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Sea Level Rise at the Southwestern Coast of Korean Peninsula

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Abstract : *Sea level (MSL, MHWL, or MLWL) change has been main concern to scientists and engineers and it can be primarily due to both change of climate and vertical movement of land. This paper reports the intensive analysis of the sea level changes and broad discussion of the future at the southwestern coast of Korean peninsula. Regression analysis was conducted to investigate general tendency and periodicity of the sea levels at the six different study sites such as Gunsan-I(inner port), Gunsan-O(outer port), Mokpo, Yeosu, Heuksan and Jeju and the results were compared with global values. Besides the changes of sea levels due to global warming, the influence of the man-made structure such as seadike and seawall was attempted to quantify using the minimization of the Root Mean Square (RMS) error. The results show that it is a general tendency that the values of mean sea level rise at the southwestern coast of Korean Peninsula, especially at Gunsan-I and Jeju, are somewhat larger compared to global average values. There is also some evidence that tidal amplifications are found just after construction of man-made structure at Gunsan-I and Mokpo. However, both sites show different mechanism in relation to tidal choking, tidal flat and river discharge. The impact due to construction of man-made structure is considerably larger at Mokpo site, while the impacts due to man-made structure and the effect of sea level rise are relatively identical at Gunsan-I site. This study is expected to provide some intuition to future design.*

Key words : *Sea level rise, Global warming, Mokpo, Gunsan, Mean sea level*

1. Introduction

Absorbed sunlight raises the earth's temperature and the earth's temperature is lowered by emitted radiation or heat. When absorbed sunlight and emitted heat balance each other, the radiation budget is in balance. Owing to the increase in atmospheric carbon dioxide caused by modern industrial combustion of fossil fuels (coal, oil, and natural gas), the emitted radiation is absorbed in the atmosphere, greenhouse effect on earth may be intensified and it might lead to long-term climatic changes.

More percentage of water existed as ice caps and glaciers in, so called, the ice age about 21000 years ago and it is inferred that sea level of the ice age was lower by approximately 125m than that of modern days. Until accelerated rise of the sea level in the 20th century, there has been no significant sea level change after the ice melting of 4000~5000 years ago(Gomitz, 1995). Flemming(1982) concluded that yearly sea level increase was 0.2mm for the past 2000 years after the broad investigation of the hundreds of measurement points near Mediterranean sea. But the global warming effect would cause the polar ice caps and mountain glaciers to melt rapidly and eventually result in noticeably higher mean sea level. The significant rise in global temperature would also produce new patterns and extremes of drought and rainfall in certain regions, which might lead to serious threatening for food production. Accordingly the sea level change has been main concern to societies and there is no exception in Korean peninsula.

As mentioned earlier the increase of the sea level, since the 20th century, is faster and it is estimated to be 1~2 mm/year (Church et al., 2001; Douglas, 1997; Warrick et al., 1996; Houghton et al., 1996). It is interesting that the range of the rise in sea level using the computer simulation is -0.8~2.2 mm/year(IPCC, 1996) and the maximum value (2.2 mm/year) is similar to the estimated value (2 mm/year). The model prediction based on physical climate model, so called the General circulation model (GCM), for the 21th century suggests the rise in sea level is in the range of 0.9~8.8 mm/year and the median value (4.8 mm/year) is about twice as the value in sea level rise for the past 100 years, which implies that the rise in the near future will be significantly faster(Knauss, 1999). It is also coincident with Church et al. (2001) which suggested that the rise in sea level in 1990's was 4 mm/year due to thermal expansion of seawater, while the rise in sea level by melting of ice fields, Greenland or Antarctica, until 1990's was

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1~2mm/year. Cabanes et al. (2001) assured that the rise was 3.2 mm/year and fast increasing based on space-borne satellite data analysis. Globally the rise in sea level can be caused by ice melt in Greenland and Antarctic, the increase in sea water volume by increase in sea water temperature, current change by El Nino, and lastly the change in hydrological cycle due to man-made structure(Knauss, 2001).

However, to a certain degree, the rise in sea level is region-dependent and this regional variation is primarily dependent on current circulation patterns, water density variations, and vertical land movements. It is also found that sea level rise at the southwestern region in Korean peninsula is partly attributed to the construction of man-made structure such as seadike and seawall(Kang, 1999). Hence, it is meaningful to investigate the regional rise in sea level intensively in Korean peninsula. There have been many regional scale models to calculate the rise in sea level but unfortunately large discrepancies in the rise in sea level between the different models. It is essential to consider more regional characteristics in the modeling approach and the rise in sea level needs to be understood in relation to the regional issues such as coastal erosion, flooding of port town, inundation of coastal area, and groundwater contamination. Recently coastal erosion and inundation of coastal area have been a main concern to the societies and this damage is considered to be related to the rise in sea level. Moreover many ocean areas in Korea are developed along the coast and the rise in sea level can lead to further economical and social damage in the near future.

In this study the change in monthly mean sea level is intensively investigated at the southwestern Korean peninsula and the effect of man-made structure construction was analyzed. In the following section we briefly describe the aspects of study region and field data. In section 3 we present general procedure to analyze the change in sea level. The results and discussions are presented in section 4 and the conclusions are finally discussed in the last section.

2. Study Region and Field Data

Southwestern coast in Korea has very large tidal range in the world, up to 10m. A lot of islands and bays are located and tidal flat is largely developed in the coastal area. Several large scale reclamation projects were accomplished to acquire land and fresh water. The study region covers six different locations along the southwestern coast of Korean peninsula and these areas are well developed along the seashore and accordingly various types of different man-made structures have been built such as seadikes and seawalls.

The location and latitude/longitude of the five different sites are shown in the Table 1 (available at http://oceandata.nori.go.kr/) and Fig. 1. In the estuary of Geum River, a seadike(1,841 m) was constructed in 1990 and Yeongsan River seadike(4,350 m), located in the estuary of Yeongsan River, was constructed in 1981. In Mokpo coastal area Yeongam(2,219 m) seawall and Geumho(2,120 m) seawall are completed in 1991, 1993, respectively.

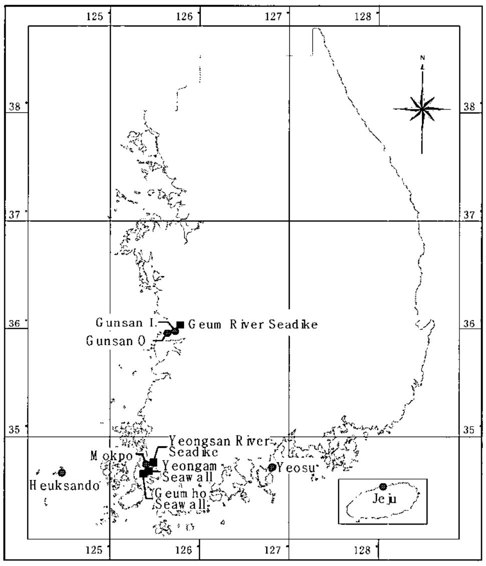

Fig. 1 Tidal station and coastal structure in southwestern oastal area of Korean peninsula

Table 1 Six different study sites. Each site present latitude/longitude and mean high water level measured by National Oceanographic Research (available at http://oceandata.nori.go.kr/)

	Name of sites	Latitude	Longitude	MHWS	MHWN
Site A	Gunsan-I(Inner port)	35-59-25N	126-42-46E	683.3	512.4
Site B	Gunsan-O(Outer port)	35-58-06N	126-37-36E	664.0	500.8
Site C	Mokpo	34-46-56N	126-23-20E	431.9	336.2
Site D	Heuksando	34-40-55N	125-26-36E	327.5	255.5
Site E	Yeosu	34-44-39N	127-46-05E	329.4	234.6
Site F	Jeju	33-30-51N	126-31-50E	243.1	182.9

The data were collected over six sites by National Oceanographic Research Institute of Korea and monthly mean sea level observations have been intensively carried out for over 30 years. Missing points in the data were interpolated, and mean sea level values of site B and C were adjusted for consistency because datum level were recalibrated by 20 cm (site B in 1982) and 28 cm (site C in 1980) at each site.

3. Procedure

3.1 Analysis of Mean Sea Level

The regression method is advantageous in that it can include meteorological factors such as atmospheric pressure and wind speed, if data is available, and the nodal tide of period 18.6 years and pole tide of period of about 436 days. Hence, regression method has been a dominant method to investigate linear trend of the change in sea level in a certain region since 1980's (Chelton et al, 1982; Thompson, 1986; Lanfredi et al.,1988). The regression method has been successfully conducted in the west coast of USA, north Atlantic coast, Trieste bay and Argentina. The results shown are very encouraging. However, studies about mean sea level in Korea focused generally on seasonal variation from a scientific point of view. They have been focused on seasonal variation of mean sea level relating atmospheric pressure, seawater density and monsoon. But man-made structure has not been any concern in the study and this man-made structure effect might cause errors or misunderstanding for analyzing the change in sea level, especially in site A, B and C(Kang, 1996).

The strategy adopted in this study was to use regression method to examine the general trend of the change and then quantitatively analyze the annual and seasonal variation in sea level at southwest of Korean peninsula. The method was originally suggested by Thomson (1980) and mainly mimicked in this study. Southwest coast of Korean peninsula is tidal flat dominant area and several large scale construction projects was carried out. The change in sea level as reinvestigated considering the influence of the man-made structure in this area. The monthly sea level data were used to determine the change due to global warming effect, while monthly mean high water level and low water level were used to determine the change due to man-made structure.

Tidal period might be a critical factor in regression method to analyze the change in sea level and caution needs to be taken to determine the period. In this study FFT analysis were chosen to determine the period. As a result of FFT analysis, 1/2 and 1 year period, which were used in the mean sea level(MSL) regression equation (1), were noticeable and similar spectrum shape was also found for the rest of sites. A typical spectrum at site C (Mokpo)

$$MSL = a_0 + a_1 M + c_{1c}\cos[\frac{2\pi M}{12}] + c_{1s}\sin[\frac{2\pi M}{12}] + c_{2c}\cos[\frac{2\pi M}{6}] + c_{2s}\sin[\frac{2\pi M}{6}] \qquad (1)$$

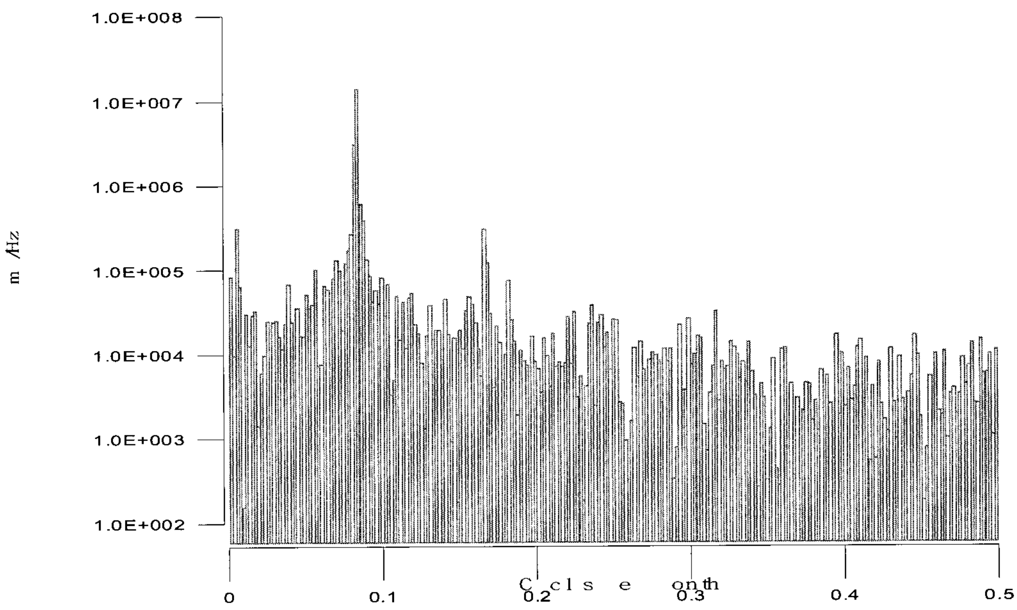

Fig. 2 Spectrum of 43 years of Mokpo sea levels

Table 2 The rate of mean sea level(MSL) rise(mm/yr)

Site	This study		Pang et al.(1994)		Seo et al.(2000)	
	Record period	MSL rise	Record period	MSL rise	Record period	MSL rise
Gunsan-I	60-94	6.3[a]	65-85	-	60-98	1.0
Gunsan-O	81-94	0.8[a]	65-85	-	60-98	1.0
Mokpo	60-80	-0.8[b]	65-85	0.8	60-98	0.8
	81-90	2.0[c]	65-85	0.8	60-98	0.8
	94-03	12.2[d]	65-85	0.8	60-98	0.8
Yeosu	68-03	2.2	65-85	-	60-98	1.6
	90-03	2.3	65-85	-	60-98	1.6
Heuksando	67-03	3.9	65-85	-	60-98	-
	90-03	-1.1	65-85	-	60-98	-
Jeju	65-03	5.4	65-85	4.7	60-98	4.4
	90-03	8.1	65-85	4.7	60-98	4.4

a : before Geum River seadike, b : before Yeongsna River seadike, c : after Yeongsan River seadike, d : after Yeongam/Geumho seawall

is shown in the Fig. 2. For mean high water level(MHWL) and mean low water level(MLWL) analysis, the 18.6 year period was included in the analysis for more accuracy, however, it was not significant to the result. Equation (1) was primarily designated to provide linear trend, annual/semi-annual tidal range in mean sea level (MSL).

In which a_0 is the long-term mean sea level, a_1 is the linear trend in a_0, c_{1c} and c_{1s} are the coefficient, in annual tide, c_{2c} and c_{2s} are the coefficients of semi annual tide and M is the month.

3.2 Analysis of Sea Level Change due to Construction

Not only global warming but also man-made structure, such as seadike and seawall, can cause the change in sea level and site A, B and C might be the case because many structures are recently built in this area. It is important to quantify the change in sea level due to man-made structure and assure the data consistency before and after construction over the whole observation period. To do this, a simple trial and error method is used. A trial value is repeatedly added or subtracted to the series of data set only after construction period until RMSE is minimized in the regression method over whole period. Once the procedure is reached to a final value, the impact due to man-made structure is quantified and the slope can be considered to be indicative of linear trend in sea level change over the whole period. The data analysis was performed in two ways as follows: One is before and after construction for site A, B and C. The other is before and after 1990 for the rest of the sites.

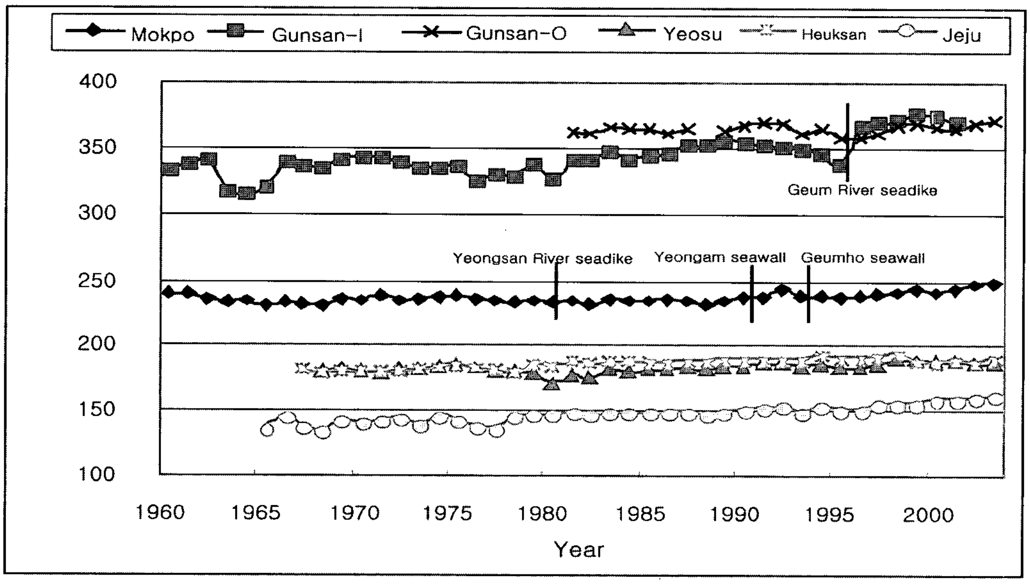

Fig. 3 Change in annual mean sea level

4. Results and Discussions

4.1 The Change in Mean Sea Level

Fig. 3 shows the change in annual mean sea level as a result of the regression analysis. There is some evidence that there is an abrupt sea level rise in mean sea level for site A(Gunsan-I) under the influence of Geum River seadike, while it is not found ovbiously in site C(Mokpo). It is also found that mean sea level rise rate after 1990's is increasing for site A and C from Fig. 3.

Regression method can provide different results depending on the study period and different study year and these effects might lead to slight different final values in Table 2. Table 2 generally shows, until 1990's, that the change in sea level is 1-3 mm/yr. It is found that the sea level rise rate after 1990's is 12.2 mm/yr and significantly increasing compared to before 1990's in site C(Mokpo). It can be attributed to man-made construction but more investigation is in need due to short data period. The sea level rise rate in site E(Heuksan) is unexpectedly decreased from 3.9 mm/yr to -1.1 mm/yr and the sea level rise rate in site F(Jeju) is shown to be extremely high(5.4 mm/yr and 8.1 mm/yr) comparing to the other sites. The global sea level rise is approximately 1-3mm/yr and the sea level rise in site E and F might be a contribution of vertical land movement and further investigations about land movement are needed. On the basis of the results above, mean sea level rise in Korea peninsula is coincident with global trend in general, but it is hard to conclude that the mean sea level rise is increasing in 1990's.

Table 3 shows annual range of mean sea level, which is the coefficient of equation (1), for each sites(A-F) and compared to previous studies. As shown in Table 3, the annual and semi-annual range was 15-20cm, 2-3cm, respectively, which was coincident with previous results.

4.2 Sea Level Change due to Construction

Sea level change can be caused by several factors; global warming, vertical land movement, construction. Korea is still growing country and there have been several large scale constructions, such as seadike and seawall, and southwest coastal area in Korean peninsula was not exceptional. It might be interesting to see how the man-made constructions affect sea level changes and we attempted to quantify the sea level change due to construction by the method described in the section 3.2. In the estuary of site A(Gunsan-I) and B(Gunsan-O) Geum River seadike was constructed in 1990, and Yeongsan River seadike, located in the estuary of site C(Mokpo), was constructed in 1981. In site C, Yeongam seawall and Geumho seawall are also completed in 1991, 1993, respectively.

Table 3 Annual/semiannual range of mean sea level(cm)

Site	This study			Oh et al.(1993)			Choi et al.(1999)		
	Record period	Annual	Semiannual	Record period	Annual	Semiannual	Record period	Annual	Semiannual
Gunsan-I	60-87	18.0	3.3	72-91	20.3	2.9	78-93	19.8	2.9
Gunsan-O	91-03	18.1	2.0	80-91	19.1	2.1			
Mokpo	60-80	17.0	2.5	60-91	17.1	2.9		15.6	2.6
	81-90	17.8	2.4						
	94-03	16.9	2.3						
Yeosu	68-03	16.1	2.3	65-90	16.7	1.8		17.1	1.8
Heuksando	67-03	15.4	2.0	70-91	14.7	2.9		16.8	1.7
Jeju	65-03	15.4	1.8	64-90	16.9	1.8		17.4	2.1

Table 4 Sea Level Rise Caused by Construction(cm)

Site	Gunsan-I(A)	Gunsan-O(B)	Mokpo(C)		
Structure	Geum River Seadike	Geum River Seadike	Yeongsan River Seadike	Yeongam seawall	Geumho seawall
Mean High Water Level	+30	+5	+14	+14(+28)a	+7(+35)
Mean Sea Level	+20	-1	+1	+5(+6)	+2(+8)
Mean Low Water Level	+2	-4	-9	+6(-3)	+3(0)

a : ( ) is accumulated value

Table 4 quantitatively shows sea level change due to construction in site A, B and C. There has been a significant sea level (MSL:30cm, MHWL:20cm) rise in site A, while there has been a little change in site B. The large sea level change in site A might be caused by disturbance of tidal current due to Geum River seadike, but site B is distant from dike and accordingly it might result in minor change. There is also some tendency of large sea level (MHWL:35cm) rise in site C after three man-made constructions. There was a previous study that the sea level change in site C is partly due to disappearance of tidal choking effect from Mokpogu(narrow channel of 500m wide located at the entrance of Mokpo harbor) due to man-made construction(Kang, 1996; Kang, 1999). To assure tidal choking effect, a numerical simulation was performed. In the simulation tidal choking effect was artificially removed by artifical enlagement of Mokpogu. As a consequence of simulation, the sea level rise(14cm, MHWL) after Yeongsan River seadike(Year 1981) was considered to consist of two part; 65% due to the disappearance of tidal choking effect and 35% due to disturbance of tidal current.

But the sea level rise(14cm and 7cm, MHWL) after Yeongam(Year 1991) and Geumho(Year 1993) seawall was considered due to the disappearance of tidal choking effect mainly.

Table 5 shows sea level rise rate for site A, B and Table 6 shows for site C, which was computed with considering the result of Table4, man-made structure effects. As shown in Table 5 and 6, evident change in sea level rise after construction was not found.

5. Conclusions

This study conducted regression analysis to investigate the change in sea level for six different sites at southwest coast of Korean peninsula and focused on the changes due to the construction of seadikes and seawalls at developed sites (site A, B and C). The change in sea level due to man-made structure was quantified by minimizing the RMSE error and the primary conclusions of the present study are as follows:

1. Mean sea level rise rate in Korea peninsula is coincident with global trend(1~3 mm/year) in general, but it is hard to conclude that the mean sea level rise rate is increasing in 1990's.
2. There has been a significant sea level (MSL:30cm, MHWL:20cm) rise in site A(Gunsan-I) after the construction of Geum River seadike. The large amount of sea level rise in site A might be caused by disturbance of tidal current due to Geum River seadike.
3. There is also some tendency of abrupt sea level (MHWL:35cm) rise in site C(Mokpo) after three man-made constructions. The sea level rise(14cm, MHWL) after Yeongsan River seadike(Year 1981) was considered to consist of two part; 65% due to the disappearance of tidal choking effect and 35% due to disturbance of tidal current. But the sea level rise(14cm and 7cm, MHWL) after Yeongam(Year 1991) and Geumho(Year 1993) seawall was considered due to the disappearance of tidal choking effect mainly.
4. Evident change in sea level rise in site A(6~8 mm/yr), B(-2~2 mm/yr) and C(-2~1 mm/yr) after construction was not found.

Table 5 Sea Level Rise at Gunsan(mm/yr)

Sea Level	Gunsan-I		Gunsan-O	
	Before Seadike (1960-1994)	Whole period (1960-2003)	Before seadike (1981-1994)	Whole period (1981-2003)
Mean High Water Level	+7.3	+7.4	+1.9	+1.2
Mean Sea Level	+6.3	+6.2	+0.8	+2.1
Mean Low Water Level	+6.3	+6.5	-1.8	+1.8

Table 6 Sea Level Rise at Mokpo(mm/yr)

Sea Level	Before Seadike (1960-1980)	Whole period (1960-1990)	Before seadike (1960-1993)	Whole period (1960-2003)
Mean High Water Level	+0.1	+0.5	+0.4	+0.7
Mean Sea Level	-0.8	-0.7	-0.7	-0.3
Mean Low Water Level	-2.4	-1.6	-1.7	-1.2

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