Chapter 8 Ships

[Public Notice] (Dimensions of Design Ships and Related Matters)

Article 18

1 The dimensions of design ships (hereinafter referred to as the ships used as the input data in the performance verification of the facilities subject to the technical standards) shall be set according to the methods prescribed respectively in the following items:

(1) In the case where design ships are identifiable, the dimensions of the design ships shall be used.

(2) In the case where design ships are unidentifiable, the dimensions shall be set appropriately based on the statistical analyses of the dimensions of ships in operation.

2 The actions from ship berthing, ship movements, and traction by ships shall be set according to the methods provided in the subsequent items in consideration of a single action or the combinations of two or more actions to be considered in the performance criteria and the performance verification of the facilities:

(1) The actions from ship berthing shall be set with appropriate methods in consideration of the dimensions of design ships, structures of the facilities, berthing methods, berthing velocities, etc.

(2) The actions from ship movements shall be set with appropriate methods in consideration of the dimensions of design ships, structures of the facilities, mooring methods, characteristics of mooring system, and the winds, waves, water currents, etc. acting on design ships.

(3) The actions from the traction by ships shall be set with appropriate methods in consideration of the dimensions of design ships, mooring methods, and the winds, waves, water currents, etc. acting on design ships.

[Interpretation]

7. Setting of Natural Conditions

(7) Items related to ships (Article 6 of the Ministerial Ordinance and the interpretation related to Article 18 of the Public Notice)

① **Principal dimension of design ships**

Design ships are those, among the ships using the facilities concerned, assumed to have the most significant effects on the performance verification of the facilities. It shall be noted that design ships vary depending on the performance criteria to be applied even for the same facilities and that they are not always the ships with the largest gross tonnage.

② **Actions due to ship berthing and traction by ships**

(a) Actions caused by ship berthing

The actions caused by ship berthing on mooring facilities shall be properly considered. In setting the actions caused by ship berthing, ship berthing energy can be calculated using proper methods based on ship masses, ship berthing velocities, virtual mass factors, eccentricity factors, flexibility factors, and the berth configuration factors.

(b) Actions caused by ship movements

The actions caused by ship motions on mooring facilities shall be properly considered as needed. Proper methods to be considered are oscillation calculation, etc.

(c) Actions due to the traction by ships

The traction caused by ships on mooring facilities shall be properly considered as needed. The setting of the actions due to the traction by ships properly takes account of the actions caused by moored and berthed ships.

1 Principal Dimensions of Design Ships

1.1 Standard Values

(1) Design ships are those, among the ships expected to use the facilities concerned, assumed to have the most significant effects on the performance verification of the facilities. Therefore, in the case where design ships are identifiable, their principal dimensions may be used.

(2) In the cases, for example, public port facilities, where design ships are unidentifiable in advance, the values by ship type in **Table 1.1.1** may be used as the standard values of tonnages, lengths overall, lengths between perpendiculars, molded breadths, and full load drafts. The standard values in **Table 1.1.1** are prepared based on the statistical analysis of the dimensions of the existing ships with a coverage ratio of 75% for each tonnage category.[1] With regard to the gross tonnage (GT), there are two different gross tonnages (GT): one is international gross tonnage and the other is domestic gross tonnage. Thus, types of the gross tonnages are specified in Items 4 to 9 of **Table 1.1.1**. In addition to gross tonnages, deadweight tonnages are also used in **Table 1.1.1** as the representative index expressing ship sizes for some types of ships. The principal dimensions used in the tables are schematically explained in **Fig. 1.1.1**. For the dimensions of the ships which are not shown in **Table 1.1.1**, such as patrol boats of the Japan Coast Guard, reference can be made to **the Manual for Disaster Prevention Base in Coastal Areas**.[2) and 3)]

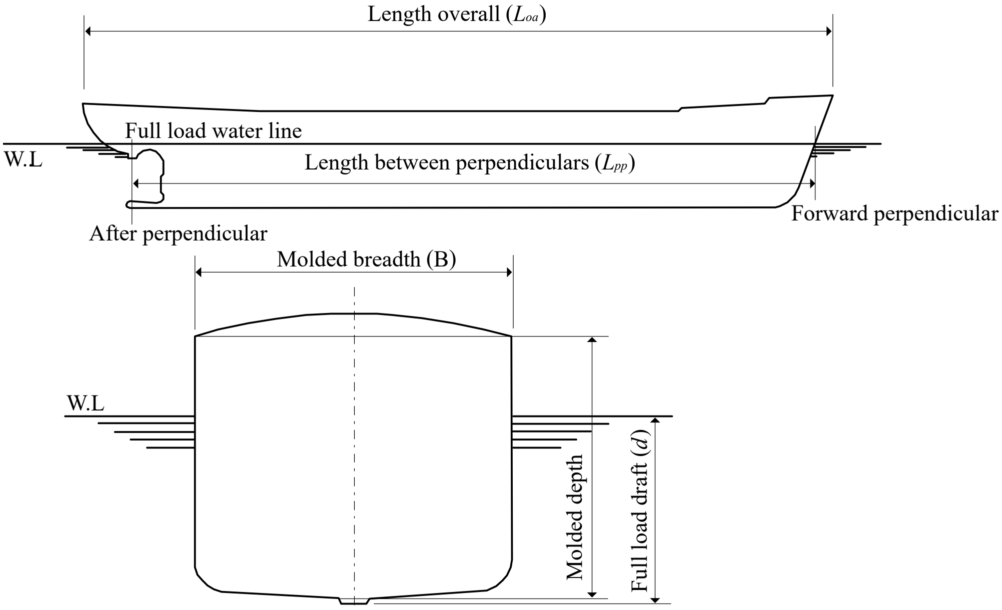

Fig. 1.1.1 Principal Dimensions of Ships

Table 1.1.1 Standard Values of the Principal Dimensions of Design Ships

1. General Cargo Ships

Deadweight tonnage DWT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
1,000	63	57	10.4	3.7
2,000	77	71	12.8	4.6
3,000	87	81	14.3	5.3
5,000	102	95	16.6	6.2
6,000	108	100	17.5	6.5
10,000	125	118	20.3	7.7
12,000	132	125	21.4	8.1
15,000	142	134	22.8	8.7
18,000	149	141	24.0	9.2
30,000	174	166	27.9	10.8
40,000	190	181	30.3	11.8
50,000	203	195	32.3	12.6
55,000	209	200	32.3	13.0
70,000	225	216	32.3	14.0
90,000	242	234	38.2	15.1
120,000	264	256	41.5	16.6
150,000	282	274	44.3	17.7
200,000	308	300	48.1	19.4
250,000	328	319	56.2	20.8
300,000	333	324	57.3	22.0
400,000	361	353	65.0	23.1

2. Container Ships

Deadweight tonnage DWT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)[Note]
10,000	138	130	22.2	7.9	900 (50–1,345)
20,000	175	165	27.0	10.2	1,700 (648–1,808)
23,000	184	173	28.1	10.8	1,700 (1,400–2,259)
27,000	194	183	29.4	11.9	1,800 (1,356–2,268)
30,000	201	190	30.3	11.9	2,500 (1,728–3,535)
40,000	228	215	31.8	11.9	2,800 (1,700–4,370)
50,000	269	255	32.3	12.8	4,300 (2,496–5,752)
60,000	285	272	35.5	13.5	4,700 (2,815–7,030)
100,000	338	322	45.3	14.6	8,500 (5,541–10,622)
140,000	367	353	48.5	15.8	13,100 (6,600–15,000)
165,000	378	360	52.0	16.2	14,000 (11,000–15,550)
185,000	400	382	59.4	16.2	17,700 (15,908–19,200)
200,000	400	382	59.4	16.2	19,200 (17,608–21,413)

Note: The reference values for the container carrying capacity of each DWT class are median (approximate), minimum, and maximum values.

3. Tankers

Deadweight tonnage DWT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
1,000	61	57	10.2	4.1
2,000	77	72	12.4	5.0
3,000	89	84	13.9	5.6
5,000	107	100	16.1	6.4
10,000	136	128	19.7	7.8
15,000	157	148	22.1	8.8
20,000	173	164	24.0	9.5
30,000	177	168	26.9	10.6
50,000	203	193	32.9	12.3
70,000	223	213	32.9	13.5
90,000	239	228	43.5	14.5
100,000	246	235	43.5	14.9
150,000	274	263	48.9	16.7
300,000	334	322	60.2	22.1

4. Roll-on Roll-off (RORO) Ships

4.1 RORO Ships (GT: Domestic gross tonnage)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
3,000	120	110	19.0	5.6
5,000	141	131	22.2	6.2
10,000	171	161	27.4	7.0
15,000	171	161	30.3	7.6

4.2 RORO Ships (GT: International gross tonnage)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
20,000	195	181	27.3	7.9
40,000	200	191	31.5	9.1
60,000	211	191	34.2	9.9

5. Pure Car Carrier (PCC) Ships

5.1 PCC Ships (GT: Domestic gross tonnage)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
3,000	114	106	17.3	5.0
5,000	140	130	21.2	6.1
40,000	200	192	33.1	10.2

5.2 PCC Ships (GT: International gross tonnage)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
12,000	147	136	24.0	6.5
20,000	162	151	26.3	7.0
30,000	175	164	28.3	7.5
40,000	184	174	31.4	9.2
60,000	201	192	33.3	10.2
70,000	230	220	33.3	10.9

6. Liquefied Petroleum Gas (LPG) Carriers (GT: International gross tonnage)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
3,000	98	92	16.2	6.0
5,000	113	106	18.5	7.0
10,000	138	130	22.3	8.6
20,000	167	159	26.7	10.5
40,000	228	219	37.3	12.2
50,000	228	219	37.3	12.2

7. Liquefied Natural Gas (LNG) Carriers (GT: International gross tonnage)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
20,000	168	159	26.8	8.0
30,000	192	183	30.6	8.9
50,000	228	217	36.0	10.1
80,000	267	255	41.9	11.5
100,000	287	275	45.0	12.2
130,000	314	301	48.9	13.1
160,000	345	333	54.6	13.8

8. Passenger Ships (GT: International gross tonnage)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
3,000	94	81	16.5	4.2
5,000	112	96	18.5	4.8
10,000	143	122	21.8	5.7
20,000	183	155	25.5	6.4
30,000	211	178	28.0	6.9
50,000	252	213	32.3	7.6
70,000	284	239	32.3	8.0
100,000	294	270	35.6	8.4
130,000	325	297	38.5	8.8
160,000	345	311	41.0	9.1

9. Ferries (GT: Domestic gross tonnage)[Note]

9.1 Intermediate and Short-Distance Ferries (Navigation Distances Less than 300 km)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
400	55	46	11.6	2.8
700	67	58	13.2	3.3
1,000	76	67	14.4	3.6
3,000	112	104	18.6	4.7
7,000	152	145	22.6	5.8
10,000	172	167	24.6	6.4
13,000	189	186	26.1	6.8

9.2 Long-Distance Ferries (Navigation Distance Not Less than 300 km)

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
6,000	149	136	22.5	6.2
10,000	176	162	25.9	6.2
15,000	202	187	27.6	6.9
20,000	222	207	27.6	7.4

Note: In international ferries, the international gross tonnages can be converted to domestic gross tonnages by the following relational equation.[4)]

$$Y = 1.868X \quad \textbf{(1.1.1)}$$

where

Y : international gross tonnage

X : domestic gross tonnage

(3) In these tables, the standard values of the principal dimensions of design ships are those for each tonnage category and obtained through statistical analyses, which has an overall coverage ratio of 75%.[1)] Thus, there may be some ships having larger dimensions than the standard values in the same tonnage categories in these tables and other

ships having smaller dimensions in a larger tonnage category than the standard values in a lower tonnage category in these tables.

(4) The sources of the data used for establishing the tables of the principal dimensions of design ships are Lloyd's (Jan. 2017),[5] Clarkson (May 2017),[6] and the Register of Ships (2017).[7]

(5) Tonnages

The definitions of various types of tonnages are as follows:

① **Domestic gross tonnage**

The gross tonnage based on the Act on Tonnage Measurement of Ships

② **International gross tonnage**

The gross tonnage based on the International Convention on Tonnage Measurement of Ships

③ **Deadweight tonnage**

The maximum weight, expressed in tons, of cargo that can be loaded on a ship

(6) There are a certain number of container ships, which are called Panamax, and have unique dimensions, including molded breadths of about 32 m, because the navigable molded breadth of the Panama Canal was about 32 m until June 2016. When setting the dimensions of the container ships categorized as Under Panamax and Panamax, **Tables 1.1.2** and **1.1.3** can be used as references. For the dimensions of the large container ships which currently exist and are planned to be built, including very large container ships exceeding 200,000 DWT, **Table 1.1.4** can be used as a reference. For the dimensions of large passenger ships exceeding 220,000 GT, **Table 1.1.5** can be used as a reference.

Table 1.1.2 Principal Dimensions of Container Ships (Under Panamax)[1)]

Deadweight tonnage DWT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)[Note]
10,000	138	129	22.2	7.8	900 (50 – 1,345)
20,000	176	165	26.9	10.2	1,700 (648 – 2,742)
30,000	202	191	30.2	11.8	2,500 (1,221 – 2,872)

Table 1.1.3 Principal Dimensions of Container Ships (Panamax)[1)]

Deadweight tonnage DWT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)[Note]
30,000	196	186	32.2	11.3	2,600 (2,096 – 4,253)
40,000	232	219	32.2	12.1	3,100 (2,400 – 4,370)
50,000	264	248	32.2	12.8	4,300 (2,758 – 5,043)
60,000	293	275	32.2	13.3	4,600 (4,014 – 5,301)

Note: The reference values for the container carrying capacity of each DWT class are median (approximate), minimum, and maximum values.

Table 1.1.4 Principal Dimensions of Container Ships Exceeding 200,000 DWT in Operation and Planned to be Built[5), 6) and 8)]

Deadweight tonnage DWT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Reference: Container carrying capacity (TEU)	Existing or planned to be built
190,326	399.0	378.0	58.6	16.5	20,568	Planned to be built
191,570	399.9	383.0	58.8	16.0	21,413	Planned to be built
191,640	399.9	383.0	58.8	16.0	21,413	Planned to be built
191,688	399.9	383.0	58.8	16.0	21,413	Planned to be built
197,059	400.0	383.0	58.8	16.0	20,150	Planned to be built
197,106	400.0	383.0	58.8	16.0	20,150	Planned to be built
197,500	400.0	383.0	58.8	16.0	20,150	Existing
197,500	400.0	383.0	58.8	16.0	20,150	Planned to be built
199,744	400.0	388.0	59.0	16.0	18,691	Existing
200,000	*	*	*	*	22,000	Planned to be built
200,148	398.5	382.4	59.0	16.0	19,224	Existing
206,000	400.0	*	58.6	16.5	20,568	Existing
201,792	400.0	383.0	59.0	16.0	19,200	Existing
202,036	400.0	383.0	59.0	16.0	19,200	Existing
202,347	400.0	383.0	59.0	16.0	19,200	Existing
202,376	400.0	383.0	59.0	16.0	19,200	Existing
218,000	400.0	384.4	58.5	16.0	20,150	Planned to be built
230,000	400.0	*	59.0	*	20,600	Planned to be built
250,000	399.9	383.0	58.8	16.0	21,413	Existing
250,000	400.0	*	58.6	16.0	20,988	Planned to be built

Note: The values in the above table are based on Lloyd's data (Jan. 2017),[5)] Clarkson's data (May 2017),[6)] and Clarkson's data (Dec. 2017).[8)] Also, the indications of existing and planned to be built are based on the data as of May 2017. In the case where there are two or more existing container ships or those planned to be built which have same DWT, the dimensions of the container ship having larger TEU is used in the table. The symbol * means that corresponding values are unknown.

Table 1.1.5 Principal Dimensions of Passenger Ships Exceeding 220,000 GT[5), 6) and 8)]

Gross tonnage GT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)	Existing or planned to be built
149,215	345.0	301.0	41.0	10.3	Existing
225,282	360.0	330.0	47.0	9.3	Existing
225,282	360.0	330.0	47.0	9.3	Existing
225,282	362.1	330.7	47.0	9.3	Planned to be built
226,963	362.1	331.0	47.0	9.3	Existing
227,000	362.1	330.7	47.0	9.3	Planned to be built

Note: The values in the above table are based on Lloyd's data (Jan. 2017),[5)] Clarkson's data (May 2017),[6)] and Clarkson's data (Dec. 2017).[8)] Also, the indications of existing and planned to be built are based on the data as of May 2017.

1.2 Others

(1) With regard to the small cargo ships, because there is the large variation on the data of the principal dimensions, reference can be made to **Table 1.2.1**, which shows reference values obtained by extracting data on the dimensions of small cargo ships with the coverage ratio of 75% in an object tonnage category.

Table 1.2.1 Reference Values of Principal Dimensions of Small Cargo Ships

Deadweight tonnage DWT (ton)	Length overall L_{oa} (m)	Length between perpendiculars L_{pp} (m)	Molded breadth B (m)	Full load draft d (m)
700	58	53	9.6	3.3

(2) The heights of ships considerably differ even among the ships of identical types or tonnages. Thus, the performance verification of the bridges crossing water ways shall be carried out with due consideration to the heights of design ships from sea surfaces to the highest points. For the heights of ships, reference can be made to the study cases by Takahashi, etc.[9) and 10)]

Particularly, there has been an increase in the number of large passenger ships calling at Japanese ports. Thus, for the purpose of showing a reference for determining whether or not large passenger ships can pass under bridges when they enter or leave ports, the correlation between the international gross tonnages (GT) and mast heights (air drafts), from sea surfaces to the highest points, of which data is obtained through hearing investigation, is shown in **Fig. 1.2.1**.[1)] And it shall be noted that the values obtainable by the regression expression and curve in **Fig. 1.2.1** are not standard ones but merely reference ones on the basis of 75% coverage ratio.

$$Mh = 2.2873 * GT^{0.2810} \quad \text{(Coverage ratio of 75\%)}$$

Mh: Mast height (m)

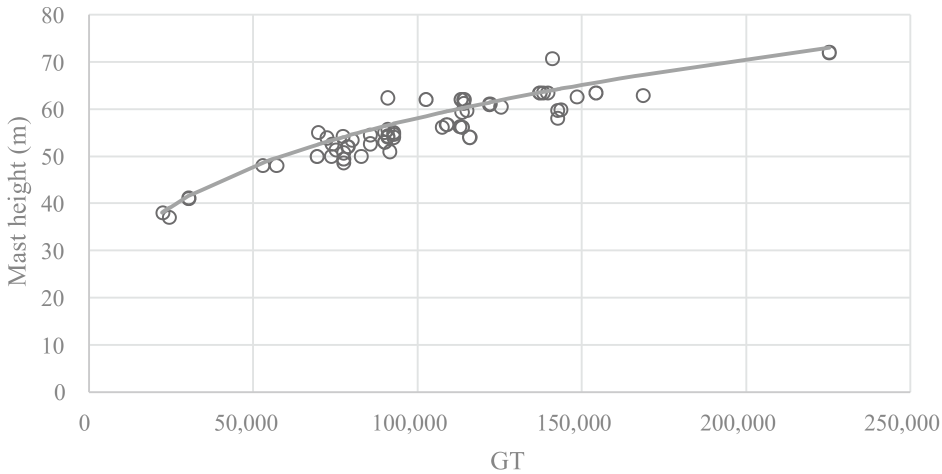

Fig. 1.2.1 Correlation between International Gross Tonnages and Mast Heights of Passenger Ships

(3) In addition to the standard values of full load drafts of cargo ships in **Table 1.1.1**, a calculation method of the maximum drafts of large cargo ships (with approximate DWT exceeding 85,000) when their drafts are reduced (lightly loaded) is explained below.[11)]

① The maximum drafts of ships when lightly loaded with no trims can be calculated by multiplying the full load drafts of design ships by corresponding draft ratios (*Cd*) (%). And the corresponding draft ratios (*Cd*) (%) are the ratios of the maximum drafts when ships are lightly loaded to the full load drafts provided that the ships have no trims and can be calculated by the following relational equation. In case of assuming trims when ships are in operation, the maximum drafts can be calculated by adding trims to the values obtained by multiplying the full load drafts by corresponding draft ratios (%).

$$Cd = 0.4724 \times e^{0.745^{*}\,Lrw} \qquad \textbf{(1.2.1)}$$

where

Cd : corresponding draft ratio (%)

Lrw : loading ratio on a weight basis (%)

② In a case where a loading ratio on a weight basis (*Lrw*) for the object ship in **equation 1.2.2** is unknown, the loading ratio on a weight basis (*Lrw*) can be calculated by using those on a volume basis (hereinafter referred to as the volume loading ratio (*Lrv*)) as shown in the following relational equation:

$$Lrw = (Hc \times Lrv \times Sg) / Dwm \qquad \textbf{(1.2.2)}$$

where

Hc : hold capacity (m^3)

Lrv : volume loading ratio (%)

Sg : specific gravity (ton/m^3)

Dwm : maximum deadweight (ton)

③ When calculating the loading ratio on a weight basis (*Lrw*) in **equation 1.2.2** without knowing hold capacity (Hc) or specific gravity (*Sg*), respective unknown values can be set in the following ways.

(a) When hold capacity (*Hc*) is unknown, it can be calculated by the following relational equation:

$$Hc = 1.1067 \times DWT \qquad \textbf{(1.2.3)}$$

(b) Setting of specific gravity

When specific gravity (Sg) is unknown, the values in **Table 1.2.2** can be referred. In the table, SF value has the same concept as specific gravity (Sg) and represents the capacity (ft^3) per unit weight (L/T) of the cargo.

For typical large cargo ships, the corresponding draft ratios (Cd) can be selected from **Table 1.2.2**, which tabulates the calculation results of the corresponding draft ratios (Cd) according to respective volume loading ratios (Lrv) and specific gravity (Sg) so as to enable the corresponding draft ratios (Cd) to be simply obtained without using **equations (1.2.2)** and **(1.2.3)**.

Table 1.2.2 Specific Gravity and Corresponding Draft Ratios of Cargo Ships by Volume Loading Ratios, Cargoes, and Ship Sizes

Volume loading ratio of 40%

Specific gravity (*Sg*)	SF value	Cargo	*Cd* (Panamax)	*Cd* (Capesize)	*Cd* (*VLOC*)
2.72	13.00	Iron ore	–	–	–
2.35	15.00	Iron ore	–	–	–
2.08	17.00	Iron ore	0.95	0.95	0.95
0.88	40.00	Coal	0.63	0.64	0.64
0.84	42.00	Coal	0.63	0.63	0.63
0.78	45.00	Coal	0.61	0.61	0.62
0.75	47.00	Coal	0.61	0.61	0.61
0.71	50.00	Grain	0.60	0.60	0.60
0.68	52.00	Grain	0.59	0.59	0.59
0.64	55.00	Grain	0.59	0.59	0.59
0.62	57.00	Grain	0.58	0.58	0.58

Volume loading ratio of 50%

Specific gravity (*Sg*)	SF value	Cargo	*Cd* (Panamax)	*Cd* (Capesize)	*Cd* (*VLOC*)
2.72	13.00	Iron ore	–	–	–
2.35	15.00	Iron ore	–	–	–
2.08	17.00	Iron ore	–	–	–
0.88	40.00	Coal	0.68	0.68	0.69
0.84	42.00	Coal	0.67	0.67	0.67
0.78	45.00	Coal	0.66	0.66	0.66
0.75	47.00	Coal	0.65	0.65	0.65
0.71	50.00	Grain	0.63	0.64	0.64
0.68	52.00	Grain	0.63	0.63	0.63
0.64	55.00	Grain	0.62	0.62	0.62
0.62	57.00	Grain	0.61	0.61	0.61

Volume loading ratio of 60%

Specific gravity (*Sg*)	SF value	Cargo	*Cd* (Panamax)	*Cd* (Capesize)	*Cd* (*VLOC*)
2.72	13.00	Iron ore	–	–	–
2.35	15.00	Iron ore	–	–	–
2.08	17.00	Iron ore	–	–	–
0.88	40.00	Coal	0.74	0.74	0.74
0.84	42.00	Coal	0.72	0.72	0.72
0.78	45.00	Coal	0.70	0.70	0.70
0.75	47.00	Coal	0.69	0.69	0.69
0.71	50.00	Grain	0.67	0.67	0.68
0.68	52.00	Grain	0.66	0.66	0.67
0.64	55.00	Grain	0.65	0.65	0.65
0.62	57.00	Grain	0.64	0.65	0.65

Volume loading ratio of 70%

Specific gravity (*Sg*)	SF value	Cargo	*Cd* (Panamax)	*Cd* (Capesize)	*Cd* (*VLOC*)
2.72	13.00	Iron ore	–	–	–
2.35	15.00	Iron ore	–	–	–
2.08	17.00	Iron ore	–	–	–
0.88	40.00	Coal	0.79	0.79	0.80
0.84	42.00	Coal	0.77	0.77	0.78
0.78	45.00	Coal	0.75	0.75	0.75
0.75	47.00	Coal	0.73	0.73	0.74
0.71	50.00	Grain	0.71	0.72	0.72
0.68	52.00	Grain	0.70	0.70	0.71
0.64	55.00	Grain	0.69	0.69	0.69
0.62	57.00	Grain	0.68	0.68	0.68

Volume loading ratio of 80%

Specific gravity (*Sg*)	SF value	Cargo	*Cd* (Panamax)	*Cd* (Capesize)	*Cd* (*VLOC*)
2.72	13.00	Iron ore	–	–	–
2.35	15.00	Iron ore	–	–	–
2.08	17.00	Iron ore	–	–	–
0.88	40.00	Coal	0.85	0.85	0.86
0.84	42.00	Coal	0.83	0.83	0.83
0.78	45.00	Coal	0.80	0.80	0.80
0.75	47.00	Coal	0.78	0.78	0.78
0.71	50.00	Grain	0.76	0.76	0.76
0.68	52.00	Grain	0.74	0.75	0.75
0.64	55.00	Grain	0.73	0.73	0.73
0.62	57.00	Grain	0.72	0.72	0.72

Note: Corresponding draft ratios based on the data on actual ships (maximum deadweight tonnage, etc.) of 87,000 DWT in Panama Class, 170,000 DWT in Capesize Class, and 300,000 DWT in VLOC Class.

(4) For the maximum number of container rows on deck of container ships, **Fig. 1.2.2** can be used as a reference.[1)]

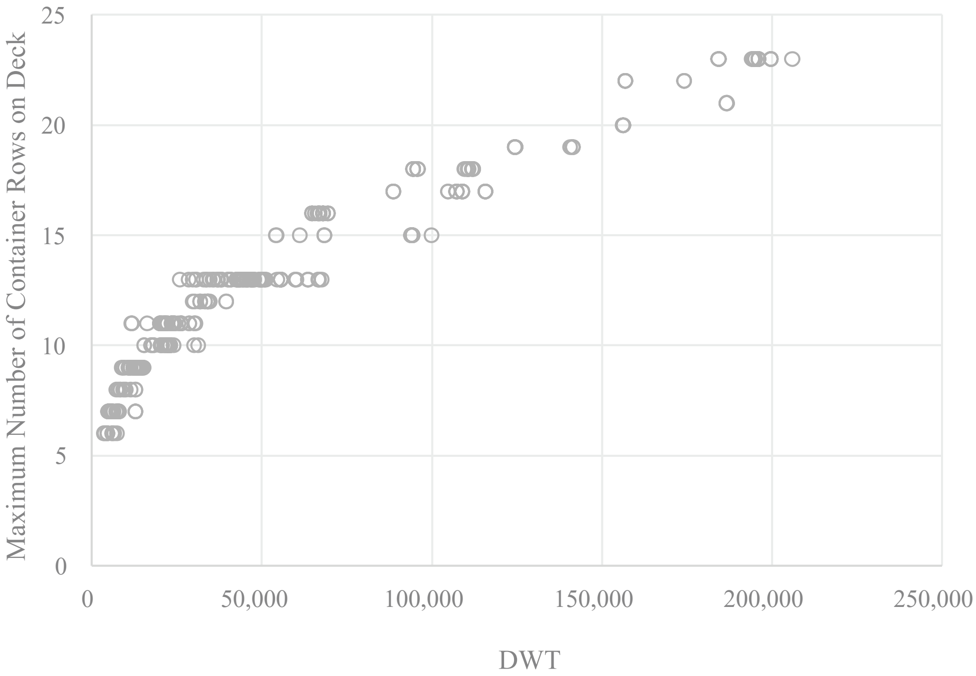

Fig. 1.2.2 Correlation between Deadweight Tonnages and Maximum Number of Container Rows on Deck in Container Ships

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2 Actions Caused by Ships

2.1 General

2.1.1 Ship Berthing

(1) The actions of berthing ships on mooring facilities shall be determined using appropriate methods by taking into account the dimensions of design ships, berthing methods and velocities, structures of mooring facilities, etc.

(2) The performance verification of general mooring facilities shall take into account the berthing forces of ships as actions caused by ship berthing. In general, the berthing force of ships that acts on mooring facilities shall be calculated using the displacement-restoration characteristics of fenders on the basis of the berthing energy of ships.

(3) The berthing force of ships is the dominant factor in the normal performance verification of general fender systems. Given that the berthing force is largely affected by the types of design ships and the berthing methods and velocities, the conditions of design ships shall be thoroughly examined in the performance verification.

(4) Generally, the actions of ships rarely become dominant factors in the performance verification of mooring facilities. However, it shall be noted that the actions of ships may become dominant factors when designing the structure in the performance verification in the following cases: offshore berths wherein large tankers and large ore carriers are moored, piled piers designed with small seismic actions, and mooring facilities for ship refuge in the ports.

2.1.2 Ship Motions

(1) The actions caused by moored ships on mooring facilities shall be determined using appropriate methods by taking into account the dimensions of design ships, structures of mooring facilities, mooring methods, characteristics of fenders and mooring ropes, and influences of winds, waves, and currents on design ships.

(2) The actions caused by moored ships on mooring facilities shall include those caused by the motions of moored ships. The performance verification of general mooring facilities shall take into account the impact and tractive forces acting on mooring facilities owing to the motions of moored ships subjected to the wave forces, wind pressure forces, and fluid pressure forces of water currents. Particular attention is required for the influence of the actions of wave forces on ships in the cases of mooring facilities: in ports expecting the invasion of long-period waves, in the open sea or at port entrances similar to the case of offshore berths, and constructed for ship refuge in the ports.

(3) The impact and tractive forces caused by the motions of moored ships can be generally calculated by using simulations of oscillation based on wave forces, wind pressure forces and fluid pressure forces of water currents, which act on ships, and characteristics of fenders and mooring ropes.

(4) In the performance verification of general fender systems, it is preferable to take into account the impact force applied to them because of the motions of moored ships, in addition to the berthing force of ships, which is generally the dominant factor. In the case of mooring posts and bollards, the tractive force due to the motions of moored ships caused by wind pressure forces acting on ships is the dominant factor in the performance verification. The impact force due to the motions of moored ships is largely affected by the types of design ships, wave characteristics, and displacement-restoration characteristics of fenders. Furthermore, the tractive force due to the motions of moored ships is largely affected by the types and superstructures of design ships. Therefore, the performance verification of fenders shall be carried out by examining the conditions of design ships, wave characteristics, structures of mooring facilities, characteristics of fenders and mooring ropes, and others.

2.2 Actions Caused by Ship Berthing

(1) Berthing Energy of Ships

① The actions caused by ship berthing shall be calculated from the berthing energy of ships in general. The berthing energy of a ship can be calculated with **equation (2.2.1)** by using the mass of the ship, the berthing velocity of the ship, the virtual mass factor, the eccentricity factor, the flexibility factor, and the berth configuration factor. In the equation, the subscript *k* indicates the characteristic values.

$$E_{f_k} = \frac{1}{2} M_{s_k} {V_{b_k}}^2 C_{m_k} C_{e_k} C_{s_k} C_{c_k} \qquad \textbf{(2.2.1)}$$

where

E_f : berthing energy of the ship (kJ)

M_s : mass of the ship (t)

V_b : berthing velocity of the ship (m/s)

C_m : virtual mass factor

C_e : eccentricity factor

C_s : flexibility factor

C_c : berth configuration factor

② In addition to the method in item ① above based on motion dynamics, there are other methods for obtaining the berthing energy of ships, including a statistical method, a method using hydraulic model tests, and a method based on hydrodynamic models.[1] The method based on motion dynamics has been generally used because necessary data has not yet been accumulated and several constants needed for the calculations have not been fully elucidated for the other methods.

③ Given that a ship moves only in a lateral direction when berthing, the kinetic energy E_s (unit: kJ) of the ship is equal to $M_s V_b^2/2$. When a ship berths at a quaywall or a dolphin with fenders, the berthing energy E_f to be absorbed by each fender can be expressed by $E_s f$ by taking into consideration various influence factors, where $f = C_m C_e C_s C_c$.

(2) Mass of Ship

The mass of ships in the calculation equation of berthing energy is the full-load displacement tonnages expressing the displacement when ships are fully loaded in the unit of weight. **Equation (2.2.2)** can be used as relational equations between the characteristic values of the full-load displacement tonnage (*DT*) of the respective types of ships and deadweight tonnages (*DWT*) or gross tonnages (*GT*) of the ships. These relational equations are the regression equations obtained from statistical data on the relation of full-load displacement tonnages with deadweight tonnages or gross tonnages covering 75% of entire ships.[2] These relational equations are applicable in the range of tonnages shown in **Table 1.1.1**. In these relational equations, the subscript *k* indicates the characteristic values. When it is evident that ships are berthing at quaywalls in ballast, regression equations[2] can be used as references for the relational equations between the ballasted displacement tonnages of ships and their deadweight tonnages or gross tonnages. When the dimensions of design ships can be specified, including the displacement, when ships are fully loaded and in ballast, these specified values shall be used.

Cargo ships:	$DT_k = 2.920DWT^{0.924}$	
Container ships:	$DT_k = 1.634DWT^{0.986}$	
Tankers:	$DT_k = 1.688DWT^{0.976}$	
Roll-on roll-off (RORO) ships:	$DT_k = 8.728GT^{0.790}$	
Pure car carriers (PCC):	$DT_k = 1.946GT^{0.898}$	
LPG carriers:	$DT_k = 4.268GT^{0.914}$	**(2.2.2)**
LNG carriers:	$DT_k = 1.601GT^{0.970}$	
Passenger ships:	$DT_k = 2.730GT^{0.871}$	
Short-to-medium distance ferries (navigation distance of less than 300 km):	$DT_k = 4.980GT^{0.855}$	
Long distance ferries (navigation distance of 300 km or more):	$DT_k = 15.409GT^{0.735}$	

where

DT : full-load displacement tonnage of the ship (ton)

DWT : deadweight tonnage of the ship (ton)

GT : gross tonnage of the ship (ton)

(3) Berthing Velocity

① The berthing velocities of ships shall be determined on the basis of actual measurements or the existing measurement data of berthing velocities by taking into consideration the types and loading conditions of design ships, locations and structures of mooring facilities, presence or absence of tugboat assistance and their sizes, and meteorological and oceanographical conditions.

② Large cargo ships and tankers berth at mooring facilities in a manner that temporarily stop at positions parallel to the mooring facilities at certain distances from them and then come alongside the mooring facilities with a few tugboats gently pushing them. If strong winds are blowing against mooring facilities, there may be cases wherein large cargo ships or tankers come alongside the mooring facilities with tugboats pulling them. When adopting the tugboat-assisted berthing method as mentioned above, the berthing velocities are normally set at approximately 10 to 15 cm/s on the basis of the existing performance records.

③ Special ships such as ferries, RORO ships, or small cargo ships may require berthing methods that are different from those used with large ships, e.g., berthing without the assistance of tugboats or approaching mooring facilities in the direction parallel to their normal lines when ships have ramps at their bows or sterns. Therefore, the berthing velocities of special ships should be carefully determined on the basis of actual measurements and others with particular focus on their berthing methods.

④ Considering that small ships, such as small cargo ships, berth at mooring facilities under their own power without tugboat assistance, it shall be noted that their berthing velocities are generally larger than those of large ships and may exceed 30 cm/s. Therefore, the berthing velocities of small ships should be carefully determined on the basis of actual measurements and others.

⑤ For the berthing velocities of medium and small ships, in anticipation of indiscreet berthing or berthing at mooring facilities subject to currents, it is necessary to determine the berthing velocities on the basis of the existing measurement data by taking into consideration the drift velocities of ships.

⑥ **Fig. 2.2.1** shows the relationship among ship maneuvering conditions, ship sizes, and berthing velocities established on the basis of the empirical data.[3] This figure suggests that larger berthing velocities should be set when ships berth at the mooring facilities that are not sheltered by breakwaters or when the sizes of design ships become smaller.

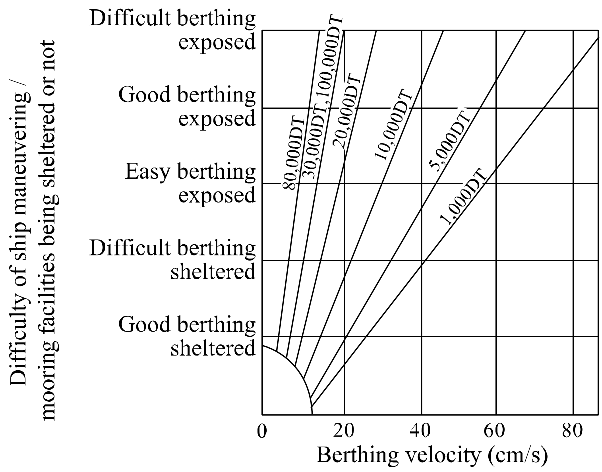

Fig. 2.2.1 Relationship among Ship Maneuvering Conditions, Ship Sizes, and Berthing Velocities[3]

⑦ According to the study reports on berthing velocities,[4) 5)] it has become clear that the loading conditions of ships largely affect berthing velocities, i.e., berthing velocities tend to decrease when ships are in a fully loaded state berth with small keel clearances and increase when ships are in a lightly loaded berth with large keel clearances.

⑧ The relationship between berthing velocities and ship sizes was studied using the measurement data collected in the previous studies on the berthing velocities of ships.[6] **Fig. 2.2.2** shows the relationship between the measurement values of berthing velocities and ship sizes for the respective types of ships. The figure shows that there is an overall trend of decreasing berthing velocities with increasing ship sizes and that berthing velocities are approximately 20 cm/s at a maximum and are distributed widely from 5 to 15 cm/s with a large variance.

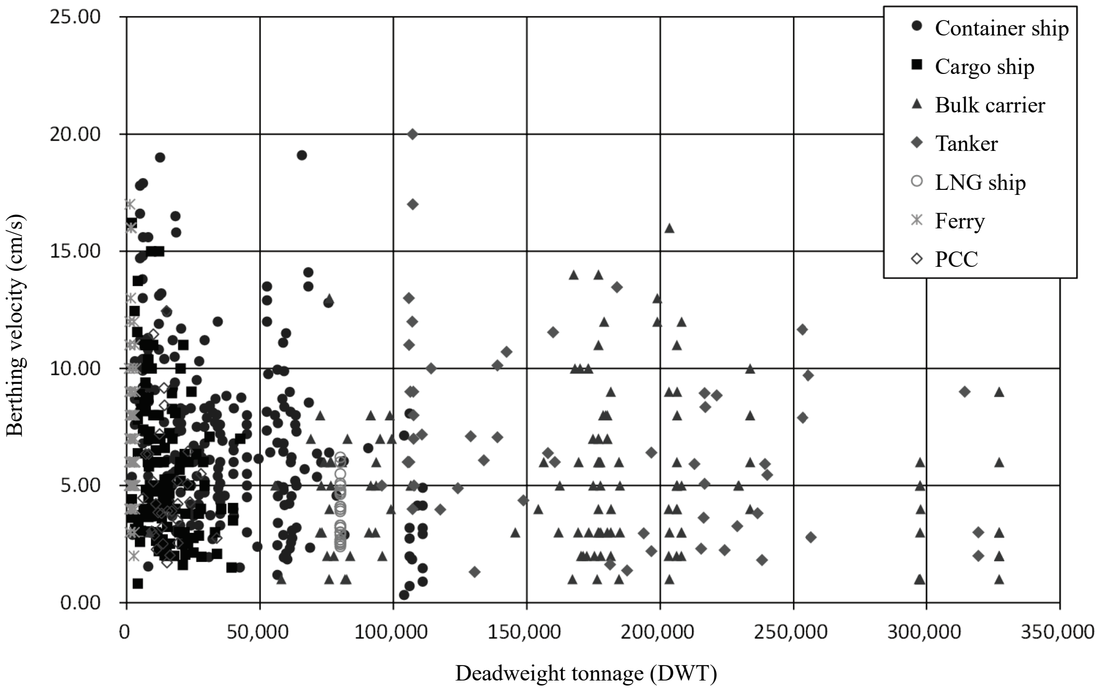

Fig. 2.2.2 Measurement Values of Berthing Velocities (by Ship Type)[6)]

Regarding the relationship between berthing velocities and ship sizes, the regression equations considering the coverage ratios were also proposed.[6)] **Fig. 2.2.3** shows the regression equations with different coverage ratios overlaid on the graph of the relationship between the measurement values of berthing velocities and ship sizes. The probability distribution of the berthing velocities of ships generally shows the logarithmic normal distribution, and the relationship between berthing velocities and ship sizes can be expressed by regression equations in the form of power functions.[7)] It shall be noted that these regression equations show extremely large berthing velocities for small ships with the deadweight tonnages less than 10,000 tons.

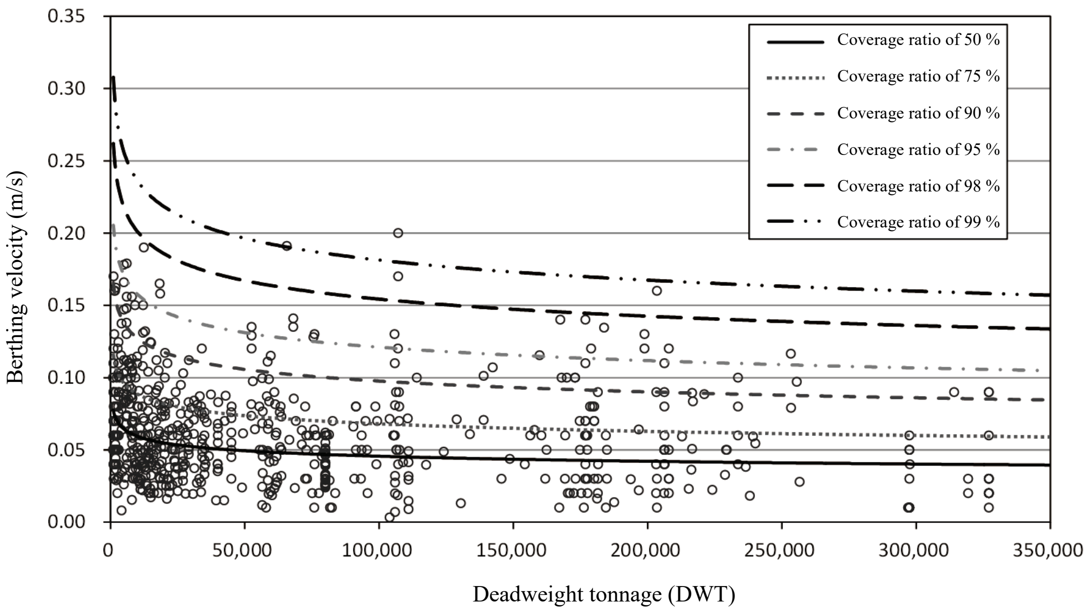

Fig. 2.2.3 Relationship between Measurement Values of Berthing Velocities of Ships and Regression Equations[6)]

(4) Virtual Mass Factor

① The virtual mass factor C_m can be calculated by the following equation:

$$C_m = 1 + \frac{\pi}{2C_b}\frac{d}{B} \quad \textbf{(2.2.3)}$$

$$C_b = \frac{\nabla}{L_{pp}Bd} \quad \textbf{(2.2.4)}$$

where

C_m : virtual mass factor

C_b : block coefficient

∇ : displacement volume of the ship (m^3)

L_{pp} : length between perpendiculars (m)

B : molded breadth (m)

d : full-load draft (m)

In the above equation, the values of the length between perpendiculars L_{pp}, molded breadth B, and full-load draft d should be those of design ships; however, the values listed in **Table 1.1.1** can be substituted for them when standard ships are used as design ships.

② When a ship berths, the velocities of not only the mass of the ship M_s but also the mass of the water body around the ship M_w are reduced simultaneously. Therefore, the inertia force due to the mass of the water body needs to be added to the motion of the ship. For this reason, the virtual mass factor can be defined by **equation (2.2.5)**.

$$C_m = \frac{M_s + M_w}{M_s} \quad \textbf{(2.2.5)}$$

where

C_m : virtual mass factor

M_s : mass of the ship (t)

M_w : mass of the water body around the ship (added mass) (t)

Ueda et al.[8)] proposed **equation (2.2.3)** on the basis of the results of the hydraulic model tests and field measurements. The second term of the equation corresponds to M_w/M_s in **equation (2.2.5)**.

(5) Eccentricity Factor

① The eccentricity factors C_e can be calculated by the following equation:

$$C_e = \frac{1}{1 + \left(\frac{l}{r}\right)^2} \quad \textbf{(2.2.6)}$$

where

C_e : eccentricity factor

l : distance measured from the ship's contact point to the center of gravity of the ship in the direction parallel to the normal line of the mooring facility (m)

r : radius of rotation around the vertical axis passing through the center of gravity of the ship (m)

② During berthing, ships approach mooring facilities that are not perfectly alongside them. Therefore, ships start yawing in horizontal planes and rolling around their longitudinal axes when they come into contact with mooring facilities (fenders). As a result, the yawing and rolling partially consume the kinetic energy of the ships. Considering that the amount of energy consumed by rolling is negligibly smaller than that by yawing, **equation (2.2.6)** considers kinetic energy consumption only by yawing.

③ r/L_{pp} is a function of the block coefficient C_b and can be obtained from **Fig. 2.2.4**.[9] **Equation (2.2.7)**, which is a linear approximation of the curve in the figure, may also be used.

$$r = (0.19C_b + 0.11)L_{pp} \quad \textbf{(2.2.7)}$$

where

r radius of rotation (also called radius of gyration with the relationship of $I_z = M_s r^2$ with the moment of inertia I_z around the vertical axis of the ship)

C_b block coefficient

L_{pp} length between perpendiculars (m)

In the equation above, the values of the lengths between perpendiculars L_{pp} should be those of design ships; however, the values listed in **Table 1.1.1** can be substituted for them when standard ships are used as design ships.

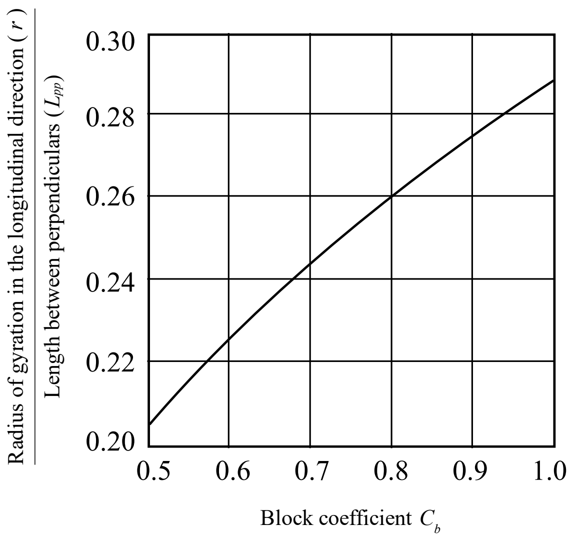

Fig. 2.2.4 Relationship between Radii of Gyration in the Longitudinal Direction and Block Coefficients[9]

④ As shown in **Fig. 2.2.5**, when a ship comes closest to a mooring facility at point P and into contact with fenders F_1 and F_2, the distance l measured from a point of contact to the center of gravity of the ship in the direction parallel to the mooring facility can be calculated by using **equation (2.2.8)** or **(2.2.9)**.[10] Here, the value of l needs to be L_1 when $k > 0.5$, L_2 when $k < 0.5$, and either L_1 or L_2 when $k = 0.5$ depending on which variable makes the value of C_e in **equation (2.2.6)** larger.

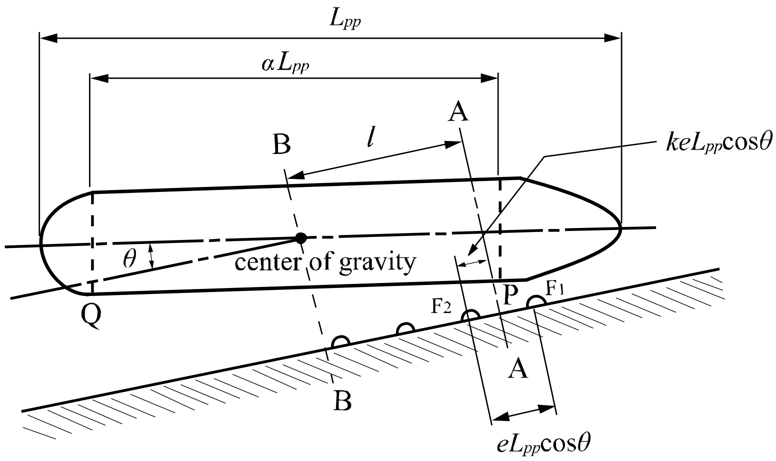

Fig. 2.2.5 Schematic Illustration of Ship Berthing[10)]

$$L_1 = \{0.5\alpha + e(1-k)\}L_{pp}\cos\theta \quad \textbf{(2.2.8)}$$

$$L_2 = (0.5\alpha - ek)L_{pp}\cos\theta \quad \textbf{(2.2.9)}$$

where

L_1 : distance measured from the point of contact to the center of gravity of the ship in the direction parallel to the mooring facility when the ship comes into contact with the fender F_1 (m)

L_2 : distance measured from the point of contact to the center of gravity of the ship in the direction parallel to the mooring facility when the ship comes into contact with the fender F_2 (m)

θ : berthing angle (generally set at around 0 to 10°)

e : ratio of the interval of fenders measured in the longitudinal direction of the ship to the length between perpendiculars

α : ratio of the length of the parallel side of the ship at the height of the point of contact with the fender to the length between perpendiculars (differs depending on the types of ships and block coefficients but is generally set at 1/3 to 1/2 or may be set at approximately 1/3 for ships with small breadths, such as container and passenger ships, or approximately 1/2 for ships with wide breadths, such as cargo ships and tankers)

k : parameter representing the point between fenders F_1 and F_2, where the ship comes closest to the mooring facility (set in the range of $0 < k < 1$ or may be set at 0.5 in general)

(6) Flexibility Factor

The flexibility factor C_s is the ratio of the berthing energy absorbed by the deformation of a ship hull to the berthing energy of the ship. Assuming that there is no energy absorption by the deformation of ship hull, the characteristic value of the flexibility factor C_{s_k} can generally be set at 1.0.

(7) Berth Configuration Factor

The water mass compressed between a berthing ship and a mooring facility behaves like a cushion and produces an effect to decrease the kinetic energy of the ship to be finally absorbed by fenders. The berth configuration factor C_c needs to be determined by taking into account this effect. Furthermore, the behavior of water mass is considered to be affected by berthing angles, shapes of ship hulls, under-keel clearances (distances between ship bottoms and the seafloor), and berthing velocities. However, the characteristic value of the berth configuration factor C_{c_k} can generally be set at 1.0.

2.3 Actions Caused by Ship Motions

(1) Motions of Moored Ship

① Generally, the actions caused by the motions of moored ships shall be obtained using motion calculations with appropriately setting wave forces, wind pressure forces, and fluid pressure forces of water currents.

② Ships that are moored at mooring facilities constructed in the open sea, close to port entrances, and in ports expecting the invasion of long-period waves or ships that are moored in rough weather are subjected to motions caused by the actions of waves, winds, and currents. In some cases, the kinetic energy of moored ships becomes larger than the berthing energy of ships. Therefore, the tractive force or impact force due to the motions of moored ships shall be examined in the performance verification of mooring posts, bollards or fenders.[11] Particular attention is required in ports facing the open sea because it has been frequently reported that the slow drift oscillations of moored ships due to long-period waves cause difficulty with smooth cargo handling.[12] [13]

③ Generally, the motions of a moored ship shall be calculated using numerical simulation by taking into consideration the irregularity in the actions of waves, winds, and currents and the nonlinearity of the displacement-restoration characteristics of the mooring system consisting of mooring ropes and fenders. When numerical simulation is not available by necessity or when the ship is moored at a mooring system that can be considered almost symmetrical, the displacement and loads on the mooring system can be obtained with reference to the results of the frequency response analysis with respect to regular waves or the motion calculations of a floating body moored at a mooring system with bilinear displacement-restoration characteristics.[14]

④ The wave forces acting on a ship consist of the wave-exciting force due to incident waves and the wave making resistance force accompanied by ship motions.[15] The wave-exciting force due to incident waves is the wave force calculated on the assumption that the motions of the ship are restrained. The wave making resistance force is the wave force acting on the ship when the ship undergoes a unit amplitude motion of respective motion components. The wave making resistance force can be expressed separately by using two terms proportional to the acceleration and velocity of ship motions. The former term can be expressed as an added mass when divided by the acceleration, and the latter term can be expressed as a damping coefficient when divided by the velocity.[16] In addition to the force mentioned above, the ship is subjected to nonlinear fluid force proportional to the square of wave heights (refer to **Part II, Chapter 2, 4.8 Actions on Floating Body and its Motions**).

⑤ The wave force acting on a ship with a block coefficient of 0.7 to 0.8, similar to the case for large tankers, can be obtained using a diffraction theory with the ship's hull approximated by an elliptical cylinder.[17]

⑥ The wave force acting on a ship with a box-shaped cross-section, similar to the case for working crafts, can be obtained by approximating the ship's hull by a floating body with a rectangular cross-section or a rectangular solid.

⑦ For the actions caused by motions of moored ships, when conducting static motion calculations by taking into consideration wind pressure forces and the fluid pressure forces of water currents, **Reference 18)** can be used as a reference. It shall be noted that design ships are generally tankers in the reference.

(2) Wave Forces Acting on Ship

① The wave forces acting on moored ships shall be calculated using appropriate methods by taking into consideration the ship sizes and wave parameters.

② The wave force acting on a moored ship can be calculated using an appropriate method selected from the following: the strip method, the source distribution method, the boundary element method, or the finite element method. Among them, the strip method is the most frequently used method for ships.

③ **Wave forces based on the strip method**[14] [15] [16] [19]

(a) Wave force of regular waves acting on the ship

The wave force acting on a ship is given by the summation of the Froude-Kriloff force and the diffraction force.

(b) Froude-Kriloff force

The Froude-Kriloff force is the force derived from the waves passing through a ship. It is given by the summation of the force of the incident waves and the force of the reflected waves from the mooring facility.

(c) Diffraction force

The diffraction force acting on a ship is the force generated by the change in pressure field when incident waves are scattered by the ship. The diffraction force can be estimated by replacing this change in the pressure field with the radiation force (namely, the wave making resistance force when the ship moves at a certain velocity in still water) in a manner that causes the ship to have a relative movement. It is assumed that the certain velocity of the ship above is equal to the relative velocity of the ship to the water particles in the incident waves. This velocity is called the equivalent relative velocity.

(d) Force acting on the ship entirely

The wave force acting on a ship entirely can be obtained by integrating the Froude-Kriloff force and the diffraction force acting on a cross-section of the ship along the longitudinal direction from $x = -L_{pp}/2$ to $x = L_{pp}/2$ (where x is the positional coordinate in the longitudinal direction of the ship).

④ **Wave forces based on diffraction theory[17)]**

In cases wherein a ship with a wide breadth (with a block coefficients C_b of approximately 0.7 to 0.8) is considered to be moving in slight motions with no wave reflecting structures, such as mooring facilities located behind the ship, the wave force can be calculated by an equation[17)] based on a diffraction theory with the ship's hull approximated by an elliptical cylinder.

⑤ When simply obtaining the wave force acting on a moored ship, it shall be obtained using an appropriate method in a manner that assumes the shape of the ship as a simplified one, such as a rectangular solid and refers to **Part II, Chapter 2, 6.4 Wave Force Acting on Structures Close to Water Surfaces** and **Part II, Chapter 2, 4.8 Actions on Floating Body and its Motions**.

(3) Wind Pressure Forces Acting on Ship

① The wind pressure forces acting on moored ships shall be determined by using appropriate calculation equations.

② It is preferable to determine the wind pressure forces acting on a moored ship by considering the temporal variability in wind velocity and the characteristics of wind drag coefficients dependent on the cross-sectional shape of the ship.

③ The wind pressure forces acting on a ship can be calculated with **equations (2.3.1)** to **(2.3.3)** by using wind drag coefficients C_X and C_Y in the X and Y directions, respectively, and wind pressure moment coefficient C_M around the midship section (the central section of the ship). The subscript k in the equations indicates the characteristic values.

$$R_{X_k} = \frac{1}{2}\rho_a U_k{}^2 A_T C_X \qquad \textbf{(2.3.1)}$$

$$R_{Y_k} = \frac{1}{2}\rho_a U_k{}^2 A_L C_Y \qquad \textbf{(2.3.2)}$$

$$R_{M_k} = \frac{1}{2}\rho_a U_k{}^2 A_L L_{pp} C_M \qquad \textbf{(2.3.3)}$$

where

R_X : component of the resultant wind pressure force in the X direction (kN)

R_Y : component of the resultant wind pressure force in the Y direction (kN)

R_M : moment around the midship section of the resultant wind pressure force (kNm)

C_X : wind drag coefficient in the X direction (the bow direction of the ship)

C_Y : wind drag coefficient in the Y direction (the side direction of the ship)

C_M : wind pressure moment coefficient around the midship section

ρ_a : density of air ($\rho_a = 1.23 \times 10^{-3}$ (t/m^3))

U : wind velocity (m/s)

A_T : above-water bow projected area of the ship (m^2)

A_L : above-water side projected area of the ship (m^2)

L_{pp} : length between perpendiculars (m)

④ It is preferable to determine wind drag coefficients C_X and C_Y and wind pressure moment coefficient C_M by using wind tunnel tests or water tank tests for specific ships. Alternatively, considering that these tests require large amounts of costs and time, respective coefficients can be obtained by using calculation equations[21) 22)] on the basis of the existing wind tunnel test results[20)] or water tank test results.

⑤ The wind velocity U used in the equations shall be the maximum (10-minute average) wind velocity at the action points of wind pressure force.

⑥ The values of the above-water bow and side projected areas of ships are preferably those of design ships.

⑦ Considering that wind velocity fluctuates in terms of time and space, the motion calculation of a moored ship shall use the wind velocity of fluctuating wind. Some of the examples of fluctuating wind include the frequency spectra of the fluctuating wind in terms of the time proposed by Davenport[23)] and Hino.[24)] The frequency spectra proposed by Davenport and Hino are given by **equations (2.3.4)** and **(2.3.5)**, respectively.

$$\left.\begin{aligned} fS_u(f) &= 4K_rU_{10}^2\frac{X^2}{\left(1+X^2\right)^{4/3}} \\ X &= \frac{1200f}{U_{10}} \end{aligned}\right\} \qquad \textbf{(2.3.4)}$$

$$\left.\begin{aligned} S_u(f) &= 2.856\frac{K_rU_{10}^2}{\beta}\left\{1+\left(\frac{f}{\beta}\right)^2\right\}^{-5/6} \\ \beta &= 1.169\times10^{-3}\frac{U_{10}\alpha}{\sqrt{K_r}}\left(\frac{z}{10}\right)^{2m\alpha-1} \end{aligned}\right\} \qquad \textbf{(2.3.5)}$$

where

$S_u(f)$: frequency spectrum (m^2/s)

U_{10} : average wind velocity at the standard height of 10 m (m/s)

K_r : friction coefficient on the surface defined by the wind velocity at the standard height (appropriate value of K_r on the sea is 0.003)

α : power exponent when the vertical distribution of wind velocity is expressed by the power law ($U \propto (z/10)^{\alpha}$)

z : height above the ground or water surface (m)

m : correction factor related to the stability of the atmosphere (m = 2 in the case of storms)

(4) Fluid Pressure Forces of Water Currents Acting on Ship

① The fluid pressure forces of water currents acting on ships shall be determined by using appropriate calculation equations.

② **Fluid pressure force of water currents from the bow**

The fluid pressure force generated between a ship and water currents from the bow can be calculated by **equation (2.3.6)**. In the equation, the subscript k indicates characteristic values.

$$R_{f_k} = 0.0014SV_k^2 \qquad \textbf{(2.3.6)}$$

where

R_f : fluid pressure force of water currents from the bow (kN)

S : hull area submerged below the draft line (m^2)

V : current velocity (m/s)

③ **Fluid pressure force of water currents from the side**

The fluid pressure force of water currents from the side can be calculated by **equation (2.3.7)**. In the equation, the subscript k indicates characteristic values.

$$R_k = 0.5\rho_0 C V_k^{\,2} B \tag{2.3.7}$$

where

R : fluid pressure force of water currents from the side (kN)

ρ_0 : density of seawater (t/m^3)

C : current pressure coefficient

V : current velocity (m/s)

B : projected area of the ship side below the draft line (m^2)

④ The fluid pressure force of water currents can be divided into friction resistance and pressure resistance. The resistance against water currents from the bow and the side is considered to be mostly friction resistance and pressure resistance, respectively. However, it is difficult to strictly divide friction resistance from pressure resistance and examine them individually. **Equation (2.3.6)** is obtained by simplifying the Froude's formula in a manner that assigns 1.025 t/m^3, 15°C and 0.14 to ρ_0, t and λ in **equation (2.3.8)**. In the equation, the subscript k indicates characteristic values.

$$R_{f_k} = \rho_0 g \lambda \left\{ \frac{1 + 0.0043(15 - t)}{1000} \right\} S V_k^{1.825} \tag{2.3.8}$$

where

R_f : fluid pressure force of water currents from the bow (kN)

$\rho_0 g$: unit weight of seawater (kN/m^3)

t : temperature (°C)

S : hull area submerged below the draft line (m^2)

V : current velocity (m/s)

λ : coefficient (e.g., λ = 0.14741 for the ship with the total length of 30 m, and λ = 0.13783 for the ship with the total length of 250 m)

⑤ The current pressure coefficient C varies according to the relative current direction θ between a ship and water currents and can be determined with reference to the values obtained from **Fig. 2.3.1**.

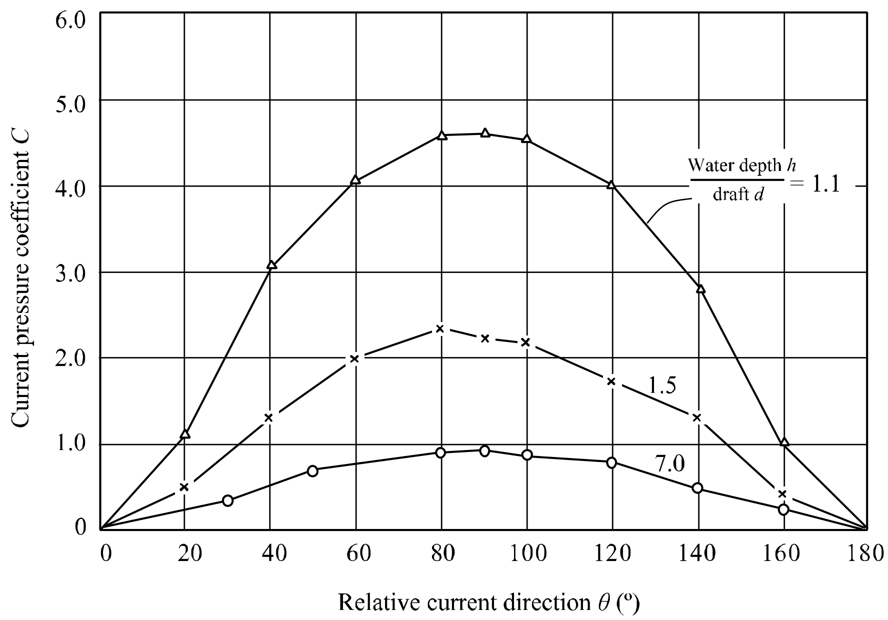

Fig. 2.3.1 Relationship between Current Pressure Coefficients and Relative Current Directions

(5) Characteristics of Mooring System

① The motion calculation of a moored ship shall be performed with appropriately modeled displacement-restoration characteristics of the mooring system consisting of mooring ropes and fenders.

② The displacement-restoration characteristics of the mooring system are nonlinear in general. Furthermore, there are cases of fenders with displacement-restoration characteristics that include hysteresis. Therefore, it is preferable to perform the motion calculation of a moored ship by using these appropriately modeled characteristics.[25)]

2.4 Actions Caused by Traction of Ships

(1) Generally, the values shown in **Table 2.4.1** shall be used as the standard values of tractive force by ships acting on mooring posts and bollards.[26)]

(2) In the case of bollards, they shall be generally subjected to the action of the tractive force by ships specified in item (1) in all directions.

(3) In the case of mooring posts, they shall be generally subjected to the simultaneous actions of the tractive force by ships specified in item (1) in the horizontal direction and half the tractive force in the vertical direction.

Table 2.4.1 Standard Values of Tractive Force by Ships

GT of ship (ton)	Tractive force acting on a bollard (kN)	Tractive force acting on a mooring post (kN)
Over 200 and not more than 500	150	150
Over 500 and not more than 1,000	250	250
Over 1,000 and not more than 2,000	250	350
Over 2,000 and not more than 3,000	350	350
Over 3,000 and not more than 5,000	350	500
Over 5,000 and not more than 10,000	500	700
Over 10,000 and not more than 20,000	700	1,000
Over 20,000 and not more than 50,000	1,000	1,500
Over 50,000 and not more than 100,000	1,000	2,000

GT of ship (ton)	Tractive force acting on a bollard (kN)	Tractive force acting on a mooring post (kN)
Over 100,000 and not more than 120,000	1,500	2,000
Over 120,000 and not more than 150,000	1,500	2,000
Over 150,000 and not more than 170,000	2,000	2,000
Over 170,000 and not more than 200,000	2,000	2,000

(4) Bollards are installed close to the face lines of mooring facilities, which are used to allow the mooring of ships and allow ships to come alongside or leave mooring facilities in calm weather. On the other hand, mooring posts are installed at or around both ends of mooring facilities away from their face lines, which are used to allow the mooring of ships in stormy weather.

(5) For the layouts and names of mooring ropes used when mooring ships **Part III, Chapter 5, 2.1.1 Dimensions of Quaywalls** shall be referred to.

(6) For the layouts and structures of mooring posts and bollards, **Part III, Chapter 5, 9.1 Mooring Posts, Bollards and Mooring Rings** shall be referred to.

(7) When setting the tractive force of ships for which deadweight tonnages are normally used, similar to the case for cargo ships, the deadweight tonnages can be converted to the gross tonnages of design ships by using regression equations.[27)]

(8) It is preferable to calculate the tractive force acting on mooring posts and bollards by taking into consideration the forces caused by berthing ships, wind pressure forces acting on moored ships, and forces caused by the motions of ships,[8) 14)] as needed on the basis of the breaking loads of mooring ropes mounted on design ships, the meteorological and oceanographical conditions of the locations where mooring facilities are constructed, and the dimensions of ships.

(9) It is necessary to determine the following types of tractive force by taking into consideration the meteorological and oceanographical conditions, the structures of mooring facilities, and the existing records of the actual measurement of tractive force: the tractive force of ships with the gross tonnages not more than 200 tons or exceeding 200,000 tons (not shown in **Table 2.4.1**), the tractive force acting on the mooring facilities allowing ships to be moored in stormy weather, and the tractive force acting on the mooring facilities in water areas under severe meteorological and oceanographical conditions such as the open sea area.

(10) The tractive force acting on bollards in **Table 2.4.1** is obtained by using the motion calculations of moored ships to allow the eight mooring ropes connected to bollards to safely moor cargo ships in ballast against winds with velocities up to 15 m/s blowing from the land side. Furthermore, the tractive force acting on mooring posts is obtained by using the motion calculations of moored ships to allow 10 mooring ropes to safely moor cargo ships in ballast against winds with velocities up to 30 m/s blowing from land sides; some of them are connected to mooring posts, whereas others are connected to bollards. The tractive force acting on bollards is also based on the condition that allows mooring ropes to be properly connected to bollards and mooring posts in storms and allows bollards to safely moored ships against winds with velocities of 30 m/s blowing from the land side. The tractive force acting on bollards corresponds to the breaking load of one or two mooring ropes specified in the **Rules for the Survey and Construction of Steel Ships; Guidance for the Survey and Construction of Steel Ships Part L (Equipment)** ,[28)] and the tractive force acting on mooring posts corresponds to the breaking load of approximately two mooring ropes.

(11) In the case of mooring facilities where ships are moored only in calm weather, half the values in **Table 2.4.1** can be used for the tractive force acting on bollards that are installed in the intermediate sections of the mooring facilities for spring lines and have no risk of being individually subjected to the tractive force of two mooring ropes or more. However, this provision cannot be applied to mooring facilities where ships using mooring ropes with large breaking loads, such as nylon ropes, are moored.

(12) It is preferable to determine the tractive force of small ships with the gross tonnages of 200 tons or less by taking into consideration the dimensions of the ships, berthing situations, and structures of mooring facilities.[29)] However, for the tractive force to be used in the actual performance verification of bollards and mooring posts for mooring ships with the gross tonnages of 200 tons or less, 50 and 150 kN are used as the standard tractive forces acting on bollards and mooring posts, respectively.

(13) Caution is required when calculating the tractive force of passenger ships, ferries, and container ships by using the values in **Table 2.4.1** because these types of ships have large wind pressure-receiving areas. When design ships can be specified, it is preferable to calculate the tractive force acting on mooring posts and bollards by using the wind pressure forces on the moored design ships and by taking into consideration their dimensions, mooring rope arrangement, breaking loads and others. For the wind pressure forces acting on moored ships, **Part II, Chapter 8, 2.3 Actions Caused by Ship Motions** shall be referred to.

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