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A Study on Under Keel Clearance of Gadeok Channel for the Safety Passage of Mega Container Ship

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초대형 컨테이너선의 가덕수로 안전운항을 위한 선저여유수심 연구

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Abstract : *The worldwide sizes of container ships are rapidly increasing. The container ship size in 2005, which was about 9,200 TEU has increased to 24,000 TEU in recent times. In addition to the increase in the sizes of the container ships, the arrivals/departures of large container vessels to/from Korea have also increased. Hence, the necessity for reviewing safe passage of such vessels is emphasized. In the present study, a 24,000 TEU container vessel was used as a model ship to calculate the under-keel clearance (UKC) at Gadeok Channel through which vessels must pass to arrive at Busan New Port, in accordance with the Korean Port and Fishing Port Design Standards and Commentary. In addition, the maximum allowable speed that meets UKC standards was calculated using various squat formulas, whose results were then compared with the current speed limit standards. The analysis results show that Busan New Port requires 10% marginal water depth, and the squat that meets this requirement is 0.95 m. Gadeok Channel requires 15% marginal water depth, and the squat that meets this requirement is 1.78 m; in this case, the maximum allowable speed is calculated as 15 kts. Busan New Port has set the speed limit as 12 kts, which is higher than the calculated 11 kts. Thus, speed limit reconsideration is required in terms of safety. However, the set speed limit for Gadeok Channel is 12 kts, which is lower than the calculated 15 kts. Thus, additional considerations may be provided to increase the speed limits for smooth navigational passage of vessels. The present study, however, is constrained by the fact that it reflects only a limited number of elements in the UKC and allowable speed calculations; therefore, more accurate UKC and safe speed values can be suggested based on extended studies to this research.*

Key Words : *Mega Container Ship, Depth, Squat, UKC, Port Design Standards*

요 약 : 전세계적으로 컨테이너선은 대형화되고 있으며, 2005년 9,200 TEU에 불과하였던 컨테이너선의 크기가 최근에는 24,000 TEU 급으로 확대되었다. 컨테이너선의 대형화와 함께 우리나라에서도 대형 컨테이너선들의 입·출항이 잦아지고 있어 안전 통항에 대한 검토의 필요성이 강조되고 있다. 이에 본 연구에서는 24,000 TEU 컨테이너선을 대상 선박으로 우리나라의 항만 및 어항 설계 기준에 따라 부산신항 및 부산신항 입항을 위해 통과해야 하는 가덕수로에서의 UKC를 산출하였다. 또한 UKC 기준을 충족하면서 항해 가능한 최대속력을 다양한 squat 식을 활용하여 구하였고, 이 결과를 현재의 속력제한 기준과 비교하였다. 연구결과 부산신항에는 흘수대비 10 % 여유수심을 요구하며 이를 만족하는 squat값은 0.95 m였으며, 가능한 최대속력은 11 kts였다. 가덕수로에서는 흘수대비 15 % 여유수심을 요구하며 이를 만족하는 squat값은 1.78 m였으며, 가능한 최대속력은 15 kts였다. 부산신항에서는 계산결과인 11 kts보다 제한속력이 12 kts로 높게 설정되어 있어 안전측면에서 재고려가 필요하며, 가덕수로에서는 계산결과인 15 kts보다 제한속력이 12 kts로 낮게 설정되어 있으므로 원활한 통항을 위하여 필요시 속력제한 규정을 높이는 것을 고려해 볼 수 있다. 본 연구는 제한된 요소만을 고려하여 UKC 및 항해 가능한 속력을 산출한 한계를 가지고 있으나 이 연구를 토대로 추가연구가 진행된다면 정확한 UKC 및 안전속력을 제한할 수 있을 것으로 판단된다.

핵심용어 : 초대형 컨테이너선, 수심, 선체침하, 선저여유수심, 항만 설계 기준

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1. Introduction

Many countries around the world have fostered the port and container industries as major national industries (Li et al., 2015). In recent years, the size of container vessels has grown faster than other types of vessels. By 2005, the world's largest container ship was only about 9,200 TEU, however, the size of the world's largest container ship reached 19,224 TEU in 2015, more than doubling its capacity in 10 years (Won et al., 2015). Following this trend, 18,000 TEU container ships were built and operated in 2016, and 24,000 TEU container ships were built in 2019. And in 2020, 24,000 TEU container ship was put into operation on Asia-Europe routes in Korea as well. With this ship's continuing enlargement trend, it is expected that a 30,000 TEU super-large container vessel will appear in the shipbuilding market in 2025 (Park and Suh, 2019).

With the advent of super-large container ships, there are growing concerns about arrival/departure and passage safety in existing Korean container ports. In particular, Busan New Port, the largest port in Korea, has an increasing traffic volume of large container ships and the vessels are subject to pass Gadeok Channel to enter the port. However, Under Keel Clearance (UKC) is insufficient compared to the recent trend of vessel's enlargement and it is high time to consider the related matters.

Especially, the ship's particular for a 24,000 TEU class container vessel which is the largest that are currently being operated, is 400m in length and 60m in width, and can reach a maximum draft of 16.5 m at a Full Loaded condition.

Meanwhile, for the smooth and safe arrival/departure of large container ships in Busan New Port, Toudo Island was removed and the port areas were dredged to 17 m in depth on May 27th 2020, and the whole fairways were dredged to 17 m in June 28th 2021. However, since the maximum draft of a large 24,000 TEU container ship reaches 16.5 m, it is necessary to throughly review whether UKC is sufficient for the current arrival/departure and passage of vessels under the maximum loading condition.

Many studies were conducted related to UKC from 1966 Tuck to 2002 Barrass. Both empirical and observational theories on ship's squat were continuously studied (Ryu, 2017).

Lee et al. (2019) utilized UKC to determine the vessel's final route by conducting UKC research in Korean ports. In this study, the optimal route from Mokpo to Jeju was proposed using the A* algorithm by considering sea state factors such as wind, sea states, and currents in the route planning process and the constant ratio parameter (0.3) for the maximum depth was used for the calculation of UKC.

According to Kim et al. (2020), Busan New Port was examined from the perspective of safe pilotage passage and the minimum safety depth within the passage was further being analyzed. Based on the maximum depth of 17 m, it was recommended to keep the speed below the Slow Ahead until the vessel passes the West breakwater and, if necessary, take extra caution by incorporating the tidal time into the passage plan.

Lee (2021) studied the reduction of UKC of large tankers and container ships in shallow water. In this research, the draft increase that occurs during the proceedings and turning of a large ship is applied to the model ship and the results were interpreted using computational fluid dynamics. Through this study, it was found that the draft gain in container ships increased significantly in the shallow water area, and the internal inclination occurred as the water depth decreased.

Although much of the related research has been conducted previously, the research that determines water depth change by incorporating water depth and various factors of the seabed to find the proper speed that ensures safe UKC as required by the Port Regulations is not yet introduced in the past.

This paper first calculated the required UKC for Gadeok Channel and Busan New Port by setting a 24,000 TEU class container ship with a draft of 16.5 m as a model vessel. Next, the maximum speed that meets UKC requirements was calculated and compared with the port design standards. Lastly, suggestions were made to take the research result as reference materials for the vessel's safe arrival/departure operation considering that continuous expansion in size and length for container vessels will occur in the future.

2. Size Increase of Container Ships

In 1957, The United States Sealand Corporation put the first container ship, Gate Way City which could load 35-foot, 226 containers in operation between Houston and New York on the coastal route. And in 1996, a container ship of 500-1500 TEU class was introduced in Atlantic route (New York-Europe), by which the second-generation container era has begun (Kim, 2010). Since then, the size of the vessel has grown to Panamax and Suezmax and was further extended to 13,000 TEU in 2008, and in

Table 1. Dimensions of Container Ship Size (Source: Hmm, 2020 and Oocl, 2021)

Size	LOA	LBP	B	D	T	H_{KT}	H_{ST}
3000 TEU	245	232	32.2	19	10.8	52.9	42.1
4000 TEU	294	281	32.26	21.5	10.8	54.4	43.6
5000 TEU	276	262	40	24.3	14.0	60.0	46.0
6000 TEU	277.23	263	40	24.3	14.0	60.0	46.0
8000 TEU	322.971	308	42.8	24.6	15.0	59.0	44.0
9000 TEU	334.95	320	42.8	24.8	14.7	60.0	45.3
13000 TEU	366.469	350	48.2	29.8	15.5	64.9	49.4
21000 TEU	399.87	383	58.8	32.5	16.0	73.5	57.5
24000 TEU	399.9	383	61.5	33.2	16.5	77.0	60.5

2020, 24,000 TEU vessels are in operation.

As shown in Table 1, the size expansion of vessels increased not only the length, width, and depth, but also the maximum draft and the Air Draft which refers to the height between keel to the mast and subtracting the maximum draft. Air Draft can be obtained as in formula (1).

$$H_{ST} = H_{KT} - T \qquad (1)$$

where,

H_{ST} : Air Draft or Height from the Sea to Top Mast (m)

H_{KT} : Height from Keel to Top Mast (m)

T: Draft (m)

The maximum draft of the 3,000 TEU class container ship was 10.8 m and the air draft was 42.1 m, but the maximum draft of the 9,000 TEU class was increased to 14.7 m with an air draft of 45.3 m. For the 24,000 TEU class, the maximum draft was 16.5 m and the air draft was 60.5 m. Many studies related to the safe passage of fairway focus on the relationship between water depth and draft, however, the Air Draft is also an important deciding factor when the vessel passes through bridges or where the airports are near for helicopters or airplanes flight operations.

In particular, in the case of Gadeok Channel, because the construction of a new airport in Gadeok Island is scheduled in the future, the following study covering the stability of a large container vessel in relation with air draft should be followed.

Fig. 1 shows the relationship between maximum draft and air draft according to the increase of TEU in container vessels.

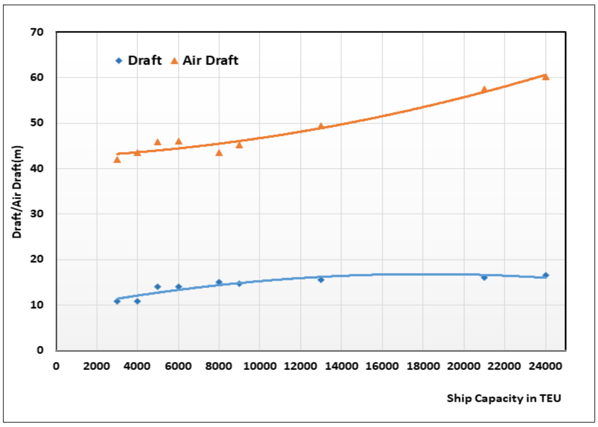

Fig. 1. Draft and Air Draft Changes by Container Size.

3. Standards for Domestic and International Water Depth

The water depth standards for domestic ports and port water areas are defined in the Korean Design Standard (2017). Port and Fishing Port Design Standards and Commentary was established in 1971 and it went through five times revisions and amendments. Korean Port and Fishing Port Design Standards and Commentary are the minimum standards required for the process of establishing a plan or designing for the construction of port-related facilities or structures installed in ports and coastal areas. In the document, the criteria for deciding the depth of the route are summarized as follows.

- Standard: For sea route depth, allowances are taken into account according to seabed, vessel's sway, trim, squat, chart error, hydrographic survey error, and dredging condition.

- Explanation: To ensure the safety of navigation, UKC between the bottom of the ship and the seabed in the maximum draft condition should be sufficiently secured over the following values.

① 10 % of the maximum draft in the case of a calm water status within the port

② 15 % of the maximum draft for a fairway approach or passage approach without a swell

③ 20 % of maximum draft if swell exists or if they are relatively long

In addition to this, the standard for berthing depth defines its detail as stated in the berth specification section as follows.

- Standard: The depth of the berth should be determined by having a maximum draft figure added with the surplus water depth corresponding to that maximum draft. However, if the target vessel is not identified, it should be determined so that there is no restriction or hindrance in utilizing the vessel.

Additionally, as a reference, fully loaded draft for each occasion is presented in the ship's particular section, and the draft, berth depth depending on deadweight capacity and its ratio are shown in Table 2.

The ratio between the depth of the berth depending on the size of the container vessel and the vessel's draft was suggested within the value of 1.07 to 1.17. Among them, the 22,000 TEU container berthing depth is suggested to be between 20 ~ 21.0 m, which the West Container Terminal in Busan City that is currently under construction only satisfied to meet the criteria. The water depth of other berths in Busan New Port was applied with a designed water depth of DL(-) 19.0 m, thus, the gap exists from the standard.

Table 2. Depth of Berth Depending on the Size (Deadweight) of the Container Ship

DWT (ton)	TEU	T: Ship Draft (m)	h: Berth Depth (m)	h/T
10,000	800	7.7	9.0	1.17
20,000	1,500	9.9	11.0	1.11
30,000	2,000	11.2	12.0	1.07
40,000	3,000	12.1	13.0	1.07
50,000	4,000	12.7	14.0	1.10
60,000	5,000	13.4	15.0	1.12
100,000	8,000	14.7	16.0	1.09
150,000	14,000	16.0	17.5	1.09
200,000	18,000	16.5	18.5	1.12
250,000	22,000	18.0	20.0~21.0	1.12~1.17

Just as in the domestic regulation, Japan's water depth standard is set to ensure the 10 % marginal surplus from the maximum draft in the port, 15 % marginal surplus from the maximum draft in the approaching route, and 20 % marginal surplus in the relatively long route with swells. When in the case of knowing the exact particulars and speed of the vessel, the hull settlement due to squat and hull sway or the sinkage caused by a large degree course change can be calculated (TSCPHF in Japan, 2009).

$$D = T + D_1 + Max(D_2, D_3) + D_4 \tag{2}$$

where,

T : Maximum Ship Draft (m)

D_1 : Squat (m)

D_2 : Bow Sink due to Heaving and Pitching Motion

D_3: Bilge Keel Sink due to Heaving and Rolling Motion

D_4 : Allowance of Depth for Sink of Ship by large Rudder Angle to Alter her Course (m)

$D_4 = 0.5m \quad T \leq 10m$

$D_4 = 0.05T \quad T > 10m$

The World Association for Waterborne Transport Infrastructure (PIANC) applies the distinction between the in-port route from the approach route, and comprehensively incorporates values such as ship speed, swell height, and seabed as shown in Table 3.

Table 3. Channel Depth Components in PIANC

(T: Maximum Ship's Draft)

Vessel Speed	Wave	Bottom	Inner Channel	Outer Channel
≤ 10kts	None	-	1.10T	-
10-15kts		-	1.12T	-
> 15kts		-	1.15T	-
All	Low (< 1m)	-	-	1.15-1.2T
	Moderate (1-2m)	-	-	1.2-1.3T
	Heavy (> 2m)	-	-	1.3-1.4T
All	All	Mud	None	None
		Sand/clay	0.4m	0.5m
		Rock/coral	0.6m	h1.0m

Source: Harbour Approach Channels Design Guidelines, PIANC, 2014

4. Considerations for securing a safe depth of water

Factors that have a vertical effect on approaching waters or passage during navigation can be broadly classified into three categories: water-related factors, ship-related factors, and seabed-related factors.

The related factors are shown in Fig. 2. Factors related to water depth include tides, currents, reference datum of the sea chart, and atmospheric pressure elements. In general, large ships enter ports at high tide to secure sufficient UKC. Under 1013 mb conditions, for every 1mb increase in atmospheric pressure leads to a decrease in depth of sea level by 1 cm.

Ship-related factors include static draft information and uncertainties (such as the inaccuracy of draft marks), changes in seawater density, and squat. Squat refers to a phenomenon in which a ship loses the extra under keel clearance as the ship proceeds, and this includes Trim. Others include an increase in heel due to wind and turning and an increase in draft due to waves. And the minimum clearance between the hull keel and the seafloor (hereinafter referred to as the minimum safe clearance depth) is included in net UKC.

Lastly, seabed factors include sounding failure, sounding error, seabed change after dredging operation, and differences caused between the original dredging plan and the actual dredging implementation, and the draft may increase depending on the quality of the seabed (PIANC, 2014).

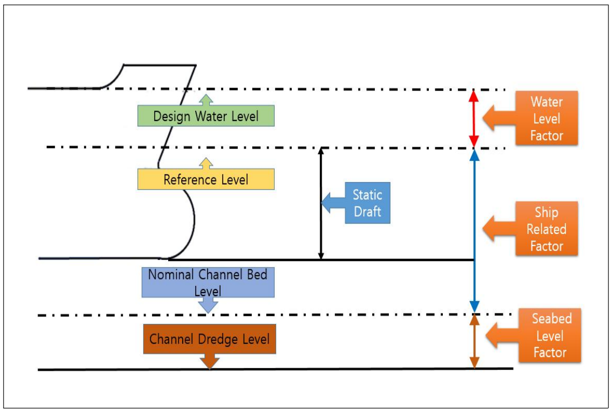

Fig. 2. Depth Factors.

The most essential factor for vertical safety in the fairway and port waterway is the maximum draft of those passing vessels. And the squat according to the dynamic movement of these ships has the greatest influence.

There are various empirical theoretical formulas for squat. In this study, considering the limiting factors of Table 4, the following theories by Tuck (3), Huuska/Guliev (4), ICORELS (International Commission for the Reception of Large Ships) (5), Barrass (6), and Yoshimura. (7) was used.

$$S_{bT} = (C_Z + C_\theta)\frac{\nabla}{L_{pp}^2}\frac{F_{nh}^2}{\sqrt{1-F_{nh}^2}} \tag{3}$$

$$S_{b_H} = C_S\frac{\nabla}{L_{pp}^2}\frac{F_{nh}^2}{\sqrt{1-F_{nh}^2}}K_S \tag{4}$$

$$S_{b,I} = C_S\frac{\nabla}{L_{pp}^2}\frac{F_{nh}^2}{\sqrt{1-F_{nh}^2}} \tag{5}$$

$$S_{MaX,\,B3} = \frac{C_B V_k^2}{100/K} \tag{6}$$

$$S_b = [(0.7+1.5\frac{1}{h/T})(\frac{C_B}{L_{pp}/B}) + 15\frac{1}{h/T}(\frac{C_B}{L_{pp}/B})^3]\frac{V_s^2}{g} \tag{7}$$

where,

S : Squat (m)

S_b : Ship's Bow Squat (m)

S_{bT} : Tuck's Squat Formula

∇ : Ship's Displacement (Ton)

F_{nh} : Depth Froude Number, $V_s/\sqrt{g \cdot h}$

V_S : Ship's Speed (m/s)

g : Gravity Acceleration

h : Depth

S_{bH} : Huuska/Guliev's Squat Formula

$S_{b,I}$: ICORES's Squat Formula

L_{pp} : Ship's Length between Perpendiculars (m)

C_Z : Coefficients for Mean Sinkage

C_θ : Coefficients for Trim

C_S : Squat Constant

K_S : Correction Factor for Channel Width

$S_{\max,B3}$: Barrass's 3rd Squat Formula

C_B: Ship's Block Coefficient

V_k: Ship's Speed (knots)

T : Ship's Draft

K : Dimensionless Coefficient

Table 4. Parameter Constaints for Squat Formulas

Formula	Constraint		
	Cb	h/T	L/B
Tuck	-	-	-
Huuska/Guliev	0.6-0.8	1.1-2.0	5.5-8.5
ICORELS	0.6-0.8	1.1-2.0	5.5-8.5
Barrass	0.5-0.85	1.1-1.4	-
Yoshimura	0.55-0.8	≥1.2	3.7-6.0

Source: Harbour Approach Channels Design Guidelines, PIANC, 2014

The details of Gadeok Channel for entering Busan New Port are shown in Fig. 3 and Table 5. It is 33 km long, 7.4 km wide on average, and 12 to 35 m deep, and is a waterway that leads to various ports such as Masan, Jinhae, and Tongyeong. In this study, the analysis was conducted based on the minimum depth of 17 m that passes through Busan New Port.

Table 5. Specifications of Gadeok Channel

Information	Value
Length	33km
Breath	7.4km
Depth	12~35m

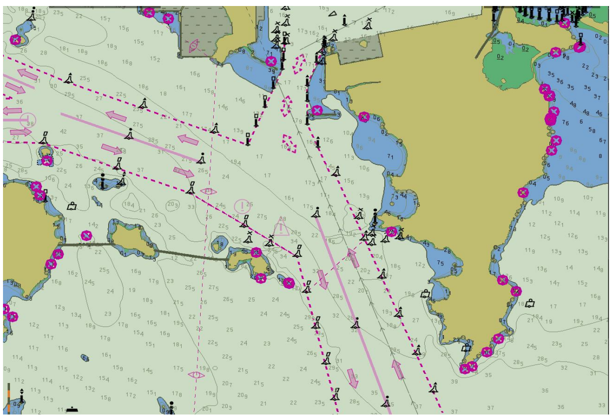

Fig. 3. Area of Gadeok Channel.

5. Safety Depth Assessment

Table 6 illustrates the detailed ship's particular for 24,000 TEU class container vessel, the largest vessel passing through Gadeok Channel, and UKC was analyzed utilizing this as a model vessel.

Within the elements that consist UKC, there are clear, definable data such as draft, squat, and seabed level, but there are also many undefinable factors that cannot be accurately measured such as uncertainties involved in sounding, changes in depth after dredging, and unclear environmental factors such as wind, atmospheric pressure, and currents at the time of vessel's passage. Also, it is difficult to obtain the increase in heel because the weather conditions constantly change every time ships arrive/depart and pass through.

Table 6. Specifications of Container Ship (24,000 TEU)

Type of ship	Container (24,000 TEU)
LOA	399.9m
LBP (LPP)	383m
Breadth (B)	61.5m
Depth (D)	33.2m
Max. Draft (T)	16.5m
Deadweight	229,039Ton
Displacement (▽)	285,229.7㎥
Main engine	59,600kW × 77 RPM
Max. speed	23knots
C_B	0.7339
Engine order : speed	Dead slow ahead : 7.0knots (3.6m/s) Slow ahead : 10.0knots (5.1m/s) Half ahead : 13.0knots (6.7m/s) Full ahead : 16.0knots (8.2m/s)

Therefore, in this study, the estimated value was used in consideration of the average climate condition of Gadeok Channel and Busan New Port, and the minimum safety UKC was established and analyzed by utilizing Korean Port and Fishing Port Design Standards and/or suggested consideration factors from other studies.

As stated in Table 7, in the case of atmospheric pressure, the average atmospheric pressure for 10 years of Gadeok Channel was 1015.3 mb and the average wind speed was 3.08 m/s (KHOA, 2019). Based on the 1013 mb set by Korean Port and Fishing Port Design Standards, 2.3 mb of atmospheric pressure was increased. Thus, UKC was decreased by 2.3 cm (0.023 m). The average wind speed was 3.08 m/s which is 6.0 kts that corresponds to Gentle Breeze in Beaufort scale 3. The wave height at this Beaufort scale was 0.6 m.

Table 7. Average Atmospheric Pressure and Wind Speed (Source: KHOA, 2019)

	Average Value
Atmospheric pressure (mb)	1015.3
Wind speed (m/s)	3.08

The wind wasn't strong enough to form the heel of the vessel at this wind speed, but according to Korean Port and Fishing Port Design Standards, UKC reduction caused by sway is considered as 1/2 of the height of the wave for large vessels, UKC reduction in this case due to height of the wave is deemed to be around 0.30 meter.

Seabed is one of the most critical factors in determining UKC. Because most of the seabed in Korea consists of Mud, there is no additional reduction in water depth, however, considering the change brought by the dredging operations, the Category Zone of Confidence (CATZOC) which is applied to ENC was used for calculation (IMO, 2006; Ncomi, 2020). Busan New Port and Gadeok Channel are A_1 Zone of CATZOC that the accuracy for the depth of the water is as follows.

$$D_A = \pm 0.5 + 0.01 \cdot D \quad (8)$$

where
D_A : Depth Accuracy
D : Depth

Through this, an error of ±0.67 m can be included as it is based on the 17 m dredging depth.

The increased value originated by the heel caused by the ship's turning was based on the sea-trial data of the 24,000 TEU container ship.

The following Table 8 organized the lists of these unstabilized elements.

Table 8. Specifications of UKC Factors except Squat and Draft

Factor	Increasing Value (m)
Pressure	0.02
Wind and Wave	0.30
Depth Accuracy	±0.67
Heel Moment	1.07 (if, Heeling angle 2°)
Total	0.73 ~ 2.06

UKC excluding draft and squat is within the range of 0.73 to 2.06. On the other hand, ICORES (1980) defined net UKC as the margin from the keel of the ship to the bottom of the waterway and said that this value can be increased from a minimum of 0.5 m to a maximum of 1.0m. Therefore, in this study, the above uncertainty factors were viewed as net UKC and made a conservative approach by selecting the figure as 0.7 m.

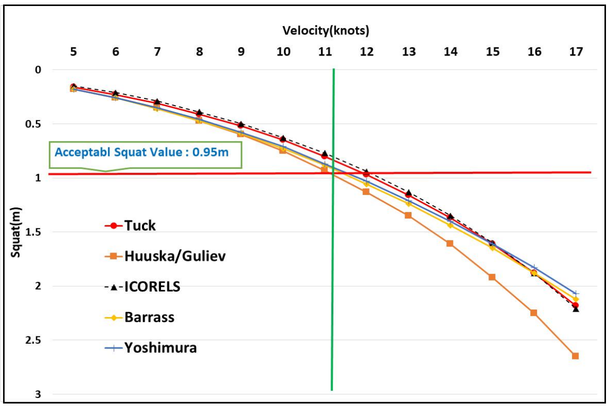

Fig. 4. Squat and Velocity with 10 % draft allowance.

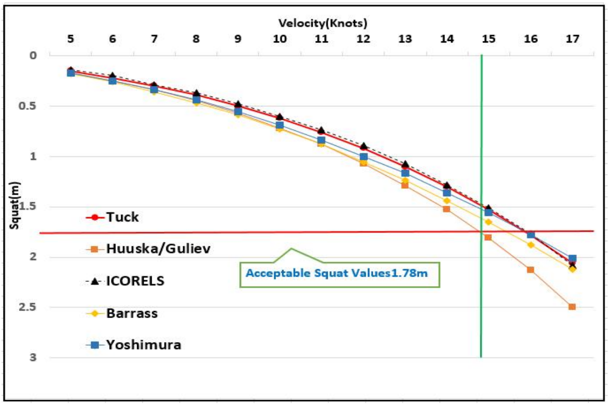

Fig. 5. Squat and Velocity with 15 % draft allowance.

Safe speed was calculated by adding net UKC 0.7 m with 10 %, 15 % of ship's draft according to the fairway depth standard from Korean Port and Fishing Port Design and the results can be found in Fig. 4 and 5.

In the case of 16.5 meters, if 10 % of the ship's draft margin is applied in accordance with port marginal depth standards, and in addition to this, if 0.7 meters of net UKC is further deducted, then the ship's squat is calculated as 0.95 meters. In this circumstance, the speed that meets all the five empirical formulas is 11 kts.

In aligning with the above calculations, based on 16.5 meters, if 15 % of the ship's draft margin is applied in accordance with the fairway approach marginal depth standard, and if 0.7 meters of net UKC is further deducted, then the ship's squat is calculated as 1.78 meters. In this circumstance, the speed that meets all the five empirical formulas is 15 kts.

On the other hand, Busan New Port and Gadeok Channel have speed limit regulations for efficient and safe passage of ships (Port Busan 2020). The speed regulated in the eastern side of the line that connects the west end of Busan New Port Pier No. 3 to the northwest end of Honamdo Island, is stated as 12 kts, as well as the area around the arrival/departure passage of Gadeok Channel.

When the safe speed limit regulations for the safe passage of vessels and the above-calculated results are compared, Busan New Port had the 1 kts higher speed limits than the 11 kts of the calculated result, and Gadeok Channel set the 3 kts lower speed limit than the 15 kts of the calculated result.

6. Conclusion

The size of container vessels is rapidly growing in time. Currently, 24,000 TEU class container ships are in operation, however, 30,000 TEU class container ships are expected to be introduced in 2025.

This research calculated the required UKC and the maximum allowable speed limit in Gadeok Channel where ever-growing, ultra-large containers must pass in order to enter Busan New Port, the largest container port in Korea. For the detailed calculation, 10 % and 15 % of the draft margin is respectively applied on the basis of the ship's draft as suggested by Korean Port and Fishing Port Design to acquire the required UKC and the ship's speed that meets this UKC requirement was further determined based on a various squat formula. This research is summarized as follows.

1) In order to analyze whether the water depth in Gadeok Channel and Busan New Port is sufficient, the various elements that affect UKC are examined. Through this process, it was confirmed that additional 0.7 m of UKC is required, excluding the ship's draft and squat.

2) Within the port area, the allowable squat value was 0.95m while ensuring 10 % of marginal depth. Thus, for 24,000 TEU class vessels, the maximum speed that meets this figure is 11 Kts which is 1 kts lower than 12 kts of Busan New Port Speed Limit. Based on this result alone, speed limit regulation in Busan New Port exceeds the calculated value by 1 kts. So it was found that it is necessary to take consideration in terms of safety aspects.

3) In the approach channel, the allowable squat value was 1.78 m while ensuring 15 % of the marginal depth. The maximum speed that meets this requirement is 15 kts which is 3 kts higher than 12 kts of Gadeok Channel speed limit. Based on this result alone, speed limit regulation in Gadeok Channel is 3 kts lower than the calculated value. So the increasing speed limit to facilitate smooth flow of vessel traffic can be considered if necessary.

This research could not reflect all UKC components and has a limitation in finding the speed limit in a specific sea area by applying only the standards from Korean Port and Fishing Port Design. Therefore, it is difficult to accurately determine UKC and maximum speed for safe passage in Busan New Port and Gadeok Channel based on this research results alone.

However, in line with the trend that the size of container ships continues to grow, by finding the required UKC for safe passage based on of the largest container ship in modern time and setting out the speed limit that satisfies safe standards, this research is worth noting by reviewing current safe speed regulations of their appropriateness and further to prepare for the near future.

As vessels with larger draft and air draft are expected to be introduced in the future, it is considered that more accurate marginal depth and speed limits can be suggested if extended research is further conducted based on this research.

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