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**WATER AND EROSION DAMAGE TO COASTAL  
STRUCTURES – SOUTH CAROLINA COAST,  
HURRICANE HUGO, 1989**

by

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ABSTRACT

Hurricane Hugo hit U.S. Mainland on September 21, 1989 just north of Charleston, South Carolina. It was billed as the most costly hurricane on record. The loss on the mainland alone exceeded 7 billion dollars, more than 15,000 homes were destroyed and the loss of lives exceeded forty.

This article documents one aspect of the multi-destructions caused by the hurricane - the water and erosion damage on water front or near water front properties. A general damage survey was given first, followed by assessment on the performance of various engineered and non-engineering structures, on the major factors contributing to failures. Conclusions were then drawn with recommendations for future improvement.

INTRODUCTION

One of the facets that sets Hugo apart from other hurricanes in recent years was its severity of inflicting water damages on coastal constructions. It could easily be ranked one of the worst, comparable to Hurricane Camille in 1969 which was the only category 5 hurricane that hit U.S. mainland (along the low land region of Louisiana and Mississippi) with full force in this century. A number of factors contributed to the great destruction:

1. The extremely high storm surge level, second only to Hurricane Camille in the history.
2. The high density of old structures constructed before adequate building code and code enforcement.
3. The high chronicle background erosion along these barrier islands (approximately 6' per year).

Damage reconnaissance was carried out at selected locations from Seabrook Island to North Myrtle Beach, an arc of about 120 miles coastal belt affected by Hugo.

Based upon visual inspection, the severity of water damages was subjectively determined, shown graphically in Figure 1.

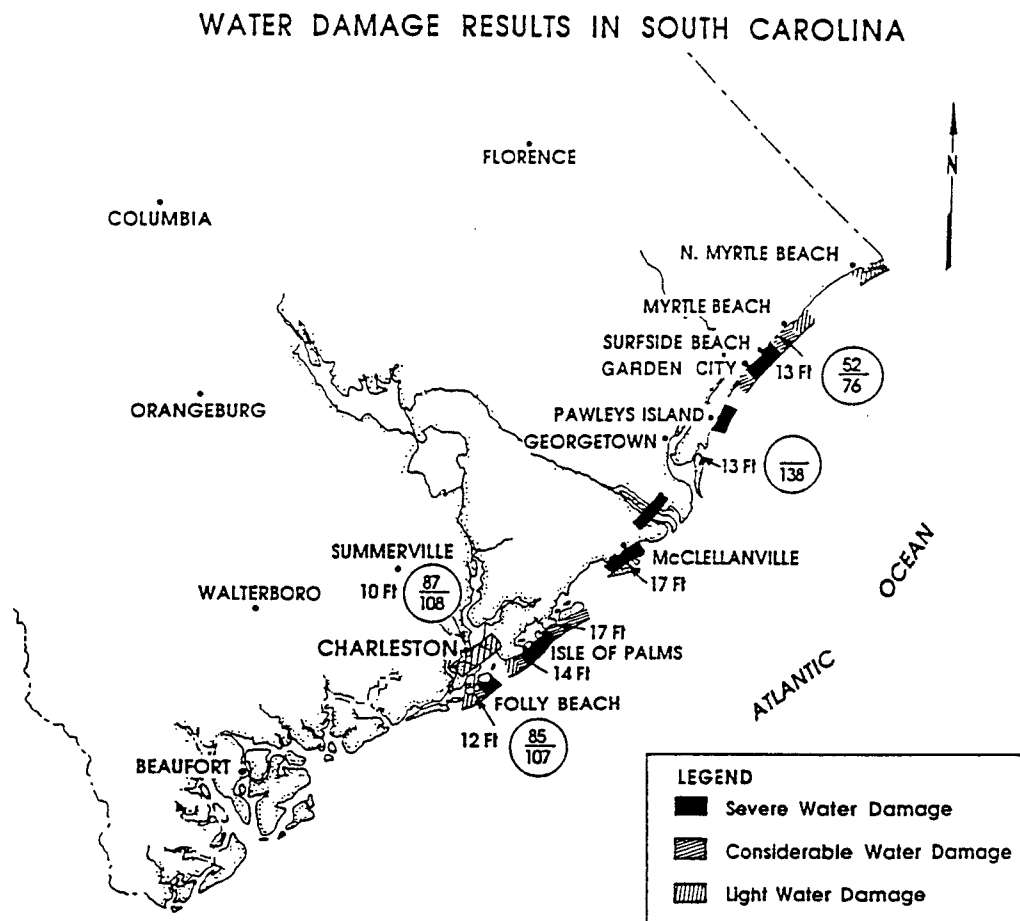


Figure 1: A General Assessment of Water Damages Along Coastal Region Under the Influence of Hugo (Surge and Wind Information From Federal Insurance Administration, 1989).

Table 1 tabulates the percentage of destructed beach front structures along the barrier coast. The destructed structure is defined as the structural damage is greater than 66.67%.

Table 1 Percentage of Destructed Beach Front Structures

Surfside	7%
Garden City	43%
Pawleys Island	23%
Folleys	20%
Others	7%

\* Source of Information, South Carolina Coastal Council

The descriptions of these damages are given in the following sections.

## NARRATIVES

### Seabrook Island

The heavily developed portion of this island is a planned resort community of town houses and multi-unit condominiums. The Island is obviously under erosional stress and portion of it is heavily armored with newly placed revetment. Both wind and water damages were light. Structure damages were limited to a few broken windows, missing roof shingles and up-rooted chimneys. The revetment structure showed differential settlement at a few locations with torn filters, thus, exposing the bank soil.

The damage was light in despite of its exposed location. This was mainly because the Island is located at the southern fringe of the Hurricane path. The storm surge never reached the structures. Wave overtopping was also minimal.

### Folly Beach

Folly Beach is on the barrier island south of Charleston. It is mainly a residential community. The only substantial commercial building fronting the beach is the Holiday Inn at the middle section of the island. The beach is under very heavy erosional stress for lack of sand supply from the north. In fact, part of the street system, West Arctic Avenue, crumbled into the sea within the last decade. A restaurant built 20 years ago on Arctic Ave was hanging over water before Hurricane Hugo and it was subsequently completely demolished by the Hurricane. Many houses on the west side of the town still have addresses of West Arctic street that no longer existed. The beach is narrow and low and is almost entirely covered with groins and revetment of marginal quality.

The measured storm surge levels were around 12 feet, slightly lower towards the two ends. The east and central sections of the island sustained severe water damage. Many single family homes fronting the beach were completely destroyed. First floor flooding was common in the second tier and to a much less extent in the third row and beyond. Damages due to dynamic force and static buoyancy were both evident as some structures were crushed and the others were simply floated off their foundation. The most devastated section was between West

2nd Street and West 7th Street. This was because many old structures built 20 years ago were clustered in this section. This section was also eroded heavily in the past years and, as mentioned earlier, had lost roads to the ocean. Amid this devastation, however, well constructed dwellings did survive and survived well. The house shown in Figure 2, for instance, escaped with hardly any visible damage among a row of completely destroyed houses.



Figure 2: A Concrete Residential Structure on Folly Island Survived With No Damage Amongst Heavy Destructions.

It is a frame structure with four concrete columns seated on four 14" square piles. By discussing with the design architect and the County building inspector, it is concluded that this structure fared so well for a number of reasons:

1. Sufficient elevation (bottom of support beam at elv.15 feet MWL).
2. Deep and strong pilings (22 feet plus 5 feet tip).
3. Simple and strong connections.
4. Low profile and low roof line.
5. Very rigid main columns.

Further west of West 7th Street, the water damage became progressively lighter but noticeable. The structures in this section were usually newer with higher elevation and better construction. The west end of Folly Beach is the County Park where only wind damage was noticeable.

The Holiday Inn is the only substantial commercial building along the open coast. It is a relatively new construction, built about 5 years ago. The building is at an exposed location with receding shorelines on both sides. The front is protected by a retaining wall and heavy revetment. The building, nevertheless, sustained heavy water damage. Practically all the ground floor facilities were destroyed (Figure 3).

Erosion behind the retaining wall was significant, causing concrete deck to collapse and undermining the swimming pool. The seawall cap was partially destroyed due to wave impact. The water damage was certainly heavier than one would expect for structures of this type built in such a recent date. A number of contributing factors are listed here:

1. The elevations of the structure as well as the protective seawall are inadequate for the surge level.
2. There is no fronting beach to dissipate wave energy, causing heavy wave runup and overtopping.
3. The structure protrudes beyond the adjacent shorelines and there is no return wall to protect its flanks.



Figure 3: Photo Shown Water Damages to the Ground Level Units and Water Front Amenity Facilities at Holiday Inn, Folly Island, a Typical Damage Mode Among High Rise Hotels and Condominiums.

#### Charleston and its Vicinity

City of Charleston and its surrounding areas including Mt. Pleasant and James Island, water damage to structures related to flooding was minor compared with wind related damage (including rain water damage due to broken windows and open roofs. The battery along the southern tip of town provided adequate protection of city streets and river front buildings. Hurricane Hugo was a relatively dry hurricane; heavy rain fall did not occur until two days later. Thus, river flooding was not a major factor. High water level in the creeks, intercoastal water ways and rivers combined with high wind did cause extensive boat damages. Numerous boats were thrown off water landed on shore and streets.

#### Sullivan's Island and Isle of Palms

Sullivan's Island and Isle of Palms belong to the same barrier island chain separated by Breach Inlet. They have a combined length of about 11 miles with the major axis oriented in the east-west direction. The only access to the mainland is Highway 703 via Ben Sawyer Memorial Bridge. This bridge has a rotating section in the center span for boat traffic. This section was severely damaged by wind during Hurricane Hugo that the bridge was closed for more than 10 days.

On Sullivan's Island, the storm surge level was estimated to be about 13 feet above mean sea level whereas on Isle of Palms, the level was about two feet higher reaching 15 feet. The all over water damage was extensive on both islands but the spacial distribution was rather uneven. As the dominant wind direction at the height of the hurricane was northeasterly the damage was less severe on the western end of Sullivan's Island. This section was also benefited by the wide beach. The sand overwash onto the streets was substantial. The damage east of 703 was very extensive and became progressively worse towards the Breach Inlet. Older houses on Marshall Blvd. were practically all destructed, some crushed by waves and the others floated off their foundation. These older houses were mostly constructed on shallow piles, piers or slabs with elevation around 12 feet or less. After the Hurricane, many of the damaged houses were raised to 14 feet or higher. A significant number of houses on the second row across the Marshal were also have to be condemned due to water damage. The bridge across the Breach Inlet sustained erosion at the west end but the bridge was not threatened. The jetties fared well.

Some of the newer constructions with adequate elevations and pilings did survive even at very exposed locations east of 29th Street. The types of damages typical to new constructions are:

1. Erosion and scouring causing decks, pools and slabs to collapse.
2. Deck structures with access ladders or ramps to the beach front. These type of structures would invariably collapse, slamming onto the main structure, causing extensive damage.

On Isle of Palms, severe damages were concentrated in two regions; one was in the commercial strip between 10th Avenue and 14th Avenue and the other was east of 42nd Avenue to 57th Avenue. The sections west of 9th and between 14th and 42nd, the damage was less severe. This appeared to be directly related to the beach width in front of the structures.

The Sea Cabin Condominiums at Ocean Blvd. and 14th Avenue sustained heavy water damage. The entire complex was prefabricated modular units seated on pile foundation. The ground units and the end unit were completely damaged. Inadequate elevation and poor structural member connections were the main reasons of failure. Two structures on the exposed Ocean Blvd. (#126 and #912) stood out with little visible damage, wind or water (Figure 4 shows the post storm condition of #912).



Figure 4: A Well  
Constructed Pile Supported  
(Wooden) Frame Residential  
Structure On Isle of Palm  
Fared Very Well Even In An  
Exposed Location.



Both structures were built by the same builder and the constructions appeared to exceed the current building code requirement. Class "B" piles (12" Dia. from butt in and 14" Dia. above ground) with 3/4" steel diagonal bracings were used. Frames were connected throughout with 1/2" and 3/4" plywood using #16 Galvanized penny nails at 4" intervals around corners to insure shear rigidity. Hurricane clips were properly installed at critical connection points around roof frame and at pile-beam junctions. Roof tiles were nailed properly to 5/8" roof plywood. Ridge vent was installed to relief pressure difference. As a consequence, only a minimal number of roof tiles were missing, uncharacteristic to the general extensive roof damages in this region. Members that are subject to lift force were connected by galvanized screws instead of nails.

Between 14th Avenue and 41st Avenue, there is no spur road south of Hwy. 703. Therefore, all the structures were set way back from the water line with exceptionally wide beach and dunes. Water damage to houses has been minimal in this reach. Washover over highway was evident.

East of 42nd Avenue, roads perpendicular to Hwy. 703 extend to the south close to the beach. Houses at the end, sometimes to second and third rows were mostly devastated due to the combined effects of high surge level and the close distance to the open water. Unlike some of the devastated areas mentioned earlier, most of the houses here were up-scale newer structures. Damages were mainly due to the dynamic forces as oppose to flooding. This section provided a classic example of diminishing damage as a function of increasing distance to the shoreline. On the 50th Avenue, there were 5

houses in a row. The first two were completely leveled to the ground; the third, and fourth houses sustained progressively less damage, some due to the debris of the destructed houses, and the fifth house which was the farthestmost from the shore had no evident water damage.

At the eastern tip of Isle of Palms is the Wild Dune luxurious condominium complex and the only high rise community on the island. Water damage was limited to washed away walk ways, local scourings near foundation and ground level utilities. Since this area bore the front assault of hurricane winds, tree, roof, window and chimney damages were extensive.

#### McClellanville and Vicinity

McClellanville is a fishing village dominated by modest wood frame houses. Mobile homes are also common in this region. Since the estimated landfall of the hurricane center was Bulls Bay just south of the town the storm surge was the highest reaching 20 feet or higher. Water damage was very extensive. Unlike on the barrier island, however, damage was mainly due to flooding.

#### Northern Coast of South Carolina

The northern coast known as the "Grand Strand" area has developed rapidly in recent years. Non conformity structures also flourished. Until the last two years or so, building code enforcement was rather lax and relied on individual communities. Now, Horry County which has the jurisdiction over most of the affected areas has adopted the Southern Standard Building Code and is intended to strengthen the enforcement and inspection procedures.

Pawleys Island is a relatively old residential community. Houses are very closely spaced. Quality of construction, in general, was marginal at best. The storm surge level was about 13 feet. Beach was very narrow during post hurricane survey. Emergency measure was taken by trucking sand from the south end near North Inlet to repair the beach on the north. Water damage was very severe due to the combined factors stated above.

Garden City is also primarily a residential community with a few condominiums and a controlled-access planned community at the south end. The main thoroughfare is the Waccamaw Ave which is also the first street parallel to the beach. The road surface is about 8 to 11 feet above MSL. The measured storm surge was about 13 feet. However, local residence claimed the water level to be much higher along the coastal front of over 20 feet. Salt spray was estimated to reach 200 to 300 feet right

after the passage of the Hurricane. This was the first observation of this kind and was based on the observation of Mr. Carlos Fredes who is also a county building official and lives on the island. He made his estimate on the mist level on a transmitting tower that has a string of stroboscopic lights.

The water damage and the sand washover were among the worst of all the areas inspected. Water damages due to flooding can be traced as far back as 1500 feet, or four or five rows deep from the first street; the sand washover was measured to top 1 foot on the second row of houses (north of Waccamaw Avenue see Figure 5). Right after the hurricane, debris were piled 20 feet high at intersections, made passage to the second row impossible from either side.



Figure 5: Sand Washover on Second Row of Houses (North of Waccamaw Avenue, Garden City).

On the north end of Garden City, south of Atlantic Avenue, the destructions on the first row were almost total for a stretch of 4 or 5 blocks. Complete destructions on second row were also common in this reach. Two fishing piers, each 1000 feet long also disappeared completely. Most of the structures here, commercial or residential, were constructed 10 years ago, some more than 20 or 30 years old. Most of them were on shallow pier footings and some were on slabs. Judging by the total crushing pattern and by the form of pier breakage, waves might have overtopped the structures.

The water damages were still very heavy south from this location till the Waccamaw Avenue took a dog-lagged turn

towards the north. In this reach, the constructions were a mixture of old and new. Some of the old ones were constructed about 20 years ago and the new ones were from 5 to 1 years old. Like the north reach, the old structures were practically wiped out completely. The new ones, particularly those built within the last two years, appeared to have largely survived with varying degrees of damage. However, not all the new constructions made it. A concrete two story structures built 5 years ago by an architect collapsed completely (Figure 6). This structure had heavy reinforced concrete roof beams and precasted concrete walls. But it was supported by cinder-block piers and bearing walls on a poured shallow footing. Waves must have hit the structure causing the concrete front walls to collapse and the piers on the back to buckle. This concrete structure indeed provided a drastic contrast to the concrete structure on Folly Beach discussed earlier.



Figure 6: A Two Story Concrete Residential Structure Collapsed Under Its Own Weight Due to Weak Foundation (Garden City).



The loss of beach and scouring around foundations were also among the severest we have witnessed along the entire coast affected by Hugo. Beach loss up to 6 feet of sand around structural piles were common. An additional 1 to 1 1/2 feet of scouring were measured around some large piles.

Further south on Waccamaw Avenue, water damage became considerably lighter. South of #336 (the junction of a dog-legged turn), only three houses were destroyed. The houses are all newer here. The beach is also wider than north because of the dog-legged turn towards inland.

Surfside is connected to the Garden City on the north. Unlike Garden City, it is full of commercial structures along the beach, mainly condominiums and high rises. Some older commercial establishment just north of Atlantic Avenue sustained considerable damage. The 1st floor of Ocean View Motel, for instance, was a total loss. Water damage became less severe further north although a few condos sustained considerable wind damage. The nature of water damage was also quite different from other regions discussed. Septic tanks, drain field and sewer lines were the most common components receiving damage because of erosion. Swimming pools, spas, decks and other water front auxiliary structures protected by seawalls and/or revetment also suffered heavy damage due to undermining. Seawalls, new or old, were found to be of insufficient elevation. Most of the return walls were too short and structurally inadequate.

Myrtle Beach and North Myrtle Beach were on the northern fringe of Hurricane influence. Surge level was also established around 13 feet. Water damage, however, was much lighter compared to Garden City or Surfside. Exposed septic tanks and sewer lines were visible at a number of locations, particularly between buildings where the sand losses were severer than at structural front. Unlike Surfside, many waterfront swimming pools and spas survived structurally, although the quality of protective seawall structures were found to be of similar quality as those on Surfside. This might be partially attributed to the recent beach nourishment along the Myrtle Beach.

#### Performance Assessment

Based upon damage surveys, factors that critically affect the structural performance against water loads are discussed here.

#### Foundation

In assessing water damage to coastal construction, the main focal point is the foundation, that is, what is the

type of foundation? where is it located? and how the super-structure is connected to the foundation?

In terms of foundation types, one found a great variety of them along this coast. Generally, they fall into one of the three categories - slab on grade and poured footings, piers of various material and construction and piles.

Slab on grade and poured footings were shown over and over again unfit for coastal application. Hugo's experience only strengthens the verdict because of the high storm surge. Structures on such foundation have very little chance to escape severe damage if water level reached above the foundation. Two common modes of failures were observed, the structure being totally demolished by the dynamic force as illustrated in Figure 7 or the structure being picked up by the flooding water and floated away as shown to be the case in Figure 8. Pier foundation is permitted by FEMA's guidelines for residential buildings as well as most of the building codes. Hugo's experience showed that this type of foundation is very vulnerable in the dynamic water force zone. Failures were frequent. The inherent problem of this type of foundations is the shallowness of the footings as most of them were dug and poured in-place. As the overburden material began to erode away, the footings simply toppled as shown in Figure 9. Bulky shallow footings fared the worst as they often promote local scouring up to 1 to 1.5 feet (Figure 10).



Figure 7: Structure With Foundation On Grade Totally Demolished By Wave Force.



Figure 8: (a) Structure Built On Slab Floated Away From Foundation And Deposited 100 Feet Away Across the Street. (b) The Arrangement Inside the Kitchen Remained Undisturbed in the House.



Figure 9: Shallow Pier Footings Up Rooted.

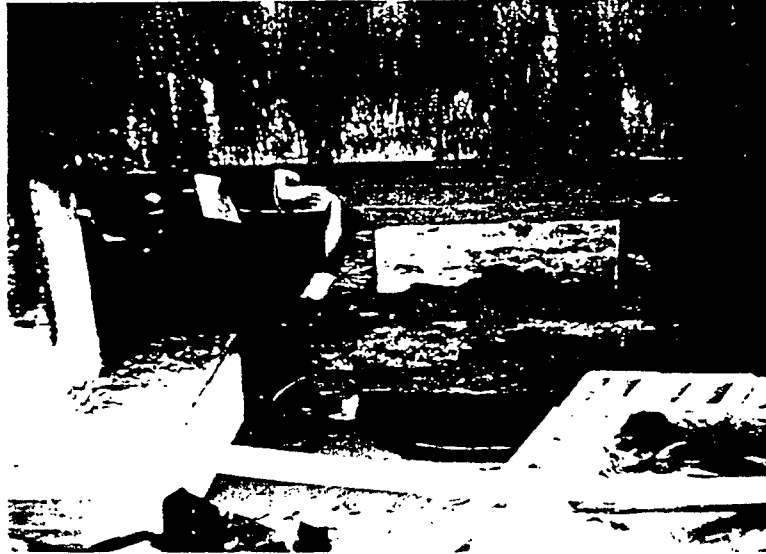


Figure 10: Bulky Shallow Footing Promoted Scouring Around It.

In the above ground section, masonry pier is inferior to wood or poured concrete piers. Masonry pier often failed due to inadequate reinforcement, sloppy job on masonry fills and weak joints between blocks (Figure 11).



Figure 11: Masonry Pier Made of Concrete Blocks Failed Due to Weak Joint and Inadequate Fill.

Failure of poured concrete piers were often due to inadequate or improper placement of reinforcing bars (Figure 12).





(a)

(b)

Figure 12: (a) Poured Concrete Piers Buckled Under Lateral Load. (b) Broken Piers Revealed Inadequate Placement of Reinforcing Bars.

The joint between the pier and the footing was also a common place of failure (Figure 13). Poor construction practice was prevalent among older structures.



Figure 13: Bad Joint Between Pier and Footing Was a Common Failure Mode.

Pile foundation is becoming the standard for modern constructions. Properly sized and installed piles

performed invariably well. It should be the only type of foundation allowed in dynamic zone. Failures were mainly due to rot. Failures attributed to inadequate penetration and pile size were also found in a few occasions. Both concrete and wooden piles were found to be effective. Concrete piles usually showed good rigidity and require simpler connections. Corrosion of re-bars and their subsequent expansion was the main source that weakened the pile and led to eventual failures. Brittle failure was also evident in a number of cases while the pile size might be inadequate. Wooden piles require more lateral bracings and closer attention to connections as they are more flexible. Steel rod bracing appeared to perform better than wood board bracing for two main reasons: wood bracings were susceptible to break or buckle under wave force and they tended to separate or rotate from the main members. The latter was because many of them were secured by nailing instead of bolts and nuts commonly used in metal bracings. For wooden pile, round piles appeared to perform better than square piles although some may prefer square pile for aesthetic reason. For square piles, the hardened outer layers were often partially sawed off exposing the younger inner fibers.

#### Elevation

Elevation undoubtedly was the dominant factor. Practically all residential type of structures sustained major damage if not complete destruction if the elevation was inadequate. Several modes of failures were observed: structures collapsed under wave force; structures floated away from foundations; water went through the structures and took every thing with it. For multi-story buildings, damage usually was associated with the third mode. The first two modes were more or less related to foundation as discussed earlier.

#### Set Back

There was a definite correlation between the extent of water damage and the set back of the structure. Wider beach clearly provided better protection by dissipating wave energy and retarding erosion when the storm surge level was not excessive. When the storm surge level significantly exceeded the dune, such beneficial effects appeared to rapidly diminish.

#### Appurtenant Structures

A surprising amount of damage was caused by failures of appurtenant structures. Deck structures with access ladders or ramps to the beach were a main source of problem. They were not designed to resist water forces,

yet, most of them were secured to the main structures. Water forces would most certainly destruct them which in turn would puncture or tear apart that portion of the main structure connected to them (Figure 14). Ground floor garage doors, air conditioners, water tanks, non-break-away walls, etc., all contributed to additional damages to the main structures. Revetment armor units sometimes behaved like missiles powered by waves as discussed earlier.



Figure 14: (a) House With Access Ramp to Beach (Prior to Hugo).



Figure 14: (b) The Access Ramp Washed Into the House Due to Wave Force.

## Connections

Connections play a major role in wind damage but a lesser one in water damage. Improper connections between floor beams and foundations caused the structures to float away, to collapse and to lean or shift. Figure 15 shows an example of a modular unit completely separated from the foundation piles. Improper nailing practice and inadequate sizes of nails were a prevailing practice causing member separations under minor shift (Figure 16). Missing and inadequate hurricane clips were also prevalent. Mobile home tie downs were found to be common. Very few mobile home units were found near the coast. One small mobile home park south of Myrtle Beach did incur heavy damage, but was mainly due to inadequate elevation as opposed to inadequate tie downs.



Figure 15: (a) Modular Unit Constructions With Poor Connections



Figure 15: (b) The End Unit of the Modular Structure Simply Disconnected From the Piles.



Figure 16: Inadequate and Improper Nailings Caused the Floor Joist to Separate From Floor Beams.

#### Coastal Structures

1. Seawalls: Sea walls are numerous in the affected region. Most of them are actually just retaining walls built for the primary purpose of supporting amenity facilities or lawns. And, most of them are grossly inadequate in height to protect the upland structures from water damage. Scouring behind seawalls due to overtopping was the most prevalent damage mode observed which then led to failures of decks and pools or collapsing of seawalls themselves (Figure 17). In addition, most of the return walls were underdesigned resulting in numerous failures (Figure 18). Once the return walls failed, water quickly rushed in from behind like a breached dam causing rapid losses of material.



Figure 17: Overtopping Induced Seawall Failure.



Figure 18: Underdesigned Return Wall Was Common Occurrences.

2. Revetment, groins and Jetties: Like seawall, revetments are everywhere in the affected area. They are particularly common on Folly Beach, Sullivan's Island and Pawley Island. Most of them are not engineered work but constructed by local contractors or even owners themselves. The quality was evidently poor with insufficient height and inadequate armor size. Some were single layer piled on bare soil. Those structures should not be expected to serve their intended function and they certainly didn't. The armor units on the revetment slope owing to insufficient height often became missiles hitting structures behind, thus causing more harm than good. Some did perform marginally in retarding erosion behind the structure.

Along Folly Beach, Sullivan's Island, Isle of Palm, Pawley Island and Garden City, groins are interspersed with few field of heavy density. The damage to them was surprisingly light possibly because the high surge level simply submerged them. Jetties at a number of inlet entrances also appeared to fared well possibly for the same reason.

3. Piers: Practically all the piers along this coast sustained severe damage, if not totally destroyed. The few surviving ones had their mid sections across the surf zone missing (Figure 19), which seemed to indicate where the most destructive water force had occurred. These piers, though, might not have savage value.



Figure 19: Piers With Mid-Section Missing Revealed the Location of Maximum Dynamic Force to be in Surf Zone.

#### CONCLUSIONS

Hurricane Hugo inflicted very severe water damage on structures near the coast. The general consensus was that in the zones reached by water force, the overall damage incurred by water far exceeded that due to wind. Under such circumstances, attempts to separate wind and water damages were often superfluous. This was quite different from some of the recent hurricanes such as Alicia and Diana where wind was clearly the dominant destructive force.

Damage reconnaissance was carried out by visual inspection and personal interviews. The important findings are summarized here:

1. Water damage was extensive but damage distribution was very uneven spatially.
2. Most of the well engineered and well constructed structures survived, some with very little damage. Both concrete and wood structures demonstrated their survivability. Wood structures usually require much more

attention in details, that is, there are more components and joints which could go wrong here than concrete structures.

3. Wide beaches and high dunes are definitely beneficial provided the surge level is not significantly higher than the dune elevation. For extremely high surge level, the beneficial effect, if any, is unclear.

4. Elevation appeared to be a pre-requisite if the structure were to escape severe water damage.

5. Of the variety of the foundation types only deep pilings of sufficient sizes (over 9 inches at least) performed consistently.

6. Appurtenant Structures were a significant factor contributing to damage.

7. Most of the protective structures were ineffective for lack of proper engineering.

8. Structures, buildings and protective structures, appeared to retard local beach erosion.

#### RECOMMENDATIONS

Structures built on open coast should be designed to avoid water force rather than resisting it. Deep pile is the only structural element that could be used, within reasonable cost, to resist hurricane induced water force. Other structural elements, if have to be exposed in this water force zone, should be designed to break away under loading. Structural set back is important for a number of reasons; it reduces the cost of construction; it reduces the vulnerability of being exposed to dynamic water forces and it reduces damage. Figure illustrates the importance of elevation and setback. Clearly, the closer to the water line the higher the structure, the deeper the foundation and the stronger the foundation are required. Both the water crest line and the scouring line shown in Figure 20 should be respected in coastal construction.



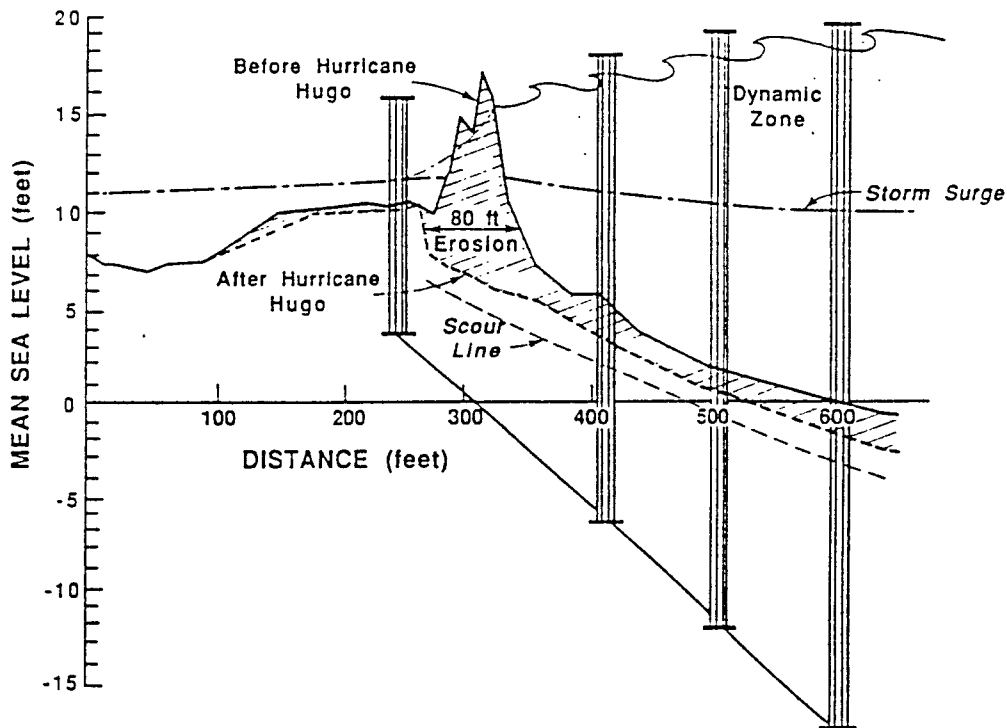


Figure 20: Sketch Shows the Beneficial Effect of Setback on Structural Foundation.

Further research should be conducted to simplify structural connections. In the meantime, connections should be designed and constructed exceeding the Standard Design Code to minimize repair cost.

Protective structures are special structures and should be engineered by personnel with special expertise. These structures owing to their important function should be regulated much the same as buildings in terms of engineering, code enforcement and inspections. The large number of inadequate structures found along this coast was the consequence of rampant unregulated activities. An inadequate, non-engineered structure not only creates a false sense of security to the upland owners but could also have adverse effects on the surrounding. Furthermore, those home-made structures with no engineering and environmental considerations only serve to reinforce the public's perception that coastal structures are uniformly harmful. As a consequence, coastal structures with legitimate purposes are becoming increasingly more difficult to be accepted.

Finally, one must realize that the Standard Building Code is a minimum standard. Certain acceptable risk and level of damage are expected. Revision of building code is not needed. Code enforcement and field inspection are definitely the weak links from the Hugo experience.

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