CHAPTER 220

DESIGNING FOR STORM AND WAVE DAMAGE IN COASTAL BUILDINGS

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1. INTRODUCTION

Gulf Shores is a small town on the Gulf of Mexico near Mobile, Alabama (Figure 1). The area is geologically part of a wide peninsula extending from the eastern side of Mobile Bay. Several brackish water lakes along the peninsula create barrier island-like features along the Gulf shoreline. Gulf Shores, like many other beach communities, gradually evolved from fishing shacks and modest beach cottages into a resort community of primarily single-family residences and second homes. By 1979, the national boom in beach resort development was beginning and several motels and condominiums had been completed, others planned.

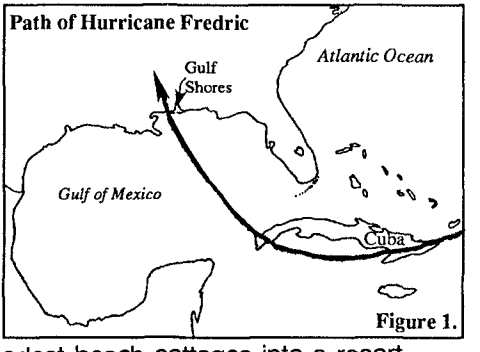

Figure 1.

2. NATIONAL FLOOD INSURANCE PROGRAM

The NFIP evolved from the National Insurance Act of 1968. The act was intended to reduce public disaster relief expenditures in river basins and to limit private flood losses, particularly in areas where such losses were severe or reoccurring. With the incentive of making federally subsidized flood insurance available to anyone in the community, local governments were encouraged to adopt and enforce certain floodplain management regulations in identified flood prone areas. The program

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received minimal interest until legislative changes in 1973 required flood insurance for any loan that is supervised, regulated or insured by a federal agency. For identified flood-prone areas, it was a simple amendment: no insurance, no bank loan. Interest in the program skyrocketed. Owners and lenders have grown to appreciate the financial protection provided by the insurance.

Floodplain management regulations evolved from the most common Riverine protection scheme: Elevate the building higher than the water so it does not get wet. The NFIP modeling and mapping of the predicted 100--year flood level, having a 1 percent chance of occurrence in any given year, has been completed in most flood prone areas. In exchange for flood insurance availability, most local governments have willingly established local ordinances requiring lowest floor elevations to be above predicted levels. Similar methods have been adopted in coastal areas even though the cause of the 100-year flood is usually a hurricane, another severe coastal storm, or in some Pacific areas, a tsunami.

Coastal flood maps denote ground elevations below the 100-year flood elevation as A-zones and prone to flooding (NFIP, 1988). Higher elevations are mapped as B-and C-zones. B-zones are flooded on an average of once in 100 to 500 years. C-zones are above the predicted 500-year flood area. Within the A-zone, the minimum floor elevation may be reached by any normal construction method, including the placement of fill.

The most significant accommodation for coastal flooding is the additional identification of "coastal high hazard" or "velocity" zones, which are denoted on the maps as V-zones. The V-zone designation attempts to define an area subject to waves 3 feet or higher during the 100-year storm. A wave threshold of 3 feet was adopted after a Corps of Engineers study estimated that it was a reasonable design limit for typical wood frame construction (Corps of Engineers, 1975). Initially, the same still water elevations were applied in the V-zone as in the adjacent A-zone. But in the V-zone, a piling foundation was required and building on fill was not allowed. The floor elevation in the V-zone was redefined as the bottom of the floor joists, in effect raising the finished floor elevation about 1 foot higher than in the A-zone. Insurance rates were higher in the V-zone.

3. CONSTRUCTION REGULATIONS

Like many resort communities, Gulf Shores developed with little or no regulation of building construction standards, even after its incorporation in 1956. Adoption of the NFIP standards was one of the first

significant regulatory changes. The first flood hazard boundary maps were published by NFIP in 1971 (NFIP). Based on those maps, minimum floor elevation standards were adopted throughout the town as part of an updated zoning ordinance in April 1972 (Alabama Development Office). The adjacent unincorporated areas of Baldwin County adopted similar elevation and construction requirements that were effective May 1973 (Baldwin County Commission). In both areas, the minimum floor elevation requirement was set at +11.5 feet NGVD (3.5 M) based on the predicted 100-year storm surge elevation. Piling foundations were required in the V-zone. In the A-zone owners of most new buildings voluntarily chose to elevate on piling foundations. This was probably to gain underhouse parking and to lower the cost over bringing in large amounts of fill.

4. HURRICANE FREDRIC

In September of 1979, Hurricane Fredric made landfall across Dauphin Island on the west side of Mobile Bay, approximately 30 miles west of the center of Gulf Shores (COE, 1981). On the Saffir/Simpson hurricane scale of 1 to 5, Hurricane Fredric was ranked as a high category 3, a major hurricane. Damage to Alabama, Mississippi and Florida was severe and widespread. The worst damage was within Gulf Shores and along Dauphin Island. The Corps of Engineers and the U.S. Geological Survey have estimated still-water elevation rose to +11.4 feet NGVD (3.5M) within the town limits. The storm surge was essentially identical to the predicted elevation on which the original construction standards were based.

One of the previously identified weaknesses of NFIP coastal flood regulations was the use of a still-water elevation to set minimum floor elevations. The minimum levels are appropriate for riverine floods, but in coastal flooding, wave damage at elevations above the recorded still-water elevation was being substantially underestimated. Even small breaking waves can generate extremely high forces on a building. Waves are often the worst cause of major structural damage in coastal floods. Before the storm, a National Academy of Science committee recommended a methodology to add wave heights to the NFIP storm surge model (National Academy of Science, 1977). After Fredric, Gulf Shores became the first community in the nation to have its flood maps revised to include wave height elevations.

Using the same storm surge elevation and applying linear wave theory, the minimum floor elevations were raised to include depth limited waves over the existing ground elevations. The lower the ground elevation, the deeper the water and the bigger the wave. Unfortunately,

the model can be substantially distorted by small sand dunes and other erodible topographic features which may be altered during a severe storm. Since the topography of Gulf Shores had already been flattened by waves during Fredric, it offered the ideal site to use the new wave model. The original still-water elevations were increased to include wave heights based on the post-Fredric ground elevations. The first flood maps to include wave heights were released April 1980 (NFIP). Significant revisions were published again in April 1981 (NFIP).

About the same time, NFIP developed a different storm surge model to predict still-water elevations specifically for flood insurance mapping purposes (Tetra Tech, 1981). The new model replaced previous models that were developed and prepared by the National Weather Service and the Corps of Engineers for other purposes, primarily life safety and evacuation. In January 1985 new flood maps were released based on the revised storm surge model and incorporating the same wave height methods applied previously. The elevation standards were reset significantly lower than any of the previous elevation requirements.

A variety of factors make Gulf Shores an ideal site for a case study of the flood regulations. Most importantly, Fredric's peak still-water elevations appear to have been extremely close to the previously predicted 100-year flood elevation. A wealth of post-storm damage data was accumulated by the Corps of Engineers and others. The topographic features that can distort the wave height predictions in most other areas were all flattened by Fredric's waves, making the post-storm wave predictions more accurate than is normally possible. The pre-storm construction was not designed for wave heights since those maps were released after the storm. However, since the predicted still-water elevation equaled the recorded elevation, the later maps should closely estimate the actual elevation of peak wave damage during Fredric. Therefore, the more recent maps should reflect relatively higher damage levels where higher waves are predicted.

If elevation requirements are an effective method of reducing damage to buildings, then there should be a difference between the damage to buildings pre-dating the 1971 flood map and the newer elevated buildings built before Fredric. The benefits of the construction standards should be most apparent in areas where the predicted still-water elevation reasonably reflected the actual conditions during Fredric.

5. METHODS

A study area was selected that was entirely within the 1985

corporate limits of Gulf Shores extending inland 1000 to 2500 feet (300 to 800 M) landward from the Gulf. After the low sand dune was flattened during Fredric, the ground elevations rose gradually inland from the Gulf. Post-storm surveys indicate that the entire study area was flooded during Fredric (U.S.G.S., 1980). The Disaster Report was the primary source of building damage data (COE, 1981). The Corps compared post-storm aerial photographs taken one day after Fredric by the Florida Department of Transportation and with aerial photos taken in March 1979 six months before the storm. The destroyed buildings were marked with a symbol on the post-storm photos. The Corps data was augmented when necessary by careful inspection of the original post-storm aerial photos or with ground inspections and ground photography made 10 days after the storm by the author.

The age of each building in the study area was determined by overlaying the Corps damage photos with transparencies of U.S.G.S. aerial photos taken in May 1972. The photos were taken around the time of the adoption of the minimum elevation requirements in Gulf Shores and Baldwin County. Buildings in existence in 1972 were coded as "old," pre-dating the elevation requirements. Buildings only appearing in the more recent photos were coded as "new", constructed after the minimum elevation requirements were implemented.

A scale-corrected, transparency of each flood map was produced, delineating the elevation zones within the study area. The transparencies were overlaid on the damage sheets previously coded by age. The buildings in each zone were tabulated. It was noted whether the building survived or was destroyed, and whether it was old or new. Any building located in more than one zone was considered to be in the higher of the two risk zones. Also, the distance between the seaward end of each building and the waterline position mapped by the Corps was measured.

To assess the effects of the elevation requirements, it is desirable to remove as much of the wind damage as possible. Wind damage can be extensive in areas with weak construction standards and sustained winds over 100 mph. Damage patterns are usually distinct. Partial damage to a roof, wall or foundation may leave the building beyond salvage, but large, visible remnants usually remain. Even small waves can create forces several orders of magnitude higher than design wind forces. Wave damage often leaves little debris nearby. It is not uncommon to find only a few leaning pilings. Most destroyed buildings in Gulf Shores appeared to be caused by water damage. Where the photography indicated extreme wind damage, buildings were considered to have "survived" for the purposes of this study even though it may have been a total insurance loss.

The majority of buildings in the study area were single-family residences. Piling-supported houses frequently had underhouse enclosures for parking, storage and finished living areas. The lower enclosures usually had "breakaway" walls. In principle, little or no damage should occur to the rest of the building when the lower walls fail. In such cases, destruction of the underhouse improvements did not affect the classification of "survived" for the rest of the piling-supported building. Buildings that floated away from their foundations were considered destroyed even though the buildings were intact and potentially salvageable. Roughly 5 percent of the buildings in the study area were larger, commercial motel and condominium buildings. Most were constructed on much heavier and deeper piling foundations. When these larger buildings lacked adequate floor elevation, the first floor rooms were frequently gutted by waves but remained structurally sound with the upper floors intact. Since the lower non-bearing walls were never intended to be breakaway, the buildings were considered destroyed even if the upper floors remained.

6. RESULTS

A typical shoreline cross section showing the required elevations of the various flood maps is shown in figure 2. Minimum elevations in the V-zones have been labeled 1 foot higher than mapped to account for the different definition of lowest floor elevation (bottom of the joists). In 1971 there were only two zones both very close to Fredric's surge elevation. In 1980 six different elevation zones were identified. In 1981 many buildings in the middle zones were reclassified into less restrictive elevations. No reason for the rapid restudy was provided. The 1985 maps, implementing the newer storm surge model, significantly lowered the predicted surge elevation therefore dropping the wave height elevation compared to all

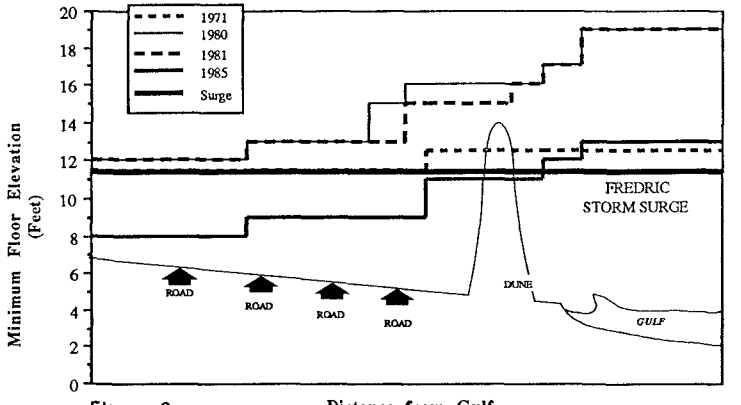


Figure 2.

previous maps. The most seaward zone in the 1980, 1981 and 1985 maps was located seaward of the mean high water line and contained no buildings. Only one new building was located in the next most seaward zone and its results cannot be considered statistically significant.

Of the 1056 buildings in the study area 377 (36 percent) were destroyed. Of the total, 777 were old, 279 new. New buildings constructed on pilings and meeting the minimum elevation standards performed slightly better than earlier designs: 32 percent of the new buildings destroyed vs. 37 percent of the old. Clearly the loss of 32 percent of the buildings in a design storm indicates significant problems with the standards. Figure 3a displays the damage distribution based on the 1971 maps. In the A-zone there was a 10 percentage point reduction of damage in new buildings over old, but 13 percent of the new buildings were still destroyed in the area where the original standards should have performed best. New buildings in the V-zone were more frequently damaged than the old. Although a modest improvement can be seen in the A-zone, the standards resulted in no improvement in the original V-zone.

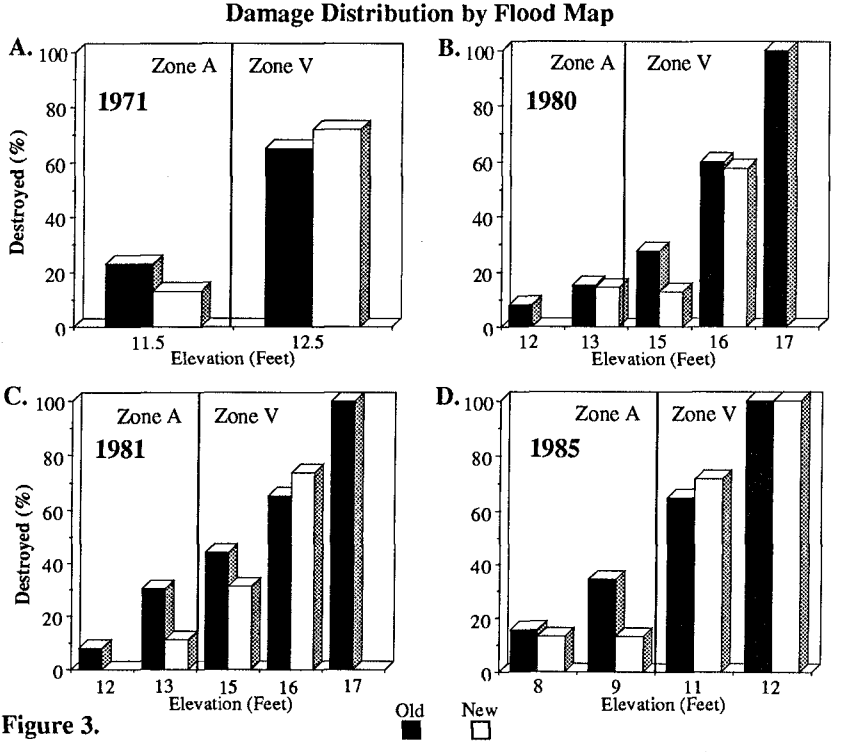


Figure 3.

The wave height predictions included in the 1980 and 1981 maps (figures 3b & 3c) were used as a hindcast of actual wave heights in the hurricane. Increasing levels of damage to both old and new buildings occurred as the predicted elevations increasingly exceed the original standard. Improved survival of new buildings can be observed in the three most landward zones (elevation 12, 13 & 15), but no improvement in the most seaward zone with a significant sample size (el. 16). No new buildings were destroyed in the most landward zone compared with losses of 8 percent of the old buildings in the same areas. Damage to new buildings rose to unacceptable levels in all zones farther seaward (14 and 11 percent at el. 13). Every old building in the most seaward, developed zone (el. 17) was destroyed.

The 1985 maps show similar damage trends but cannot be considered a wave hindcast since the revised storm surge prediction is 3.5 feet (0.9 M) lower than the predicted still water elevation used in all earlier maps and measured after Fredric (figure 3d). After the addition of wave heights, the minimum elevation standards in 1985 were lowered 4 to 7 feet (1.2 to 2.1 M) below the 1980-81 maps and 0.5 to 4 feet (0.2 to 1.2 M) below the standards adopted with the 1971 maps.

One week before Fredric, the Alabama Coastal Area Board voted to establish a statewide, gulf-front construction setback line (Hegenbarth, 1985). The Town of Gulf Shores eventually adopted a setback ordinance requiring all new construction to be located more than 40 feet landward of the pre-Fredric dune crest, except in the central, commercial district where the setback for larger buildings was reduced to five feet landward of the crest. The regulation took effect in March 1981.

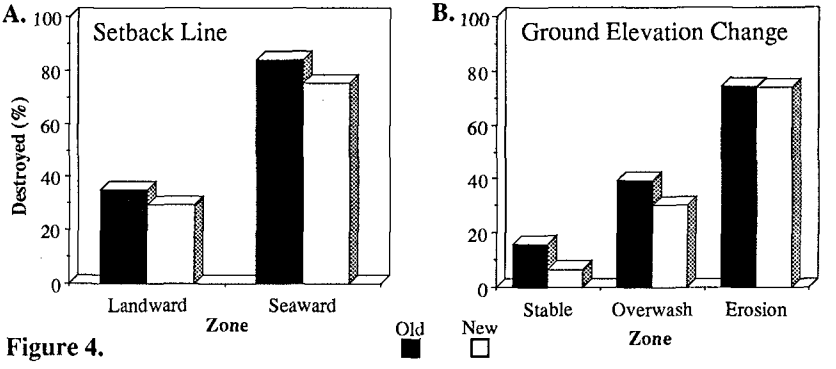


Figure 4.

The study analyzed what the effect of the setback would have been if it had been enforced for all earlier construction. A pre-development setback would have relocated or reduced in size less than 5 percent of

the buildings in the study area. But it would have included many of the largest motels and condominiums. Eleven percent of the damaged buildings were seaward of the setback. Eighty-four percent of those old buildings and 75 percent of the new buildings were destroyed (Figure 4a). Although an earlier implementation of the setback would appear to have reduced damage levels, the setback without other construction regulations farther landward would not have reduced damage to acceptably low levels in the community. Even if the most seaward buildings had been constructed a few feet farther inland, most would still have been damaged. Eighty-nine percent of the damaged buildings were landward of the setback. If an even more restrictive setback had been established along to the north side of the Gulf-front road, prohibiting up to three rows of single-family houses, 39 percent of the destroyed buildings would have been even farther inland.

The influence of ground elevation changes was also measured. The Corps of Engineers (1981) reported erosion occurred 300 feet landward of the post-storm waterline. Overwash deposition was mapped from post-storm photography and appeared to correlate with wave damage to low elevation buildings. On average the overwash penetrated 700 feet (210 M) inland of the waterline. In figure 4b there are similar percentage point improvements in stable ground and overwash but much higher overall levels in overwash. In the erosion area approximately 75 percent of both the old and new buildings were destroyed.

Buildings in the study area were sorted by distance from the waterline and grouped in increments of 100 feet (30 M). The results are displayed in Figure 5. The most dependable points are more than 100 feet and less than 900 feet. Outside that range there were too few buildings for reliable results.

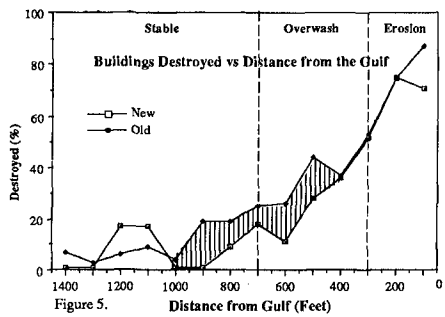


Figure 5.

When the average hazard zone distances are added to the graph, the benefits and limitations of the NFIP construction regulations become more apparent. The effect of the regulations is revealed as the shaded difference between the two lines. The reliable points in the stable but flooded zone show significantly lower damage levels for new NFIP standard buildings than for pre-NFIP buildings. Throughout most of the overwash zone, the damage rates of new buildings show a similar relative improvement as in the stable zone, averaging 13 percentage points better than the older ones. However, the overall likelihood of damage in both

groups increases moving seaward, from an overall average of 22 percent to 37 percent. The steep trend of higher losses closer to the ocean is continued through the erosion zone. All groups closer than 400 feet to the waterline showed remarkably consistent damage levels in old and new buildings.

7. DISCUSSION

The construction standards based on the 1971 maps reduced losses during Hurricane Fredric. The shaded area in figure 5 represents the benefits of the NFIP standards. The survival of 19 buildings out of the 279 constructed between 1972 and 1979 appears to be attributed to the regulations, preventing damage in 7 percent of new construction (Photo 1). If equally effective regulations had been implemented for the 777 older buildings in the study area, about 72 buildings could have been saved by the construction standards as adopted from the 1971 maps.

Photo 1. Typical buildings elevated to meet construction standards. Note foundation of demolished building in foreground.

For design storm conditions, unacceptable levels of damage were allowed by the regulations. Eighty-nine new buildings (32 percent) were destroyed during Fredric. The initial maps show the improvement occurred only in the original A-zone (Figure 3a). The V-zone revealed higher damages in new buildings than in old, the opposite of the desired effect. The addition of wave heights in the 1980 and 1981 maps was an obvious and necessary improvement. The V-zone construction standards specify minimum floor elevations for piling construction but do not address piling embedment. Field inspections indicated that local practice prior to the storm provided 3 to 10 feet (1-3 M) of embedment below existing grade, consistently too little to survive in the erosion zone (photo 2). At its best the A/V zone designations still used by NFIP can address wave height

Photo 2. Undermined foundation of "new" building in erosion zone.

variations and floor elevations but are not suited to address erosion or foundation embedment requirements. The most likely benefit of the wave height additions will be improved survival in the overwash (wave) area in figure 4b and 5 as well as photo 3.

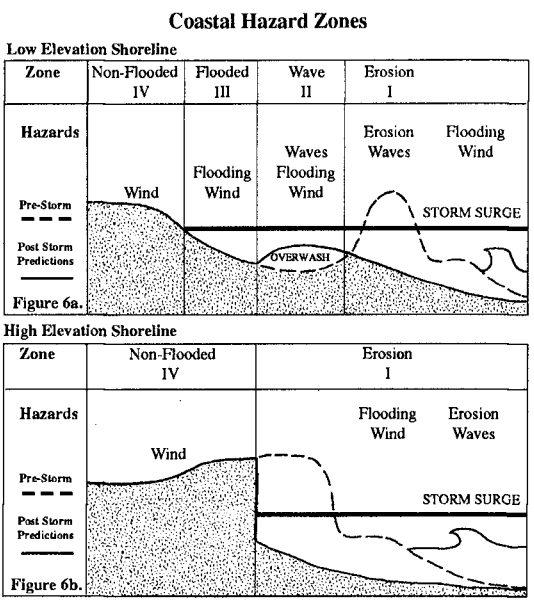
Photo 3. Wave damage to "old" building in the overwash zone. Originally and presently an A-zone, but a V-zone in 1980-1.

Construction setback lines could have reduced the number of damaged buildings but not enough to be the sole method of damage prevention in extreme, but relatively rare storms such as Fredric. Adequate construction standards are necessary to adequately control

building damage on low elevation shorelines that are expected to be overtopped by waves like Gulf Shores. Setbacks appear more likely to be successful if properly applied along high elevation shorelines or if used to control damage caused by long-term erosion.

More realistic coastal hazard zones have been previously suggested in the literature. The Model Minimum Hurricane Resistant Standards for the Texas Gulf Coast (Texas Coastal and Marine Council, 1978) proposed the use of hazard zones for scour, battering by debris, flooding, and wind. The results of this study suggest slightly different designations. On low elevation shorelines where inland flooding is likely, the threats to buildings can be separated into four zones: I) erosion, II) waves (overwash), III) flooded (without waves) and IV) wind (without flooding) as in figure 6a.

High velocity winds can be expected in the entire coastal area, all four zones. Flooding takes place in the three most seaward zones, comparable to the present NFIP flood maps. In the two most seaward zones wave heights must be addressed as well as some foundation considerations for overwash deposition, similar to present V-zones standards. The most seaward zone by definition receives all of the erosion as well as the worst of the previous hazards. Foundation embedment is a critical design consideration that is not adequately addressed in NFIP standards.



On high elevation shorelines the hazard zones can be further simplified. The eroded dune or bluff defines both the limit of erosion and all flooded areas. Zone II and III cannot occur. The erosion of zone I is bounded by the high winds without flooding of zone IV (figure 6b).

It should be noted that this study only addressed the effect of a single, but very severe, short-duration storm. The construction standards

in this study have been in place for only seven years, too short a period to be significantly affected by the long-term erosion in Gulf Shores. In areas of significant long-term erosion it seems prudent to expect the zones to move landward with the erosion rate over the lifetime of any new building constructed. Additional approaches like setbacks or erosion control projects may be required to adequately protect buildings.

5. CONCLUSIONS

The NFIP building construction standards in Gulf Shores significantly reduced damage in buildings constructed between 1972 and 1979. However damage levels were far too high to be considered successful in meeting the reasonable damage-reduction goals in design storm conditions. Damage patterns indicate that wave height considerations in 1980 and 1981 were an appropriate improvement that should reduce damage to buildings constructed after the storm but prior to the 1985. Due to the large drop in the predicted storm surge, buildings constructed to the minimum standards after 1985 can expect higher levels of damage than 1971-1985 buildings if a storm of equal severity occurs. In such a storm, post-1985 buildings are likely to receive damage at levels similar to the unregulated, (old) buildings.

The original construction standards proved to be totally ineffective in areas that experienced erosion. Appropriate foundation penetration standards must be established if damage to small buildings is to be reduced to acceptable levels in 100-year design conditions along the coast.

The identification of more realistic hazard zones is already technically feasible. A variety of existing two-dimensional, dune erosion models can be used to define the erosion zone when the dune is not overtopped (figure 6b). The models are less precise in predicting overtopping and overwash but are still useful when applied with sufficient engineering judgement. Additional considerations for long-term erosion are necessary for buildings to avoid storm damage over a normal useful life.

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