Estimation of Optimum Tug Capacity for VLCC and Its Application to VLCC Terminal in Gwang-Yang Harbor

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ABSTRACT

The total tug capacity needed for berthing/de-berthing operations of a ship may vary depending on the ship type, size, loading conditions, and environmental circumstances. Traditionally, total tug capacity is determined based on the local guidelines of port authorities or on the rule of thumb. However, the social demands for the enhancement of ship safety at harbor and the economical demands for the cost-effectiveness of tug usage makes it necessary for port authorities to develop more reasonable and detailed guidelines on tug usage which takes various conditions into account.

In this paper, the method to estimate the optimum tug capacity of VLCC is suggested by considering various ship conditions such as its size, loading conditions, and environmental circumstances such as wind, wave, tidal currents, and geographical characteristics of a terminal.

This method is applied to a VLCC terminal located in Gwang-Yang Harbor of Korea and the results are compared with the local guidelines of the harbor, which shows that there may be a room for the amendment of local guidelines on tug usage.

1. Introduction

The total tug horsepower and the number of tugs for berthing or de-berthing operations of a ship may vary depending on the ship type, size, loading conditions, and environmental circumstances in which they are working. Traditionally, total tug capacity has been determined by local guidelines which are largely based on the experiences. As the ship size increases, however, the determination of the optimum tug capacity is becoming more important and difficult.

The local guidelines on the tug usage presently used by major port authorities are based on the gross tonnage (GT) of a ship and are almost same regardless of the local characteristics of harbor, loading conditions of a ship, ship type, and environmental conditions available at the time of tug operations.

As a consequence, the tug capacity based on the local guidelines may be too much in case of calm weather conditions, which entails cost increase for tug usage. On the contrary, it may not be enough in case of severe weather conditions, such as strong wind or tidal current, which may result in dangerous situation.

In this paper, the method to estimate the optimum tug capacity of VLCC is suggested by considering various ship conditions such as its size, loading conditions, and environmental circumstances such as wind, wave, tidal currents, and geographical characteristics of a terminal where it is to berth or de-berth. This method can be used when developing more reasonable guidelines on tug usage in the future.

In Chapter 2, the methods to estimate the various external forces are briefly described. In Chapter 3, brief explanations on how to consider the hydrodynamic forces of a ship approaching to or getting away from a berth are given together with the local guidelines on tug usage and tug characteristics of Gwang-Yang Harbor. In Chapter 4, specific application results of this method to a VLCC terminal located in Gwang-Yang Harbor are shown, which are compared with local guidelines of the harbor. In Chapter 5, the optimum tug capacity is assessed by estimating maximum forces acting on a ship under every possible combination of environmental condition, which shows that there may be a room for the amendment of local guidelines on tug usage.

2. Estimation of the Tug Capacity

2.1 Synopsis

Since the tugs should be fully able to control a ship which is dead-float without any capabilities to cope with wind and/or tidal current, berthing or de-berthing situation is usually most important when determining the necessary tug capacity.

In this paper, the optimum tug capacity of VLCC is determined so that the tugs can control the ship floating in the vicinity of a terminal without any speed, which means that the ship does not have any means but tugs to cope with the external forces due to wind, wave, and tidal current. The size, loading conditions of VLCC, water depth/draft ratio are taken into account together with the environmental conditions prevailing at the time of berthing or de-berthing, such as wind, wave, and tidal current.

2.2 Forces and Moment due to Wind

The forces and moment acting on a ship due to wind can be expressed as follows:

$$F_{X_{WIND}} = \frac{1}{2} C_{X_{WIND}} \rho_A V_W^2 A_T$$

$$F_{Y_{WIND}} = \frac{1}{2} C_{Y_{WIND}} \rho_A V_W^2 A_L$$

$$M_{XY_{WIND}} = \frac{1}{2} C_{XY_{WIND}} \rho_A V_W^2 A_L L_{PP}$$

Here, $C_{X_{WIND}}$, $C_{Y_{WIND}}$, $C_{XY_{WIND}}$ mean longitudinal, lateral wind force coefficients, and yaw moment coefficient, respectively. ρ_A means air density, V_W means relative wind speed. A_T and A_L mean transverse and longitudinal projected area of a ship above waterline, respectively. L_{PP} means the length of a ship between perpendiculars.

The wind coefficients of VLCC as a function of its configuration above waterline, loading conditions, relative wind directions can be found in the reference [1].

2.3 Forces and Moment due to Tidal Current

The forces and moment acting on a ship due to tidal current can be expressed as follows:

$$F_{X_{CURRENT}} = \frac{1}{2} C_{X_C} \rho_W V_C^2 L_{PP} D$$

$$F_{Y_{CURRENT}} = \frac{1}{2} C_{Y_C} \rho_W V_C^2 L_{PP} D$$

$$M_{XY_{CURRENT}} = \frac{1}{2} C_{XY_C} \rho_W V_C^2 L_{PP}^2 D$$

Here, C_{X_C}, C_{Y_C}, C_{XY_C} mean longitudinal, lateral current force coefficients, and yaw moment coefficient, respectively. ρ_W means sea water density, V_C means relative current speed. D means the average draft of a ship. The tidal current coefficients as a function of ship configuration under the waterline, water depth/draft ratio, and relative current direction can be found in reference [1].

2.4 Forces due to Wave

Usually, the effectiveness of tug boats cannot be guaranteed if the significant wave height is higher than 2.0 ~ 3.0m, which means that the significant wave height is not so high if tug boats are operating. In this paper, the wave height during berthing or de-berthing operations is assumed to be not so high compared to the size of a ship. This makes it possible to assume that the major effect of wave on a ship is wave drift force in lateral direction, which can be expressed as follows [2] :

$$F_{Y_{WAVE}} = 0.0875 \rho_W g H_S^2 L_{WL} \sin \theta_{WAVE}$$

Here, H_S, L_{WL}, θ_{WAVE} mean significant wave height, waterline length of a ship, and relative wave direction, respectively.

2.5 Yaw Moment due to Rotation of a Ship

When a ship is rotating without any lateral or longitudinal speed, so called stand-still rotation, the yaw moment acting on a ship can be estimated as follows[3];

$$M_R = \rho_W L_{PP}^4 D r^2 C_{D0} C_{rN}^2 / 64$$

Where r means yaw rate of a ship, and C_{D0} and C_{rN} are stand-still rotation coefficients, the value of which can be found in reference [3].

2.6 Yaw Moment and Equivalent Forces

When there exist wind and/or tidal current, there exists yaw moment as well as longitudinal and lateral forces, which the tugs should be able to cope with. The yaw moment, M, can be replaced with equivalent two forces acting on fore and aft parts of ship, Y_F and Y_A whose acting positions are λ_F and λ_A from midship, respectively.

$$Y_F = \frac{M}{\lambda_F + \lambda_A}, \quad Y_A = \frac{-M}{\lambda_F + \lambda_A}$$

2.7 Estimation of Necessary Tug Capacity

The resultant longitudinal force(X_E), lateral force(Y_E), and yaw moment(M_E) due to wind, wave, and tidal current can be expressed as follows:

$$X_E = F_{X_{WIND}} + F_{X_{CURRENT}}$$

$$Y_E = F_{Y_{WIND}} + F_{Y_{CURRENT}} + F_{Y_{WAVE}}$$

$$M_E = M_{XY_{WIND}} + M_{XY_{CURRENT}} + M_R$$

If it is assumed that tugs are operating at fore and aft part of a ship and their average positions of operation are λ_F and λ_A from midship, respectively, then the lateral force, Y_E and yaw moment, M_E, exerted by tugs can be replaced with equivalent two forces acting on fore and aft parts of ship, Y_{EF} and Y_{EA}, respectively, as follows:

$$Y_{EF} = \frac{\lambda_A Y_E + M_E}{\lambda_F + \lambda_A}, \quad Y_{EA} = \frac{\lambda_F Y_E - M_E}{\lambda_F + \lambda_A}$$

Finally, to cope with the environmental forces acting on a ship due to wind, current, and wave, the tugs should be able to exert resultant forces equivalent to the total sum of these forces as follows:

$$F_{TUG} = |X_E| + |Y_{FE}| + |Y_{EA}|$$

2.8 Safety Margin

Theoretically, it would be sufficient if the resultant forces exerted by tug boats are same with the external forces acting on a ship. However, the tug capacity should have some margin due to following reasons:

(1) The tugs should be able to move a ship to a desired direction while coping with environmental forces.

(2) The resultant force direction of tugs does not always coincide with the desired direction.

(3) The tugs usually cannot exert their full power due to the capability deterioration with its age.

(4) When tugs are operating both in bow and stern of a ship, undesirable yaw moment usually occurs, which usually make it difficult to use full power of tug boats.

(5) There exists a phenomenon known as "wash effect", which reduces effectiveness of tug boats due to the interaction of tug wake and a ship.

To consider these various uncertain factors which may weaken tug effectiveness, it is usual to introduce safety margin factor when determining tug capacity. In this paper, as a safety margin factor, 25% of external forces acting on a ship are taken into account. Finally, the necessary horsepower of tugs can be written as follows:

$$HP_{TUG} = 100 \times \frac{F_{TUG}}{T_{100HP}} \times f_{Safety}$$

where, f_{Safety} means safety margin factor(1.25) and T_{100HP} means average tug force per one hundred HP, as described in section 3.7 of this paper.

3. Characteristics of VLCC Terminal in Gwang-Yang Harbor

3.1 VLCC Terminal

The VLCC terminal is located at the entrance of Gwang-Yang Harbor, as shown in Fig. 1. In the vicinity, there exists main fairway to Gwang-Yang Harbor.

3.2 Target Ships

The methods described in chapter 2 are applied to the ships calling at Gwang-Yang VLCC Terminal as described above, the principal dimensions of which are shown in Table 1. It is assumed that the average position of tug boats are 40% of ship length from midship to bow and stern direction, respectively.

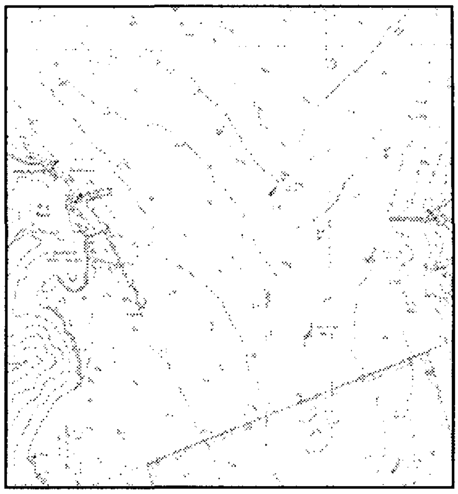


Fig. 1 VLCC Terminal in Gwang-Yang Harbor

Table 1 Principal Dimension of Target Ships

Ship	DWT	GT	Lpp(m)	B(m)	Draft(Full / Ballast, m)
R	45K	28,547	172.0	32.2	12.67 / 7.40
O	135K	76,971	260.0	46.0	15.30 / 7.60
A	305K	160,079	318.0	60.0	22.03 / 9.60

3.3 Heading Angle Range of a Ship during Berthing or De-Berthing

The heading angle of a ship may vary during berthing or de-berthing, which results in the variation of relative wind and current direction and hence the variation of external forces acting on the ship. The possible range of heading angles may vary depending on the berthing or de-berthing method.

In this paper, the possible range of heading angle is set from 0 to 360 degrees, that is, without any restrictions on heading angles. For all heading angles, the necessary tug forces are calculated as described in section 2.7, the maximum value of which are used to estimate the necessary tug capacity.

3.4 Tidal Current around VLCC Terminal

The tidal current and elevation both affect the hydrodynamic forces acting on a ship. The direction and speed of tidal current directly changes the magnitude and direction of hydrodynamic forces, whereas the tidal elevation changes the effective water depth/draft ratio and hence the hydrodynamic forces acting on a ship. The amplitudes of tidal elevation and tidal current speed are about 1.58m and 1.7 knot at spring range in this area.

3.5 Lateral Movement or Rotation of a Ship during Berthing/De-berthing

Tug boats should be able to control the movement of a ship coping with the environmental forces. The hydrodynamic forces acting on a ship due to its lateral translation can be estimated simultaneously with the tidal current effects by assuming that the tidal current corresponding to its lateral translation speed is superposed to the prevailing tidal current field.

As shown in Fig.2, the direction of VLCC terminal is 335 or 155 degrees, respectively, whereas the moving direction of a ship is almost perpendicular to these directions, that is, 245 degree for berthing and 65 degree for de-berthing operation.

When there exists tidal current around the VLCC terminal, the inflow velocity to a ship can be expressed as vector sum of tidal current speed and speed component due to lateral translation of a ship as schematically shown in Fig. 3.

In this paper, when the heading angle of a ship is between 335 ± 10 degrees or between 155 ± 10 degrees, it is assumed that the tugs should be able to move the ship at 0.5 knot speed towards or from the terminal coping with the environmental forces. Otherwise, it is assumed to be sufficient if the tugs can cope with the environmental forces. On the other hand, if there's a need to change the direction of a ship, the yaw rate is assumed to be 0.5 deg/sec.

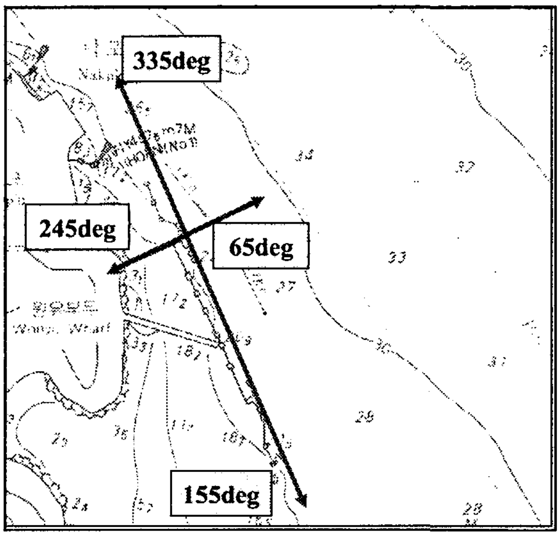


Fig. 2 Principal Direction of VLCC Terminal and Direction during Berthing/De-Berthing

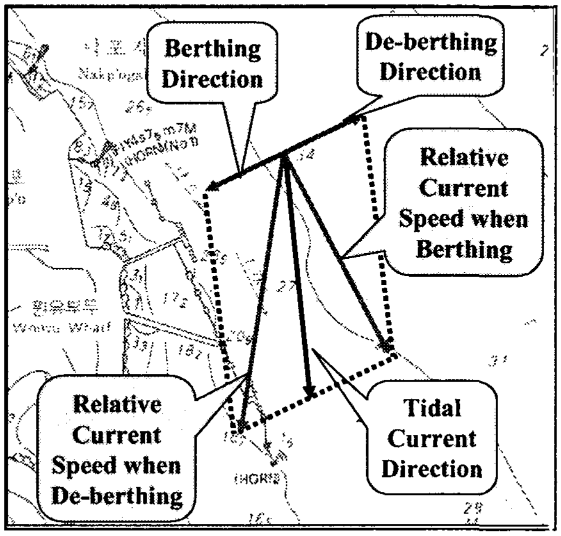


Fig. 3 Schematic Diagram of Relative Current Speed when Berthing or De-berthing

3.6 Local Guidelines on Tug Usage at Gwang-Yang Harbor

The local guideline on tug usage which is currently used when determining necessary tug capacity at Gwang-Yang Harbor is shown in Table 2[4].

Table 2 Guidelines on Tug Usage for Gwang-Yang Harbor

G/T of Ship	Total Tug Capacity(HP)	Tug Classes
Less than 5,000	Less than 2,000HP	Below 1,000 HP Class
5,000 ~ 10,000	2,000 HP - 4,000 HP	1,000 HP Class
10,000 ~ 20,000	3,000 HP - 5,000 HP	1,000 HP Class 2,000 HP Class
20,000 ~ 40,000	5,000 HP - 8,000 HP	2,000 HP Class Above 3,000 HP Class
40,000 ~ 70,000	7,000 HP - 12,000 HP	2,000 HP Class Above 3,000 HP Class
70,000 ~ 100,000	10,000 HP - 17,000 HP	2,000 HP Class Above 3,000 HP Class
100,000 ~ 130,000	12,500 HP - 20,000 HP	2,000 HP Class Above 3,000 HP Class
Larger than 13,000	Larger than 16,000 HP	2,000 HP Class Above 3,000 HP Class

3.7 Tug Forces per Unit Horsepower

Average tug force per unit horsepower is necessary to estimate the necessary total tug horsepower from the estimated tug forces as described in section 2.8. The average force of Gwang-Yang tugs per 100HP can be summarized as follows [5].

Table 3 Tug Forces per 100HP(Gwang-Yang Harbor)

Tug HP Classes	Tug Force(tonf) per 100HP of Tug Capacity		
	Maximum	Minimum	Average
1,000 HP Class	1.67	1.13	1.30
2,000 HP Class	1.35	1.01	1.18
3,000 HP Class	1.25	1.08	1.20
4,000 HP Class	1.17	1.10	1.13
Total	1.67	1.10	1.20

In this paper, the average value for 3,000 and 4,000 HP class tugs, 1.16 tonf/100HP, is used as average tug force which tug forces can exert for every 100 HP, which is expressed as T_{100HP} in section 2.8.

4. Application to a Ship calling at VLCC Terminal in Gwang-Yang Harbor

4.1 Synopsis

The optimum tug capacity means minimum tug capacity which is capable of carrying out necessary operation for a ship coping with external environmental forces such as wind, wave, and tidal currents.

If it is assumed that the wind speed and direction, tidal current speed and direction, wave direction and wave height, and water depth during berthing or de-berthing operation are almost constant, the external forces acting on a ship vary depending only on the heading angle of a ship. The necessary tug capacities are estimated for every possible heading angles during berthing or de-berthing operations including the necessary tug capacity for lateral translation of 0.5 knot speed toward or from the terminal as described in section 3.5.

4.2 De-berthing of 45,000 DWT Ship "R" (Full Load)

The necessary tug capacities for every heading angle of a ship "R" are estimated for specific situation as described in 4.2.1. And the results are shown in Fig. 4.

4.2.1 Situation

- Date of Operation : Apr. 7, 2000, 13:00 – 13:30
- Ship : 45,000DWT Ship, Full Load(D = 11.8m)
- Departing from Portside Berthing
- Tidal Current : Strong Ebb(1.71 Knot, 165.8 deg.)
- Wind : SE 12 Knots
- Wave : SE, Significant Wave Height 1.0m
- Water Depth : 25.6m (h/D = 2.17)
- Guideline on Tug Usage : 5,000 HP ~ 8,000 HP
- Tugs Used : One 4,200HP Tug and One 3,200HP Tug (2 Tugs and 7,200 HP)

4.2.2 Estimation and Discussion

According to the daily work records of VLCC Terminal, it seemed that there were some difficulties when carrying out de-berthing operation of the ship. This could be expected from the predicted results of necessary tug capacity as shown in Fig. 4. At the initial stage of de-berthing, the necessary tug capacity to pull the ship with 0.5 knot speed from the terminal is about 7,000 HP which is almost full power of used tugs. It would be safer if one more tug of 2,000 ~ 3,000HP is used.

Also known from the figure is that the necessary tug capacity may increase rapidly beyond the available limit if the ship rotates counterclockwise, which implies that clockwise rotation of a ship is more desirable.

As seen in this figure, the necessary tug capacity to cope with the external forces varies significantly depending on the heading angle of a ship, which would be expected under this strong tidal current condition. The maximum value occurs at the heading angle of 251 degrees where the ship lies almost perpendicular to wind and current direction. To cope with external forces at this heading angle, total tug capacity of about 14,000HP is necessary, which means that the tug capacity based on the guideline may not be enough under emergency conditions.

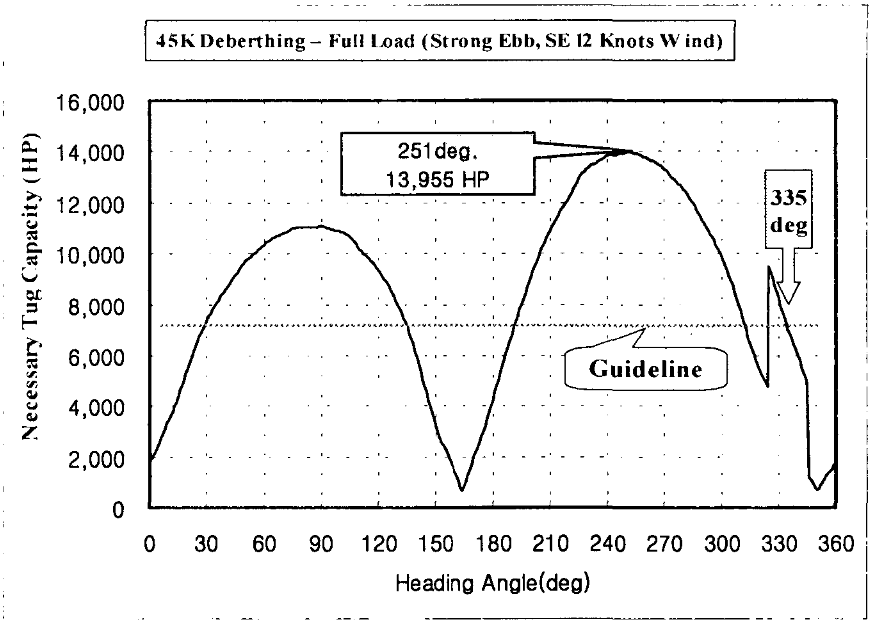


Fig. 4 Variation of Necessary Tug Capacity for Ship "R" with Heading Angle

4.3 Berthing of 135,000 DWT Ship "O" (Full Load)

The necessary tug capacities for every heading angle of a ship "O" are estimated for specific situation as described in 4.3.1. And the results are shown in Fig. 5.

4.3.1 Situation

- Date of Operation : May 26, 2000, 07:20 – 08:40
- Ship : 135,000DWT Ship, Full Load(D = 15.3m)
- Arrival and Portside Berthing
- Tidal Current : Weak Ebb(0.6 Knot, 165.8 deg.)
- Wind : S 9 Knots
- Wave : SE, Significant Wave Height 0.3m
- Water Depth : 26.96m (h/D = 1.76)
- Guideline on Tug Usage : 10,000 HP ~ 17,000 HP
- Tugs Used : Three 4,200HP Tugs (3 Tugs and 12,600 HP)

4.3.2 Estimation and Discussion

According to the daily work records of VLCC Terminal, it seemed that there was little difficulty when carrying out berthing operation of the ship. This could also be expected from the predicted results of necessary tug capacity as shown in Fig. 5. At the initial stage of berthing, the necessary tug capacity to push the ship with 0.5 knot speed toward the terminal is about 3,000 HP which is almost quarter of used tug capacity.

As seen in this figure, the necessary tug capacity to cope with the external forces for all possible heading angles and to push the ship towards the terminal is less than 4,500 HP, which means that it might be possible to reduce the number of tugs and tug capacity under these favorable environmental circumstances.

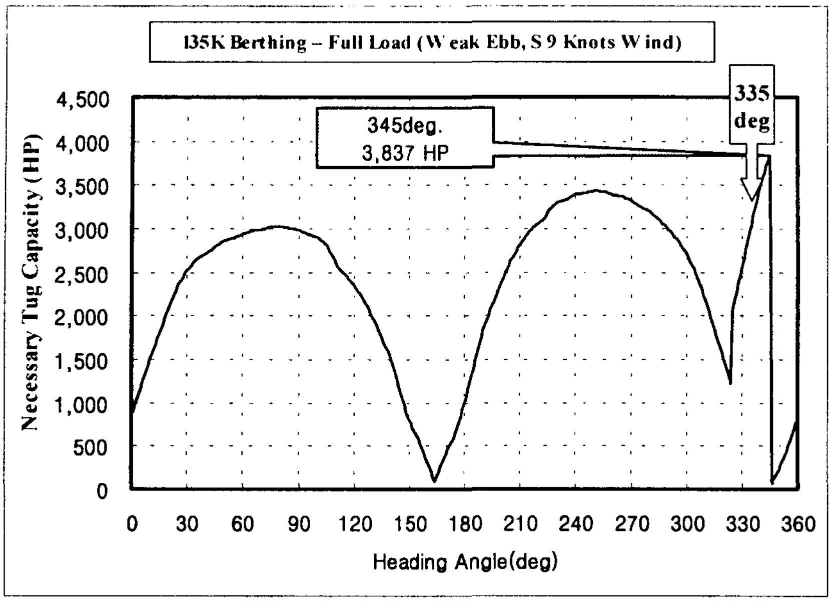


Fig. 5 Variation of Necessary Tug Capacity for Ship "O" with Heading Angle

5. Estimation of Optimum Tug Capacity for VLCC Terminal

For every possible combination of environmental conditions, the necessary tug capacity is estimated, the maximum value of which is considered as optimum tug capacity at that situation. If a ship size and its loading conditions are given, then the principal factors affecting the maximum tug capacity of a ship calling at VLCC Terminal are thought to be tidal current and wind conditions.

5.1 Environmental Condition

Shown in Fig. 6 are tidal current and elevation conditions used when estimating the optimum tug capacity. Wind speeds of 3 ~ 35 knots with 8 wind directions are also applied. Mean sea level(MSL) is 25.59m and tidal elevation is ± 1.58m. Swell of 1.0m wave height is assumed to be incident from SE direction. Various notations (eg., SFP, MEM,....) shown in Fig. 5 represent specific combination of tidal current speed and elevation.

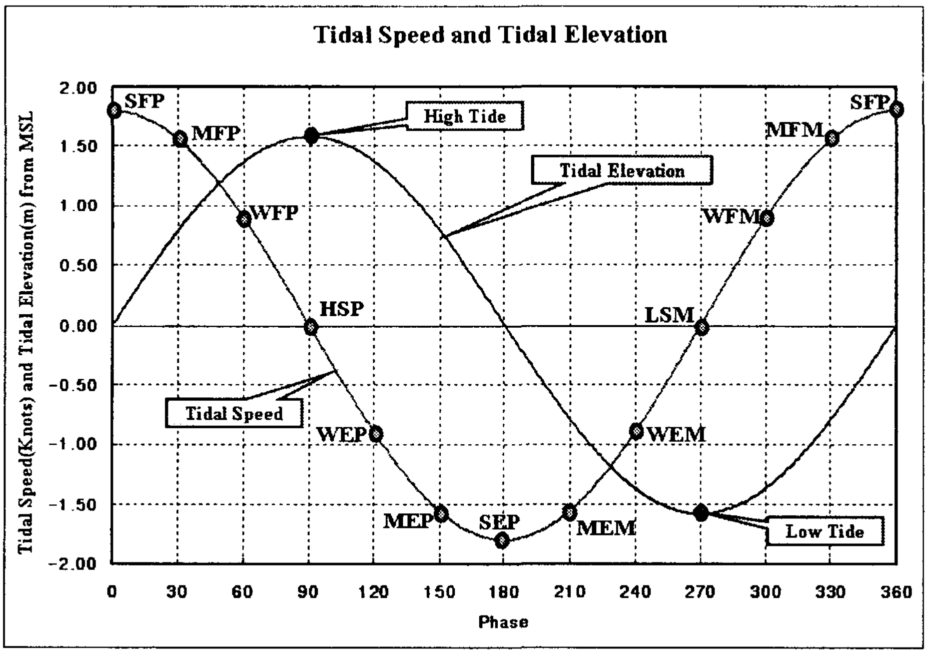
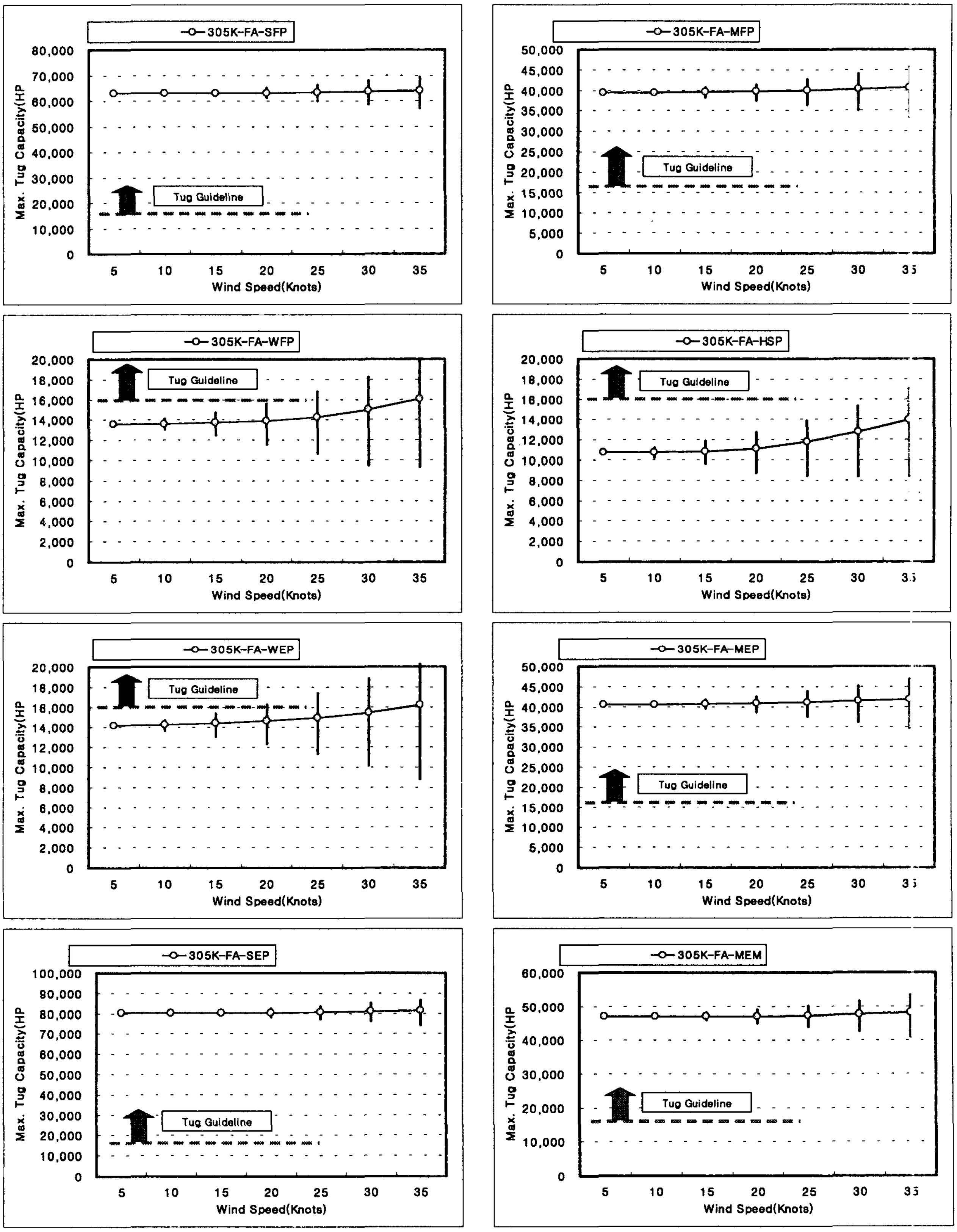


Fig. 5 Notation for Tidal Current/Elevation Condition

5.2 Optimum Tug Capacity for 305,000 DWT Ship "A" (Full Load)

Fig. 6 shows the estimated tug capacity variation due to wind speed and direction for 305K DWT VLCC(full load) at each tidal condition, where local tug guideline is also shown in each figure.



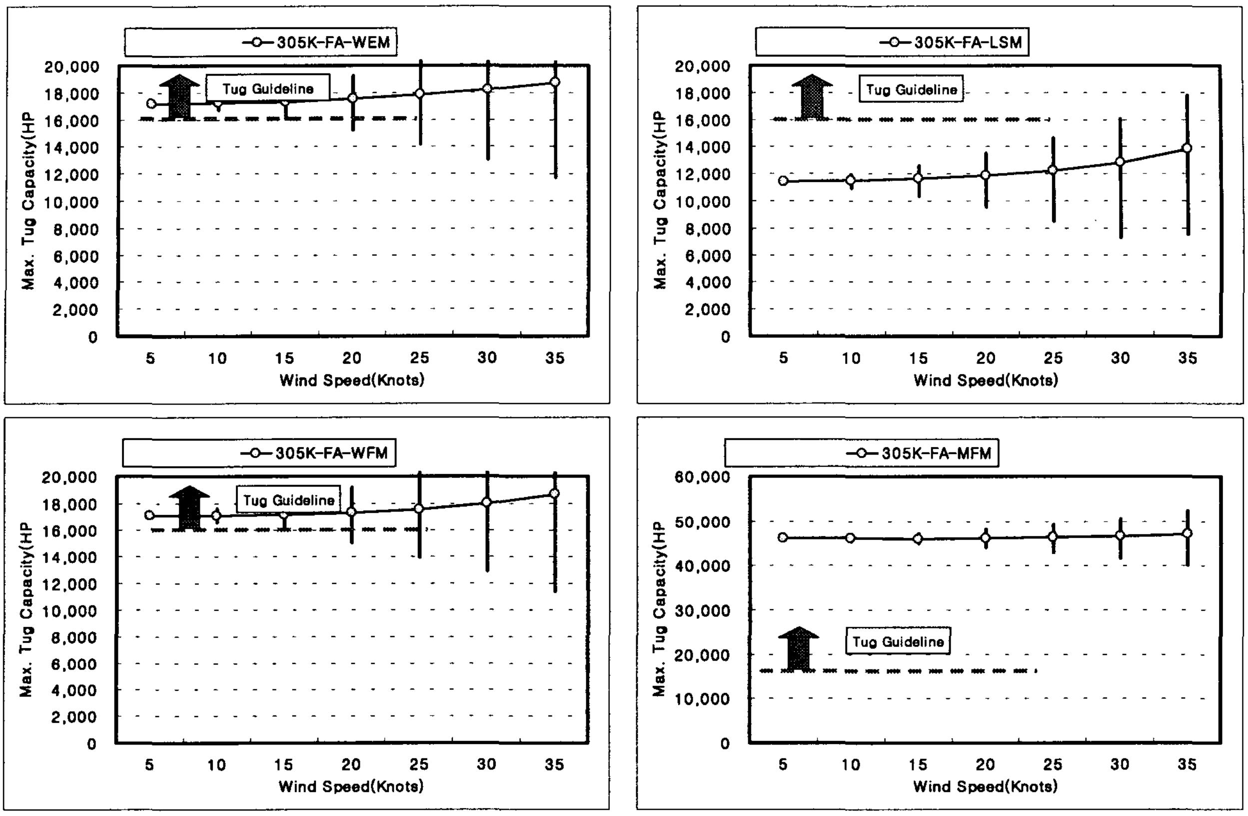


Fig. 6 Variation of Maximum Tug Capacity for 305K VLCC(Full Load)

From Fig. 6, it can be seen that tug capacity based on the guidelines are not enough when the ship is berthing or de-berthing under strong or medium tidal conditions. Also it can be seen that the tug capacity is somewhat excessive when operating in slack water conditions(high and low tide). Fig. 7 shows summarized results of this assessment for 305K VLCC for full load condition. Summarized result for 305K ballast condition is shown in Fig. 8.

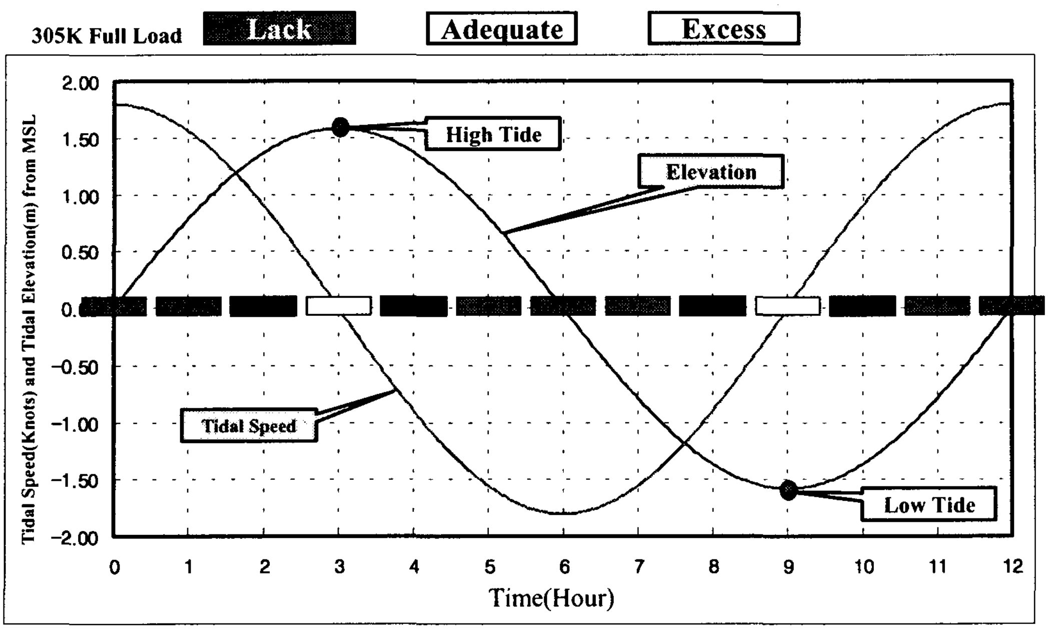


Fig. 7 Comparison of Estimated Optimum Tug Capacity and Guideline(305K VLCC-Full Load)

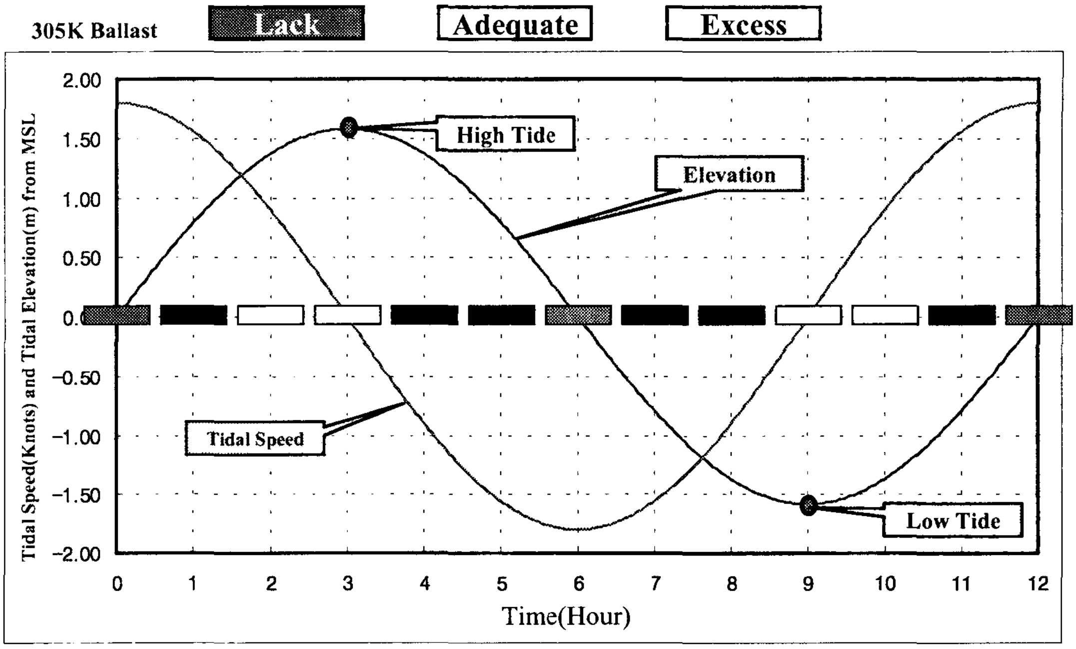


Fig. 8 Comparison of Estimated Optimum Tug Capacity and Guideline(305K VLCC-Ballast)

6. Concluding Remarks

The method to estimate the optimum tug capacity for a VLCC to cope with the external environmental forces such as wind, wave, and tidal currents are briefly reviewed. This method is applied to some specific ships calling at VLCC Terminal in Gwang-Yang Harbor and the results are compared with the tug capacity suggested by local guidelines on tug usage.

From the above considerations, it can be seen that the necessary tug capacity varies significantly depending on ship size, loading conditions, and environmental conditions. This suggests the necessity of reasonable amendments of guidelines on tug usage by taking various conditions into account, which makes it possible to increase safety and to reduce cost.

Acknowledgement

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