This picture illustrates dramatically what happens to a poorly constructed house in a strong wind. Poorly constructed buildings, regardless of material used, are the principal source of loss in storm areas.

Figure 2. -- A well-constructed house that withstood two hurricanes. Good construction gives an excellent account of itself in hurricane areas.
In this publication, typical findings of surveys conducted in afflicted areas are presented, together with suggested construction methods and design details of buildings that have either demonstrated their superiority by withstanding the violent forces of wind and water or are known to possess inherently greater resistance to such forces as a result of research and general experience in the field of structural design. This information was developed as a part of the overall objective of the Forest Products Laboratory's research -- to improve the utility and serviceability of wood and its products.

The publication emphasizes the need for firm foundations. Adequate ties between foundation, floor system, walls, and roof are cited as among the most effective ways to strengthen a house against wind and wave damage, and means of securing such ties, including toenailing of walls to sills and the use of strapping and commercial metal framing members, are described. The great stiffness contributed by plywood and diagonally laid lumber sheathing is emphasized, and the advantages and disadvantages of various wall and roof covering materials, such as lumber siding and shingles of different kinds, are discussed.

Foundations

The foundation of a house functions primarily as a solid base to keep the superstructure level and free of distortion and damage that could result from settlement as the unevenly distributed weight of the building and its contents bears upon subsoil. In northern States, foundations must go below the frost line to avoid effects of expansion and contraction as soil water freezes and melts.

Another important function of the foundation, often ignored, is to serve as an anchor to the superstructure so it can resist such forces as high winds and waves. To serve this purpose, the foundation must be strong enough to withstand such forces, and the superstructure must be fastened securely to the foundation. The direct force of wind and waves is more or less uniformly distributed over the exposed area of the foundation wall. In regions subject to high winds and waves, this function of the foundation needs to be carefully considered by house builders.


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Figure 3. -- The walls of this house collapsed when the unit type foundation was washed out by high waves during a hurricane.

Figure 4. -- The mortar bond between the foundation blocks of this house was inadequate to withstand the force of high waves hurled against it during a hurricane.
Figure 5. -- Hurricane-driven waves badly damaged the foundation of this house and part of the brick veneer fell off.

Figure 6. -- When pounded by hurricane-driven waves this interior house partition collapsed after the water had broken through the exterior block wall.

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Figure 7. -- The load-bearing brick piers of this house resisted the force of hurricane-driven waves better than the filler block wall between them. Diagonal wood sheathing helped prevent distortion of the superstructure.

Figure 8. -- Formwork for poured concrete walls.
Types of Foundations

Foundations of houses are usually built of poured concrete, concrete block, stone, or brick. Masonry columns and wood posts or piles are sometimes used in lieu of continuous foundations. As far as structural resistance to winds and waves is concerned, continuous foundations and columns or posts each have their merits and disadvantages. Generally, however, a poured concrete foundation offers the greatest resistance and durability to direct forces as well as the best base to which to tie the superstructure.

Examples of damage to foundations by hurricane-driven waves are shown in figures 3, 4, 5, 6, and 7.

Masonry columns and wood posts or piles, frequently used to support basementless houses, have certain advantages in coastal areas where wave damage is likely. Water can flow around and past the supports, rather than tending to dam up as against a continuous foundation wall.

Construction of Poured Concrete Foundations

Poured concrete foundations (fig. 8) require forming that must be tight and also braced and tied to withstand the forces of the pouring operation and the pressure of the fluid concrete.

Poured concrete walls should be double-formed (formwork constructed for each wall face). The forms may be constructed of dressed and matched or shiplap sheathing, studs, and joists. It is usually advisable to use special concrete-form nails with two heads, as they can be removed easily and without damage to the wood. The forms can be built in sections and then erected. Reusable forms made of wood, plywood, or steel can also be used.

Spacer blocks of a length equal to the finish thickness of the wall are generally used between the faces of the wood forms as separators. Wire or steel-bar ties hold the forms rigidly against the separators. Steel separators are used with steel forms.

Frames for cellar windows, doors, and other openings are set in place when the forming is built, along with boxes that will form notches for the ends of floor beams. Framing and bracing are used to keep the forms in place during pouring.

Nails are often driven into wood forms to mark the level to which the concrete should be poured (fig. 8). The concrete should be poured without
Figure 9. --Concrete-block walls.

Figure 10. --Combined slab and foundation. The gravel fill should be of a size that will be retained on a 1-inch-mesh screen.
interruption. During the pouring operation it should be continuously puddled
to remove air pockets and to work the material under window frames and
other blocking. Where wood spacer blocks are used, they should be re-
moved, and not permitted to become buried in the concrete. Anchor bolts
for sills should be placed while the concrete is still in a plastic condition.

Forms should not be removed until the concrete has hardened and become
strong enough to support loads imposed during early construction. At least
2 days and preferably a week are required.

Poured concrete walls can be damp-proofed with a heavy coat of hot asphalt
or hot tar applied on the outside from the footings to the finish gradeline.
Such coatings usually make a wall watertight against ordinary seepage, such
as may occur after a rainstorm. If the soil is poorly drained, a membrane
such as that described for concrete-block walls may be necessary.

**Construction of Concrete-block Walls**

Concrete blocks are available in various sizes and shapes. Those most
widely used come in nominal sizes 8 inches high, 16 inches long, and 8, 10,
or 12 inches wide. The actual size is somewhat less than the nominal size
and allows for the joint.

Concrete-block walls require no formwork. Block courses start at the foot-
ing and are laid up with 3/8- to 1/2-inch mortar joints. Joints should not
exceed 3/4 inch, and should be tooled smooth to resist water seepage. Full
bedding of mortar should be used on all contact surfaces of the block. When
pilasters (column-like projections) are required by building codes or to
strengthen a wall, they are placed on the interior side of the wall and termi-
nated at the bottom of the beam or girder supported. Concrete-block walls
can be reinforced by (a) mesh or pencil rods between each horizontal joint
and (b) vertical reinforcing rods at piers, pilasters, and corners. After
placement of the vertical rods the openings in the blocks should be filled
with concrete. Basement door and window frames should be set with keys
for rigidity and to prevent air leakage (fig. 9). Block walls should be capped
with 4 inches of solid masonry or concrete reinforced with wire mesh.

Freshly laid block walls should be protected in temperatures below freezing.
Freezing of the mortar before it is set will result in low adhesion, low
strength, and joint failures.

Concrete-block walls should be calked with an elastic calking compound at
the outside joint between the footing and the wall and then coated with 1/2 inch
of Portland-cement plaster from the footings to the gradeline. A cove should
Figure 11. -- This house on stilts, with foundation posts securely fastened to deep concrete footings and good lateral bracing, remained intact in an area where most of the houses were destroyed by a hurricane. Waves washed under the house but were not high enough to damage seriously the upper structure.

Figure 12. -- Only wood posts and girders remained of what had been a warehouse before a hurricane swept through. The superstructure was completely swept off the foundation timbers because its framing had not been sufficiently tied down to withstand the high wind. The cans and bottles strewn about the foreground had been stored in the warehouse.
be formed at the juncture of the wall and footings (fig. 9). At least one coat of hot asphalt or hot tar should be applied over the plaster to provide acceptable protection from water seepage. For added protection where wet soil conditions may be encountered, a waterproof membrane of roofing felt can be mopped on, with shingle-style laps of 4 to 6 inches, over the plastic coating. Hot tar or hot asphalt can be mopped over the membrane. This covering will prevent leaks if minor cracks develop in the blocks or joints between the blocks.

Construction of Masonry Piers

Masonry or poured concrete piers are often used to support floor framing in one-story houses without basements. The minimum sizes for masonry piers are 8 by 16 or 12 by 12 inches, those for poured concrete piers 10 by 10 inches square or 12 inches in diameter. The spacing of piers should not exceed 8 feet on center under exterior wall beams and interior girders set at right angles to the floor joists, and 12 feet on center under exterior wall beams set parallel to the floor joists. Exterior wall piers should not extend above grade more than 4 times their least dimension unless supported laterally by masonry or concrete walls. The minimum height above grade should be 8 inches, and piers of hollow masonry units should be capped with at least 6 inches of solid masonry or concrete. A 12- by 12-inch hollow brick pier with a 4- by 4-inch core filled with concrete is strong and provides good anchorage for the sill anchor.

Combined Slab and Foundation

The combined slab and foundation, sometimes referred to as the thickened-edge slab, is suited to warm climates where frost penetration is not a problem and where soil conditions are especially favorable to its use. It consists of a shallow perimeter reinforced footing poured integrally with the slab (fig. 10). The bottom of the footing should be at least 1 foot below the natural gradeline and be supported on solid, unfilled, and well-drained ground.

Wood Piles

The use of wood piles may prove desirable in localities where houses are subjected to high wind and severe wave action. A house, built on piles, that withstood a hurricane with waves washing under but not reaching the main structures, is shown in figure 11.
Figure 13. -- Although this house stood on a poured concrete foundation, there was no anchorage and it was blown some 30 feet from the foundation by a tornado.

Figure 14. -- Wave action moved this unanchored house several feet off its block foundation.
Wood piles should be pressure treated with an approved preservative to prevent decay. For coal-tar creosote or creosote-coal tar solutions, the minimum net retentions should be 14 pounds per cubic foot for Douglas-fir, and 20 pounds per cubic foot for southern yellow pine, as stipulated in Federal Specification TT-W-571. Requirements of American Wood-Preservers' Association standards for penetration and treating conditions are recommended.

**Anchoring House to Foundation**

Even the most sturdily built foundation is of little use unless the superstructure is adequately anchored to it. An unanchored house has only its dead weight to resist the forces that bear against it in violent storms.

Figure 12 shows the intact wood pile-and-girder foundation of a warehouse that was demolished in a hurricane. The tie of the main structure to the wood girders had been inadequate to withstand high wind.

The house shown in figure 13 had a poured concrete foundation but no anchorage. The house was blown about 30 feet.

Wave action shifted the unanchored house shown in figure 14 several feet off its block foundation.

The house shown in figure 15 was undamaged by a hurricane because the owner had tied it down with lightweight rails set in concrete buried in the ground. The tops of the rails were fastened to the floor system with heavy straps and bolts.

**Sill-to-Foundation Anchorage**

A sill plate is a means of anchoring a frame house to a continuous masonry foundation (fig. 16). This plate should be laid level on top of a bed of mortar that has been spread across the top of the foundation to smooth off irregularities that usually develop in poured concrete.


6—Obtainable from Secretary-Treasurer, American Wood-Preservers' Association, 839 Seventeenth Street N.W., Washington 6, D.C.
Figure 15. -- The block piers of this house were reinforced with steel rails set in concrete below ground level and these were bolted to the superstructure. The house withstood a hurricane.

Figure 16. -- Method of anchoring floor system to poured concrete walls, showing bolt for wood sill.
Figure 17. -- Joist. Header joist nailed to other joists with twenty-penny nails, three to end joist and two to others. End and header joist toenailed to sill with ten-penny nails 16 inches on centers.

Figure 18. -- Studs toenailed to sole plate with two eight-penny nails on each wide face. Note: One nail on each wide face is sufficient if diagonally laid boards or plywood are used as sheathing.
Figure 19. --Metal strap anchorage of studs to sill. Strap not less than 22 gage (0.028 inch) in thickness by 1 inch wide nailed to inner and outer edges of sill with one nail, and to outer face of alternate studs with three eight penny nails. Note: Such anchorage is not needed if diagonally laid boards or plywood are used as wall sheathing and nailed as shown in figure 21 or figure 22.

Figure 20. --Although lifted off its foundation by wave action, this house showed little distortion from hurricane winds because of the excellent tie to wall and floor framing provided by its diagonal sheathing.
Table 1.--Comparison of the rigidity and maximum loads for various types of stud-to-sill connections fabricated of nominal 2 by 4 Douglas-fir lumber. The straps and gusset were made from 24-gage galvanized metal. The straps were 1 inch wide, and the gusset at base was 5 inches wide.

<table>
<thead>
<tr>
<th>Joint Construction</th>
<th>Uplift Percent</th>
<th>Side Thrust Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UPLIFT</strong></td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>THRUST</strong></td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Four eightpenny common nails, two toenailed on each wide face. Nails were started 3/4 to 7/8 inch from end of stud and driven at a 30° angle with stud.

Two sixteenpenny common nails driven through 2 by 4 plate member into stud.

Stud toenailed to sill with two eightpenny nails. Metal strap attached to narrow face of stud with three eightpenny nails and one eightpenny nail in each narrow face of sill.

Stud toenailed to sill with two eightpenny nails. Gusset attached to narrow faces of stud and sill with three eightpenny nails.

| | 240 | 510 | 70 | 170 |
| | 90 | 220 | 70 | 120 |
Figure 21.--Wood sheathing installed diagonally (right) gives an excellent tie of walls to the floor system. Wood installed horizontally (left) gives a very inefficient tie. The two types of sheathing shown here for illustration would not be combined in any one building.

Figure 22.--Plywood wall sheathing. Plywood less than 1/2 inch thick is nailed with sixpenny nails spaced 5 inches on centers along edges and 10 inches on intermediate framing members. Plywood at least 1/2 inch thick is nailed with eightpenny nails at same spacings. Vertical joints between plywood sheets should not be on the same stud or joist in succeeding rows of sheathing. For the horizontal joints, nailing strips are set between the studs and nailed to them.
The plate is anchored to the foundation with 1/2-inch bolts spaced 6 to 8 feet apart; at least 2 bolts are used for each sill piece. Anchor bolts should be embedded at least 6 inches deep in poured concrete and at least 15 inches deep in concrete-block walls. A large, flat washer is placed in the mortar joint between block courses to fix the end of the bolt firmly. Bolt holes of the same diameter as the anchor bolts should be accurately spaced in the sill plate to assure a snug, tight fit when it is laid in place. If termite shields are to be used, they should be installed before the mortar bed is laid.

**Joist-to-Sill Anchorage**

It is just as essential that the joists of the house be tied to the sill plate as it is that the plate be anchored to the foundation. An adequate tie can be obtained with tenpenny nails driven slantwise at a 30-degree angle through the joist into the sill (fig. 17), and spaced 16 inches apart around the perimeter of the house. Where driven through headers, these nails should be spaced about midway between the joists that butt against the header. Headers should be nailed to end joists with three twentypenny nails and to intermediate joists with two twentypenny nails (fig. 17).

**Stud to Sole Plate**

Inadequate fastening of stud to sole plate is often the cause of failure from high winds. Studs are usually fastened to sole plates with two eightpenny nails on each wide face as shown in figure 18.

If more secure anchorage is desired, metal strapping as shown in figure 19 may be used. The relative merits of other methods of attaching studs to plates are shown in table 1. Commercial framing anchors of 18-gage zinc-coated sheet steel are also available for this purpose.

**Sheathing**

Diagonal wood sheathing or plywood sheathing helps to tie the walls to the floor system or the sill plate if it is extended over the outer edges of the joists or sole plate and nailed to them. Figure 20 shows diagonal wood sheathing extending to the foundation wall, and figure 21 shows how diagonal wood sheathing can be attached to obtain this desirable tie. Figure 22 shows how plywood sheathing can be placed and nailed to obtain an excellent tie between wall and floor system.
Figure 23. -- Roof of house at left severely damaged because of insufficient fastening to side walls.

Figure 24. -- Rafters (beveled or notched) and ceiling joist resting on wall plate. a. Five ten-penny nails through joist into rafter (or through rafter into joist). b. Overlap of joists at bearing partition nailed with five ten-penny nails. c. Joist and rafter toenailed to plate with four ten-penny nails, two on each side of assembly. Additional security against uplift is afforded by metal straps placed as shown and nailed with four eight-penny nails to studs and with two eight-penny nails to upper edges of joist.
Figure 25. -- Rafter nailing. This is a suggested framing that provides superior resistance to the forces to which rafters are subjected and, with the addition of the rafter tie or collar beam shown in figure 26, affords a very secure arrangement. The weight of the roof is carried by the plate with the rafter placed directly above the stud.  

a. Rafter toenailed to plate with one tenpenny nail. Five tenpenny nails join, b, rafter and joist, c, joist and stud, and, d, overlap of joists. Note: Thrust is resisted by the connection of rafter to joist, and the nailing of the joist to the stud gives resistance to uplift. Ribbon may be let into either the outer or the inner edge of stud.

Figure 26. -- Roof peak.  

a. Ridge nailed to first rafter of pair with two nails (tenpenny for 1-inch ridge or sixteenpenny for 2-inch ridge).  

b. Second rafter of pair nailed through its top edge to ridge with one tenpenny nail and toenailed to ridge with one tenpenny nail.  

c. Rafter tie or collar beam placed near peak and nailed to each rafter with four tenpenny nails. Such a rafter tie is desirable to resist the spreading tendency resulting from wind action, whether or not a ridge is used.
Figure 27. -- Damage to brittle composition shingles caused by flying debris during an extremely high wind.

Figure 28. -- This roof illustrates what can happen during high wind to asphalt shingles that are not tacked down with adhesives near the exposed edges.
Table 2.—Comparison of the rigidity and maximum loads for various types of rafter-to-plate connections. The test members were fabricated of nominal 2 by 4 and 2 by 6 Douglas-fir lumber. The straps were made from 20-gage galvanized metal 1 inch wide.

<table>
<thead>
<tr>
<th>Joint Construction</th>
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<th>Thrust</th>
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<tbody>
<tr>
<td></td>
<td>Relative</td>
<td>Relative</td>
</tr>
<tr>
<td></td>
<td>rigidity</td>
<td>maximum</td>
</tr>
<tr>
<td>Six tenpenny nails.</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Two nails toenailed into top of plate and one into narrow edge of top plate on each wide face of rafter.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rafter toenailed to wide face of upper plate with two tenpenny nails. One metal strap attached to each face of rafter and stud with six fourpenny nails.</td>
<td>50</td>
<td>140</td>
</tr>
<tr>
<td>Rafter toenailed to wide face of upper plate with two tenpenny nails. Metal strap 21 inches long nailed to rafter, plate, and stud with fourpenny nails as shown.</td>
<td>40</td>
<td>110</td>
</tr>
<tr>
<td>Twenty-four-inch strap nailed to each face of notch with two tenpenny nails and to each narrow face of stud, and to interior face of each plate with fourpenny nails as shown.</td>
<td>25</td>
<td>95</td>
</tr>
</tbody>
</table>
Figure 29. -- Metal roofing was rolled back during a hurricane.

Figure 30. -- Well-constructed houses (left) give a good account of themselves in storm areas, and poorly constructed houses (right) regardless of the material used, give a poor account.
Roof System

High winds frequently severely damage roofs and necessitate a good tie of roof to side walls. Figure 23 illustrates damage to a house that resulted because the roof was inadequately fastened to the walls.

A good tie of rafter and ceiling joists to wall plates is illustrated in figure 24, and a better tie of roof to wall is illustrated in figure 25. The peak of the roof, too, should be well tied. One method of obtaining this tie is shown in figure 26. Other methods of connecting rafters to plates are compared in table 2.

Exterior Wall Coverings

Hurricane propelled debris may severely damage all types of exterior wall coverings. Repair costs, though less than those for major structural damages, may be considerable (fig. 27).

Roof Covering

Practically all types of roof coverings, such as shingles and sheet metal, are susceptible to damage from exceedingly high winds (figs. 28 and 29). Adhesives near the exposed edges or wind seals on asphalt shingles are helpful in preventing breakage caused by flapping and bending during high winds. Regardless of type of roofing, it is obvious that proper attachment is a most important factor in eliminating or minimizing damage by high winds.

Conclusion

Observations have shown that well-constructed houses give a good account of themselves in hurricane and flood areas. And poorly constructed buildings, regardless of the material used, are the principal source of loss in storm areas, figure 30.
Forest Utilization Research representatives can be reached at the following Forest Service Experiment Stations:

California Forest & Range Experiment Station  
P. O. Box 245  
Berkeley 1, California

Pacific Northwest Forest & Range Experiment Station  
729 N. E. Oregon Street  
P. O. Box 4059  
Portland 8, Oregon

Central States Forest Experiment Station  
111 Old Federal Building  
Columbus 15, Ohio

Rocky Mountain Forest & Range Experiment Station  
221 Forestry Building  
Colorado A & M College  
Fort Collins, Colorado

Intermountain Forest & Range Experiment Station  
Forest Service Building  
25th Street and Adams Avenue  
Ogden, Utah

Southeastern Forest & Range Experiment Station  
225 Federal Building  
P. O. Box 2570  
Asheville, North Carolina

Northeastern Forest Experiment Station  
102 Motors Avenue  
Upper Darby, Pennsylvania

Southern Forest & Range Experiment Station  
704 Lowich Building  
2026 St. Charles Avenue  
New Orleans 13, Louisiana

FOREST SERVICE EXPERIMENT STATIONS  
AND FOREST PRODUCTS LABORATORY

[Map of the United States indicating locations of the forest experiment stations and forest products laboratory.]