Journal of Korean Society of
Coastal and Ocean Engineers
Vol. 9, No. 3, pp. 155~164, September 1997

Analysis of Shoreline Changes from Aerial Photographs at Oregon Inlet Terminal Groin

Oregon 河口에 위치한 防砂堤 주위에서의 航空사진을 이용한 해안선 變化해석

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Abstract □ A comprehensive and systematic field monitoring program was initiated since October 1989, in order to investigate the temporal and spatial variation of shoreline position at northern part of Pea Island, North Carolina. Aerial photographs were taken every two months on the shoreline extending from the US Coast Guard Station at the northern end of Pea Island to a point 6 miles to the south. Aerial photographs taken were digitized initially to obtain the shoreline position data, in which a wet-dry line visible on the beach was used to identify the position of shoreline. Since the wet-dry line does not represent the "true" shoreline position but includes the errors due to the variations of wave run-up heights and tidal elevations at the time the photos taken, it is required to eliminate the tide and wave runup effects from the initially digitized shoreline position data. Runup heights on the beach and tidal elevations at the time the aerial photographs taken were estimated using tide data collected at the end of the FRF pier and wave data measured from wave-rider gage installed at 4 km offshore, respectively. A runup formula by Hunt (1957) was used to compute the run-up heights on the beach from the given deepwater wave conditions. With shoreline position data corrected for wave runup and tide, both spatial and temporal variations of the shoreline positions for the monitoring shoreline were analyzed by examining local differences in shoreline movement and their time dependent variability. Six years data of one-mile-average shoreline indicated that there was an apparent seasonal variation of shoreline, that is, progradation of shoreline at summer (August) and recession at winter (February) at Pea Island, which was unclear with the uncorrected shoreline position data. Determination of shoreline position from aerial photograph, without regard to the effects of wave runup and tide, can lead to mis-interpretation for the temporal and spatial variation of shoreline changes.

Keywords : aerial photograph, shoreline change, shoreline rhythm, wave runup, seasonal variation

要 旨 : 미국 노스-캐롤라이나주 Pea 섬 북단에 위치한 해안선의 시간적 공간적 변화를 연구/조사하기 위하여 포괄적이고 체계적인 현장관측이 시작되었다. Pea 섬의 북단 끝에 위치한 US 해안경비대로부터 남단으로 6 mile에 걸친 해안선이 2달에 한번씩 항공 촬영되었다. 촬영된 항공사진은 해안선 위치 자료를 도출하기 위해 디지털 처리 되었으며, 이 과정에서 해빈상에 보이는 wet-dry line이 해안선 위치 식별 기준으로 사용되었다. 해빈상의 wet-dry line은 정확한 해안선 위치를 나타내는 것이 아니라 항공사진을 촬영하는 그 시점에서의 도파고와 조위의 변화로 인한 오차를 포함하고 있으므로, 초기에 디지털 처리 된 해안선 위치 자료로부터 조석과 도파에 의한 영향을 삭감하는 것이 필요하다. FRF 잔교 끝에서 관측된 조석자료와 4 km 떨어진 심해에 설치된 파랑 계측기에서 관측된 심해파랑 자료를 사용하여, 항공사진이 촬영된 시점에서의 해빈에서의 도파고와 조위가 평가되었다. Hunt (1957)의 도파고 산정공식이 주어진 심해파랑에 대한 해빈상에서의 도파고를 계산하기 위하여 사용되었다. 도파와 조석에 따른 오차에 대해 수정된 해안선 위치 자료를 사용하여 현장관측 지역에서의 해안선 이동의 지역적인 차

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이와 시간에 따른 변화 정도를 조사함으로써 해안선의 공간적 시간적 변위가 분석되었다. 1-mile 평균을 취한 해안선의 6년치 자료 분석 결과는 Pea 섬에서는 여름에는 해안선이 전진하고 겨울에는 후퇴하는 상당히 큰 계절적 변화가 있다는 것을 명확하게 보여 주었으며, 이러한 결과는 수정이 안된 해안선 위치자료 사용시 파악하기 어려운 결과였다. 도파와 조석의 영향을 무시한 항공사진으로 부터의 해안선 위치결정은 공간적 시간적 해안선 변화 양상의 해석시 큰 오류를 유발할 수 있다.

핵심용어 : 항공사진, 해안선 변화, 해안선 리듬, 파의 쳐올림, 계절변화

1. INTRODUCTION

In order to stabilize the northern end of Pea Island, and thus to protect the southern end of the Herbert C. Bonner Bridge over the inlet, construction of the terminal groin on the south side of Oregon Inlet, NC, began in October 1989 and was completed in March 1991. After construction of the groin, a comprehensive monitoring program was initiated in October 1989 to document the shoreline changes along the northern end of Pea Island. Key elements of the program include aerial photography every two months with supplementary field surveys every six months. The shoreline investigated through the monitoring program extends from the US Coast Guard Station (Transect 170), at the north end of Pea Island, to a point six miles to the south (Transect 381), Fig. 1.

One of the main purposes of this study is to document the shoreline movement at monitoring site at the northern end of Pea Island, for which series of shoreline position data were obtained by digitizing the aerial photographs taken every two months. When aerial photographs are employed to obtain the shoreline position data, the position of shoreline in photo is identified in general as the wet-dry line visible on the beach. A problem arising by adapting this method is that the wet-dry beach boundary is mobile depending on wave and tidal conditions at the time when aerial photographs were taken.

Intuitively, it is easily recognized that the wave runup on the beach will change the position of the wet-dry line depending on the intensity of waves approaching to the shore, and the variation of tidal elevation also will change the position of the wet-dry line on the beach.

If very big waves are uprushing on the beach resulting in high runup heights at the time when the aerial photography was taken, for example, the wet-dry line will be marked more landward than as it is. The same phenomenon is applied to the tide, too. It means that the shoreline positions determined from the aerial photographs do not represent the "true" shoreline position but include the errors due to the variations of wave and tidal conditions at the time of photos taken. Thus, some mapped shoreline changes are an artifact of differences in water levels rather than actual changes in sediment volume. Therefore, this study includes the estimation of the tidal elevations and wave runup heights at the time of aerial photographs taken and correction of the digitized shoreline positions.

In this study, an attempt is also made to obtain a reliable estimation on shoreline change rate, which are

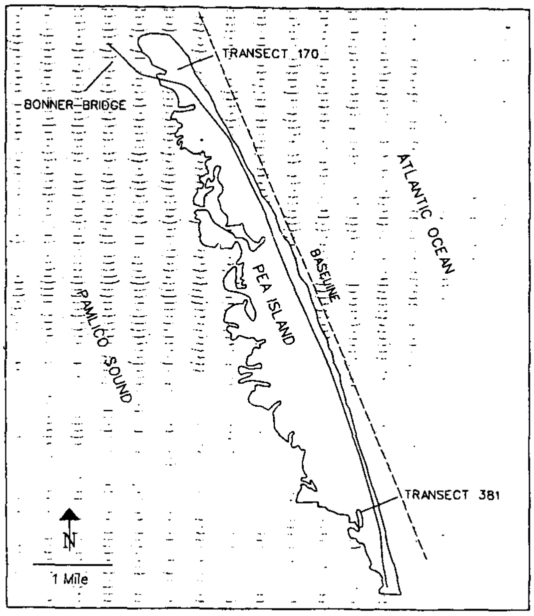

Fig. 1. Shoreline study area and transect locations.

fundamental to the planning and interpretation of beach monitoring programs. Both spatial and temporal variations of shoreline change on the northern end of Pea Island, within six miles of terminal groin are analyzed using the corrected shoreline position data. Regional and local differences in shoreline movement are examined and their time-dependent variability is also investigated.

2. BACKGROUND

It is well known that sandy coastal areas commonly exhibit temporal and spatial variations in shoreline positions. Shorelines recede during rising onshore wind and wave conditions, and prograde during falling energy conditions. Shoreline change rates are not constant with time. Instead, there are accelerations and decelerations, as well as changes in the sign of the trend as the beach switches between erosional and depositional states (Chapman and Smith, 1981). Such changes are well known on beaches where there is a marked variation between summer and winter wind and wave conditions. They may also involve longer periods of time than a year and be a response to longer term variation in storminess (Clarke and Eliot, 1988).

Accurate shoreline change predictions cannot be made unless the causes of the changes and their effects are accurately forecasted. To predict shoreline changes, the physics involved in the changes must be known, and the future nature of the variables involved in the changes must be known. Variables that control the position of the shoreline are waves, littoral currents and wind; the volume of sediment available on the beach and shoreface; the vertical position of the water surface; and the shape of the water-sediment interface. Among them, the primary variables are waves, currents and wind.

There is no present capability to forecast with certainty the earth's weather, even a year ahead. There is a consequent range of uncertainty in forecasting the absolute magnitude of changes in shoreline position because of the range of uncertainty in forecasting changes in waves, winds and currents. The effect of these governing processes on the shoreline is also imperfectly known. Therefore, even if the complex movement of beach sediment by waves and currents were predictable, accurate predictions of shoreline change rates would be lacking because the nature of future changes in wave and wind climate remains unpredictable to an unknown degree.

It is well known that the storm events play a major role in changing the shoreline position. Hayden (1975) found the number of extratropical (northeasters) storm events per year, where waves exceeded 2.5 m, increased 1.9 times between the period 1942 to 1965 and the 1965 to 1974 period. Simpson and Riehl (1981) showed a usual tropical storm between 1895 and 1930 was frequency below average, while between 1931 and 1960 it was above average. From 1961 to 1980 it was again below average. Average significant wave heights in the study area may be given by Thompson (1977).

Beach shape and environments around may exert a major control on the processes that affect shoreline position. For example, the shoreline adjacent to an inlet is strongly affected by the existence of the inlet. Based on the fact that the loss in plan area had been relatively steady, Everts and Gibson (1983) reported that changes in waves, currents, wind, and sea level all appeared to be subordinate to changes caused by local inlet (Oregon Inlet) processes. They also suggest that long-term shoreline change predictions can be made for the inlet reach 8-km north and 8-km south of the inlet as long as the inlet remains natural and continues to migrate to the south. Another factor that may affect shoreline movement is relative sea-level position. The major components of this variable are eustatic sea-level rise and drought. In the following subsections, topics on spatial and temporal variation of shoreline positions are described in more detail, since these considerations were necessary in understanding and interpreting the trend of shoreline change at northern part of Pea Island, NC

2.1 Spatial Variation and Shoreline Rhythms

The variable rates of change are related to beach processes and the formation of shoreline rhythms (Sonu, 1973). The shoreline rhythms are manifested with the accelerated and decelerated shoreline movement in comparison with adjacent areas. Apparently accelerated accretion or decelerated erosion results from greater sediment storage, whereas decelerated accretion or accelerated erosion suggests greater sediment transport.

Spatial variations in rates of change are clearly a wave phenomenon. Goldsmith (1976) related differential rates of net shoreline changes for the Virginian Sea to a non-uniform distribution of energy from refracted waves. Dolan et al (1986) proposed that edge waves were responsible for differential rates of shoreline change along a segment of the North Carolina coast. These processes could explain shoreline periodicities along the coast. Wave analyses adequate for testing this explanation are not presently available.

2.2 Temporal Variation of Shoreline Change

Time series describing variation in the position of shoreline on sandy beaches are comprised of secular trends, cyclic fluctuations, and irregular, aperiodic variations (Miller, 1983). Procedures for establishing the three components of shoreline change from quantitative sources of information have been detailed by Aubrey (1983), Miller (1983), and Clarke and Eliot (1983).

The secular trend is the tendency of a shoreline to prograde, recede, or maintain a steady state (Miller, 1983) over the period for which regular documentation of the shoreline position have been maintained.

Cyclic and aperiodic fluctuation in shoreline position are superimposed on the secular trend. Cyclic fluctuations are recurrent episodes of shoreline recession and progradation that occur at specific intervals of time. They are not truly cyclic in a mathematical sense. The near-cycle, or quasi-cycles, are commonly a response to seasonal shifts in the wave regime and mean sea-level elevation. The seasonal cycle, originally thought to involve accretion of the beach in spring and summer followed by erosion during fall and winter, was first recognized from Californian beaches (Komar, 1976). This cycle is known to be apparent on beaches that experience a marked seasonal change in the wave climate. Cyclic shoreline fluctuations also occur as responses to other oceanographic and atmospheric changes (Clarke and Eliot, 1988). Their effects are additive so that several cycles may combine to produce a "beat" effect, with some groups of years showing a high range of shoreline fluctuation, whereas the intervening groups are comparatively low.

Aperiodic fluctuations in the shoreline position are unpredictable. They are short-term variations that cannot be accounted for by the secular trend or the cyclic changes. They include isolated, occasionally catastrophic, depositional, and erosional events that are due to storm impact, unusual periods of sustained low-energy conditions, and sand bar migration associated with changes in the nearshore water circulation system. Aperiodic fluctuations commonly involve up to 50 percent of, may equal, the maximum range of shoreline movement occurring on a sandy beach.

Cyclic and aperiodic fluctuations define the active beach zone. This is a zone where shoreline migration occurs regularly as a result of seasonal and longer period changes in sea level, wave regime, and sediment supply; and irregularly, with the onset of storm events.

3. DOCUNMENTATION AND ANALYSIS OF SHORELINE CHANGES AT OREGON INLET GROIN

In this field monitoring study, aerial photographs were used to document the shoreline position data at northern part of Pea Island, from the US CGS to a point six miles to the south (see Fig. 1). When aerial photographs are employed to determine the shoreline position, the wet-dry line visible on the beach is used in general to identify the shoreline position. As indicated before, the shoreline positions determined from the wet-dry line do not represent the "true" shoreline position but include the errors due to the variations of wave and tidal conditions at the time of photos taken. Thus, some mapped shoreline changes from these data can be an artifact of differences in water levels rather than actual changes in sediment volume. Consequently, it is necessary to estimate the tidal elevations and wave runup heights at the time of photos taken and to correct the digitized shoreline positions by eliminating the errors due to the wave and tide action.

In following sections, the procedures for these correction are given first and then the spatial and temporal variation of shoreline changes at northern part of Pea Island are examined and discussed using the corrected shoreline position data.

3.1 Correction of Shoreline Position due to Waves and Tidal Effects

3.1.1 Tidal conditions at the time of shoreline photo taken

Tide data were collected at 6 minutes increments at the end of the FRF pier. The datum is NGVD and the units are meters. Tidal conditions at the time of photo taken were determined from the measured tide data. Examples of tidal variations measured during the day of photo taken are given in Fig. 2. Note that the measured tidal variation includes the storm surge effects. Tidal conditions at each time shoreline mapping photographs were taken during 6 years are summarized in Fig. 3. It is noticed that the most photos were taken when tide

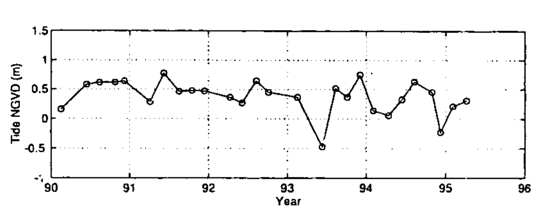

Fig. 3. Summary of tide conditions at each time of flights for aerial photographs.

elevation was about 0.5 m. The tidal condition for the shoreline photograph of June 1993 was the minimum with an elevation of -0.5 m while the maximum of 0.8 m was the tidal condition for that of June 1991.

3.1.2 Wave conditions at the time of shoreline photo taken

Wave height and period at the time of photo taken were determined from the wave data measured at Gage #630 (waverider) which was located at 4 km offshore. Examples of wave height and period variations during the day of photo taken are given in Fig. 4 and 5, respectively. Here, wave height and period represent the significant wave height from spectrum analysis and the spectral peak wave period, respectively.

Variations of wave height around the time of photo taken appears to be relatively quite small while wave

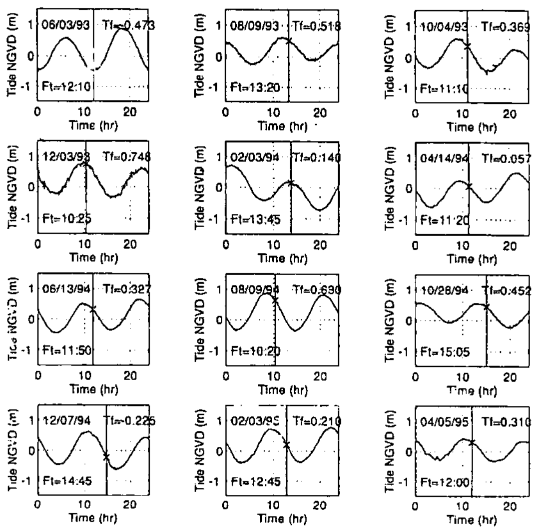

Fig. 2. Examples of measured tidal conditions at the time when aerial photographs were taken. In the figures, the legends Ft and Tf represent the flight time and tidal elevation at the time of flight, respectively.

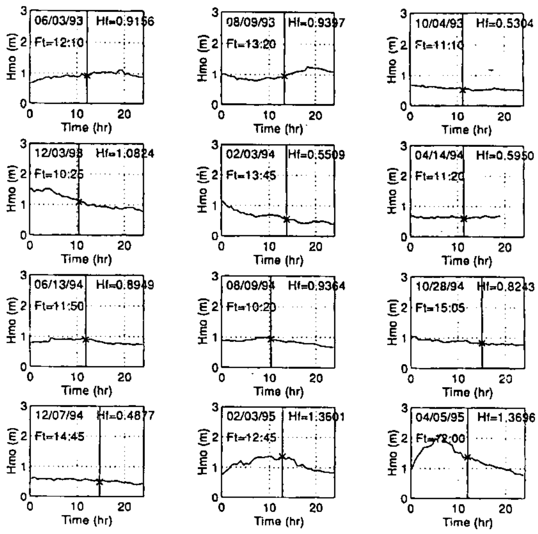

Fig. 4. Examples of measured wave height at the time when aerial photographs were taken. In the figures, the legends Hmo and Hf represent the deepwater mean wave height and its value at the time of flight.

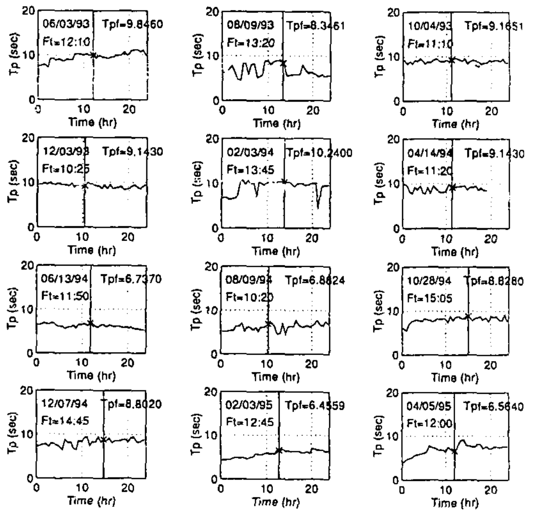

Fig. 5. Examples of measured wave period at the time when aerial photographs were taken. In the figures, the legends Tp and Tpf represent a peak period of deepwater waves and its value at the time of flight.

period varies rapidly for some data as illustrated in a plot for August 1993. Wave period is used for the calculation of wave runup to correct the shoreline positions from aerial photographs, which will be discussed in later section. Since there is a time lag between waves measured offshore and waves climbing up on the beach face (and making wet/dry line), the large variation of wave condition around the time of photo taken may cause the use of the wrong data input for the calculation of runup height.

Wave height and period at each time shoreline mapping photographs were taken during 6 years are summarized in Fig. 6 and 7. The minimum wave height during 6 years was 0.4 m which was for the shoreline photograph of August 1991 while the maximum of 2.1 m was for that of June 1990. For the wave period, the maximum was 13 sec what was for that of December

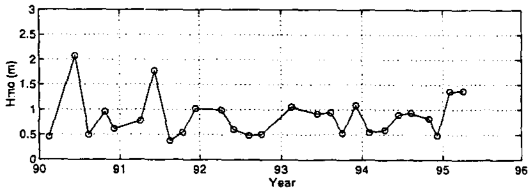

Fig. 6. Summary of wave height conditions at each time of flights for aerial photographs.

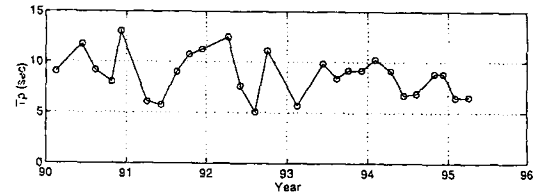

Fig. 7. Summary of wave period conditions at each time of flights for aerial photographs.

1990, while the minimum of 5 sec was for that of August 1992.

3.1.3 Beach slope at the time of shoreline photo taken

Beach slope data are required for the estimation of wave runup at the time of photo taken. Beach slopes (m) were determined from the ground survey data applying the linear fit line to the data point on the beach face. NCDOT provides the ground survey data at 6 month interval starting on October 1989 at the selected 33 locations. Note that the slope data estimated from the ground survey was limited in time and location. Therefore, a polynomial smoothing was applied to beach slope data twice over the time (6 years) and the space (6 miles) in order to determine the slope at the time of photo taken at each transects over 6 miles.

Examples of measured slope variations and polynomial cross (smoothing over the time and the space) fit line along 6 miles are shown in Fig. 8. It is noted that slopes over a first quarter miles are quite mild. It is also interesting to notice that the time variation of beach slopes over a first mile is quite larger than the variations over the remaining 5 miles (from mile 2 to mile 6). The reason for this might be attributed to the frequent activities of beach nourishment over a first mile.

3.1.4 Estimation of wave runup at the time of shoreline photo taken

At present there are no theoretical approaches to calculate either monochromatic or irregular wave runup on beaches. Present approaches to calculating *monochromatic* wave runup on smooth steep slope coastal structures (or beach) have been limited to empirical expressions of a Hunt (1957) equation form.

A run-up height model proposed by Hunt (1957) is given as:

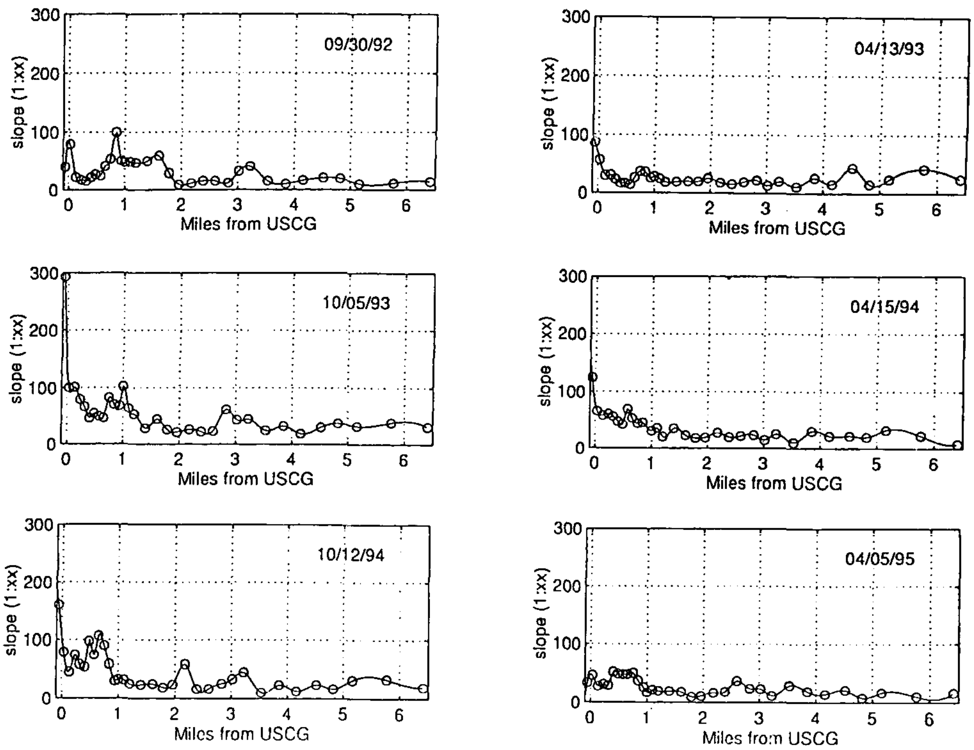

Fig. 8. Measured beach slopes and cross spline fit over 6 miles shoreline.

$$\frac{R}{H_o} = \xi \tag{1}$$

where R is the run-up height and ξ is the Iribarren number (or surf similarity parameter) defined as

$$\xi = \frac{\tan\theta}{\sqrt{H_o/L_o}} \tag{2}$$

where θ ($=1/m$) is the beach face slope, H_o and L_o are the deep water (or offshore) wave height and wave length, respectively. Note that significant waves were used for H_o and L_o, since the dried beaches were assumed intuitively wet by the process of uprush of significant waves.

In this study Equation 1 was used for the calculation of runup height at the time of shoreline photo taken. Examples of runup height estimated over 6 miles are shown in Fig. 9. Tidal conditions at each time of photo taken are also shown in each figure. While runup height varies over 6 miles depending on the beach slope, the tidal elevation is uniform over 6 miles. Note that tide, wave height and period are assumed to be constant over 6 miles. Thus, the addition of runup height with tidal elevation results in just the shift of runup height up or down.

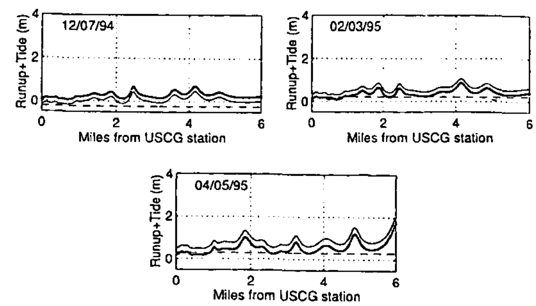

Fig. 9. Wave runup height and tidal elevation estimated over 6 miles shoreline. In the figures, the dotted line and the thick straight line represent the tidal elevation and the runup height, respectively, and the plain straight line represents the sum of them.

The maximum runup height estimated was approximately 3 m at 1 mile from USCG station for the shoreline photograph of June 1990 while the minimum was near zero frequently.

3.1.5 Corrected shoreline position

Shoreline positions determined from aerial photograph were corrected by eliminating the tidal and wave run-up effects on shoreline positions. Assuming a planar beach profile, wave runup and tidal effects on shoreline position from aerial photo were estimated by multiplying the sum of the tidal elevation and runup height with beach slope *m*. The positive value in elevation resulted in the advancement of shoreline and the negative led to the retreat of the shoreline.

Examples of plots of the corrected shoreline positions and the shoreline positions directly from the aerial photographs are given in Fig. 10. It is interesting to notice that a form of corrected shoreline over 6 miles is not quite different from that of shoreline by photo and appears just to be shifted up (or down). It seems to indicate that the tidal effects on shoreline position are larger than those of wave run-up. However, it is not true. As shown in Fig. 9, both the tide and wave runup height has a same order in quantity for the adjustment of shoreline position. Neither of them should be neglected in determining the corrected shoreline position. However, the variations of adjustment of shoreline position are relatively small over 6 miles, resulting in the shifted form of the corrected shoreline with locally small changes.

3.2 Shoreline Position Analysis

In this study both spatial and temporal changes of shoreline positions are analyzed by examining regional and local differences in shoreline movement and their time-dependent variability. The corrected shoreline position data estimated in previous section were used for these purposes.

3.2.1 Spatial variation

Spatial variation of shoreline was examined by checking the existence of shoreline rhythms. Examples of plot of shoreline over 6 miles are shown in Fig. 11. Based on Fig. 11, it appears that there is no shoreline rhythm. Further analyses with more detailed data for the shoreline, wave climate and depth contour are required.

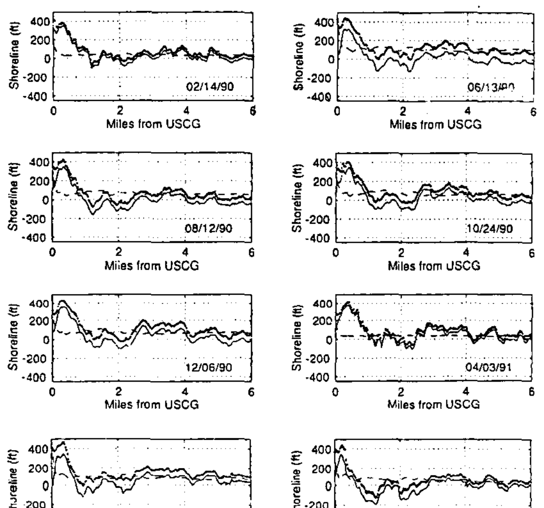

Fig. 10. Shoreline position digitized directly from aerial photographs (thick straight line) and corrected shoreline position (plain straight line). In the figures the dotted line represents the tidal and wave run-up effects on shoreline positions in distance. Note that positive value of vertical axis (shoreline) means the retreat of the shoreline, and negative value represents the accretion of the shoreline.

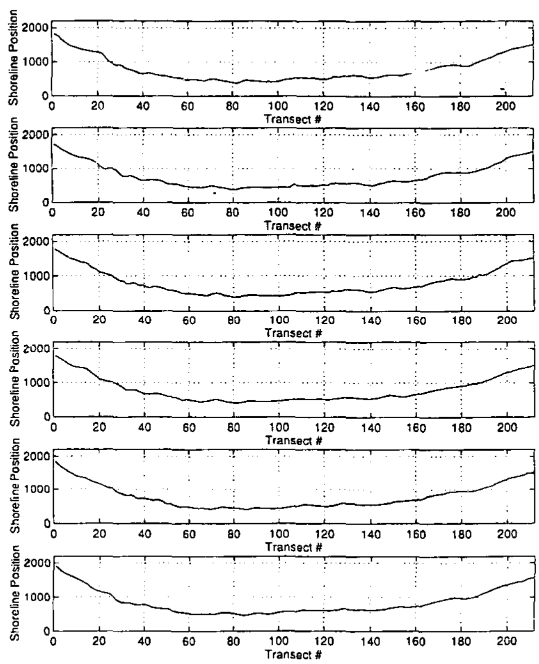

Fig. 11. Examination of shoreline rhythms. From the top to the bottom, each figures illustrate shoreline positions for February, April, June, August, October and December of 1994, respectively.

3.2.2 Temporal variation

Temporal variation of shoreline was examined by plotting the shoreline in a yearly interval. Fig. 12 shows shorelines over 6 miles in a yearly interval. It is noted that there is a tendency of accelerating erosion from 6/1994 to 4/1995.

It is important to recognize major turning points in spatial and temporal trends of shoreline movement. In

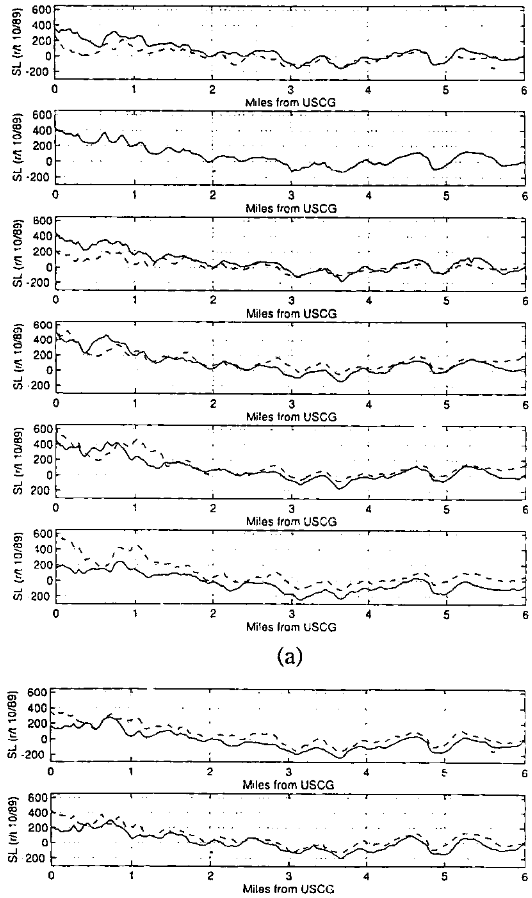

Fig. 12. (a) Shoreline change over 6 miles during a year interval. Each figures from the top to the bottom illustrate the shoreline positions for February, April, June, October and December of 1994 (straight line) and 1993 (dotted line), respectively. Note that no aerial photographs was taken for the shoreline of April 1993 due to the frequent severe storms during those period. (b) Shoreline change over 6 miles during a year interval. Each figures from the top to the bottom illustrate the shoreline position for February and April of 1995 (straight line) and 1994 (dotted line), respectively.

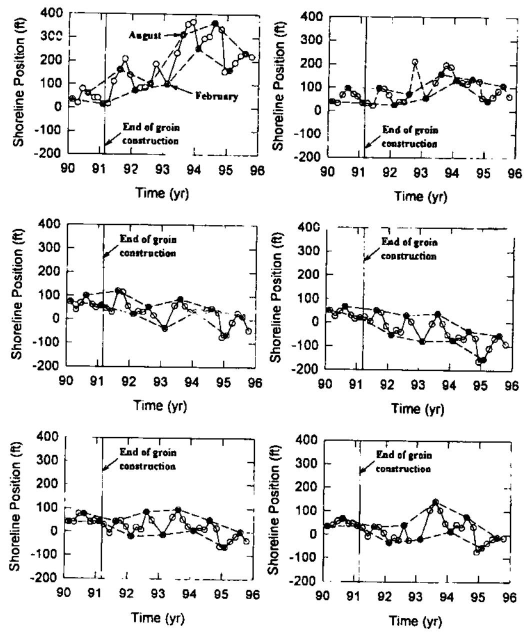

Fig. 13. Temporal variation of 1-mile averaged shoreline during monitoring period. In the figures, the circle represents the data for the winter and the circle represents the data for the summer. Note that the shoreline of December 1989 was used as the base shoreline. Therefore, the shoreline position values in the figures are the value relative to the shoreline position of December 1989.

order to examine the temporal variation of shoreline in more detail, shoreline was averaged over 1 mile (which gives 6 data point over 6 miles). Variations of one-mile-averaged shoreline over 6 years are shown in Fig. 13. It is interesting to notice that there is an apparent seasonal variation of shoreline at Mile 3, 4, 5 and 6. That is, progradation of shoreline at summer (august) and recession at winter (February). This yearly cycle of seasonal variation of shoreline does not fit well in Mile 1 and 2. This is attributed to the activities of beach nourishment.

4. SUMMARY AND CONCLUSIONS

Both spatial and temporal variations of shoreline changes at the northern end of Pea Island were investigated using data from aerial photographs. It is common to use the wet-dry line in order to identify the position of the shoreline when aerial photographs are employed to obtain the shoreline position data. Analysis of the shoreline position data digitized directly from aerial photographs confirmed that the considerable errors could be involved in those digitized data due to the mobility of wet-dry line depending on wave intensity and tidal variation at the time of photos taken. Both tidal elevation and wave runup was shown to have the same order of effects in quantity. Analysis with shoreline position data corrected for wave runup and tide effects indicated that there was an apparent seasonal variation of shoreline. That was, progradation of shoreline at summer (August) and recession at winter (February) with tendency of accelerating erosion at northern part of Pea Island, which was unclear with the uncorrected shoreline position data. With regard to the spatial variation of shoreline changes, no shoreline rhythm was observed. However, further analysis is required to confirm it. The primary conclusion is that determination of shoreline position from aerial photograph, without regard to the effects of wave runup and tide, can lead to mis-interpretation for the temporal and spatial variation of shoreline changes.

ACKNOWLEDGEMENT

A support provided by the DOT (Department of Transportation), Raleigh, North Carolina is appreciated. Special thanks are extended to Drs. M.F. Overton and J. S. Fisher at Civil Engineering Department of North Carolina State University for their valuable advice, suggestions, and guidance throughout this study. Digitizing of aerial photographs were carried out by KUNAN Natural Disaster Laboratory at North Carolina State University.

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