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Sand Retaining Structure to Increase Longevity of Beach Nourishment – A Case Study in the USA

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Abstract: Beach nourishment is the primary soft solution for coastal erosion and has been widely used in the USA. However, where a site's erosion rates are high, or the duration of construction has to be short, nourishment alone may not provide a sustainable solution. In such cases, sand-retaining structures can be incorporated into the nourishment design to increase project longevity. The authors have successfully implemented this combined design at several project sites. Folly Beach County Park, South Carolina was nourished at least 13 times between 1979 and 2005. After the 2005 nourishment, the restored beach eroded at an accelerated rate and was no longer providing storm damage reduction along the park. A combination of a terminal groin and nourishment was determined as the optimal means of restoring and maintaining the beach and protecting park infrastructure. The project was completed on 19 June 2013 and has been monitored since then. The results show that the once eroding beach has become an accreting beach. Adverse downdrift impacts of the structure have been negligible, primarily due to a continued updrift sand supply and efficient bypassing around the low profile structure.

Keywords: sand-retaining structure, groin, beach nourishment, longevity, Folly Beach

1 Introduction

Defense against coastal erosion generally takes two forms – hard solutions involving shore-protection structures and soft solutions involving the manipulation of sediment supplies. An intermediate defense can also be implemented whereby hard solutions (such as groins, breakwaters, and jetties) are combined with soft solutions (such as beach nourishment) to achieve the most sustainable results.

Beach nourishment (i.e., the addition by artificial means of non-littoral sediment along the shoreline) is the primary soft solution for coastal erosion and has been widely used in the USA. It rapidly preserves the recreational beach and protects upland in addition to other benefits, including storm damage reduction and environmental enhancement (Dean 2002). However, where a site's erosion rates are high, or the length of the project area has to be short, nourishment alone may not provide a sustainable solution. In such cases, sand-retaining structures such as groins are sometimes incorporated to increase nourishment longevity.

The authors have combined groins and nourishment at several project sites in South Carolina. In this paper, the Folly Beach County Park (FBCP) project will be used to quantitatively evaluate project performance and sustainability in relation to pre-project conditions.

Erosion problems have persisted along FBCP for many decades, and nourishment at the frequency performed along the park was not keeping pace with erosion. After evaluating several alternatives, a terminal groin combined with nourishment was determined as the optimal solution for restoring and maintaining a recreational beach and protecting park infrastructure. The project was completed on 19 June 2013. FBCP re-opened on 3 July 2013 and remains a premier recreational destination in the Charleston area. The American Shore and Beach Preservation Association (ASBPA) announced in May 2015 that the FBCP project is a winner of its 2015 Best Restored Beach Award for its successful enhancement of storm protection, habitat restoration, and recreation restoration.

2 Project Setting and History

Folly Beach County Park is situated along the most southwestern 1 km (~3,300 ft) of Folly Beach, Charleston County, South Carolina (Fig. 1). Folly Beach is a 10 km (~6-mile) barrier island located 11 km (~7 miles) southwest of Charleston Harbor. FBCP is bounded by the Folly Beach groin field to the northeast and Stono Inlet to the southwest, and it is dependent on the migration of sand from updrift (easterly) areas of Folly Beach. FBCP provided public beach access in the metropolitan area for 30 years before closing in 2011 due to erosion.

Erosion along Folly Beach, partly associated with the Charleston Harbor jetties (Hansen et al. 1987, USACE 1991), led to a number of shore-protection measures during the past century. A field of 45 groins was built beginning around 1947. The last group of groins was built in 1970 (Jones, 1989). Revetments and bulkheads of various styles and dimensions were built in the 1930s through the 1980s by individual property owners.

Fig. 1. Location map showing Folly Beach County Park (FBCP).

FBCP is the only section of Folly Beach that is unprotected by groins, and is dependent on the migration of sand from updrift areas and direct nourishment along the Park. In 2002, the authors recommended Charleston County Park & Recreation Commission (CCPRC as the Owner of the park) to combine beach nourishment with a low-profile, sheet-pile terminal groin for erosion control and beach restoration. However, before permits and funds were available for the project, a federal renourishment restored the beach in 2005. Due to limited park funds and the relatively healthy condition of the beach following the 2005 renourishment, CCPRC decided to forgo construction of the terminal groin.

Between 1979 and 2005, FBCP was nourished at least 13 times, and 745,500 m^3 (975,000 cy) of sand was added to the park shoreline (CSE 2012a). Among these nourishment projects, eleven were disposal events connected with the federal Folly River navigation project and were conducted between 1979 and 2000. The other two were island-wide nourishments completed by the US Army Corps of Engineers (USACE) in 1993 and 2005. However, the 107,000 m^3 (140,000 cy) of nourishment sand placed along the FBCP in the 2005 federal project provided limited protection. The restored beach eroded at an accelerated rate over the next seven years and was no longer providing the design level of storm damage reduction along the park by 2012.

The authors were retained by CCPRC in 2012 to further evaluate the erosion and outline alternatives for restoration. Overall, erosion problems have persisted along Folly Beach for many decades, and the previous nourishment efforts have restored the beach and provided some level of storm protection from time to time. Beach management experience in this area lends support to the rationale for a terminal groin. Upon review of the alternatives and direction from CCPRC officials, the most viable alternative to achieve the goals and objectives of the project was determined to be nourishment combined with a terminal groin.

3 Beach and Inshore Conditions before Project

Beach and inshore surveys were conducted in March 2012 during the planning and design phase. Results were compared with historical data to estimate rates of shoreline recession and volumetric sand loss (Kaczkowski et al. 2015).

Fig. 2 shows the network of survey profiles established and monitored along FBCP at various times since February 2002. Stationing, in engineering nomenclature, runs north(east) to south(west) with station 79+00 located at the upcoast end of the park (the location of the first groin along the City of Folly Beach property is situated near station 79+00) and station 98+00 near the 2002 proposed terminal groin (stations at 100 ft or 33 m distance). Representative profiles for station 98+00 covering the period February 2002 to March 2012 are shown in Fig. 3. The datum (NAVD – North American Vertical Datum of 1988) is close to local mean sea-level elevation. Three of the profiles (2005, 2006 and 2012) extend offshore well beyond the active beach.

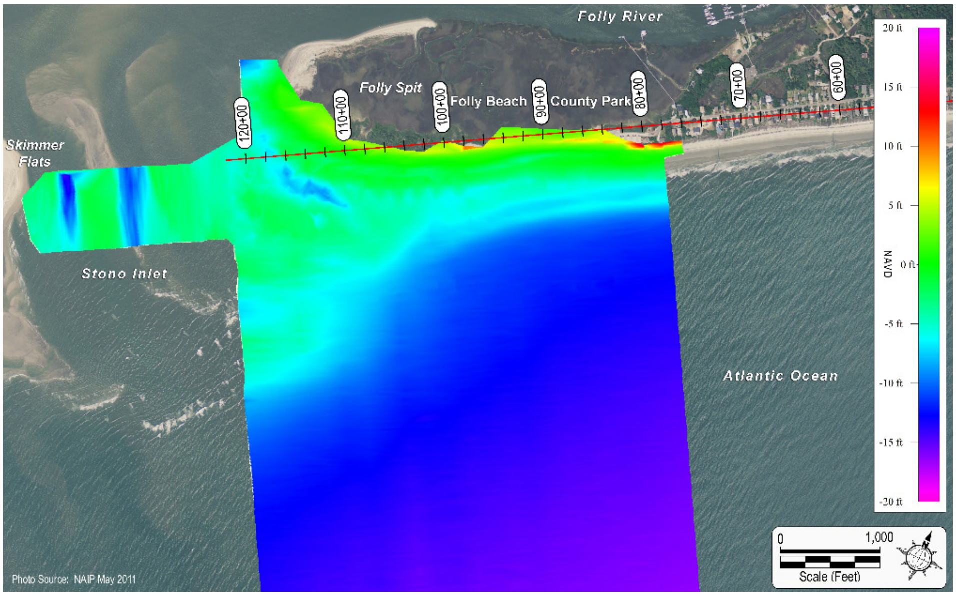

Fig. 2. Location of baseline stations for beach profile monitoring along FBCP over the past decade. The image is a digital terrain model (DTM) based on surveys by CSE in March 2012. [Underlying image is courtesy of NAIP – October 2011]

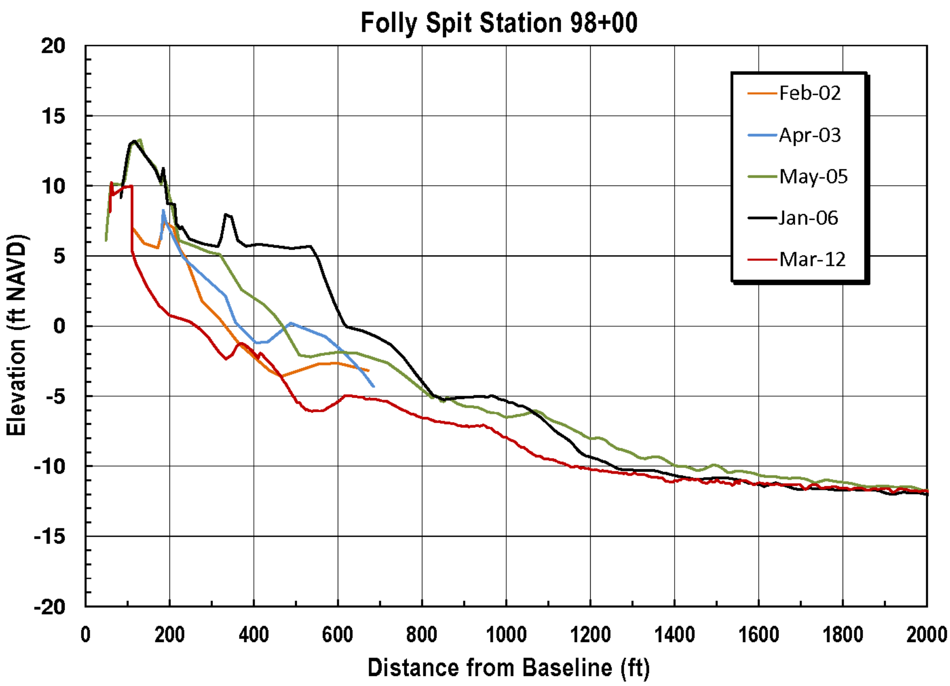

Fig. 3. Representative profiles (February 2002 to March 2012) for station 98+00 located near the proposed terminal groin.

The visible beach is situated at distances of 30–180 m (100 – 600 ft: Fig. 3) from the survey baseline. Review of the profiles in Fig. 3 shows a major advance of the visible beach between 2005 and 2006. This period coincides with the federal renourishment of Folly Beach (using an offshore borrow source off the eastern end of the island). Between 2006 and 2012, the visible beach eroded nearly 135 m (measured at the +1.5 m contour). The net change compared with February 2005 is a recession of 38 m (125 ft). In other words, the beach at station 98+00 advanced seaward from 2005 to 2006 (due to nourishment) before retreating over the next six years. Net sand volume loss within the park upcoast of the 2002 proposed terminal groin was 275,200 m^3 between January 2006 (post-nourishment condition) and March 2012. In August 2011, FBCP suffered heavy erosion after Hurricane Irene passed off the South Carolina coast. The storm rendered certain facilities inaccessible, forcing closure of the property and eliminating public access and parking on the west end of Folly Island.

The shoreline was divided into three segments for calculations of average annual volume changes:

- Updrift from Folly Beach Groin 1 to the proposed FBCP terminal groin (stations 80+00 to 98+00 : 550 m or 1,800 ft).
- Downdrift from the proposed groin to the end of the spit along the oceanfront (station 98+00 to 108+00 : 300 m or 1,000 ft).
- Seaward tip of the spit as it curves into Folly River (stations 108+00 to 120+00 : 365 m or 1,200 ft).

Average, annual sand losses were computed for available periods to −0.9 m NAVD (limit of survey data for 2002 and 2003) and to −2.1 m NAVD (a distance of 300 m offshore). The results (Tab. 1) show volume loss rates between May 2005 and January 2006 in the range 60 − 72 m^3/m/yr (24–29 cy/ft/yr) (downdrift and updrift of station 98+00, respectively). The tip of the spit eroded at 17.5 m^3/m/yr (~7 cy/ft/yr) during the subsequent period (2006–2012). For the period of 2005 – 2012, annual loss rates are around 37.5 m^3/m/yr (15 cy/ft/yr). Rates of this magnitude total 19,100 − 22,900 m^3/yr (25,000 – 30,000 cy/yr) lost along the main access area of FBCP and 30,600 − 36,700 m^3/yr (40,000 – 48,000 cy/yr) lost downcoast of the proposed terminal groin (measured to −2.1 m or –7 ft NAVD and estimated to approximately −3.6 m or –12 ft NAVD). Note: Downcoast erosion rates prior to groin installation will be important criteria for evaluating impacts and determining potential mitigation (CSE 2012b).

Tab. 1. Average annual sand volume losses per foot of shoreline for three reaches along FBCP relative to the March 2012 beach condition. See text for further explanation.

Folly PRC Total Annual Erosion Rate (m^3/m /yr) Relative to March 2012 [Note: March 2012 data is used as the baseline and therefore, is not shown in the.]						
Reach/Station		**Distance (m)**	**Feb-02**	**Apr-03**	**May-05**	**Jan-06**
1 to Proposed roin	**80+00 to 98+00**	550	−11.5	−15.8	−35.5	−71.8
Proposed roin to South	**98+00 to 108+00**	300	−6.0	−12.5	−39.5	−60.5
Tip of Spit	**108+00 to 120+00**	365	−7.0	−7.0	−18.0	−17.0
Calculation Limits			Backshore to −0.9 m NAVD	Backshore to −0.9 m NAVD	Backshore to −2.1 m NAVD	Backshore to −2.1 m NAVD

4 Project Formulation

4.1 Overall Plan

The total volume and distribution of nourishment sand were based on the analysis of potential downdrift impacts, which evaluated the sediment trapping capacity of the terminal groin. Considerations were also made for reestablishment of the recreational area, protection of remaining infrastructure, reconstruction of the parking area, and the need to construct the groin using land-based equipment. A total of 317,300 m^3 (415,000 cy) nourishment and a 225 m (745 ft) steel sheet-pile system with a concrete cap and toe protection were determined as the optimal final design to achieve the project objectives (Fig. 4).

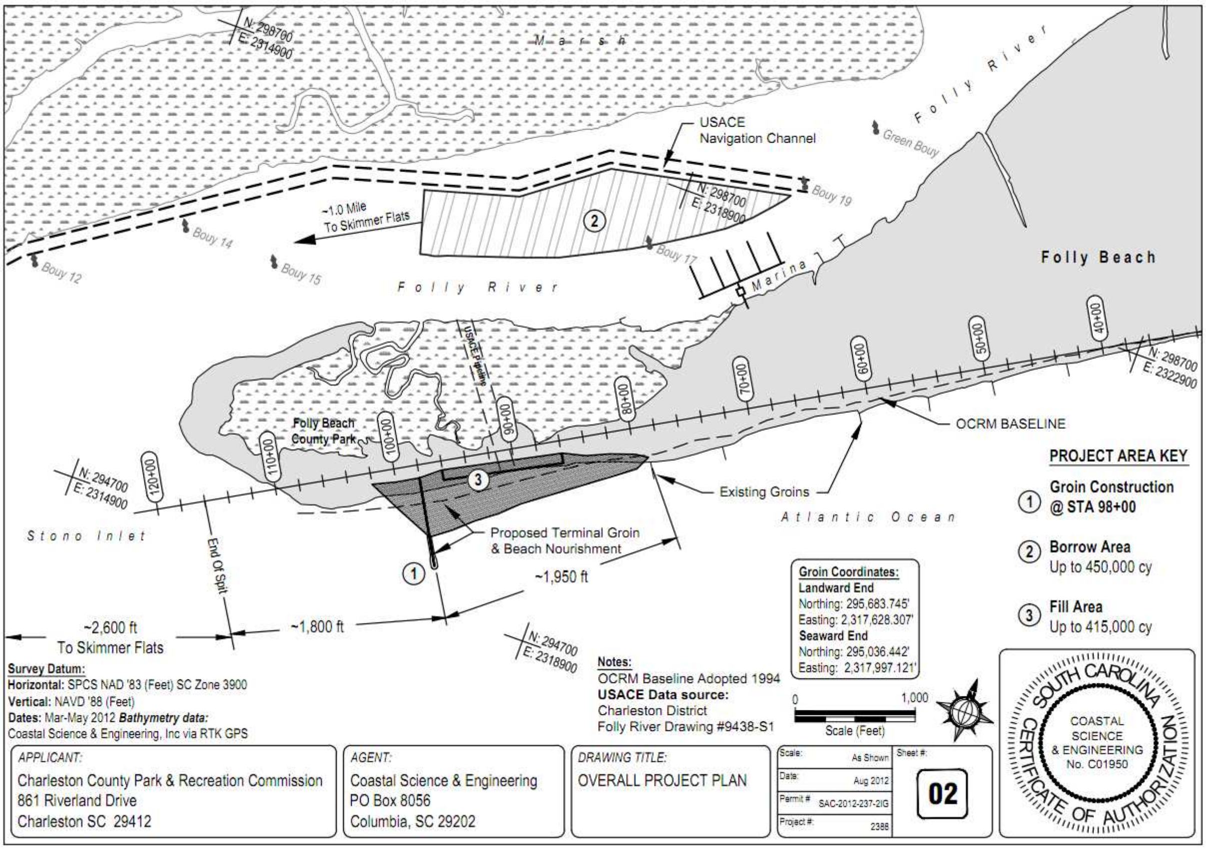

Fig. 4. Project plan for permit application. The plan called for nourishment of up to 317,300 m^3 (415,000 cy) from a borrow area spanning a mid-channel shoal in the Folly River. The limits of the borrow area were modified.

4.2 Nourishment Plan

The nourishment and groin construction project encompassed 685 m (2,250 ft) along the west end of Folly Beach from the westernmost timber groin (station 79+50) near the entrance of the county park to station 102+00, 120 m (400 ft) west of the terminal groin location (see Fig. 4). The pre-project beach was mostly in a washover condition with the only high-ground areas being near the park entrance (station 81+00) and a narrow vegetated area at the western limit of the project. The total volume needed to restore the 2006 condition was 275,200 m^3 (360,000 cy) and the total design fill volume was 15% higher than this value, yielding a maximum of 317,300 m^3 (415,000 cy). The project called for excavation of the material from a borrow area in the Folly River immediately adjacent to the western spit of Folly Beach. Sediment quality in the borrow area was determined by fifteen borings reaching the target dredge depth of approximately −4 m NAVD. Results of sediment tests showed that mean grain size for all samples in the borrow area is 0.15 millimeters (mm) with less than 1 percent of fines (finer than 4.0 phi). Native beach mean grain size range from 0.169 mm (visible beach) to 0.124 mm (ocean) prior to the 2012 nourishment. Analysis of borrow area and native beach showed that the proposed borrow area contained beach-quality and compatible sediment. Sand was pumped through a pipe crossing the marsh between the river and the spit along a designated easement for projects performed by the USACE.

Planned fill quantities varied from 87.5 m^3/m (35 cy/ft) at the east end of the project area to 575 m^3/m (230 cy/ft) near the groin (station 98+00). The fill template was designed to facilitate groin construction. Excess material was placed in the vicinity of the groin to allow construction of the groin using land-based equipment, eliminating the need for cofferdams or barges. The initial plan was for the groin to be built beginning at the landward end and progressing seaward. To accommodate this, the nourishment contractor would periodically pump sand at the groin location to gradually increase the beach width and provide a platform for construction.

4.3 Groin Design

Groin trapping capacity is a function of the groin length and profile relative to the beach profile. A goal of the present project was to construct a groin that has a profile closely matching the natural slopes of the beach to the extent practicable. Design guidance by American Society of Civil Engineers (ASCE 1994), Basco and Pope (2004), and others indicate that groins should typically consist of three sections (Fig. 5) — inshore (berm) section, sloping intermediate section, and horizontal seaward section. The inshore (berm) section is designed to control the width of the dry beach in the updrift fillet. The sloping section is intended to follow the average slope of the beach across the intertidal wave swash zone. The seaward section is intended to retain the low-tide terrace such that the profile above the low watermark remains stable.

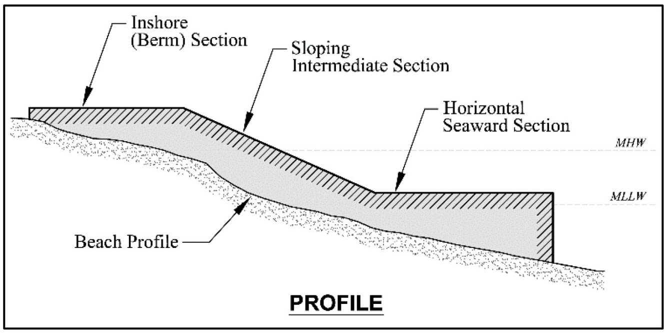

Fig. 5. Typical groin profile showing inshore (berm) section, sloping intermediate section, and horizontal seaward section. [From ASCE 1994]

Few groins in the USA adhere to this three-section configuration because:

1. Most groins from the 1930s to the 1960s consisted of a single gently sloping crest that terminated above or near the high-tide level, and
2. Few groins have been constructed in the US since the 1970s.

Early groins terminated above high water for ease of construction. The result was structures that did not follow the natural profile of a South Carolina beach. As the beach equilibrated around the timber groins, the head section was left well above the sand level, adding to structural stresses experienced at this critical point. Timber failures led to sand leakage and further lowering of the profile until the structures failed at the heads due to excessive exposure. Timber groins constructed by the South Carolina Highway Department in the 1950s and 1960s typically sloped at ~1:50 from the base of the foredune (starting at +2.1 m to +2.7 m or +7 ft to +9 ft NGVD) to mean high water or higher. Their lengths were typically 75 m (250 ft), terminating landward of the low-tide beach. Because their crests did not follow the natural profile of the beach, the head sections of the structure were more exposed (Kana et al. 2004).

The proposed groin at FBCP was designed to follow the local beach profile to the extent practicable. The average slope of the natural beach served as a basis for establishing the sloping section of the groin. The proposed groin at FBCP was designed to be located at station 98+00, and composed of three sections: berm section, beach-face section, and low-tide terrace section (Fig. 6).

The final profile of the groin included a 60 m (200 ft) backshore section at +1.8 m (+6 ft) NAVD, a 60 m (200 ft) berm portion sloping from +1.8 m to +1.5 m (+6 to +5 ft) NAVD, a 75 m (245 ft) beach-face section sloping 1:35 from +1.5 m to −0.6 m (+5 ft to –2 ft) NAVD, and a 30 m (100 ft) low-tide-terrace section at −0.6 m (–2 ft) NAVD. Elevations are to the top of the steel sheet piles—the concrete cap increased the elevation of the final groin by 25 cm (10 inches). Granite armor stone (SC DOT Class F – 36-inch [91 cm] maximum diameter), bedding stone, and a filter cloth layer were to be placed at the seaward end for toe protection.

To estimate groin-trapping capacity, the groin profile was superimposed on the beach section of nearby station 98+00. Beach fill was placed over the profile, then assumed to adjust to an equilibrium shape matching the natural profile. The berm section width (of the groin) was used to establish the point at which the adjusted profile closely matched the groin cross-sectional area. Some allowance was made to round values for simplification of the design and in consideration of the fact that a natural profile will not exactly match the groin profile because it is continually being modified by waves and tides.

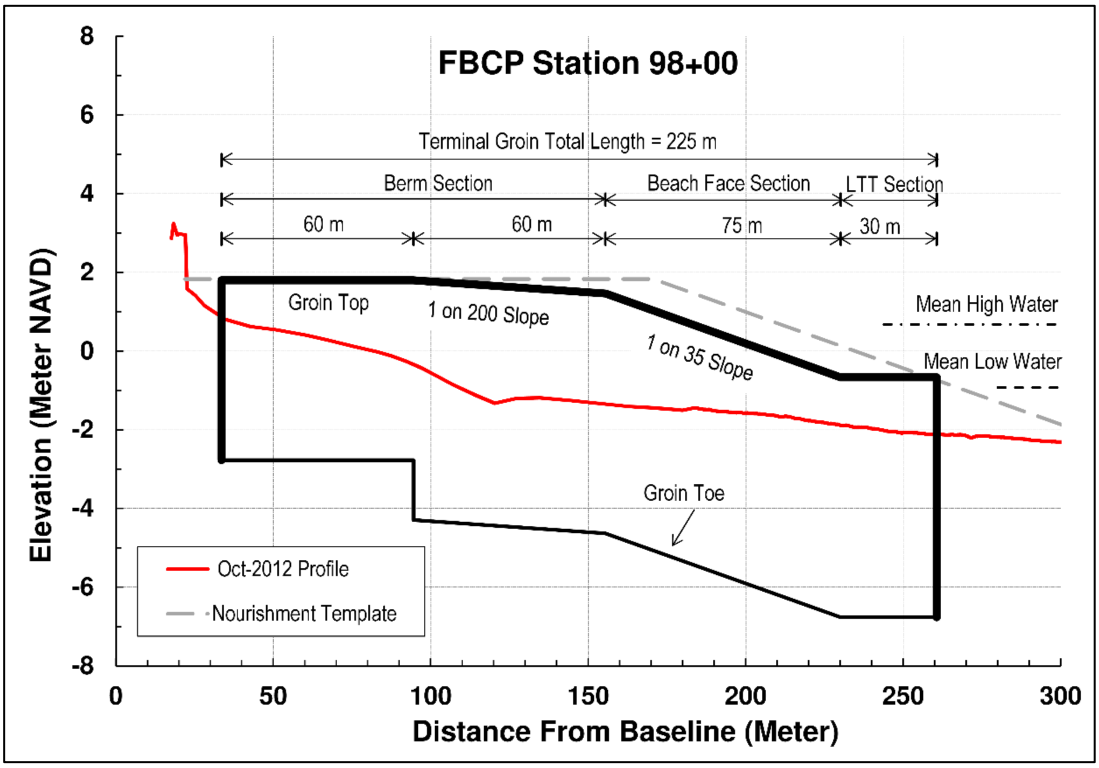

Fig. 6. Generalized cross-section profile of the design groin, calling for slopes to match the natural profile of the beach (1:35) along the beach face section. Sheet pile lengths were 4.5 m along the back berm section and 6 m along the front berm, beach face, and low tide sections.

A fillet length to berm width ratio of 5:1 was adopted for the present project based on the estimation from the shoreline planform around existing South Carolina groins, particularly around the Hunting Island groin field. The 120 m (400 ft) berm width on the updrift side of a groin would be expected to produce a fillet extending about 600 m (2,000 ft) upcoast (i.e. from the proposed location at station 98+00 to the southernmost existing groin near station 80+00), yielding the total groin-trapping volume of 137,600 m^3 (180,000 cy). The seaward section would be expected to have a maximum reveal of 1 m (3 ft) at full capacity.

Obviously, more or less sand may accrete at various times against the groin. However, for purposes of establishing the trapping capacity in a uniform manner, the above-stated design was proposed as being realistic for the FBCP setting and the project objectives.

5 Project Implementation

Nourishment commenced on 5 May 2013 and continued through 20 May 2013 (CSE 2013). The nourishment design sought to restore the recreational beach and provide a sand platform to facilitate groin construction. This required a tapered fill plan, where most of the sand was concentrated near the groin location at the west end of the park. Post-project berm widths increased by up to 150 m (500 ft) compared to the pre-project condition. Pre- and post-project surveys performed in March and July 2013 show a net increase of 333,883 m^3 (436,703 cy) of sand over FBCP and Folly Spit (quantities above the excavation volume of 317,300 m^3 [415,000 cy] are likely due to natural accretion occurring during construction).

The groin profile followed modern design guidelines (ASCE 1994) applied to the conditions at the site. The basic structure consisted of SKZ cold-formed, steel sheet pile supplied by Skyline Steel. Steel material was ASTM A572 Grade 50, and sheet-pile lengths varied between 4.5 m and 6 m (15 ft and 20 ft). The structure was topped by a formed and poured concrete cap, 80 cm (32 inches) wide by 40 cm (16 inches) deep. Concrete reinforcing steel was ASTM A615 Grade 60 epoxy-coated. The concrete cap raised the final crest by 25 cm (10 inches). Erosion control (scour protection) around the head of the groin consisted of a 1.2 m (4 ft) layer of SCDOT Class F quarry stone on top of a 46 cm (18 inch) layer of 5 cm (2 inch) bedding stone. The base of the bedding stone and filter material extended 7.6 m (25 ft) from the groin, covered the last 38 m (125 ft) of the structure, and extended 7.6 m (25 ft) seaward of the end.

Installation of the groin occurred between 15 May and 20 June 2013 and began at the seaward end of the groin. A 91 cm (36-inch) diameter steel column, filled with concrete and extending to +3 m (+10 ft) NAVD, was installed to mark the end of the structure during all tides. Construction was completed using land-based equipment, utilizing sand dikes and working around the tide as necessary.

Following construction, CCPRC installed sand fencing, parking posts, and limited infrastructure necessary to reopen the park. A public grand reopening was held on 3 July 2013. CSE completed a post-construction as-built survey of the park, Folly Spit, and the borrow area in late July 2013 to serve as an immediate post-project condition and baseline for post-project monitoring.

6 Project Performance

A third party surveyor, GEL (located in Charleston, South Carolina) was retained by CCPRC and conducted annual beach monitoring surveys after project completion. Their results show that shoreline change rates in the vicinity of the terminal groin have trended significantly more accretional than historical rates indicating that the terminal groin is effectively stabilizing the FBCP (see Tab. 2). The 2017/2018 shoreline change rate in the monitoring area was 29 m^3/m/yr (+11.61 cy/ft/yr). FBCP has gained sand each year between 2014 and 2018. The history of erosion has been reversed, and beach performance at the FBCP has stabilized.

Tab. 2. Folly Beach erosion and accretion values provided by a third party surveyor, GEL (Charleston, SC). Results were calculated from parking or vegetation line to −0.9 or −1.8 m NAVD by annual surveys from April 2014 to April 2018 (GEL 2018). Survey stations are shown in Fig. 2.

Reach	Distance (m)	April 2014 vs. April 2015 (m^3)	April 2015 vs. April 2016 (m^3)	April 2016 vs. April 2017 (m^3)	April 2017 vs. April 2018 (m^3)	Previous Erosion (−) Accretion (+) Rate (m^3/m/yr)	2017/2018 Annual Erosion (−) Accretion (+) Rate (m^3/m/yr)
80+00 – 98+00 East of Groin to -1.8 m NAVD	**550**	+31,130	+12,815	+1,100	+8,390	+2.2	+15.3
98+00 – 108+00 West of Groin to -1.8 m NAVD	**300**	+10,025	−1,390	−4,215	+14,670	−14.5	+48.9
108+00 – 120+00 To -0.9 m NAVD	**365**	−4,975	+19,555	−11,765	+5,035	−31.9	+13.8
98+00 – 102+00 Permit Study Area to -1.8 m NAVD	**670**	+38,955	+13,930	+680	+19,660	+1.0	+29.3

The authors have also been surveying the project area using a set of stations established by the State of South Carolina, as illustrated in Fig. 7. Profiles of a representative station are plotted in Fig. 8. The overall results are consistent with GEL's annual survey results and show that the once eroding beach has become an accreting beach (Fig. 9). Downdrift stations (2801E and 2803E) have gained an average of 15 m^3/m/yr (6 cy/ft/yr) of sand between November 2013 and November 2018, indicating that the groin reached the maximum sand-trapping capacity and excess sand has bypassed the structure and migrated downdrift. Updrift stations (2805E and 2810) have also gained sand at a rate of 17 m^3/m/yr (6.8 cy/ft/yr) over the past five years. Adverse downdrift impacts of the structure have been negligible primarily due to a continued updrift sand supply and efficient bypassing around the low profile structure.

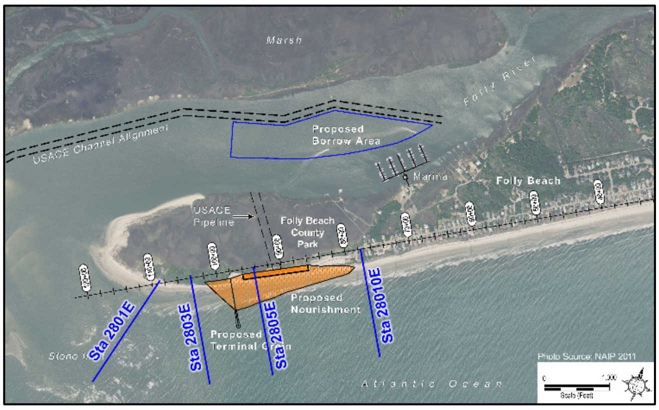

Fig. 7. Overall plan of the 2013 terminal groin and beach nourishment, and the locations of the post-project survey stations (2801E to 2810E).

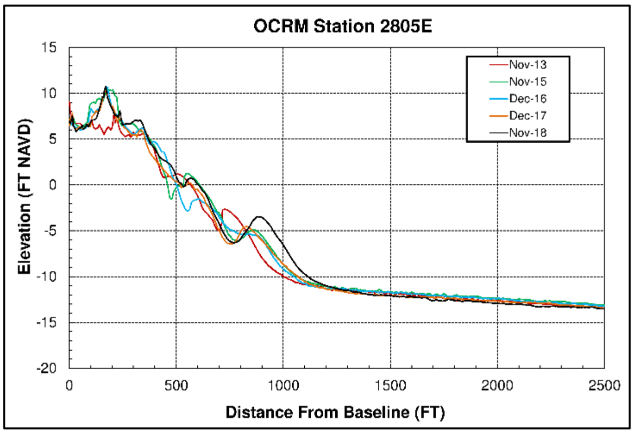

Fig. 8. Post-project survey profiles along station 2805E (~500 feet updrift of the groin.).

Fig. 9. Aerial photos of FBCP before and after the 2013 project.

[UPPER] Photo taken on 24 March 2013 before the project.

[MIDDLE] Photo taken on 24 July 2013 after project completion.

[LOWER] Photo taken on 17 August 2018 five years after project completion.

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