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A Comparative Analysis on the Application of Harbor Design Criteria to Channels at Ulsan Port

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Abstract : *Ulsan Port is the main port for handling liquid cargo because of natural environmental conditions and the distribution of port infrastructures in Korea. Damage to both liquid cargo vessels and the port structure caused by maritime accidents could have a serious impact on property and human lives as well as the marine environment. For safe navigation, the parties concerned should ensure the suitability of various design criteria at the harbor design stage. In this paper we analyze and compare various domestic and international harbor design criteria, and then apply each criteria to Ulsan port to evaluate its overall safety. Additionally, this paper specifies certain precautions in terms of reviewing a ship's safety for each channel at Ulsan Port, and suggests possible improvements to optimize channel design.*

Key words : *Ulsan Port, Liquid Cargo Port, Channel, Depth of Water, Turning Basin, Harbor Design Criterion*

1. Introduction

The port of Ulsan, on southeastern of Korean Peninsula, has played the leading role to the development of economic and industrial growth since 1960's with the help of geographical location and port infrastructure. The port is located at the artery of transportation for the liquid cargoes prepared for the large liquid cargo storage facilities. The port is divided into the main port of Ulsan, Onsan Port, Ulsan New Port and Mipo Port depending on the geographic location and primary function of the port complex.

Generally, the important factors for water facility design in a harbor are channel alignment, channel width and length, depth of water, and size of turning basin, etc. The design procedure for each element of waterway geometry is provided to optimize the design(Fisheries an Oceans Canada, 2013). There are many guidelines for design of the channel including European rule, American rule, and Japanese rule. This paper compared and figured out the differences among the PIANC Rule (Permanent International Association of Navigation Congress Rule, 2014), USACE's Rule (US Army Corp of Engineers, USACE, 2006), and Korean rule. And this specified precautions for the safe navigation based on the comparison results of the numerical values for suitability of harbor design criteria for each channel on Ulsan Port.

2. Korean Harbor Design Criteria

The Korean port design criteria detailed in, "The guideline of design for harbor and fishing port (MOF, 2014)", was applied for the suitability for safety on Ulsan Port with special attention to chapter 6 was included the criteria for the harbor facilities, dredge and reclamation.

The harbor facilities have to plan with regard the effects of the berthing facilities including channel, anchorage, turning basin, small dock and the relation with counter facilities and the waters, submarine topography, the flow of the seawater, marine traffic, and other environment and the harbor concerned, and future developed plan of harbor concerned and fishing port. Also, they need to consider the ships' use of the waters including the ship's characteristics, maneuvering performance, the cargo handling, and expansion of ship's size.

The main factors for harbor design criteria in Korea are detailed below.

2.1 Channel Width

The width of channel must take into account weather condition effect, including target ship's particulars, marine traffic situation and the traffic flow, the length of channel, marine traffic quantity, the current velocity and direction and other environmental situations. But the minimum width of channel should be constructed so as not to affect

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to ship's safe navigation when establishment of refuge or having very short length of channel using a tugboat. The width of general channel would be set up referring as following.

① In a two-lane channel, the width should be over 1L(Length of all)

- cases in which the length of the navigation channel is relatively long: 1.5L
- cases in which the target vessels frequently pass in both ways through the channel: 1.5L
- cases in which the target vessels frequently pass in both ways through the channel and the length of th channel is relatively long: 2L

② For a one-way channel, an appropriate width that is 0.5L or larger is adopted. When the width becomes less than 1.0L, it is desirable to introduce sufficient safety measures such as the provision of facilities to assist navigation.

2.2 Depth of Water

The depth of channel should allow for an appropriate under keel clearance for safe navigation as follows.

① cases in which the ports secure harbor calmness: 10% of maximum draft.

② cases where swell does not enter the approach channel or entrance: 15% of maximum draft.

③ cases in which a channel is relatively long or where swell enter the channel: 20% of maximum draft.

The keel clearance with wave-induced ship motion is generally set up two third of wave height in small and medium-sized ships and half of wave height in large sized ships. In the shallow waters or narrow cross-section water area, the water adjacent a vessel is accelerated, this makes the pressure lowered that causes the ship to be closer to the seabed and ship's rotational performance would be bad but ship's course-keeping ability would be better in the drastic change of trim that may cause the vessel to dip towards the stern or towards the bow.

2.3 Turning Basin

The water area necessary for ship's turning is desirable to make sure of over certain scale. Also, the water area should be secure the appropriate depth and harbor calmness and the turning basin is suited to the design in the front berth facility, taking into account other harbor facilities. The standard area of tuning basin is as follows.

① Bow turning without assistance of tugboats: Circle having a diameter of 3L.

② Bow turning using tugboats: Circle having a diameter of 2L.

When a ship is equipped with thruster of appropriate propulsion, the design water area could be less than the standard above if making sure the safety through the simulation verification.

As for small ships, when the above standard area cannot be provided due to topographic conditions, the area of turning basin may be reduced to the following level by using mooring anchors, winds, or tidal currents.

① Bow turning without assistance of tugboat: Circle having a diameter of 2L.

② Bow turning using tugboat: Circle having a diameter of 1.5L.

In those cases where the standard size cannot be provided due to topographical constraints but a water area adjacent to the basin can be used in case of emergency, the basin area smaller than the standard size may be used as long as the smaller area is considered sufficient to meet the safety requirements.

Korean channel design criteria are presented in Table 1.

Table 1 Design Criteria in Korea

Factors	Design Criteria
Width(Single)	0.5L~1.0L
Width(two-lane)	1.5L~2.0L
Depth(Min/Max)	Under Good Harbor calmness : 1.1D With Wind and current : 1.2D
Turning Basin	Self turning : 3L With tugboat assistance : 1.5L

3. Foreign Harbor Design Criteria

Generally, there are two widely used global standard. One is the PIANC Rule(Soehngen & Eloot, 2014) in European countries, the other is “Hydraulic Design of Deep-draft Navigation Projects(USACE, 2006)” in USA.

This paper compared and figured out the important factors to establish the harbor in aspect of the width, the depth and the turning basin of the channel.

3.1 PIANC Rule

One of the most useful channel design criterion is the PIANC Rule in European countries. In this section, a concept design method for approach channels is introduced. It is meant for use in early design and trade-off studies. It represented good modern practice, and channels designed through this method should result in an adequate level of navigational safety. The concept design method deals with the width and depth of straight sections and gives guidelines for bends.

(1) Channel Width

The bottom width of the waterway is given for a one-way traffic channel by:

$$w = w_{BM} + \sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} \qquad (1)$$

and for a two-way traffic channel by:

$$w = 2w_{BM} + 2\sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} + \sum w_p \qquad (2)$$

where, w_{Br} and w_{Bg} are the bank clearances on the red and green sides of the channel, $\sum w_p$ is passing distance comprising the sum of a separation distance based on ship speed and an additional distance based on traffic density and the w_i are given in Table 2.

The basic maneuvering width w_{BM} which is a multiple of the beam B of the design ship, is given in Table 3. This basic maneuvering width is that required by the design ship to sail safely in very favourable environmental and operational conditions.

Table 2 Additional Widths for Straight Channel Sections

w_i	Width
With Prevailing cross wind and current	1.5B
Without Prevailing cross wind and current	0.6B
Aids to Navigation	Optional

Table 3 Basic Maneuvering Lane

Ship maneuverability	Good	Moderate	Poor
w_{BM}	1.3B	1.5B	1.8B

To the basic maneuvering lane width are added additional widths to allow for the effects of wind, current, etc., which gives the maneuvering lane w_M. In two-way traffic situation, w_p could add maximum 2.0B depending on the ship's speed or traffic density, and bank clearance (w_{Br} or w_{Bg}) could do maximum 1.3B by sloping channel edges and shoals or steep and hard embankments, structures and so on.

To sum up, the channel width is 1.6 to 7.2B in one-way traffic, depending on the navigational aids and 4.2 to 15.1B for two-way traffic.

(2) Depth of Water

Depth is estimated from at-rest draft of design ship, tide level throughout transit of channel, squat, wave-induced motion, a margin depending on type of bottom, and water density and its effect on draft. All these values for draft, squat, wave action and margin are additive. This rule is recommended minimum depth of water as below.

① If the ship's speed is over 15 knots in the inland waterway, it is necessary for the depth of 1.15D.

② If the outer waterway with over 2.0 meters swell, it is necessary for the depth of 1.4D.

In the absence of other information minium values of depth/draft ratio should be taken 1.1 in sheltered waters, 1.3 in waves up to one meter in height and 1.5 in higher waves with unfavourable periods and directions.

(3) Turning Basin

The size of turning area should be satisfied with below.

① If with tugboat assistance, it is necessary for the circle with 2.0L diameter.

② If without tugboat assistance, it is necessary for the circle with 4.0L diameter.

The turning basin is the area where vessels are often assisted by tugs to their berths and may be turned beforehand. In the Concept Design phase, the nominal diameter of the turning basin should be over 2L diameter. In some cases, in particular for small ports, or where no tugs are available, the diameter should be 3.0L. Depending on the weather condition, the turning basin could be reduced. The ship will have 1.5 times the length design ship with tugboat assistance, or 3.0 times the length without tugboat assistance under the good weather condition.

PIANC Rule channel design criteria is presented in Table 4.

Table 4 Design Criteria of PIANC Rule

Factors	Design Criteria
Width (Single)	Ship's speed 5~8kts in the open sea : 1.6B~7.2B
Width (two-lane)	Ship's speed 5~8kts in the inland sea: 4.2B~11.7B Ship's speed 5~8kts in the open sea: 4.4B~15.1B
Depth	Ship's speed over 15kts in the inland sea : 1.15D With over 2m swell in the open sea : 1.4D
Turning Basin	Self turning : 3.0L With tugboat assistance : 1.5L

3.2 USA

There are some rules like “Hydraulic Design of Deep-Draft Navigation Projects” (USACE, 2006), “Naval Facilities Engineering Command” (NAVFAC, DM-26.1, 2008), “Unified Facilities Criteria” (UFC), “Military Harbors and Coastal Facilities(USACE, 2010)” etc., in USA.

This section is presented the design criteria based on the USACE’s.

(1) Channel Width

Numerous studies have been made reviewing generally accepted design practice in dimensioning channel widths for ship navigation. For one-way ship traffic, values vary from 2.0 to 6.0 or even 7.0 times the design ship beam. Based on some test results, a value of 2.5 times the design ship beam for canals with negligible currents should be conservative. Using this value and other available data, the width would vary from 3.0 to 5.0 times the beam of the design ship in one-way ship traffic channel. Developing a similar allowance for two-way ship traffic is that the width would vary from 5.0 to 8.0 times the beam of the design ship.

The design channel width for navigation projects with maximum currents greater than 3.0 knots should be developed with the assistance of a ship simulator design study. Furthermore, bank suction can significantly affect ship maneuvering in narrow channels, however, there is no simple analytical relationship between these effects and channel width design criteria. Bank effects should be considered during channel design and can be handled most efficiently through the use of numerical modeling techniques such as those used in a ship simulator.

(2) Depth of Water

The depth of water should preferably maintain to sail the biggest draft ship and afford the safe navigation when the ship’s squat, additional subsidence in fresh water, trim, wave, safe clearance depth and so on.

(3) Turning Basin

The size of the turning basin should provide a minimum turning diameter of at least 1.2 times the length of the design ship where prevailing currents are 0.5 knot or less. Recent simulator studies have shown that turning basin should provide minimum turning diameters of 1.5 times the length of the design setup where tidal currents are less than 1.5 knots. The turning basin should be elongated along the prevailing current direction when currents are greater than 1.5 knots and designed according to tests conducted on a ship simulator. Turning operations with tankers in ballast condition or other ships with high sail areas and design wind speeds of greater than 25 knots will require a special design study using a ship simulator.

Port design criteria by USACE is presented in Table 5.

Table 5 Design Criteria of USACE

Factors	Design Criteria
Width (Single)	Consecutive Ship’s crossing area with 0~0.5kts current : 3B Various ships’ crossing area with 1.5~3kts current : 5.5B
Width (two-lane)	Consecutive Ship’s crossing area with 0~0.5kts current : 5B Various ships’ crossing area with 1.5~3kts current : 8B
Depth	Under 1.0m Wave : 1.3D Over 1.0m Wave : 1.5D
Turning Basin	With tugboat assistance : 1.2~1.5L

4. Suitability of Design Criteria

The Ulsan Port is classified into 5 channel. No.1 channel is the main waterway from outer port to main port. No.2 is to Jangsaengpo, No.3 is to Onsan, No.4 is to Oil-Hub Southern breakwater of Ulsan New Port, and No.5 is to Oil-Hub Northern breakwater of Ulsan New Port from outer port(Refer to Fig 1).

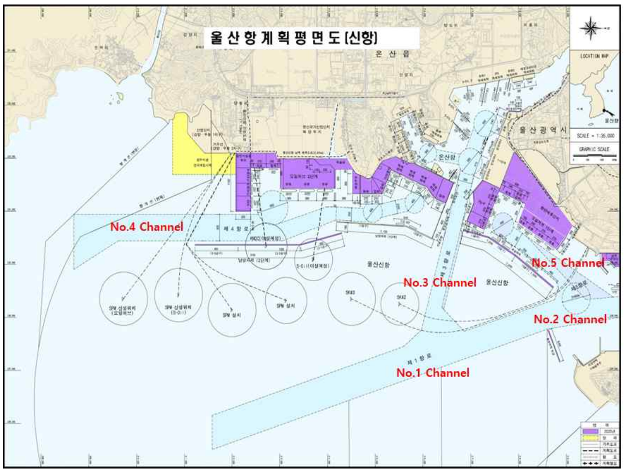

Fig. 1 Overview of Ulsan Port(Ground Plan of Ulsan port, Ulsan Regional Office of Oceans and Fisheries)

The particulars by channel create the design ship, which is based on the data from Port-MIS in 2014, in accordance with being presented by “Guideline of Design for Harbor and Fishing Port (2014)". Table 6 is shown the particulars by channel in Ulsan Port. Also, Table 7 is presented the available maximum ships' particulars in Ulsan Port.

Table 6 Channels' Particulars (unit: m)

Channel	Min. Width	Max Width	Min Depth	Max Depth	Length
No.1	320	520	12.2	52	12,500
No.2	220	926	12.7	13.7	1,250
No.3	300	1,630	18.5	27.5	3,250
No.4	370	755	25.5	28.5	3,000
No.5	300	390	15.0	17.0	2,250

This paper makes the maximum ships' size based on the ships' particulars entered or departed the typical Ulsan Port by channel. Table 7 is presented the result complying with Design Criteria of Harbor and Fishing Port.

This section compared and analyzed the suitability of the individual design criteria based on maximum ships' particular by channel.

Table 7 Maximum Ships' Particulars in Ulsan Port

Channel	Max. (DWT)	Ship's Type	LOA (M)	B (M)	D (M)
No.1	150,000	Oil Product Carrier	277	48.6	17.2
No.2	50,000	Chemical Tanker	209	34.3	12.0
No.3	120,000 (100,000)	Crude Oil Tanker	(250)	(42.7)	(14.8)
No.4	200,000	Crude Oil/ Chemical Tanker	300	50	25.0
No.5	70,000 (60,000)	Crude Oil Tanker	228	38.1	12.9
	120,000 (100,000)	Crude Oil Tanker	(250)	(42.7)	(14.8)

4.1 No.1 Channel

No.1 Channel is from outer port to main port of Ulsan. Based on the Channel's particular and maximum ship's particular, this section is shown the result applying for domestic and other design criteria in Table 8.

Firstly, the width of channel would allow for 320 meters to 520 meters in the channel width according to Table 6. But the result does not meet the domestic design criteria(554m) and PIANC Rule(734m). Secondly, the depth of water is not satisfied with all criteria, but the channel of Ulsan Port fulfilled the minimum depth with appropriate harbor calmness in accordance with domestic design criteria which is counted as 10% maximum draft of the design ship. Lastly, the turning basin is classified into turning basin (360º turning for changing ship's direction or leaving berth) and berth basin (usual 180º turning for berthing). In the case of No.1 channel, there is appropriate depth of water from the beginning of the channel to eastern breakwater and ample waters in outer waterway for ship's emergency turning. But the ship should ask enough number of tugboats and close contact with VTS for safe navigation from eastern breakwater to the entrance of No.2 channel if need to ship's emergency turning.

Table 8 Result of Design Criteria in No. 1 Channel (unit: m)

	Korea (Min./Max.)	PIANC (Min./Max.)	USA (Min./Max.)
Width (Single)	139/277 (O/O)	78/350 (O/X)	146/268 (O/O)
Width (two-lane)	416/554 (X/X)	205/734 (O/X)	243/389 (O/O)
Depth	18.92/20.64 (X/O)	19.78/24.08 (X/O)	22.36/25.8 (X/O)
Turning Basin	416/831 (with tug)	416/831	333/416 (with tug)

4.2 No.2 Channel

No.2 Channel is from the outer port to Jangsaengpo Port with 1,250 meters of total channel length. According to each criterion, the result is presented in Table 9.

Table 9 Result of Design Criteria in No.2 Channel (unit: m)

	Korea (Min./Max.)	PIANC (Min./Max.)	USA (Min./Max.)
Width (Single)	105/209 (O/O)	55/247 (O/X)	103/189 (O/O)
Width (two-lane)	314/418 (X/O)	145/518 (O/O)	172/275 (O/O)
Depth	13.2/14.4 (X/X)	13.8/16.8 (X/X)	15.6/18 (X/X)
Turning Basin	314/627 (with tug)	314/627	251/314 (with tug)

(O : Satisfaction, X : Unsatisfaction)

The width(220m) of No.2 channel is satisfied with the all minimum criteria. In the case of the depth of water from 12.7m to 13.7m are not proper any design criteria, and then the full loaded 50,000DWT ship should sail in

No.2 channel at the time of high water or manage the appropriate safe draft. Also, the size of turning basin does not comply with any criteria. But the ship could use the ample depth and waters to turn in the beginning of the channel, and ship should increase the number of tugboat and keep the close cooperation with VTS in the front waters of Jangsaengpo Port.

4.3 No.3 Channel

According to each criterion, the result of No.3 Channel is presented in Table 10.

Table 10 Result of Design Criteria in No.3 Channel

(unit: m)

	Korea (Min./Max.)	PIANC (Min./Max.)	USA (Min./Max.)
Width (Single)	125/250 (O/O)	69/308 (O/O)	129/235 (O/O)
Width (two-way)	375/500 (X/O)	180/645 (O/O)	214/342 (O/O)
Depth	16.28/17.76 (O/O)	17.02/20.72 (O/O)	19.24/22.2 (X/O)
Turning Basin	375/750 (with tug)	375/750	300/375 (with tug)

(O : Satisfaction, X : Unsatisfaction)

The width (300m) is satisfied with minimum width in two-way lane except the domestic Rule. The depth of water is from 18.5m to 27.5m, and that is satisfied with criteria except the USACE. In the case of turning basin, the minimum diameter(300m) of USACE is the result when current is less 0.5 knot with assistance of tugboats and a pilot, and the navigator should sail very carefully. Especially, the navigator must sail very carefully in the waters of breakwater of Onsan in the end of the channel because of any other assistance.

4.4 No.4 Channel

According to each criterion, the result is presented in Table 11. The width (370m) of single traffic channel is satisfied with three criteria and maximum width in two-way traffic does. The depth of water varies from 25.5m to 28.5m, but that is not satisfied with any criteria. The turning basin of 700m will be established in the harbor, and then ship will be safe when with assistance of a pilot and tugboats.

Table 11 Result of Design Criteria in No.4 Channel

(unit: m)

	Korea (Min./Max.)	PIANC (Min./Max.)	USA (Min./Max.)
Width (Single)	150/300 (O/O)	80/360 (O/O)	150/275 (O/O)
Width (two-lane)	450/600 (X/O)	210/755 (O/O)	250/400 (O/O)
Depth	27.5/30 (X/X)	28.8/35 (X/X)	32.5/37.5 (X/X)
Turning Basin	450/900 (with tug)	450/900	360/450 (with tug)

(O : Satisfaction, X : Unsatisfaction)

4.5 No.5 Channel

According to each criterion, the result of No.5 Channel is presented in Table 12.

Table 12 Result of Design Criteria in No.5 Channel

(unit: m)

	Korea (Min./Max.)	PIANC (Min./Max.)	USA (Min./Max.)
Width (Single)	125/250 (O/O)	69/308 (O/X)	129/235 (O/O)
Width (two-lane)	375/500 (X/X)	180/645 (O/X)	214/342 (O/O)
Depth	16.28/17.76 (X/X)	17.02/20.72 (X/X)	19.24/22.2 (X/X)
Turning Basin	375/750 (with tug)	375/750	300/375 (with tug)

(O : Satisfaction, X : Unsatisfaction)

No.5 Channel was not yet complete, but its design complies with all criteria in one-way traffic lane. In the two-way traffic lane, the width is only satisfied with minimum size in PIANC Rule(180m) and USACE(214m). The depth of water will be dredged 17 meters from the entrance to 200 meters of the inner channel in T/S wharf for 120,000DWT ship, and 15 meters to inside for 70,000DWT ship. Also, 15 meters and/or 17 meters depth of closed channel due to northern breakwater are not satisfied with the maximum size of 120,000DWT tanker. But the turning basin will be established the size of 600 meters diameter near the entrance between No.1 and No.5 channel, and that for 70,000DWT ship is satisfied with minimum with tugboat assistance. The 120,000DWT tanker with tugboat assistance will able to turn without any problem in the intersection with 600 meters diameter.

4.6 Summary

When one-way traffic channel, every channels complied with Korean design criteria. When two-way traffic channel, No.1 channel having relatively long length is satisfied with the design criteria. In No.2 channel, when 50,000DWT chemical carrier sailed in one-way traffic channel, VTS should serve all information about the traffic situation for safe navigation. In No.3 channel, large carriers should sail by one-way traffic instead of two-way transit at the narrowest entrance of Onsan Port, carefully monitored by VTS. When the 120,000DWT ship goes to T/S wharf, she should sail in one-way traffic in No.5 channel.

Secondly, the depth of water securing harbor calmness regarded as being suitable if minimum criterion is maximum ship's draft by 10%. All channels are satisfied with design criteria except 150,000DWT carrier in No.1 channel. The minimum depth of water of SK8 wharf is 18 meters, which depth needed is 17.2 meters, the ship of 16.5m maximum draft is able to enter and depart to the berth through flexile operation by VTS. However, they fundamentally need to secure the proper depth of water through further researches for the ships' safe navigation upon consideration of the advent of mega ship and increasing marine traffic.

Thirdly, turning basin is not satisfied with design criteria in No.2 and No.3 channel even if tugboat assistance. But they are able to turn at the emergency situation in the affordable waters with appropriate depth of water from the beginning of the channel to the entrance of berth.

5. Conclusion

The Ulsan Port is the first liquid cargo handling port with an natural environmental condition and hinterland, which plays important role in international trade in Korea. The design of the channel will be determined to accommodate the design ship representative of the project forecasted user fleet.

The discussion of this paper focuses on the comparison of numerical values which applied individual channel of Ulsan Port to three different harbor design criteria. Based on those results, this specified several precautions to get rid of risk elements for safe navigation. As with the application of any criteria, good judgement, experience and common sense will be required in their application. Each factor of design process is provided to optimize the waterway geometry. The government is necessary to review, update and, where appropriate, expand on the design recommendations on vertical and horizontal dimensioning as presented in various criteria. Because of recent developments in ship design, from better understanding of ship maneuverability and behaviour in waves through further research in ship simulation and modelling, it is necessary to update to existing guidelines comprehensively.

More precautions should be made for safe navigation considering the primary ship's type and individual environmental characteristics of port. Further researches would follow up on other ports to figure out the improvements for safe navigation.

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