

# A Study on the Establishment of Design Criteria for Anchorage According to Port Characteristics

Jun-Mo Park\*\*

\* Sea Training Center of the Korea Maritime and Ocean University, Busan 49112, Korea

**Abstract :** *This study suggests design criteria to evaluate the availability of anchorage in Korea to contribute to ship safety by presenting necessary design criteria for anchorage volume according to port development. Accordingly, the concept of "necessary volume of anchorage" is introduced to evaluate the volume of anchorage available in Korea's major ports, and classify these ports into three types according to the characteristics of incoming ship. Numerical simulations designed using MATLAB-SIMULINK have been carried out to track the irregularly of arrival and, waiting times along with the environmental conditions that affect anchorage and necessary volume of anchorage have been suggested based on these tests. Finally, in order to complete a function equation analysis, the necessary volume of anchorage with reference to cargo volume is addressed using regression analysis as follows. Group A -  $Y_{NA} = 0.0002X_{HA} - 3.67$ , Group B -  $Y_{NB} = 0.0002X_{HB} - 6.82$ , Group C -  $Y_{NC} = 0.0001X_{HC} + 9.02$ . This study contributes to a review of anchorage volume from the perspective of harbor development.*

**Key Words :** *Design Criteria, Necessary Volume of Anchorage, MATLAB-SIMULINK, Port Characteristics, Cargo volume, Regression Analysis*

## 1. Introduction

For marine traffic, anchorage refers to an area with sufficient volume for safe berthing, smooth maneuvering, and cargo working. Also, anchorage can be designated as an entry obstacle, waiting area, bunking area, or space for the supply of goods according to the circumstances of a given port.

In order to designate which berths play an important role in the operation of a port, size and capacity should be determined according to the relevant design standards.

This study was conducted to analyze the adequacy of anchorage volume both domestically and internationally. Jia (2011) and Xiaoliang et al. (2012) implemented a port transportation system through computer simulation to examine the appropriateness of the port capacity of Dalian Port. In addition, Jun (2013) and Zhang (2013) designed "Arrival - Inbound - Cargo Operation - Departure" procedures through mathematical methods and presented conclusions regarding the volume of anchorage in Tianjin Port.

In Korea, Lee and Lee (2014) conducted a study on the appropriateness of anchorage according to the volume of a port in Pyeongtaek, and Park (2016) conducted a simulation of a maritime transportation system centering on berthing to examine the appropriateness of Ulsan Port berth size and consider the necessity

of expansion.

However, existing research is targeted only at specific ports, which limits the results.

Because it is essential to present a function that can be generally applied in order to easily, objectively, and quantitatively determine volume of anchorage along with increases in port cargo volume and the number of inbound vessels.

In this study, ports are classified into three types according to the types of vessels present. The anchorage volume analysis method in order to review appropriateness and suggest a reasonable model to estimate what volume will be necessary when considering future maritime traffic. The correlation between anchorage volume and port trade volume was also analysed. Finally, this paper proposes and verifies a relevant function using regression analysis.

The results presented in this paper can be used as a safety analysis tool for anchorage, to ensure harbor safety.

## 2. Classification of ports by ships characteristics

The characteristics of cargo, waiting time in anchorage, and number of ships present vary by port. For example, if the cargo in question is bulk freight, the waiting time of a ship in anchorage will be longer. Also, due to the characteristics of bulk freight, since more time is required for loading and unloading the cargo, the waiting time for other ships will also increase.

† jmpark@kmou.ac.kr, 051-410-4206

On the other hand, a port that mainly deals with containers (specialized ships) will tend to focus on punctuality due to the characteristics of this cargo, and ships will also try to enter and gain clearance on schedule. For unloading cargo, exclusively prepared piers will allow the process to be completed within a short period of time. Therefore, compared with ports that mainly handle bulk freight, the waiting time in anchorage for ports dealing with containers will be short and the number of ships using such a port will be less.

For this reason, since the capacity of a port differs due to cargo and ship types, the main type of cargo and the entrance and clearance characteristics of ships were used to classify different types of ports.

**2.1 Number of ships entering major ports in Korea**

To analyze the major types of ships entering ports, data from 2016 (Ministry of Oceans and Fisheries, 2016) provided by the Shipping and Port Integrated Data Center (SP-IDC) was used to analyze the types of ships in each port. The results are shown in Table 1.

Table 1. Analysis of vessel types in ports

Port	Container ship	Bulk carrier	Tanker ship	Passenger ship	Car carrier
Ulsan	1,764	1,401	6,496	10	512
Daesan	337	83	3,337	0	0
Pohang	338	2,658	46	27	22
Donghae	13	1,119	17	102	0
Incheon	2,655	3,118	1,516	1,357	637
Pyeongtaek	798	2,819	1,024	456	873
Busan	15,375	5,050	1,967	3,639	359

(Unit : Number of ships)

**2.2 Classification of ports according to characteristics**

Ports with more than 50% of a particular type of ship as total incoming vessels were classified in the same category. Other cases have been classified as complex ports.

The results of classifying ports according to incoming ship types are as follows: Ulsan Port (64%) and Daesan Port (89%) had mostly ships with refined petroleum products and chemicals; Pohang Port (86%) and Donghae Port (89%) had general cargo and bulk ships; and Incheon, and Pyeongtaek Port had various ships. Therefore, based on this data, ports were classified into the 3 groups, A, B, and C, as shown in Fig. 1.

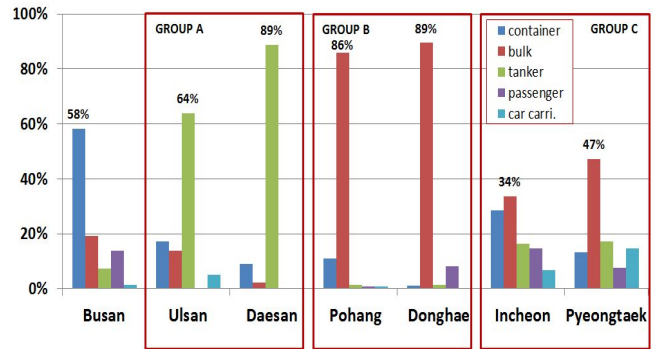


Fig. 1. Classification of ports via vessel type.

**3. Method for analyzing anchorage volume**

To analyze the appropriateness of anchorage volume, considering the psychological influence on a ship’s operator of using anchorage along with the logistic characteristics of a port, it is essential first to establish design criteria for defining the area of anchorage. For this, as an index for analyzing anchorage volume while considering traffic-related environmental characteristics, the concepts of occupied capacity of anchorage and required anchorage volume as suggested by Usui and Inoue (1999) and Park (2016) were used. The following is a description of these concepts.

**3.1 Average occupancy volume of anchorage,  $V_{oA}$**

Ships using anchorage vary by ton, waiting time, and environmental impact. Therefore, the occupied capacity of anchored ships changes as time passes. In order to evaluate anchorage volume, anchorage volume at a predetermined point of time should be established. Likewise, the occupied volume of anchorage shall be defined as shown in Equation (1).

$$V_{oA} = \frac{1}{n} \sum_{i=1}^n V_{oi} \quad (i = 1, 2, 3, \dots, n) \quad (1)$$

Where  $V_{oi}$  - Total volume of occupancy(km<sup>2</sup>) at  $i$  time (occupancy volume as derived from a computerized, numerical simulation with reference to the number of incoming ships’ anchorage, waiting time, ship capacity, environmental factors, etc.)

The design standards for anchorage require the radius of anchorage to be calculated according to seabed conditions and

## A Study on the Establishment of Design Criteria for Anchorage According to Port Characteristics

wind scale on the basis of the length over all (LOA) of ships and the depth (D) of anchorage. Accordingly, the turning radius of anchorage was analyzed on the basis of a single anchor, which is generally used in practice when anchoring. The relevant formula is as follows in Table 2.

Table 2. Capacity of anchorage guidelines

Objective	Bottom	Radius
Waiting or cargo operation	Good	L(Ship Length)+6D(Depth)
	Bad	L+6D+30

### 3.2 Necessary volume of anchorage, $V_N$

Occupied anchorage capacity differs according to entrance time, irregularities in waiting time, diversity in ship size, etc. Considering also psychological aspects and navigational habits of ship operators, the required area for a harbor can be defined, as shown in Equation (2).

$$V_N = V_{oA} \times 0.5\sigma \quad (2)$$

Where  $V_{oA}$  - Average Occupancy Volume of Anchorage

$\sigma$  - The standard deviation of the distribution of occupancy volume based on numerical simulation (hereafter referred to as "SD")

## 4. Numerical simulation for anchorage volume analysis

### 4.1 Numerical simulation design

Algorithm design and a simulation model are necessary for anchorage volume analysis. In this study, complex mathematical operations and simulations of various conditions were completed using MATLAB-SIMULINK Ver. 2015 (Korea Maritime and Ocean University).

The anchorage volume analysis simulation concept is shown in Fig. 2, including a system for entering variables into the simulation model. This system was used to output analysis data using various algorithms.

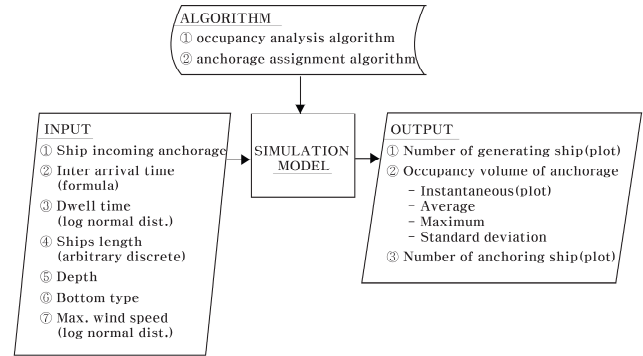


Fig. 2. System architecture for anchorage simulations.

### 1) Simulation model algorithm design

The simulation model algorithm consists of "ship generation and attribute assignments," which define vessels arriving for anchorage and allocate properties; "anchorage assignments," which allocate anchorable positions; and an "occupancy volume calculation" for analyzing anchorage volume.

The algorithm for this simulation model is shown in Fig. 3.

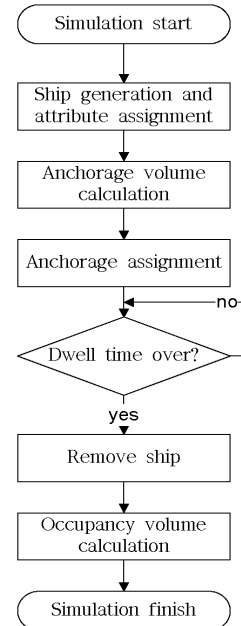


Fig. 3. Simulation model design.

### 2) MATLAB-SIMULINK Simulation Design

For anchorage volume analysis, a model was developed using MATLAB-SIMULINK, a commonly-used numerical simulation program. This model was designed to be divided into sub-programs according to the simulation sequence, so that the program can be

modified and supplemented easily. The result is shown in Fig. 4.

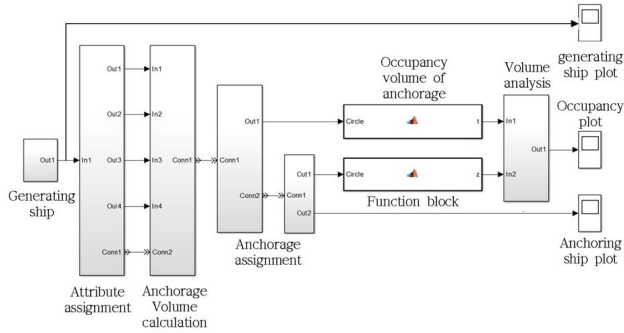


Fig. 4. Simulation system model architecture using MATLAB-SIMULINK.

### 4.2 Model verification of numerical simulation

Model verification was performed by simulating output for Ulsan Port, which is the representative liquid cargo handling port in Korea, and the output anchorage volume was analyzed based on this simulation.

Verification for the numerical simulation model consisted of a comparison of the output data from the simulation with the actual number of ships that entered and anchored in 2015. If the simulation results were less than 20% of the actual data, they were used for the simulation model.

Table 3. Verification results for the number of incoming ships and relevant anchorage

	E1 Anchorage	E2 Anchorage	E3 Anchorage
Simulation results (number of ships)	5,538	1,990	1,345
Number of incoming and anchoring ship in 2015	5,779	2,084	1,409
Accuracy rate	95.8 %	95.5 %	95.5 %

Table 4. Verification of the number of anchoring ships

	E1 Anchorage	E2 Anchorage	E3 Anchorage
Simulation results (number of ships)	17.0	6.8	5.4
Number of incoming and anchoring ship anchoring ship in 2015	16.9	6.6	5.1
Accuracy rate	100.1 %	103.0 %	105.8 %

As shown in Tables 3 and Table 4, the model was successfully verified because each figure was lower than 20%, which was the validation criterion for the simulation model.

### 4.3 Execution and results of numerical simulation

Using the simulation model for the analysis of anchorage volume, occupied anchorage volumes in major ports in Korea were derived. The results were used to calculate required anchorage volume.

The period of analysis included 3 years, 2005, 2010, and 2014, in order to reveal changes in annual anchorage volume and easily determine regression result for required anchorage volume using multiple regression.

#### 1) Input Variables

For numerical simulation to analyze anchorage, the normalized distribution of entering ship quantity, waiting time in anchorage, average tons of ships entering anchorage, log-normal distribution of maximum wind speed, and depth and type of bottom materials in anchorage were required. This data was analyzed via records for anchorage usage in the years considered, thereby setting the input variables as shown in Table 5.

Table 5. Input variables by ports

Port	Variables	2005	2010	2014
Ulsan	Incoming ship anchorage (ships)	11,848	12,682	13,001
	Lognormal distribution ( $\mu, \sigma$ )	2.24, 1.17	2.30, 1.20	2.45, 1.30
	Avg. waiting time (h)	18.56	19.37	26.80
	Avg. tons (ton)	3,541	4,117	4,273
	Depth, bottom type	10-70m, mud		
	Max. wind speed ( $\mu, \sigma$ )	2.04, 0.33		
	Daesan	Incoming ship anchorage (ships)	2,794	3,168
Lognormal distribution ( $\mu, \sigma$ )		2.23, 1.06	2.60, 1.12	2.58, 1.16
Avg. waiting time (h)		16.30	22.60	25.90
Avg. tons (ton)		2,678	3,520	4,779
Depth, bottom type		12-15m, mud		
Max. wind speed ( $\mu, \sigma$ )		2.04, 0.33		

A Study on the Establishment of Design Criteria for Anchorage According to Port Characteristics

Port	Variables	2005	2010	2014
Pohang	Incoming ship anchorage (ships)	4,044	4,349	3,863
	Lognormal distribution ( $\mu, \sigma$ )	2.49, 1.18	2.63, 1.20	3.06, 1.34
	Avg. waiting time (h)	24.26	28.64	32.40
	Avg. tons (ton)	3,976	4,534	5,436
	Depth, bottom type	15-26m, mud		
	Max. wind speed ( $\mu, \sigma$ )	2.04, 0.33		
Donghae	Incoming ship anchorage (ships)	724	965	1,349
	Lognormal distribution ( $\mu, \sigma$ )	2.27, 1.10	2.62, 1.32	2.77, 1.42
	Avg. waiting time (h)	18.29	32.67	51.83
	Avg. tons (ton)	3,129	7,094	8,951
	Depth, bottom type	12-15m, mud		
	Max. wind speed ( $\mu, \sigma$ )	2.04, 0.33		
Incheon	Incoming ship anchorage (ships)	3,662	3,697	3,455
	Lognormal distribution ( $\mu, \sigma$ )	2.24, 1.35	2.54, 1.38	2.78, 1.44
	Avg. waiting time (h)	24.35	36.84	41.23
	Avg. tons (ton)	6,953	6,977	5,252
	Depth, bottom type	6-30m, mud		
	Max. wind speed ( $\mu, \sigma$ )	2.04, 0.33		
Pyeongtek	Incoming ship anchorage (ships)	2,045	3,509	4,933
	Lognormal distribution ( $\mu, \sigma$ )	2.43, 1.53	2.12, 1.24	2.88, 1.85
	Avg. waiting time (h)	15.30	19.62	21.13
	Avg. tons (ton)	2,575	3,514	4,320
	Depth, bottom type	8-22m, mud		
	Max. wind speed ( $\mu, \sigma$ )	2.04, 0.33		

about 5.1-39.3 km<sup>2</sup>; for Pohang and Donghae Ports, 1.5-15.5 km<sup>2</sup>; and for Incheon and Pyeongtaek Ports, 14.6-38.7 km<sup>2</sup>.

Table 6. Resulting anchorage volume

Port	Year	Analysis	Technical analysis anchorage volume(km <sup>2</sup> )			V <sub>N</sub> (km <sup>2</sup> )
			Min.	SD	Max.	
Ulsan	2005	Volume	22.8	2.5	27.8	24.0
		SD	0.01	0.01		
	2010	Volume	25.1	4.4	28.9	27.3
		SD	0.02	0.01		
	2014	Volume	35.8	7.0	49.7	39.3
		SD	0.03	0.02		
Deasan	2005	Volume	4.4	1.5	7.3	5.1
		SD	0.01	0.006		
	2010	Volume	8.1	2.3	12.7	9.3
		SD	0.01	0.009		
	2014	Volume	10.7	2.9	16.4	12.1
		SD	0.01	0.01		
Pohang	2005	Volume	10.2	2.8	15.7	11.6
		SD	0.01	0.001		
	2010	Volume	11.4	3.4	18.3	13.2
		SD	0.01	0.01		
	2014	Volume	13.0	4.9	22.9	15.5
		SD	0.02	0.01		
Donghae	2005	Volume	0.8	0.1	1.1	0.9
		SD	0.02	0.01		
	2010	Volume	1.4	0.2	1.7	1.5
		SD	0.02	0.02		
	2014	Volume	3.1	0.3	3.7	3.3
		SD	0.02	0.007		
Incheon	2005	Volume	19.6	2.8	25.2	21.0
		SD	0.01	0.001		
	2010	Volume	27.4	2.9	33.2	28.8
		SD	0.01	0.006		
	2014	Volume	37.1	3.3	43.5	38.7
		SD	0.02	0.01		
Pyeongtek	2005	Volume	13.1	3.0	19.1	14.6
		SD	0.01	0.01		
	2010	Volume	18.4	3.8	26.0	20.3
		SD	0.02	0.02		
	2014	Volume	27.5	4.7	36.9	29.8
		SD	0.01	0.01		

2) The result of numerical simulation

The resulting required anchorage volume for each port, as calculated by numerical simulation, is shown in Table 6.

The required anchorage volumes for Ulsan and Daesan Ports are

### 5. Establishing criteria for designing anchorage volume

Volume of anchorage is determined by the number of ships using anchorage, ship scale, waiting time, and environmental conditions in surrounding waters. The scale of ships is determined by cargo volume, the number of ships entering, berth scale, etc. Therefore, analyzing the relationship between the current status of ports and the required anchorage volume, to suggest design criteria is feasible by completing a review on the appropriateness of anchorage volume during port development, which is the purpose of this study. Likewise, to suggest criteria for designing anchorage, the functional relationship between independent and dependent variables should be investigated. To estimate variables of interest using a functional-based relationship, regression analysis was used.

#### 5.1 Regression analysis on anchorage volume in each port

Groups A, B, and C were derived from an analysis on the types of ships entering each port, and a regression analysis was conducted accordingly. The regression method used required anchorage volume as a dependent variable and cargo volume as an independent variable to conduct simple regression analysis. In order to estimate required anchorage volume, the future number of ships that will enter a port, cargo volume, and number of berths should be estimated. However, in the Basic Plan for Nationwide Ports, which is a long-term plan for domestic ports, only estimated cargo volumes for 10 and 20 years periods were included. Therefore, by deriving a regression formula for anchorage and cargo volume, the scale of required anchorage was easily estimated.

Regression analysis on anchorage volume for each port group applied a method of curve estimation by assuming the relationship between the two was non-linear (curved regression). Also, to prove the validity of this analysis method,  $R^2$  values for linear and curved regression analysis were compared. Here,  $R^2$  (the coefficient of determination) was a statistical measure of how close the data were to a fitted regression line. The result with the highest explanation power (Choung et al., 2012) was adopted.

##### 1) Group A, Simple regression analysis

For Ulsan and Daesan Ports, which were classified as Group A, a simple regression analysis on required anchorage and cargo volume was conducted, as shown in Table 7.

Table 7. Dependent and independent variables for Ulsan and Daesan Ports

Year	Ulsan		Daesan	
	Cargo volume (ktons)	$V_N$ (km <sup>2</sup> )	Cargo volume (ktons)	$V_N$ (km <sup>2</sup> )
2005	162,414	24.0	44,720	5.1
2010	171,664	27.3	66,122	9.3
2014	191,717	39.3	72,900	12.1

The linear regression analysis model and curved regression model for anchorage volume ( $Y_{NA}$ ) and cargo volume( $X_{NA}$ ) for Group A (Ulsan and Daesan Ports), are shown in Fig. 5.

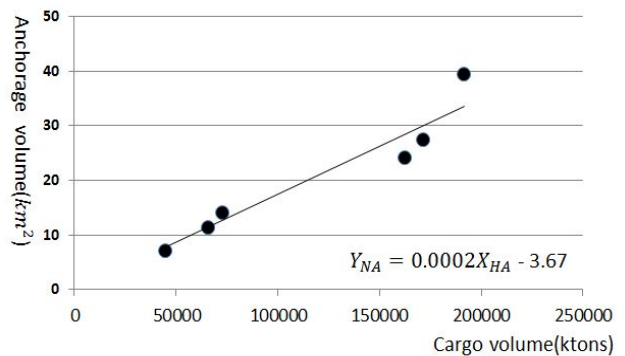


Fig. 5. Group A regression analysis trend line.

##### 2) Group B, Simple regression analysis

For Pohang and Donghae Ports, which were classified as Group B, a simple regression analysis on required anchorage and cargo volume was conducted as shown in Table 8.

Table 8. Dependent and independent variables for Pohang and Donghae Ports

Year	Pohang		Donghae	
	Cargo volume (ktons)	$V_N$ (km <sup>2</sup> )	Cargo volume (ktons)	$V_N$ (km <sup>2</sup> )
2005	54,692	11.6	19,923	0.9
2010	63,108	13.2	28,030	1.5
2014	65,241	15.5	32,540	3.3

The linear and curved regression analysis for anchorage volume ( $Y_{NB}$ ) and cargo volumes for Group B (Pohang and Donghae Ports) are shown in Fig. 6.

## A Study on the Establishment of Design Criteria for Anchorage According to Port Characteristics

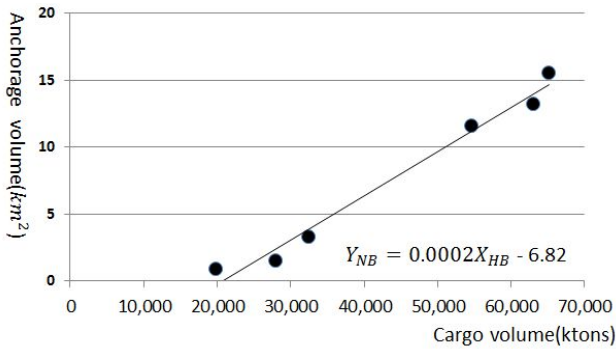


Fig. 6. Group B regression analysis trend line.

### 3) Group C, Simple regression analysis

For Incheon and Pyeongtaek Ports, which were classified as Group C, a simple regression analysis on required anchorage and cargo volume was conducted as shown in Table 9.

Table 9. Dependent and independent variables for Incheon and Pyeongtaek Ports

Year	Incheon		Pyeongtaek	
	Cargo volume (ktons)	$V_N$ (km <sup>2</sup> )	Cargo volume (ktons)	$V_N$ (km <sup>2</sup> )
2005	126,453	25.1	42,514	14.6
2010	149,785	28.8	76,681	20.3
2014	150,083	32.4	117,012	29.8

The linear and curved regression analysis model for anchorage volume ( $Y_{NC}$ ) and cargo volume ( $X_{HC}$ ) for Group C (Incheon and Pyeongtaek Ports) are shown in Fig. 7.

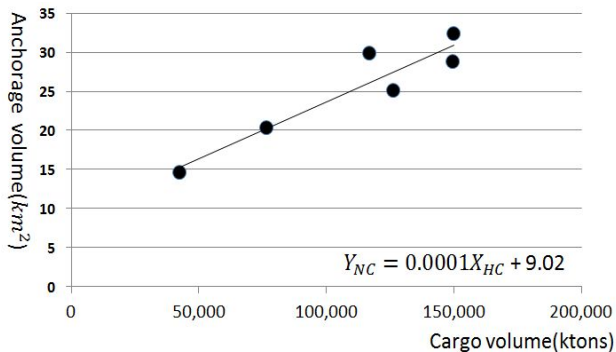


Fig. 7. Group C regression analysis trend line.

### 5.2 Verification of anchorage volume regression model

Statistical analysis using SPSS was carried out in order to test the significance of these formulas via regression analysis; the

findings are as follows in Table 10.

The result of a suitability analysis of the regression model revealed that the explanatory power of all formulas was over 80%, and the Durbin-watson test gave results within a range of 1-3, confirming the independence of residuals. The result of a significance test for the dispersion model, indicated that the significance probabilities against "F" 0.05, suitable for a regression model. Furthermore, a test for significance on the regression coefficients was conducted and the levels of significance (p) were 0.05, 0.04, and 0.01, as shown in Table 10, statistically accurate at a level of 95 % or more.

Table 10. Descriptive statistics for regression analysis

Regression	Data Set	Group A		Group B		Group C	
Model summary	R <sup>2</sup>	0.93		0.98		0.88	
	Durbin-watson	1.76		2.13		1.16	
Analysis of variance	F	56.19		207.90		29.88	
	Significance level	0.002		0.00		0.005	
Coefficients	Coefficients	-3.67	0.0002	-6.82	0.0002	9.02	0.0001
	p	0.05	0.00	0.00	0.00	0.04	0.01

## 6. Conclusions

Considering the entrance and clearance characteristics of ships and cargo types, Korean ports were classified into 3 groups, A, B, and C. Furthermore, required anchorage volume was determined as a dependent variable, and cargo volume was assigned as an independent variable to conduct a simple regression analysis with curve estimation. By comparing R<sup>2</sup> values, the result with the highest explanatory power was adopted. As a consequence, statistically significant anchorage volume models to provide design criteria for each port group were suggested, as shown in Table 11. The models were linear for all groups.

Table 11. Summary of anchorage volume design criteria

Port Group	Design Criteria for Anchorage Volume
Group A	$Y_{NA} = 0.0002X_{HA} - 3.67$
Group B	$Y_{NB} = 0.0002X_{HB} - 6.82$
Group C	$Y_{NC} = 0.0001X_{HC} + 9.02$

In this study, a numerical simulation was used to analyze anchorage volume. Required anchorage volume was derived and used as a base to conduct a regression analysis, thereby suggesting design criteria for anchorage volume, which was verified. This model for analyzing anchorage volume using simulation is meaningful since it takes into consideration maritime transportation systems that actually exist. Also, since the present study shed light on the relationship between the anchorage volume and cargo volume of a port, it enabled a review of anchorage volume from the perspective of harbor development.

In the future, additional studies analyzing the correlation between required anchorage area and such traits as cargo volume, berth size, number of ships entering a port, docking time, etc. should be conducted to quantitatively suggest the area of anchorage that should be designated according to increasing berth and cargo volume. Also, in case of demurrage, some ships do not queue in anchorage space, drifting on the open sea without mooring or temporarily standing by in seas not designated as anchorage, entering port by adjusting navigational speed. Therefore, additional studies should be conducted to consider this behavior via simulation as well, included such drifting ships along with those using anchorage. Moreover, since there are limitations to objectivity when conducting regression analysis, additional data on anchorage should be secured to perform further simulation and regression.

The present study is the first to establish design criteria for determining required anchorage volume. In the future, this model should be applied to ports outside Korea to verify its validity. By applying a range of variables in the simulation algorithms and regression analysis, details could be reconstructed to suggest design criteria for anchorage volume while accurately considering actual anchorage situations.

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