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MORPHOLOGICAL RESPONSE OF A NOURISHED BEACH WITH BURIED GROINS TO A SERIES OF WINTER STORMS

REPONSE MORPHOLOGIQUE D'UNE PLAGE NOURRIE AVEC DES EPIS ENFOUIS A UNE SERIE DE TEMPETES HIVERNALES

RESPUESTA MORFOLÓGICA DE UNA PLAYA NUTRIDA CON ESPIGONES ENTERRADOS A UNA SERIE DE TORMENTAS INVERNALES

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ABSTRACT
Ortley Beach, located along the Atlantic coast of New Jersey, is an erosional hot spot with shore protection measures including beach nourishment and a buried groin field. 5 beach profiles were measured with dense spatial (about 100 m apart along the shoreline) and temporal intervals (2-3 weeks) from February 10 to May 12 in 2023. During the energetic winter season from February 10 to March 17, a large longshore variation of beach changes was measured. Beach accretion was observed at southern part of the study area due to impoundment effect of buried groin interacting with northerly-directed longshore sediment transport. Severe beach/dune erosion was measured at profiles at the northern part of the study area adjacent to the downdrift of the groin field. The shoreline offset did not occur exactly at the place of the groin, instead sediment bypassed the buried groin and the deposition extended tens of meters downdrift of the groin. Later, as the weather transitioned to spring, the frequency and intensity of large waves subside, substantial beach accretion occurred at all the measured beach profiles. Another winter storm in late April eroded the beaches back to the previous stage. With wider pre-storm beach profile, no distinctive shoreline offset was created by buried groin field induced by this storm in late April. This suggests the status of the pre-storm beach profile playing an important role in controlling long-shore variations of beach changes. Systematic beach profile monitoring is essential to investigate the threshold of beach width for the occurrences of shoreline offset induced by the buried groins. In addition, this study was conducted with undergraduate students when the coastal study program at Kean University (Hispanic-Serving Institution) just started, thus it can also serve as an example in initiating and conducting field-based coastal research with students.
Keywords: Seasonal beach changes, Winter storms, Hard structures, Coastal processes, New Jersey

RESUMO
Ortley Beach, localizada ao longo da costa atlântica de Nova Jersey, é um ponto quente de erosão com medidas de proteção da costa, incluindo alimentação da praia e um campo de espigões enterrados. Cinco perfis de praia foram medidos com curtos intervalos espaciais (cerca de 100 m ao longo da costa) e temporais (2-3 semanas) de 10 de fevereiro a 12 de maio de 2023. Durante a enérgica temporada de inverno de 10 de fevereiro a 17 de março, foi medida uma grande variação na faixa de praia. Uma acreção na praia foi observada na parte sul da área de estudo devido ao efeito de represamento do espigão enterrado interagindo com o transporte longitudinal de sedimentos direcionado para o norte. Uma erosão severa das praias/dunas foi medida em perfis na parte norte da área de estudo, a jusante do campo do espigão. O deslocamento da linha de costa não ocorreu exatamente no local do espigão, em

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vez disso, o sedimento contornou o espigão enterrado e a deposição se estendeu por dezenas de metros a jusante. Mais tarde, quando o clima mudou para as condições de primavera, a frequência e a intensidade das grandes ondas diminuíram, e ocorreu um acréscimo substancial de praia em todos os perfis de praia medidos. Outra tempestade de inverno no final de abril erodiu as praias de volta ao estágio anterior. Com um perfil de praia pré-tempestade mais amplo, nenhum deslocamento distintivo da linha costeira foi criado pelo campo de espigões enterrados induzido por esta tempestade no final de abril. Isso sugere que o perfil da praia pré-tempestade desempenha um papel importante no controle das variações litorâneas das mudanças na praia. O monitoramento sistemático do perfil da praia é essencial para investigar o limite da largura da praia para as ocorrências de deslocamento da linha de costa induzida pelos espigões enterrados. Este estudo foi realizado com alunos de graduação do programa de estudos costeiros da Kean University (Instituição Hispanic-Serving), e também pode servir como um exemplo para iniciar e conduzir pesquisas costeiras de campo com alunos.
Palavras-chave: Mudanças sazonais de praias, Tempestades de inverno, Estruturas duras, Processos costeiros, Nova Jersey

RESUMEN
Ortley Beach, ubicada a lo largo de la costa atlántica de Nueva Jersey, es un punto crítico de erosión con medidas de protección costera que incluyen alimentación en la playa y un campo de ingle enterrado. Se midieron cinco perfiles de playa con intervalos espaciales densos (alrededor de 100 m de distancia a lo largo de la costa) y temporales (2-3 semanas) del 10 de febrero al 12 de mayo de 2023. Durante la enérgica temporada de invierno del 10 de febrero al 17 de marzo, una gran variación de los cambios de rango se midió. Se observó acumulación de playa en la parte sur del área de estudio debido al efecto de embalse de la ingle enterrada que interactúa con el transporte de sedimentos costeros dirigido hacia el norte. Se midió la erosión severa de la playa/dunas en los perfiles de la parte norte del área de estudio adyacente a la deriva aguas abajo del campo de espigones. El cambio de línea de costa no ocurrió exactamente en la ubicación de la ingle, pero el sedimento pasó por alto la ingle enterrada y el depósito se extendió por decenas de metros aguas abajo de la ingle. Más tarde, cuando el clima cambió a primavera, la frecuencia y la intensidad de las olas grandes disminuyeron, y se produjo una acumulación significativa de playa en todos los perfiles de playa medidos. Otra tormenta de invierno a fines de abril erosionó las playas al nivel anterior. Con un perfil de playa más amplio antes de la tormenta, no se crearon cambios distintivos en la costa debido al campo de ingle enterrado inducido por esta tormenta a fines de abril. Esto sugiere que el estado del perfil de la playa antes de la tormenta juega un papel importante en el control de las variaciones litorales de los cambios de playa. El monitoreo sistemático del perfil de la playa es esencial para estudiar el umbral del ancho de la playa para casos de desplazamiento de la línea de costa inducido por espigones enterrados. Además, este estudio se realizó con estudiantes de pregrado cuando el programa de Estudios Costeros de la Universidad de Kean (institución que atiende a hispanos) apenas comenzaba, por lo que también puede servir como ejemplo para iniciar y realizar investigaciones de campo costeras con estudiantes.
Palabras clave: cambios estacionales en las playas, tormentas de invierno, estructuras duras, procesos costeiros,Nueva Jersey

INTRODUCTION

The beach is a dynamic system typically characterized by energetic waves and anthropogenic alterations. Hard structures such as groins, revetment, and sea wall can hold the beach fronting the infrastructure. Field observations indicate that the usage of hard structures can affect longshore sediment transport creating impoundment at one side of the structures, while reducing the sand supply to beaches downdrift (Roberts and Wang, 2012). A properly designed notched groins can allow bi-directional sediment transport and result in relatively symmetrical shoreline as indicated at Deal beach, New Jersey, USA (Zimmerman and Miller, 2021). An alternative approach for shore protection is through soft solution such as beach nourishment and living shoreline.

The first beach nourishment project conducted in the United States was at Coney Island, New York in 1922-1923. As time passed, this methodology became common on the long Island and New Jersey coasts, then along the coast of states southward (Davis, 2018). Over the past 30 years, beach nourishment has become a widely used method for sandy shore protection against chronic and storm-induced erosion (Houston, 2022). The aftermath of hurricane Sandy made landfall in Atlantic County New Jersey in October 2012 demonstrates the effectiveness of the beach/dune nourishment. Communities that suffered the greatest damages to structures and infrastructure from Sandy were those where dunes were non-existent, or where elevations of the beaches and dunes were low or had narrow beach widths (Barone et al., 2014). Nowadays, the coexiting of hard structures and beach nourishment is a common shore protection measure, and hard structures are most often being used to help retain nourished sand and extend the life of a nourishment project. Shore protection is an important task especially under the circumstance of

increasing storm activities due to climate change. Systematic monitoring of beach profiles is the first and foremost approach to unravel various processes that governs their changes. In this study, time series of beach profiles were measured at an erosional hot spot at a stretch of nourished beach where a buried groined field exists. It is worth noting that the study was conducted with undergraduate students when the coastal study program at Kean University just started, thus it can also serve as an example in initiating and conducting field-based coastal research with students.

STUDY AREA AND METHODOLOGY

The study area is located at the north end of Ortley Beach in New Jersey, facing the Atlantic Ocean. The dominant wave direction is from the southeast and east. This is due to Long Island, located in New York, blocking the northeast wind and the north-eastly wind becomes fetch limited. The net longshore transport in the area is to the north and has been estimated at between 245,000 and 375,000 m^3/yr (Lemke and Miller, 2017). During hurricane Sandy, the study area experienced severe infrastructure damage as indicated by post storm LiDAR (Light Detection And Ranging) surveys (Hatzikyriakou et al., 2015). As a shore protection measure, beach nourishment has been regularly conducted in this area approximately every 6 years. Groin field was constructed in the late 19th and early 20th centuries, and currently was buried by the nourished sand.

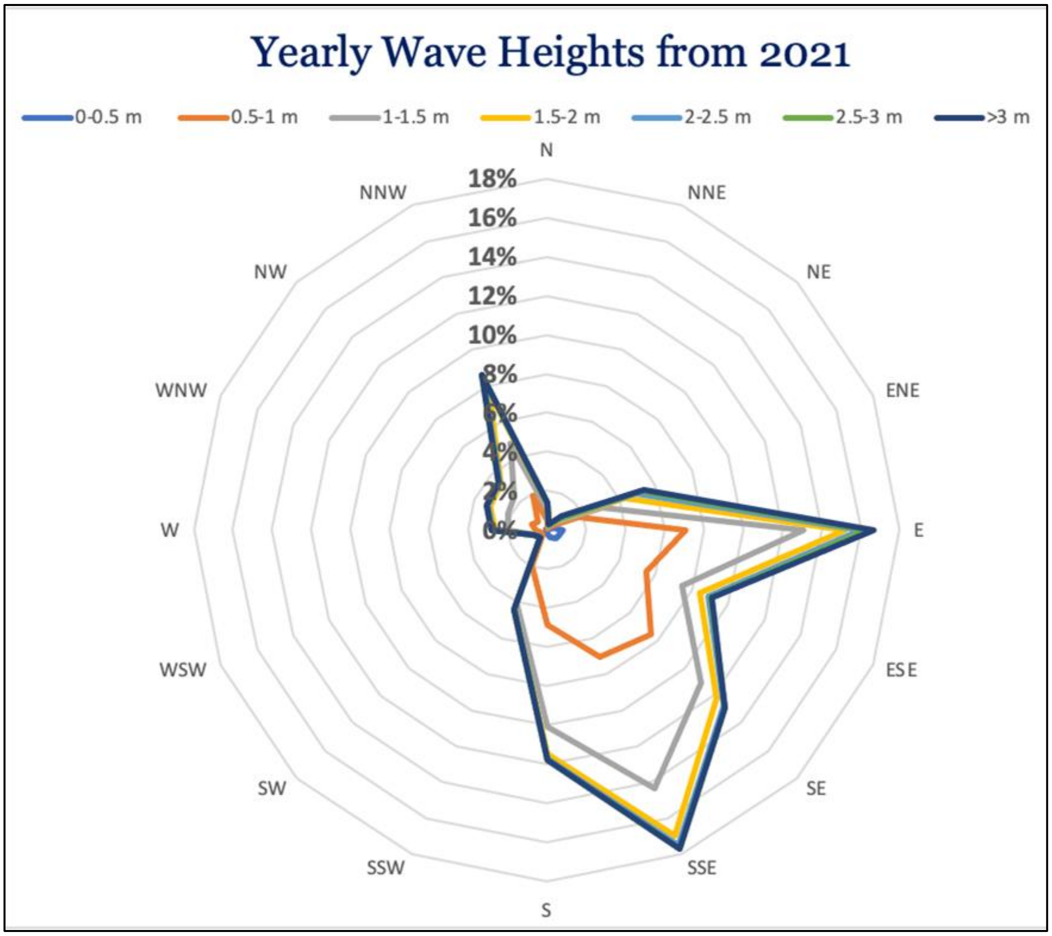
Five beach profiles were surveyed from February to May 2023 with a spatial interval of 100 m and temporal interval of 2-3 weeks. The location of these survey lines was at the boundary of a groin field (Figure 1). Given the northward longshore sediment transport, the survey lines 3,4,5 were located downdrift of the groin field, and survey line 1, 2 located updrift of the groin field (Figure 1). The beach profile from the edge of dune field to water edge was surveyed using RTK-GPS. The system is composed of a Topcon Hiper VR receiver and a FC-6000 data logger. The Topnet Live services are used for real-time position and elevation correction, which eliminates the need to establish a local GPS base station.

Fig 1. Study area with location of measured beach profiles and a groin field

Source: Google Earth, 2023

Rose diagram of one-year wave is presented in Fig. 2 with the data extracted at the gauge of NDBC 44091 located at 25 km offshore of the study site. The Rose diagram is generated using Excel, which is easily accessible to students with an online tutorial (https://www.youtube.com/watch?v=goLqJp2g87c). In order to obtain the nearshore wave field, CMS-Wave model (Lin et al., 2011) developed by U.S Army Corps of Engineers was used to propagate the offshore wave towards the shoreline. CMS wave is an interface-driven model and user friendly to beginners in numerical modeling (https://www.aquaveo.com/software/sms-cms-wave). Wave fields were generated by CMS wave with two representative input conditions: A) wave H=3 m; T=9 S; Angle=150˚(Fig 3A); and B) H=3 m; T=9 S; Angle=90˚(Fig. 3B). It is apparent that northward longshore transport exists under the typical wave patterns coming from southeast. The nearshore modeled wave field also indicates that the coast located to north of the study area experiences smaller wave heights (green color in the contour map indicates smaller waves), while the Ortley beach experienced larger wave (blue color in the contour map indicates larger waves). This can explain an erosional hotspot exists at the study site. The study area is micro-tidal with a mean tidal range of 1.3 m**.**

Fig 2. Wave climate obtained from NOAA gauge 44091 during the year of 2021.

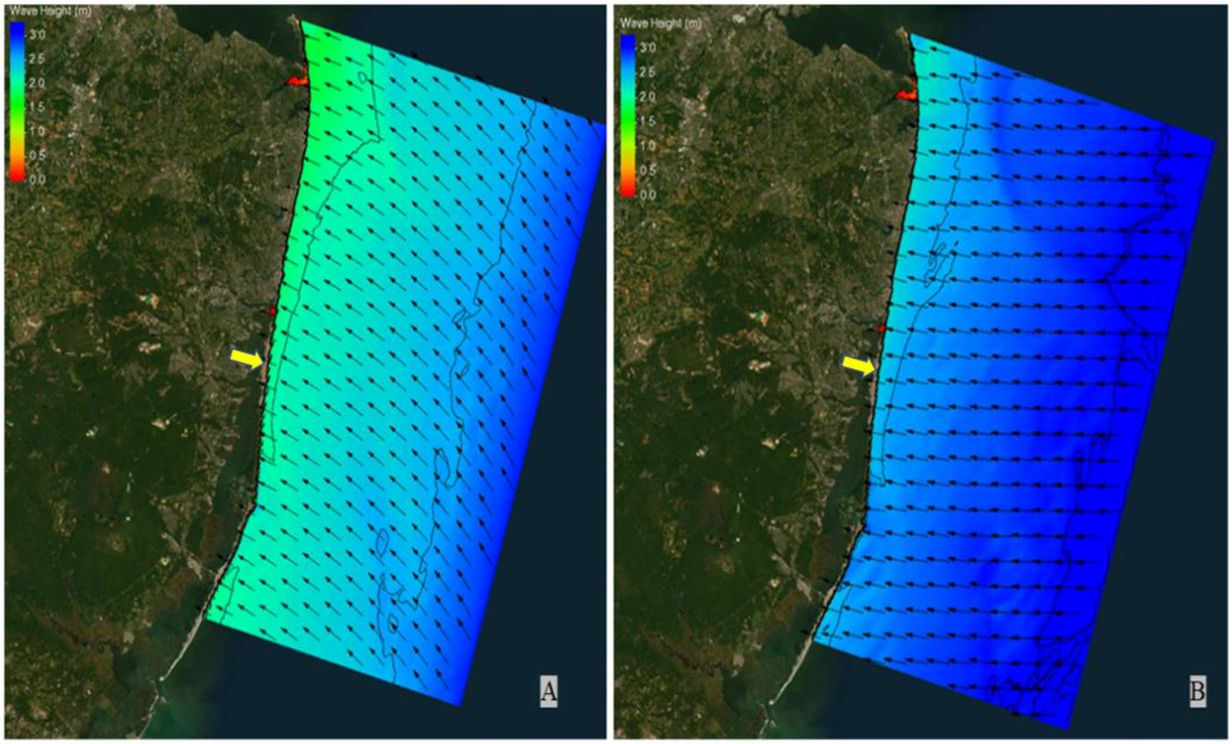


Source: The authors

RESULTS AND DISCUSSION

In total, 5 beach profiles were measured from February to May of 2023 (Fig. 1). As the profile 1, located at the southern end of the study area, experienced a similar change pattern as that of profile 2. Thus profile 1 was not included here and only 4 profiles (profiles 2 to 5) were presented (Fig. 4). The field photos were presented in Fig. 5. Although the study area only expands a few hundred meters alongshore and the survey lasted about 3 months, beach changes exhibit a large spatial and temporal variation. The existence of the end of the groin field in the study site is the major factor for the considerable longshore variation. From the February 10 to March 17, there are a series of winter storm impacted the study area (Fig. 6). The peak significant wave height reached 4 m, with a period of 12 s, and 100° of wave direction (mostly coming from the east and southeast). Under these wave conditions, beach profile 2 located at the updrift of the groin field experiencing accretion from Feb 10 to March 17 (Fig. 4A).

Fig 3. modeled wave field under A) Input wave H=3 m; T=9 S; Angle=150, B) Input wave H=3 m; T=9 S; Angle=90˚. Yellow allows indicates where the study site is.

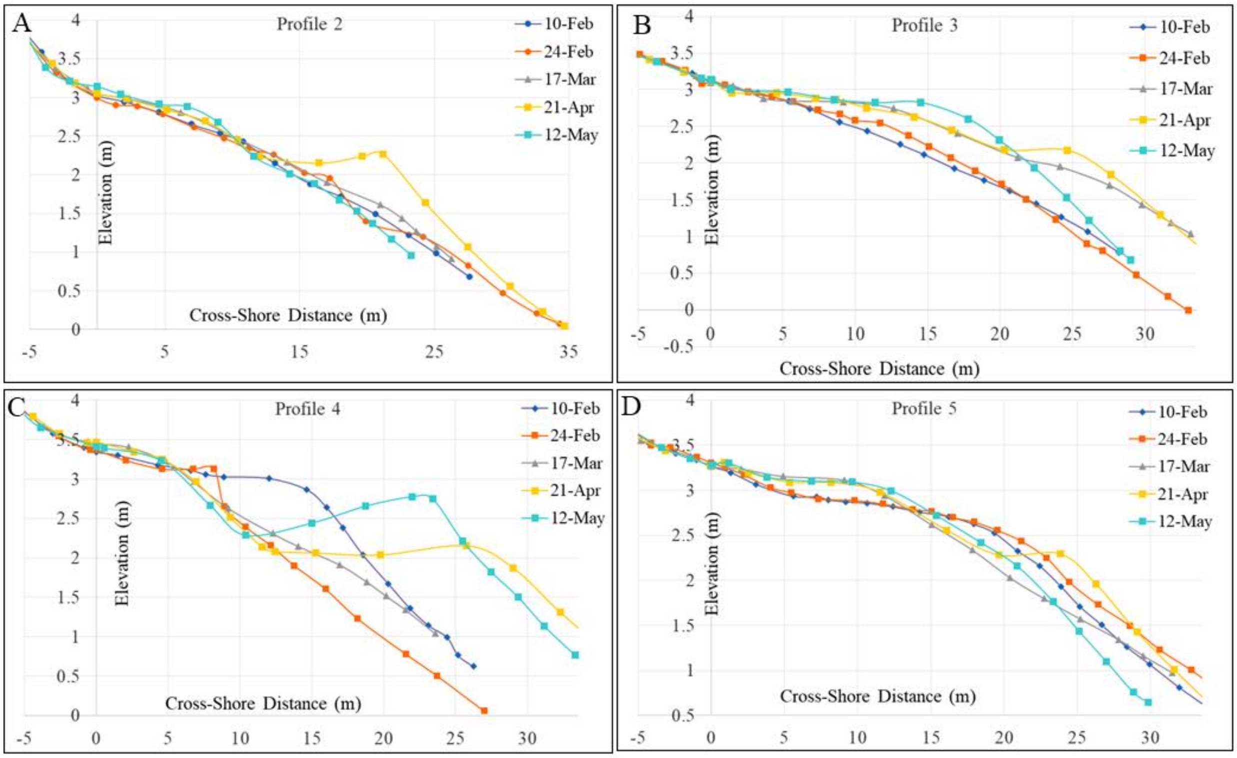


Source: The authors

It is interesting to note that, although profile 3 is located downdrift of the groin (Fig. 1), considerable beach accretion (1 m contour line moved seaward 8 m) occurred there during the time from February 10 to March 17 (Fig. 4B). Due to the effect of buried groins, the northward longshore sediment transport was able to bypass the buried groin and deposited at the location of profile 3. Despite the closeness between profile 3 and 4 (they were spaced about 50 meters apart), severe beach/dune erosion was measured at profile 4 (Fig. 4C). The shoreline at 1 m contour at profile 4 retreat landward 5 m from Feb 10 to Feb 24 (Fig. 4C).

A significant shoreline offset was also evidenced by a ground photo taken at line 3 looking towards the line 4 (Fig. 5A): beach was much wider at profile 3 and dramatically became narrow at line 4. A stretch of beach scarp with a length of 50 meters was observed at the location of profile 4 (Fig. 5B). An extensive stretch of dune scarp was there throughout the entire winter season (Fig. 5C). All these geomorphology features (dune scarp and beach scarp) are indicative of erosion. Profile 5 located further downdrift of the groin experienced erosion from Feb 10 to March 17 (Fig. 4D). Overall, the longshore variations of these beach changes of accretion (profile 2 and 3) transitioning to beach erosion (profile 4 and 5) are as the result of buried groin impounding and interrupting longshore transported sediment. It is worth noting again that the transition location is not exactly at the place of the groin, as sediment bypassed it and deposited on the downdrift side of the buried groin (Profile 3 in Fig. 1).

Fig. 4 Example beach profile changes

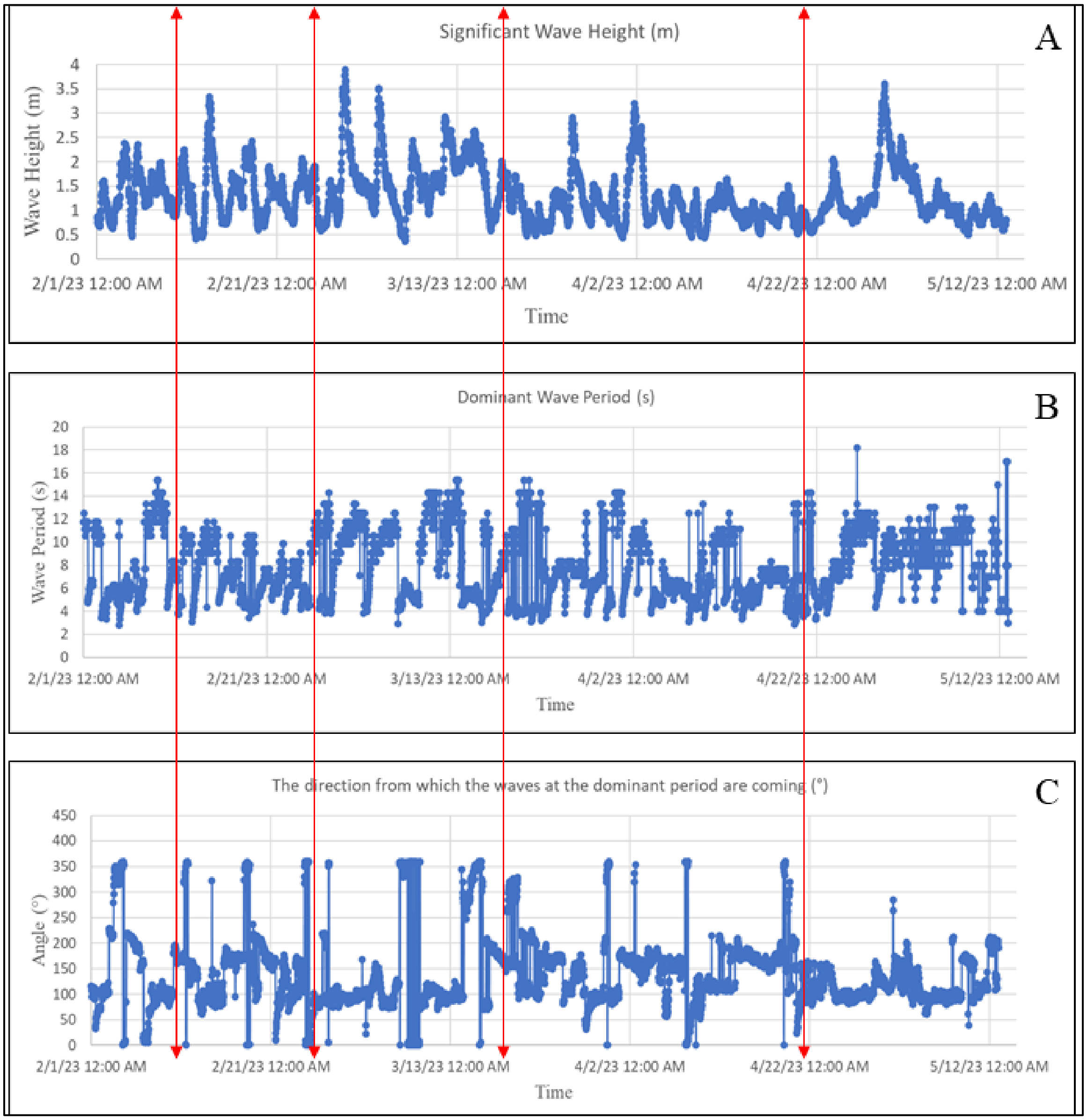


Source: The authors

Fig.5 field photos A) was taken on March 17 at the survey line 3, looking towards the line 4. The beach was much wider at line 3 and abruptly became narrow at line 4. B) was also taken on March 17 at profile 4, where a beach scarp formed. C) an existing dune scarp measured on Feb 10, 2023.

Source: The authors

Fig. 6 Wave conditions from February to May 2023. A) wave height, B) dominant wave period, C) dominant wave direction. The red lines indicate the times when the beach profile surveys were conducted.



Source: The authors

From March 17 to April 21, as the weather transitioned to spring, the frequency and intensity of large waves considerably subside. Prior to the beach survey, on April 21, there were approximately 20 days of calm period with the offshore wave height less than 1.5 m (Fig. 6). Under this condition, substantial beach accretion occurred at all the measured beach profiles (Fig. 4A-D). This consistent beach accretion at the boundary of groin field indicates that the cross-shore (onshore) sediment transport instead of longshore sediment transport is the main driving force for beach accretion. The maximum shoreline accretion of (10 m) towards the ocean occurred at profile 4 (Fig. 4C). This tremendous amount of beach changes within a few weeks of timeframe in the spring season suggest that mid-Atlantic beaches have a much larger seasonal variation as compared to those located at subtropical area. Seasonal beach changes along Florida Gulf coast and Florida Atlantic coast are much less distinctive (Cheng and Wang, 2018; Cheng and Wang 2019; Hauptman et al., 2022).

After the beach accretion during mid-March to April, another strong winter storm occurred in late April with peak wave height exceeding 3.5 m (Fig. 6A), and southeast wave direction (Fig. 6C). Induced by this storm, all the beach profiles in the study area have experienced erosion. Profile 2 and 5 were eroded to the previous stage before the spring beach accretion a few weeks ago. Profile 3 and 4 also experienced erosion on the beach (contour between 0 and 2 m), the eroded beach sand was deposited at the back beach and dune field in the form of storm berm and washover fans. Similar overwash events were also observed during the impact of hurricanes (Claudino-Sales et al., 2008; Wang et al., 2021). Contrast to the significant shoreline offset when the pre-storm beach widths were narrower (Fig 5A), no apparent shoreline offset induced by this late winter storm (occurred in late April) when the pre-storm beaches were wider. This suggests the status of pre-storm beach profile play an important role in controlling long-shore variations of beach changes. When the beach is wider, groins were buried further away from the energetic wave actions.

Thus, the effect of buried groins was negligible, and a consistent erosion occurred for the entire stretch of beach. On the other hand, when the beach was narrower, the effect of buried groin became closer to wave action and its effect was significant, which resulted in the offset in longshore changes with beach accretion/erosion near the updrift/ downdrift of the groin field. Systematic beach profile monitoring is essential to answer the questions regarding the threshold of beach width for the occurrences of shoreline offset. Furthermore, if it does occur, where exactly the location of the offset. These are important questions for future research for shore protection.

In addition to the above-mentioned technical aspects, we would like to point out some educational merits of this study. Selecting a stretch of dynamic shoreline (an erosional hotspot in this paper) as a study area is the first step. In order to motivate our students with a diversified background to study complicated coastal processes, various tasks were designed. 1) Multiple field trips were arranged for students to the site to gain impression on shoreline erosion induced by large waves during a winter season. 2) Field observation was conducted on beach/dune scarps, shoreline changes using RTK-GPS. 3) Students get hands-on experiences with analyzing and interpreting the publicly available dataset from NOAA wave and tide. 4) user friendly numerical model (e.g., CMS-Wave) was introduced to students. We believe the combination of field observations, data analysis and numerical modeling would be an efficient way to enhance the effect of students' learning.

CONCLUSION

Ortley Beach in New Jersey is an erosional hot spot with shore protection measures such as beach nourishment and buried groin field. 5 beach profiles were measured with dense spatial and temporal intervals from February 10 to May 12 in 2023. During the energetic winter season from February 10 to March 17, a large longshore variation of beach change was measured. Beach accretion was observed at southern part of the study area as a result of impoundment effect of buried groin interacting with northerly-directed longshore sediment transport. Severe beach/dune erosion was measured at profiles at northern part of the study area mostly downdrift of the groin field. Thus, a substantial shoreline offset was observed, and it is important to note that the offset did not occur exactly at the place of the groin, instead sediment bypassed the buried groin and the deposition extended tens of meters downdrift of the groin.

As the weather transitioned to spring from March 17 to April 21, the frequency and intensity of large waves subsided, and substantial beach accretion occurred at all the measured beach profiles. Another late season winter storm in late April eroded the beaches back to the previous stage. With wider pre-storm beach profile, no obvious alongshore variations of shoreline changes were observed under this late winter storm, in other words, no distinctive shoreline offset was created by buried groin field. This suggests the status of pre-storm beach profile played an important role in controlling long-shore variations of beach changes. Systematic beach profile monitoring is essential to investigate the threshold of beach width for the occurrences of shoreline offset induced by the buried groins.

In addition, this study was conducted with undergraduate students when the coastal study program at Kean University just started, thus it can also serve as an example in initiating and conducting field-based coastal research with students.

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