FOUNDATIONS AND BREAKAWAY WALLS OF SMALL COASTAL BUILDINGS IN HURRICANE HUGO

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ABSTRACT

After Hurricane Hugo a survey of damage to small, coastal buildings was conducted in North and South Carolina. The performance of elevated foundations, breakaway walls and foundation cross bracing was assessed. Adequately imbedded piling foundations were generally effective. Masonry and cast-in-place concrete foundations revealed major construction flaws and experienced widespread failures. Existing practices of constructing cross bracing and breakaway walls were found to have substantial weaknesses but their failure caused only isolated structural damage. Modified construction practices are suggested. Highly elevated, masonry foundations with shallow footings experienced widespread failures and were found to be inappropriate in coastal flooding.

HURRICANE HUGO

The hurricane made landfall on September 22, 1989 affecting the Atlantic coastline from Folly Beach, S.C., just south of Charleston, to Cape Fear in North Carolina. Approximately 150 miles of shoreline was seriously affected. Wind speed, flood elevation and erosion varied throughout the study area. The worst winds and flooding occurred along the sparsely developed marsh shoreline around Bulls Bay, S.C. Most of the developed beach communities received conditions equal to or less severe than design conditions, often substantially lower. Due to low pre-storm ground elevations, the vertical loss of soil under existing buildings was relatively low, seldom over 6 feet and often only 2 or 3 feet. The depth of erosion was occasionally greater when seawalls or other erosion control structures failed.

BREAKAWAY WALLS

Background: Breakaway walls are commonly used to enclose underhouse areas of elevated buildings. The walls are designed to collapse from flood or wave forces prior to causing damage to the foundation or the rest of the elevated building. The National Flood Insurance Program (NFIP) has funded research and adopted regulations on such construction. It is required that the walls be designed to collapse at substantially lower loads than required for winds forces in most building codes. Normal wall panels may be constructed but only a few widely-spaced connections to the foundation are allowed.

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__Observations:__ Breakaway walls consistently collapsed under even shallow flooding and small waves regardless of the design of the wall, or the strength of the connections to the foundation. Damage directly to the foundation was minimal in almost all cases. Damage to the elevated building was more common but was not affected by the strength or number of connections to the foundation or elevated building.

Even though the stronger connections did not cause damage as expected, there were other causes of damage in a significant number of buildings. Damage commonly resulted from utilities imbedded in the walls, even though the plumbing or electrical wiring may have been located above the design flood elevations. When the walls failed, the imbedded utilities created surprisingly strong connections between collapsed wall panels and elevated building above. The breakaway wall therefore caused expensive wiring and plumbing damage in the rest of the building. The intended function of breakaway walls, failing without damaging the elevated building, was frequently not successful when the walls included underhouse utilities.

In addition, construction materials used to enclose the floor joists for protection of floor insulation and utilities of elevated buildings are often selected as an interior ceiling rather than a storm exposed floor. Moisture and wind sensitive sheathing was damaged or collapsed resulting in unnecessary water, insulation and utility damage.

__Suggestions:__ The hurricane re-emphasized that in small buildings, **ANY WALL THAT GETS HIT BY A WAVE IS A BREAKAWAY WALL.** Wood frame and masonry walls consistently collapse in small waves regardless of the strength of commonly used connections. The benefits of the NFIP regulations do not justify the added construction and code enforcement efforts required to insure a weakly connected wall.

Specifications for breakaway walls are best defined by purpose rather than by a specific load limit required for collapse. A breakaway wall should be designed to collapse due to flood or wave forces without causing damage to the foundation or elevated building. Most construction methods in general use for small buildings are also acceptable for breakaway designs. Unusually strong connections (such as bolts and plywood overlaps) to the foundation or elevated building should be avoided. The building should be constructed and materials selected as if the underhouse was to remain open. Utilities, plumbing and electrical service below the elevated floor should be limited to the minimum necessary to supply the building above. If utilities are required within the underhouse enclosure they should be restricted to the ceiling, avoiding service within the breakaway walls.

FOUNDATION CROSS BRACING

<u>Background:</u> Piling foundations are commonly used along the coast to elevate small buildings above anticipated flooding and storm waves. Cross bracing or X-bracing is used between the pilings to create stiffer, stronger foundations. The bracing redistributes wind and water forces over the exposed length of each piling. It improves lateral resistance over unbraced pilings by preventing rotation at the top of each pile. If one or more of the pilings is undermined or damaged the bracing can spread the extra load more evenly to the rest of the foundation.

Elevated buildings are more prone to sway in moderate, gusty winds to the point of personal discomfort (i.e. seasickness). This can occur even though the building is adequately designed to resist much more severe storm conditions. Flexibility is not necessarily a sign of weakness but it can still be uncomfortable. Cross bracing is often used to stiffen foundations but is not necessary for storm resistance.

In exchange for these benefits, underhouse bracing requires certain tradeoffs. Braces are usually attached by holes through the pilings, at least marginally weakening each pile. A more serious problem is the added surface area of the foundation likely to be impacted by storm waves and surge. In some cases extensive bracing can more than double the wave forces on the building. It had been previously observed that wooden cross bracing can be severely damaged by relatively small waves.

<u>Observation:</u> Cross bracing was found to be unreliable in conditions less severe than anticipated in normal designs. Wooden bracing, 2 to 3 inches thick and 6 to 12 inches wide, frequently broke. As expected, bracing parallel to the shoreline was damaged most often since it is more likely to receive the full force of a wave. Some bracing perpendicular to the shoreline also failed. The most common point of failure was around the bolted connection at each piling. The centers of the brace, simply overloaded by lateral wave forces, also failed.

Cross bracing can also be constructed with steel rods, threaded on each end to be anchored through adjacent piles. Surprisingly, steel rods up to 1/2 inch in diameter were also unreliable. The surface area of the rods was thought to be too small to be affected by waves, avoiding the high forces common with larger wood bracing. But the rods are apparently highly susceptible to damage from floating debris. Lateral loading bends the rods inward, overloading the fasteners tensioning each end of the rod at the pile. The failure on wooden pilings commonly occurred as the fasteners were imbedded deeper into the foundation pile even when the pile was appropriately notched and large washers were used under the nuts to distribute the load. To provide any useful bracing the rod must be under tension between the pilings. Once the fasteners were imbedded in the pile, the rod was no longer under tension and served no useful purpose. Rods larger than 1/2 inch were generally not used and could not be evaluated.

It was common to find several wooden braces on the same building broken but most in place. But when any steel rods were bent generally most of the bracing under the building had similar problems. Therefore rods were provided less reliable for the foundation than wood braces. Although both wood and steel rods were unreliable in cross bracing, none of the failures caused any significant damage to the foundation or elevated building. Observations of a variety of buildings, from single story homes to three story condominiums indicate that the bracing appears to have been unnecessary to survive the conditions received during Hugo.

Suggestions: In coastal areas subject to storm waves, avoid the use of underhouse bracing to resist design conditions whenever possible. Wave and floating debris damage make them unreliable in coastal buildings. When additional foundation strength is required consider alternatives such as: 1) larger diameter and longer piles, 2) more piles in the foundation, 3) structural decks to widen the footprint of the building and spread the lateral loads to more piles or 4) batter piles sloped at a slight angle around the perimeter of the building enlarging the foundation footprint and resisting the lateral forces in compression rather than only in bending. If the building requires added stiffness for personal comfort in gusty winds, cross bracing can be used effectively but should be considered expendable in extreme storm conditions.

ELEVATED FOUNDATIONS

Background: In many coastal areas buildings are elevated above minimum flood elevations on piling foundations. But in coastal South Carolina many buildings have been elevated on masonry piers.

Observations: Wood and prestressed concrete piling foundations consistently performed well as long they were adequately imbedded and the floor joists were located above any wave activity. No building meeting those two criteria had major structural failures caused by flooding, waves or erosion.

Two piles in separate buildings were found broken after Hugo. A round wood pile had broken approximately three feet below the original ground elevation. The fracture appeared to have occurred when originally driven into place. Even with the damaged pile, the building appeared to be unaffected by Hugo. A prestressed concrete pile under a three story condominium was fractured during the hurricane when a heavy wood retaining wall was pushed landward by waves, impacting the pile just above the ground elevation. The pile remained in column and the building appeared to be unaffected.

As previously indicated, underhouse cross bracing frequently failed but the piling foundation and elevated building remained stable. The success of foundations with damaged bracing and those constructed without bracing during Hurricane Hugo suggests that the lateral strength of wood piles and/or the lateral soil resistance of all types of piles in sandy soils, typical of many coastal shorelines, is significantly underestimated. The foundations appear to consistently survive conditions where, based on standard design calculations, damage would have been anticipated. This implies much less need for cross bracing than is indicated by present design methods.

In isolated cases, piles failed due to wood decay. Rotting had occurred within one foot above and below the original ground elevation and should have been visible prior to the storm. Several feet of erosion exposed the damage and in several cases led to fractured piles. Problems were commonly found in buildings 15 to 20 years old and constructed on square piles. If one bad pile was found, generally all piles in the building showed signs of decay. Many seemingly identical piles in other older buildings were undamaged. The decayed piles probably received substandard preservative treatment prior to construction.

In inland areas, a common method to increase the bearing capacity and lateral resistance of shallow pilings is to encase the pile in a concrete collar just below the ground elevation. The method works well in stable soils. The method, however, resulted in the total loss of a number on oceanfront buildings. The collars around shallowly embedded piles provide adequate support for small buildings in calm conditions but are highly susceptible to collapse when erosion exceeds the shallow imbedment. The collars also significantly increase the surface area of the foundation exposed to the waves and therefore increase the wave forces affecting the building. Localized wave scour around the base of a pile has been shown to be directly related to the diameter of the pile. Since the collars can more than triple the effective diameter of each pile these shallow foundations are even more likely to be undermined.

<u>Suggestions:</u> The continued use of piling foundations is encouraged in coastal locations subject to storm waves and erosion. The piles should be imbedded deep enough to remain stable under both storm-induced and long-term erosion losses. The pilings must elevate the rest of the building above any wave activity or severe damage will result. All wood piles should be adequately treated to resist decay. Look for preservative grade marks or get written confirmation from the supplier. The use of

concrete collars should be avoided at any location that is even remotely prone to erosion.

MASONRY AND CONCRETE COLUMNS

<u>Background:</u> Along the South Carolina coast, the most common method of elevating small buildings is the use of concrete block columns on shallowly imbedded concrete pad footings. Failure of these foundations appeared to be the most common cause of total building collapses along the coast and also resulted in isolated collapses, due to wind, farther inland.

A concrete footing two to three feet square is poured one foot below the existing ground elevation. Square concrete blocks, 16 inches on each side and 8 inches tall are laid to make a column eight to ten feet tall. The hollow center of the column is filled with concrete after several steel reinforcing rods are added.

Cast-in-place concrete columns were also used to elevate buildings. Shallow concrete footings supported steel reinforced columns cast in 6 inch diameter tubes.

<u>Observations:</u> Quality control in this type of construction was consistently very poor. In the worst cases the concrete and reinforcing were completely omitted, supporting the building on hollow masonry. In other buildings the concrete was in place but the reinforcing was omitted. The majority of columns inspected had too little and poorly-placed steel reinforcing. One or two small-diameter rods were often either grouped together near the center or placed against the masonry. General construction practice apparently made no effort to properly place the rods where they might actually do some good.

The worst weakness of the masonry columns proved to be the shallow imbedment of the footings in oceanfront buildings. Several hundred buildings were destroyed or severely damaged when the concrete pads were undermined. Even though erosion depths in most areas were mild when compared to storms in other areas, the columns collapsed with less than 2 feet of erosion under the building. Fortunately the columns were poorly connected to elevated floor beams and usually detached when undermined. Ironically, if the columns had remained attached their heavy weight would have quickly split the building or overloaded the rest of the foundation. In a surprisingly large number of cases the building remained supported on more landward columns that had not yet been undermined.

Column failures also occurred at locations sheltered from waves and erosion. Wind speeds at or below design levels apparently created lateral loads sufficient to fracture the columns at a mortared joint or rotate the foundation at the footing until the building collapsed. As would be expected the hollow block and un-reinforced columns were most likely to be damaged.

Cast-in-place concrete columns also received severe damage. Quality control in construction was even worse than with masonry. Reinforcing was consistently placed against the outside of the forms leaving it exposed when the forms were removed and of no structural benefit. Shallowly imbedded steel was found to be completely corroded. Large voids were left in the concrete due to poor casting. Even if the cast-in-place columns had been properly constructed their narrow diameter was probably inadequate to resist wind loads on the building.

Most of the foundations that failed did not appear to be designed by a professional designer. However architects and engineers did design the foundations of several of the more expensive small buildings that were damaged. In those cases quality control was much better. Reinforcing and connections were properly constructed but no provision for erosion around the shallow footing was considered in oceanfront buildings.

Suggestions: The use of shallowly imbedded masonry or narrow concrete columns to elevate buildings 8 to 10 feet above grade is inappropriate at any location subject to erosion, storm surge or waves. Their use in more sheltered areas should only be considered if properly engineered, constructed with careful quality control and preferably limited to much lower elevated buildings.

CONCLUSIONS

The coastal damage caused by Hurricane Hugo revealed few surprises. The construction methods expected to do well survived in some of the worst storm conditions. The buildings destroyed or severely damaged were expected to be damaged. If there was any surprise it would be that for every poorly constructed building that failed there were 5 to 10 equally damage prone buildings nearby. In many areas if the conditions had been only slightly worse or if the storm had lasted slightly longer the level of damage along the developed beaches could have been much higher.

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