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Study on Ship Height by Statistical Analysis
-Standard of Ship Height of Design Ship(Draft)-

Hironao TAKAHASHI and Ayako GOTO

統計解析による船舶の高さに関する研究
－船舶の高さの計画基準（案）－

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審査委員会（港湾空港分野）

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No.33　March 2007
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Study on Ship Height by Statistical Analysis
-Standard of Ship Height of Design Ship (Draft)-

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Ayako GOTO**

Synopsis

This research first examines the reasons why dimensional values for the height of ships were not given in previous “Technical Standards for Port and Harbour Facilities.” Based on this, the first objective of this research is to propose values for the height from the keel to the highest point of the ship as dimensional values of the same level as length over all, full load draft, and similar ship dimensions in the “Technical Standards.”

The second objective is to propose dimensional values for height from the sea surface to the highest point of the ship, which is necessary when designing bridges over fairways, arranging the relationship with the obstruction assessment surface (OAS) in maritime airports, etc. by applying two statistical analysis techniques.

Key Words: ship height, statistical analysis, Technical Standards and Commentaries of Port and Harbor Facilities

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統計解析による船舶の高さに関する研究
－船舶の高さの計画基準（案）－

高橋宏直*　・後藤文子**

要　　旨

本研究では，船舶の高さに関する諸元値が従来の「港湾の施設の技術上の基準」において示されていなかった理由を整理したうえで，第１に「港湾の施設の技術上の基準」での船舶の全長や満載喫水等と同水準の諸元値としてキールから船舶の最高点までの高さの値を提示した．

第２に２種類の統計解析手法を適用することにより，航路上の橋梁の設計や海上空港の制限表面との関係調整等に際して必要となる海面上から船舶の最高点までの高さについての諸元値を提示した．

キーワード：船舶の高さ，統計解析 ，港湾の施設の技術上の基準

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Contents

1. Introduction

In the planning and design of mooring facilities, fairways, and other port and harbor facilities and port facilities, the dimensional values of the design ship, such as length over all, full load draft, and the like, become important conditions. Therefore, the National Institute for Land and Infrastructure Management (hereinafter, NILIM) of Japan's Ministry of Land, Infrastructure and Transport carries out statistical analyses of dimensional data on ships and proposed values for length over all (Loa), length between perpendiculars (Lpp), breadth molded (B), full load draft (d), and similar dimensions as main dimensions by ship class for respective ship types.[1)2)] These results are cited in the current "Technical Standards and Commentaries of Port and Harbour Facilities"[3)] (hereinafter, "Technical Standards"), and citations from new NILIM research results[4)] in a revision scheduled for application beginning in fiscal year 2007 are also expected.

However, dimensional values related to the height of ships have not been indicated in either former or current "Technical Standards."[5)6)] Furthermore, as in the Japanese "Technical Standards," dimensional values for ship height are not given in the international literature[7)-11)] which propose standard dimensional values for length over all and full load draft.

The reasons why it has not been possible to carry out analyses of dimensional values related to ship height at other research institutes, not limited to NILIM, are thought to include the following problems.

① The number of available data on ship height is remarkably small in comparison with other dimensions such as Loa, d, etc.

For example, in the fundamental data from other countries for cargo ships, which represent the largest number of ships in analyses, the number of available data on ship height is only about 10% of that for Loa, d, etc., giving rise to questions about analytical results which are presented as equivalent to those for Loa, d, and other dimensions.

② The reliability of values obtained from fundamental data related to ship height is low.

The data obtained from the fundamental data contain numerous deviations, and also include a large number of data which can be judged as clearly anomalous values. As one factor in this, because there is no clearly-defined concept of ship height analogous to that of Loa in the case of ship length, it can be supposed that there are errors in recording ship height by persons supplying the data. Therefore, the results of statistical analyses based on these fundamental data are open to question.

③ It is not possible to apply the statistical analysis method (logarithmic regression analysis method) used with Loa, d, etc. to ship height.

In the case of Loa, d, and the like, statistical analyses are carried out on the precondition that these dimensions are approximately proportional to the 1/3 power of the hull scale (DWT or GT), based on the assumption that the shapes of ships of each type have roughly similar figures spatially. However, because ship height has a low correlation with hull scale, the results of analyses applying the conventional logarithmic regression analysis technique are open to question. For example, there are excessive differences between the results of conventional analyses of large-scale ships and the values for actual ships.

On the other hand, because dimensional values for ship height are extremely important when designing bridges over fairways, arranging the relationship with the obstruction assessment surface (OAS: height of ships and other obstructions which must be cleared by aircraft) in maritime airports, and similar problems, indications of the dimensional values for ship height similar to those for Loa and d in the "Technical Standards" has been an urgent required for many years.

Therefore, the first objective of the present research was to propose height dimensions for ships with the same accuracy as other main dimensions such as Loa, d, etc. in the "Technical Standards" by solving the problems which have existed until now in the follow manner.

① The dispersion of data on ship height and data on other dimensions was analyzed by ship class, and it was confirmed that there were no deviations in the distribution of the data for ship height corresponding to ship class. The aim of this analysis was to make it possible to obtain the same accuracy as with the other dimensions, even though the number of data on ship height is markedly smaller.

② New data for analysis of concrete dimensional values were constructed by statistically eliminating anomalous values from the fundamental data. The aim here was make it possible to obtain analytical results having high reliability, even though the number of data was reduced to a certain extent as a result.

③ The fact that application of the statistical analysis technique used with Loa, d, etc. to ship height is not appropriate in statistical analyses was reconfirmed. Based on this, one aim of this work was to apply a new statistical analysis technique which makes it possible to obtain appropriate analytical results.

In addition, because the height from the sea surface to the highest point on the ship is a practical necessity when designing bridges over fairways and arranging the relationship with OAS at marine airports, the second objective of this research was to propose a table of dimensional values for the height of ships from the sea surface. Concretely, the objective was to construct a technique for analyzing the height from the sea surface to the highest point on ships and fundamental data on the height from the sea surface from the beginning, by analyzing the research results obtained in accomplishing the first objective, together with research results in connection with full load draft in previous research,[12] and then to obtain analytical results having high reliability by applying two direct analysis techniques.

In actual application, when it is possible to designate the design ship in such a way that it is specified in the "Technical Standards," the dimensional values of the designated ship should be applied. In cases where it is not possible to designate the design ship, the results of this research can be used as reference.

2. Basic Concepts of Analysis

2.1 Definitions of dimensional values related to ship height

As shown in **Figure1**, two types of dimensional values are used for ship height, these being the height from the keel (keel: keel at ship bottom ≒ lowest point) to the top (highest point) and the height from the sea surface to the top (also called "air draft" in some cases). In order to clarify these concepts and avoid confusion in terminology, these are defined as follows in this research.

- Total height : H_{kt} (Height – Keel to Top)
- Height above surface : H_{st} (Height – Surface of the sea to Top)

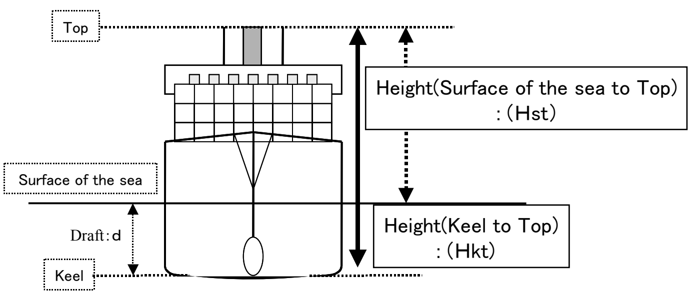


Figure1 Dimensional values related to height of ships

2.2 Data used in analysis

The fundamental data used in the statistical analysis was the Lloyd's Register Fairplay Data for September 2006 (hereinafter, LRF Data). Lloyd's Register Fairplay Ltd. (see *Note) possesses fundamental data comprising ship data on 158,000 vessels of 100GT or more, including newly- constructed ships, existing ships, and scrapped ships, and information on shipping lines, maritime disasters, ports and harbors, etc. covering 200,000 cases. Among these approximately 800 items, for the present research, the authors obtained data on the height measured from the keel to the highest fixed point (mast, or stack or other highest point) as ship height data. This ship height data corresponds to total height (H_{kt}) as defined in this research. This LRF Data is different from the Lloyd's Maritime Intelligence Unit Shipping Data (hereinafter, LMIU Data) of January 2004 in **Ref. 4)** and **12)**, which is the fundamental data used to analyze the main dimensions of Loa, Lpp, B, d, etc. shown in the "Technical Standards."

2.3 Classification of ship types

Because the aim of this research is to propose dimensions for ship height of the same accuracy as main dimensions such as Loa, d, etc. in the "Technical Standards," the types of ships were set up in conformity with the "Technical Standards" as a basic assumption. However, where ferries are concerned, because the LRF Data was used as the fundamental data, the object is foreign vessels, and as a result, the dimensional characteristics differ greatly from those of domestic Japanese ferries. Therefore, ships were classified in the following 8 types, and ferries were excluded from the scope of study. Here, "cargo ship" includes "general cargo ship," "bulk carrier," and "ore carrier."

① Cargo ship
② Container ship
③ Oil tanker
④ Roll-on/Roll-off ship (RORO ship)
⑤ Pure car carrier (PCC)
⑥ LPG ship
⑦ LNG ship
⑧ Passenger ship

2.4 Age of ships in analysis

In research[1)2)4)8)] related to the "Technical Standards," statistical analyses were performed covering ships with ages of 15 years or less. The reasons for this were as follows.

① In spite of the fact that decommissioning of ships navigating the world's seas begins around 25 years after completion of construction, the "Technical Standards" are revised at an interval of roughly 10 years. For this reason, it is considered desirable to include ships up to 25 years after completion in the final period of application of the Standard. Accordingly, a ship age of 15 years (25 years – 10 years) at the time of analysis is thought to be appropriate.

② In regulations concerning the service life of depreciable assets established by the Japan's Ministry of Finance, the useful life of steel ships of 2,000GT and more is set at 15 years.

However, the analysis covers passenger ships with ages of 30 years or less because the ship age at decommissioning is higher for passenger ship than for general ships.

As noted above, the second objective of this research is to propose the height above surface (H_{st}) by analyzing the dimensional values related to ship height in combination with the full load draft, as previously analyzed. Because the use of previous research results[1)2)4)8)] of statistical analyses of full load draft is adopted as one technique, as a basic condition of the present research, statistical analyses are also performed for ships with ages of 15 years or less to ensure consistency with the results of this previous research.

However, the number of data which could be obtained from the LRF Data was essentially small, and the data decreased further when this condition of a ship life of 15 years or less was applied. Therefore, statistical analyses were performed for ships of all ages, without setting this restriction by ship age, covering a total of 4 ship types, including 3 types for which the original data were limited to 100 ships or fewer (PCC ships, LNG ships, passenger ships) and one type (RORO ships) for which the number of data when the age condition was applied was less than 100 vessels as a threshold value. The actual numbers of ships used as fundamental data for the statistical analysis as a result of this procedure are given in the following section **2.5**.

2.5 Number of ship data in analysis

The numbers of ship data which were subject to analysis by ship class for each ship type are shown in **Table1**. In **Table1**, "Dimensional analysis (A)" cites the numbers of fundamental data presented in **Ref. 4)**, which analyzed Loa, Lpp, B, and d, and "Total height analysis (B)" presents the fundamental data obtained based on the ship age conditions laid out in section **2.4**. This **Table1** shows the numbers of data and the cumulative ratios by ship class when the ship classes are set closely for small-scale ships and roughly for large-scale ships, conforming to the table shown in **Ref. 4)**. Here, the Vessel Type Decode shown in **Table2** of the LMIU Data was used in the classification of ship types.

The dispersion of data by ship class was analyzed for data related to ship height and other data, and the two were compared in order to confirm for each ship type that there are no deviations in the distribution of the data related to ship height corresponding to the ship class. In order to conform by ship type that there are no deviations in the two distributions, the ratio, [(B)/(A)] of the "Total height analysis (B)" to the "Dimensional analysis (A)" was calculated. As a result, in spite of the fact that anomalous values could be seen in ship classes with small numbers of data in each ship type, overall, the values were on the same order, corresponding to the ship class. It can therefore be concluded that no remarkable deviations occur, for example, concentrating on small-scale ships.

A comparison of the respective cumulative ratios in **Table1**is shown in **Figure2** through **Figure9**. It can also be concluded from these results that there are no remarkable deviations.

Table1 Number of data on ships by ship type and ship class

Type	Cargo Ship					Container Ship				
	Dimensional analysis(A)		Total height analysis(B)		Relative ratio (B)/(A)	Dimensional analysis(A)		Total height analysis(B)		Relative ratio (B)/(A)
DWT	N of data	Cumulative ratio	N of data	Cumulative ratio		N of data	Cumulative ratio	N of data	Cumulative ratio	
0 ー 499	74	1.3%	0	0.0%	0.0%	0	0.0%	0	0.0%	ー
500 ー 999	136	3.6%	0	0.0%	0.0%	0	0.0%	0	0.0%	ー
1,000 ー 1,999	462	11.5%	3	0.5%	0.6%	1	0.0%	2	0.7%	200.0%
2,000 ー 2,999	425	18.8%	35	6.7%	8.2%	7	0.3%	0	0.7%	0.0%
3,000 ー 4,999	946	34.9%	108	25.6%	11.4%	82	3.8%	7	3.0%	8.5%
5,000 ー 9,999	902	50.4%	56	35.4%	6.2%	371	19.6%	29	12.5%	7.8%
10,000 ー 14,999	159	53.1%	12	37.5%	7.5%	259	30.5%	46	27.6%	17.8%
15,000 ー 29,999	673	64.6%	71	50.0%	10.5%	592	55.6%	83	54.9%	14.0%
30,000 ー 49,999	687	76.4%	94	66.5%	13.7%	520	77.7%	66	76.6%	12.7%
50,000 ー 99,999	971	93.0%	122	87.9%	12.6%	499	98.9%	64	97.7%	12.8%
100,000 ー 199,999	382	99.5%	67	99.6%	17.5%	27	100.0%	7	100.0%	25.9%
200,000 ー	29	100.0%	2	100.0%	6.9%	0	100.0%	0	100.0%	ー
Total	5,846		570		9.8%	2,358		304		12.9%

Type	Oil Tanker					RORO Ship				
Oil Tanker : DWT	Dimensional analysis(A)		Total height analysis(B)		Relative ratio (B)/(A)	Dimensional analysis(A)		Total height analysis(B)		Relative ratio (B)/(A)
RORO Ship : GT	N of data	Cumulative ratio	N of data	Cumulative ratio		N of data	Cumulative ratio	N of data	Cumulative ratio	
0 ー 499	0	0.0%	0	0.0%	ー	59	11.8%	14	4.4%	23.7%
500 ー 999	0	0.0%	0	0.0%	ー	44	20.5%	28	13.3%	63.6%
1,000 ー 1,999	4	0.4%	0	0.0%	0.0%	42	28.9%	26	21.5%	61.9%
2,000 ー 2,999	2	0.6%	1	0.1%	50.0%	33	35.5%	13	25.6%	39.4%
3,000 ー 4,999	3	0.8%	1	0.2%	33.3%	35	42.4%	38	37.7%	108.6%
5,000 ー 9,999	5	1.3%	3	0.4%	60.0%	110	64.3%	82	63.6%	74.5%
10,000 ー 14,999	1	1.4%	0	0.4%	0.0%	41	72.5%	39	75.9%	95.1%
15,000 ー 29,999	7	2.1%	0	0.4%	0.0%	96	91.6%	57	94.0%	59.4%
30,000 ー 49,999	4	2.4%	10	1.3%	250.0%	17	95.0%	18	99.7%	105.9%
50,000 ー 99,999	212	22.4%	214	20.0%	100.9%	25	100.0%	1	100.0%	4.0%
100,000 ー 199,999	446	64.3%	544	67.6%	122.0%	0	100.0%	0	100.0%	ー
200,000 ー	380	100.0%	371	100.0%	97.6%	0	100.0%	0	100.0%	ー
Total	1,064		1,144		107.5%	502		316		62.9%

Type	PCC					LPG Ship				
	Dimensional analysis(A)		Total height analysis(B)		Relative ratio (B)/(A)	Dimensional analysis(A)		Total height analysis(B)		Relative ratio (B)/(A)
GT	N of data	Cumulative ratio	N of data	Cumulative ratio		N of data	Cumulative ratio	N of data	Cumulative ratio	
0 ー 499	1	0.5%	0	0.0%	0.0%	46	4.5%	2	0.6%	4.3%
500 ー 999	1	1.0%	1	1.2%	100.0%	218	26.1%	2	1.1%	0.9%
1,000 ー 1,999	4	2.9%	1	2.4%	25.0%	94	35.3%	13	4.8%	13.8%
2,000 ー 2,999	0	2.9%	1	3.6%	ー	101	45.3%	27	12.3%	26.7%
3,000 ー 4,999	1	3.4%	1	4.8%	100.0%	191	64.2%	114	44.3%	59.7%
5,000 ー 9,999	22	14.1%	7	13.1%	31.8%	138	77.8%	79	66.4%	57.2%
10,000 ー 14,999	5	16.5%	5	19.0%	100.0%	35	81.2%	11	69.5%	31.4%
15,000 ー 29,999	24	28.2%	9	29.8%	37.5%	62	87.4%	40	80.7%	64.5%
30,000 ー 49,999	58	56.3%	33	69.0%	56.9%	123	99.5%	69	100.0%	56.1%
50,000 ー 99,999	90	100.0%	26	100.0%	28.9%	4	99.9%	0	100.0%	0.0%
100,000 ー 199,999	0	100.0%	0	100.0%	ー	1	100.0%	0	100.0%	0.0%
200,000 ー	0	100.0%	0	100.0%	ー	0	100.0%	0	100.0%	ー
Total	206		84		40.8%	1,013		357		35.2%

GT		Type	LNG Ship					Passenger Ship				
			Dimensional analysis(A)		Total height analysis(B)		Relative ratio (B)/(A)	Dimensional analysis(A)		Total height analysis(B)		Relative ratio (B)/(A)
			N of data	Cumulative ratio	N of data	Cumulative ratio		N of data	Cumulative ratio	N of data	Cumulative ratio	
0	―	499	1	0.6%	0	0.0%	0.0%	61	16.0%	1	1.4%	1.6%
500	―	999	2	1.9%	0	0.0%	0.0%	18	20.7%	3	5.4%	16.7%
1,000	―	1,999	1	2.5%	1	1.4%	100.0%	34	29.6%	4	10.8%	11.8%
2,000	―	2,999	1	3.1%	0	1.4%	0.0%	13	33.0%	5	17.6%	38.5%
3,000	―	4,999	0	3.1%	0	1.4%	―	29	40.6%	2	20.3%	6.9%
5,000	―	9,999	0	3.1%	0	1.4%	―	42	51.6%	9	32.4%	21.4%
10,000	―	14,999	0	3.1%	0	1.4%	―	31	59.7%	11	47.3%	35.5%
15,000	―	29,999	9	8.7%	3	5.5%	33.3%	30	67.5%	11	62.2%	36.7%
30,000	―	49,999	11	15.5%	1	6.8%	9.1%	37	77.2%	10	75.7%	27.0%
50,000	―	99,999	77	63.4%	55	82.2%	71.4%	72	96.1%	15	95.9%	20.8%
100,000	―	199,999	59	100.0%	13	100.0%	22.0%	15	100.0%	3	100.0%	20.0%
200,000	―		0	100.0%	0	100.0%	―	0	100.0%	0	100.0%	―
Total			161		73		45.3%	382		74		19.4%

Table2 Vessel Type Decode

Type	Vessel Type Decode	
Cargo Ship	bulk	BBU
	ore carrier	BOR
	general cargo	GGC
Container Ship	container carrier	UCC
Oil Tanker	crude oil tanker	TCR
Roll-on/Roll-off Ship	ro/ro	URR
Pure Car Carrier	vehicle carrier	MVE
LPG Ship	lpg	LPG
LNG Ship	lng	LNG
Passenger Ship	passenger	MPR

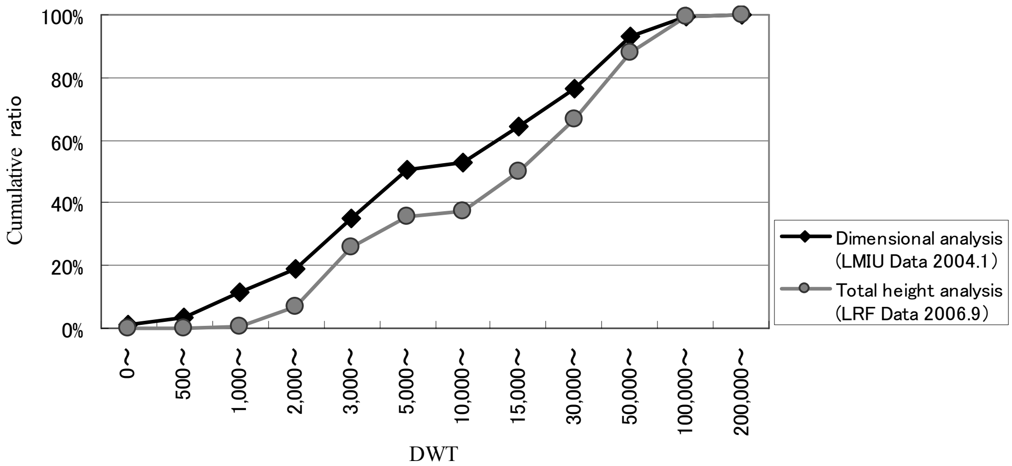


Figure2 Comparison of relative ratios by ship class (cargo ship)

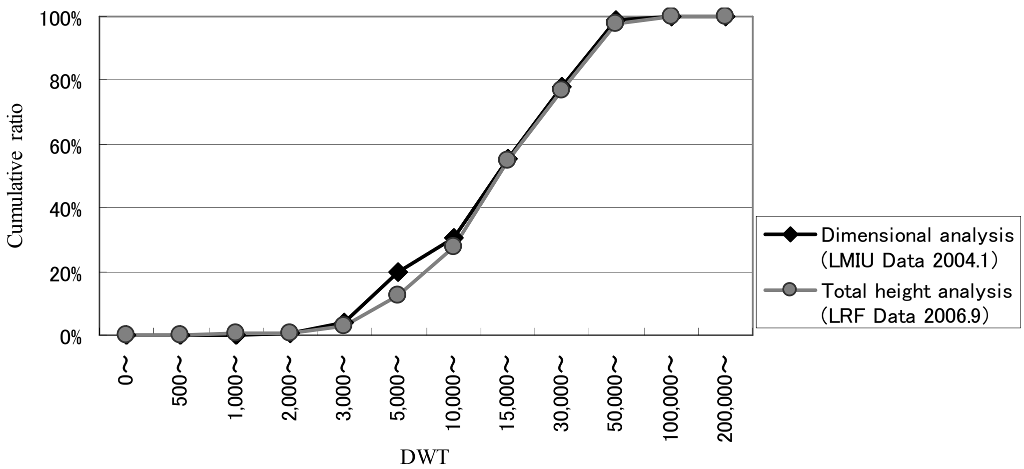


Figure3 Comparison of relative ratios by ship class (Container ship)

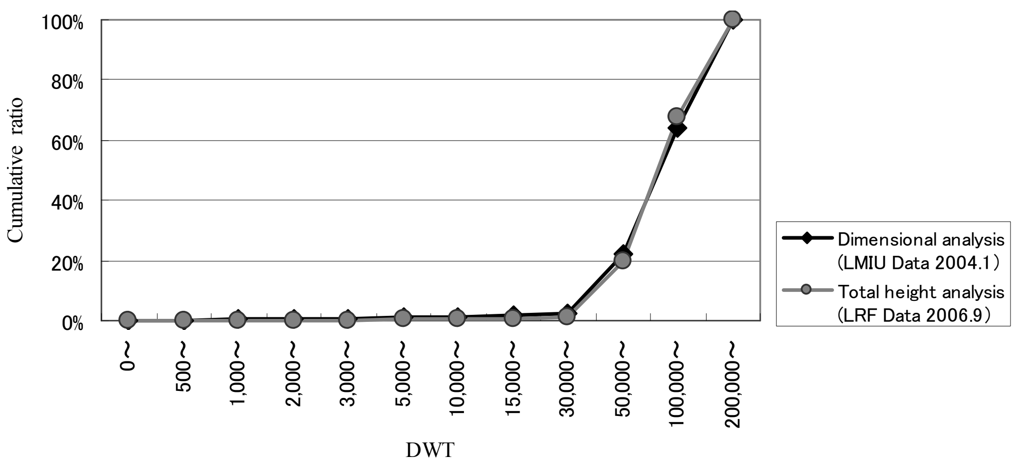


Figure4 Comparison of relative ratios by ship class (Oil tanker)

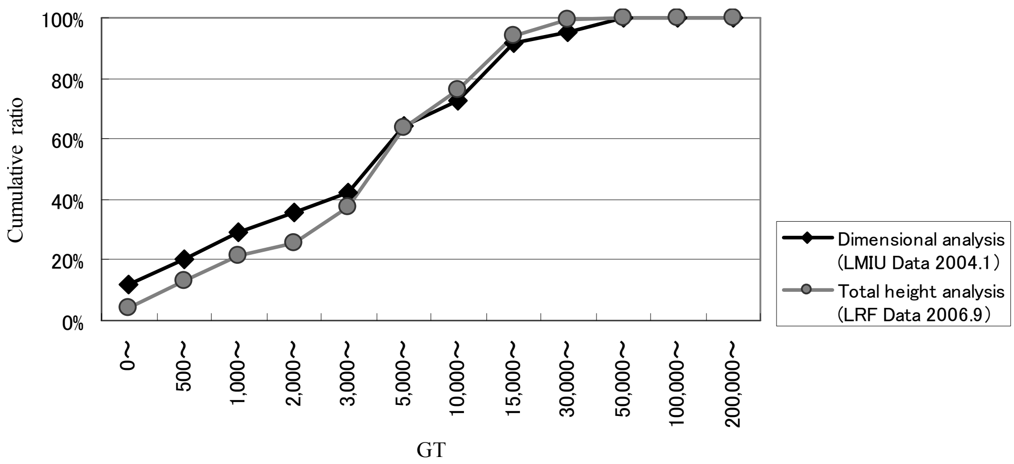


Figure5 Comparison of relative ratios by ship class (RORO ship)

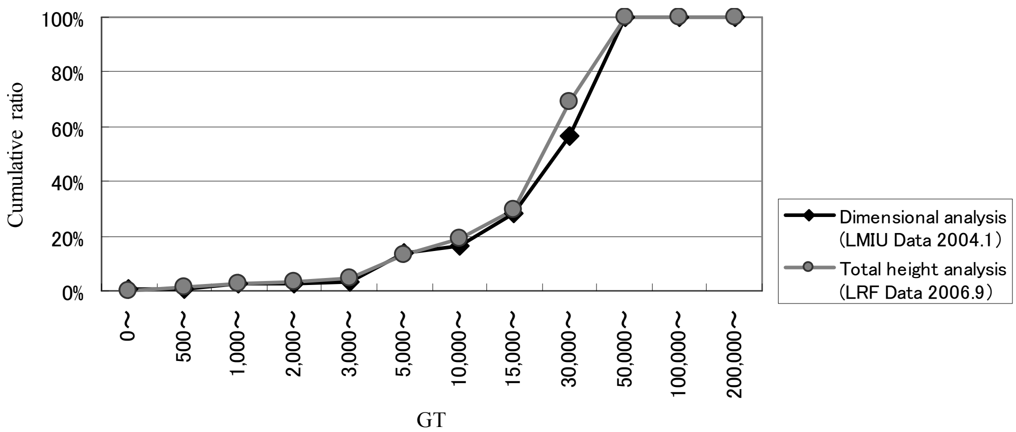


Figure6 Comparison of relative ratios by ship class (PCC)

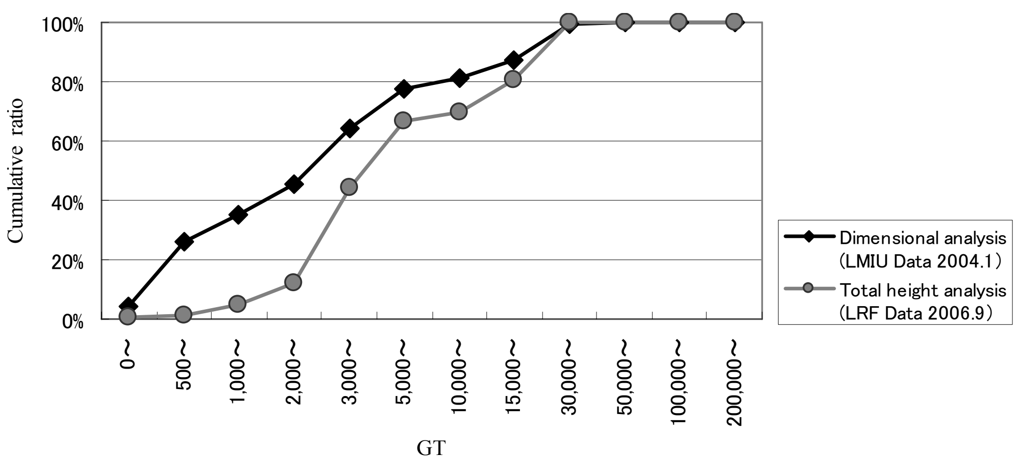


Figure7 Comparison of relative ratios by ship class (LPG ship)

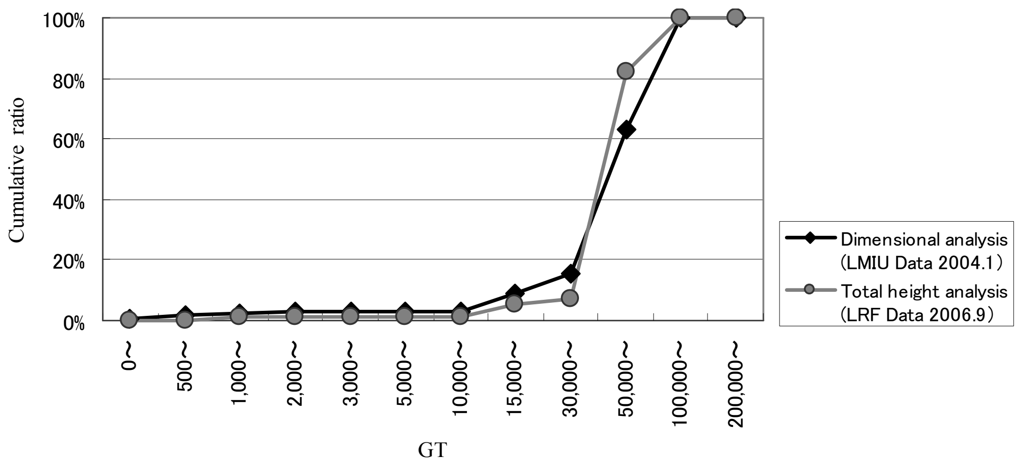


Figure8 Comparison of relative ratios by ship class (LNG ship)

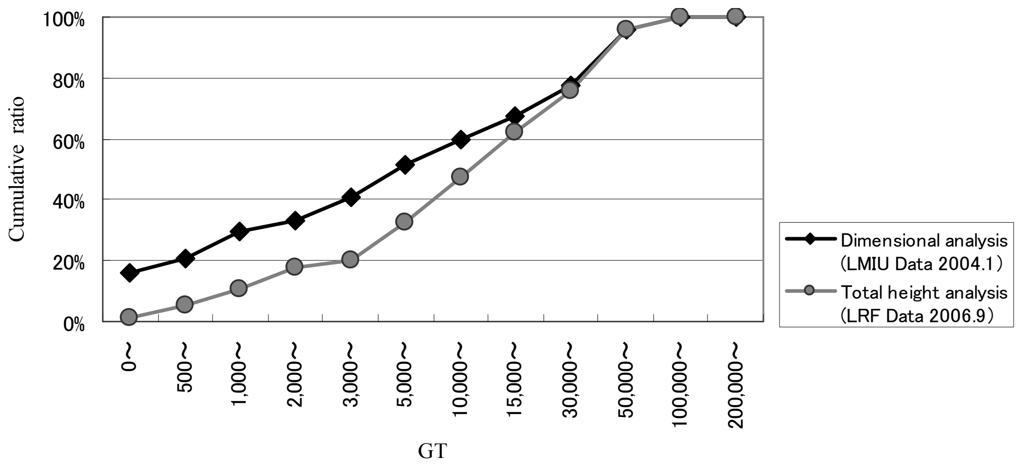


Figure9 Comparison of relative ratios by ship class (Passenger ship)

3. Analysis Method

3.1 Conventional statistical analysis method (logarithmic regression analysis method) and concept of coverage rate

(1) Background of application of logarithmic regression analysis method to Loa, d, etc.

Because ships of the same type have roughly similar figures spatially, irrespective of their scale, the main dimensions of Loa, d, etc. are considered to be approximately proportional to the 1/3 power of the ship hull scale. Therefore, the relationship between the main dimensions of Loa, d, etc. and the ship hull scale can be expressed by the following equations:

$$Y=\alpha X^{\beta} \quad (1)$$

$$\log Y = \log \alpha + \beta \log X \quad (2)$$

where,

Y: Loa, Lpp, B, d

X: GT, DWT

$\beta \fallingdotseq 1/3$

The above Eq. (1) becomes Eq. (2) when the two sides are converted to common logarithms, and simple linear regression analysis and statistical analyses such as calculation of the standard deviation (σ), etc. can be performed with ease.

Here, in the analysis of standard dimensions, a common logarithm with a base of 10 is used. Although the notation of the base as ($\log_{10}$) is not used in the (log) notations in this research, the meaning is the common logarithm in all cases.

(2) Concept and setting of coverage rate

The values obtained by simple linear regress equations for GT and DWT here are the average value (50%). In other words, statistically, fewer than 50% of the object number of ships are below this average value, and more than 50% are above it. However, the objective of this research is to propose dimensional values which cover more than 50% of the object ships when necessary, and not the simple average value. For this purpose, the value which shows the ratio included (statistically) relative to the total number is called the “coverage rate.”

Here, on the precondition that the distribution of data around the regression equation can be assumed to display a regular distribution, regression equations corresponding to arbitrary coverage rates can be set by a parallel shift of the regression equation for the average value by a value obtained from the standard deviation σ . It is also assumed as a precondition that the condition of data dispersion corresponding to the ship classes is also on the same order. The concept of this parallel shift is shown in **Figure.10**. The amount of the parallel shift is calculated by [k x σ (standard deviation]. The relationship between this k value and the coverage rate is shown in **Table3**.

The figures and tables in this research show the results for a coverage rate of 50% as a basic condition, the results for 75%, which is applied in the “Technical Standards,” and the results for 95%, which is analyzed in Reference **12)**.

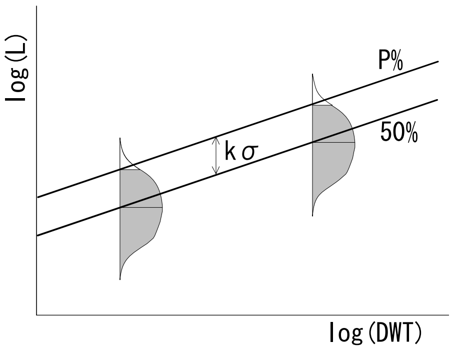


Figure10 Line by arbitrary coverage rate

Table3 k value and coverage rate

P	50%	60%	75%	90%	95%	99%
k	0.000	0.253	0.674	1.282	1.645	2.326

3.2 Problems in application of the conventional method

The facts that the number of data used in the analysis of total height is small in comparison with the level when Loa and other dimensions analyzed in the “Technical Standards,” the reliability of the total height data is low, and the conventional statistical analysis method (logarithmic regression analysis method) cannot be applied to ship height will be discussed in the following. The object of the discussion here is passenger ships, which provide a remarkable example of the inapplicability of the conventional method, and which also become a restricting condition in many cases when designing bridges in ports.

First, the condition of the distribution of the total height for passenger ships is shown in **Figure11**. As is clear from this **Figure11**, some passenger ships of less than 20,000GT have total heights exceeding 60m and approaching 70m, and conversely, some ships of more than 70,000GT have total heights which do not reach even 40m. Although there is a possibility that passenger ships showing these data actually exist, these are recognized as abnormally large values when compared with other ships of the same scale.

The results when the logarithmic regression analysis method was applied to these data are shown in **Figure12**. **Figure12** shows the regression equation obtained from the results of a log-log linear regression analysis, together with the regions for $\pm 2\sigma$ and $\pm 3\sigma$. Here, data exceeding the region of $\pm 3\sigma$ are excluded as abnormal values based on general statistical treatment. The log-log results after again applying the logarithmic regression analysis method are shown in **Figure13**, and the results expressed by the antilogarithms are shown in **Figure14**. As mentioned previously, **Figure13** and **Figure14** show regression equations for a coverage rate of 50% (average value), 75%, and 95%. The regression equation for the 95% coverage rate in **Figure14** is not considered to show appropriate results. Specifically, the value for a 95% coverage rate with the 150,000GT class, which is the largest ship class, reaches more than 90m, or approximately 20m more than the actual value of 70m. The results of a similar analysis for cargo ships are shown in **Figure15**. Here as well, the value for a 95% coverage rate with the 200,000GT class, which is the largest class of cargo ships, exceeds 70m, which is more than 10m higher than the actual value of approximately 60m.

These results clearly reveal that appropriate analytical results cannot be obtained by excluding data which exceed the $\pm 3\sigma$ region and applying the logarithmic regression analysis method.

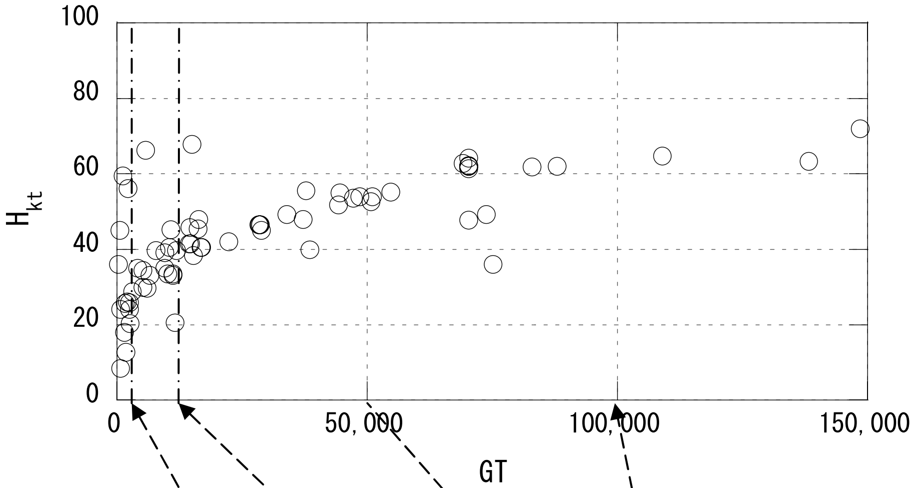


Figure11 Distribution of total height data (passenger ship)

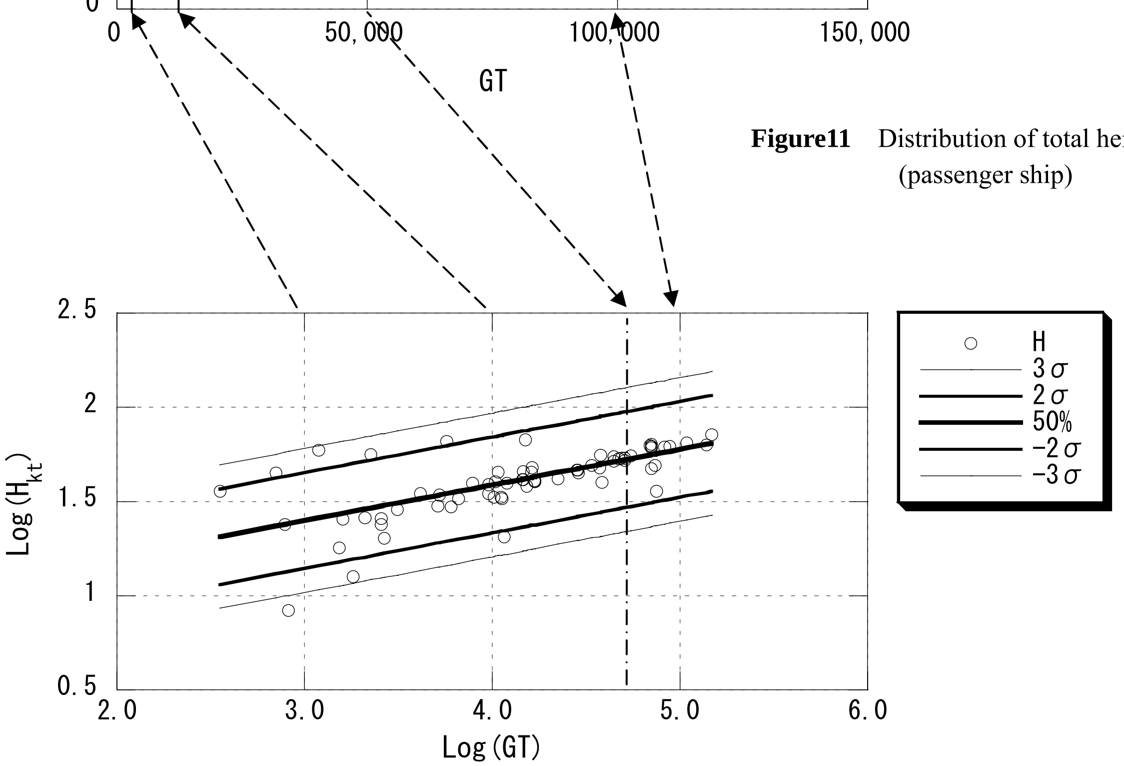


Figure12 Log-log regression analysis (passenger ship)

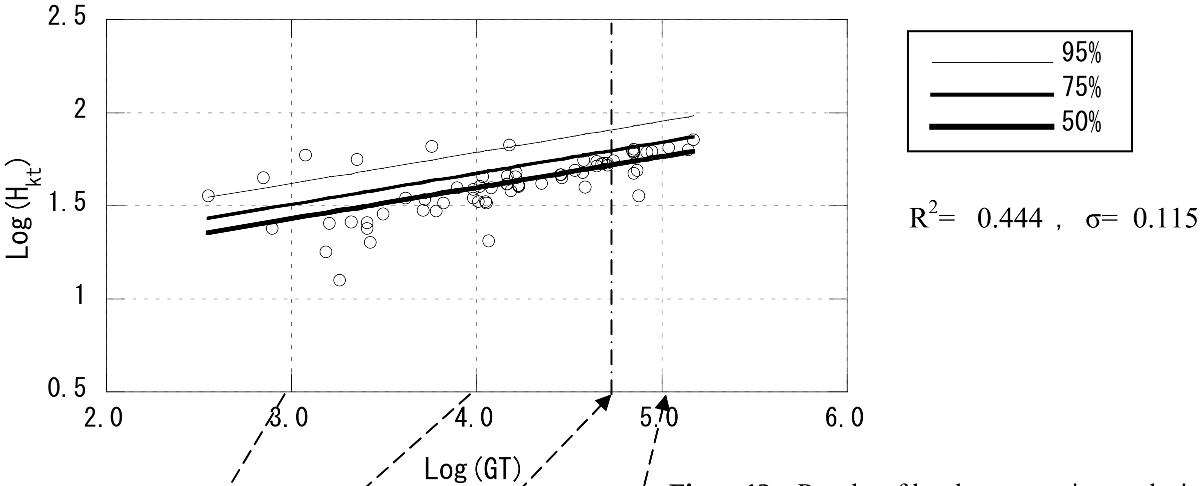


Figure13 Results of log-log regression analysis ①
: After exclusion of data exceeding ±3σ (passenger ship)

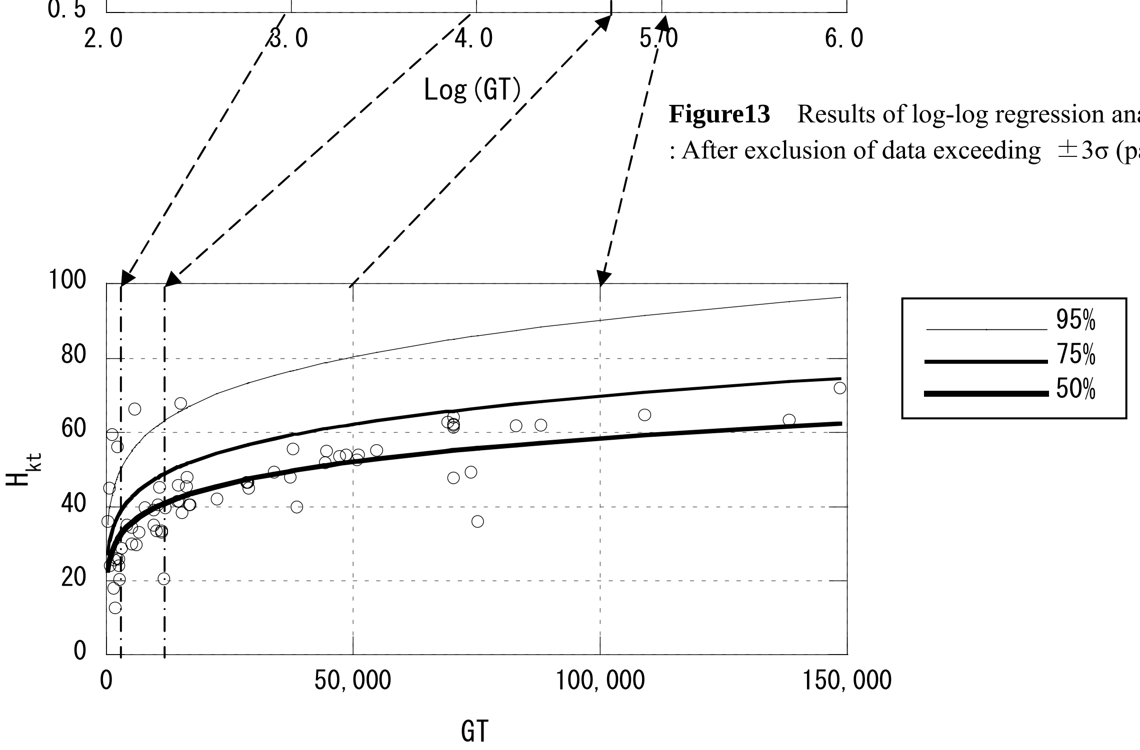


Figure14 Results of log-log regression analysis ②: After exclusion of data exceeding ±3σ (passenger ship)

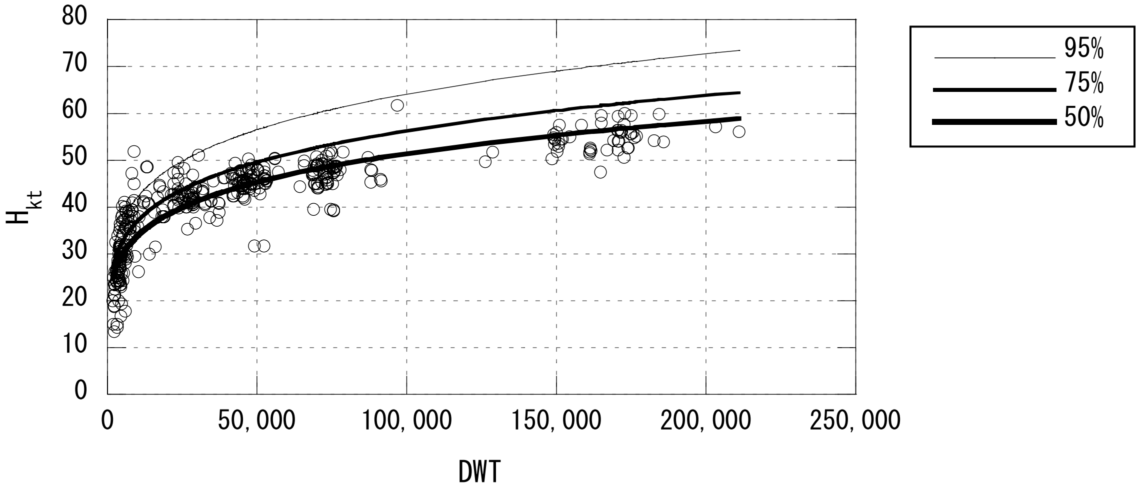


Figure15 Results of log-log regression analysis : After exclusion of data exceeding ±3σ (cargo ship)

3.3 New statistical analysis method applied to total height (H_{kt})

From the results of the analysis of passengers ships in section **3.2**, it became clear that the conventional method is inadequate with the region exceeding $\pm 3\sigma$ as a data exclusion region. Therefore, exclusion of the data in the region exceeding $\pm 2\sigma$ was attempted in order to further narrow the data. However, it was not possible to obtain appropriate analytical results when the logarithmic regression analysis method was applied in the conventional manner after excluding the region exceeding $\pm 2\sigma$. Concretely, the results for cargo ships when the logarithmic regression analysis method was applied after excluding the data in the region exceeding $\pm 2\sigma$ are shown in **Figure16**. Although the results in **Figure16** are more appropriate than in **Figure15**, in which only the region exceeding $\pm 3\sigma$ was excluded, the estimated results with a coverage rate of 95% for the 200,000DWT class, which is the largest class of cargo ships, are far removed from realistic values. Accordingly, it was concluded that application of the logarithmic regression analysis method in the conventional manner is not appropriate, even after excluding the region exceeding $\pm 2\sigma$.

Therefore, application of various regression analysis methods was attempted in order to obtain appropriate analytical results. The results of this study revealed that the most effective method is not the log-log regression analysis method, but rather, a semi-logarithmic regression analysis method in which only DWT or GT is converted to log form, as shown by the following equation.

$$Y = a \log X + b \quad (3)$$

where,

Y: H_{kt}

X: GT, DWT

Concretely, the results of an analysis of passenger ships, which were discussed previously, applying the semilog regression analysis method with only GT converted to log form, followed by analysis after excluding the data in the region exceeding $\pm 2\sigma$, are shown in **Figure17-19**. **Figure18** and **19** also show the regression equations for coverage rates of 50%, 75%, and 95%. **Figure17** shows the regression equation for linear regression analysis results when only the *x*-axis (GT) is converted to log form, together with the regression equations for $\pm 2\sigma$ and $\pm 3\sigma$. Based on these results, the logarithmic regression analysis method was applied once again after excluding the data for the region exceeding $\pm 2\sigma$, and only GT was expressed in semilog form. The results are shown in **Figure18**. The results expressed by the antilog axis are shown in **Figure19**. Based on the fact that the estimated results are on the same order as the maximum values of actually-existing ships, even with the maximum ship class of 150,000GT, for which appropriate results could not be obtained in **Figure14**, it can be concluded that appropriate analytical results have been obtained in **Figure19**.

The results when this method was applied to cargo ships are shown in **Figure20**. Here as well, appropriate results were obtained, as the estimated results are on the same order as the maximum values of actually-existing ships, even with the maximum ship class of 200,000GT, for which appropriate results could not be obtained in **Figure16**.

Accordingly, in analyses of total height, a semilog regression analysis method was adopted, in which a semilog regression analysis method is applied to the original data, converting only DWT or GT to log form, followed by an analysis after excluding the data for the region exceeding $\pm 2\sigma$.

Here, it should be noted that there are actual ships which greatly exceed the 95% coverage rate values due to exclusion of the data for the region exceeding $\pm 2\sigma$. Therefore, when using the analytical results shown in **Ch. 4** and the following, it is necessary to pay attention to the analytical method in this section **3.3**.

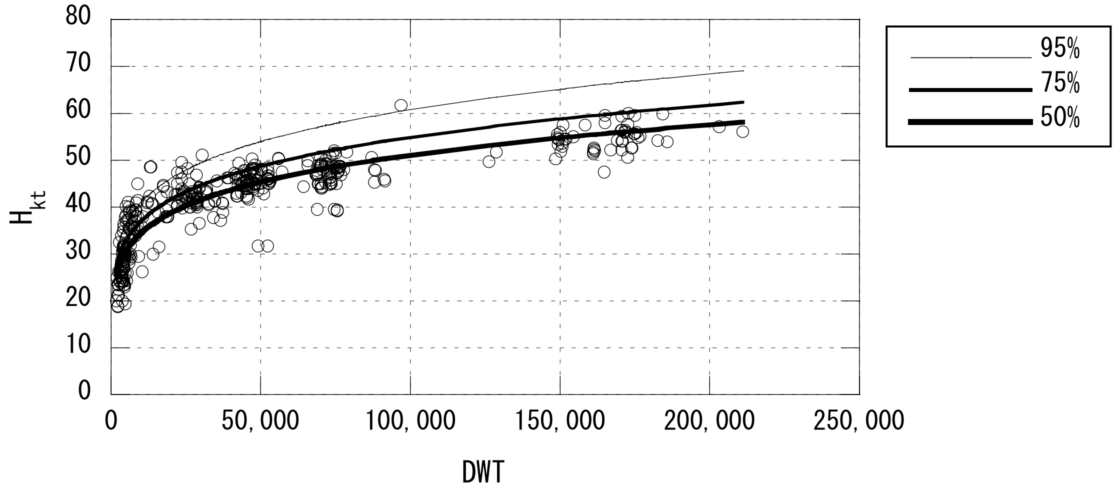


Figure16 Results of log-log regression analysis : After exclusion of data exceeding ±2σ (cargo ship)

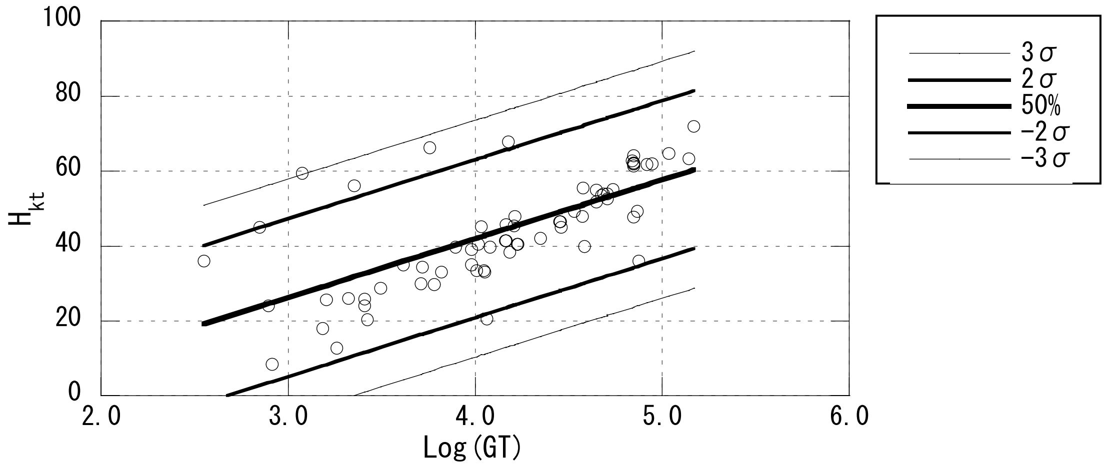


Figure17 Semilog regression analysis (passenger ship)

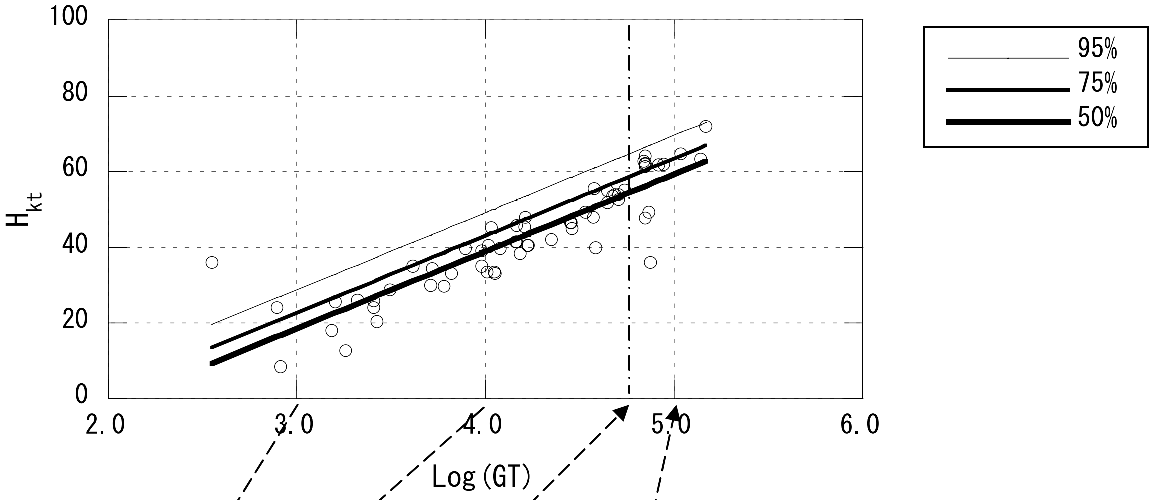


Figure18 Results of semilog regression analysis ①
: After exclusion of data exceeding ±2σ (passenger ship)

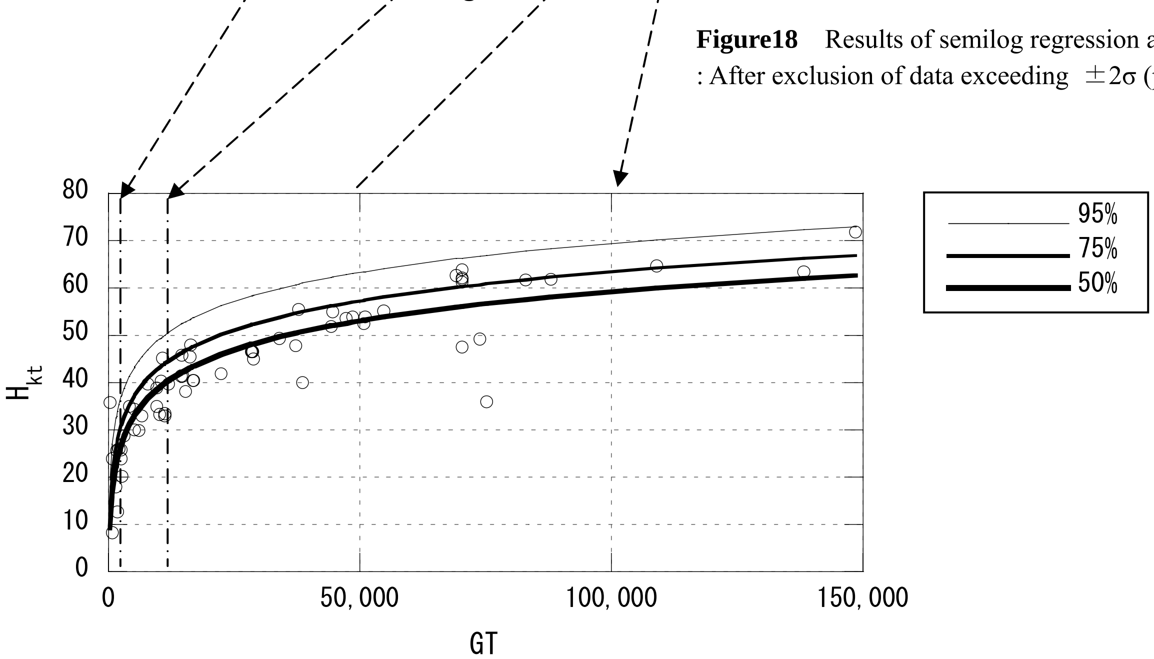


Figure19 Results of semilog regression analysis ②: After exclusion of data exceeding ±2σ (passenger ship)

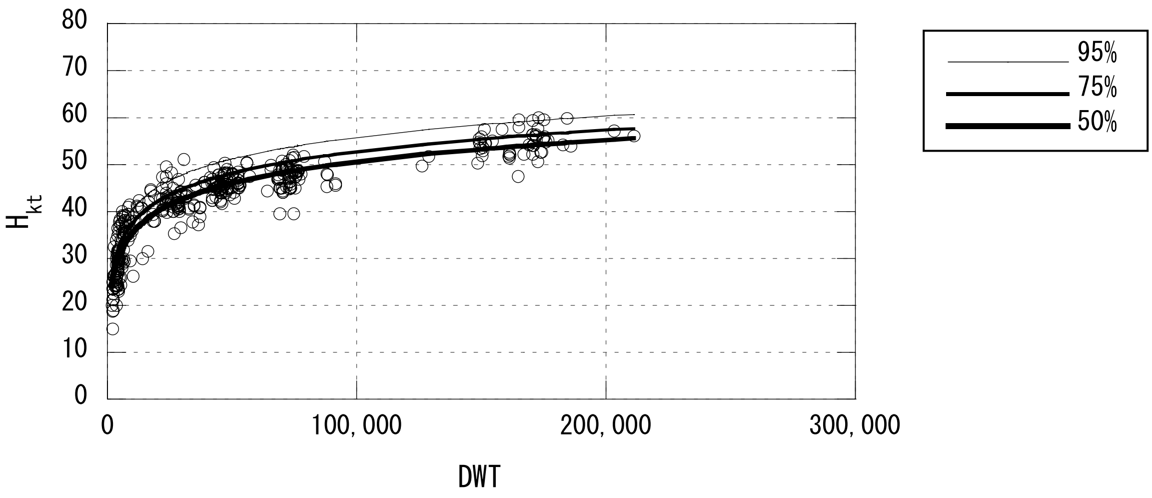


Figure20 Results of semilog regression analysis : After exclusion of data exceeding ±2σ (cargo ship)

4. Analysis of Total Height (H_{kt}) by Ship Type

4.1 Cargo ship

A distribution diagram of the total height (H_{kt}) data for cargo ships is shown in **Figure21–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding $\pm 2\sigma$ are shown in **Figure21–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding $\pm 2\sigma$ are shown in **Figure21–3**. The results when the log expressions of DWT in this figure are expressed as antilogs are shown in **Figure21–4**. These **Figure21–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure21–3** also shows the value of the coefficient of determination (0.887) and the coefficients of the regression equation for each coverage rate. From this **Figure21–4**, it can be concluded that meaningful regression equations for cargo ships have been obtained.

Accordingly, based on the regression equations obtained here, total height values were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table4**.

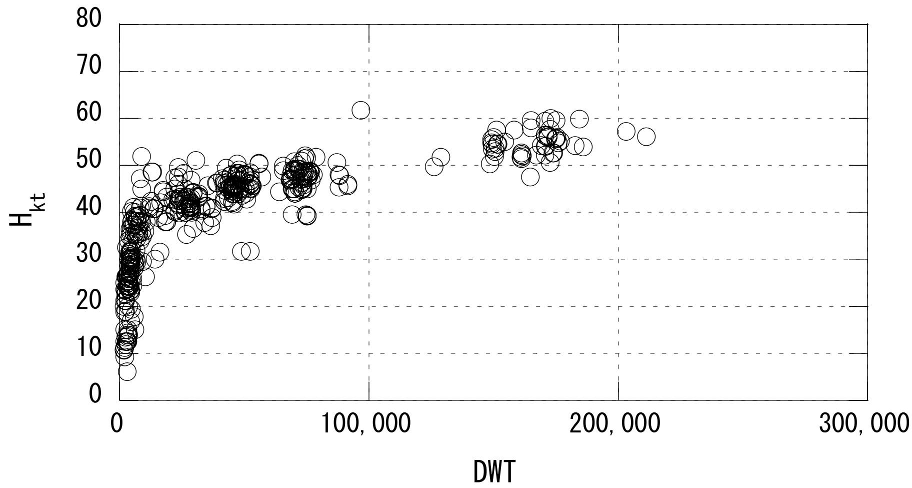


Figure21–1 Distribution of H_{kt} data (cargo ship)

Table4 Results of analysis of total height (H_{kt}) (cargo ship)

Dead Weight Tonnage (t)	50% (m)	75% (m)	95% (m)
1,000	20.2	22.3	25.4
2,000	24.8	26.9	30.0
3,000	27.5	29.6	32.6
5,000	30.8	33.0	36.0
10,000	35.4	37.5	40.6
12,000	36.6	38.7	41.8
18,000	39.3	41.4	44.5
30,000	42.7	44.8	47.9
40,000	44.6	46.7	49.8
55,000	46.7	48.8	51.9
70,000	48.3	50.4	53.5
90,000	49.9	52.1	55.1
120,000	51.8	54.0	57.0
150,000	53.3	55.4	58.5

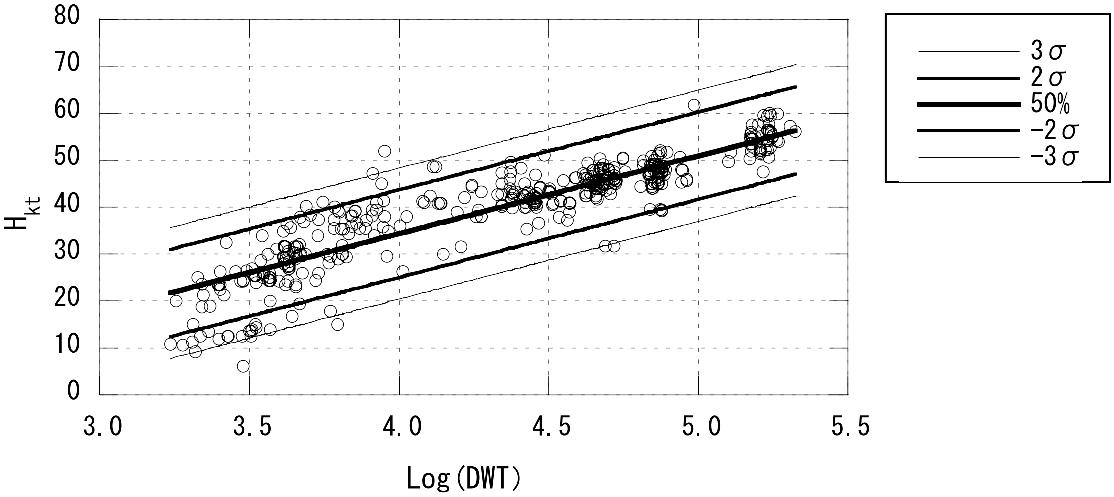
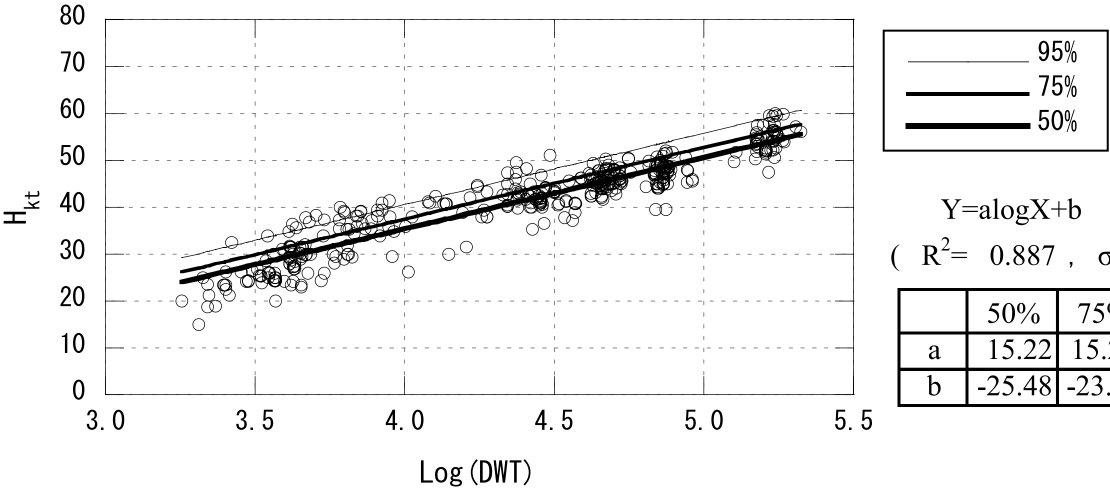


Figure21–2 H_{kt} – semilog regression analysis (cargo ship)



Y=alogX+b

(R^2= 0.887 , σ= 3.151)

	50%	75%	95%
a	15.22	15.22	15.22
b	-25.48	-23.36	-20.30

Figure21–3 Results of H_{kt} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (cargo ship)

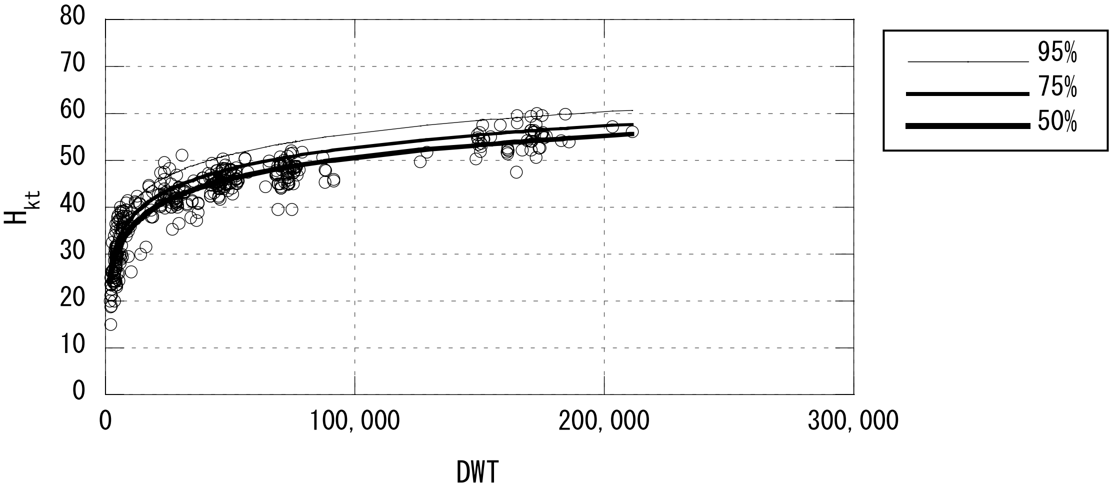


Figure21–4 Results of H_{kt} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (cargo ship)

4.2 Container ship

A distribution diagram of the total height (H_{kt}) data for container ships is shown in **Figure22–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure22–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure22–3**. The results when the log expressions of DWT in this figure are expressed as antilogs are shown in **Figure22–4**. These **Figure22–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure22–3** also shows the value of the coefficient of determination (0.842) and the coefficients of the regression equation for each coverage rate. From this **Figure22–4**, it can be concluded that meaningful regression equations for container ships have been obtained.

Accordingly, based on the regression equations obtained here, total height values were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table5**.

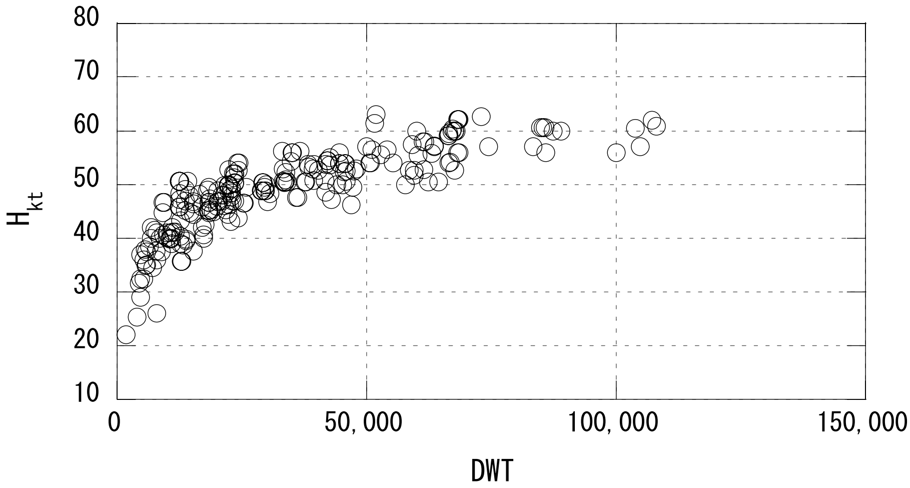


Figure22–1 Distribution of H_{kt} data (container ship)

Table5 Results of analysis of total height (H_{kt}) (container ship)

Dead Weight Tonnage (t)	50% (m)	75% (m)	95% (m)
10,000	40.5	42.5	45.4
20,000	46.6	48.6	51.5
30,000	50.1	52.1	55.0
40,000	52.6	54.6	57.5
50,000	54.5	56.5	59.4
60,000	56.1	58.1	61.0
100,000	60.5	62.5	65.4

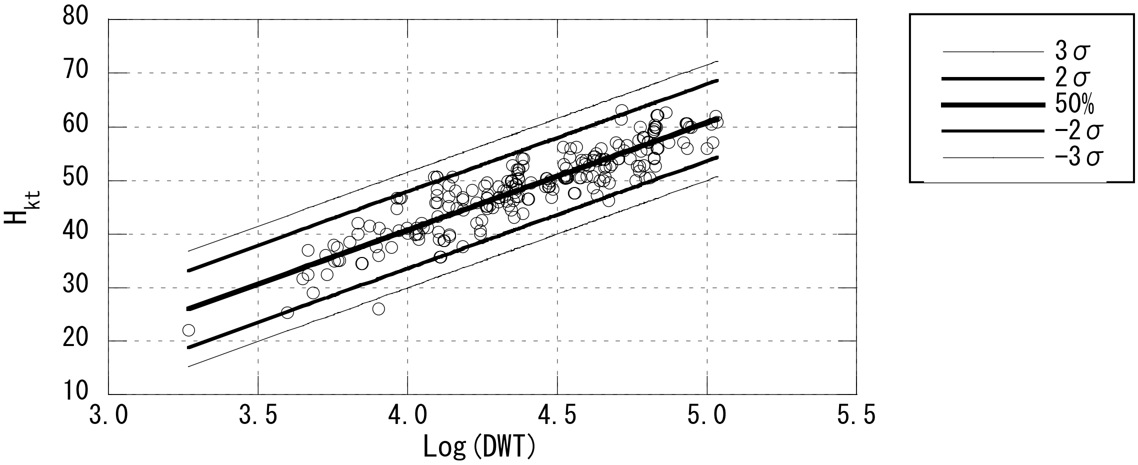
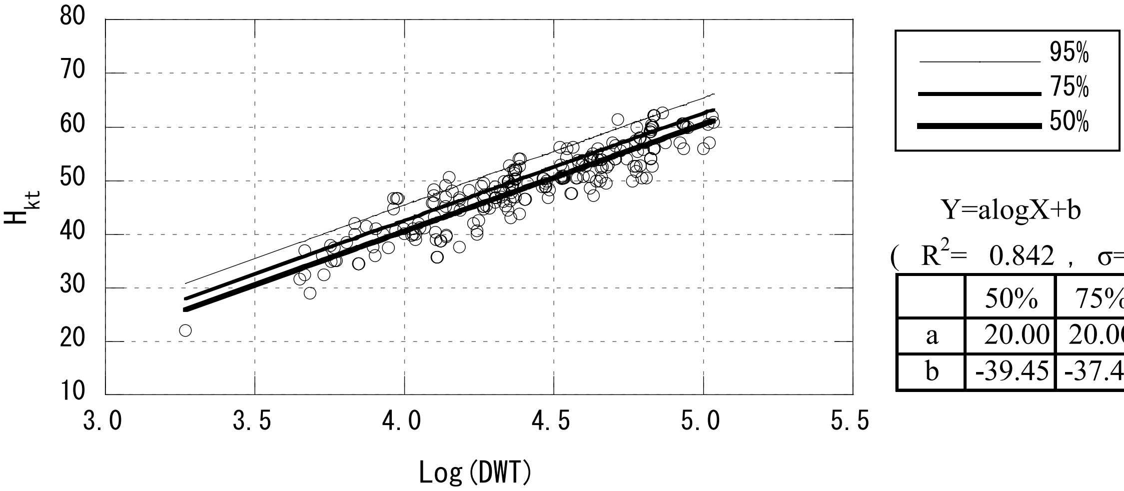


Figure22–2 H_{kt} – semilog regression analysis (container ship)



Y=alogX+b

(R^2= 0.842 , σ= 2.979)

	50%	75%	95%
a	20.00	20.00	20.00
b	-39.45	-37.44	-34.55

Figure22–3 Results of H_{kt} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (container ship)

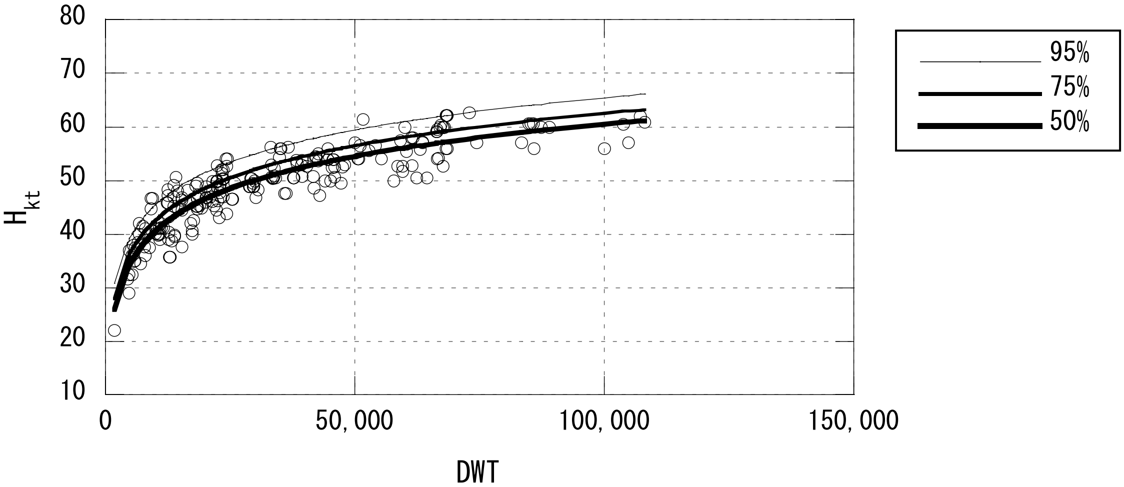


Figure22–4 Results of H_{kt} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (container ship)

4.3 Oil tanker

A distribution diagram of the total height (H_{kt}) data for oil tankers is shown in **Figure23–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure23–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure23–3**. The results when the log expressions of DWT in this figure are expressed as antilogs are shown in **Figure23–4**. These **Figure23–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure23–3** also shows the value of the coefficient of determination (0.850) and the coefficients of the regression equation for each coverage rate. From this **Figure23–4**, it can be concluded that meaningful regression equations for oil tankers have been obtained.

Accordingly, based on the regression equations obtained here, total height values were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the “Technical Standards.” The results are shown in **Table6**.

It may be noted that **Table6**, which concerns oil tankers, shows only 50,000DWT and larger, which are the data for analysis after excluding the data for the region exceeding ±2σ.

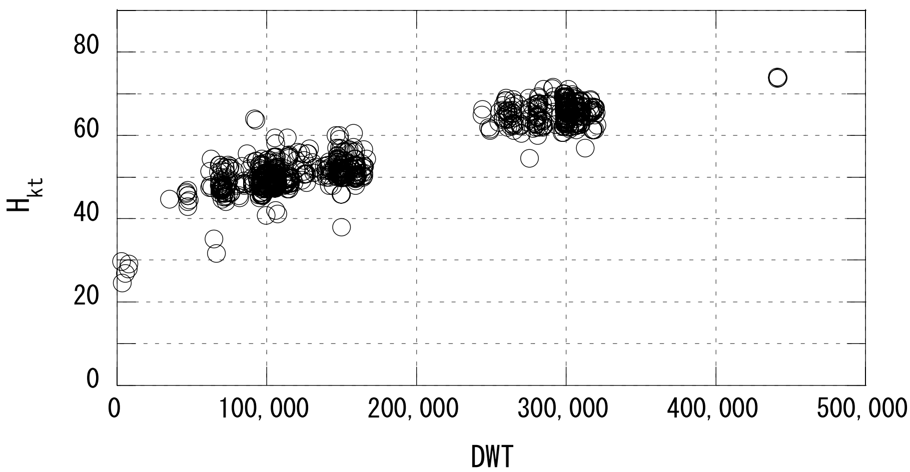


Figure23–1 Distribution of H_{kt} data (oil tanker)

Table6 Results of analysis of total height (H_{kt}) (oil tanker)

Dead Weight Tonnage (t)	50% (m)	75% (m)	95% (m)
50,000	39.1	41.1	44.1
70,000	43.9	45.9	48.9
90,000	47.5	49.5	52.4
100,000	49.0	51.0	53.9
150,000	54.8	56.8	59.7
300,000	64.7	66.7	69.6

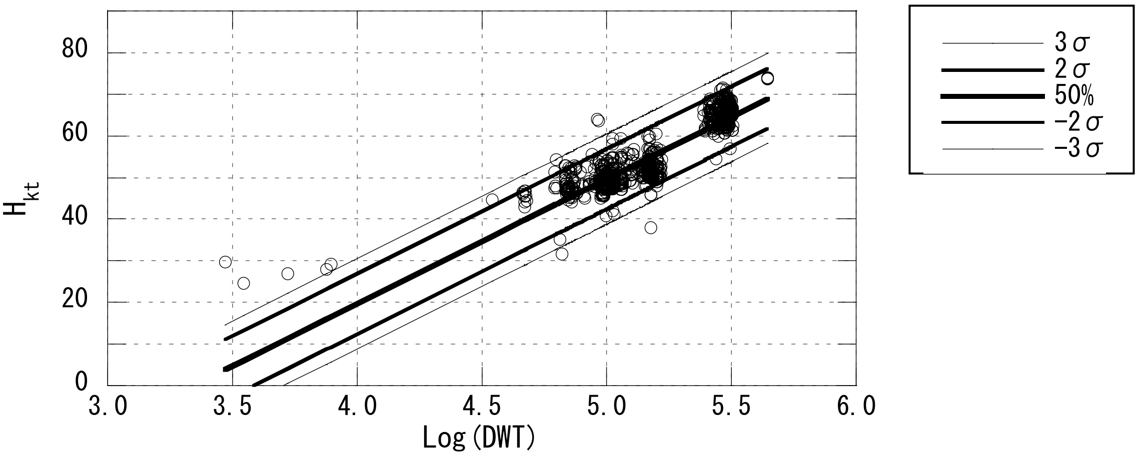
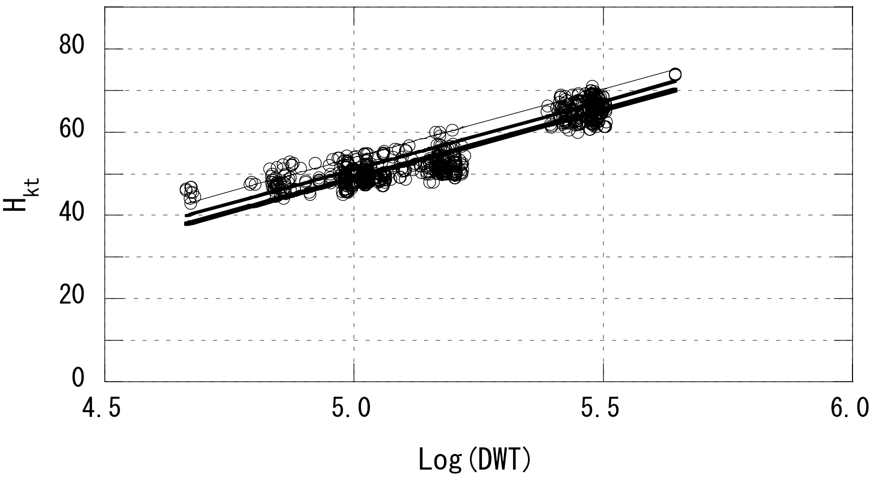


Figure23–2 H_{kt} – semilog regression analysis (oil tanker)



Y=alogX+b

(R^2= 0.850 , σ= 3.001)

	50%	75%	95%
a	32.82	32.82	32.82
b	-115.10	-113.07	-110.16

Figure23–3 Results of H_{kt} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (oil tanker)

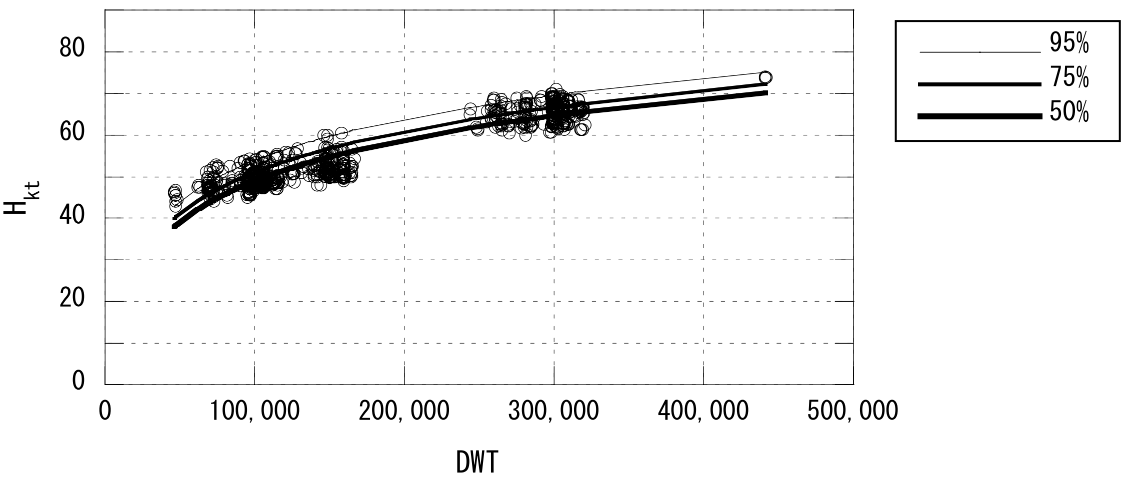


Figure23–4 Results of H_{kt} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (oil tanker)

4.4 RORO ship

A distribution diagram of the total height (H_{kt}) data for RORO ships is shown in **Figure24–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure24–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure24–3**. The results when the log expressions of DWT in this figure are expressed as antilogs are shown in **Figure24–4**. These **Figure24–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure24–3** also shows the value of the coefficient of determination (0.797) and the coefficients of the regression equation for each coverage rate. From this **Figure24–4**, it can be concluded that meaningful regression equations for RORO ships have been obtained.

Accordingly, based on the regression equations obtained here, total height values were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table7**.

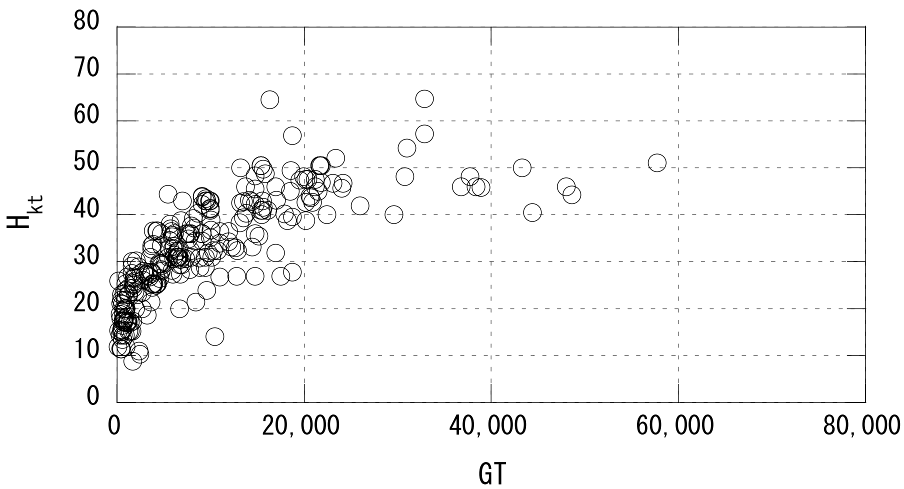


Figure24–1 Distribution of H_{kt} data (RORO ship)

Table 7 Results of analysis of total height (H_{kt}) (RORO ship)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
3,000	28.5	31.7	36.3
5,000	32.4	35.6	40.2
10,000	37.7	40.9	45.5
20,000	42.9	46.1	50.7
40,000	48.2	51.4	56.0
60,000	51.3	54.5	59.1

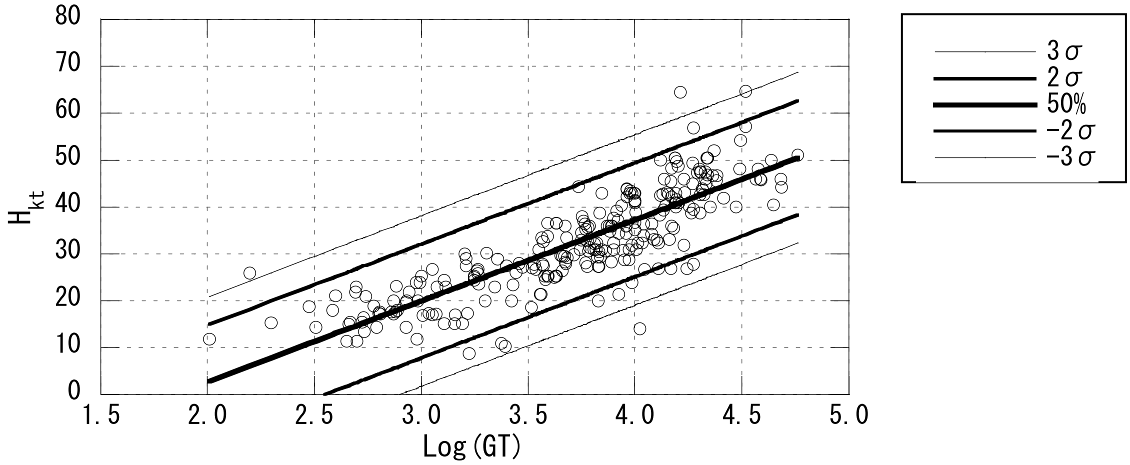
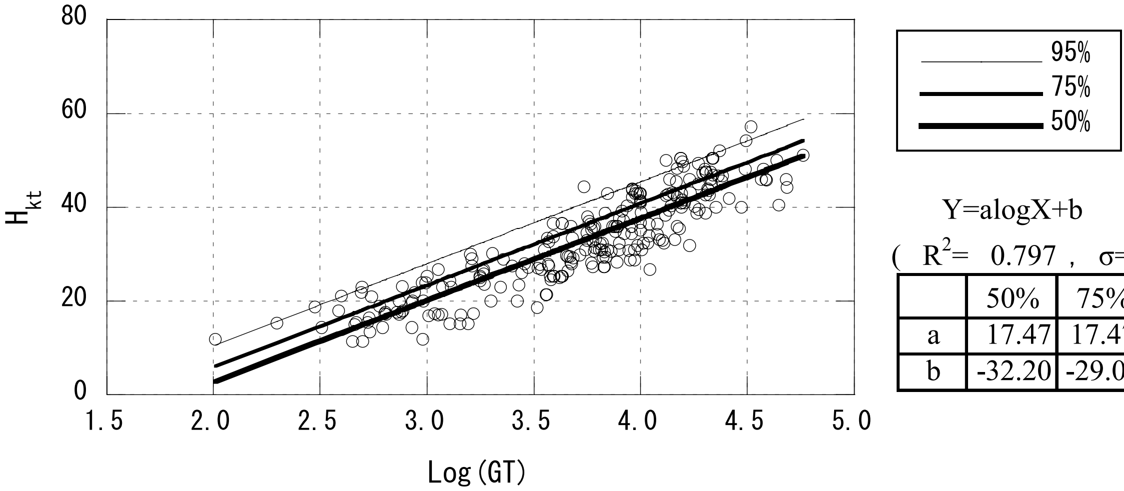


Figure24–2 H_{kt} – semilog regression analysis (RORO ship)



Y=alogX+b

(R^2= 0.797 , σ= 4.736)

	50%	75%	95%
a	17.47	17.47	17.47
b	-32.20	-29.00	-24.41

Figure24–3 Results of H_{kt} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (RORO ship)

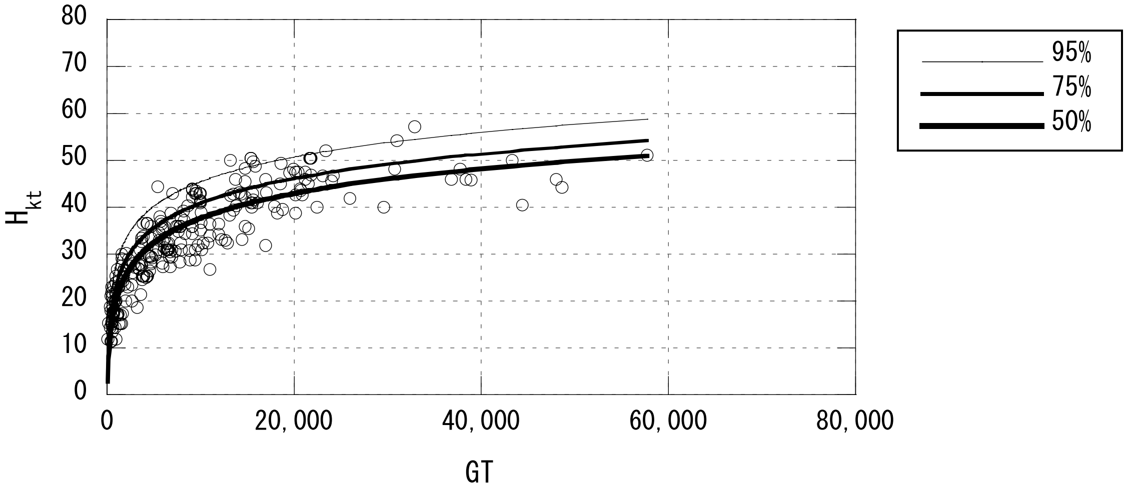


Figure24–4 Results of H_{kt} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (RORO ship)

4.5 PCC

A distribution diagram of the total height (H_{kt}) data for PCC ships is shown in **Figure25–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure25–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure25–3**. The results when the log expressions of DWT in this figure are expressed as antilogs are shown in **Figure25–4**. These **Figure25–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure25–3** also shows the value of the coefficient of determination (0.746) and the coefficients of the regression equation for each coverage rate. From this **Figure25–4**, it can be concluded that meaningful regression equations for PCC ships have been obtained.

Accordingly, based on the regression equations obtained here, total height values were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table8**.

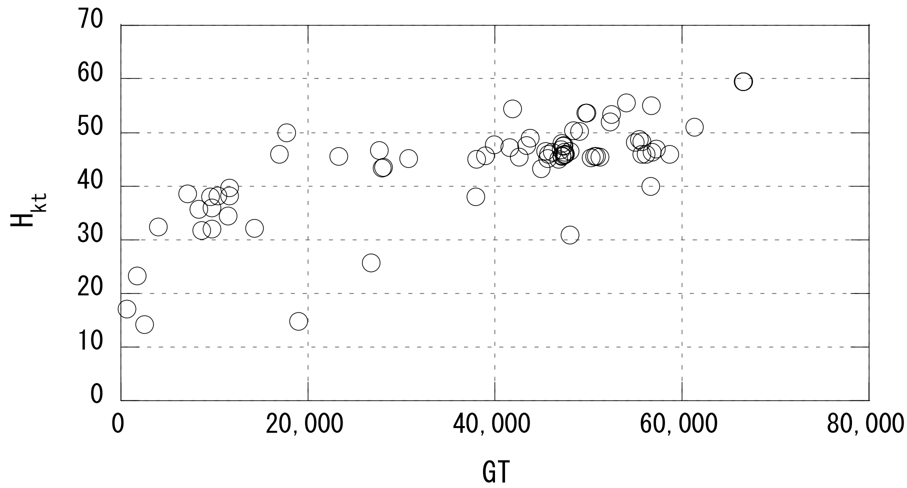


Figure25–1 Distribution of H_{kt} data (PCC)

Table8 Results of analysis of total height (H_{kt}) (PCC)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
3,000	26.9	29.6	33.5
5,000	30.8	33.5	37.3
12,000	37.4	40.1	44.0
20,000	41.3	44.0	47.8
30,000	44.4	47.0	50.9
40,000	46.5	49.2	53.1
60,000	49.6	52.3	56.2

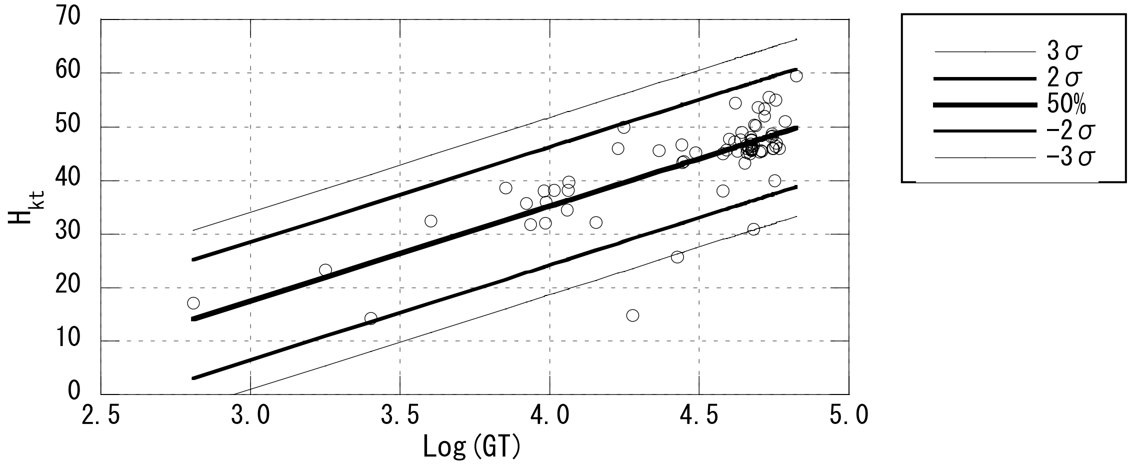
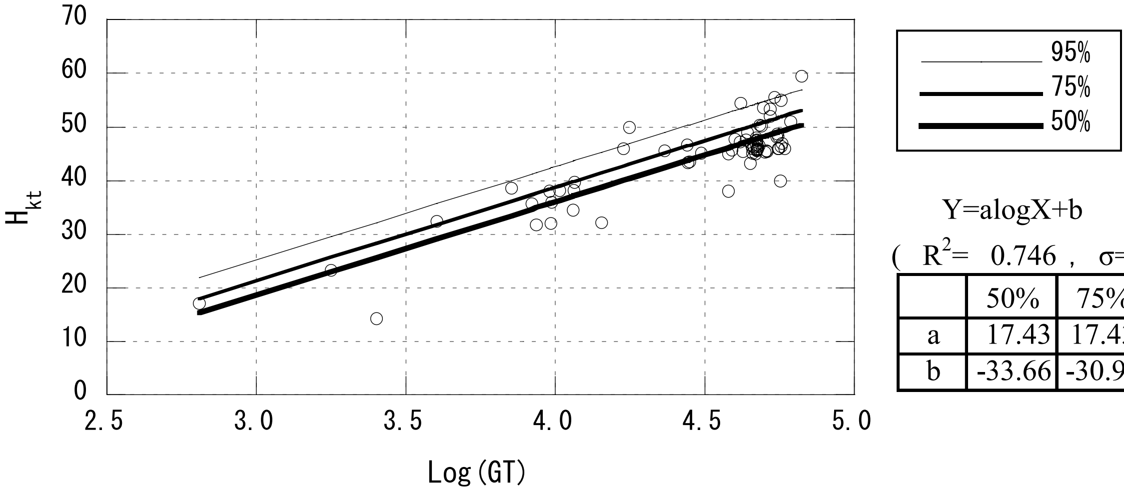


Figure25–2　H_{kt} – semilog regression analysis (PCC)



Y=alogX+b

(R^2= 0.746 , σ= 3.972)

	50%	75%	95%
a	17.43	17.43	17.43
b	-33.66	-30.98	-27.13

Figure25–3　Results of H_{kt} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (PCC)

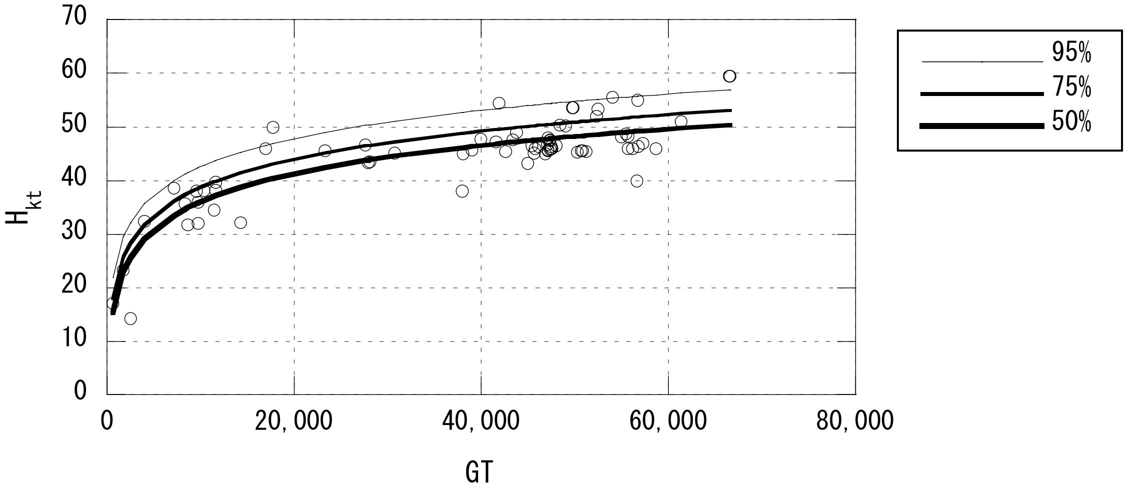


Figure25–4　Results of H_{kt} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (PCC)

4.6 LPG ship

A distribution diagram of the total height (H_{kt}) data for LPG ships is shown in **Figure26–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding $\pm 2\sigma$ are shown in **Figure26–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding $\pm 2\sigma$ are shown in **Figure26–3**. The results when the log expressions of DWT in this figure are expressed as antilogs are shown in **Figure26–4**. These **Figure26–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure26–3** also shows the value of the coefficient of determination (0.928) and the coefficients of the regression equation for each coverage rate. From this **Figure26–4**, it can be concluded that meaningful regression equations for LPG ships have been obtained.

Accordingly, based on the regression equations obtained here, total height values were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the “Technical Standards.” The results are shown in **Table9**.

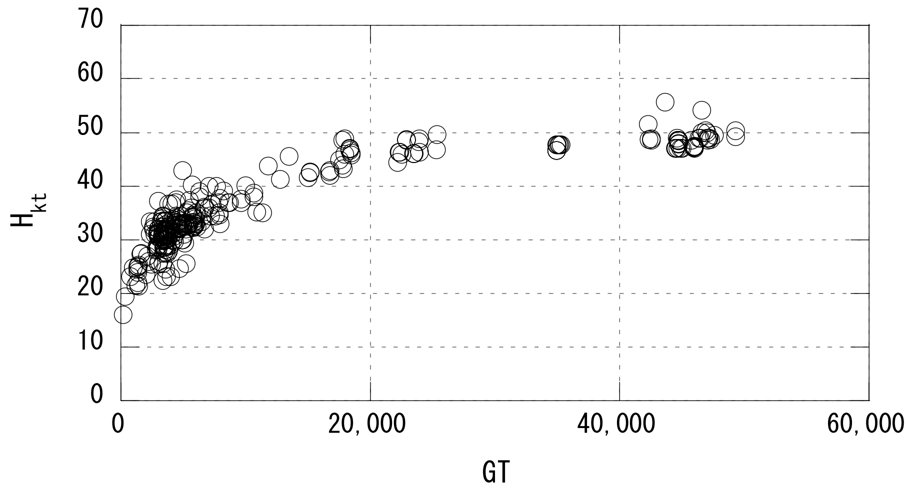


Figure26–1 Distribution of H_{kt} data (LPG ship)

Table9 Results of analysis of total height (H_{kt}) (LPG ship)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
3,000	29.8	31.2	33.3
5,000	33.5	34.9	37.0
10,000	38.4	39.8	41.9
20,000	43.4	44.8	46.9
30,000	46.3	47.7	49.8
40,000	48.3	49.8	51.8
50,000	49.9	51.3	53.4

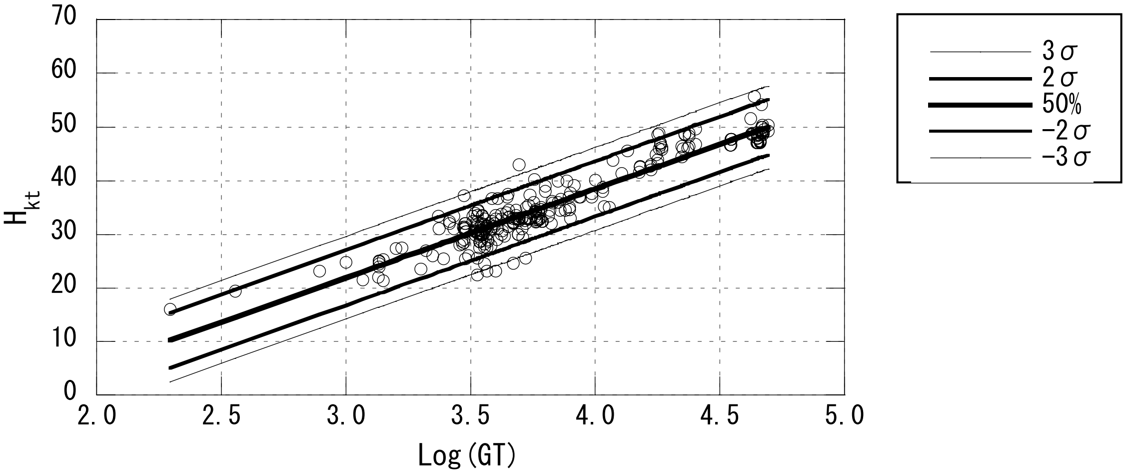
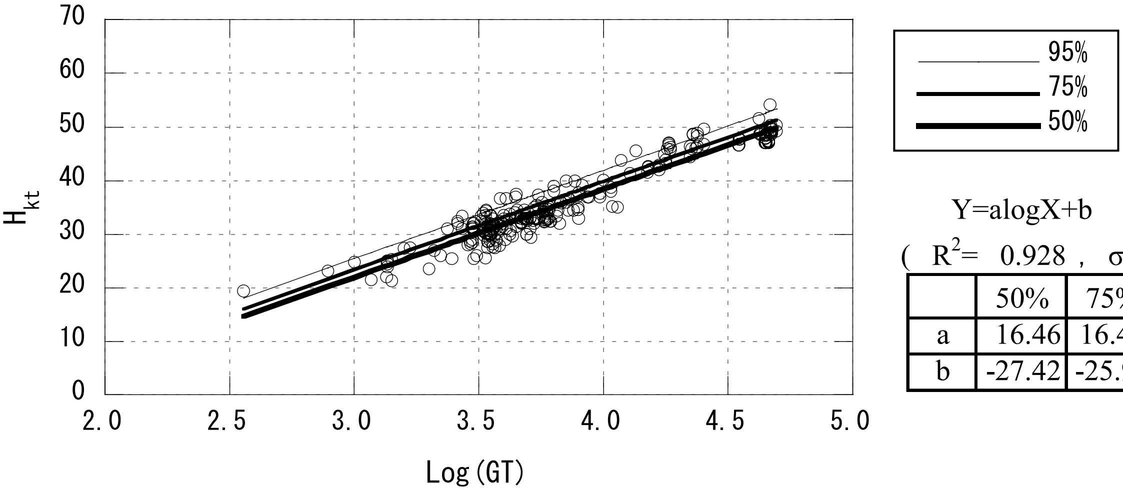


Figure26–2 H_{kt} – semilog regression analysis (LPG ship)



Y=alogX+b

(R^2= 0.928 , σ= 2.130)

	50%	75%	95%
a	16.46	16.46	16.46
b	-27.42	-25.98	-23.91

Figure26–3 Results of H_{kt} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (LPG ship)

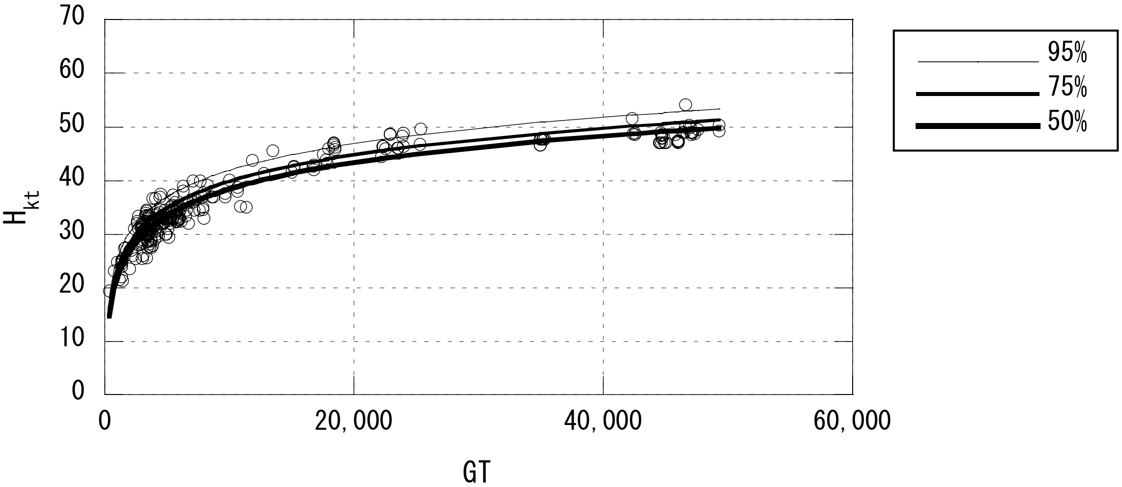


Figure26–4 Results of H_{kt} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (LPG ship)

4.7 LNG ship

A distribution diagram of the total height (H_{kt}) data for LNG ships is shown in **Figure27–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding $\pm 2\sigma$ are shown in **Figure27–2**. Ships of less than 50,000GT were excluded as the number of data is small. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding $\pm 2\sigma$ are shown in **Figure27–3**. The results when the log expressions of DWT in this figure are expressed as antilogs are shown in **Figure27–4**. These **Figure27–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure27–3** also shows the value of the coefficient of determination (0.183) and the coefficients of the regression equation for each coverage rate. In spite of the fact that the coefficient of determination is low here, unlike that for the other ship types, it is thought that these results reflect the special characteristics of this region.

Accordingly, based on the regression equations obtained here, total height values were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the “Technical Standards.” The results are shown in **Table10**.

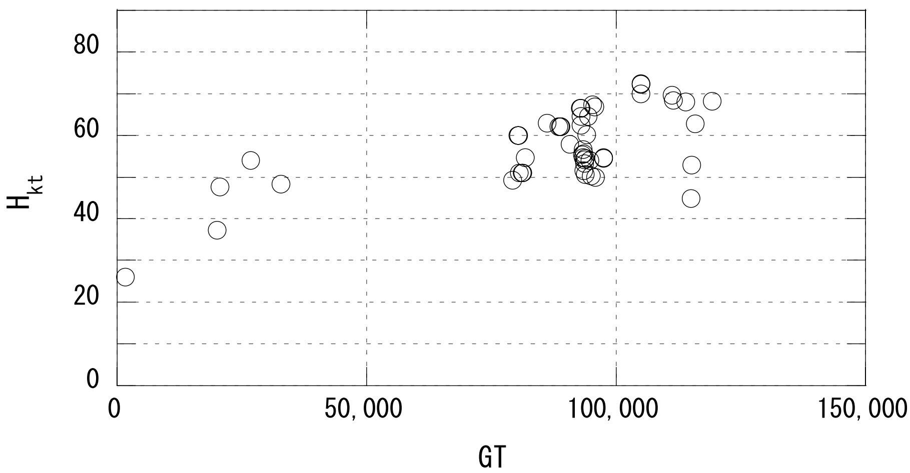


Figure27–1 Distribution of H_{kt} data (LNG ship)

Table10 Results of analysis of total height (H_{kt}) (LNG ship)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
80,000	54.0	58.3	64.5
100,000	60.9	65.2	71.5
120,000	66.6	70.9	77.1

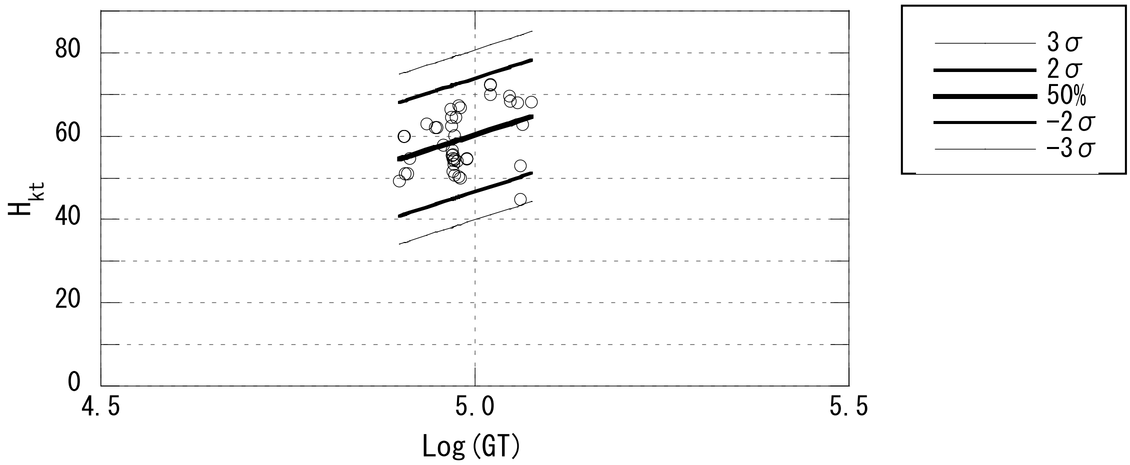
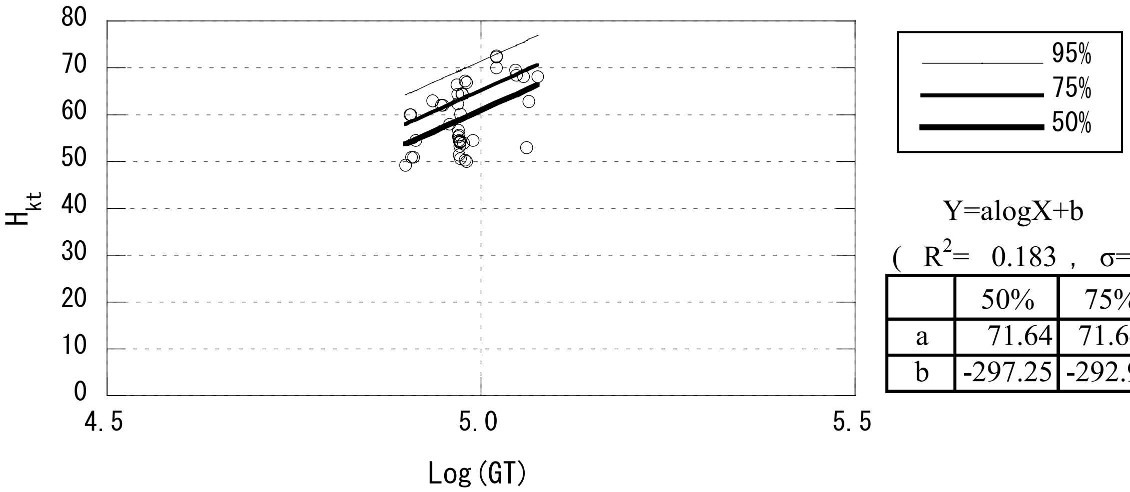


Figure27–2 H_{kt} – semilog regression analysis (LNG ship)



Y=alogX+b

(R^2= 0.183 , σ= 6.404)

	50%	75%	95%
a	71.64	71.64	71.64
b	-297.25	-292.93	-286.71

Figure27–3 Results of H_{kt} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (LNG ship)

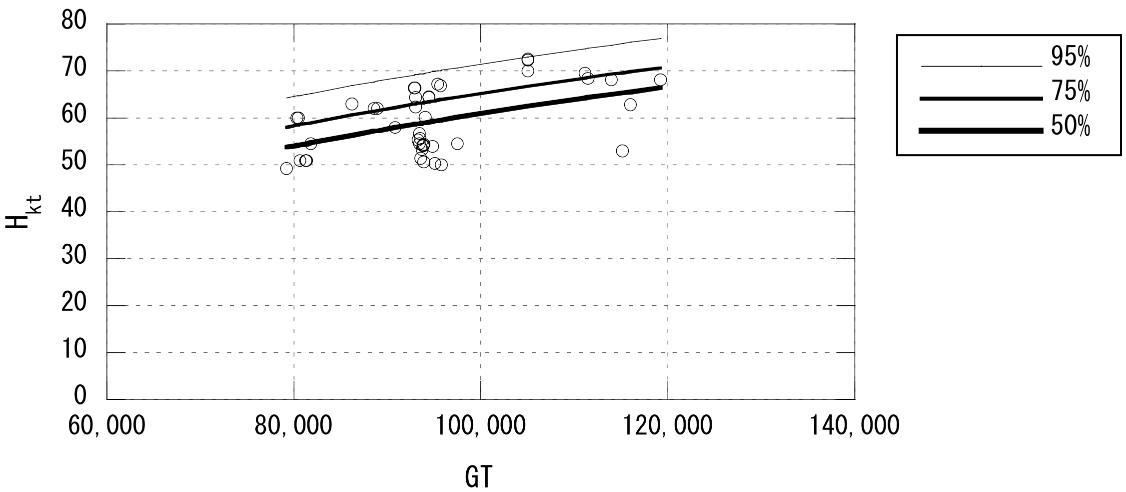


Figure27–4 Results of H_{kt} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (LNG ship)

4.8 Passenger ship

A distribution diagram of the total height (H_{kt}) data for passenger ships is shown in **Figure28–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure28–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure28–3**. The results when the log expressions of DWT in this figure are expressed as antilogs are shown in **Figure28–4**. These **Figure28–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure28–3** also shows the value of the coefficient of determination (0.799) and the coefficients of the regression equation for each coverage rate. From this **Figure28–4**, it can be concluded that meaningful regression equations for passenger ships have been obtained.

Accordingly, based on the regression equations obtained here, total height values were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table11**.

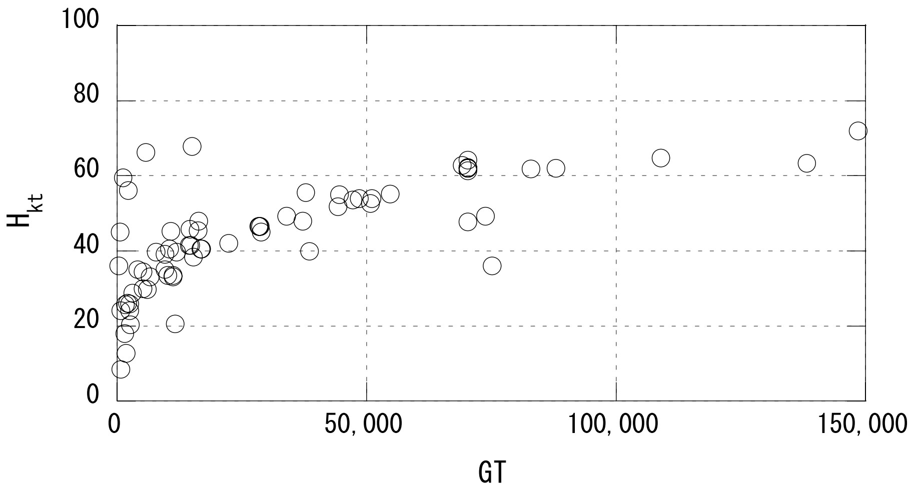


Figure28–1 Distribution of H_{kt} data (Passenger ship)

Table11 Results of analysis of total height (H_{kt}) (Passenger ship)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
3,000	28.2	32.4	38.5
5,000	32.7	36.9	43.0
10,000	38.8	43.1	49.1
20,000	45.0	49.2	55.2
30,000	48.6	52.8	58.8
50,000	53.1	57.3	63.4
70,000	56.1	60.3	66.3
100,000	59.2	63.4	69.5

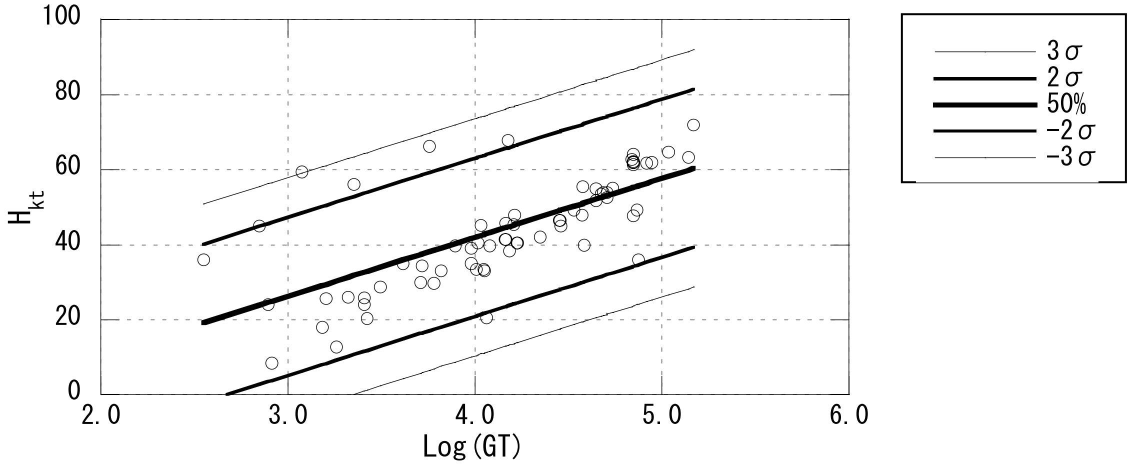


Figure28–2 H_{kt} – semilog regression analysis (Passenger ship)

Y=alogX+b

(R^2= 0.799 , σ= 6.238)

	50%	75%	95%
a	20.38	20.38	20.38
b	-42.67	-38.46	-32.41

Figure28–3 Results of H_{kt} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (Passenger ship)

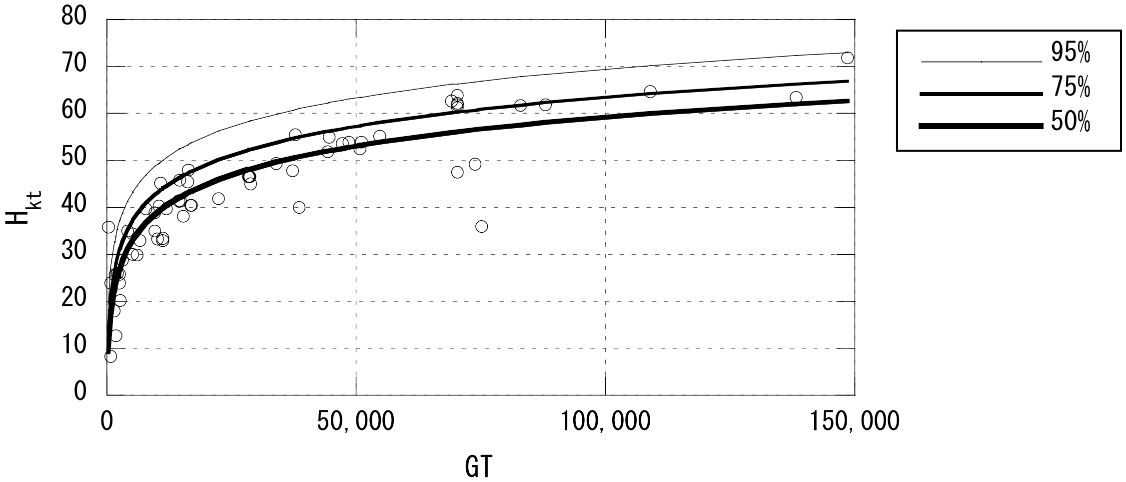


Figure28–4 Results of H_{kt} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (Passenger ship)

5. Analysis of Height Above Surface (H_{st}) by Ship Type – 1

A value which is a practical necessity when designing bridges over fairways, arranging the relationship with the obstacle assessment level (OAS) at maritime airports, etc. is the height from the sea surface to the highest point on a ship, in other words, the height above surface (H_{st}). Here, the height above surface (H_{st}) is calculated by the following equation.

$$H_{st} = H_{kt} - \beta d \quad (4)$$

where,

H_{kt}: Total height

H_{st}: Height above surface

β : Draft factor

d: Full load draft

The total height (H_{kt}) and full load draft (d) of an assumed design ship are basically invariable. However, the actual draft of a ship changes during navigation depending on the cargo loading condition and other factors, and as a result, the height above the sea surface (H_{st}) will also vary. Because the height above the surface (H_{st}) obtained here by subtracting the full load draft (d) from the total height (H_{kt}) is only the minimum value, the height of bridge girders and OAS at maritime airports will be evaluated in way which invites risk if studied using this value.

Therefore, a parameter which termed the “draft factor” (β) is introduced as an index of the draft condition, which varies depending on cargo loading condition, etc. That is, the draft factor (β) will be the maximum value, 1.0, when the design ship is in a fully-loaded condition, and will be less than 1.0 under conditions other than full load. Naturally, as shown in **Figure29**, the height above surface (H_{st}) will increase as β decreases, in other words, as the ship’s draft becomes shallower, and may pose a danger to structures of interest such as bridges.

The following **Table12-19** show the results when height above surface (H_{st}) was calculated by ship type for cases assuming the total height (H_{kt}) shown in **Ch. 4**, the full load draft (d) shown in the results of previous research,[12] and draft factors (β) from 1.0 to 0.8 (in increments of 0.05) using coverage rates of 50%, 75%, and 95%. However, due to the large effect of ballast conditions in cargo ships and container ships, calculations were made assuming β in the range of 1.0 to 0.5 (increments of 0.1) limited to these two types of ships.

When setting concrete values for β, appropriate setting is necessary based on the points for attention in the analysis method described in section **3.3**, the actual and planned cargo loading conditions, the bow trim and stern trim of the ship while sailing, and other relevant factors.

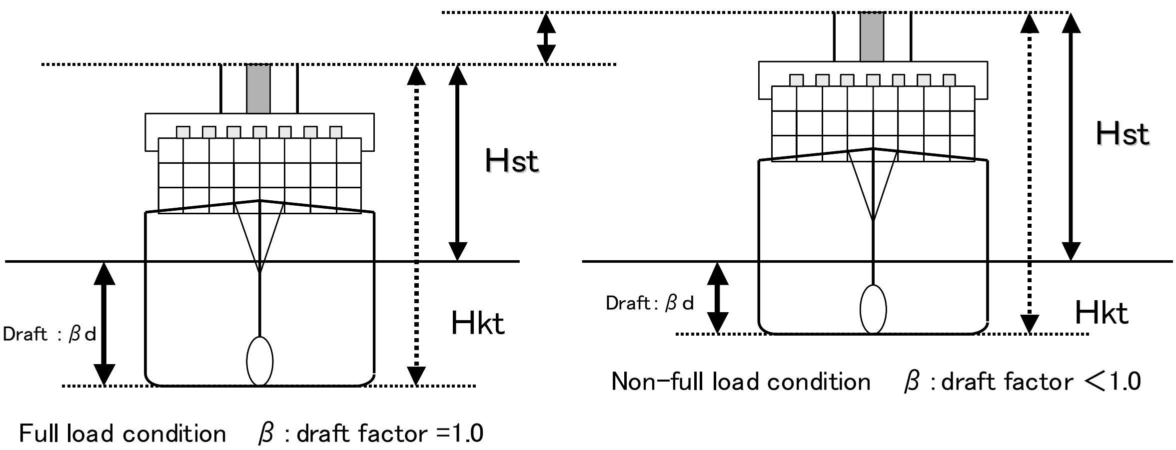


Figure29 Height above surface (H_{st}) and draft factor

Table12 Cargo ship: Height above surface (H_{st}) corresponding to draft factor (β)

Coverage rate	DWT (t)	H_{kt} (m)	d (m)	$H_{st}=H_{kt}-\beta d$ (m)					
				β=1.0	β=0.9	β=0.8	β=0.7	β=0.6	β=0.5
50%	1,000	20.2	3.4	16.8	17.1	17.5	17.8	18.1	18.5
	2,000	24.8	4.3	20.5	20.9	21.3	21.8	22.2	22.6
	3,000	27.5	4.9	22.6	23.0	23.5	24.0	24.5	25.0
	5,000	30.8	5.8	25.0	25.6	26.2	26.8	27.3	27.9
	10,000	35.4	7.3	28.1	28.8	29.6	30.3	31.0	31.8
	12,000	36.6	7.8	28.8	29.6	30.4	31.2	31.9	32.7
	18,000	39.3	8.9	30.4	31.3	32.2	33.1	34.0	34.8
	30,000	42.7	10.0	32.7	33.7	34.7	35.7	36.7	37.7
	40,000	44.6	11.0	33.6	34.7	35.8	36.9	38.0	39.1
	55,000	46.7	12.2	34.5	35.7	36.9	38.1	39.4	40.6
	70,000	48.3	13.2	35.1	36.4	37.7	39.0	40.4	41.7
	90,000	49.9	14.3	35.6	37.1	38.5	39.9	41.4	42.8
	120,000	51.8	15.7	36.1	37.7	39.3	40.9	42.4	44.0
	150,000	53.3	16.9	36.4	38.1	39.8	41.5	43.2	44.9
75%	1,000	22.3	3.8	18.5	18.9	19.3	19.7	20.0	20.4
	2,000	26.9	4.8	22.1	22.6	23.1	23.5	24.0	24.5
	3,000	29.6	5.4	24.2	24.7	25.3	25.8	26.3	26.9
	5,000	33.0	6.4	26.6	27.2	27.8	28.5	29.1	29.8
	10,000	37.5	8.1	29.4	30.2	31.1	31.9	32.7	33.5
	12,000	38.7	8.6	30.1	31.0	31.9	32.7	33.6	34.4
	18,000	41.4	9.8	31.6	32.6	33.6	34.6	35.5	36.5
	30,000	44.8	10.5	34.3	35.3	36.4	37.4	38.5	39.5
	40,000	46.7	11.5	35.2	36.4	37.5	38.7	39.8	41.0
	55,000	48.8	12.8	36.0	37.3	38.6	39.8	41.1	42.4
	70,000	50.4	13.8	36.6	38.0	39.4	40.7	42.1	43.5
	90,000	52.1	15.0	37.1	38.6	40.1	41.6	43.1	44.6
	120,000	54.0	16.5	37.5	39.1	40.8	42.4	44.1	45.7
	150,000	55.4	17.7	37.7	39.5	41.3	43.0	44.8	46.6
95%	1,000	25.4	4.4	21.0	21.4	21.9	22.3	22.7	23.2
	2,000	30.0	5.5	24.5	25.0	25.6	26.1	26.7	27.2
	3,000	32.6	6.3	26.3	27.0	27.6	28.2	28.9	29.5
	5,000	36.0	7.4	28.6	29.4	30.1	30.8	31.6	32.3
	10,000	40.6	9.3	31.3	32.2	33.2	34.1	35.0	35.9
	12,000	41.8	9.9	31.9	32.9	33.9	34.9	35.9	36.9
	18,000	44.5	11.3	33.2	34.3	35.4	36.6	37.7	38.8
	30,000	47.9	11.2	36.7	37.8	38.9	40.0	41.1	42.3
	40,000	49.8	12.3	37.5	38.7	39.9	41.2	42.4	43.6
	55,000	51.9	13.7	38.2	39.5	40.9	42.3	43.6	45.0
	70,000	53.5	14.8	38.7	40.1	41.6	43.1	44.6	46.1
	90,000	55.1	16.0	39.1	40.7	42.3	43.9	45.5	47.1
	120,000	57.0	17.6	39.4	41.2	42.9	44.7	46.5	48.2
	150,000	58.5	18.9	39.6	41.5	43.4	45.3	47.2	49.0

Table13 Container ship: Height above surface (H_{st}) corresponding to draft factor (β)

Coverage rate	DWT (t)	H_{kt} (m)	d (m)	$H_{st}=H_{kt}-\beta d$ (m)				
				β=1.0	β=0.95	β=0.9	β=0.85	β=0.8
50%	10,000	40.5	7.6	32.9	33.3	33.7	34.1	34.5
	20,000	46.6	9.5	37.1	37.5	38.0	38.5	39.0
	30,000	50.1	10.8	39.3	39.8	40.4	40.9	41.4
	40,000	52.6	11.7	40.9	41.5	42.0	42.6	43.2
	50,000	54.5	12.3	42.2	42.8	43.4	44.1	44.7
	60,000	56.1	13.1	43.0	43.6	44.3	45.0	45.6
	100,000	60.5	14.6	46.0	46.7	47.4	48.2	48.9
75%	10,000	42.5	7.9	34.6	35.0	35.4	35.8	36.2
	20,000	48.6	9.9	38.7	39.2	39.7	40.2	40.6
	30,000	52.1	11.2	40.9	41.4	42.0	42.6	43.1
	40,000	54.6	12.1	42.5	43.1	43.7	44.3	44.9
	50,000	56.5	12.7	43.9	44.5	45.1	45.8	46.4
	60,000	58.1	13.4	44.7	45.4	46.1	46.8	47.4
	100,000	62.5	14.7	47.9	48.6	49.3	50.1	50.8
95%	10,000	45.4	8.3	37.1	37.6	38.0	38.4	38.8
	20,000	51.5	10.4	41.1	41.6	42.1	42.6	43.1
	30,000	55.0	11.9	43.1	43.7	44.3	44.9	45.5
	40,000	57.5	12.7	44.8	45.5	46.1	46.7	47.4
	50,000	59.4	13.2	46.3	46.9	47.6	48.2	48.9
	60,000	61.0	13.7	47.3	48.0	48.7	49.3	50.0
	100,000	65.4	14.9	50.6	51.3	52.1	52.8	53.5

Table14 oil tanker: Height above surface (H_{st}) corresponding to draft factor (β)

Coverage rate	DWT (t)	H_{kt} (m)	d (m)	$H_{st}=H_{kt}-\beta d$ (m)					
				β=1.0	β=0.9	β=0.8	β=0.7	β=0.6	β=0.5
50%	50,000	39.1	10.9	28.2	29.3	30.4	31.5	32.6	33.7
	70,000	43.9	12.3	31.6	32.9	34.1	35.3	36.5	37.8
	90,000	47.5	13.5	34.0	35.4	36.7	38.1	39.4	40.8
	100,000	49.0	14.0	35.0	36.4	37.8	39.2	40.6	42.0
	150,000	54.8	16.4	38.4	40.0	41.7	43.3	44.9	46.6
	300,000	64.7	21.3	43.4	45.5	47.6	49.8	51.9	54.0
75%	50,000	41.1	12.0	29.1	30.3	31.5	32.7	33.9	35.1
	70,000	45.9	12.9	33.0	34.3	35.6	36.9	38.2	39.5
	90,000	49.5	14.2	35.3	36.7	38.2	39.6	41.0	42.4
	100,000	51.0	14.8	36.2	37.7	39.2	40.7	42.1	43.6
	150,000	56.8	17.2	39.6	41.3	43.0	44.8	46.5	48.2
	300,000	66.7	22.4	44.3	46.5	48.8	51.0	53.2	55.5
95%	50,000	44.1	13.8	30.3	31.6	33.0	34.4	35.8	37.2
	70,000	48.9	13.8	35.1	36.4	37.8	39.2	40.6	42.0
	90,000	52.4	15.2	37.2	38.8	40.3	41.8	43.3	44.8
	100,000	53.9	15.8	38.1	39.7	41.3	42.9	44.5	46.0
	150,000	59.7	18.5	41.2	43.1	44.9	46.8	48.6	50.5
	300,000	69.6	24.0	45.6	48.0	50.4	52.8	55.2	57.6

Table15 RORO ship: Height above surface (H_{st}) corresponding to draft factor (β)

Coverage rate	GT (t)	H_{kt} (m)	d (m)	$H_{st}=H_{kt}-\beta d$ (m)				
				β=1.0	β=0.95	β=0.9	β=0.85	β=0.8
50%	3,000	28.5	3.9	24.6	24.8	25.0	25.2	25.4
	5,000	32.4	4.7	27.7	28.0	28.2	28.4	28.7
	10,000	37.7	5.9	31.8	32.1	32.4	32.7	33.0
	20,000	42.9	7.4	35.5	35.9	36.3	36.7	37.0
	40,000	48.2	9.5	38.7	39.2	39.7	40.1	40.6
	60,000	51.3	9.5	41.8	42.3	42.7	43.2	43.7
75%	3,000	31.7	4.6	27.1	27.4	27.6	27.8	28.1
	5,000	35.6	5.5	30.1	30.4	30.7	30.9	31.2
	10,000	40.9	6.9	34.0	34.3	34.7	35.0	35.4
	20,000	46.1	8.7	37.4	37.9	38.3	38.7	39.2
	40,000	51.4	9.7	41.7	42.2	42.7	43.1	43.6
	60,000	54.5	9.7	44.8	45.3	45.7	46.2	46.7
95%	3,000	36.3	5.9	30.4	30.7	31.0	31.3	31.6
	5,000	40.2	7.0	33.2	33.6	33.9	34.3	34.6
	10,000	45.5	8.8	36.7	37.1	37.6	38.0	38.4
	20,000	50.7	11.0	39.7	40.3	40.8	41.4	41.9
	40,000	56.0	9.9	46.1	46.6	47.1	47.6	48.1
	60,000	59.1	9.9	49.2	49.7	50.2	50.7	51.1

Table16 PCC: Height above surface (H_{st}) corresponding to draft factor (β)

Coverage rate	GT (t)	H_{kt} (m)	d (m)	$H_{st}=H_{kt}-\beta d$ (m)				
				β=1.0	β=0.95	β=0.9	β=0.85	β=0.8
50%	3,000	26.9	4.2	22.7	23.0	23.2	23.4	23.6
	5,000	30.8	4.8	26.0	26.2	26.5	26.7	27.0
	12,000	37.4	6.1	31.3	31.6	31.9	32.3	32.6
	20,000	41.3	7.1	34.2	34.6	34.9	35.3	35.6
	30,000	44.4	7.9	36.5	36.9	37.3	37.7	38.1
	40,000	46.5	8.8	37.7	38.2	38.6	39.1	39.5
	60,000	49.6	9.9	39.7	40.2	40.7	41.2	41.7
75%	3,000	29.6	4.7	24.9	25.2	25.4	25.6	25.9
	5,000	33.5	5.4	28.1	28.4	28.6	28.9	29.2
	12,000	40.1	6.8	33.3	33.7	34.0	34.3	34.7
	20,000	44.0	7.9	36.1	36.5	36.9	37.3	37.7
	30,000	47.0	8.8	38.2	38.7	39.1	39.6	40.0
	40,000	49.2	9.3	39.9	40.4	40.9	41.3	41.8
	60,000	52.3	10.4	41.9	42.4	42.9	43.4	44.0
95%	3,000	33.5	5.5	28.0	28.3	28.5	28.8	29.1
	5,000	37.3	6.4	30.9	31.3	31.6	31.9	32.2
	12,000	44.0	8.1	35.9	36.3	36.7	37.1	37.5
	20,000	47.8	9.3	38.5	39.0	39.5	39.9	40.4
	30,000	50.9	10.4	40.5	41.0	41.5	42.1	42.6
	40,000	53.1	10.0	43.1	43.6	44.1	44.6	45.1
	60,000	56.2	11.2	45.0	45.5	46.1	46.6	47.2

Table17 LPG ship: Height above surface (H_{st}) corresponding to draft factor (β)

Coverage rate	GT (t)	H_{kt} (m)	d (m)	$H_{st}=H_{kt}-\beta d$ (m)				
				β=1.0	β=0.95	β=0.9	β=0.85	β=0.8
50%	3,000	29.8	5.7	24.1	24.4	24.7	25.0	25.2
	5,000	33.5	6.6	26.9	27.2	27.5	27.8	28.2
	10,000	38.4	8.0	30.4	30.8	31.2	31.6	32.0
	20,000	43.4	9.7	33.7	34.1	34.6	35.1	35.6
	30,000	46.3	10.9	35.4	35.9	36.4	37.0	37.5
	40,000	48.3	11.9	36.4	37.0	37.6	38.2	38.8
	50,000	49.9	12.6	37.3	37.9	38.6	39.2	39.8
75%	3,000	31.2	6.3	24.9	25.3	25.6	25.9	26.2
	5,000	34.9	7.3	27.6	28.0	28.3	28.7	29.0
	10,000	39.8	8.9	30.9	31.4	31.8	32.3	32.7
	20,000	44.8	10.8	34.0	34.5	35.1	35.6	36.2
	30,000	47.7	12.1	35.6	36.2	36.8	37.4	38.0
	40,000	49.8	13.1	36.7	37.3	38.0	38.6	39.3
	60,000	51.3	14.0	37.3	38.0	38.7	39.4	40.1
95%	3,000	33.3	7.3	26.0	26.4	26.7	27.1	27.5
	5,000	37.0	8.4	28.6	29.0	29.4	29.8	30.2
	10,000	41.9	10.3	31.6	32.1	32.6	33.2	33.7
	20,000	46.9	12.5	34.4	35.0	35.6	36.2	36.9
	30,000	49.8	14.0	35.8	36.5	37.2	37.9	38.6
	40,000	51.8	15.2	36.6	37.4	38.1	38.9	39.7
	60,000	53.4	16.2	37.2	38.0	38.8	39.6	40.5

Table18 LNG ship: Height above surface (H_{st}) corresponding to draft factor (β)

Coverage rate	GT (t)	H_{kt} (m)	d (m)	$H_{st}=H_{kt}-\beta d$ (m)				
				β=1.0	β=0.95	β=0.9	β=0.85	β=0.8
50%	80,000	54.0	11.0	43.0	43.5	44.1	44.6	45.2
	100,000	60.9	11.6	49.3	49.9	50.5	51.1	51.7
	120,000	66.6	12.1	54.5	55.1	55.7	56.3	56.9
75%	80,000	58.3	11.5	46.8	47.4	48.0	48.5	49.1
	100,000	65.2	12.1	53.1	53.8	54.4	55.0	55.6
	120,000	70.9	12.6	58.3	58.9	59.6	60.2	60.8
95%	80,000	64.5	12.3	52.2	52.8	53.5	54.1	54.7
	100,000	71.5	13.0	58.5	59.1	59.8	60.4	61.1
	120,000	77.1	13.5	63.6	64.3	65.0	65.7	66.3

Table19 Passenger ship: Height above surface (H_{st}) corresponding to draft factor (β)

Coverage rate	GT (t)	H_{kt} (m)	d (m)	$H_{st}=H_{kt}-\beta d$ (m)				
				β=1.0	β=0.95	β=0.9	β=0.85	β=0.8
50%	3,000	28.2	3.4	24.8	25.0	25.1	25.3	25.5
	5,000	32.7	4.0	28.7	28.9	29.1	29.3	29.5
	10,000	38.8	5.0	33.8	34.1	34.3	34.6	34.8
	20,000	45.0	7.0	38.0	38.3	38.7	39.0	39.4
	30,000	48.6	7.0	41.6	41.9	42.3	42.6	43.0
	50,000	53.1	7.0	46.1	46.4	46.8	47.1	47.5
	70,000	56.1	8.0	48.1	48.5	48.9	49.3	49.7
	100,000	59.2	8.0	51.2	51.6	52.0	52.4	52.8
75%	3,000	32.4	4.3	28.1	28.3	28.5	28.7	29.0
	5,000	36.9	5.0	31.9	32.2	32.4	32.7	32.9
	10,000	43.1	6.4	36.7	37.0	37.3	37.6	37.9
	20,000	49.2	7.8	41.4	41.8	42.2	42.6	42.9
	30,000	52.8	7.8	45.0	45.4	45.8	46.1	46.5
	50,000	57.3	7.8	49.5	49.9	50.3	50.7	51.1
	70,000	60.3	8.1	52.2	52.6	53.0	53.4	53.8
	100,000	63.4	8.1	55.3	55.7	56.1	56.5	56.9
95%	3,000	38.5	6.1	32.4	32.7	33.0	33.3	33.6
	5,000	43.0	7.2	35.8	36.1	36.5	36.9	37.2
	10,000	49.1	9.1	40.0	40.5	40.9	41.4	41.8
	20,000	55.2	8.9	46.3	46.8	47.2	47.7	48.1
	30,000	58.8	8.9	49.9	50.4	50.8	51.3	51.7
	50,000	63.4	8.9	54.5	54.9	55.3	55.8	56.2
	70,000	66.3	8.3	58.0	58.4	58.9	59.3	59.7
	100,000	69.5	8.3	61.2	61.6	62.0	62.4	62.8

6. Analysis of Height Above Surface (H_{st}) by Ship Type – 2

Chapter 5 presented a procedure for estimating height above surface (H_{st}) using the values of total height (H_{kt}) and full load draft (d), which were analyzed separately. Here, in contrast, the height above surface (Hst) in a fully-loaded condition is first calculated directly from the total height (H_{kt}) and full load draft (d) of individual ships, and the height above surface (H_{st}) is then estimated directly by applying the statistical analysis method proposed in **Ch. 3** to the data obtained in the first step.

Therefore, unification of the fundamental data was performed by IMO No. for the LRF Data, which comprises the data on total height (K_{kt}) and LMIU Data, which comprises the data on full load draft (d). The numbers of ships for which data are available on total height (K_{kt}) and full load draft (d) as the objects of this analysis are shown by ship type in **Table20**. Based on this fundamental data, fundamental data on H_{st} (= H_{kt} – d) were constructed independently.

Considering the points regarding the analysis procedure discussed in section **3.3** and the fact that the H_{st} given here is a minimum value, when this method is used practically in the design of bridges over fairways and setting of the OAS for maritime airports, a safety factor γ ($\geqq$1.0) based on the ratio of the full load draft of the design ship and the actual draft during navigation must be applied. The result of the simple H_{st} (= H_{kt} – d) here is the same concept as the results when the draft factor (β) discussed in **Ch. 5** equals 1.0. In order to compare the two, a comparison with the results when β = 1.0 is shown on the *x*-axis. Although inconsistencies can be seen in large-scale and small-scale ships with some ship types, rough agreement can be confirmed.

The following presents the results of an analysis by ship type in the same manner as in **Ch. 4**.

Table20 Number of ships for which total height (H_{kt}) and full load draft (d) data are available

Type	N of ship
Cargo Ship	568
Container Ship	304
Oil Tanker	1,140
RORO Ship	310
PCC	84
LPG Ship	357
LNG Ship	73
Passenger Ship	73

6.1 Cargo ship

A distribution diagram of the height above surface (H_{st}) data for cargo ships is shown in **Figure1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure30–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure30–3**. The results when the log expressions on the *x*-axis in **Figure30–3** are expressed as antilogs are shown in **Figure30–4**. These **Figure30–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure30–3** also shows the value of the coefficient of determination (0.721) and the coefficients of the regression equation for each coverage rate. From this **Figure 30–4**, it can be concluded that meaningful regression equations for cargo ships have been obtained.

Accordingly, based on the regression equations obtained here, the values for total height (H_{kt}) were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table21**.

The results in this **Table21** show the same concept as the results when the draft factor (β) in **Ch. 5** equals 1.0. In order to compare the two, **Figure30-5** shows the results when the draft factor (β) = 1.0 on the *x*-axis and the results in **Table21** on the *y*-axis. To clarify the distinction between the two, in contrast to the expression H_{kt} – 1.0d on the *x*-axis, the *y*-axis shows (H_{kt} – d).

Table21 Results of analysis of height above surface (H_{st}) (cargo ship)

Dead Weight Tonnage (t)	50% (m)	75% (m)	95% (m)
1,000	18.8	20.9	23.9
2,000	21.4	23.5	26.6
3,000	22.9	25.0	28.1
5,000	24.8	27.0	30.0
10,000	27.5	29.6	32.6
12,000	28.1	30.3	33.3
18,000	29.7	31.8	34.9
30,000	31.6	33.7	36.8
40,000	32.7	34.8	37.9
55,000	33.9	36.0	39.1
70,000	34.8	36.9	40.0
90,000	35.8	37.9	40.9
120,000	36.8	39.0	42.0
150,000	37.7	39.8	42.9

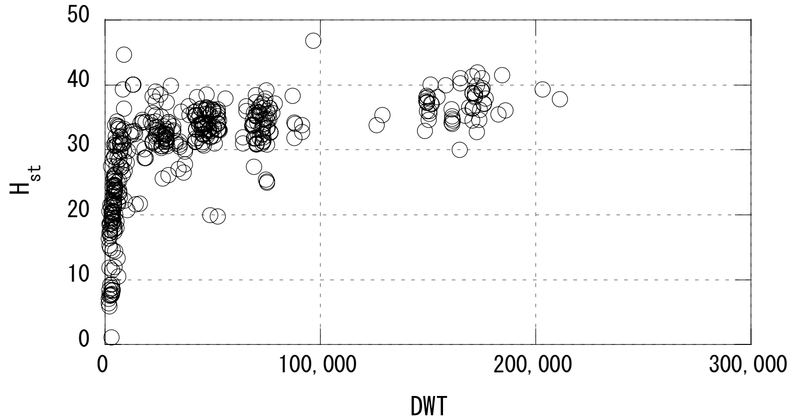


Figure30–1 Distribution of H_{st} data (cargo ship)

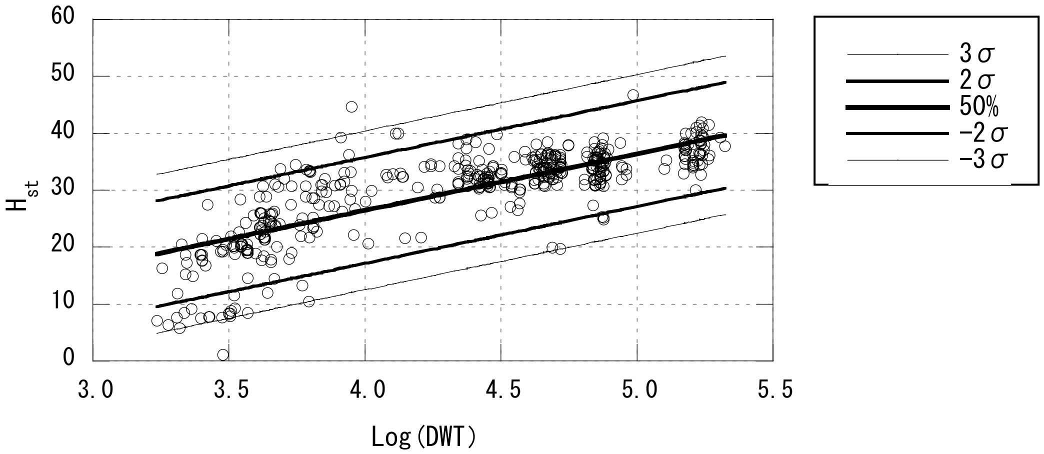
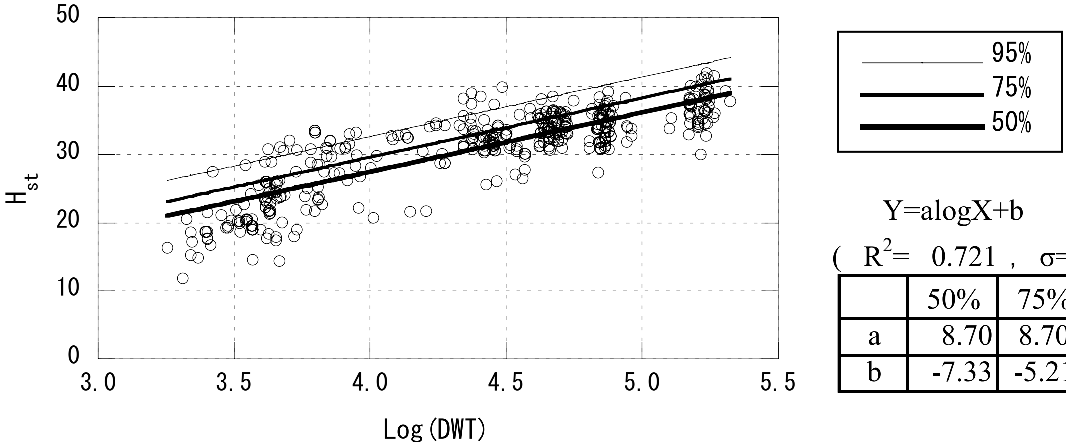


Figure30–2 H_{st} – semilog regression analysis (cargo ship)



Y=alogX+b

(R^2= 0.721 , σ= 3.149)

	50%	75%	95%
a	8.70	8.70	8.70
b	-7.33	-5.21	-2.15

Figure30–3 Results of H_{st} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (cargo ship)

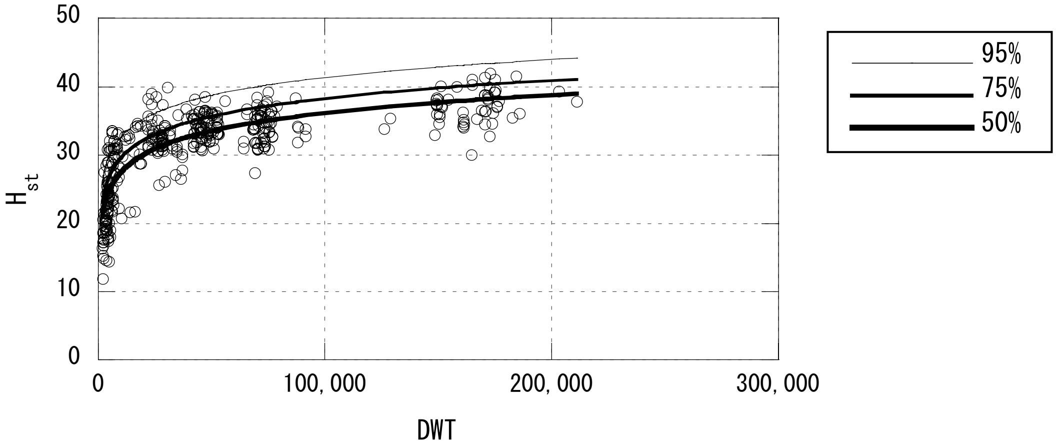


Figure30–4 Results of H_{st} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (cargo ship)

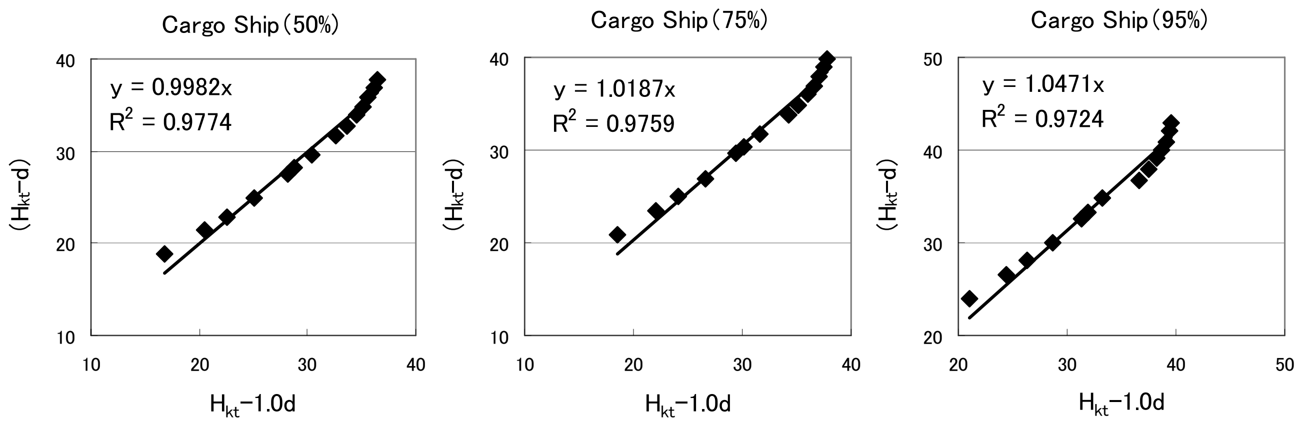


Figure30–5 Comparison with draft factor (β) = 1.0

6.2 Container ship

A distribution diagram of the height above surface (H_{st}) data for container ships is shown in **Figure31–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure31–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure31–3**. The results when the log expressions on the *x*-axis in **Figure 31–3** are expressed as antilogs are shown in **Figure31–4**. These **Figure31–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure31–3** also shows the value of the coefficient of determination (0.724) and the coefficients of the regression equation for each coverage rate. From this **Figure31–4**, it can be concluded that meaningful regression equations for container ships have been obtained.

Accordingly, based on the regression equations obtained here, the values for total height (H_{kt}) were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table22**.

The results in this **Table22** show the same concept as the results when the draft factor (β) in **Ch. 5** equals 1.0. In order to compare the two, **Figure31-5** shows the results when the draft factor (β) = 1.0 on the *x*-axis and the results in **Table22** on the *y*-axis. To clarify the distinction between the two, in contrast to the expression H_{kt} – 1.0d on the *x*-axis, the *y*-axis shows (H_{kt} – d).

Table22 Results of analysis of height above surface (H_{st}) (container ship)

Dead Weight Tonnage (t)	50% (m)	75% (m)	95% (m)
10,000	32.6	34.5	37.4
20,000	36.7	38.7	41.5
30,000	39.1	41.1	43.9
40,000	40.8	42.8	45.6
50,000	42.1	44.1	47.0
60,000	43.2	45.2	48.0
100,000	46.2	48.2	51.1

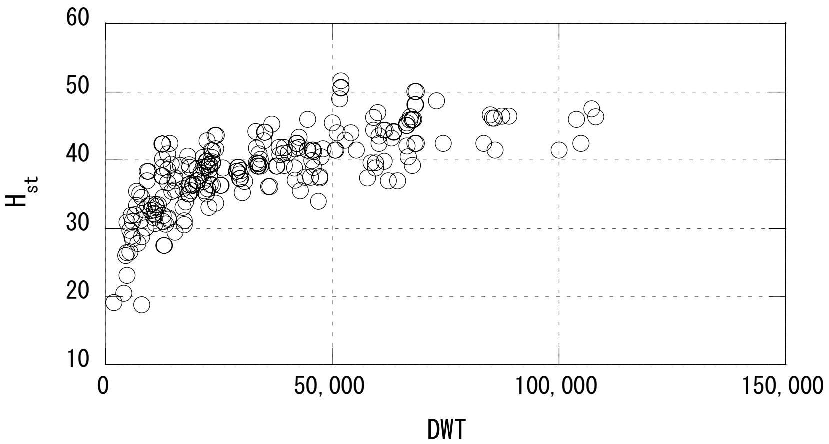


Figure31–1 Distribution of H_{st} data (container ship)

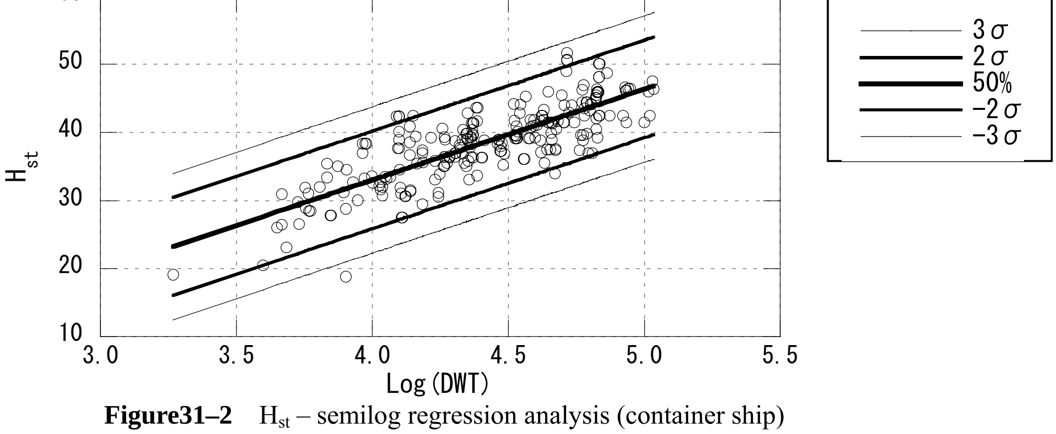
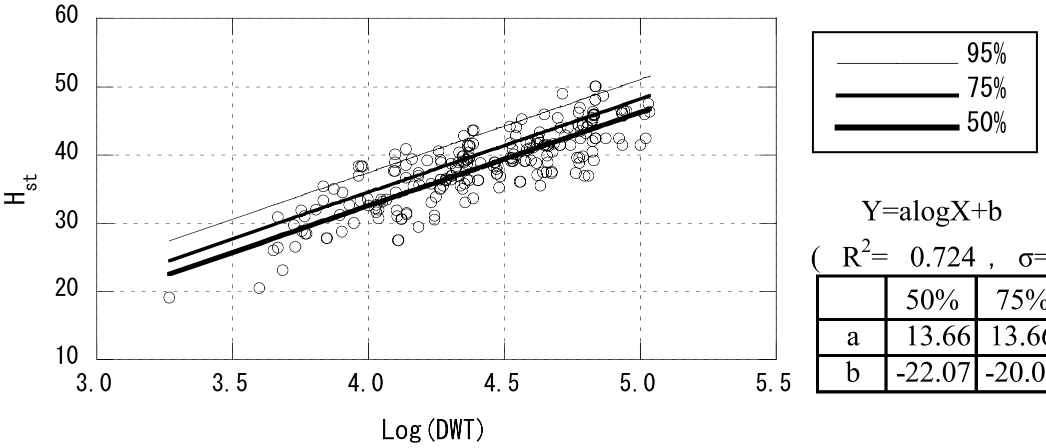


Figure31–2 H_{st} – semilog regression analysis (container ship)



Y=alogX+b

(R^2= 0.724 , σ= 2.949)

	50%	75%	95%
a	13.66	13.66	13.66
b	-22.07	-20.08	-17.22

Figure31–3 Results of H_{st} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (container ship)

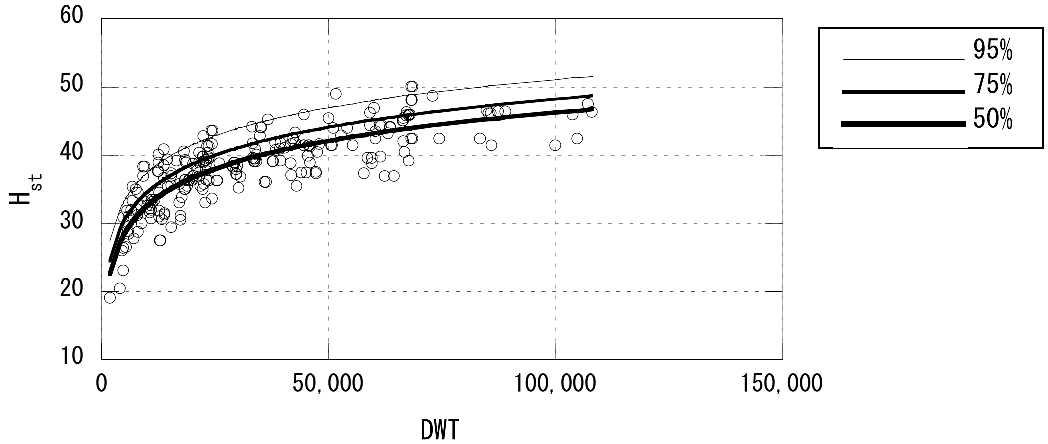


Figure31–4 Results of H_{st} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (container ship)

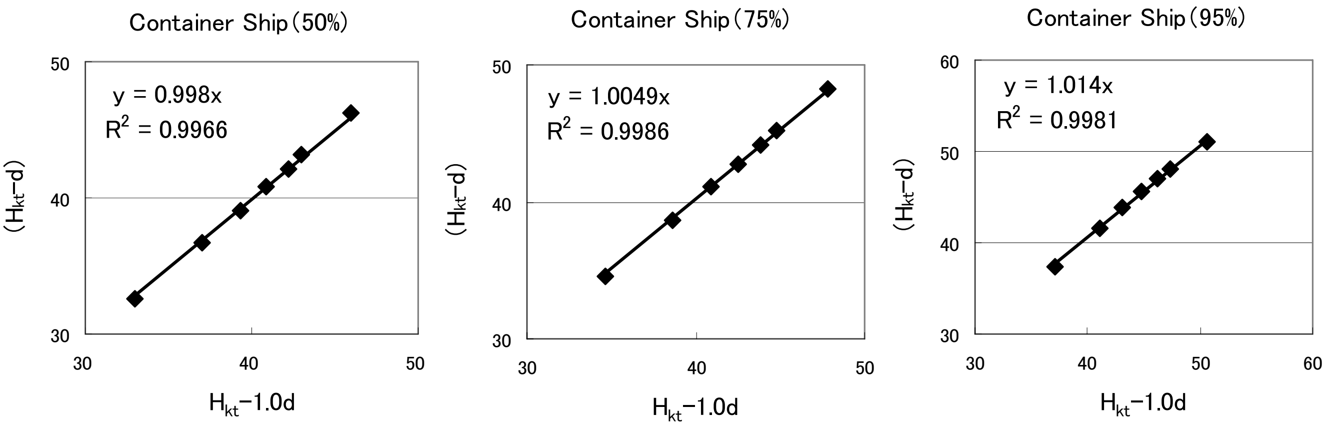


Figure31–5 Comparison with draft factor (β) = 1.0

6.3 Oil tanker

A distribution diagram of the height above surface (H_{st}) data for oil tankers is shown in **Figure32–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure32–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure32–3**. The results when the log expressions on the *x*-axis in **Figure 32–3** are expressed as antilogs are shown in **Figure32–4**. These **Figure32–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure32–3** also shows the value of the coefficient of determination (0.673) and the coefficients of the regression equation for each coverage rate. From this **Figure32–4**, it can be concluded that meaningful regression equations for oil tankers have been obtained.

Accordingly, based on the regression equations obtained here, the values for total height (H_{kt}) were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table23**.

The results in this **Table23** show the same concept as the results when the draft factor (β) in **Ch. 5** equals 1.0. In order to compare the two, **Figure32-5** shows the results when the draft factor (β) = 1.0 on the *x*-axis and the results in **Table23** on the *y*-axis. To clarify the distinction between the two, in contrast to the expression H_{kt} – 1.0d on the *x*-axis, the *y*-axis shows (H_{kt} – d).

Table23 Results of analysis of height above surface (H_{st}) (oil tanker)

Dead Weight Tonnage (t)	50% (m)	75% (m)	95% (m)
50,000	29.3	31.2	34.0
70,000	32.0	33.9	36.6
90,000	33.9	35.8	38.6
100,000	34.7	36.6	39.4
150,000	37.9	39.8	42.6
300,000	43.4	45.3	48.0

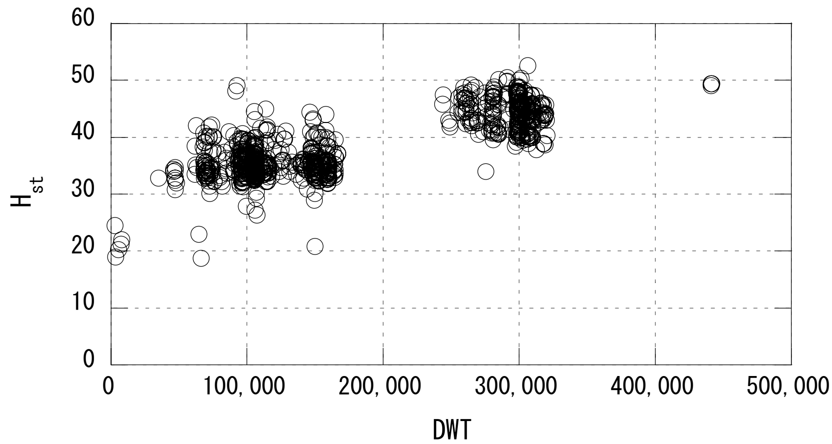


Figure32–1 Distribution of H_{st} data (oil tanker)

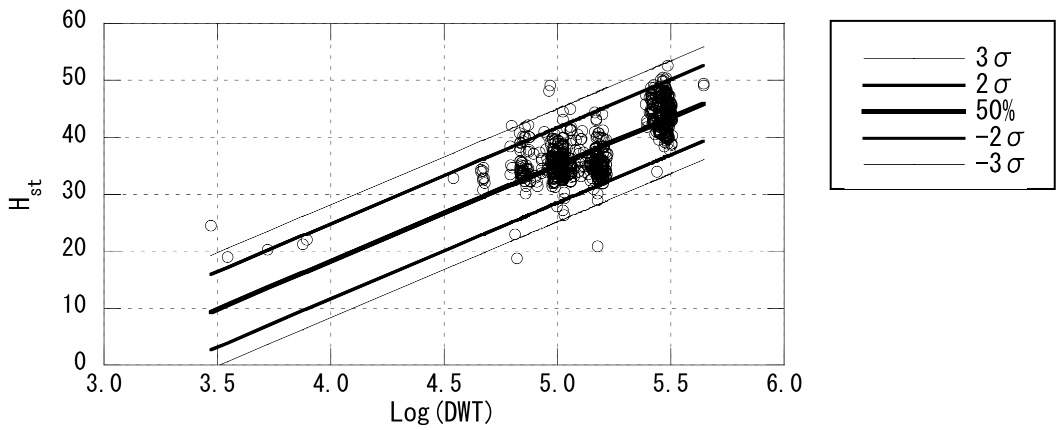
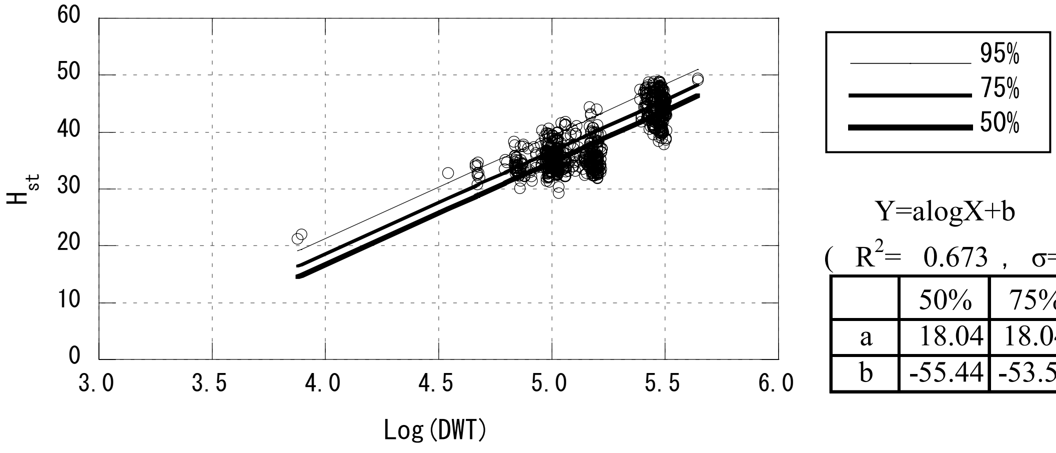


Figure32–2 H_{st} – semilog regression analysis (oil tanker)



Y=alogX+b

(R^2= 0.673 , σ= 2.817)

	50%	75%	95%
a	18.04	18.04	18.04
b	-55.44	-53.54	-50.81

Figure32–3 Results of H_{st} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (oil tanker)

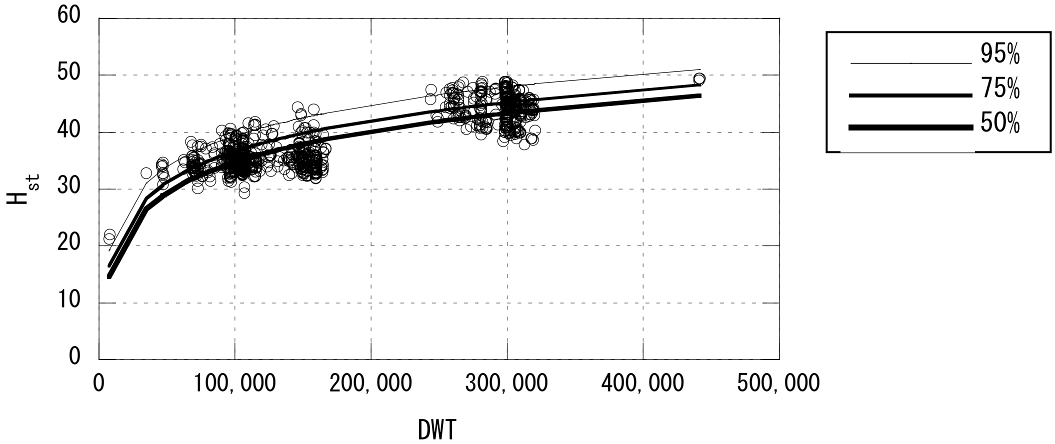


Figure32–4 Results of H_{st} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (oil tanker)

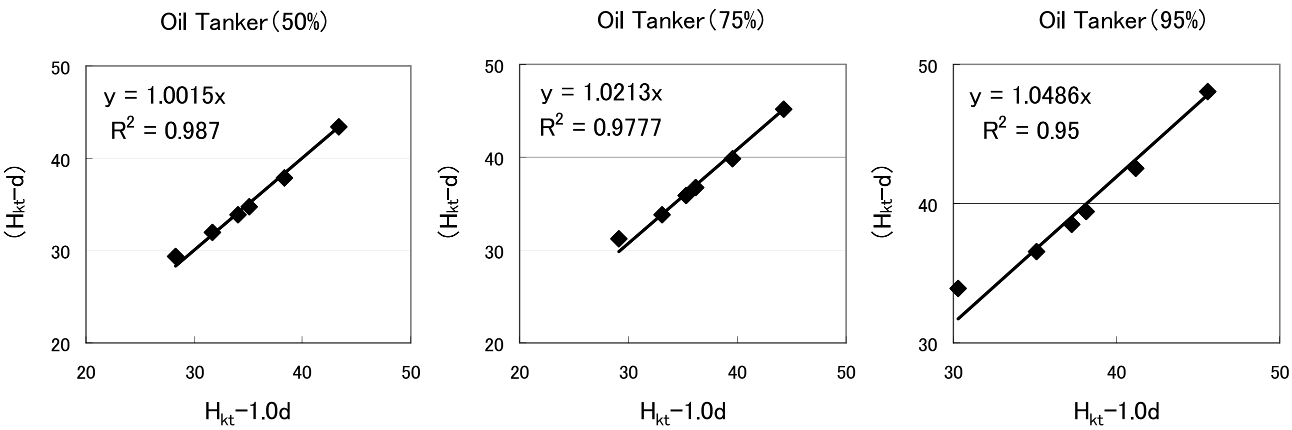


Figure32–5 Comparison with draft factor (β) = 1.0

6.4 RORO ship

A distribution diagram of the height above surface (H_{st}) data for RORO ships is shown in **Figure.33–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure33–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure33–3**. The results when the log expressions on the *x*-axis in **Figure33–3** are expressed as antilogs are shown in **Figure33–4**. These **Figure33–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure33–3** also shows the value of the coefficient of determination (0.725) and the coefficients of the regression equation for each coverage rate. From this **Figure33–4**, it can be concluded that meaningful regression equations for RORO ships have been obtained.

Accordingly, based on the regression equations obtained here, the values for total height (H_{kt}) were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table24**.

The results in this **Table24** show the same concept as the results when the draft factor (β) in **Ch. 5** equals 1.0. In order to compare the two, **Figure33-5** shows the results when the draft factor (β) = 1.0 on the *x*-axis and the results in **Table24** on the *y*-axis. To clarify the distinction between the two, in contrast to the expression H_{kt} – 1.0d on the *x*-axis, the *y*-axis shows (H_{kt} – d).

Table24 Results of analysis of height above surface (H_{st}) (RORO ship)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
3,000	23.7	26.6	30.9
5,000	26.7	29.7	33.9
10,000	30.8	33.7	38.0
20,000	34.9	37.8	42.1
40,000	39.0	41.9	46.2
60,000	41.4	44.3	48.6

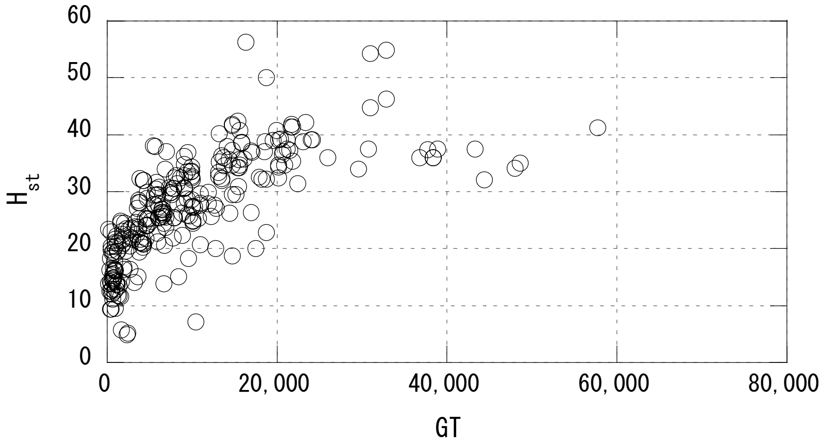


Figure33–1 Distribution of H_{st} data (RORO ship)

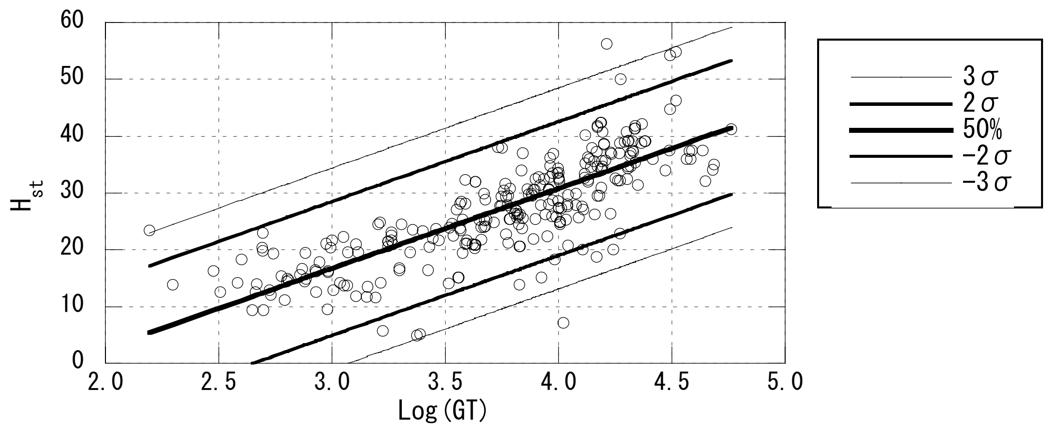
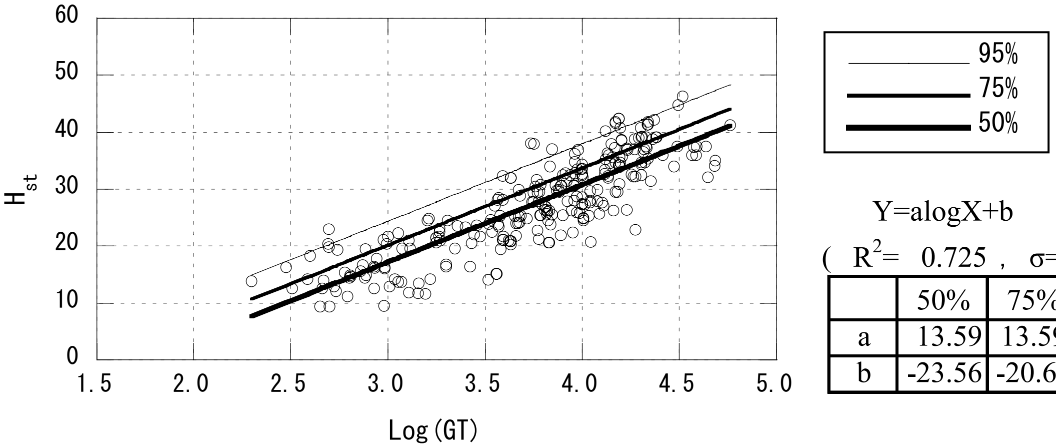


Figure33–2 H_{st} – semilog regression analysis (RORO ship)



Y=alogX+b

(R^2= 0.725 , σ= 4.374)

	50%	75%	95%
a	13.59	13.59	13.59
b	-23.56	-20.62	-16.37

Figure33–3 Results of H_{st} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (RORO ship)

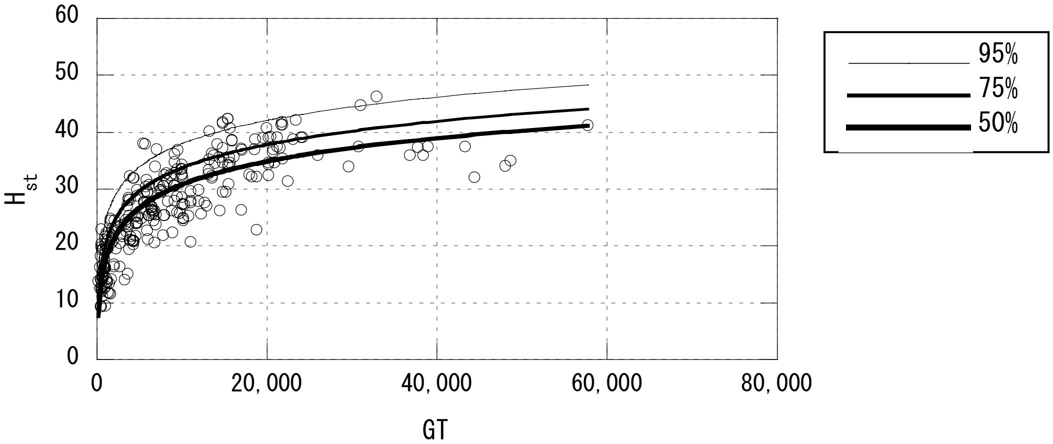


Figure33–4 Results of H_{st} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (RORO ship)

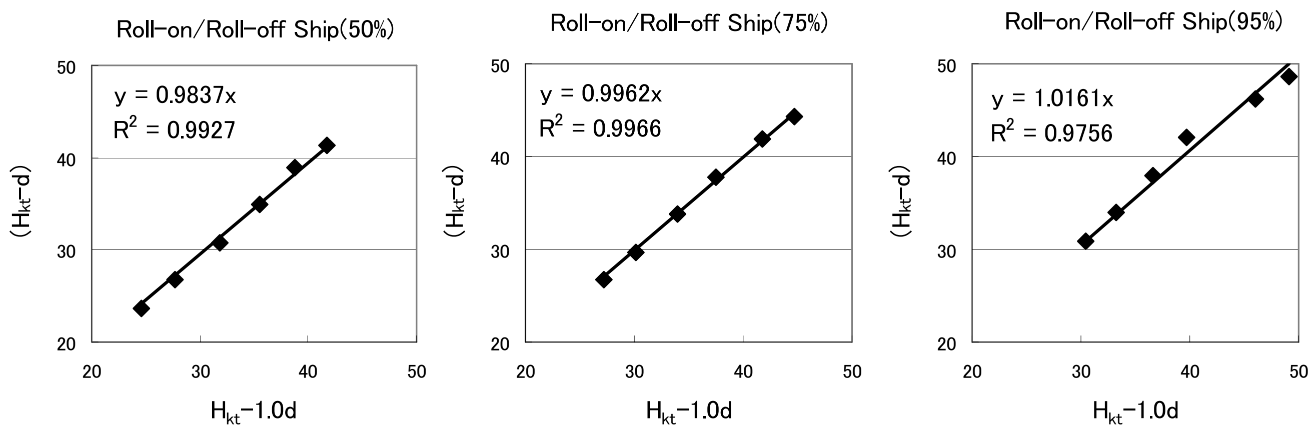


Figure33–5 Comparison with draft factor (β) = 1.0

6.5 PCC

A distribution diagram of the height above surface (H_{st}) data for PCC ships is shown in **Figure34–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure34–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure34–3**. The results when the log expressions on the *x*-axis in **Figure34–3** are expressed as antilogs are shown in **Figure34–4**. These **Figure34–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure34–3** also shows the value of the coefficient of determination (0.573) and the coefficients of the regression equation for each coverage rate. From this **Figure34–4**, it can be concluded that meaningful regression equations for PCC ships have been obtained.

Accordingly, based on the regression equations obtained here, the values for total height (H_{kt}) were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table25**.

The results in this **Table25** show the same concept as the results when the draft factor (β) in **Ch. 5** equals 1.0. In order to compare the two, **Figure34-5** shows the results when the draft factor (β) = 1.0 on the *x*-axis and the results in **Table25** on the *y*-axis. To clarify the distinction between the two, in contrast to the expression H_{kt} –1.0d on the *x*-axis, the *y*-axis shows (H_{kt} – d).

Table25 Results of analysis of height above surface (H_{st}) (PCC)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
3,000	24.0	26.5	30.2
5,000	26.6	29.2	32.9
12,000	31.1	33.7	37.4
20,000	33.7	36.3	40.0
30,000	35.8	38.4	42.1
40,000	37.3	39.8	43.5
60,000	39.4	41.9	45.6

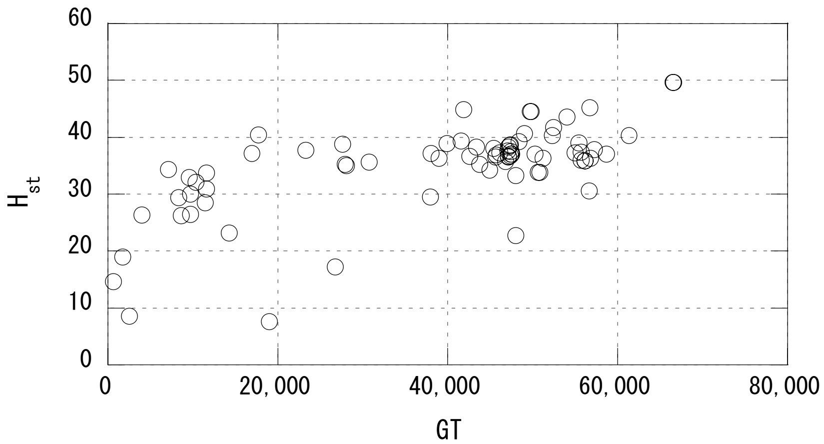


Figure34–1 Distribution of H_{st} data (PCC)

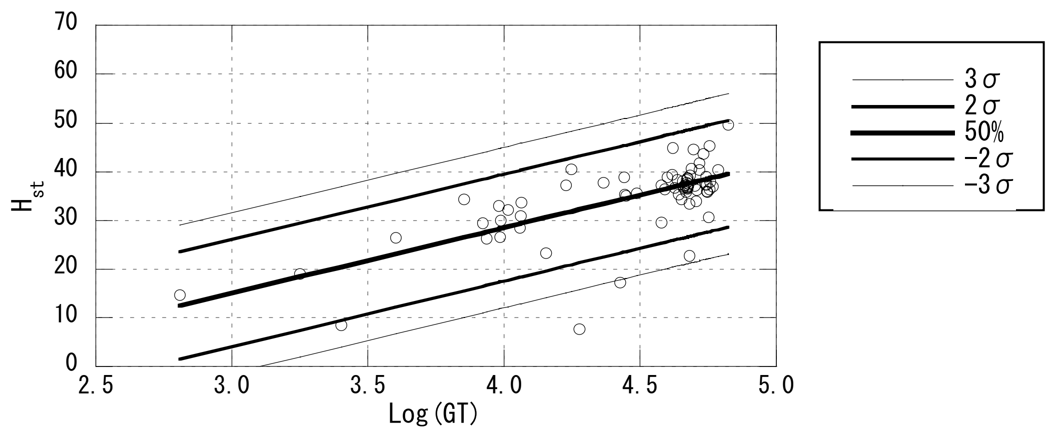
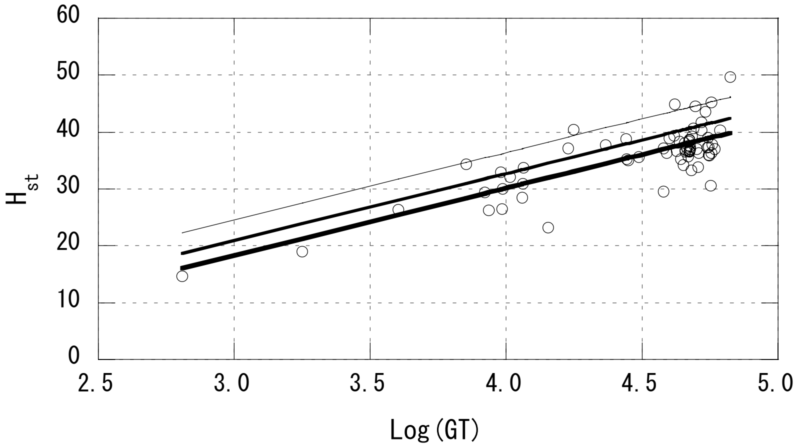


Figure34–2 H_{st} – semilog regression analysis (PCC)



Y=alogX+b

(R^2= 0.573 , σ= 3.801)

	50%	75%	95%
a	11.82	11.82	11.82
b	-17.11	-14.55	-10.86

Figure34–3 Results of H_{st} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (PCC)

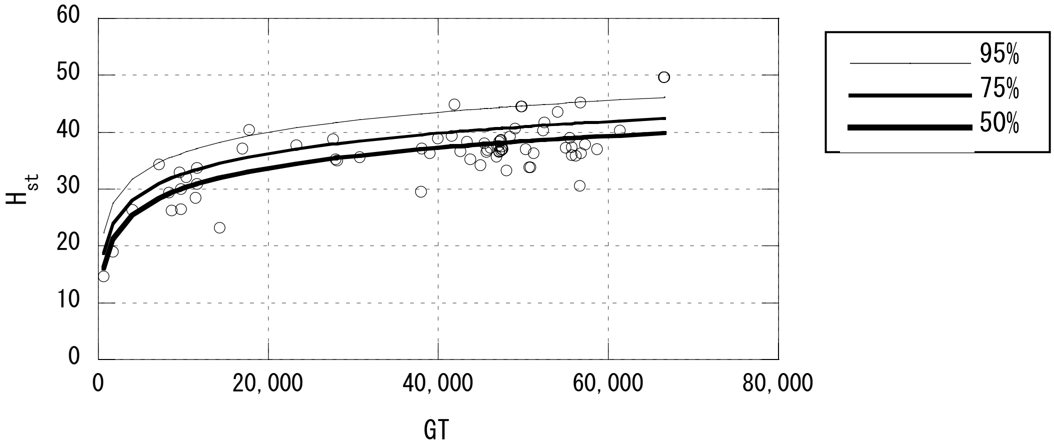


Figure34–4 Results of H_{st} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (PCC)

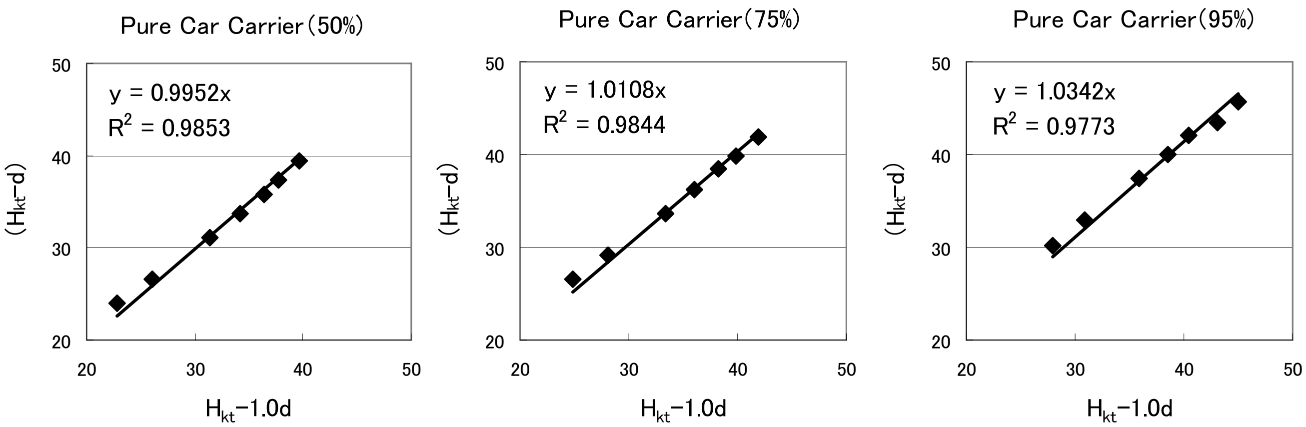


Figure34–5 Comparison with draft factor (β) = 1.0

6.6 LPG ship

A distribution diagram of the height above surface (H_{st}) data for LPG ships is shown in **Figure35–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure35–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure35–3**. The results when the log expressions on the *x*-axis in **Figure35–3** are expressed as antilogs are shown in **Figure35–4**. These **Figure35–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure35–3** also shows the value of the coefficient of determination (0.878) and the coefficients of the regression equation for each coverage rate. From this **Figure35–4**, it can be concluded that meaningful regression equations for LPG ships have been obtained.

Accordingly, based on the regression equations obtained here, the values for total height (H_{kt}) were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table26**.

The results in this **Table26** show the same concept as the results when the draft factor (β) in **Ch. 5** equals 1.0. In order to compare the two, **Figure35-5** shows the results when the draft factor (β) = 1.0 on the *x*-axis and the results in **Table26** on the *y*-axis. To clarify the distinction between the two, in contrast to the expression H_{kt} – 1.0d on the *x*-axis, the *y*-axis shows (H_{kt} – d).

Table26 Results of analysis of height above surface (H_{st}) (LPG ship)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
3,000	24.4	25.7	27.6
5,000	26.8	28.2	30.1
10,000	30.2	31.6	33.5
20,000	33.6	34.9	36.9
30,000	35.6	36.9	38.8
40,000	37.0	38.3	40.2
50,000	38.0	39.4	41.3

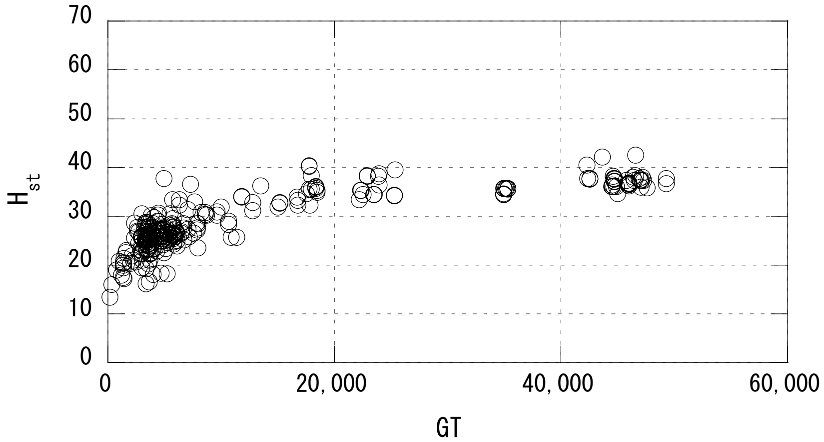


Figure35–1 Distribution of H_{st} data (LPG ship)

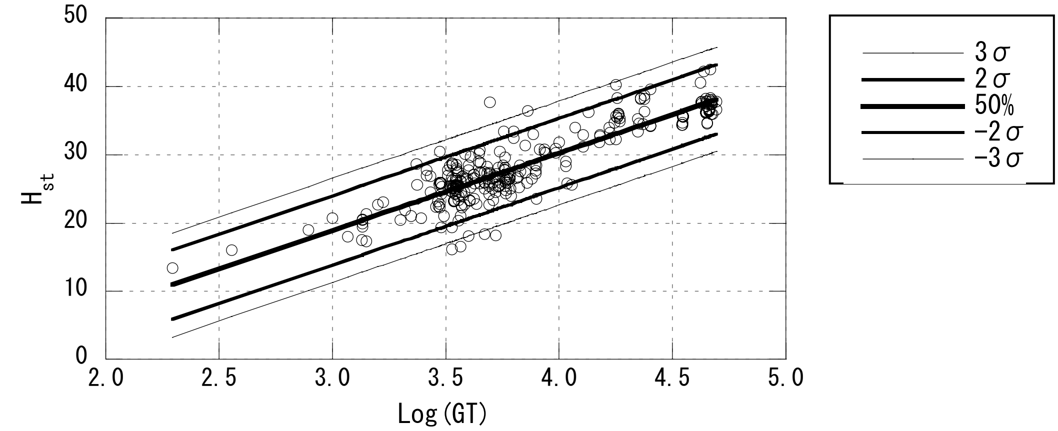
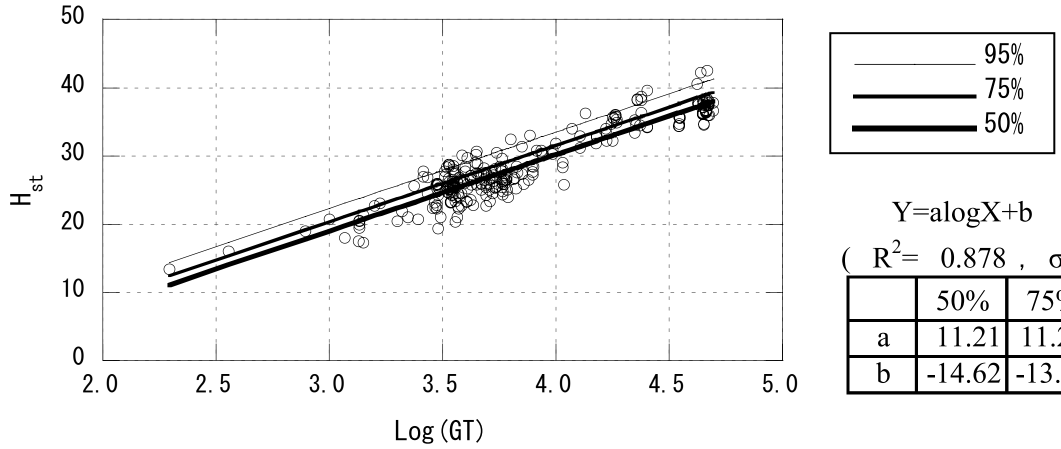


Figure35–2 H_{st} – semilog regression analysis (LPG ship)



Y=alogX+b

(R^2= 0.878 , σ= 1.994)

	50%	75%	95%
a	11.21	11.21	11.21
b	-14.62	-13.27	-11.34

Figure35–3 Results of H_{st} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (LPG ship)

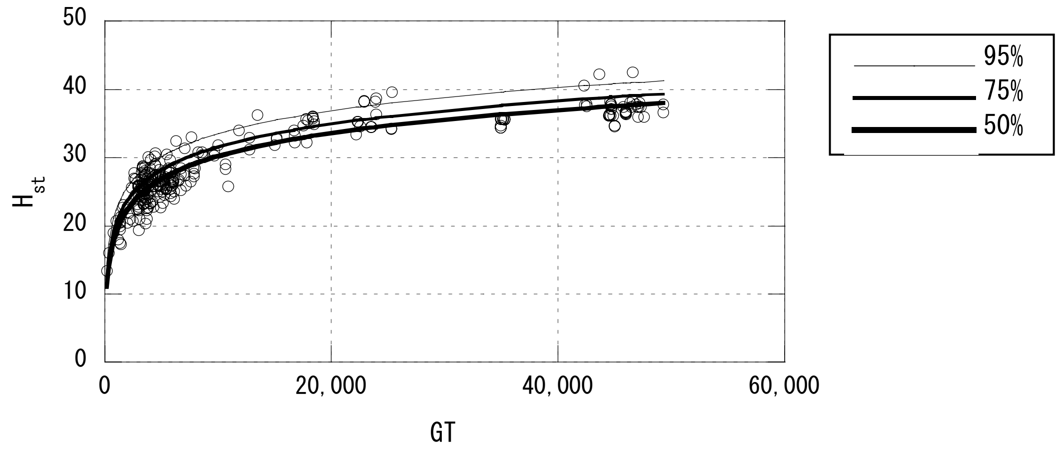


Figure35–4 Results of H_{st} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (LPG ship)

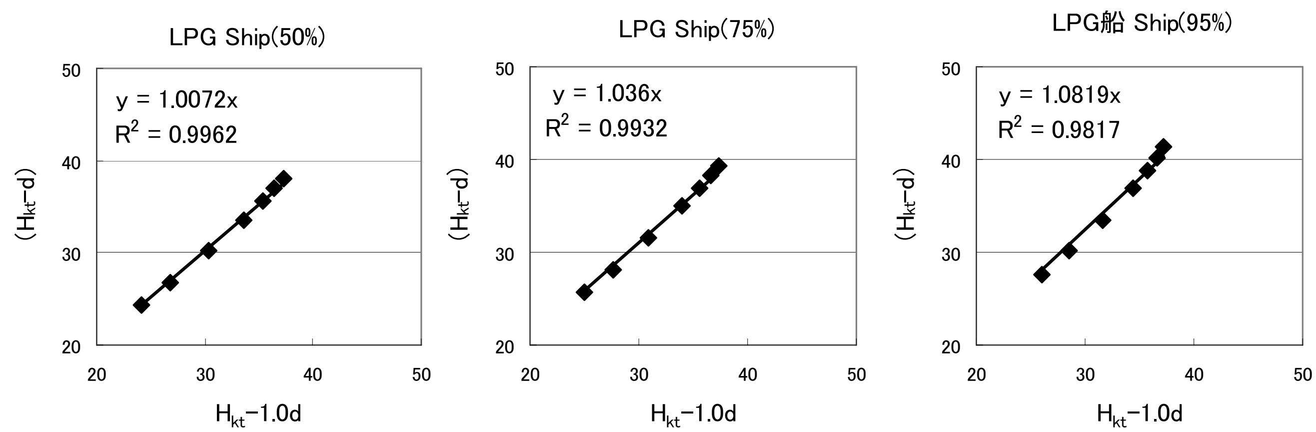


Figure35–5 Comparison with draft factor (β) = 1.0

6.7 LNG ship

A distribution diagram of the height above surface (H_{st}) data for LNG ships is shown in **Figure36–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure36–2**. It may be noted that ships of 50,000GT and less were excluded due to the small number of data. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure36–3**. The results when the log expressions on the *x*-axis in **Figure36–3** are expressed as antilogs are shown in **Figure36–4**. These **Figure36–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure36–3** also shows the value of the coefficient of determination (0.192) and the coefficients of the regression equation for each coverage rate. In spite of the fact that the coefficient of determination is low here, unlike that for the other ship types, it is thought that these results reflect the special characteristics of this region.

Accordingly, based on the regression equations obtained here, the values for total height (H_{kt}) were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table27**.

The results in this **Table27** show the same concept as the results when the draft factor (β) in **Ch. 5** equals 1.0. In order to compare the two, **Figure36-5** shows the results when the draft factor (β) = 1.0 on the *x*-axis and the results in **Table27** on the *y*-axis. To clarify the distinction between the two, in contrast to the expression H_{kt} – 1.0d on the *x*-axis, the *y*-axis shows (H_{kt} – d).

Table27 Results of analysis of height above surface (H_{st}) (LNG ship)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
80,000	42.3	46.6	52.8
100,000	49.4	53.7	59.9
120,000	55.2	59.5	65.7

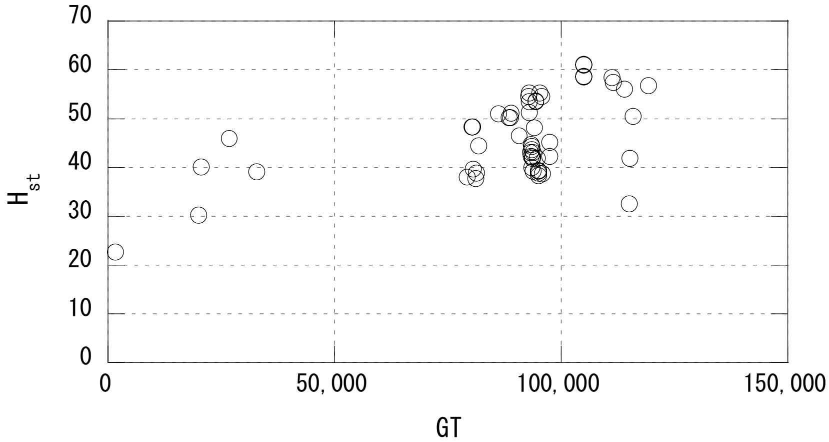


Figure36–1 Distribution of H_{st} data (LNG ship)

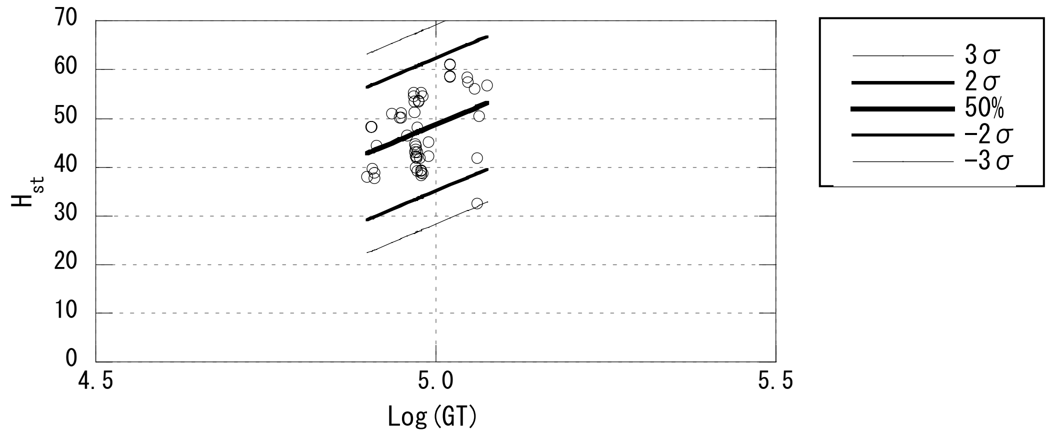
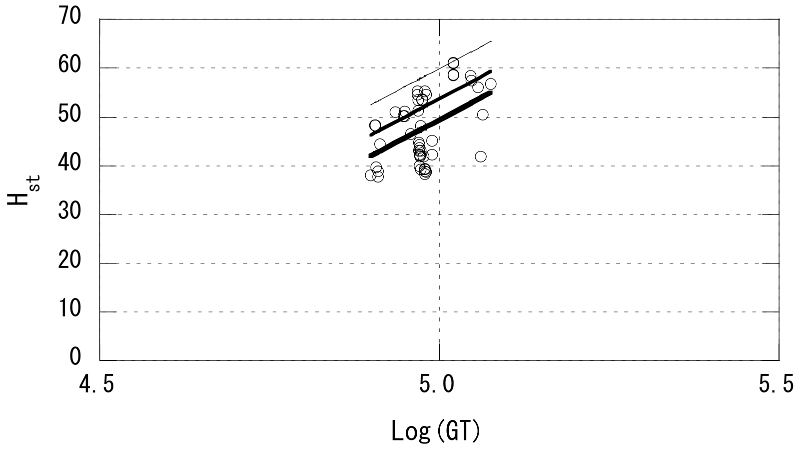


Figure36–2 H_{st} – semilog regression analysis (LNG ship)



Y=alogX+b

(R^2= 0.192 , σ= 6.374)

	50%	75%	95%
a	73.37	73.37	73.37
b	-317.44	-313.14	-306.95

Figure36–3 Results of H_{st} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (LNG ship)

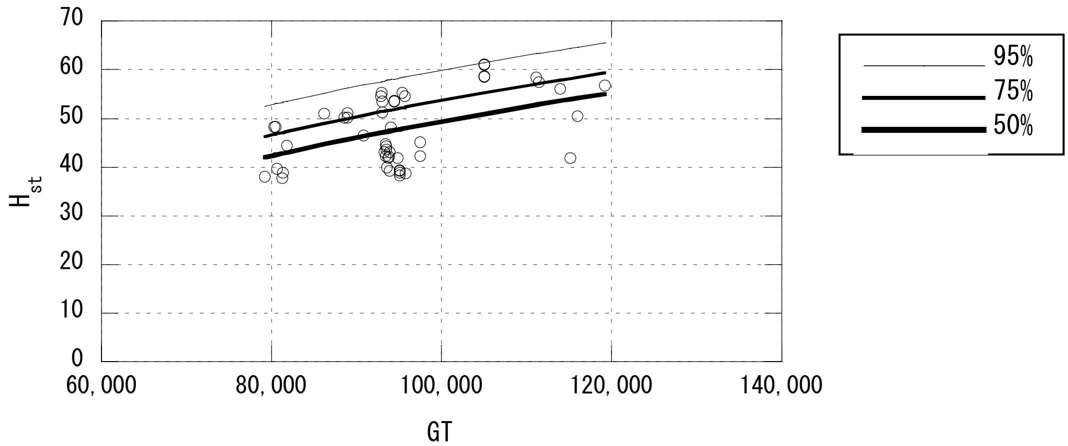


Figure36–4 Results of H_{st} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (LNG ship)

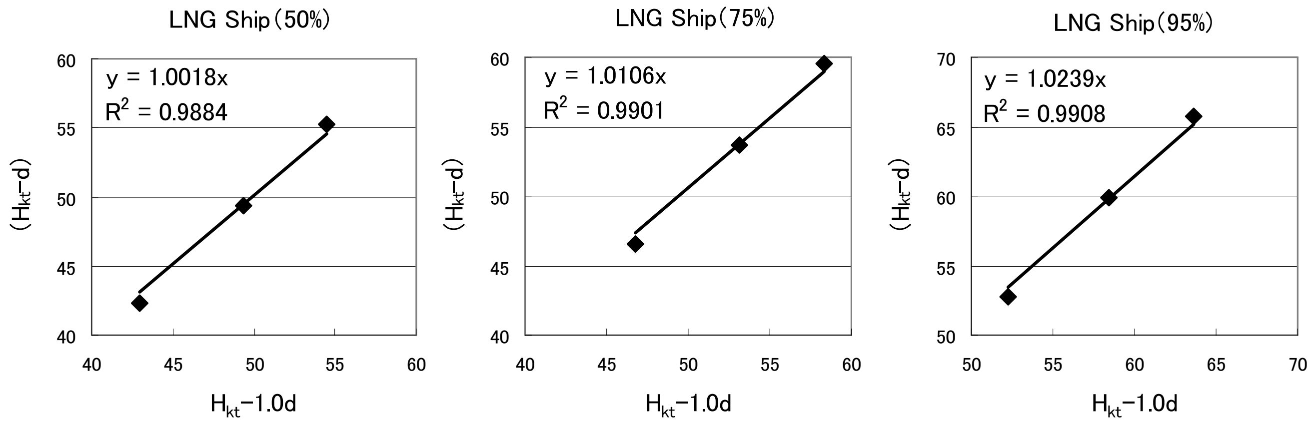


Figure36–5 Comparison with draft factor (β) = 1.0

6.8 Passenger ship

A distribution diagram of the height above surface (H_{st}) data for passenger ships is shown in **Figure37–1**. Next, the results of a semilog regression analysis to exclude the data for the region exceeding ±2σ are shown in **Figure37–2**. The results of a regression analysis obtained by applying the semilog regression analysis method to the data being analyzed after excluding the region exceeding ±2 σ are shown in **Figure37–3**. The results when the log expressions on the *x*-axis in **Figure37–3** are expressed as antilogs are shown in **Figure37–4**. These **Figure37–3, –4** show the results of regression equations for coverage rates of 50%, 75%, and 95%, and **Figure37–3** also shows the value of the coefficient of determination (0.678) and the coefficients of the regression equation for each coverage rate. From this **Figure37–4**, it can be concluded that meaningful regression equations for passenger ships have been obtained.

Accordingly, based on the regression equations obtained here, the values for total height (H_{kt}) were calculated for coverage rates of 50%, 75%, and 95%, corresponding to ship classes set in the same manner as in the "Technical Standards." The results are shown in **Table28**.

The results in this **Table28** show the same concept as the results when the draft factor (β) in **Ch. 5** equals 1.0. In order to compare the two, **Figure37-5** shows the results when the draft factor (β) = 1.0 on the *x*-axis and the results in **Table28** on the *y*-axis. To clarify the distinction between the two, in contrast to the expression H_{kt} – 1.0d on the *x*-axis, the *y*-axis shows (H_{kt} – d).

Table28 Results of analysis of height above surface (H_{st}) (passenger ship)

Gross Tonnage (t)	50% (m)	75% (m)	95% (m)
3,000	25.7	30.3	37.0
5,000	29.2	33.9	40.5
10,000	34.0	38.6	45.3
20,000	38.8	43.4	50.0
30,000	41.6	46.2	52.8
50,000	45.1	49.7	56.3
70,000	47.4	52.0	58.6
100,000	49.8	54.5	61.1

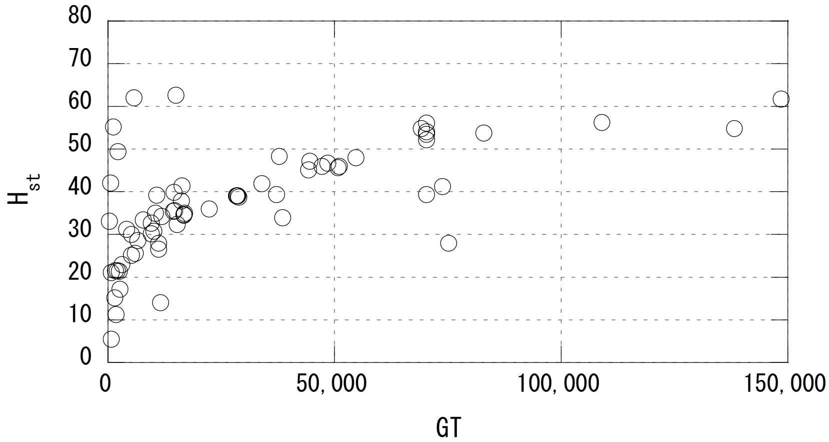


Figure37–1 Distribution of H_{st} data (passenger ship)

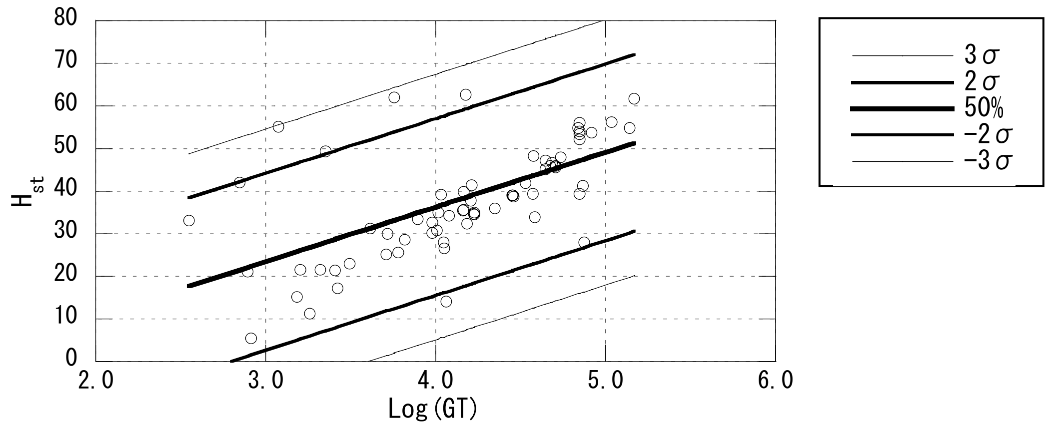
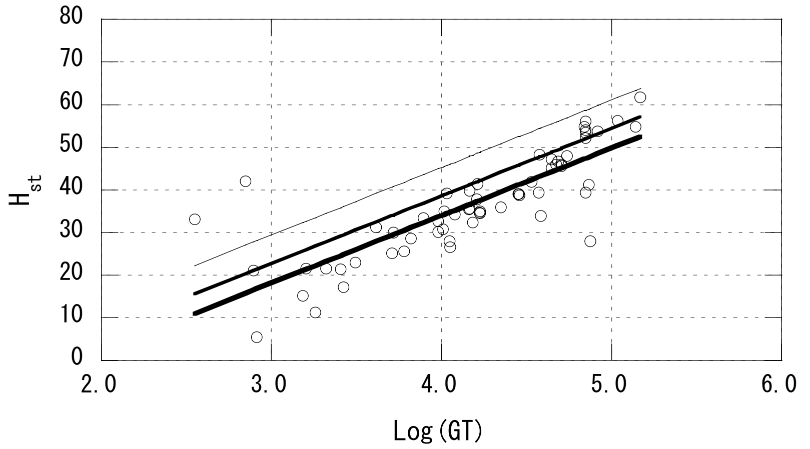
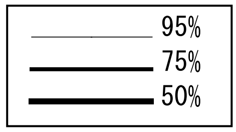


Figure37–2 H_{st} – semilog regression analysis (passenger ship)





Y=alogX+b

(R^2= 0.678 , σ= 6.843)

	50%	75%	95%
a	15.83	15.83	15.83
b	-29.31	-24.69	-18.05

Figure37–3 Results of H_{st} – semilog regression analysis ①: After exclusion of data exceeding ±2σ (passenger ship)

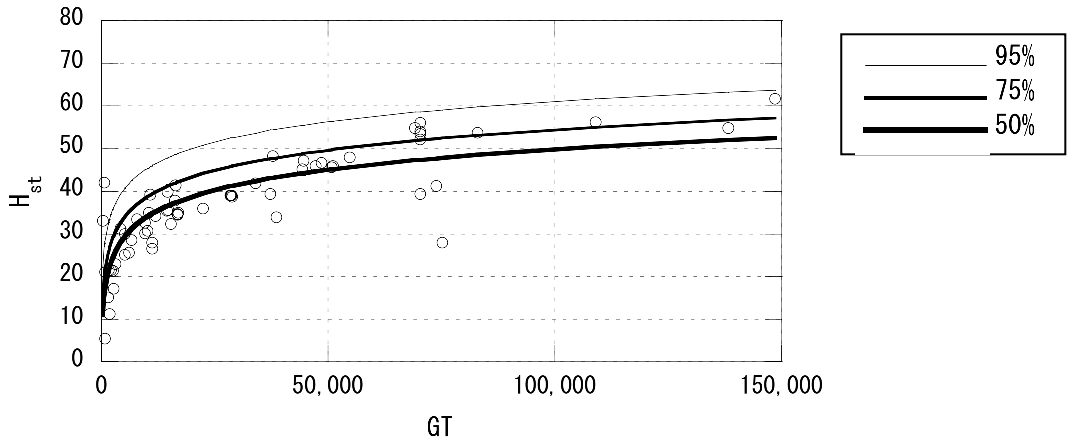


Figure37–4 Results of H_{st} – semilog regression analysis ②: After exclusion of data exceeding ±2σ (passenger ship)

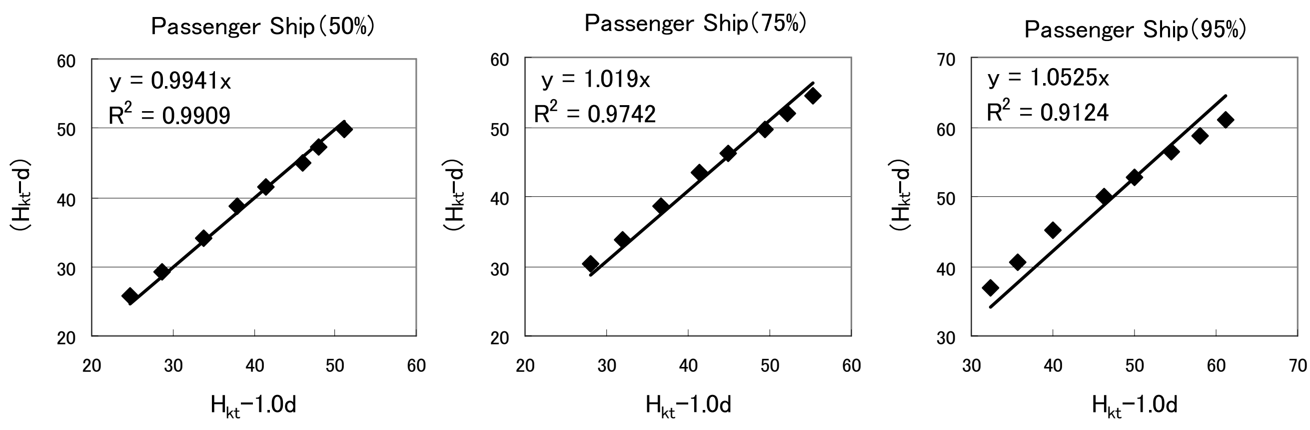


Figure37–5 Comparison with draft factor (β) = 1.0

7. Conclusion

Based on an examination of the reasons why dimensional values related to the height of ships were not given in the existing “Technical Standards for Port and Harbour Facilities” (Ministry of Land, Infrastructure and Transport), the first objective of this research was to propose dimensions for the height of ships with accuracy equal to that of the ship main dimensions, such as length over all, full load draft, etc., in the “Technical Standards.”

Concretely, this research included:

① Comparative analysis of the dispersion with data on main dimensions by ship class.

② Exclusion of statistically anomalous values from data in the fundamental data.

③ Application of a new statistical analysis method.

Based on the above, the values of total height (height from keel to top) for coverage ratios of 50%, 75%, and 95% were calculated for ship classes set in the same manner as in the “Technical Standards,” and the results were presented in table form.

The second objective was to propose ship height dimensions with the same accuracy as main dimensions such as length over all, full load draft, etc. in the “Technical Standards” for the height from the sea surface to the highest point on the ship, which is necessary when designing bridges over fairways, arranging the relationship with the obstruction assessment surface (OAS) in maritime airports, etc.

This research focused on:

① Technique for estimating height above surface (H_{st}) using the values of total height (H_{kt}) and full load draft (d), which are analyzed separately.

② Technique for estimating height above surface (H_{st}) in a fully-loaded condition directly from total height (H_{kt}) and full load draft (d) for individual ships.

Using these techniques, the values of the height above the sea surface for coverage ratios of 50%, 75%, and 95% were calculated for ship classes set in the same manner as in the “Technical Standards,” and the results were presented in table form.

Because examples which present dimensional value tables of this type for ship height cannot be found elsewhere, including non-Japanese sources, reflection of these results in a future revision of the “Technical Standards” is expected. On the other hand, it is also necessary to present these results in various forums for external evaluation. In order to base such a revision on these evaluations and respond to changes in the circumstances surrounding the “Technical Standards,” it will be necessary to carry out an analysis of ship height in combination with the other main ship dimensions such as length over all, full load draft, etc. in the future.

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(* Note): Outline of Lloyd’s Register Fairplay Ltd.

Lloyd’s Register Fairplay Ltd. (LRF) is a company which was established in 2001 by merging the maritime information publishing division of Lloyd’s Register (LR) and Fairplay Publications Limited.

As the origin of Lloyd’s Register of Shipping, the company was established in 1760 at a London coffee shop owned by Edward Lloyd for the main purpose of classifying merchant ships from the viewpoints of their structures and seakeeping capabilities. The first Register of Ships was published in 1764. In 1975, LR was registered as a philanthropic organization, i.e., a non-profit organization. Today, LR has offices in approximately 120 countries and determines the class of merchant ships worldwide.

On the other hand, Fairplay Publications Limited was established by its founder, Tomas Hope Robinson, in 1883 as a publishing house. The company published weekly magazines, and LRF continues to publish the Fairplay International Shipping Weekly even today. Subsequently, in the 1970s, Fairplay was sold to the Pearson Group, which publishes the Financial Times.

In 2001, the maritime information publishing division of LR and Fairplay were merged, creating Lloyd’s Register-Fairplay Ltd. as a company specializing in providing information to the world shipping industry. The company is headquartered in England and has opened offices in Singapore, Sweden, and the United States.

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