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Shoreline Change Based on Long Term Wind Statistics in Suyeong Bay
長期 바람 觀測 統計値에 의한 水營灣의 海岸線 變化

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Abstract □ Shoreline change due to the littoral drift in Suyeong bay, especially the Gwanganri and Haeundae beaches, was investigated. Average monthly frequency, speed, and direction of winds blowing from between east and south for the last 15 years were analysed, and offshore significant waves were hindcasted using the JONSWAP model. Wave refractions, shoaling, and breaking were also investigated for the calculation of littoral drift. At the Gwanganri beach major longshore transport of sands occurs from the southwest to the northeast and the shoreline seems to advance in the northeast while it recedes in the southwest. At the Haeundae beach the sands mainly move from the east to the west and the shoreline retreats in the east and advances in the west.

要 旨 : 연안 퇴적물 이동에 의한 수영만의 광안리와 해운대 지역의 해안선 변화를 조사하였다. 이 지역에 가장 큰 영향을 미칠 것으로 추정되는 동쪽과 남쪽 사이에서 부는 바람의 15년간 풍향별 발생빈도를 이용한 월별 평균 풍향과 풍속을 계산하여 JONSWAP법에 의한 심해 유의파를 추정하고, 굴절 및 천수효과에 의한 쇄파고와 쇄파각을 계산하였으며, 그에 의한 연안 퇴적물 이동량을 계산하고 퇴적물 이동량의 수급에 따른 해안선의 변화를 계산하였다. 광안리 지역에서는 주된 연안 퇴적물 이용이 남서에서 북동방향으로, 해운대 지역에서는 동쪽에서 서쪽으로 이동하는 것으로 나타났으며, 광안리 지역의 해안선은 북동쪽이 전진, 남서쪽이 후퇴하는 양상을 보이고, 해운대 지역은 동쪽이 후퇴, 서쪽이 전진하는 결과를 보이고 있다.

1. INTRODUCTION

Suyeong Bay, which is located at the southeastern part of Korean Peninsula, is open to the southeast and the coastline consists of rocky shore to the south and Gwanganri, Suyeong, and Haeundae beaches to the east (Fig. 1). Along the coastline except for the rocky shore, the beaches are protected by seawalls and breakwater. However, especially at the Gwanganri and Haeundae beaches, a significant shoreline change is taking place in spite of the many coastal structures to protect the beach from erosion (Kim, 1988; Park and Lee, 1989).

For the construction of a yachting wharf for the 1988 Seoul Olympic Games at the Suyeong beach, several preliminary oceanographic surveys were conducted in Suyeong Bay (Pusan City, 1983, 1984a, 1984b; Seoul Olympic Organizing Committee and Korea Meteorological Service, 1988), and several numerical studies for the shoreline change also have been conducted (Pusan City, 1984a; Park and Lee, 1989; Kim, 1988). However, most of the studies deal with a numerical modeling based on a short term field observation or meteorological data. The studies also ignored the information on overall physiography and sediment distribution of the bay.

For the present study, wind data of the past 15 years from 1975 to 1989 (Korea Meteorological Service. 1975~1989) in Pusan area were used to analyz the frequency distribution of the wind speed and direction at Suyeong Bay. The frequency distribution was then used to estimate the monthly variation of the height and direction of deep sea significant waves coming into the bay. Wave refraction,

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shoaling, and breaking have been calculated by using the overall physiographic information of the bay. Longshore drift by the longshore currents and the shoreline change were investigated based on the information on the sediment distribution of the bay and by numerical calculation. A numerical prediction of the shoreline change at the Gwanganri and haundae beaches has also been conducted for the next 25 years.

2. PHYSIOGPAPHY AND SEDIMENTS

The bay is generally flat with a depth of about 10 to 20 m deepening gently southeastward. The bottom is featureless except for the small islands near the Haeundae area (Fig. 1). The coastline can largely be divided into two parts. The southward coastline is characterized by a steep slope to the depth of about 10 to 20 m bordered by rocky mountains and cliffs. However, the coastline to the east is composed of sand beaches which have gentle slope with a shallow depth of about 2 to 5 m except for the Suyeong area, where a yachting wharf has been built for the 1988 Olympic Games (Fig. 1). The foreshore slope of the Haeundae beach is slightly steeper than that of the Gwanganri beach, and a long series of seawall is built along the beaches at the Gwanganri and Haeundae areas.

Sediment input to Suyeong Bay is extremely limited. Except for the nearshore area the bay is covered by thin silty sediments with occasional occurrence of rocky outcrops. However, relatively thick fine sand and silty sand cover the granitic basement at the nearshore area reaching up to 5 to 20 m (Pusan City, 1984b). The sediments off the bay towards the Korea Strait become coarse and thick again up to 20 to 30 m (A. D. D., 1988).

Most of the bay sediments are fine and poorly sorted containing less than 10% of sand. Sands only occur along the shoreline of the Gwanganri and Haeundae areas. Sands at the Gwanganri beach are mostly medium to fine sands. However, coarse sands containing some gravels occur at about 500 m from the southwestern end of the beach and the grain size decreases to fine sand both southwest- and northeast-wards. Sands at the Haeundae beach

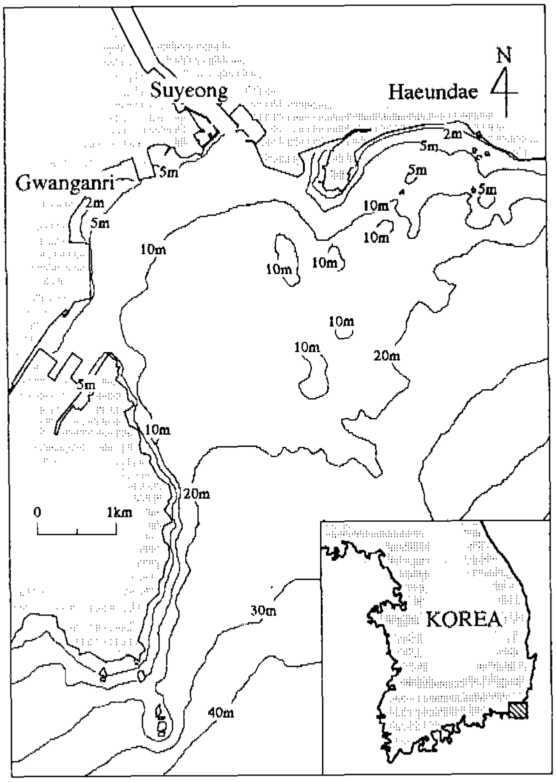

Fig. 1. Location and physiography of Suyeong Bay.

are mostly comprised of medium sand without any local variation. However, the shoreline coincides with the seawall at the eastern part of the beach, where very large rocks and pebbles are found with no sand (Kang, 1991).

3. WINDS AND WAVES

3.1 Winds

Direction and speed of the winds in the bay generally follow the wind trend in Pusan area (Seoul Olympic Organizing Committee and Korea Meteorological Service, 1988). The analysis of wind speed and direction in Pusan area for the past 15 years shows that the wind from NNE and NE is most frequent and the wind from SE and SSE is the rarest. Otherwise, the wind direction is generally variable with less than 10% of occurrence at each direction (Fig. 2). The monthly average wind speed is generally between 3.5~4.5 m/sec. The wind is strongest during the spring time and weakest in

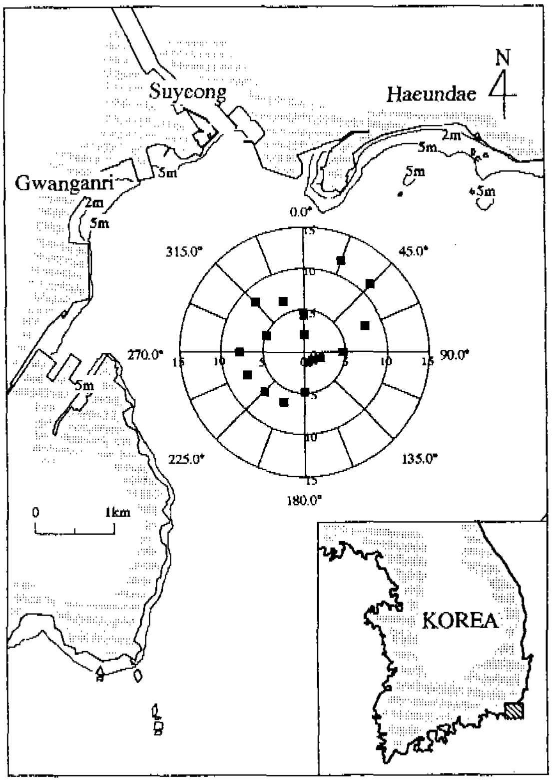

Fig. 2. Frequency distribution of wind direction in Pusan area for the 15 years between 1975 and 1989.

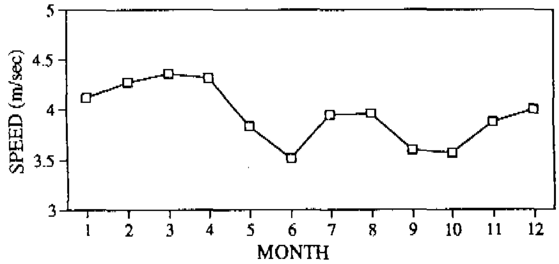

Fig. 3. Monthly average wind speed in Pusan area for the 15 years between 1975 and 1989.

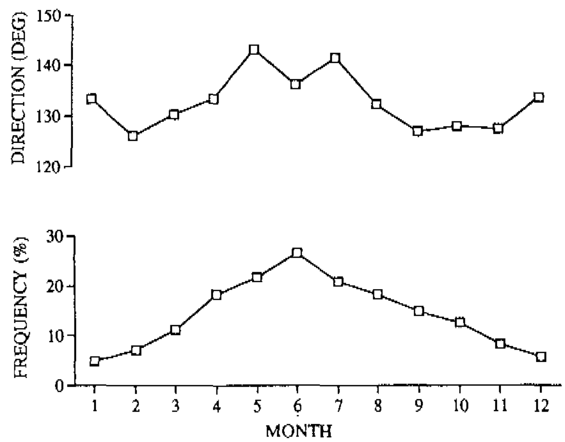

Fig. 4. Monthly frequency distribution and frequency-weighted average direction of the wind between east and south in Pusan area for the 15 years between 1975 and 1989.

June and fall (Fig. 3).

Even though the northeasters are most frequent in Pusan area, because the bay is open to the southeast and the landward side is surrounded by high mountains, winds blowing from between east and south may be most affective to the sediment distribution in Suyeong Bay (Pusan City, 1983, 1984a). Fig. 4 shows the monthly frequency distribution and the frequency-weighted average direction of the winds blown from between east and south in Pusan area for the past 15 years. The winds between east and south are most frequent between spring and summer when the average wind speed is relatively low.

3.2 Waves

The monthly average speed and frequency of the winds between east and south were used to estimate the monthly significant period and height of deep sea wave using the JONSWAP wave prediction model (U. S. Army Corp of Engineers, 1984; Bishop and Donelan, 1989). The frequency-weighted average direction was used as the direction of incoming deep sea waves. the calculated monthly significant wave height was mostly lower than 0.5 m and the period was about 3 seconds, which implies that the bay is more or less in calm condition on the average. The actual measurement showed that 88% of the waves measured inside the bay for 6 months was lower than 0.5 m coming from southern directions (Pusan City, 1984a). The measurement by Seoul Olympic Organizing Cemmittee and Korea Meteorological Service (1989) also implied that higher waves (0.6~1 m) with longer periods (5~6 seconds), which were mostly caused by northern winds, were dominant out of the bay and the lower waves (lower than 0.5 m) with shorter period (3~4

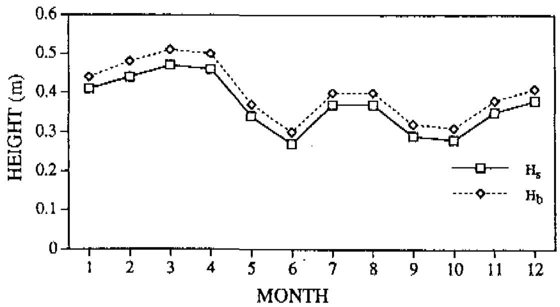

Fig. 5. Calculated deep sea significant wave height (H_s) and breaker height (H_b) in Suyeong Bay.

seconds) caused by southern winds were most affective inside the bay.

The change of direction while the deep sea waves travel into the bay was calculated by the ray tracing method on x-y coordinate system (Dean and Dalrymple, 1984; Townend and Savell, 1985),

$$\frac{\partial \alpha}{\partial s}=\frac{1}{C}\left(\frac{\partial C}{\partial x}\sin\alpha-\frac{\partial C}{\partial y}\cos\alpha\right) \tag{1}$$

where s is the travel distance of wave orthogonal, C is the wave celerity, and α is the angle between wave orthogonal and x-axis.

The change of wave height by shoaling was also calculated by the shoaling formula given by U. S. Army Corps of Engineers (1984) until the waves broke near the shoreline:

$$\frac{H}{H_o}=\frac{1}{\left[\tanh kd\left(1+\frac{2kd}{\sinh 2kd}\right)\right]^{1/2}} \tag{2}$$

where H is the local wave height, H_o is the deep sea wave height, k is the wave number, and d is the local depth.

Breaking of the waves was calculated by the simple relationship which can be used on a mild sloping beach (Komar, 1976):

$$\frac{H_b}{d_b}=0.78 \tag{3}$$

where H_b is the breaker height, and d_b is the depth of breaker.

Local variation of wave heights by refraction was neglected to calculate an average condition along the shoreline. Fig. 5 shows the calculated monthly average significant deep sea wave and breaker heights.

4. LITTORAL DRIFT AND SHORELINE CHANGE

Breaking of waves near the shoreline generates longshore currents in the surf zone, and the volume rate of quartz sand transport by the longshore currents can be calculated by the energy flux factor (Komar and Inman, 1970; Komar, 1983a, b):

$$Q_s=6.8P_l \tag{4}$$

where Q_s is the volume rate of quartz sand transport in m^3/day, and P_l is the energy flux fator in W/m, which can be expressed as

$$P_l=(ECn)_b\ \sin\alpha_b\cos\alpha_b \tag{5}$$

where α_b is the angle between the breaker crestline and the shoreline, and $(ECn)_b$ is energy flux by waves at the breaker zone, which can be calculated in shallow water ($n=1$) by

$$E=\frac{1}{8}\rho g\ H_b^2 \tag{6}$$

$$C=(gd_b)^{1/2} \tag{7}$$

Breaker height in Eq. (6) should be the root mean square value, and the volume rate calculated by Eq. (4) should be divided by 2 if the significant wave height is used in Eq. (6) (Komar, 1983a, b).

Neglecting the cross-shore transport of sand, shoreline change due to the littoral drift can be calculated by the change of volume transport rate at a place along the shoreline (Dean and Maurmeyer, 1983; Hansen and Kraus, 1991),

$$\frac{\partial y}{\partial t}=-\frac{1}{B+D_c}\frac{\partial Q_s}{\partial x} \tag{8}$$

where, x and y are the axes parallel and perpendicular to shoreline, respectively, B is the berm height, and D_c is the depth of closure.

The depth of closure, offshore limit of the littoral drift, may change according to the characteristics of sediment and incident waves (Kraus, 1983). However, it can be approximated as twice the breaker height (Hansen and Kraus, 1991).

5. RESULTS AND DISCUSSIONS

Shoreline change for the next 25 years has been calculated assuming no sediment could enter or escape from the beaches because both the Gwanganri and Haeundae beaches were protected by breakwaters and seawalls at both ends. For the calculation monthly frequency of the winds between east and south was converted in terms of duration, and it was also assumed that a constant wave height from the average direction was continuously acting on the beach for the duration of each month.

Fig. 6 shows the shoreline change for the next 25 years together with the average of several field measurements in 1990 at the Gwanganri beach. For the present berm width is narrowest at about 500 m from the southwestern end it becomes wider towards both ends of the beach. It is generally wider at the northeastern side than at the southwestern side. Considering the general shape of the shoreline together with the trend of grain size distribution along the beach that the coarsest sediment occurs at the narrowest berm and the sediments become finer towards both ends, littoral drift at the Gwanganri beach generally seems to be northeastwards, and thus the shoreline may advance at the northeastern side and may retreat at the southwestern side. However, the shoreline may not change very much or may advance very slowly near the southwestern end.

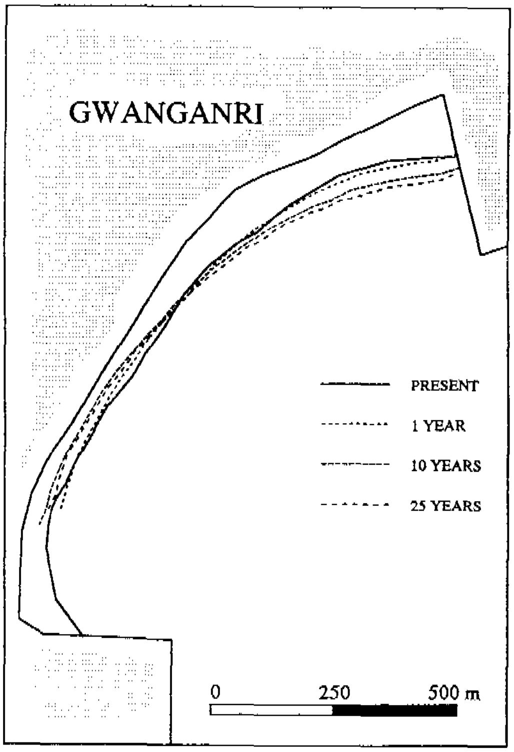

Fig. 6. Shoreline change for the next 25 years at the Gwanganri beach. Solid line (present) represents the average of several field measurements in 1990.

The calculation of shoreline change for the next 25 years also shows a similar trend that the shoreline is advancing at the northeastern side and generally retreating at the southwestern side with repeated advance and retreat. Considering the direction of incident waves, diffraction of waves may be more affective than the refraction near the southwestern end, and thus the calculation was not carried out near the southwestern end. Reflection effect at the northeastern end was also neglected for the calculation.

At the Haeundae beach the eastern side was severely eroded and the shoreline already reached the seawall. Only large gravels and rocks are found at the eastern side, and the sandy berm becomes wider towards the western side (Fig. 7). Even though a size grading of the sand was not very clear at the Haeundae beach, overall shape of the shoreline and the severe erosion at the eastern end strongly imply

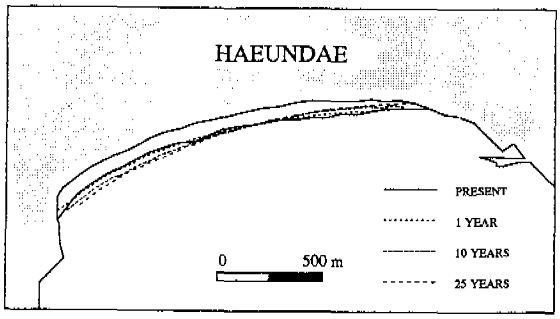

Fig. 7. Shoreline change for the next 25 years at the Haeundae beach. Solid line (present) represents the average of several field measurements in 1990.

that the direction of the littoral drift is westwards. Therefore, shoreline may retreat at the eastern side and advance at the western side.

For the next 25 years the calculation also shows that the shoreline is advancing at the western side and retreating at the eastern side. It also shows that the end of sand berm is moving westwards since the shoreline could not retreat any more due to the seawall at the eastern side.

The above calculations may be too conservative since the calculation was carried out under the assumption that the sand in the beach was conserved. However, sands may escape from the beaches along the blocking walls at both ends, and sands can also be carried offshore by rip currents of wave orbital motion. Therefore, Figs. 6 and 7 only show a long-term general trend of shoreline change. Even though any strong and constant rip currents were not found during the field measurements at both beaches, Kim (1988) suggested the existence of rip currents by numerical calculation and drifter tracking outside the surf zone at the Haeundae beach. Offshore loss of sand may also occur during occasional storm events. If the offshore loss of sand is considered, shoreline retreat may be faster, advance may be slower, and the beaches may lose sand gradually in total since sediment input to the bay is extremely limited.

6. CONCLUSION

Even though winds are most frequent from the northern directions and rarest from the southern directions in Pusan area, Suyeong bay seems to be affected mostly by the waves generated by the winds blowing from southeast direction since the bay is open to the southeast. The significant waves inside the bay are found to be generally lower than 0.5 m with the period of about 3 seconds by the winds blown from the directions between east and south.

Direction of littoral drift in Gwanganri beach is considered to be mostly northeastwards. However, a small amount of southwestward movement is also expected near the southwestern end. In Haeundae beach littoral drift seems to move westwards overall.

Numerical calculation of shoreline change due to the littoral drift shows that the shoreline of the Gwanganri beach might advance in the northeastern side and retreat in the southwestern side. It is also shown that the shoreline of the Haeundae beach might show a retreat in the eastern side and an advance in the western side. The shoreline already coincides with the seawall at the eastern side of the Haeundae beach, and the eastern end of sand berm seems to move westwards. If the offshore loss of sand continues, the shoreline change may show a general trend of faster retreat and slower advance than the calculation shows, and the beaches may lose sand gradually.

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