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Shoreline Responses to Hurricane Bonnie in Southwestern Louisiana

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ABSTRACT

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Hurricane Bonnie made landfall in June 1986, with an intensity upon landfall uniform across southwestern Louisiana. This provided a unique opportunity to monitor the short-term response of three different types of shorelines to the same high-energy event. The shorelines included a natural system, one that had been slightly modified by scraping the backbeach, and one that had been artificially stabilized by a revetment and partially fronted by segmented breakwaters. Although these shorelines were connected at slight angles, each shoreline type was relatively straight, had open exposure to the Gulf of Mexico, and was not affected by additional storms during the monitoring period, which lasted six months.

The natural and modified systems recovered favorably and followed the well-documented cyclic trend of storm-induced erosion to poststorm deposition. Deposition occurred primarily at the lower foreshore from ridge-and-runnel migration. Prestorm volumes were either approached or achieved. The revetment shoreline exhibited persistent erosion throughout the study. The initial losses were minimal at the artifically stabilized shoreline, but because of continued poststorm erosion, the overall response suggests a much longer recovery time for it than for a natural or slightly modified system.

ADDITIONAL INDEX WORDS: *Cyclic beach response, Hurricane Bonnie, natural beach, modified or scraped beach, revetment*

INTRODUCTION

On the Gulf Coast, the 1986 hurricane season was relatively quiescent compared to the previous year when five hurricanes made landfall in the Gulf of Mexico. Hurricane Bonnie was the only Gulf Coast storm of 1986, making landfall near Port Arthur, Texas, on June 26. The onshore winds and concomitant storm waves and storm surge generated some impacts along the neighboring Louisiana coast that were worthwhile to examine. This paper outlines these impacts and evaluates the responses of three different shoreline types to this regionally high-energy event. The shoreline types studied were a natural beach system, a beach that had been modified or scraped by a road grader, and a beach that had been artificially stabilized by a revetment. It was anticipated that the shoreline's response to the hurricane and its return to equilibrium conditions would differ according to the type of shoreline or the extent of human modification.

Previous Research

The effects of major storms on natural beaches have been widely documented (Tanner, 1961; Hayes, 1967; Wranke *et al.*, 1966; Sonu, 1970; Wright *et al.*, 1970; Fisher and Stauble, 1977; Leatherman, 1979). The beach response has been modeled as a cyclic change from storm-induced erosion to poststorm deposition by Hayes (1969), Davis and Fox (1971), Hayes (1972), and Fox and Davis (1973). According to Hayes (1969:50), the early poststorm beach displays a flat to concave-upward profile which subsequently undergoes an accretionary phase. This includes the formation of small berms, cusps, and particularly ridge-and-runnel systems which migrate landward to form broad, convex berms. The storm-generated profile can also display a scarp which forms at the landward limit of the swash zone as a result of high-angle incident waves. If a dune is pres-

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ent, it can be either scarped or slightly eroded at its base. The beach usually recovers in three to six months.

Comparatively fewer studies have been conducted on the effects of storms on shorelines hardened by artificial structures (DEAN, 1976; MORTON, 1976; FITZGERALD, 1980). This was further amplified by KRAUS (1987) who reviewed literature pertaining to seawalls, revetments, breakwaters, and dikes. He indicated that field studies often document the response of structures but they neglect to identify their regional effects in the context of littoral processes. The most pertinent work is that of SEXTON and MOSLOW (1981). They monitored the recovery of natural inlet-facing beaches and open-ocean beaches in front of and adjacent to stabilized shorelines for five weeks at Seabrook Island, South Carolina. The stabilization measures included seawalls, bulkheads, and groins, all of which incurred considerable damage from a hurricane. They found that the beach's response followed the cyclic pattern of change. However, a significant departure was observed in the rate of recovery of the different types of beaches over the five-week period. The natural beaches recovered from the hurricane more rapidly than the beaches adjacent to or fronting the coastal structures. The recovery of the natural beaches may have been accelerated by their relatively sheltered location facing an inlet. Beaches with an open exposure to the coast and adjacent to the coastal structures did not totally recover during the monitoring period.

The present study also focused on the response of natural and stabilized shorelines in southwestern Louisiana. It departs from the work of SEXTON and MOSLOW (1981) by lasting a period of six months rather than five weeks. The beach exposures and coastal structures were different. In this paper, sheltered inlet beaches, the effects of shoreline curvature, and inlet processes responsible for poststorm berm growth (HINE, 1979) are obviated because all of the shoreline types are uniformly oriented along fairly straight, exposed segments of the Gulf Coast (Figure 1). The response and recovery of revetments and segmented breakwaters have not been previously examined. Information provided in this study will augment that already available for seawalls, bulkheads, and groins.

STUDY AREA

The area in question is a 54-km length of shoreline that lies at the western extremity of coastal Louisiana, and is flanked by the Sabine and Calcasieu rivers (Figure 1). This is a microtidal environment (DAVIES, 1964) with diurnal tides having a mean range of 60 cm and a spring range of 74 cm. Annual wind data indicate that locally generated wind waves dominate out of the south and southeast quadrants 18 and 22 percent of the time, respectively. Wave energy is typically low; breaking wave heights average 50 cm with a 5-sec period (NAKASHIMA *et al.*, 1987). The nearshore is morphodynamically dissipative with slopes averaging Tan 0.03 and multiple bars occupying the surf zone. The frequency of nearshore bars decreases with proximity to the artificially stabilized shoreline. The formation of bars is restricted because wave reflection off the revetment has increased the nearshore slope (Tan 0.05) and decreased the local sediment supply by promoting longshore transport through this shoreline segment.

This stretch of shoreline can also be characterized according to the extent of human influence (Figure 1). Three distinct shorelines typify this area. The first is a natural beach-foredune complex extending 15 km from the Sabine River eastward to a revetment. Homes and camps occupy this portion of the coast but they are set well back from the foredune. The second shoreline type comprises a 7.2 km-long revetment. The sole purpose of this structure is to prevent State Highway 82 from being undermined. The different stabilization materials have been used but they have inadequately protected the highway, forcing its relocation landward. West of this lies the third shoreline type, which has been modified by grading the backshore to accommodate the camps and dwellings of Holly Beach. There is no protective dune at Holly Beach, but one has been reconstructed by a bulldozer east of the community. Coastal structures are absent in this segment of the coast.

Hurricane Bonnie

Hurricane Bonnie was only the eleventh hurricane of this century to strike the United States coast during the month of June (NATIONAL OCEANIC and ATMOSPHERIC ADMIN-

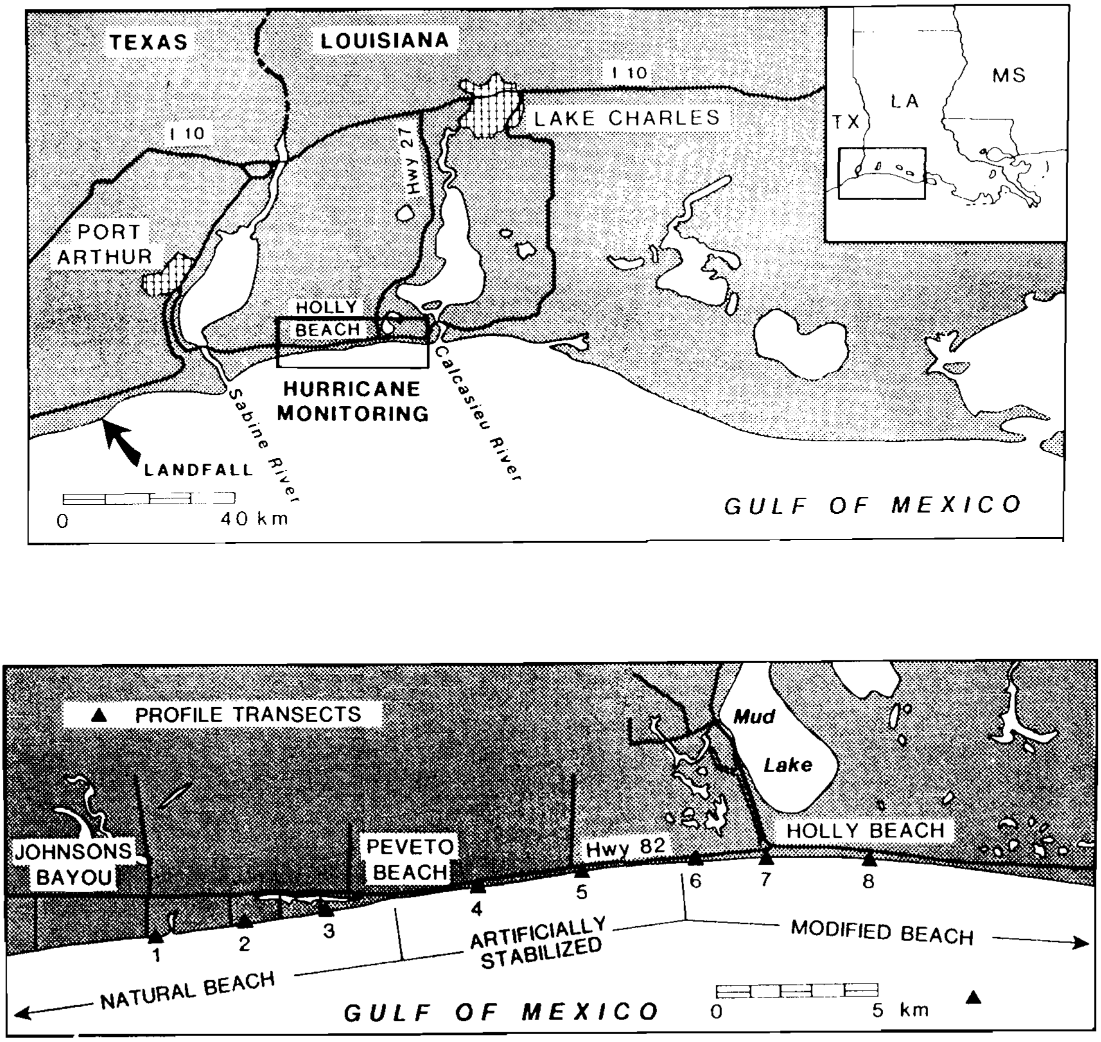

Figure 1. Shoreline types within the study area.

ISTRATION, 1986). Bonnie grew from a tropical depression in the central Gulf of Mexico to a hurricane within 24 hours, attaining hurricane status at noon on June 25, 1987. The storm had a relatively straight path and made landfall the following day at 0445 hr, five days after a spring tide.

Hurricane Bonnie was a severe storm but not a major hurricane. Its maximum sustained wind speed was 74 kt, and its width offshore was 240 km. The minimum pressure was 990 Mb as recorded 22 km south of its point of landfall. Wave heights and meterological data were recorded hourly during passage of Hurricane Bonnie on an offshore oil rig about 140 km south of Peveto Beach. The significant and maximum wave heights were 2.13 and 5.1 m, respectively, and the average wave period was 5.8 sec. The significant wave heights and wave period data were averaged from four sets of hourly readings immediately before the hurricane passed the oil rig. Thus, the data included the maximum deep water waves that were being driven by onshore winds. The data, however, are not representative of nearshore hydrodynamic conditions because shoreline orienta-

Table 1. *Storm surge levels recorded at the mouth of the Calcasieu River. (Data from U.S. Army Corps of Engineers, 1985).*

	WATER LEVEL ABOVE MEAN SEA LEVEL		
DATE	(m)	(ft.)	DESCRIPTION
9/23/41	2.26	(6.88)	
7/27/43	1.37	(4.18)	
10/4/49	1.53	(4.65)	
8/29/50	1.44	(4.38)	
7/16/52	1.54	(4.69)	
9/23/56	1.37	(4.18)	Hurricane Flossy
6/27/57	4.23	(12.90)	Hurricane Audrey
9/11/61	2.64	(8.05)	Hurricane Carla
8/29/62	1.74	(5.31)	
10/3/64	1.49	(4.54)	Hurricane Hilda
9/20/67	1.73	(5.28)	Hurricane Beulah
6/24/68	1.58	(4.81)	Hurricane Candy
9/16/71	1.93	(5.87)	Hurricane Edith
9/5/73	2.04	(6.21)	Hurricane Delia
6/8/74	1.83	(5.58)	
9/7/74	1.36	(4.15)	Hurricane Carmen
9/8/78	1.63	(4.98)	
7/24/79	2.06	(6.28)	
8/17/83	1.45	(4.42)	
Mean	1.85	(5.65)	

tions differ slightly, and breaking wave heights, breaker angles, and littoral drift vary rapidly with shifts in wind direction during passage of the hurricane.

Under non-storm conditions, the average upper spring tide limit is +0.37 m MSL. Data from a tide gauge located at the mouth of the Calcasieu River indicated a storm surge level of +1.60 m MSL just before landfall. This is less than one-half the maximum recorded storm surge of +3.97 m MSL generated by Hurricane Audrey on June 27, 1957. However, the Hurricane Bonnie water level did approach the average hurricane and tropical storm-induced water level of +1.85 m MSL (Table 1).

The passage of Hurricane Bonnie provided a unique opportunity to examine beach response associated with different types of shorelines. Monitoring the recovery of the beaches was not affected by subsequent storm activity or beach restoration projects. This permitted the documentation of beach response through to the maximum time interval for recovery as previously identified in the cyclic beach response studies.

Methods

Eight beach profile transects were established before Hurricane Bonnie. Three profile lines were set along the natural beach, two along the revetment, and the remaining three along the modified beach at Holly Beach. Surveys were conducted before the hurricane and at three intervals afterwards. The first survey was conducted on 12 June 1986, two weeks before the hurricane. Monitoring of beach response began four days after landfall on 30 June 1986, as well as on 18 September 1986 and 18 December 1986. Each profile transect was surveyed out to the maximum limit of wading using an automatic level and stadia rod. The data were transcribed from a micro-cassette tape recorder and reduced using a survey data reduction program written for a microcomputer (BIRKEMEIER, 1984). Computer plots of profile changes were generated on a plotter.

RESULTS

The impact of Hurricane Bonnie and the recovery characteristics of the different shorelines are shown in Table 2. The hurricane resulted in net erosion throughout the entire study area (12 June 1986 to 30 June 1986). The amounts ranged from 2.32 to 13.97 m^3/m. The greatest losses occurred at transects 1 (10.15 m^3/m) and 2 (7.03 m^3/m) of the natural shoreline and at transects 7 (10.45 m^3/m) and 8 (13.97 m^3/m) of the modified shoreline. The natural beach profiles 1 and 3 displayed similar patterns of erosion (Figure 2). They were concave upward with most of the losses occurring across the backshore and the seaward face of the foredune. The greatest erosion from the initial impact occurred at Holly Beach, shown by transect 8. Here, sediments of the entire backshore are highly susceptible to erosion as a result of continuous reworking by road graders to maintain a recreational beach. As a result, erosion occurred across a greater length of the profile. Although losses were large, recovery was taking place as lower foreshore deposition through ridge-and-runnel migration (Figure 2).

Erosion along the armored shoreline (transects 4 and 5) amounted to 3.83 and 4.45 m^3/m, respectively. Sediment losses extended from the toe of the structure through the entire width of the surf zone (Figure 3). Losses at the toe of the

Table 2. *Hurricane Bonnie beach profile volumetric changes (m^3/m).*

PROFILE TRANSECT	HURRICANE IMPACT 6/12-6/30	INITIAL RECOVERY 6/30-9/18	SUCCEEDING RECOVERY 9/18-12/18	NET RECOVERY 6/30-12/18	NET CHANGE 6/12-12/18
NATURAL					
1	−10.15	+6.13	+3.20	+11.12	+1.90
2	−7.03	+5.25	+1.55	+6.78	+1.07
3	−5.95	+4.28	+4.20	+7.45	+3.42
	(−7.71)	(+5.52)	(+2.98)	(+8.45)	
REVETMENT					
4	−3.83	−0.65	−1.59	−1.67	−6.51
5	−4.45	2.53	−3.23	−5.97	−8.80
	(−4.14)	(−1.59)	(−2.41)	(−3.82)	
MODIFIED					
6	−2.32	+0.40	+7.72	+6.88	+4.73
7	−10.45	N/S	N/S	+8.06	−1.99
8	−13.97	+5.90	+6.93	+9.42	−3.26
	(−8.91)	(+3.15)	(+7.33)	(+8.12)	

+ = Accretion − = Erosion ( ) = Mean change
N/S = No survey 18 September 1986

revetment were exceeded by erosion of the nearshore, which resulted in an increase in water depth and nearshore slope. Transect 4 lies in a gap between breakwaters and the amount of erosion there was similar to that at transect 5, where there were no breakwaters.

The initial recovery and succeeding recovery data revealed similar trends (Table 2). Poststorm accretion characterized both the natural and modified beaches (transects 1 to 3 and 6 to 8), whereas erosion typified the revetment segment (transects 4 and 5). The upper foreshore of the natural and modified shorelines accreted due to continuous onshore migration of sediment in the form of ridge-and-runnels. The average amount of initial recovery in the natural and modified shorelines was 5.52 and 3.15 m^3/m, respectively. Although no storms occurred during the recovery period, losses in front of the revetment segment persisted. Sediment loss at transect 4 during the initial recovery period was 0.65 m^3/m. This was minimized by the presence of the breakwaters, which limited wave transmission to the revetment. Erosion amounted to 2.53 m^3/m along the portion of revetment unprotected by the breakwaters. The succeeding recovery of the natural and modified shorelines was one of net accretion averaging 2.98 and 7.33 m^3/m, respectively. However, along the revetment, sediment losses increased with time to 2.41 m^3/m.

The net recovery data in Table 2 apply to the interval between the first poststorm survey (30 June 1986) and the succeeding survey (18 December 1986). The data indicate that each type of shoreline can be relegated to either a depositional (+) or erosional (−) trend for the recovery period. The natural and modified beaches exhibited a depositional trend but the revetment segment was totally erosional. The quantity of deposition at the natural and modified shorelines was similar, averaging +8.45 and +8.12 m^3/m, respectively.

The quantity of storm-induced erosion in the artifically stabilized shoreline was shown to be usually less than that occurring in natural and slightly modified shorelines. However, sediments were not replenished in this system during the initial and succeeding recovery phases as they were in the natural and modified shorelines. The net recovery yielded losses of −1.67 and −5.97 m^3/m with an average of −3.82 m^3/m at the revetment shoreline, which suggests that any recovery is preceded by further poststorm erosion.

The net change data in Table 2 are the volumetric differences between the prestorm (12 June 1986) and succeeding (18 December 1986) surveys. Return to the prestorm volume was achieved in four of the six transects in the natural and modified shorelines (transects 1, 2, 3 and 6). This trend of beach recovery does not apply to the revetment shoreline (transects 4 and 5). These recovery trends are evident in the representative net change profiles shown in Figure 4. Berm welding and ridge-and-runnel

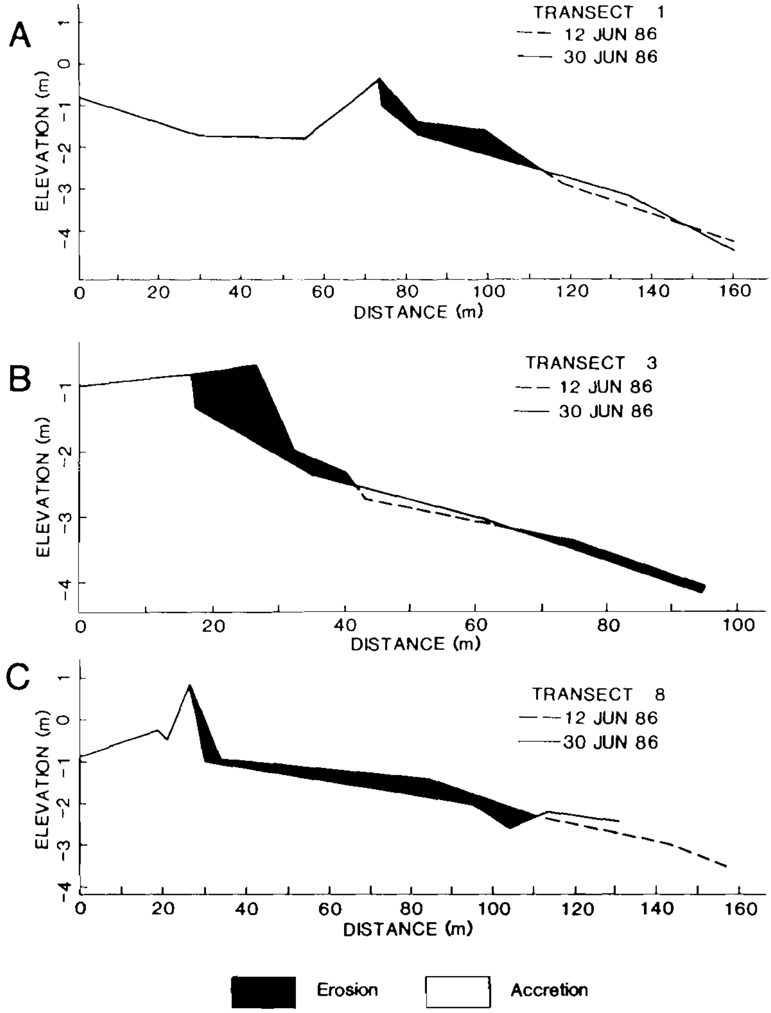

Figure 2. Initial response of the natural and modified beach systems to Hurricane Bonnie (12 June 1986 to 30 June 1986).

migration characterize the depositional zone in the natural and modified shorelines (transects 1 and 8). The areas that were unreplenished were the upper backshore and the dune, which accounted for the deficits in the net change data. Eolian sedimentation in these areas was observed to be negligible during the study. Net losses at the revetment are shown along transect 4. A depositional phase, which would define a cyclic beach profile response, did not occur during the course of this study. Erosion continued in the artificially stabilized shoreline, whereas poststorm deposition occurred in the natural and modified shoreline segments.

DISCUSSION AND CONCLUSIONS

Monitoring the recovery of beaches over a six-month period in response to a high-energy storm has revealed that natural and modified beaches respond differently than artificially stabilized ones. The well-accepted cyclic model of storm-induced beach erosion through poststorm recovery applies to the natural and modified beaches of this study. The response of the revetment is one of storm-induced erosion that is accompanied by further erosion while recovery occurs elsewhere. It appears that wave reflection is a dominant factor in this type of

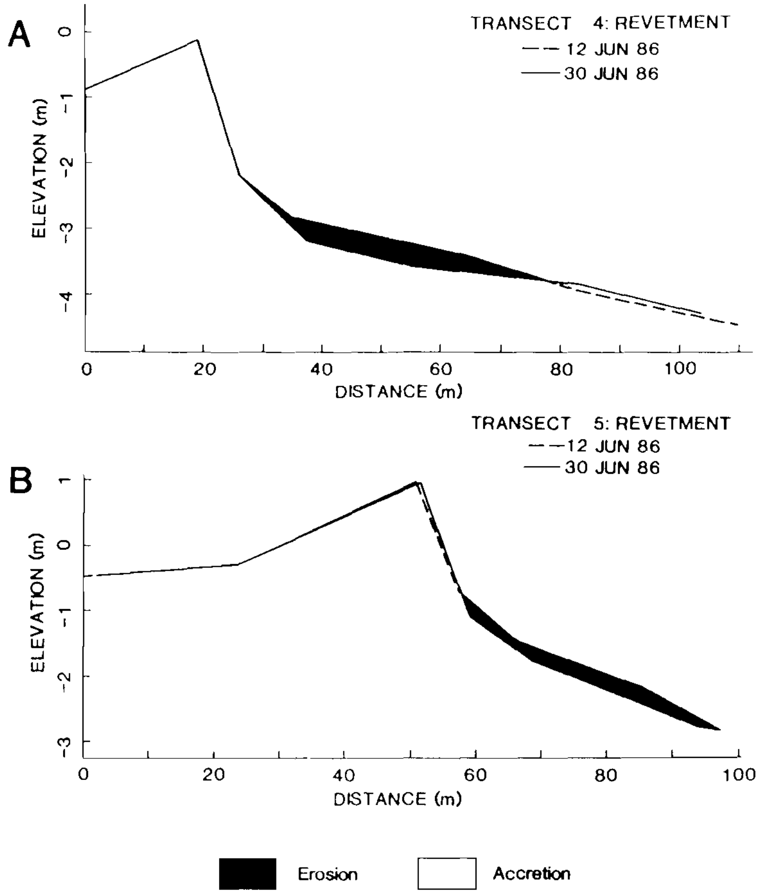

Figure 3. Initial response of the revetment to Hurricane Bonnie (12 June 1986 to 30 June 1986).

response. Kraus (1987) states that erosion results from a portion of the incident wave flux being reflected offshore rather than being transferred as shear stresses to drive a current. Stive and Wind (1986) indicate that the shear stresses are related to a cross-shore component of seaward flow at the trough level of incident waves, causing seaward transport to exceed landward movement of material. The conversion from an erosional dissipative beach to an accretionary reflective system did not occur as observed by Terwindt *et al.* (1984) for natural beach response to hurricane-induced swells. The immobility of the revetment results in a more erosional reflective shoreline than its natural beach counterpart.

Within this study, the nature of beach response to a regionally high-energy event differed markedly between the revetment shoreline and the natural or modified beaches. The hurricane caused erosion at all of the shorelines. Net volumetric change data for the natural and modified shorelines indicated that their recovery was persistent and, in many cases, the prestorm volume had been surpassed. However, the net response over a longer term indicated that a return to prestorm volumes at the revetment segment had not occurred: erosion dominated the entire monitoring period. This suggests that, for this region, a totally natural or slightly modified natural beach system consisting of a dune (artificial or natural), a wide backbeach, and a gentle foreshore slope withstands storms more effectively than a revetment. It is also clear that the natural system has the potential for recovering sediment vol-

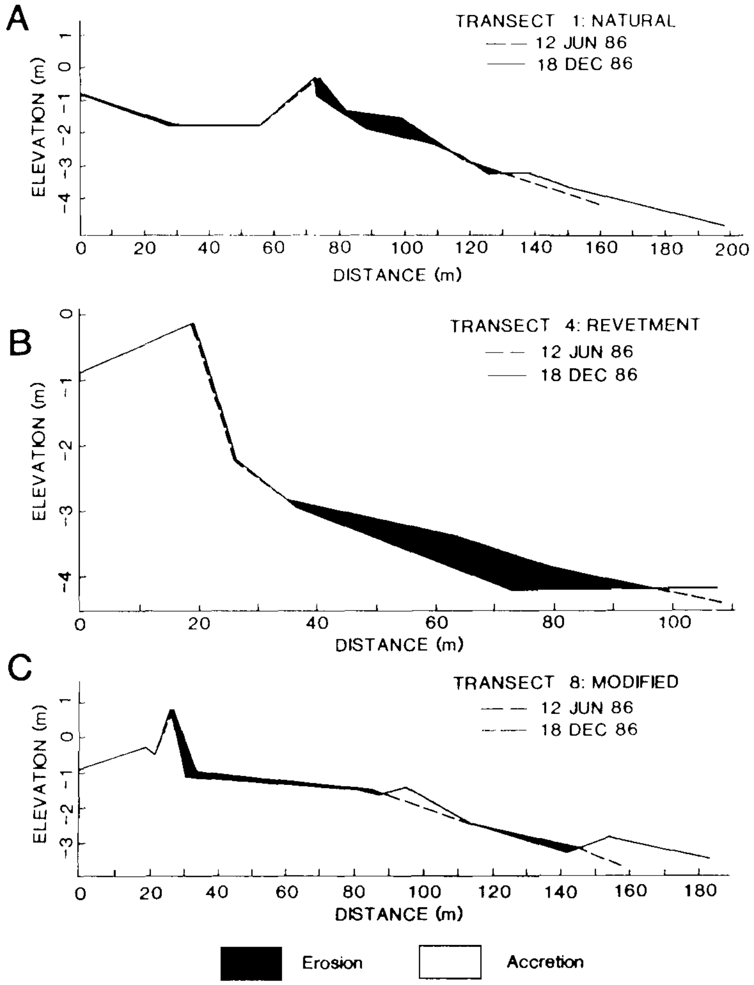

Figure 4. Net recovery of beaches along representative beach profile transects (12 June 1986 to 18 December 1986).

ume more quickly than the artificially stabilized shoreline. Although armoring the shoreline may be required to protect infrastructure, the stability of the structures and the longevity of the beaches fronting them can be jeopardized by the slow poststorm recovery of such beaches, especially if additional storms occur.

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RESUMEN

El huracán Bonnie alcanzó la costa en 1986, con una intensidad uniforme a lo largo de la costa suroeste de Louisiana. Esta circunstancia aportó una opportunidad única para controlar las repsuestas a corto plazo de tres tipos diferentes de lineas de costa ante semejante acontecimiento de alta energia. Las lineas de costas incluian un sistema natural, otro que habia sido ligeramente modificado mediante el aporte de arena desde el lado del mar del perfil hacia la playa seca y, por último, un tercero que se habia estabilizado artificialmente mediante un revestimiento y protegido parcialmente por rompeolas frontales extenos. Aunque estos tramos de costa forman entre si pequeños ángulos, cada tipo de costa es relativamente recto, está expuesto directamente al Golfo de Méjico y no fue afectado por otros temporales durante los seis meses del periodo de control.

Los sistemas natural y modificado se recobraron favorablemente y siguieron las tendencias ciclicas, bien documentadas, de erosión en el temporal y acrección en el periodo de calma posterior. La acrección se produjo en principio en la parte inferior del frente de playa por migración de las barras. Finalmente, se alcanzaron aproximadamente los volúmenes de playa seca anteriores al temporal. La costa protegida con revestimiento mostró una erosión persistente a lo largo de todo el estudio. Las pérdidas iniciales fueron minimas en el tramo estabilizado artificialmente pero, debido a la continuada erosión posterior al temporal, la respuesta del conjunto sugiere un tiempo de recuperación mucho más largo que para los sistemas naturales o los ligeramente modificados.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

ZUSAMMENFASSUNG

Der Hurrikan Bonnie erreichte die amerikanische Festlandsküste im Juni 1986 und beeinträchtigte den Südwesten von Louisiana in einheitlicher Weise. Dadurch ergab sich die einzigartige Möglichkiet, kurzfristige Veränderugen in drei unterschiedlichen Küstenabschnitten (naturbelassener Strand, Strand mit einem abgetragenen rückwärtigen Bereich und einen durch eine Ufersicherung und Wellenbrecher künstlich stabilistierten Strand) als Folge der Naturgewalten zu ermitteln und miteinander zu vergleichen. Die unterschiedlichen Strandbereiche bilden einen zusammenhängenden gestreckten Küstenabschnitt, der sich zum

Golf von Mexiko hin uöffnet. Der Küstenabschnitt ist im 6 monatigen Untersuchungszeitraum nicht durch weitere Stürme beeinflußt worden.

Die Entwicklung im naturbelassenen und im abgetragenen Strandabschnitt verlief günstig und folgte dem gut dokumentierten Kreislauf von orkanbedingten Erosionen hin zu Sedimentationen in der Zeit nach dem Hurrikan. Die Ablagerungen erfolgten hauptsächlich am unteren Vorstrand im Bereich der Wasserlinie durch die Verlangerung von Sandbänken und Rinnen. Die ursprünglich vorhandenen Volumen wurden im Untersuchungszeitraum entweder nahezu oder völlig erreicht. Im künstlich stabilisierten Strandabschnitt ergaben sich dagegen anadauernde Erosionen. Die ursprünglich in diesem Bereich vorhandenen Verluste waren gering. Wegen der auch nach dem Hurrikan andauernden Erostionen ist insgesamt von einer sehr viel längeren Erneuerungszeit dieses Strandabschnittes im Vergleich zu den beiden anderen Stränden auszugehen.—*Reinhard Dieckmann, WSA Bremerhaven, West Germany.*

□ RÉSUMÉ □

Le cyclone Bonnie a touché le continent en juin 1986, avec une intensité uniforme sur l'ensemble du SW de la Louisiane. De telles conditions permettent de controler les réponses à court-terme d'évènements analogues en énergie pour trois types de littoraux: un système naturel, un autre légèrement modifié par la mise à niveau de l'arrière plage, un autre stabilisé artificiellement au moyen d'un revêtement et l'aménagement de brise-lames segmentés. Bien que la plupart de ces plages se joignent avec un léger angle, chacune d'elles est rectiligne, ouverte sur le golfe du Mexique, et aucune n'a été affectée par d'autre tempête pendant la période d'observation qui a dépassé 6 mois. Les trois types de littoraux suivent une évolution depuis l'érosion induite par la temp̂te, jusqu'au dépôt postérieur à la tempête. Le dépôt se fait essentiellement dans les parties basses de l'avant plage, à partir de la migration des crêtes et sillons prélittoraux. L'érosion a persisté sur le revètement de plage pendant toute la durée de l'étude. Les pertes initiales ont été minimales sur le littoral stabilisé artificiellement, mais la persistance de l'érosion après la tempête suggère qu'il faut ici un temps de reconstruction plus long que pour le système naturel ou peu modifié.—*Catherine Bressolier, U.A. 910 du CNRS, EPHE, Montrouge, France.*