April 21, 2002

Erosion Damage Thresholds in North Carolina

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INTRODUCTION

As the coast of North Carolina developed over the last century, coastal construction has experienced significant damage from hurricanes and other coastal storms, as well as long-term erosion. Construction practices have evolved due to changes in public perception of storm risk and several construction regulation programs. Several important changes in practice did not occur as a gradual process but instead in a series of identifiable steps in time. Significant events affecting construction practice include: a series of severe hurricanes and coastal storms in the 1950s; the mid-1960s adoption and later revision of the North Carolina State Building Code, the second oldest hurricane-resistant building code in the U.S.; and the 1978 implementation and later revisions of the NC Coastal Area Management Act. The evolution of coastal construction practice and general thresholds for damage has been described by Rogers (2001). This report applies to those observed changes to develop methods to estimate damage to coastal structures due to storm-induced erosion in North Carolina. A comprehensive inventory of building construction details and other structures can be combined with commonly unmeasurable construction details that can be inferred from the construction date and the known evolution of general construction practices.

The effect of construction regulations is always limited by the effectiveness of local enforcement and the speed of adoption as general construction practice. Experience from severe storms and long-term erosion in North Carolina has shown that the building code and regulatory enforcement has been generally good; regulatory compliance in coastal communities has been consistently high; and the adoption of new standards by local contractors timely. The use of construction dates to estimate hidden construction parameters affecting erosion resistance is therefore a reasonable assumption and an improvement over previous methods to estimate erosion damage.

North Carolina's buildings and other development have evolved due to a unique storm and regulatory history. The recommendations in this report will not directly apply to other coastal areas. However, locally-customized construction factors can be developed for any shoreline that could be used to significantly improve erosion damage predictions over previously used methods.

The most accurate method to predict future damage is to perform a building by building damage evaluation of historical severe storms on shorelines with similar development and construction standards. At this time detailed studies do not exist. Therefore, the damage thresholds suggested for North Carolina and the erosion damage curves in Appendix A are based on the opinion of the author, formed over 27 years of building damage evaluations, following most of the worst storms on the East and Gulf coasts, and for most of that time, observations of the North Carolina coast on a daily basis. A resume is included as Appendix B.

GENERAL APPROACH

To improve erosion damage estimates, buildings can be separated into two general classes: small buildings (primarily single family houses) and larger commercial buildings. Each class is further separated by construction details determined by a local building inventory and assumed local construction practice based on construction date. The erosion resistance of a building can seldom be determined by construction details alone. The local ground elevation significantly affects the effectiveness of the construction standards. Local topographical data can be used to separate shorelines into two general types with high or low elevation building sites.

SHORELINE TYPES

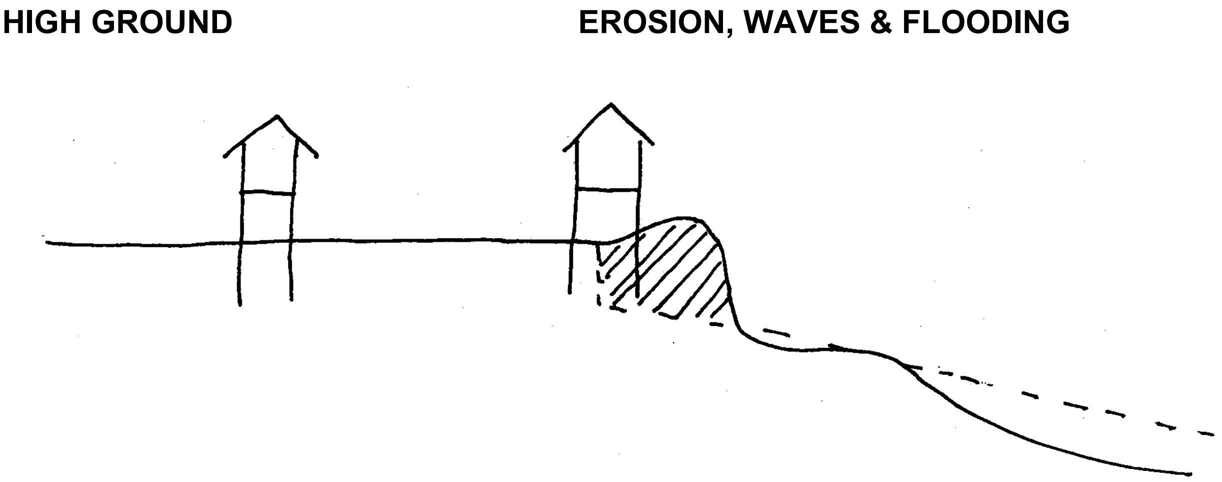
On ocean shorelines, zones of storm damage have been observed that can separated by ground elevation into two types (Rogers, 1990) shown in **Figure 1**. The high elevation type is defined as sufficiently elevated to prevent wave effects unless subject to erosion (**Figure 1-A**). The seaward of two damage zones is defined by the area subject to erosion. Buildings in the erosion zone are subject to combined damage from erosion, wave impacts and flooding. The high elevation of the more landward zone protects the buildings from erosion, waves and flooding. Both zones are subject to storm winds.

Low elevation shorelines with overtopped dunes have four building damage zones (**Figure 1B**). The seaward zone is defined as the area experiencing erosion but also subject to waves, and flooding. The next landward zone is defined as the area subject to breaking waves capable of destroying solid building walls and foundations. It includes the area subject to overwash deposition. The National Flood Insurance Program has traditionally identified the threshold for destructive wave heights as 3 feet (Corps of Engineers, 1975). More recent research indicates that a breaking wave of 1.5 feet will destroy common solid walls and foundations (Tung et al, 1999) . The next landward zone is defined by flooding but no significant wave damage. The landward-most zone has sufficient elevation to avoid erosion, waves and flooding but like the more seaward zones, may be subject to high winds.

Figure 1: SHORELINE TYPES

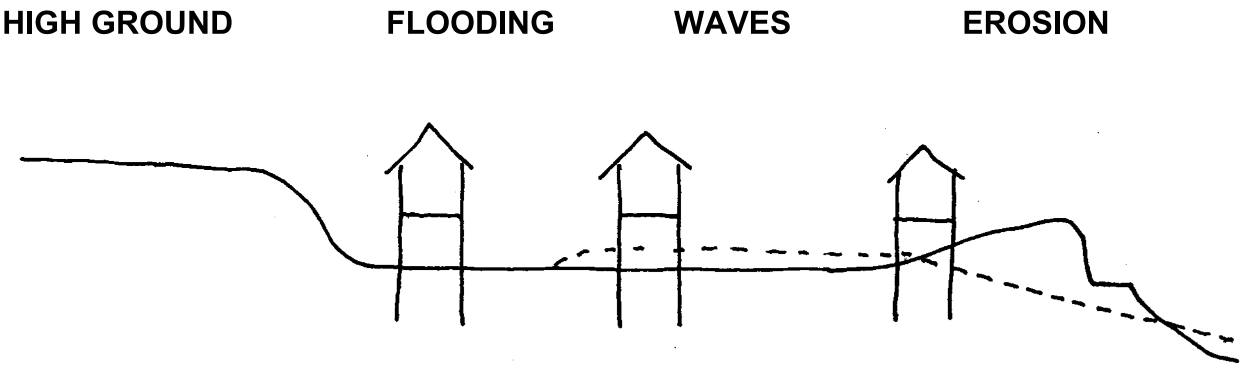
A. High dune, no overtopping

1. Erosion zone with waves and flooding
2. High ground (no erosion, waves or flooding)



B. Small overtopped dune

1. Erosion zone with waves and flooding
2. Waves zone with overwash deposition and flooding
3. Stable ground elevation with flooding
4. High ground: (no erosion, waves or flooding)



CLASSES OF STRUCTURES

To predict erosion damage within the described zones, it is useful to separate structures into several different classes as shown in **Figure 2.** Buildings are separated by general size, typically single-family houses and larger commercial buildings. Both classes of buildings commonly use breakaway walls and enclosures under piling supported, elevated buildings. The behavior of the enclosures is sufficiently different and often independent of the elevated buildings therefore justifying a separate class and damage calculations for the enclosures. A broad class of structures including mobile homes, swimming pools and other expendable structures, including decks seaward of oceanfront houses, are grouped as highly erosion sensitive structures. Dune walkways, roads and erosion control actions are listed as separate classes. It is useful to separate the buildings and several other classes into subclasses, based on similar construction characteristics. Suggested erosion damage tables for Classes 1-5 are included as an appendix.

Class 1: Single-Family Houses

Single-family houses are by far the most common class of buildings along the North Carolina coast. They are used as primary residences, second homes and rental property. The class includes similarly designed small buildings such as duplexes, small condos and some small commercial buildings. The class can be further divided by foundation type, determined by a detailed building inventory and the date of initial construction. Class 1a includes erosion-sensitive foundations including concrete slabs, shallow spread footings and most others not on pilings. Class 1b buildings are constructed on relatively shallow pilings. Building code requirements beginning in the mid-1960s led to the common use of pilings installed to a depth of 8 feet below grade. It includes most non-oceanfront houses up to present and oceanfront houses constructed through 1985. Class 1c consists of oceanfront houses constructed from 1986 to present, following an increase in the piling foundation standard to -5 feet NGVD or 16 feet below grade, whichever is shallower.

The shallow foundations in Class 1a are equally erosion damage prone in both shoreline elevation types. The shallow pilings in Class 1b are ineffective on high elevation, Type A shorelines, and perform like Class 1a (**Figure 3**). At lower ground elevations of Type B a moderate level of erosion resistance is provided (**Figure 4**). For short pilings, +12' NGVD is suggested as an effective ground elevation separation for shoreline type. Shallow piling foundations in Type A shorelines have a piling tip penetration above +4' or slightly above the mean high water elevation, too little embedment to improve the erosion-resistance over Class 1a. Significant damage to deeper imbedded pilings is likely to begin when the erosion depth exceeds 4', half the embedment depth of 8'.

On high elevation Type A shorelines the deeper pilings of Class 1c are limited in effectiveness by the 16' feet below grade requirement. The shoreline types can be separated by a ground elevation of +16' NGVD. On A shorelines, the piling embedment will be no deeper than 0.0' NGVD and can be expected to perform similar to the other grossly eroded foundations in 1a and 1b(A) (**Figure 5**). When piling embedment approaches or exceeds the -5' NGVD piling standard on lower ground elevations (Type B) the erosion resistance of 1986 piling standards proved very effective during Hurricane Fran (FEMA, 1997 and Woodward-Clyde, 1997.) See **Figure 6.** An erosion threshold of 4 feet is suggested.

Figure 2: CLASSES OF COASTAL BUILDINGS AND OTHER STRUCTURES

1. Single-family house (includes duplexes & small condos)
    a. Slab foundation or shallow perimeter footing and interior piers
    b. Shallow piling foundation (~ 8' below grade: oceanfront, 1965 thru 1985 and farther inland, all dates.)
    c. Deeper piling foundation (piling penetration to -5' NGVD or 16' below grade, whichever is shallower, 1986 and later, oceanfront only)

2. Commercial or large multi-family buildings
    a. Slab or other on-grade foundation
    b. Second floor and above piling supported, lowest floor on grade (common in hotel and condos)
    c. Fully piling supported, deep pilings, [some wood-frame, pre-1985 oceanfront condos may have shallow pilings as in 1b above]
    d. Building specific evaluation (fishing piers, etc.)

3. Underhouse enclosures: may be unfinished or finished interior
    Unfinished enclosures have fixed cost per either SF or linear wall footage
    Finished enclosure valued as ratio of total finished floor area
    a. None (parking slab?)
    b. Small (<300 SF)
    c. Partial (>300 SF, < full)
    d. Full enclosure

4. Mobile homes, utility buildings, detached garages, decks seaward of oceanfront houses, gazebos, pools etc

5. Dune walkways
    a. Houses
    b. Public/commercial

6. Paved roads and parking lots
    a. Damage
    b. Overwash excavation
    c. Sand sifting operations

7. Erosion control structures and actions
    a. Beach scraping
    b. Emergency sandbags

Figure 3: Short piling foundation failures (Class 1b) on high-elevation shoreline (Type A). Location: Kure Beach NC after Hurricane Fran.

Figure 4: Short piling foundation (Class 1b) near failure on low-elevation shoreline (Type B). Location: Surf City NC after Hurricane Fran.

Figure 5: House under construction with piling 16 feet below grade (Class 1c) on high-elevation dune (Type A). Dune elevation above +16 feet NGVD makes erosion failure more likely. Location: Emerald Isle NC.

Figure 6: Houses on 1996 pilings (Class 1c) on low-elevation shoreline (Type B). Location: Topsail Island after Hurricane Fran.

Figure 7: Slab foundation failure (Class 1a & 2a) beside commercial/deep-piling structure (Class 2c) on high-elevation shoreline (Type A). Location: Surf City NC after Hurricane Fran.

Figure 8: Piling-supported hotel with lower floor on unsupported slab (Class 2b) on low-elevation shoreline (Type B). Location: Wrightsville Beach NC after Hurricane Fran.

Class 2: Large Commercial Buildings

Figure 9: Piling-supported hotel after failure of unsupported, first-floor slab (Class 2b) on low-elevation shoreline (Type B). Location: Horry County after Hurricane Hugo.

The class of large buildings includes hotels, large condos, restaurants, and most other commercial buildings. These generally larger buildings are constructed to a separate performance building code that does not include the specific piling depth requirements found in Class 1. The large mass of the buildings typically dictates, that where used, piling embedment depths are significantly greater than for small buildings. Class 2a buildings are constructed on shallow, erosion-sensitive foundations, typical of older commercial buildings (**Figure 7**). Class 2c is fully supported on a piling foundation and has an erosion tolerance as good or better than the best small buildings (**Figure 7.)** Class 2b is a hybrid foundation common in hotel construction. All of the building walls and all floors above the first floor are supported on pilings and buried grade beams that are relatively erosion tolerant (**Figure 8**). The lowest finished floor is supported on a slab foundation supported on grade between the foundation pilings **(Figure 9**). The lowest floor is therefore highly erosion sensitive. Wave and erosion damage occurs to the lowest floor where much of the value of the building is concentrated, but higher floors are relatively undamaged. It is suggested that total erosion damage be estimated by treating the lowest floor as a slab (Class 1a and 2a)but weighted for twice the average square-foot value for the building, and added to damage in higher floors as applied in Class 1c and 2c.

Class 3: Under-building Enclosures

Many buildings of all ages enclose part or all of the area under piling-supported elevated buildings. Present regulations allow lower level enclosures for the purposes of parking, storage or access to the elevated building. Any enclosure must be unfinished and include no equipment such as a heat pump, water heater, washer or dryer. In some communities it is common for piling-supported houses constructed prior to adoption of minimum floor elevation requirements, to have fully finished underhouse enclosures supported on a slab foundation. Although prohibited in more recent construction, small finished enclosures and unauthorized equipment are not uncommon. Erosion or waves frequently destroy the lower level and equipment, leaving the elevated floors in place.

Some near-ocean buildings are required to use specific designs for breakaway enclosure walls. More recent research has shown that standard wood framing adequately functions to breakaway from the piling foundation and elevated building, negating the need for a specific breakaway design (Tung et al, 1999). Whether it was designed to breakaway is a moot issue. Waves and/or erosion will predictably cause all enclosure walls to breakaway.

Enclosures are common in both Class 1 and Class 2 buildings. Enclosures are supported on slab foundations that behave quite differently in erosion than the rest of a piling-supported building. Recent building inventory collections have included separate descriptions of the size and finish of the enclosures. Therefore overall damage calculations can be simplified and improved by considering enclosures as Class 4 structures, separate from the rest of the elevated buildings. The National Flood Insurance premium rating system serves to encourage enclosure sizes into four groups as outlined in **Figure 2**. Open buildings with no enclosures may still have parking slabs that are subject to erosion damage. In NFIP V-zones, enclosures smaller than 300 SF can be rated by local flood insurance agents. Larger enclosures must submit information to Washington for rating. Full enclosures are common near some shorelines particularly in A-zones where flood insurance rates are not affected by the size or presence of the enclosures.

The value of the enclosure will vary depending on whether it is finished or unfinished. Finished areas can be reasonably valued at the SF rate of the elevated building. Unfinished enclosures are obviously lower in value.

Class 4: Mobile Homes and Other Expendable Structures

Mobile homes and a group of other expendable structures are highly erosion sensitive, failing quickly after only partial undermining. Mobile homes in this class use shallow, mortarless concrete block piers, tied down with screw anchors. A small number of mobile homes have recently been installed on traditional piling foundations and should be evaluated as Class 1 structures. North Carolina has historically considered expendable structures to include small utility buildings, parking surfaces, gazebos, swimming pools and tennis courts. Also included are the open decks seaward of most oceanfront houses. Building setback lines generally apply to the roofed building, but expendable decks of limited size are allowed to be constructed contiguous to the building, seaward of the setback line. The building code allows the common practice of using short pilings on the decks compared to required depth for the building (FEMA, 1997.) Oceanfront decks are therefore far more erosion-sensitive than the adjacent buildings and are more accurately grouped with Class 4. Detached garages are more common in older development and are affected similarly by erosion.

Class 5: Dune walkways

Dune walkways are permitted as expendable structures and restricted in piling depth to require erosion damage rather than interfering with access along the beach. Walkway damage differs from Class 4 only in the rate that erosion damage progresses. The relatively long, shore perpendicular structures can be assumed to experience a linear increase in damage with the percentage of erosion rather than a quick total loss as in Class 4. Houses and commercial/public walkways differ primarily in value per linear foot of walkway . Commercial/public walkways tend to be a few feet wider and use heavier materials, therefore have a higher value per unit length.

Class 6: Paved Roads and Parking Areas

On-grade paving is destroyed by shallow erosion, requiring replacement and/or relocation. In contrast overwash deposits bury the paving without significant damage. Damage values result from the effort required to excavate the surface, returning it to its intended function. Road repair and replacement costs should be available from the NC Department of Transportation. Overwash excavation costs may also be available from the same source for Highway 12 or from local governments. Most near-ocean overwash deposits that are excavated from roads or developed areas are required to be replaced on or near the beach. In our recent hurricanes, the abundance of construction debris excavated with overwash sand has led to major sand sifting projects before being returned to the beach. The cost of handling has been estimated in some communities to have exceed $15/CY of excavated sand. The cost of past efforts should be available from local governments or NC Emergency Management since they are included in FEMA Public Assistance reimbursements.

Class 7: Erosion control structures and responses

Most erosion control structures on the oceanfront are prohibited by NC regulations. However emergency sandbag revetments and several other practices are pre-authorized by general permits and are in common use. Most permanent structures, including buildings, are eligible for an emergency sand bag permit if erosion moves the vegetation line closer than 20 feet from the building. Roads and septic tanks are included. Mobile homes and detached garages would also qualify but most other expendable structures in Class 4, including oceanfront decks, would not be eligible. The emergency sandbag revetments are limited in time (two to five years, depending on building size, longer if beach nourishment is under study) and in size. The size limit is approximately 6 feet high and 20 feet wide. Typical practice uses bags filled to roughly 2 feet high by four feet wide in a sloping revetment three bags high and three wide for a total of 6 rows of bags. A property owner on Topsail Island recently received three bids of approximately $20 per linear foot of row of bags or $120 per linear foot for a typical 6-bag cross section. Cooperating adjacent owners pay for their oceanfront lot width. Isolated owners must pay for extra bags to protect the one or both sides of their structures.

Beach scraping, excavating sand from the berm or foreshore and pushing it to just landward of the vegetation line or erosion scarp is the most common erosion control response in use on the NC coast. Funding and permitting varies by community. Work is contracted by individual property owners, or in some cases by local government or homeowners associations for longer shorelines under their management. Several research projects have concluded that beach scraping within the limits of the state permit conditions has no significant positive or negative impact on the local erosion rate. Although proven to be of little benefit, beach scraping is a common and real cost, directly by the property owner or indirectly through government or homeowner association assessments. The frequency and cost of beach scraping can usually be determined by contacting the local government or building inspector.

USING SBEACH TO PREDICT BUILDING DAMAGE

SBEACH erosion model was developed to predict two-dimensional beach profile changes with varying storm surge, wave and sediment size conditions. It is intended to predict bar movement, overwash and shoreline recovery better than previously available models. It was not developed to predict erosion damage to buildings and has limitations if directly used for that purpose. Most of the model calibration came from large scale wave tank data and field studies following storms with moderate surge elevations. Calibration for design level storms (50 to 100-year events) appears to have been minimal.

Since SBEACH was designed to better model dune overtopping and overwash deposition it should better represent low elevation shorelines where dunes are flattened and overwash is deposited farther landward. The predicted overwash terrace should provide a better profile for predicting depth limited wave heights around buildings on the second row and farther inland. For predicting erosion threats to typical oceanfront buildings it is suspected that the model underestimates erosion depth. It may not be a significant issue on shallow foundations, such as slabs, but becomes a particular problem when predicting the erosion failure threshold for shallow pilings. Reasonable results are likely to be obtained by using a modeled erosion depth threshold that is shallower (2' maybe?) than observed in the field (on the order of 4' for 8' pilings in severe storms.) Several sections of Topsail Island that lost 150+ similar buildings on short pilings in Fran would be useful area to calibrate SBEACH for the erosion failure threshold for low elevation shorelines with overtopped dunes.

During extreme storms, those most likely to cause erosion damage to buildings, high dunes or unconsolidated bluffs are observed to retreat with near vertical erosion scarps. Slopes steeper than 75 degrees appear common. There is sufficient soil moisture in the dune sands to allow the steep slope to remain stable for a period of days to weeks. Eventually the bluff face will dry and avalanche to a slope flatter than the angle of repose for the sand. The severe erosion depth caused by the retreat of the bluff during the storm places extreme conditions on both shallow and deep piling foundations. However, after the storm there is usually sufficient time to stabilize the top of the bluff, avoiding the additional horizontal erosion that would otherwise occur by avalanching.

In contrast, SBEACH adjusts the erosion scarp by continuously avalanching the eroded scarp (SBEACH Report #1 VI, page 171.) When the slope exceeds 28 degrees the model retreats the top of the erosion scarp and redistributes the sand volume to a slope of 10 degrees at each time step. The assumptions appear to be coded into the software and are not variable parameters. The theoretical slope may approach 28 degrees, much flatter than observed following severe storms. However, a few sample runs in dunes higher than the wave runup limit, consistently resulted in slopes of only 8 to 9 degrees, far flatter than the roughly 75 degrees observed in the field. The model profile output gives the appearance of a steep eroded dune face but is misleading due to the horizontal to vertical distortions in the default profile scales. The affect is not unique to SBEACH. Report #1 VII p. 217-9 indicates the Kriebel model predicts even flatter slopes.

There is no obvious method to adjust SBEACH to generate a more realistic erosion scarp or to adjust the observed erosion threshold depths of the different foundation types to fit the model. Selection of an erosion threshold in the model is necessary to determine the percentage of structure erosion in **Figure 2** before the percentage of damage can be estimated. Calibration tests in SBEACH Report #4 appear to indicate the model underestimates the horizontal dune retreat more often than overestimates. The best vertical erosion depth for the model is likely to be lower than observed for actual damage. For shallow foundation classes an erosion threshold of 0.5' to 1' appears reasonable. For the piling foundation classes, an erosion threshold of 4' is realistic in the field but 2' or less in SBEACH may generate more realistic damage estimates. It may be feasible to calibrate the damage estimates using the high ground elevations of Kure Beach during Hurricane Fran when 15 to 20 building were destroyed. The choice of an erosion threshold depth on the flat eroded dune slope from SBEACH is likely to result in extreme variations in the percentage of damage for each class of structure. It is likely additional calibration will be necessary to select an arbitrary erosion threshold depth for reasonable damage estimates. The selected threshold for piling supported buildings is likely to be considerably different than observed in the field, a necessary correction due to limitations in the model.

SUGGESTED HURRICANE FRAN CALIBRATION AREAS FOR SBEACH

Kure Beach, NC in the vicinity of Avenue E	Figure 3
1226 N. Shore Drive & Jones Avenue, Surf City, NC Area includes: Severely leaning house on short pilings Post-1986 house on long piles, undamaged Multiple pre-1986 houses destroyed.	Figure 4
341 Topsail Road & 11th Avenue, North Topsail Beach, NC Second-row house has been protected by overwash deposit left in place after Hurricane Fran.	Figure10

Figure 10: Second-row dune left after Hurricane Fran provided protection during Hurricanes Bonnie, Dennis and Floyd. Location North Topsail Beach after Hurricane Floyd.

References

Corps of Engineers, 1975. “Guidelines for Identifying Coastal High Hazard Zones.” US Army Corps of Engineers, Galveston District.

Federal Emergency Management Agency, 1997. “Building Performance Assessment: Hurricane Fran in North Carolina.” FEMA 290.

Rogers, Spencer, 2001. “Evaluating Potential Hurricane and Erosion Damage to Buildings in Coastal North Carolina,” North Carolina Sea Grant, UNC-SG-01-04.

Rogers, Spencer M. Jr., 1990. "Designing for Storm Surge and Wave Damage in Coastal Buildings." Coastal Engineering Conference, Delft, The Netherlands. ASCE. pp. 2908-2921.

Tung, C.C., B. Kasal, Spencer M. Rogers, Jr., and S.C. Yeh, 1999. "Behavior of Breakaway Wall Subjected to Wave Forces: Analytical and Experimental Studies." NC Sea Grant (UNC-SG-99-03).

Woodward-Clyde Federal Services, 1997. “Pile Damage Assessment: Topsail Island, North Carolina.” Federal Emergency Management Agency, Region IV, EMW-95-C-4678, Task Order # 111.

APPENDIX A: Erosion-Damage Curves

Contents damage assumed to be the same curve as structural damage

Class 1 Structures: Single-family residential buildings, duplexes and small condos

Structure Class	1a. Slab	1b. Short Pilings		1c. Long Pilings	
Shoreline Type	A & B All ground elevations	A: High Dune ground el >12' piling tip > el +4'	B: Low Elevation ground el <12' piling tip < el +4	A: High Dune ground el >16' piling tip > el 0	B: Low Elevation ground el <16' piling tip < el 0'
Erosion depth threshold	0.5 feet	4 feet		4 feet	
% Erosion	% Damage				
0	0.05	0.05	0.05	0.05	0
0.1	0.2	0.1	0.1	0.1	0.01
0.2	0.4	0.2	0.2	0.2	0.02
0.3	0.6	0.4	0.3	0.4	0.03
0.4	0.8	0.8	0.4	0.8	0.04
0.5	1	1	0.5	1	0.05
0.6	1	1	0.6	1	0.06
0.7	1	1	0.7	1	0.07
0.8	1	1	0.8	1	0.08
0.9	1	1	0.9	1	0.09
1	1	1	1	1	0.1

Class 2 Structures: Commercial buildings, hotels, large condos

Structure Class	2a non-piling foundation	2b piling foundation lowest floor slab	2c full piling foundation
	Same as 1a	f(# floors) * below	Same as Type B-1c
Erosion depth threshold	0.5 feet	0.5 feet	4 feet
% erosion	% Damage		
0	0.05	*	0
0.1	0.2	*	0.01
0.2	0.4	*	0.02
0.3	0.8	*	0.03
0.4	1	*	0.04
0.5	1	*	0.05
0.6	1	*	0.06
0.7	1	*	0.07
0.8	1	*	0.08
0.9	1	*	0.09
1	1	*	0.1

* Class 2b: % damage = [2 x (% erosion) / (# floors)] + (% damage Class 2c)

Class 3 Structures: Underhouse enclosures below piling supported buildings, equipment, utilities, etc.

Non-piling foundation	Same as 1a
% erosion	% Damage
0	0.05
0.1	0.2
0.2	0.4
0.3	0.8
0.4	1
0.5	1
0.6	1
0.7	1
0.8	1
0.9	1
1	1

Erosion depth threshold = 0.5 feet

Class 4 Structures: Mobile homes, utility buildings, oceanfront residential decks, detached decks, gazebos, pools, detached garages, buried public utilities

	Shallow foundations
% erosion	% Damage
0	0
0.1	0.5
0.2	1
0.3	1
0.4	1
0.5	1
0.6	1
0.7	1
0.8	1
0.9	1
1	1

Erosion depth threshold = 0.5 feet

Class 5 Structures: Dune walkways

	Shallow foundations
% erosion	% Damage
0	0
0.1	0.1
0.2	0.2
0.3	0.3
0.4	0.4
0.5	0.5
0.6	0.6
0.7	0.7
0.8	0.8
0.9	0.9
1	1

Erosion depth threshold = 2 feet

APPENDIX B: BUILDING DAMAGE ASSESSMENT EXPERIENCE

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EMPLOYMENT:

1978 to Present: Job title: Coastal Engineering Specialist, NC Sea Grant. Work through the NC Sea Grant Marine Advisory Service to advise private property owners, builders, designers, and governmental agencies on hurricane-resistant construction methods, shoreline erosion alternatives and marine construction techniques. Faculty: University of North Carolina - Wilmington, Center for Marine Science. Adjunct faculty: North Carolina State University, Department of Civil Engineering in Raleigh NC.

1975-78: Coastal Engineer for the Bureau of Beaches and Shores, Florida Department of Natural Resources, Tallahassee. Conducted evaluations of proposed Atlantic and Gulf front development for variances of the coastal construction setback line. Evaluated erosion control alternatives and impacts.

AFFILIATIONS: National Association of Coastal Engineers
American Society of Civil Engineers
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REGISTRATIONS: Registered Geologist, State of North Carolina, # 684

APPOINTMENTS:

North Carolina Coastal Resources Advisory Council, 1992 to present.
Representing marine science and technology. The Council advises the NC Coastal Resources Commission on coastal management regulations in North Carolina.

NC Science Panel on Coastal Hazards, 1997 to present.
NC university coastal engineers and geologists advising the NC Coastal Resources Commission on technical issues related to coastal processes.

PERTINENT PUBLICATIONS: 35 selected from 47

Rogers, Spencer M. Jr. and Chris Jones, 2002. “Selecting Erosion Setbacks For Balanced Multi-hazard Risk.” Solutions to Coastal Disasters Conference, San Diego CA, ASCE.

Jones, Chris and Spencer Rogers, 2002. “Establishing Standards for Building Setbacks: Incorporation of Erosion Rate Variability.” Solutions to Coastal Disasters Conference, San Diego CA, ASCE.

Rogers, Spencer, 2001. “Evaluating Potential Hurricane and Erosion Damage to Buildings in Coastal North Carolina.” North Carolina Sea Grant, UNC-SG-01-04.

Rogers, Spencer M. Jr., 2000. "Beach Nourishment For Hurricane Protection: North Carolina: Project Performance in Hurricanes Dennis and Floyd." National Beach Preservation Conference. August 2000.

Kriebel, David, Larry Buss and Spencer Rogers, 2000. “Impact Loads from Flood-bourne Debris” ASCE report for FEMA. Other research on floating debris is in progress.

Rogers, Spencer M. Jr., 1999. "Design and Construction Guidance for Breakaway Walls Below Elevated Coastal Buildings in accordance with the National Flood Insurance Program." FEMA Technical Bulletin, FIA-TB 9-99.

Yeh, S. C., Spencer M. Rogers, Jr., C. C. Tung, and B. Kasal, 1999. " Behavior of Breakaway Walls Under Wave Action." Journal of Structural Engineering. ASCE. October 1999. pp. 1162-1169.

Tung, C. C., B. Kasal, S. C.Yeh, and Spencer M. Rogers, Jr., 1999. "Ultimate Capacity of Nailed Connections for Design of Breakaway Walls." Forest Products Journal. Vol. 49. No. 10. October 1999. pp. 76-81.

Tung, C.C., B. Kasal, Spencer M. Rogers, Jr., and S.C. Yeh, 1999. "Behavior of Breakaway Wall Subjected to Wave Forces: Analytical and Experimental Studies." NC Sea Grant (UNC-SG-99-03). February 2.

Work, Paul A., Spencer M. Rogers, Jr., and Robert Osborne, 1999. "Flood Retrofit of Coastal Residential Structures: Outer Banks, North Carolina." Journal of Water Resources Planning and Management. March/April 1999.

Pratt, Anthony P., Christopher P. Jones, Spencer M. Rogers, Jr., and Darryl J. Hatheway, 1998. "Delaware Coastal Vulnerability and Construction Standards Study." Association of State Floodplain Managers Conference Proceedings.

Rogers, Spencer M., Jr. and Sam Houston, 1997. “Hurricane Surge and Wave Conditions: Research Needs.” Waves ‘97 Conference Proceedings, ASCE.

Jones, Christopher P., Spencer M. Rogers, Jr., and Darryl Hatheway, 1997. "Coastal Vulnerability and Construction Standards Study." Delaware Department of Natural Resources and Environmental Control. Dewberry & Davis. September 17, 1997.

Clark, Walter, and Spencer M. Rogers, Jr., 1996. "Questions and Answers on Purchasing Coastal Real Estate in North Carolina." NC Sea Grant & NC Real Estate Commission. (UNC-SG-96-10).

Rogers, Spencer M., Jr., 1996. “Corrosion Protection for Metal Connectors in Coastal Areas,” Technical Bulletin TB 8-96, FEMA.

Rogers, Spencer M., Jr., 1995. “The Effects of Corrosion on Sheet-Metal Connectors in Coastal Buildings: A Summary of Present Knowledge,” FEMA.

Rogers, Spencer M., Jr. 1995. "Getting the Most from Oceanfront Setback Lines" Coastal Zone '95, Tampa, FL, ASCE.

Rogers, Spencer, M. 1995. "Preliminary Summary of Conditions and Damages: Hurricane Emily". *Shore & Beach*, Journal of the American Shore and Beach Preservation Association, Berkeley, CA. January 1995.

Rogers, Spencer M. Jr., 1995. "Coastal Hazard Analysis for North Carolina Aquarium/Fort Fisher." NC Sea Grant.

Rogers, Spencer M. Jr., 1994. "Hurricane Andrew & the South Florida Building Code: Relevance to the North Carolina Building Code." NC Sea Grant.

Rogers, Spencer, M. Jr. 1993. "Relocating Erosion-Threatened Buildings: A Study of NC Housemoving". Coastal Zone '93, New Orleans, LA, ASCE.

Rogers, Spencer M. Jr., 1991. "Foundations and Breakaway Walls of Small Coastal Buildings in Hurricane Hugo." Coastal Zone '91, Long Beach, CA, ASCE. Also published in National Hazard Center Quick Response Report, #37.

Rogers, Spencer, M., Jr. 1991. "Flood Insurance Construction Standards: Can They Work on the Coast?". Coastal Zone '91, Long Beach, CA, ASCE, and Natural Hazards Research Center, U. of Colorado, 1990.

Rogers, Spencer M. Jr. 1990. "Designing for Storm Surge and Wave Damage in Coastal Buildings." Coastal Engineering Conference, Delft, The Netherlands, ASCE.

Rogers, Spencer M., Jr., 1990. "Performance of Building Resistance to Water, Waves and Erosion." Proceedings from "Hugo: One Year After." Charleston, SC, ASCE.

Rogers, Spencer M., and Peter R. Sparks, 1991. "Damage to Buildings: Hurricane Hugo". *Shore & Beach*, Journal of the American Shore and Beach Preservation Association, Berkeley, CA. Oct. 1990.

Rogers, Spencer M. Jr., 1990. "The Cost of Oceanfront Erosion in North Carolina: An Analysis of Flood Insurance Claim Payments 1977-1989." NC Sea Grant.

Rogers, Spencer M., Jr., 1986. "Coastal Erosion Issues in Flood Hazard Mapping,". Report to the Coastal Committee, Association of State Floodplain Managers.

Rogers, Spencer M., Jr., Sparks, Peter R. and Sparks, Katharine M., 1985. "A Study of the Effectiveness of Building Legislation in Improving the Wind Resistance of Residential Construction", National Conference on Wind Engineering, Lubbock, TX, Wind Engineering Council.

Rogers, Spencer M., Jr., 1985. "Hurricane Diana: Impact on Coastal Development." Coastal Zone '85, Baltimore, MD, ASCE.

Stutts, Alan T., Chrystos D. Siderelis, and Spencer M. Rogers. 1985. "Effect of Ocean Setback Standards on the Location of Permanent Structures in Coastal North Carolina." Coastal Zone '85, Baltimore, ASCE.

Cox, John W., with Spencer M. Rogers, Jr., 1984. "Performance of Offshore and Coastal Structures During Alicia", Alicia: One Year Later, Galveston, TX, ASCE.

Rogers, Spencer M. Jr., 1982. "Coastal Environment and Site Characteristics." Coastal Residential Construction Workshop. FEMA, Emmitsburg, MD.

Rogers, Spencer M. Jr., 1982. "Coastal Flood Forces", Proceedings from Intergovernmental Seminar on Flood-Loss Reduction Through Improved Building Practices, FEMA, Emmitsburg, MD.

Tayfun, M. Aziz, Spencer M. Rogers, Jr. and Jay Langfelder, 1979. "Delineation of an Ocean Hazard Zone for North Carolina Department of Marine Science and Engineering", NC State University.

POST-STORM BUILDING DAMAGE ASSESSMENTS

(not including northeasters or other storms)

Named Storm	Year	Location	Support
Hurricane Floyd	1999	NC	NC Sea Grant
Hurricane Dennis	1999	NC	NC Sea Grant
Hurricane Bonnie	1997	NC	NC Sea Grant
Hurricane Fran	1996	NC	FEMA Building Performance Assessment Team
Hurricane Bertha	1996	NC	NC Sea Grant
Hurricane Opal	1995	FL	Florida State Emergency Response Team
Hurricane Emily	1993	NC	FEMA Damage Assessment Team
Hurricane Andrew	1992	FL	NC Sea Grant
Hurricane Hugo	1989	SC/NC	Natural Hazards Research Center
Hurricane Gloria	1985	NC	NC Sea Grant
Hurricane Diana	1984	NC	NC Sea Grant
Hurricane Alicia	1983	TX	NC Sea Grant
Hurricane Fredric	1979	AL/MS	NC Sea Grant
Hurricane David	1978	NC	NC Sea Grant
Hurricane Eloise	1975	FL	Florida Bureau of Beach and Coastal Systems

OTHER WORK

Project member for FEMA's 2001 revisions of the Coastal Construction Manual.

Flood Hazard Committee, HAZUS Flood Loss Estimation Model, National Institute of Building Sciences. Committee is guiding development of a flood damage assessment model to estimate economic losses from future floods.

Member, ASCE Standards Committee: Flood Damage Resistant Design and Construction, 1995 to 1999.

Project committee member, "Compatibility of Flood Loss Reduction Standards of the National Flood Insurance Program with the National Model Building Codes and Standards," National Institute of Building Sciences, Washington, D.C., 1992.

Congressional Testimony, on "Issues Relating to Erosion, Erosion Management and Erosion Insurance H.R. 3456, H.R. 4461 and Managing Coastal Erosion by the National Research Council". Before the Committee on Banking, Finance and Urban Affairs, Subcommittee on Policy Research and Insurance. Rehoboth, DE, July 1990.

Technical Consultant, "Property Eligibility Requirements for Wind Storm Coverage" Property Insurance Underwriting Association, State of New York, 1988. NY now requires existing buildings to be retrofitted to minimum storm resistance standards for coverage through the state-sponsored wind insurance pool for high risk coastal buildings.

Technical Editor, America's Vanishing Coastlines: A New Concern For The Voluntary And Residual Property Insurance Markets, National Committee on Property Insurance, 1988.

Co-author, "Coastal and Flood Plain Construction Standards," NC State Building Code, NC Dept. of Insurance, 1986.

FEASIBILITY REPORT
AND
ENVIRONMENTAL IMPACT STATEMENT

COASTAL STORM DAMAGE REDUCTION PROJECT
SURF CITY AND NORTH TOPSAIL BEACH
NORTH CAROLINA

Appendix C
Geotechnical Analysis

Note: The Appendix contains 3 attachments. These attachments are included in the electronic version of the document, but due to size are not being included in the printed version.

Appendix C: Geotechnical Analyses

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Appendix C: Geotechnical Analyses

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Attachments

Attachment 1 – Final Report Marine Geophysical Investigation for the Evaluation of Sand Resource Areas Offshore Topsail Island North Carolina, prepared by Greenhorne & O'Mara with Ocean Surveys, Inc.

Attachment 2 - Boring logs

Attachment 3 - Lab Data

Appendix C: Geotechnical Analyses

1. Regional Geology

A. Physiography and Geomorphology. The study area encompasses Topsail Island and nearshore Onslow Bay. Topsail Island is a 40 km long barrier island, which lies within the Atlantic Coastal Plain Physiographic Province. It is bounded by New River Inlet to the northeast, New Topsail Inlet to the southwest, Onslow Bay to the southeast, and the Atlantic Intracoastal Waterway (AIWW) to the northwest. Onslow Bay is a modern embayment of the Atlantic Ocean. It is bounded by Cape Lookout to the north and Cape Fear to the south. Present on Topsail Island are beaches, dunes, and marshes, landforms typical of barrier island complexes. On the nearshore floor of Onslow Bay are submarine scarps, shoals, and bars.

B. Stratigraphy. The Atlantic Coastal Plain and the inner continental shelf of Onslow Bay are both underlain by relatively flat-lying sedimentary units which gently dip and thicken to the southeast. This large sedimentary wedge includes both sediments which have not been indurated or cemented and rock units. The oldest (lowest units) were deposited during the Cretaceous Period, from 144 to 65 million years ago. The youngest part of the wedge dates to the Quaternary Period, from 1.8 million years ago to 10,000 years ago. This sediment and sedimentary rock wedge overlies pre-Mesozoic (older than 248 million years ago) crystalline basement rock (Horton and Zullo, 1991). A patchy veneer of Holocene (10,000 years ago to present) sand and gravel overlies the Quaternary strata in the project area.

C. Coastal Processes. Dynamic coastal processes continually shape the barrier islands of southeastern North Carolina. Rivers and streams entering Onslow Bay are generally small with low gradients. Their continentally derived sediment loads are therefore not very large. In addition, much of this fluvial sediment becomes trapped within the river estuaries. This lack of significant sediment discharge into Onslow Bay limits the build-up of nearshore continental shelf sand deposits. In other areas along the Atlantic coast these nearshore deposits are an important source of sand. When deprived of this source of sand as at Topsail Island, seasonal storms and longshore currents can cause episodic severe shoreface erosion and migration (Cleary, 1968; Sarle, 1977; Riggs and others, 1996; Cleary 2002).

2. Site Geology

A. Topsail Island. Several Oligocene formations outcrop on the nearshore floor of Onslow Bay. These strata extend westward under Topsail Island, vertically removed from the island surface. The stratigraphy and lithology of these strata are described below in paragraph “Onslow Bay.” The geologic materials of concern to the project on Topsail Island are the surficial sand soils.

Sand soils encountered on the Topsail Island beaches are classified as fine- to medium-grained poorly-graded sands according to the Unified Soils Classification System. These sands are the result of a complex combination of factors. Part of the sand is accumulated from storm overwash and longshore drift. Another part results from the biological, chemical, and physical erosion of nearshore sedimentary rocks. Winnowing by wind and wave action results in the predominantly fine- to medium-grained poorly-graded sands on the beach today.

B. Onslow Bay. The continental shelf in Onslow Bay is composed of a complex sequence of seaward dipping Tertiary age (65 million to 1.8 million years ago) strata, which was deposited during an age of periodic sea-level fluctuations (Hine and Riggs, 1986; Snyder and others, 1985, 1986; Snyder and others, 1991).

The oldest rocks outcropping within the study area are Oligocene age (33.7 million to 23.8 million years ago) limestones submerged offshore of Topsail Island (Attachment 1, Figure 2). Riggs and others (1985) describe these limestones as the Belgrade and Trent formations, which consist of “moldic biomicrudite (Folk, 1974) limestones with interbedded calcarenite sands and grayish-green calcareous quartz sands.” A stratigraphically similar unit named the River Bend Formation, which consists of olive green quartz sand and silt, is reported to also underlie areas offshore of Topsail Island (OSI, 2004). Northeast and east of the survey area lies a major unconformity separating the Oligocene rock and sediments from the younger Miocene (23.8 million to 5.3 million years ago) Pungo River Formation.

Quaternary paleofluvial channels, which generally trend normal to shore, crosscut the older strata offshore of Topsail Island. These channels were down cut during a period of lower sea level elevation. The paleofluvial channels are remnant streambeds, which were infilled with sediments during Pliocene to Pleistocene times (1.8 million years ago to 10,000 years ago) (Hoffman, C. W. and others, 1994), and were drowned during the Holocene sea-level rise (Belknap, 1982; Hine and Snyder, 1985, Snyder and Snyder, 1992).

Surficial Holocene sedimentary deposits are scarce offshore of Topsail Island in Onslow Bay. Much of the native beach sand is derived from the physical and biological erosion of Oligocene rock and strata submerged in Onslow Bay. These sediments are then reworked, redistributed and deposited within submarine valleys and ridges, or along the shoreface of Topsail Island (Cleary, 1968; HDR, 2002; HDR, 2003; Meisburger, 1979; McQuarrie, 1998; Riggs and others, 1996; Snyder and Snyder, 1992).

3. Subsurface Investigation

A. Historical Data

Information in the offshore areas of Topsail has not been studied or documented in the past. HDR Engineering Inc. of the Carolinas (HDR) was hired in fall of 2002 to gather information about the area and to make recommendations of where the most promising areas are for borrow material for the Topsail Beach Coastal Storm Damage Reduction Project. HDR hired Dr. William Cleary of the University of North Carolina at Wilmington as a consultant to assist in the assessment. The area offshore of Topsail Island is one of the areas of interest for Dr. Cleary. The study included mapping (side scan sonar) and classifying the seafloor composition by collecting physical samples of the bottom. This information was used to locate areas with the most promise for use as borrow for beachfill. HDR along with Dr. Cleary submitted a report in March of 2003 outlining the recommended areas offshore of Topsail Beach for use as potential borrow sites. This report was titled “Assessment of the Availability of Beachfill Quality Sand Offshore Topsail Island, Topsail Beach, Pender County, North Carolina”. The recommended offshore areas were the focus of the subsequent geophysical investigation.

B. Geophysical Investigation (Attachment 1)

1. General. A search for suitable beach fill materials for this project was begun offshore in Onslow Bay. A marine geophysical investigation was conducted by Ocean Surveys March 27 to April 17, 2004 in order to locate and evaluate potential sand resource areas. Approximately 315 miles of bathymetric and subbottom data were collected along 60 tracklines. Twenty-two (22) tracklines were shore-parallel and twenty-eight (28) tracklines were run perpendicular to shore along with 10 diagonal tie lines to insure thorough coverage.

2. Sand Borrow Search Area. Geophysical data was collected in the area between 0.5 nautical miles (30 foot isobath) to 5.0 nautical miles offshore of Topsail Island. The site stretches nearly 23 nautical miles from Rich Inlet to northeast of New River Inlet. Survey limits were established to further resolve sand resource areas identified by earlier surveys.

3. Geophysical Methods. Two types of sub-bottom methods were used: a “CHIRP Sonar” seismic reflection profiler, which generates a high frequency, short duration acoustic pulse providing high resolution of shallow sub-bottom strata; and a “Boomer” seismic reflection profiler which uses a low frequency pulse to achieve deeper penetration of the sub-bottom strata. These were run simultaneously to achieve the best possible resolution and penetration. Augmenting the seismic equipment was survey equipment that allowed real-time depth sounding, positioning, and motion (heave) corrections.

4. Positioning System. A differential global positioning system was used to determine position along the seismic lines. Equipment included a Trimble 4000 Global positioning System (GPS) and a Leica MX52R U.S. Coast Guard (USCG) Differential Beacon Receiver interfaced with HYPACK software. Navigation fixes were recorded on an onboard PC every second with an accuracy of better than 3 feet.

5. Depth Sounder. Bathymetric data was collected at a near continuous rate using an Innerspace Model 448 Digital Depth sounder, which operated at a frequency of 200 kHz. Tidal data from the NOAA station in Beaufort, North Carolina were used for tidal corrections.

6. CHIRP Sonar System. The Contractor accomplished the high-resolution subbottom profiling utilizing an EdgeTech Xstar Full Spectrum “CHIRP” Subbottom Profiler system operating with frequencies of 0.5-12 kHz. The system has three components: a deck unit that is comprised of a PC system and amplifier, an underwater cable, and a Model 512 towed vehicle that houses the transducers. The tow fish vehicle emits a high frequency FM pulse over the full spectrum range of 0.5-12 kHz for a 20 millisecond period, and the acoustic return is received by a hydrophone array, which allows high resolution of the shallow subsurface. The higher frequency yields higher resolution with a tradeoff in lesser depth penetration.

7. Seismic Reflection Profiling System. Deeper sub-bottom penetration was accomplished using an Applied Acoustics 100-300 joule “boomer” system comprised of a boomer plate, power supply, hydrophone array, TSS-model 360 filter and time-varied-gain system, and an EPC 1086 thermal paper recorder. The “boomer” employs a sound source that utilizes electrical energy discharged from a capacitor bank to rapidly move a metal plate in the transducer bed. The short duration motion of the metal plate creates a broad-band (500-8000 Hz) pressure wave capable of penetrating hundreds of feet of marine sediments under favorable site conditions.

8. Summary of Geophysical Results

a. Stratigraphy. The geophysical and bathymetric surveys showed that shallow rock scarps and outcrops dominate and control the submarine topography offshore of Topsail Island. A surficial sand horizon was resolved. However, it is very discontinuous and broken by Oligocene rock outcrops. Erosion and reworking of this rock contributes coarse and fine-grained materials to the surficial sand. This decreases its aesthetic value as beach fill. The thickest sequence of unconsolidated sediment occurs in or adjacent to the paleochannels. These sediments tend to be dominated by estuarine muds and fine sands and thus unsuitable as beach fill. Borrow areas must generally be configured to avoid these channels.

b. Vibracore Targets. The subsurface investigation was performed between May and November 2003. The boring locations were based on the seismic data available from the geophysical investigation conducted by OSI.

c. Borrow Areas. The results of the 2004 geophysical survey in combination with vibracore data were used to identify potential borrow areas within the study area.

B. Vibracore Investigation

1. Field Investigation. The subsurface investigation was performed between May and November 2003. The criteria for the boring locations was between 1 and 6.5 miles from the beach, water depth greater than 30 feet Mean Lower Low Water (MLLW), and change in seismic profile, which could represent differing soil types. A total of 369 borings were performed in the Topsail Island area. Boring locations are shown in Appendix A, Figure A-6. The boring logs are included in Attachment 2. Borings were performed offshore of Topsail Island, in the Banks Channel behind Topsail Beach, in the connecting channel between the Atlantic Intracoastal Water Way (AIWW) and New Topsail Inlet, in New Topsail Inlet, and New River Inlet.

Borings were performed from the USACE Snagboat *SNELL* using a 3 7/8 inch diameter, 20-foot long, Alpine vibracore drill machine. The sampler consists of a metal barrel in which a plastic cylinder or tube is inserted. After the plastic tube was inserted, a metal shoe was screwed onto the plastic tube and then the metal barrel. The shoe provided a cutting edge for the sampler and retained the plastic tube. An air-powered vibrator was mounted at the upper-most end of the vibracore barrel, and the vibrator and the vibracore barrel was mounted to a stand. This stand was lowered to the ocean floor by the Snell's crane, the vibrator was activated and vibrated the vibracore barrel into the ocean sediment. The sediment sample is retained in the plastic tube. All borings were drilled to a depth of 20 feet below the ocean floor, unless vibracore refusal was encountered.

Vibracore refusal was defined as a penetration rate of less than 0.1 feet in 10 seconds.

2. Laboratory Analysis. The recovered vibracore tubes were visually classified by Wilmington District personnel in accordance with the Unified Soils Classification System (USCS). Samples were taken at a minimum of every two feet or at each change of material. A total of 1327 samples were collected in the Topsail Island area. Grain size tests were performed in accordance with ASTM D-422 using a fourteen-sieve test and visual classifications were performed in accordance with ASTM D-2488, by Wolf Technologies, Inc. The sieves used in these tests were the 3/4, 3/8, Number 4, Number 7, Number 10, Number 14, Number 18, Number 25, Number 35, Number 45, Number 60, Number 80, Number 120, and Number 230. Grain size test results are located in Attachment 3.

4. Compatibility Analysis

The compatibility analysis compares the grain size of the “native beach” or the “reference beach” with the material in the proposed borrow material. The procedure for calculating the overfill ratio for borrow areas in relation to the reference beach was performed in accordance with the U.S. Army Corps of Engineers Coastal and Hydraulics Laboratory Automated Coastal Engineering System (ACES) software version 4.01. This procedure is discussed in section V-4-1.e(3)(i) of the U.S. Army Corps of Engineers Engineer Manual (EM) 1110-2-1100, part V, dated 1 August 2008, titled Coastal Engineering Manual. As stated in this manual, the overfill ratio is the primary indicator of the compatibility of the borrow material to the beach material, with a value of 1.00 to 1.05 considered optimum for sediment compatibility. Obtaining this level of compatibility is not always possible due to limitations in available borrow sites and an overfill ratio of 1.5 is generally considered acceptable. See Appendix E for more information regarding the compatibility analysis.

5. Archeological Resources Survey

Mid-Atlantic Technology and Environmental Research, Inc. (MATER) conducted magnetometer and side-scan sonar (acoustic) surveys to identify archeological resources that may be present in the preliminary borrow areas from the fall 2004 to spring 2005. The side-scan sonar survey was used to further delineate hard bottom identified in the borrow areas in the geophysical investigation. Line spacing for this survey was approximately 65 feet and the survey covered an area of approximately 14.1 square nautical miles. Hard bottom consisting of high, moderate, and low relief based on the elevation changes were identified in several of the preliminary borrow areas. As a result, three preliminary borrow areas (I, K, and M) were eliminated from further consideration as borrow sources.

6. Hard Bottom Resource Confirmation and Characterization Study

Anamar Environmental Consulting, Inc. conducted in-situ diver groundtruthing of several borrow areas in the spring 2008. Twelve transects were conducted to confirm and characterize hard bottom at five borrow areas (G, J, L, O, and T). Transects were planned for locations where hard bottom was identified by MATER in the archeological resources survey. Hard bottom of low and moderate relief were identified for all of the transects with the exception of one transect in borrow area J (J1), where no hard bottom was identified. Concurrently, applicability of the North Carolina hard bottom buffer rule (NCAC 07H. 0208(b)(12)(A(iv)), which identifies a 500 meter buffer for dredging operations around high relief hard bottom had been discussed for the coastal storm damage reduction projects potentially impacting hard bottom. In August 2008, State and Federal resource agencies concurred with a USACE, Wilmington District proposal to establish a hard bottom buffer consisting of 500 meters (1,640 feet) for high and moderate relief hard bottom and 122 meters (400 feet) for low relief bottom.

7. Sand Borrow Areas

After completion of the archeological resources survey, eleven offshore borrow areas were identified for the Surf City/North Topsail Beach project and are labeled as G, H, J, L, N, O, P, Q, R, S, and T (See Appendix A, Figure A-6). The material classification ranged from clean sand (SP), slightly silty sand (SP-SM), with minor amounts of silty sand (SM), silt (MH and ML), and clay (CH) (See attachment 2). The boundaries of the borrow areas have been limited to preclude material with classification of silty sand, silt, and clay by adjusting the depth of the borrow area at vibracore locations.

The State of North Carolina implemented new rules in 2007 governing sediment compatibility for beach nourishment. The rules are titled “Technical Standards for Beach Fill Projects” and are found in 15A North Carolina Administrative

Code (NCAC) 07H.0312. The standards require compatibility of the native beach with borrow sources in regards to the percentage of silt, granular sediment, gravel, and calcium carbonate (or shell content for existing projects). Borrow Area R was subsequently eliminated due to elevated silt concentration. Based on the results of the compatibility analysis, the total estimated volume in the remaining ten borrow areas is approximately 27.59 million cubic yards (yd^3). This amount of material is insufficient to meet the required volume for the NED plan of 32.3 million yd^3.

Therefore, borrow areas identified for the Topsail Beach Federal coastal storm damage reduction project were considered. By evaluating the borrow areas for all Topsail Island coastal storm damage reduction projects, sufficient material is available for the two Federal and two non-Federal projects. The six borrow areas identified for the Topsail Beach Federal coastal storm damage reduction project (A, B, C, D, E, and F) have been included with the aforementioned ten borrow areas for the Surf City/North Topsail Beach project. By evaluating all Topsail Island offshore borrow areas together, the sixteen borrow areas contain approximately 50.4 million yd^3 of borrow material. The two Federal and two non-Federal coastal storm damage reduction projects currently planning to use material from these borrow areas have volume requirements of approximately 46.3 million yd^3 or about 92% of the available borrow material in all of the borrow areas evaluated for the Federal projects.

All of the remaining borrow areas comply with the beach fill standards with the exception of borrow areas A F, L, S and P. Borrow areas A and L exceed the silt standard by 0.4 and 0.1% respectively. Borrow areas F and S exceed the granular sediment standard by 0.9 and 0.5% respectively. Borrow area F and P exceed the gravel standard by 3 and 1.1% respectively. See Appendix E for more information on the compatibility analysis of the borrow sources.

The borrow areas in which the standards were exceeded for the various characteristic (A, F, L, S, and P) have been retained as all borrow areas will be further characterized during the plans and specification phase of this project. Additional borings will be performed to comply with the NC beach fill standard of 1 core/acre or 1,000 feet spacing. The characteristics of the remaining ten borrow areas is shown in Table C-1. As shown in this table, the borrow areas are typically between 1 and 6 miles offshore and have pre-dredge bottom depths of 50 feet or less.

8. Conclusion

An extensive investigation was conducted for borrow sources for the Surf City/North Topsail Beach Federal coastal storm damage reduction project which included seismic and sonar studies, subsurface investigation using numerous vibracores, an archeological resources survey, and a hard bottom confirmation and characterization study. The number and configuration of borrow areas for the project has been continuously modified throughout the process to incorporate the additional data.

The borrow areas were re-evaluated after the North Carolina beach fill standards were implemented in 2007. At that time ten borrow areas were identified for the project. However, the volume of material in these borrow areas is insufficient to meet the project requirements. Therefore, borrow areas identified for the Topsail Beach Federal coastal storm damage reduction project were considered. By evaluating the borrow areas for all Topsail Island coastal storm damage reduction projects, sufficient material is available for the two Federal and one non-Federal projects.

Currently sixteen borrow areas have been identified for the Surf City/North Topsail Beach Federal coastal storm damage reduction project. Five of these borrow areas (A, F, L, P, and S) exceed the NC beach fill standards slightly for various characteristics. Because all borrow areas will be evaluated further during the plans and specifications phase of this project, these borrow areas have been retained. Additional vibracores will be performed in all borrow areas to comply with the NC beach fill standards of 1 core/acre or 1,000 feet spacing. For a complete description of the borrow area materials and the sand compatibility see Appendix E, Sand Compatibility Analysis.

9. References

Snyder, Stephan.W., Snyder, Scott., Riggs, S.R., Hine, A.C., 1991, Sequence Stratigraphy of Miocene Deposits, North Carolina Continental Margin; *The Geology of the Carolinas*, Carolina Geological Society, Fiftieth Anniversary Volume, p. 263-273.

Hine, A.C., and Riggs, S.R., 1986, Geologic Framework, Cenozoic History, and Modern Processes of Sedimentation on the North Carolina Continental Margin, in Textoris, D.A., ed., SEPM Field Guidebooks, Third Annual Midyear Meeting, Southeastern United States: Society of Economic Paleontologists and Mineralogists, Field Trip No.5, p.129-194.

Snyder, Stephen W., Snyder, Scott, W., Waters, V.J., Steinmetz, J.C., Hine, A.C., and Riggs, S.R., 1985, More evidence for glacial world prior to the Middle Miocene Oxygen Isotope Enrichment Event: Resolution of Early Miocene Glacioeustatic Sea-level Cyclicity from North Carolina: Geological Society of America Abstracts with Programs, v.17, p. 721.

Snyder, Stephen W., Hine, A.C., and Riggs, S.R., and Snyder, Scott W., 1986, Miocene Unconformities, Chronostratigraphy, and Sea-level Cyclicity: Fine-tuning the Early Neogene Relative Coastal Onlap Curve for the North Carolina Continental Margin [abstract]: American Association of Petroleum Geologists Bulletin, v. 70, p. 651.

Harris, B.W., and Zullo, V.A., 1979, Structural and Stratigraphic Framework for the Coastal Plain of North Carolina, Field Trip Guidebook, Carolina Geological Society and Atlantic Coastal Plain Geological Association, 111 p.

Riggs, S.R., Snyder, Stephen, W., Hine, A.C., Snyder, Scott, W., Ellington, M.D., and Mallette, P.M., 1985, Geologic Framework of the Phosphate Resources in Onslow Bay, North Carolina Continental Shelf: Economic Geology, v. 80, p. 716-738.

Snyder, Scott, W., and Snyder, Stephen, W., 1992**,** Translating Biostratigraphic and High Resolution Seismic Data into a Sequence Stratigraphic Framework-Insights Gained from the Study of the NC Neogene, Third Bald Head Island Conference, Nov. 4-8, Hilton Head Beach and Tennis Resort, Hilton Head Is., SC, 67 p.

Folk, R.L., 1974, Petrology of Sedimentary Rocks, 190p.

Snyder, Stephen, W., Mallette, P.M., Snyder, Scott, W., Hine, A.C., and Riggs, S.R., 1988, Overview of Seismic Stratigraphy and Lithofacies Relationships in Pungo River Formation Sediments of Onslow Bay, North Carolina Continental Shelf. Cushman Foundation Special Publication No. 25, p. 1-14.

Belknap, D.F., 1982, Amino Acid Racemization from C14 Dated “Mid-Wisconsin” Mollusks of the Atlantic Coastal Plain, Geological Society of America Abstracts with Programs, v. 14, 4p.

Hine, A.C., and Snyder, S.W., 1985, Coastal Lithosome Preservation: Evidence from the Shoreface and Inner Continental Shelf off Bogue Banks, North Carolina: Marine Geology, v. 63, p. 307-330.

Sarle, L. L., 1977**,** Processes and Resulting Morphology of Sand Deposits within Beaufort Inlet, Carteret County, North Carolina, Duke University, MS, 150 p;

Riggs, S.R., Snyder, S.W., and others, 1996, Hardbottom Morphology and Relationship to the Geologic Framework: Mid-Atlantic Continental shelf, Journal of Sedimentology Research, vol. 66, no. 4, p 830-846.

HDR Engineering, Inc., 2002, An Assessment of the Availability of Beachfill Quality Sand Offshore Topsail Beach, Pender County, NC, Project Report for the U.S. Army Corps of Engineers, Wilmington District, 28p.

HDR Engineering, Inc., 2003, An Assessment of the Availability of Beachfill Quality Sand Offshore North Topsail Beach and Surf City, North Carolina, Project Report for the U.S. Army Corps of Engineers, Wilmington District, 41p.

Meisburger, E.P., 1979 Reconnaissance Geology of the Inner Continental Shelf, Cape Fear Region, North Carolina, U.S. Army Corps of Engineers, Coastal Engineering and Research Center, Technical Report TP79-3, 135p.

McQuarrie, M.E., 1998, Geologic Framework and Short-term, Storm Induced Changes in Shoreface Morphology: Topsail Beach, NC, unpublished M.S. Thesis, Department of the Environment, Duke University, Durham, 105p.

Ocean Surveys, Inc., 2004, Marine Geophysical Investigation for the Evaluation of Sand Resource Areas Offshore Topsail Island, North Carolina: Final Report prepared for the U.S. Army Corps of Engineers Wilmington District, 44p.

Mid-Atlantic Technology and Environmental Research (MATER), 2005, An Archaeological Remote Sensing Survey of Surf City – North Topsail Beaches Offshore Borrow Areas.

Boss, S.K., and Hoffman, C.W., 2000, Sand Resources of the North Carolina Outer Banks: Final Report, prepared for the Outer Banks Task Force and the North Carolina Department of Transportation, 87p.

Cleary, W.J., 1968, Marine Geology of Onslow Bay, Dept. Geology, Duke University, M.S. Thesis, 73p.

Table C-1
Borrow Area Characteristics

Borrow Area	Mean Grain Size	Estimated Volume (Million yd^3)	Distance offshore (miles)	Pre-Dredge Surface/Bottom Elevation (ft. MLLW)
A	2.36 phi (0.20 mm)	*	1 to 3	-38.5 to –49.0
B	2.17 phi (0.22 mm)	*	1.5 to 2.5	-42.2 to –43.2
C	2.32 phi (0.20 mm)	*	4 to 5.5	-45.5 to -47.7
D	2.13 phi (0.23 mm)	*	3.5 to 4.5	-43.5 to –46.9
E	2.15 phi (0.23 mm)	*	4.5 to 5.5	-49 to –50
F	1.09 phi (0.47 mm)	*	4.5 to 5.5	-47.2 to -48
G	2.05 phi (0.24 mm)	2.41	4 to 5.5	-46.5 to -49
H	2.21 phi (0.22 mm)	0.72	3.5 to 4.5	-44.4 to -45.2
J	2.12 phi (0.23 mm)	3.67	3 to 4.5	-42 to -47.4
L	2.05 phi (0.24 mm)	6.13	3 to 5.5	-42.3 to -47
N	1.86 phi (0.28 mm)	5.64	4 to 6	-43.6 to -46.7
O	2.12 phi (0.23 mm)	3.85	1.5 to 4	-40.6 to -43.9
P	2.01 phi (0.25 mm)	2.73	2 to 3.5	-39.5 to -40.5
Q	2.30 phi (0.20 mm)	0.73	1 to 1.5	-35.2 to -35.4
S	1.62 phi (0.32 mm)	1.46	3.5 to 4.5	-43.8 to -44.8
T	1.78 phi (0.29 mm)	0.25	2 to 4	-37.2 to -42

* - These borrow area are planned to be used for the Topsail Beach Federal and non-Federal projects. The excess material not used for these projects is expected to be available for the Surf City/North Topsail Beach project. This amount is approximately 9.29 million cubic yards.
yd^3 - cubic yards
mm - millimeter
MLLW – Mean Low Low Water