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The Construction and Impacts of a Groin Lengthening Project at a Southeast US Beach

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Abstract: A project to lengthen an existing groin field was recently completed at Edisto Beach, SC on the southeast coast of the US. Erosion has historically affected the island, especially at the northern (upcoast) end of the groin field. This has often left private residences with little or no dune or dry sand beach within a few years of a nourishment project. While initial erosion rates are high, monitoring has shown that after several years, the beach reaches a point of near equilibrium with the existing groin field and erosion slows. The project was completed in conjunction with a ~765,000 m3 nourishment project and included lengthening 26 groins a total of ~500 m, with individual groin extensions ranging between 12 and 30 m. Extensions were constructed with fiberglass reinforced vinyl sheetpile, armor stone, bedding mattresses, and concrete. Beach profiles show the effects of nourishment and adjustment of the profile, and improved sand retention in the lower portion of the profile. While it is still too early to consider the long-term impacts to nourishment project longevity, beach profile analysis and aerial photography show sand trapping along the extended portion of the groins, suggesting the extensions are aiding in holding a wider section than the pre-project condition. This wider beach has allowed for natural dune building, which has not been observed at a significant scale at this site previously. Finally, this paper discusses potential improvements to the project design and construction methods that may benefit future projects.

Keywords: Groin, Construction, Beach Nourishment, Structures, Project Design, Beach Slope

1 Introduction

Edisto Beach is a ~9 km barrier island positioned at the southern end of a littoral system adjacent to a large sound in southern South Carolina, USA (Fig 1). The "L-shaped" barrier includes ~2 km of developed shoreline along the inlet channel and 5 km of developed shoreline along the ocean-facing beach. The majority of ocean-front development is comprised of single-family residential housing, the first row of which is situated seaward of the main highway entering the island. The setting is a mixed-energy system (Hayes 1979) with a mean tidal range of 2 m and a typical significant wave height of 1 m. Alongshore transport is typically directed to the south in the more energetic winter months, and north during the calmer summer months (CSE 2006).

Fig. 1. Edisto Beach, South Carolina with the southern end (downcoast) of the island in the foreground.

During the past century, depletion of the sand supply along Edingsville Beach and Botany Bay Island has left a low washover beach and exposed marsh at the seaward edge. The result is high erosion rates and insufficient downcoast movement of sand toward Edisto Beach.

Edingsville Beach (just north of Edisto Beach) has been retreating at upward of 5 meters per year (m/yr) (Stephen et al 1975, CSE 2003). Further, the sediments being supplied to Edisto Beach tend to have a high proportion of mud and shells derived from the eroding marsh deposits.

By the 1950s, erosion near the Pavilion (Groin 1) on Edisto Beach reached upward of 3 m/yr (Fig 2). Erosion along Edisto Beach led to construction of the first groins in 1948 near the Pavilion and the first nourishment in 1954. The nourishment project excavated sand and mud from the marsh lagoon on the landward side of the island and pumped the material to the north end of the beach. The downcoast end of Edisto Beach (at “The Point” and along St. Helena Sound) has generally remained stable or accretional during the past century.

During the next decade, 17 groins were built from north to south in an attempt to halt the loss of sand, or at least to slow its southerly movement. However, erosion continued downcoast of the structures as each group of groins was built, sometimes to “The Point” where houses were washed out (CSE 2001). This prompted construction of more groins up to 1975 (Table 1). Groin 34 (the last one built) is situated along the South Edisto River Inlet shoreline about 1,000 m from Big Bay Creek. Groin 1-27 were constructed of timber sheets and piles, followed by additions of armor stone once the seawards ends of the timber deteriorated. Over time, the armor stone was displaced by settlement and wave impacts, and a project was completed in 1995 to restack the groins and add concrete to the void spaces to solidify the structures. The stones were placed to improve the seaward slope of the structures in an attempt to match the natural beach slope; however, the lengths of the structures were too short to reach the low-tide elevation (Fig 3).

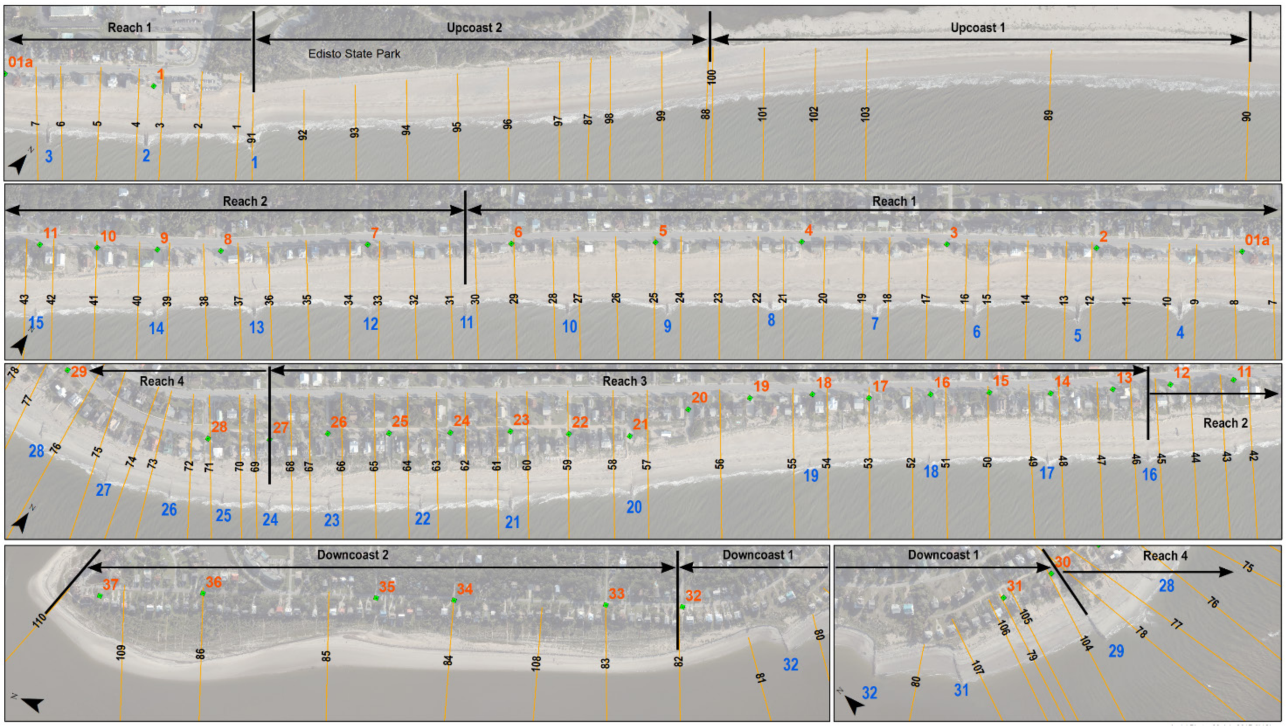


Fig. 2. Station map of Edisto Beach. Groin locations are numbered in blue, beach survey lines in black.

Tab. 1. Dates of Groin Construction at Edisto Beach

Groin Number	Date Constructed
1-2	1948
3-4	1949
5-8	1954
9-12	1953
13-17	1958
18-19	1962
20-21	1964
22-25	1969
26	1970
27-29	1972
30-33	1974

Fig. 3. Example of damaged timber/stone groin prior to 1995 rehabilitation project.

The Town constructed another large-scale nourishment project in 2006, adding 700,000 m^3 to the beach from a deposit on the shoals of the south Edisto River Inlet. While portions of the beach project performed well over time, some areas showed significant erosion within three years of the project (CSE 2015), especially near the northern (upcoast) end of the groin area. Annual volume changes in the 2006 project area ranged from −20.5 cubic meters per meter per year (m^3/m/yr) to + m^3/m/yr with an average annual loss of 7.5 m^3/m/yr between August 2006 and December 2016. This includes the impacts of Hurricanes Joaquin and Matthew in 2015 and 2016 (respectively). Generally, the northern end of the island was more erosional, losing an average of 8.8 m^3/m/yr along the northern half of the beach. The southern half of the ocean facing beach lost ~5 m^3/m/yr (respectively), while the downcoast reaches along St. Helena Sound were stable or accretional. Including the non-nourished areas, all of Edisto beach lost an average of 4.5 m^3/m/yr of sand between 2006 and 2016. Overall, the project reaches lost 445,000 m^3 of the 705,000 m^3 gained in the 2006 project, which equals ~63 percent. Approximately 37 percent of the sand placed in 2006 remained in the project area as of December 2016.

Beach volume analysis showed that following a period of rapid erosion along the northern end of the groin field, the beach volume would stabilize at a similar condition as the pre-project volume. This suggest that the groins were effective at trapping a certain quantity of sand; however, an insufficient quantity to provide suitable protection for ocean-front structures. The authors theorized that the length of the groins along the northern end of the groin field were shorter than required to hold the desired beach width, and were also shorter than areas of the beach historically maintaining a stable dune (Fig 4).

Fig. 4. Typical groin condition prior to the 2017 extension project.

2 Groin Project Design

The authors completed an independent, groin-lengthening feasibility study in 2013 (CSE 2013a,b), obtaining two alternatives for lengthening. One alternative was based on an ideal beach profile, while the other was based on comparison of the widths of vegetated areas and existing groin conditions (Fig 5). The latter method uses an emperical relationship of the in place groin length (measured from the structure line to the point on the groin matching the elevation of the dry-sand berm) and the width of the stable vegetation seaward of the structure line. These relative lengths were compared to Groin #16, which was used as a standard for the minimum acceptable vegetation width as this area has maintained an adquate width over the last several decades. This assumed that the beach in this area was in an equilibrium with the existing groins. Results of the studies were compiled into a proposed groin lengthening plan, which called for extension of up to 26 groins at a cumulative total of up to 540 meters, with some groins being lengthened beyond the length suggested by the emperical method mentioned above to comply with a separate plan being considered by the US Army Corps of Engineers. The maximum extension for a single groin would be limited to 33 m and the minimum extension for any groin would be 12 m justify the expense of mobilizing equipment and material to any structure.

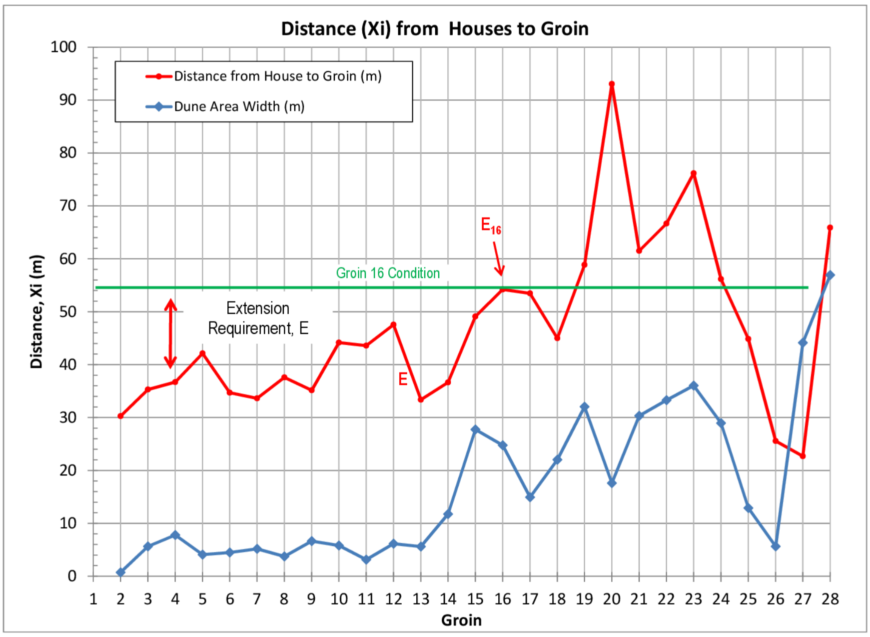


Fig. 5. Relationship bewteen groin length (relative to houses) and width of vegetated area seaward of houses.

The original groins were built by South Carolina Department of Transportation (SCDOT) and were constructed solely of timber with a typical slope of ~1 on 50. Deterioration of the timber led to the addition of armor stone and, in some cases, overall shortening of some groins. A 1995 restacked loose stone and added grout in the void spaces to make a monolithic structure, but did not lengthen the groins. The extension design attempted to adjust the profile of the groins to match modern design guidelines, which include a beach-face section sloping to match the native beach and horizontal low-tide-terrace section (Figs 6). The slope of the extension was determined by the length of each extension and the existing profile of each groin, seeking to match the native beach to the maximum extent practicable (generally 1 on 15 to 1 on 20).

Per state regulations, enough sand to meet or exceed the trapping capacity of each extension had to be placed into the updrift (north) groin cell of any lengthened groin. Trapping capacity was determined by applying the Brunn (1952) Rule to each extension and assuming a triangular fillet extending four times the length of the extension. This method was based on recent observations at Hunting Island (SC) (Traynum et al 2010) and Folly Beach (SC) and is considered conservative (requiring more sand) as it assumes a 1 to 1 ratio of groin lengthening to increased berm width. For the maximum 33 m individual groin lengthening, ~12,000 m^3 of sand are required in each applicable cell to meet the trapping capacity of the extension with a project total trapping volume of ~169,000 m^3.

3 Groin Project Construction

The groin extension project was completed over a period of 6 months (January through June 2017) for a total cost of ~$5.4 million USD. The groins were constructed using fiberglass-reinforced vinyl composite sheet pile, marine mattresses, armor stone, and concrete. Groin extensions exceeding 20 m were constructed using sheet pile with concrete caps and armor stone. Groin extensions of less than 20 m were constructed using stone only; however, concrete grout was added to these groins.

The Town received bids for steel and composite sheet pile, electing to use the composite sheets for increased longevity and reduced maintenance of the piles. The sheets were model UC–95 from Crane Materials International (Atlanta GA). Each sheet was 6 m long with a 43 cm width and 76 cm longitudinal run (meaning each pair of sheets creates a 152 cm length of wall). The sheeting is 1.42 cm-thick, fiberglass-infused vinyl that will not rust as steel sheets are prone to do. Sheets are connected via integrated channel locks running the vertical length of each sheet.

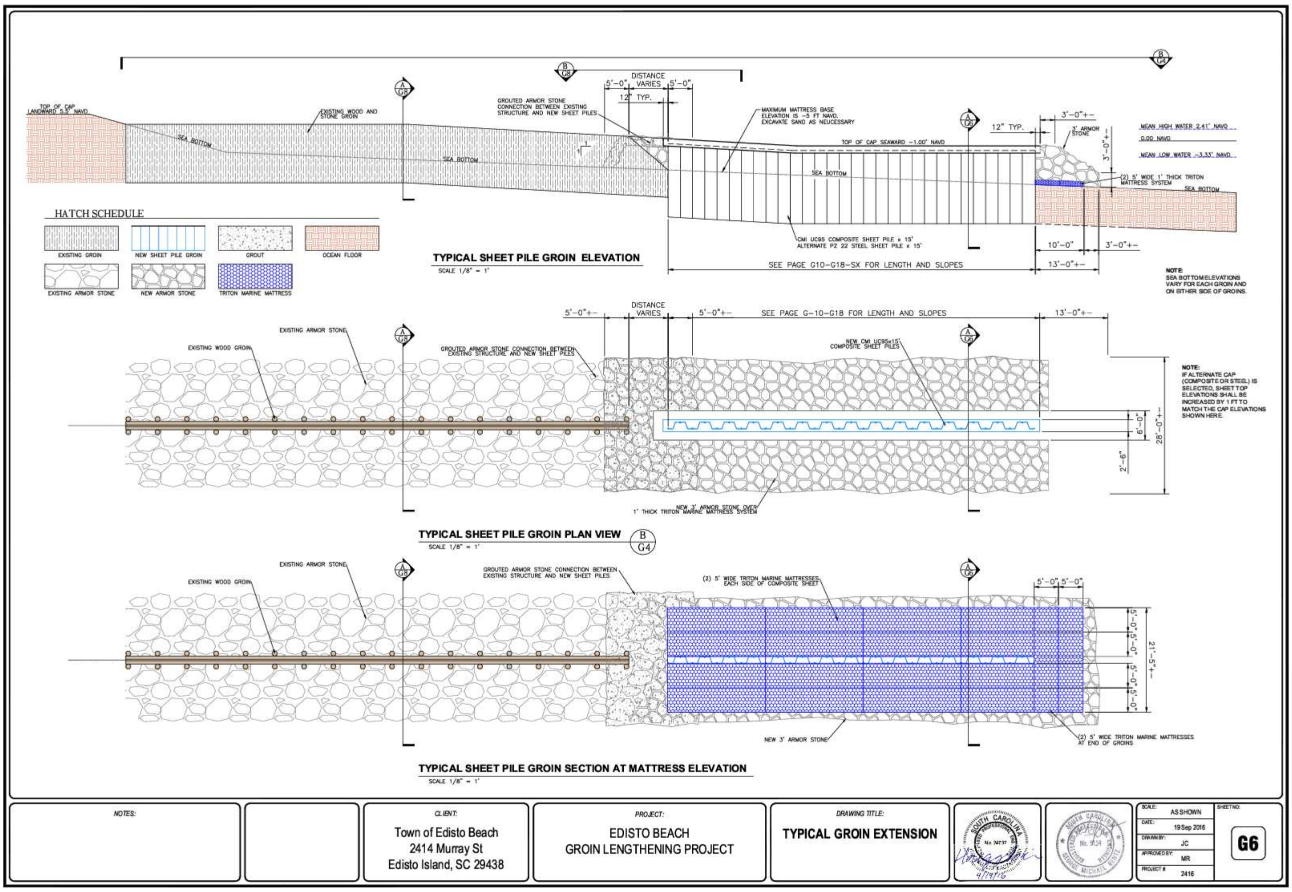


Fig. 6. Groin extension design including marine mattress, armor stone scour protection, and fiberglass/vinyl composit sheet piles.

Sheet piles were capped with a reinforced poured concrete cap. The design called for a 76 cm-wide by 46 cm -deep cap to cover at least the top 15 cm of each sheet. Concrete would be poured in sections up to 12 m in length with expansion joints between sections. Six lengths of rebar ran the length of the cap, and stirrups were spaced 76 cm on center and running through handling holes of the sheets. The top of the concrete cap was crowned to improve water runoff.

South Carolina Department of Transportation (SCDOT) Class F armor stone would serve as scour protection for sheet-pile groins and would serve as the main sand-trapping component of the shorter groins when coupled with grout. Class F stone includes 100% smaller than 1.10 m (1,814 kg), 50% smaller than 0.87 m (907 kg), and 5% smaller than 0.67 m (453 kg). The stone design included a 1 m crest width extending on either side of the cap and a slope extending a total of 4 m on either side of the sheets. With a relatively low freeboard height and large stone sizes, the slope would be fairly insignificant along most of the stone width. Stone would also extend 4 m past the seaward end of the sheet pile in a similar configuration.

The design called for armor stone to be placed on 30 cm-thick marine mattresses manufactured by Tensar®. Marine mattress were utilized to facilitate proper placement of the bedding stone when working below the low-tide line, as previous projects using filter cloth and lose stone proved difficult to complete working around the ~2m tide range. The mattresses are made of a heavy-duty plastic grid woven together with UV-resistant polyrope. Mattresses would be filled with granite stone between 5-15 cm diameter. Each mattress section is 1.5 m wide and of a variable length.

The contractor elected to complete all of the armor-stone-only extensions before completing the sheet-pile groin extensions. Armor-stone groins were extended by excavating sand to the design depth, then placing mattresses with an excavator or crane. Once the mattresses were in place, armor stone was placed to the design grade using an excavator. The contractor installed grout to the armor-stone-only groins as weather, tides, and availability allowed.

For the sheet pile groins, the contractor elected to begin at the landward end of the extension and initially used a moveable platform as a guide to drive the sheets; however, they quickly determined that a more robust template would be required to accurately drive the sheets (Fig 7). The contractor constructed a new form out of I–beams that would surround the sheet piles on two sides as they were being driven. The first sheets were driven using the excavator, which proved to be difficult with the composite sheets, as any variation from vertical would result in cracking of the top of the sheet. They switched the vibratory hammer to the crane, and sheet driving improved. The workers would drive a series of sheets until they reached the end of the template, and then would shift the template seaward. Once all of the sheets were driven to an elevation near mean sea level, the operators would drive the sheets to the final grade, checking elevations with a rod and level.

Following installation of the sheet pile, the contractor placed mattresses and a portion of the armor stone alongside the sheets. Once the armor stone was at an elevation near the bottom of the concrete cap design, workers placed forms around the tops of the sheets in preparation for pouring the concrete caps. Concrete pours needed to occur during periods of lower-than-average tides and very calm weather to prevent the concrete from washing away before it could cure. Once the concrete was poured, workers shaped a crown on the surface and the forms were left in place for at least 24 hours to allow the concrete to cure. Once the concrete was cured and the forms were removed, the contractor added additional armor stone to bring the section to the design grade. At that point, the groin extension was complete. Generally, multiple groin extensions were being constructed at any given time.

Fig. 7. Photos of groin extension construction showing driving of sheets, placement of marine mattresses and armor stone, forming of concrete cap, and a completed extension.

4 Project Performance

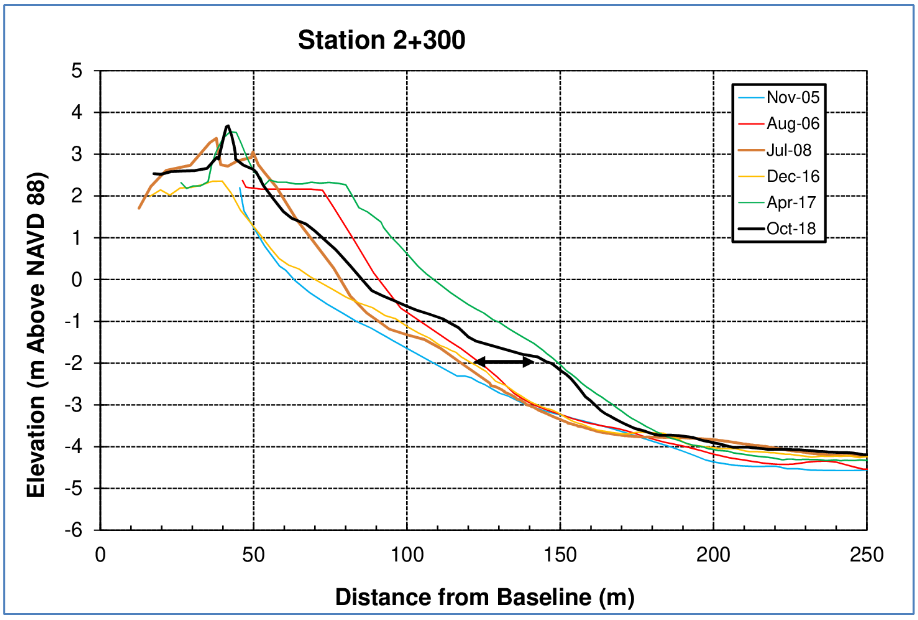
At the time of completion, the majority of the extensions were mostly buried by nourishment sand which was added during a separate, but concurrent project conducted by the Town. The nourishment project added ~765,000 m^3 of sand to the beach, which greatly exceeded the trapping capacity of the extended groins. Coastal Science & Engineering (CSE) monitored the beach volume for the Town before and after the project, as well as in 2017 after Hurricane Irma impacted the beach in the fall. Additional surveys were obtained in 2018 before hurricane season and following two hurricane impacts from Florence and Michael. Irma resulted in 1.4 m of storm surge above MHHW and mean waves of ~3.5 m offshore with a period of 11.5 s, leading to significant erosion along portions of the beach, including minor overwash of the dune along the north end of the groin field. It also modified the beach profile, eliminating any residual "construction" profile and creating a typical posts-storm profile with a shallower slope than typical for the setting. Florence and Michael were modest events at Edisto Beach and did not result in significant damage.

Fig 8 shows beach profiles from the northern end of the groin field from before and after the 2006 and 2017 projects. Each plot includes before and after project profiles, as well as a profile from 1.5-2 years after each project. At each station, the profiles from the 2006 project show that the shallow inshore zone (-2 to -4 m) was eroded to near the pre-project condition by 2008. For the 2017 project (including the groin lengthening), the lower portion of the profile maintained sand, with the -2 m contour ~25 m seaward compared to the earlier project. This compares well with the ~27-30 m groin extension length for the groins extended in this area. The groin extensions in this area were placed at an elevation of -.3 m relative to NAVD, which should more of a direct impact on the lower beach profile. The goal of the extension was to stabilize the foundation of the profile while reducing the exposure of the groins.

While these results are promising, the authors acknowledge that additional surveys in the future will be necessary to determine if these trends hold over time, or if the sand in the lower profile is a function of recent storm events and overfilling of the trapping capacity. Compared to the previous project, the percentage of nourishment fill remaining in the 2017 project is improved along most of the groin compartments in the northern end of the project area (which was the most erosional area) compared to similar post-project surveys following the 2006 project. The vertical exposure of the groins appears to have improved as well, with typical heights of 1 m exposed in 2018, compared to up to 2.5 m prior to the project.

Regarding the materials and methods of construction, the most significant issue faced to date was damage to some of the structures due to impacts of Hurricane Irma. Settlement and displacement of the armor stone at the seaward ends of some of the extensions occurred during the storm. Damage was confined to only those groins extended by sheetpile which did not have the concrete grout placed between the armor stones. A repair project was completed in 2018 to add additional stones to return the profile to the design grade, and to add grout to help stabilize the ends for future storms. As was the case for the initial construction, attempting to work with concrete at an elevation close to the mean low water elevation proved to be the most challenging aspect of groin construction or repair. To place concrete at the design elevation (reaching a depth of -1 m NAVD), there must be a suitable combination of lower than average tides, waves less than 30 cm, and the concrete plant supplying the material must be open and be able to schedule deliveries at the appropriate time (which included nights and weekend work to match tides). While construction of coffer dams would be an alternative, it would likely increase construction costs and time substantially. In the author's opinion, placement of the marine mattresses was a preferable alternative to placing loose bedding stone over filter fabric. The mattress could be placed quickly and with more precision than loose stone when working below the water line. Out of the ~200 mattress units placed, the authors observed less than 5 units showing partial damage following Hurricane Irma, and these were confined to areas where the mattresses were exposed above the sand elevation. Ideally, the mattresses would be buried to a depth exceeding the equilibrium profile elevation.

Potential modifications to the design or construction methods may improve future projects. While sheet piles were chosen for groins longer than 20 m, it is likely that these extensions could have been constructed with grouted armor stone and marine mattresses only. The major uncertainty with this alternative would be the potential for sand piping through the underwater portion of the structure that would not be grouted. Concrete caps covering the exposed top ends of the sheet pile work well once in place; however, can be difficult to construct near the low-tide elevation, especially when considering the method to form the bottom of the cap around the "z-shaped" sheets. If the structure is buried, sand can be excavated to the required elevation and used as the bottom form; however, if the sand is below grade, then sand must be added to build the grade (while waves are impacting the site) or some other method used. For this project, the contractor added gravel on top of armor stone to form the bottom of the cap. Once built, this gravel then was unrestrained and ended up on other areas of the beach. The authors suggest the most advantageous methods is that enough sand to bury the groin is added via nourishment, sheets be driven to grade, sand excavated to the necessary cap grade, and then the cap formed and poured on the excess sand prior to armor stone placement.



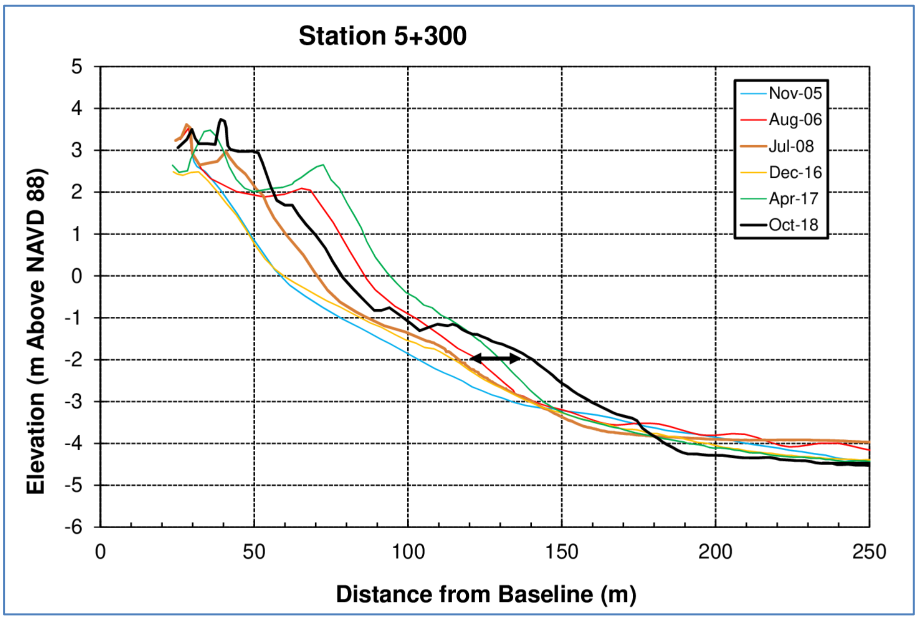


Fig. 8. Beach profiles from pre-, post-, and ~1 year post 2006 and 2017 project conditions at Edisto Beach. Groin extensions ~27m in length were included in these areas in the 2017 project which appear to be holding the lower portion of the beach profile further seaward than the 2006 project.

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