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Comparative Study of Berthing Mechanism and Optimum Fender System for RCC Pile Supported Wharf as Per Indian Standard IS4651 Part-3:1974 and British Standard BS6349 Part-4:1994

Research Article

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Abstract

Berthing force is a critical dynamic lateral force in design of berthing structures, having equal relevance when compared to seismic forces. Besides, the construction costs of berthing structures are very high which can be optimized by selecting proper fender system. In the present study, berthing mechanism of bulk carriers having size from 5000 DWT to 250000 DWT is compared as per Indian Standard (IS) and British Standard (BS) so as to design an optimum fender system for a pile supported wharf. It is observed that British standard gives more precise values for berthing velocities for different vessel sizes and metocean conditions. Moreover, Indian Standard provides constant value of berthing velocity for vessel sizes more than 250000 DWT, which is not the case with British Standard. Comparative charts are prepared to understand the disparity in energy absorption capacity of different fender system for different vessel sizes and metocean conditions along with its consequences on the wharf. Study concludes with the preparation of suitability matrix, serving as a ready reckoner for selection of fender system for different size of vessels and metocean conditions.

Keywords: Bulk Carriers; Berthing Energy; Fender Systems; Berthing Velocity; Pile Supported Wharf; Dead Weight Tonnage.

Introduction

Maritime transport is one of the most important logistical systems, supporting universal movement of passengers and cargos cost effectively, thereby acting as a backbone for economic growth of country. The most common type of merchant ships used for freight transport are bulk carriers, container vessels, oil tankers, gas carriers, RORO ships, general cargo carriers, military ships and coastal trading vessels. Looking to the diversity of merchant ships visiting a particular port in view of their size, dead weight tonnage and type of cargo they carry, an adequate berthing facility is must to minimize the large impact spectrum of these vessels in terms of lateral force. India currently has 13 major and 187 minor ports. Nearly 95% of foreign trade by volume and 70% by value takes place through ports [3]. Newer ports are flourishing at a rapid pace in terms of cargo movement and hence a suitable understanding of berthing aids is essential for safe and economical berthing facilities.

Berthing force is one of the major forces accounted for the design of port structures. Various literature and design standards reveal that it might be a prevailing force in combination with other forces compared to seismic force. Berthing a vessel demands its kinetic energy to be absorbed/dissipated to avoid structural or vessel damage, which is done through buffers mounted on berthing structures, known as fenders. Fender systems work on the principle of high energy absorption and low reaction force. This reaction force is the design berthing force for the wharf and is a function of the size and type of fender units selected [13]. The reaction force can be obtained from energy-deflection-reaction diagrams of the fender system, provided by the fender manufacturer as shown in Figure 1 [14]. Higher the energy absorption of the fender system, lower is the lateral force on berthing structure. Selection of a wrong fender system does impact the life, safety and efficiency of the berthing structure. Hence it becomes vital to select an optimum fender system, designed and

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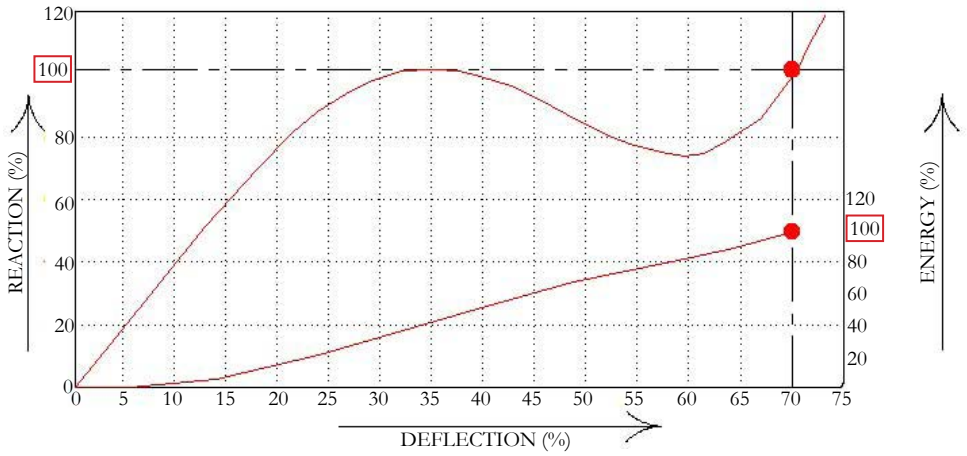
Figure 1. Energy Absorption Curve (reaction – deflection curve) [14].



manufactured as per the functional and operational requirements of the specific port and terminal in order to optimize significant investment made, reduce interruption and maintenance needs as well as maximizing fender's desired service life. Selecting an appropriate fender system does have a major impact on the overall project cost. This study will provide clear understanding about the consequences of berthing reaction of various fender systems in a prevailing berthing condition on pile supported wharf.

Vessel Characteristics and Different Fender Systems

Appropriate vessel information is must to estimate the berthing energy of a vessel. Critical inputs pertaining to vessel in order to calculate berthing energy are vessel size, shape and mass. In the present study, berthing mechanism of bulk carriers with sizes from 5000 DWT to 250000 DWT has been considered. The statistical information for the vessels considered is given in Table 1 below. DWT is the dead weight tonnage i.e. the weight in tons of cargo, stores, fuel, passengers and crew carried by the vessel when loaded to her maximum summer load line. Displacement tonnage – DT is the actual weight of the vessel or the weight of 'T' water she displaces when afloat and may be either 'loaded' or 'light'. Displacement, loaded is the weight, in long tons, of the ship and its contents when fully loaded with cargo, to the Plimsoll mark or load line. Displacement, light, is the weight, in long tons, of the ship without cargo, fuel and stores.

Cell fender system, cone fender system, arch fender system, pneumatic fender system, parallel motion fender system, unit element fender system and V-type fender system are included in the present study, referring Trelleborg catalogue, approved by PIANC guideline for fender design 2002.

Berthing Energy Calculation

Berthing Energy as per Indian Standard

According to Indian standard IS4651 part-3 [11], the design berthing energy is given as:

$$E_D = \frac{W_D v^2}{2g} C_m C_e C_s F_s \quad \text{----- (1)}$$

where,

W_D = Displacement tonnage (DT) of the vessel in tonne
v = Approach velocity of the vessel in m/s, normal to berth
g = Acceleration due to gravity in m/s^2
C_m = Mass coefficient
C_e = Eccentricity coefficient
C_s = Softness coefficient: 0.95 for soft fenders and 0.9 for hard fenders
F_s = Factor of safety = 1.4

Indian standard has specified five metocean berthing conditions as shown in Table 2.

As per Indian standard, C_m depends on the size as well as displacement tonnage of the vessel and is calculated as:

$$C_m = 1 + \frac{2D}{B} \quad \text{for vessels with DT < 20000 ----- (2)}$$

$$C_m = 1 + \frac{\frac{\pi}{4} D^2 \mathrm{L\,w}}{W_D} \quad \text{for vessels with DT >= 20000 ---- (3)}$$

where,

D = Fully loaded draught of the vessel in m
B = Beam of the vessel in m
L = Length of the vessel in m
w = unit weight of water = 1.03 tonne/m^3 for sea
W_D = Displacement tonnage of the vessel in tonne

The eccentricity coefficient - C_e is calculated as:

$$C_e = \frac{1 + (l/r)^2 \sin^2\theta}{1 + (l/r)^2} \quad \text{----- (4)}$$

where,

l = Distance from the center of gravity of the vessel to the point of contact projected along the water line of the berth in m as shown in Figure 2.
r = Radius of gyration of rotational radius on the plane of the vessel from its center of gravity in m.

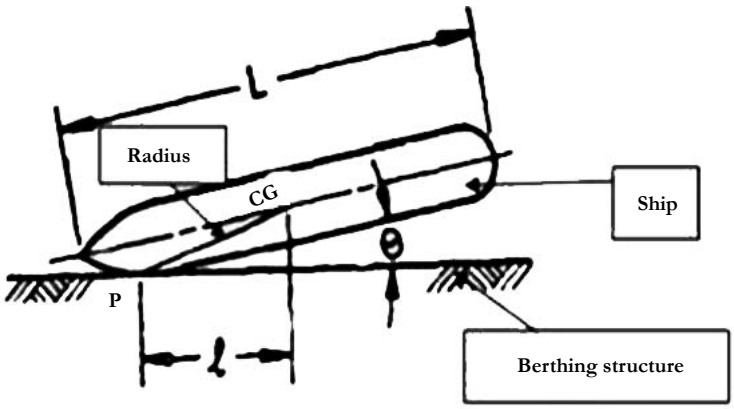
Table 1. Ship Characteristic [12].

Vessel Type	DWT (T)	DT (T)	Overall Length (m)	Length (m)	Breadth (m)	Depth (m)	Maximum Draft (m)
Bulk Carrier	5000	6740	106	98	15	8.4	6.1
	7000	9270	116	108	16.6	9.3	6.7
	10000	13000	129	120	18.5	10.4	7.5
	15000	19100	145	135	21	11.7	8.4
	20000	25000	157	148	23	12.8	9.2
	30000	36700	176	167	26.1	14.4	10.3
	50000	59600	204	194	32.3	16.8	12
	70000	81900	224	215	32.3	18.6	13.3
	100000	115000	248	239	37.9	20.7	14.8
	150000	168000	279	270	43	23.3	16.7
	200000	221000	303	294	47	25.4	18.2
	250000	273000	322	314	50.4	27.2	19.4

Table 2. Berthing Velocity of Vessels as per Indian Standard.

Sr. no	Site condition	Berthing condition	Berthing velocity normal to berth in (m/s)			
			up to 5000 DT	up to 10000 DT	up to 100000 DT	more than 100000 DT
1	Strong wind and swells	Difficult	0.75	0.55	0.40	0.20
2	Strong wind and swells	Favorable	0.60	0.45	0.30	0.20
3	Moderate wind and swells	Moderate	0.45	0.35	0.20	0.15
4	Sheltered	Difficult	0.25	0.20	0.15	0.10
5	Sheltered	Favorable	0.20	0.25	0.10	0.10

Figure 2. Geometry of Vessel Approach to Berth as per Indian Standard.



θ = Approach angle of the vessel

Indian standard provides eccentricity coefficient values for different l/r ratio as shown in Table 3.

Berthing Energy as per British Standard

According to British Standard BS6349 part-4 [1], the design berthing energy is given as:

$$E_D = 0.5 M_D (V_B)^2 C_M C_E C_S C_C F_s \quad \text{----- (5)}$$

where,

M_D = Displacement tonnage (DT) of the vessel in tonne
V_B = Approach velocity of the vessel in m/s, normal to berth
C_M = Hydrodynamic mass coefficient
C_E = Eccentricity coefficient
C_S = Softness coefficient: between 0.9 and 1.0

Table 3. Eccentricity coefficient values as per Indian Standard.

	Angle θ		
l/r	0°	10°	20°
1	0.5	0.51	0.56
1.25	0.39	0.41	0.46

C_C = Berth configuration coefficient
F_s = Factor of safety = 2.0

British standard has specified five berthing velocities as per the navigation conditions and size of the vessel as shown in Figure 3. The navigation conditions are:

a). Good berthing, sheltered
b). Difficult berthing, sheltered
c). Easy berthing exposed
d). Good berthing, exposed
e). Navigation conditions difficult, exposed

British standard has specified berthing velocity of vessel with respect to site conditions in graphical form. Each curve represents different navigation condition. Hence interpolated values can be obtained for intermediate size of vessels having different navigation conditions. British standard gives precise values of berthing velocity as compared to Indian standard.

As per British standard, C_M for any size of vessel is calculated as:

$$C_M = 1 + \frac{2D}{B} \quad \text{----- (6)}$$

where,

D = Fully loaded draught of the vessel in m
B = Beam of the vessel in m

C_M value generally ranges from 1.3 to 1.8 as per the above formula.

As per British standard, the eccentricity coefficient - C_E, is calculated as:

$$C_E = \frac{K^2 + R^2 Cos^2\gamma}{K^2 + R^2} \quad \text{---- (7)}$$

where,

K= Radius of gyration of the vessel and is calculated as:

$$\mathrm{K} = (0.19C_b + 0.11)L \quad \text{----- (8)}$$

where,

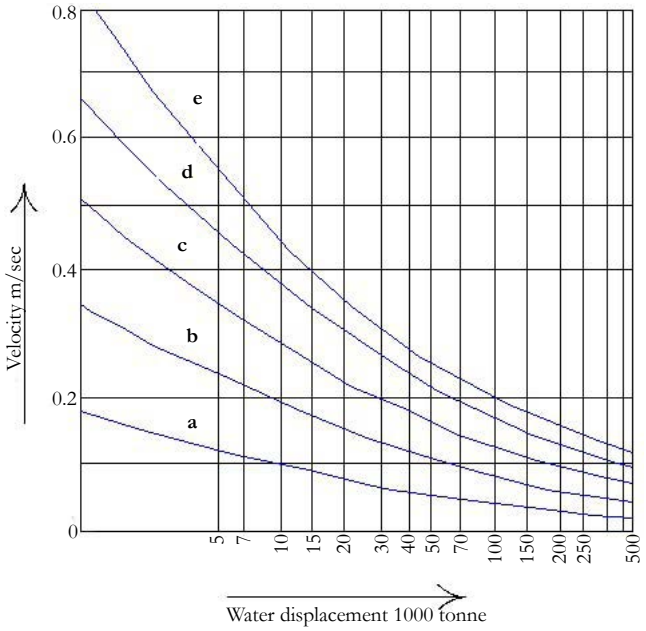
L = Length of the hull between perpendiculars
C_b = Block coefficient, a function of hull shape and is given as:

$$C_b = \frac{M_D}{\mathrm{L}B\ D\mathrm{w}} \quad \text{----- (9)}$$

where,

M_D = Displacement tonnage (DT) of the vessel in tonne
L = Length of the hull between perpendiculars
B = Beam of the vessel in m

Figure 3. Design Berthing Velocity as per British Standard.



D = Fully loaded draught of the vessel in m
w = unit weight of water = 1.03 tonne/m^3 for sea
D = Distance of point of contact of vessel from the center of mass in m
γ = Angle between the line joining point of contact to the center of mass and the velocity vector as shown in Figure 4.

British standard lists typical ranges of value for the block coefficient for various vessel types as shown in Table 4.

As per British standard, for open piled jetty structure, C_C is taken as 1.0 whereas for a solid quay wall, C_C is taken in between 0.8 and 1.0.

Problem formulation

A typical pile supported wharf module 25m wide and 45.805m long, housing bulk carriers is selected for the present study. The site is assumed to be in seismic zone V with Maximum Considered Earthquake (MCE) as 0.36g and Design Base Earthquake (DBE) as 0.18g as per IS1893 part-1 [7]. The wharf is constructed with precast/in-situ RC beamswith 0.5m thick deck supported on 40 bored cast in-situ piles having 1m diameter. Pile spacing is 6 m in longitudinal and transverse direction. Size of main beam is 0.5m x 1.5m whereas the size of pile muff is 1.5m x 1.5m respectively. The size of fender block is 1.5m x 1.5m x 8.24m. 75mm thick wearing coat is assumed on the deck. Design current velocity of 1.0m/s in the critical direction is considered. Marine growth of 50mm on piles is taken into account. Maximum and minimum recorded tidal levels are + 5.0 m and 0.0m at the proposed site, per Indian Naval Chart (Admiralty). Tidal levels are incorporated in the numerical model while applying wave force, berthing force, current force and hydrodynamic force on the wharf, at high tide level and low tide level. Other primary forces taken into consideration are Dead load and Live load [11]. Current force is calculated as per IRC6 [4]. Wave force on wharf is calculated using shore protection manual [2]. Hydrodynamic force is calculated as per IS1893 [6]. Berthing force is calculated as per IS4651 part-3 [11] with reference to PIANC guidelines and Trelleborg catalogue for fender systems. The wharf is designed and detailed for the load combinations using above forces, as per IS4651 part-4 [10]. Type of soil assumed is medium. M40 grade of concrete mix, having characteristic compressive strength f_{ck} as 40 MPa of 150 mm cube at 28 days [9] and Fe500 steel reinforcement having minimum yield stress f_y as 500 MPa [5] is used. The wharf profile and layout is shown in Figure 5 and Figure 6. 3D models of wharf are prepared in STAAD software. Beams and piles are modeled using frame element. Pile fixity depth approach has been considered to define support as per IS2911 [8].

Design Berthing Force on Bulk Carriers

In order to obtain design berthing force on wharf as per different fender systems considered, design berthing energy is calculated first as per Indian Standard and British Standard. Approach velocity of vessels as per Indian Standard and British Standard are correlated for five metocean conditions and compared. Using energy-reaction curve provided by fender system manufacturer, berthing energy is converted into berthing force assuming magnitude of deflection in fender system. For different vessel sizes, design berthing energy calculated and design berthing reaction obtained as per Indian Standard and British Standard, for different fender systems along with five metocean conditions are shown from Table 5 to Table 14.

Post Analysis Result

Post analysis of wharf includes comparison of limit state of service ability and limit state of collapse criteria for different types of fender systems. Limit state of service ability comprises

Figure 4. Geometry of Vessel Approach to Berth as per British Standard.

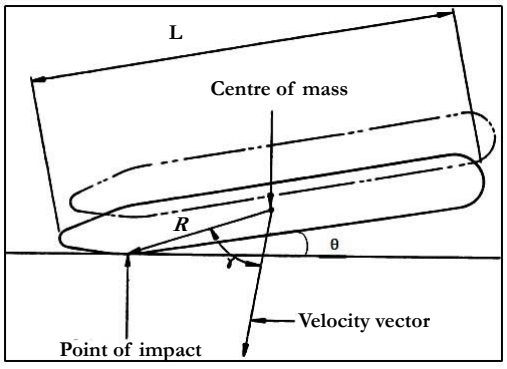


Table 4. Block Coefficient Values as per British Standard.

Vessel Type	Range of C_b
Tanker / Bulk	0.72 to 0.85
Container	0.65 to 0.70
Ro-Ro	0.65 to 0.70
Passenger	0.65 to 0.70
Dry cargo / combi	0.60 to 0.75
Ferry	0.50 to 0.65

Figure 5. Profile of the Berth.

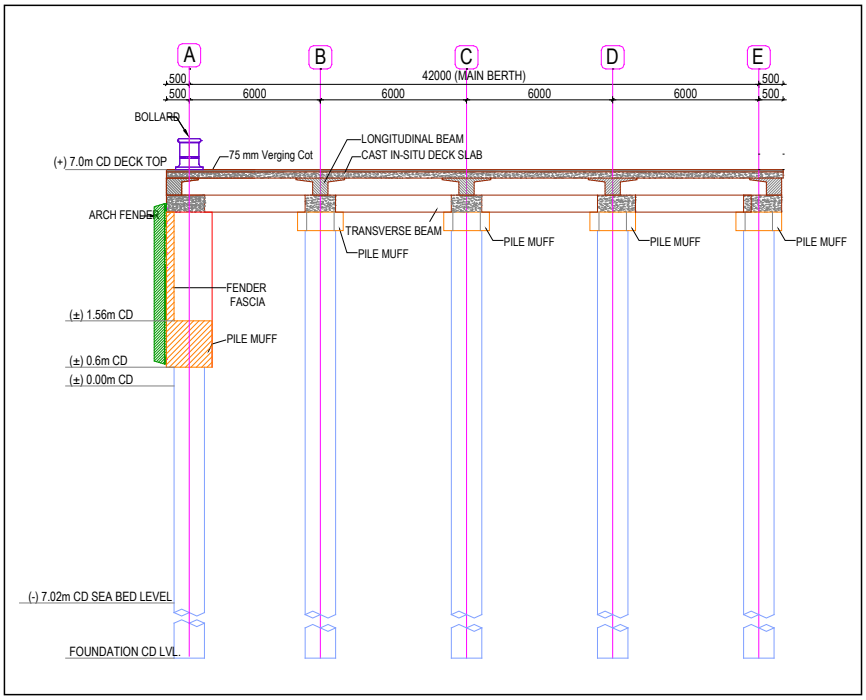


Figure 6. Layout of the Berth.

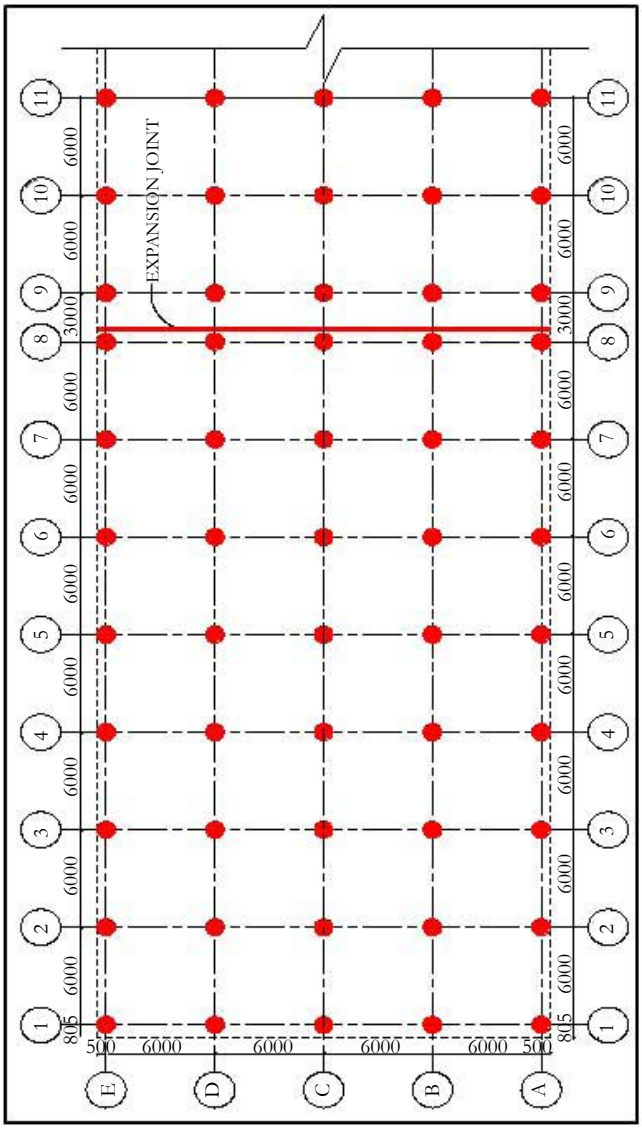


Table 5. Berthing Condition: Strong Wind and Swells – Difficult (IS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	2430	2918	2740	2610	3993	-	-	-
7000	1790	2514	2345	2115	2764	-	-	-
10000	2520	2908	2875	3278	4100	-	-	-
15000	1950	2560	2436	2514	2850	-	-	-
20000	2010	2660	2336	2550	2900	-	-	-
30000	2910	3139	3236	3278	4200	-	-	-
50000	4690	4464	4292	5216	6700	-	-	-
70000	6410	-	5856	-	7100	-	-	-
100000	8950	-	7363	-	-	-	-	-
150000	3250	-	3285	-	5000	-	-	-
200000	4250	-	4146	-	6300	-	-	-
250000	5220	-	4765	-	5990	-	-	-

Table 6. Berthing Condition: Strong Wind and Swells – Favorable (IS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	1560	2141	2083	2167	2786	-	-	-
7000	1200	1804	1715	1848	2560	-	-	-
10000	1690	2285	2132	2514	2764	-	-	-
15000	1100	1638	1584	1848	2500	-	-	-
20000	1130	1680	1628	1848	2530	-	-	-
30000	1640	2237	2132	2167	2800	-	-	-
50000	2640	3278	2942	3278	4000	-	-	-
70000	3610	3775	3668	4253	4400	-	-	-
100000	5030	5126	4528	5216	5870	-	-	-
150000	3250	-	3285	3278	4200	-	-	-
200000	4250	-	4561	4253	6650	-	-	-
250000	5220	-	4765	5216	6800	-	-	-

Table 7. Berthing Condition: Moderate Wind and Swells – Moderate (IS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	1560	1551	1372	1515	1875	-	-	-
7000	1200	1292	1229	1414	1700	939	-	712
10000	1690	1645	1497	1848	2400	-	-	-
15000	1100	945	913	1040	1315	499	-	1016
20000	1130	969	913	1040	1350	678	-	1016
30000	1640	1292	1269	1441	1700	939	-	1270
50000	2640	1361	1337	1551	2246	-	-	-
70000	3610	2285	2132	2167	2600	-	-	-
100000	5030	2668	2538	3278	3500	-	-	-
150000	3250	2514	2345	2514	2800	-	-	-
200000	4250	2855	2673	3278	3800	-	-	-
250000	5220	3139	3236	3278	4500	-	-	-

Table 8. Berthing Condition: Sheltered – Difficult (IS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	270	652	619	627	850	587	800	762
7000	240	606	585	627	837	522	708	762
10000	330	820	737	820	915	597	769	812
15000	270	652	619	820	850	587	769	812
20000	280	668	636	527	875	507	681	812
30000	410	885	818	527	1100	644	1000	1016
50000	660	1282	1269	1040	1500	939	-	1270
70000	900	1467	1444	1282	1864	-	-	-
100000	1260	1887	1802	1551	2670	-	-	-
150000	810	1410	1265	1250	1800	-	-	-
200000	1060	1597	1497	1551	2405	-	-	-
250000	1310	1929	1889	2167	2700	-	-	-

Table 9. Berthing Condition: Sheltered – Favorable (IS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	170	462	510	419	650	414	544	610
7000	130	440	377	315	500	358	531	558
10000	190	522	585	430	697	545	695	558
15000	120	400	366	320	490	358	462	775
20000	130	440	377	315	500	358	531	558
30000	180	498	510	419	650	537	681	762
50000	290	699	670	527	880	627	1000	762
70000	400	865	795	720	1050	756	-	812
100000	560	1092	1020	971	1285	-	-	812
150000	810	1410	1310	1551	1780	-	-	1270
200000	1060	1680	1497	1848	2390	-	-	-
250000	1310	1853	1889	2167	2700	-	-	-

Table 10. Berthing Condition: Navigation Difficult – Exposed (BS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	1690	2285	2345	2514	2800	-	-	-
7000	2050	2480	2436	2514	3200	-	-	-
10000	2150	2605	2470	2600	3400	-	-	-
15000	2550	3278	2875	3278	4100	-	-	-
20000	2660	3278	2942	3278	4200	-	-	-
30000	2980	3319	3236	3278	5000	-	-	-
50000	3260	3457	3285	4253	5250	-	-	-
70000	3660	3775	3668	4253	5515	-	-	-
100000	4130	3974	4146	5216	6300	-	-	-
150000	4870	4660	4410	5216	6500	-	-	-
200000	5110	5126	4647	5216	6600	-	-	-
250000	5600		5119		6750	-	-	-

Table 11. Berthing Condition: Good Berthing – Exposed (BS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	1140	1680	1628	1848	2560	-	-	-
7000	1340	1970	1889	2167	2600	-	-	-
10000	1530	2093	2034	2167	2700	-	-	-
15000	1840	2514	2345	2514	2800	-	-	-
20000	1940	2514	2400	2514	2950	-	-	-
30000	2190	2605	2470	2514	3400	-	-	-
50000	2390	2855	2673	3278	3600	-	-	-
70000	2730	3278	3236	3278	4200	-	-	-
100000	2990	3219	3236	3278	4350	-	-	-
150000	3380	3616	3381	4253	4550	-	-	-
200000	3640	3775	3668	4253	5000	-	-	-
250000	3890	4153	3955	4253	6500	-	-	-

Table 12. Berthing Condition: Easy Berthing – Exposed (BS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	670	1231	1153	1282	1500	939	-	1270
7000	780	1414	1220	1414	1750	939	-	1270
10000	880	1551	1372	1551	1864	-	-	-
15000	1080	1680	1707	1848	2405	-	-	-
20000	1100	1680	1725	1848	2500	-	-	-
30000	1230	1846	1758	2167	2650	-	-	-
50000	1320	1970	1889	2167	2700	-	-	-
70000	1590	2189	2132	2167	2750	-	-	-
100000	1620	2237	2345	2514	2775	-	-	-
150000	1820	2514	2345	2514	2800	-	-	-
200000	1920	2550	2336	2514	2915	-	-	-
250000	2010	2600	2336	2514	2950	-	-	-

Table 13. Berthing Condition: Difficult Berthing – Sheltered (BS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	300	730	687	820	900	552	323	812
7000	370	805	773	820	960	600	372	1016
10000	400	865	795	1040	1050	627	420	1016
15000	430	925	863	1040	1150	662	420	1016
20000	490	1040	976	1040	1200	748	-	1016
30000	560	1158	1020	1282	1285	756	-	1270
50000	590	1158	1073	1282	1300	815	-	1270
70000	680	1258	1269	1282	1525	939	-	-
100000	700	1285	1269	1414	1560	939	-	-
150000	960	1538	1516	1848	1750	-	-	-
200000	1120	1680	1584	1848	2510	-	-	-
250000	1220	1804	1758	1848	2650	-	-	-

Table 14. Berthing Condition: Good Berthing – Sheltered (BS).

Vessel Size DWT	Berthing Energy kNm	Berthing Reaction (kN)						
		Cone Fender (kN)	Cell Fender (kN)	Parallel motion Fender (kN)	Pneumatic Fender (kN)	Unit element Fender (kN)	Arch Fender (kN)	V – Fender (kN)
5000	70	283	257	225	374	253	341	406
7000	90	350	319	385	404	320	443	508
10000	90	350	319	385	404	320	443	508
15000	100	385	366	385	449	313	500	508
20000	120	400	366	440	490	375	500	508
30000	130	440	377	440	500	413	531	558
50000	130	440	377	440	500	413	531	558
70000	150	462	431	450	600	443	600	610
100000	160	462	453	450	625	443	600	762
150000	240	606	585	527	850	522	708	812
200000	320	745	737	653	900	582	769	-
250000	340	820	811	653	950	627	769	-

of deflection incritical pile at pile-deck junction. Limit state of collapse comprises of axial force and moments in critical pile.

Deflection in critical pile is obtained for different fender systems with five metocean conditions, and compared as per Indian Standard and British Standard, as shown from Table 15 to Table 19.

Axial force in critical pile is obtained for different fender systems with five metocean conditions, and compared as per Indian Standard and British Standard, as shown from Table 20 to Table 24.

Moment in critical pile is obtained for different fender systems with five metocean conditions, and compared as per Indian Standard and British Standard, as shown from Table 25 to Table 29.

Results and Discussions

- It is observed that British Standard gives more precise values for design berthing velocities. Moreover, Indian standard provides constant value of berthing velocity for vessel sizes more than 250000 DWT, which is not the case with British standard.
- For all metocean conditions and different fender types, British Standard provides higher values of moment in critical pile. Hence British standard governs.
- For all metocean conditions and different fender types, British Standard and Indian Standard provide almost similar value of axial force in critical pile.
- For all metocean conditions and different fender types, Indian Standard provides higher values of deflection in critical pile.
- As per limit state of serviceability, Indian Standard governs

Table 15. Deflection in Pile (mm).

Vessel Size DWT	Strong Wind and Swells - Difficult (IS) and Navigation Difficult – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	170	142	162	144	156	152	218	165	-	-	-	-	-	-
7000	165	162	156	160	145	164	177	198	-	-	-	-	-	-
10000	208	192	207	184	229	191	274	235	-	-	-	-	-	-
15000	216	260	208	235	213	261	234	312	-	-	-	-	-	-
20000	247	289	225	266	239	289	263	351	-	-	-	-	-	-
30000	316	322	308	316	319	354	390	453	-	-	-	-	-	-
50000	501	406	485	390	572	481	711	575	-	-	-	-	-	-
70000	-	528	754	517	-	581	889	717	-	-	-	-	-	-
100000	-	614	1042	635	-	771	-	907	-	-	-	-	-	-
150000	-	847	637	808	-	931	898	1127	-	-	-	-	-	-
200000	-	1069	883	970	-	1070	1258	1310	-	-	-	-	-	-
250000	-	-	1102	1171	-	-	1340	1487	-	-	-	-	-	-

Table 16. Deflection in Pile (mm).

Vessel Size DWT	Strong Wind and Swells - Favorable (IS) and Good Berthing – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	135	115	133	113	137	122	164	153	-	-	-	-	-	-
7000	129	138	125	134	131	147	167	168	-	-	-	-	-	-
10000	175	164	166	160	187	168	201	197	-	-	-	-	-	-
15000	159	213	156	202	172	213	216	231	-	-	-	-	-	-
20000	180	237	177	229	191	237	238	266	-	-	-	-	-	-
30000	238	267	230	256	233	294	282	328	-	-	-	-	-	-
50000	389	349	357	332	390	431	457	419	-	-	-	-	-	-
70000	528	474	517	470	581	474	596	574	-	-	-	-	-	-
100000	759	541	684	520	758	521	853	661	-	-	-	-	-	-
150000	-	687	632	652	635	784	778	829	-	-	-	-	-	-
200000	-	818	956	799	901	901	1319	1031	-	-	-	-	-	-
250000	-	984	1102	953	1189	1003	1496	1438	-	-	-	-	-	-

Table 17. Deflection in Pile (mm).

Vessel Size DWT	Moderate Wind and Swells – Moderate (IS) and Easy Berthing – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	109	95	101	91	109	97	123	107	-	81	-	-	-	96
7000	104	110	101	101	110	111	124	127	87	87	-	-	103	103
10000	139	134	131	125	150	134	181	151	-	-	-	-	-	-
15000	117	162	115	163	122	169	139	206	89	-	-	-	121	-
20000	132	180	128	183	137	192	158	236	112	-	-	-	135	-
30000	165	208	163	201	172	233	197	270	138	-	-	-	163	-
50000	209	266	206	258	227	284	292	335	-	-	-	-	-	-
70000	367	356	350	350	354	354	401	417	-	-	-	-	-	-
100000	449	394	432	407	525	423	554	462	-	-	-	-	-	-
150000	520	519	494	494	520	520	563	563	-	-	-	-	-	-
200000	658	596	626	568	731	598	822	668	-	-	-	-	-	-
250000	787	683	806	632	815	666	1051	751	-	-	-	-	-	-

Table 18. Deflection in Pile (mm).

Vessel Size DWT	Sheltered - Difficult (IS) and Difficult Berthing – Sheltered (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	69	72	67	70	68	76	78	80	66	64	76	54	74	76
7000	71	80	70	79	72	81	82	88	67	70	76	59	81	91
10000	59	97	90	93	94	106	100	107	82	84	91	73	94	106
15000	99	115	97	112	109	125	111	129	95	99	106	84	109	121
20000	112	137	110	133	102	137	126	148	101	117	113	-	121	133
30000	133	155	128	145	106	164	150	165	115	123	142	-	144	140
50000	201	190	200	181	178	201	221	203	170	157	-		201	201
70000	278	256	276	257	257	258	321	284	-	221	-	-	-	-
100000	350	273	339	271	307	290	449	309	-	230	-	-	-	-
150000	352	371	329	368	327	418	411	434	-	-	-	-	-	-
200000	438	453	421	436	430	482	579	597	-	-	-	-	-	-
250000	553	530	545	520	599	538	702	693	-	-	-	-	-	-

Table 19. Deflection in Pile (mm).

Vessel Size DWT	Sheltered - Favorable (IS) and Good Berthing – Sheltered (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	50	53	63	51	59	50	69	57	58	51	64	55	67	68
7000	63	58	60	57	66	60	108	60	58	57	67	63	68	66
10000	82	69	82	67	73	71	88	71	79	67	88	74	92	77
15000	83	83	81	82	78	83	89	86	81	78	87	89	89	90
20000	96	94	92	91	88	97	100	97	91	92	102	100	104	101
30000	103	98	104	94	97	99	115	104	106	97	118	106	124	109
50000	146	122	144	116	130	122	163	128	140	119	175	131	152	133
70000	213	169	205	166	197	168	233	168	210	167	-	169	207	185
100000	249	170	240	168	234	184	273	190	-	167	-	187	214	207
150000	352	229	336	226	373	217	404	266	-	217	-	245	330	261
200000	452	290	421	288	482	274	621	317	-	261	-	494	-	-
250000	538	338	545	337	599	306	702	364	-	301	-	309	-	-

Table 20. Axial Force in Pile (kN).

Vessel Size DWT	Strong Wind and Swells - Difficult (IS) and Navigation Difficult – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	2551	2545	2550	2546	2504	2551	2549	2548	-	-	-	-	-	-
7000	2541	2624	2540	2541	2542	2545	2539	2541	-	-	-	-	-	-
10000	2624	2541	2624	2624	2624	2624	2624	2624	-	-	-	-	-	-
15000	2630	2625	2631	2628	2628	2325	2631	2625	-	-	-	-	-	-
20000	2588	2579	2592	2584	2584	2567	2589	2579	-	-	-	-	-	-
30000	2706	2702	2704	2704	2682	2664	2703	2693	-	-	-	-	-	-
50000	2722	2759	2729	2766	2690	2693	2694	2703	-	-	-	-	-	-
70000	-	3605	3506	3611	3446	3522	-	3583	-	-	-	-	-	-
100000	-	6821	6610	6810	-	6680	-	6746	-	-	-	-	-	-
150000	-	3175	3304	3139	2836	3002	-	3135	-	-	-	-	-	-
200000	-	2874	2969	2924	3143	2751	-	2879	-	-	-	-	-	-
250000	-	-	2956	2921	2836	2761	-	-	-	-	-	-	-	-

Table 21. Axial Force in Pile (kN).

Vessel Size DWT	Strong Wind and Swells - Favorable (IS) and Good Berthing – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	2543	2538	2543	2538	2551	2584	2544	2540	-	-	-	-	-	-
7000	2537	2538	2536	2537	2541	2542	2537	2539	-	-	-	-	-	-
10000	2624	2624	2624	2624	2643	2624	2624	2624	-	-	-	-	-	-
15000	2637	2631	2637	2632	2631	2629	2635	2631	-	-	-	-	-	-
20000	2601	2590	2602	2591	2589	2590	2699	2590	-	-	-	-	-	-
30000	2727	2718	2719	2721	2714	2700	2728	2720	-	-	-	-	-	-
50000	2766	2782	2778	2788	2739	2754	2766	2749	-	-	-	-	-	-
70000	3605	3629	3611	3631	3575	3585	3583	3712	-	-	-	-	-	-
100000	6751	6556	6787	6865	6706	6758	6751	6863	-	-	-	-	-	-
150000	-	3273	3307	3295	3218	3185	3305	3213	-	-	-	-	-	-
200000	-	3001	2932	3011	2747	2893	2959	2959	-	-	-	-	-	-
250000	-	3016	2956	3032	2750	2786	2912	3007	-	-	-	-	-	-

Table 22. Axial Force in Pile (kN).

Vessel Size DWT	Moderate Wind and Swells – Moderate (IS) and Easy Berthing – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	2537	2533	2535	2535	2537	2535	2541	2536	-	2530	-	-	-	2534
7000	2534	2534	2533	2535	2534	2535	2536	2536	2532	2532	-	-	2534	2534
10000	2624	2624	2624	2624	2624	2624	2624	2624	-	-	-	-	-	-
15000	2642	2637	2642	2636	2641	2635	2639	2631	2645	-	-	-	2641	-
20000	2611	2601	2612	2600	2610	2599	2606	2590	2615	-	-	-	2610	-
30000	2748	2735	2749	2737	2745	2728	2739	2717	2756	-	-	-	2749	-
50000	2837	2814	2838	2851	2830	2807	2804	2787	-	-	-	-	-	-
70000	3677	3681	3684	3684	3682	3682	3662	2655	-	-	-	-	-	-
100000	6990	6926	6908	6919	6863	6909	6849	6893	-	-	-	-	-	-
150000	3377	3377	3393	3393	3377	3377	3350	3350	-	-	-	-	-	-
200000	3083	3114	3099	3129	3045	3113	2999	3078	-	-	-	-	-	-
250000	3116	3169	3106	3195	3102	3177	2982	3135	-	-	-	-	-	-

Table 23. Axial Force in Pile (kN).

Vessel Size DWT	Sheltered - Difficult (IS) and Difficult Berthing – Sheltered (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	2527	2528	2527	2527	2529	2530	2527	2529	2526	2526	2529	2523	2528	2529
7000	2541	2531	2529	2531	2531	2532	2530	2531	2529	2530	2530	2528	2531	2532
10000	2625	2640	2625	2625	2625	2624	2625	2624	2625	2625	2625	2625	2625	2624
15000	2644	2642	2644	2642	2643	2640	2643	2641	2645	2644	2643	2646	2643	2541
20000	2615	2610	2615	2611	2612	2608	2617	2610	2617	2614	2615	-	2613	2610
30000	2757	2751	2759	2754	2752	2748	2764	2748	2763	2760	2755	-	2754	2751
50000	2840	2844	2840	2847	2832	2839	2849	2840	2852	2857	-	-	2840	2840
70000	3716	3726	3747	3725	3697	3713	3725	3725	-	3741	-	-	-	-
100000	6947	6983	6952	6984	6900	6968	6967	6976	-	7004	-	-	-	-
150000	3481	3469	3495	3471	3444	3430	3496	3490	-	-	-	-	-	-
200000	3194	3187	3203	3195	3123	3113	3198	3172	-	-	-	-	-	-
250000	2840	3247	3239	3252	3123	3164	3212	3243	-	-	-	-	-	-

Table 24. Axial Force in Pile (kN).

Vessel Size DWT	Sheltered - Favorable (IS) and Good Berthing – Sheltered (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	2525	2523	2525	2523	2527	2524	2524	2535	2524	2523	2565	2524	2527	2524
7000	2529	2528	2628	2528	2534	2528	2529	2528	2528	2528	2529	2529	2529	2529
10000	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625	2625
15000	2646	2646	2646	2646	2645	2646	2646	2646	2646	2647	2645	2645	2645	2645
20000	2818	2619	2619	2619	2617	2618	2620	2618	2619	2619	2617	2617	2616	2617
30000	2766	2767	2766	2769	2763	2706	2768	2767	2765	2768	2762	2765	2760	2765
50000	2861	2871	2862	2873	2855	2869	2868	2871	2864	2872	2850	2868	2859	2867
70000	3745	3764	3748	3766	3736	3758	3752	3765	3750	3765	-	3758	3747	3757
100000	6995	7033	6999	7034	6983	7023	7002	7034	-	7034	-	7025	7012	7015
150000	3481	3557	3491	3559	3446	3543	3468	3564	-	3565	-	3547	3494	3537
200000	3187	3270	3203	3270	3124	3256	3172	3278	-	3284	-	3263	-	-
250000	3243	3349	3239	3345	3330	3331	3212	3360	-	3363	-	3349	-	-

Table 25. Moment in Pile (kN).

Vessel Size DWT	Strong Wind and Swells - Difficult (IS) and Navigation Difficult – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	778	631	741	634	1078	757	705	680	-	-	-	-	-	-
7000	708	698	660	686	778	900	596	708	-	-	-	-	-	-
10000	854	766	845	726	1203	998	963	645	-	-	-	-	-	-
15000	786	1005	748	882	875	1063	772	1005	-	-	-	-	-	-
20000	846	1051	743	935	822	903	811	1041	-	-	-	-	-	-
30000	1041	1101	1073	1073	1392	1656	1087	1236	-	-	-	-	-	-
50000	1566	1213	1504	1153	2346	1839	1827	1491	-	-	-	-	-	-
70000	-	1373	2127	1334	2577	2003	-	1546	-	-	-	-	-	-
100000	-	1497	2769	1562	-	2370	-	1963	-	-	-	-	-	-
150000	-	1762	1244	1668	2435	2455	-	1971	-	-	-	-	-	-
200000	-	2087	1661	1860	1090	2639	-	2087	-	-	-	-	-	-
250000	-	-	1939	2082	2435	2711	-	-	-	-	-	-	-	-

Table 26. Moment in Pile (kN).

Vessel Size DWT	Strong Wind and Swells - Favorable (IS) and Good Berthing – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	641	673	645	676	753	692	639	661	-	-	-	-	-	-
7000	609	595	616	602	721	732	605	610	-	-	-	-	-	-
10000	672	649	645	654	812	793	739	642	-	-	-	-	-	-
15000	733	772	737	720	768	859	710	772	-	-	-	-	-	-
20000	752	799	758	763	805	799	733	799	-	-	-	-	-	-
30000	743	865	709	820	929	1127	720	835	-	-	-	-	-	-
50000	1150	1002	1033	939	1402	1263	1150	1307	-	-	-	-	-	-
70000	1373	1193	1336	1178	1559	1527	1546	1250	-	-	-	-	-	-
100000	1930	1282	1705	1220	2209	1768	1930	1236	-	-	-	-	-	-
150000	-	1369	1234	1260	1589	1721	1241	1609	-	-	-	-	-	-
200000	-	1513	1826	1470	2659	2001	1703	1703	-	-	-	-	-	-
250000	-	1691	1939	1627	2763	2642	2121	1731	-	-	-	-	-	-

Table 27. Moment in Pile (kN).

Vessel Size DWT	Moderate Wind and Swells – Moderate (IS) and Easy Berthing – Exposed (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	681	703	694	709	659	658	681	700	-	724	-	-	-	701
7000	649	639	654	655	617	613	639	639	677	677	-	-	651	651
10000	689	698	703	714	706	699	671	698	-	-	-	-	-	-
15000	803	728	806	725	765	739	793	710	849	-	-	-	796	-
20000	832	752	839	747	789	795	824	733	865	-	-	-	827	-
30000	706	637	710	648	655	880	691	720	751	-	-	-	709	-
50000	740	693	744	665	790	948	713	762	-	-	-	-	-	-
70000	833	820	829	829	947	1002	824	824	-	-	-	-	-	-
100000	1007	846	959	886	1320	1047	1236	950	-	-	-	-	-	-
150000	854	954	890	890	1061	1061	954	954	-	-	-	-	-	-
200000	1145	1004	1073	939	1523	1170	1314	1010	-	-	-	-	-	-
250000	1280	1061	1319	954	1831	1203	1336	1026	-	-	-	-	-	-

Table 28. Moment in Pile (kN).

Vessel Size DWT	Sheltered - Difficult (IS) and Difficult Berthing – Sheltered (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	743	738	746	741	730	726	745	732	748	750	733	766	736	532
7000	704	668	705	690	685	675	702	687	710	704	695	722	691	671
10000	764	782	772	766	756	743	764	744	784	782	769	800	765	746
15000	833	805	836	811	813	782	816	793	840	832	821	857	817	796
20000	866	824	870	832	843	806	882	824	885	857	865	-	850	827
30000	758	724	766	741	731	707	803	708	788	774	743	-	741	710
50000	752	770	754	782	720	749	786	752	801	819	-	-	753	753
70000	933	965	936	963	871	924	961	961	-	1015	-	-	-	-
100000	730	831	745	834	1008	785	787	810	-	889	-	-	-	-
150000	865	842	891	846	794	766	894	785	-	-	-	-	-	-
200000	880	865	899	883	966	1008	889	833	-	-	-	-	-	-
250000	752	1087	862	888	966	1082	886	870	-	-	-	-	-	-

Table 29. Moment in Pile (kN)

Vessel Size DWT	Sheltered - Favorable (IS) and Good Berthing – Sheltered (BS)													
	Cone Fender		Cell Fender		Parallel motion Fender		Pneumatic Fender		Unit element Fender		Arch Fender		V - Fender	
	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS	IS	BS
5000	756	769	753	771	743	763	759	770	763	771	751	765	746	760
7000	717	724	722	726	643	720	712	721	723	726	709	716	707	711
10000	791	807	801	810	775	802	799	804	789	809	775	798	768	792
15000	923	923	862	862	850	854	867	861	863	868	853	849	848	848
20000	892	897	899	900	885	891	906	892	901	899	882	885	879	884
30000	806	814	805	822	787	806	816	814	802	817	783	802	773	799
50000	835	873	840	882	809	864	860	873	846	876	792	860	826	856
70000	1026	1089	1037	1094	998	1068	1049	1091	1092	1092	-	1068	1035	1066
100000	864	969	876	971	831	942	884	971	-	872	-	946	910	919
150000	865	1012	883	1016	797	967	839	1026	-	1027	-	993	891	974
200000	865	1042	899	1043	960	1012	833	1059	-	1073	-	1037	-	-
250000	869	1071	862	1073	1102	1046	886	1104	-	1107	-	1081	-	-

the design of the wharf.

- As per limit state of collapse, British Standard governs the design of the wharf.

Figure 7. Suitability Matrix for Strong Wind and Swells - difficult Condition (IS).

Conclusions

Suitability matrix to prioritize fender system for all vessel sizes and metocean condition as per IS and BSare shown from Figure 7 to Figure 16.

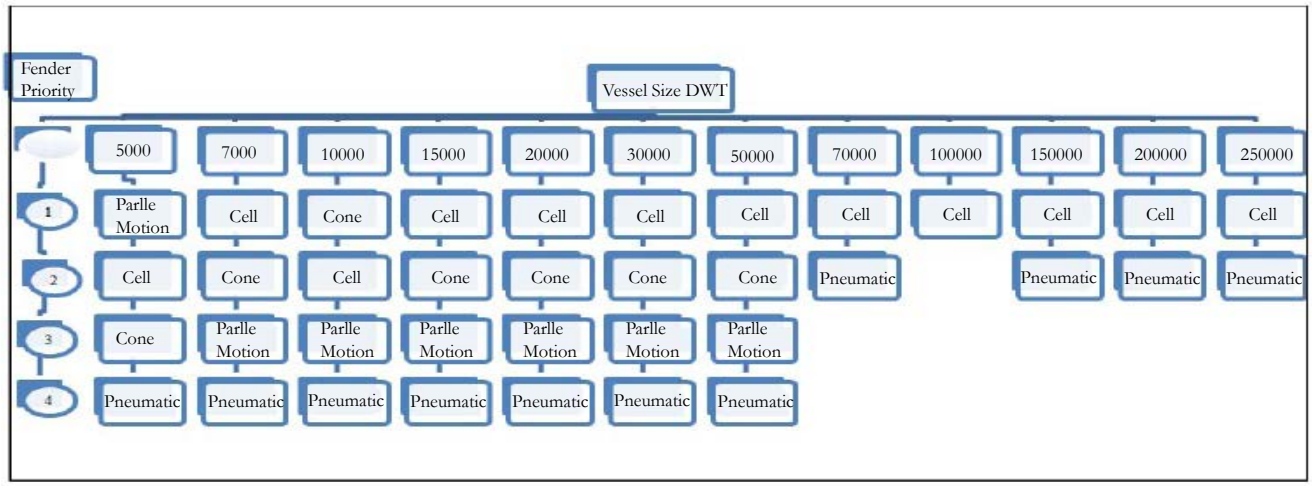


Figure 8. Suitability Matrix for Strong Wind and Swells - Favorable Condition (IS).

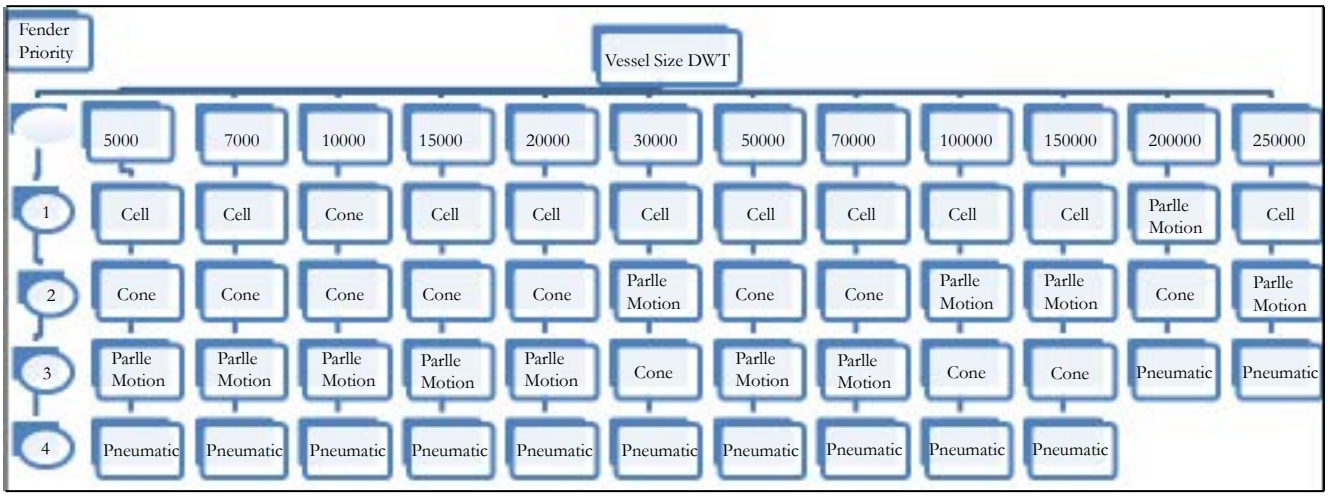


Figure 9. Suitability Matrix for Moderate Wind and Swells - Moderate Condition (IS).

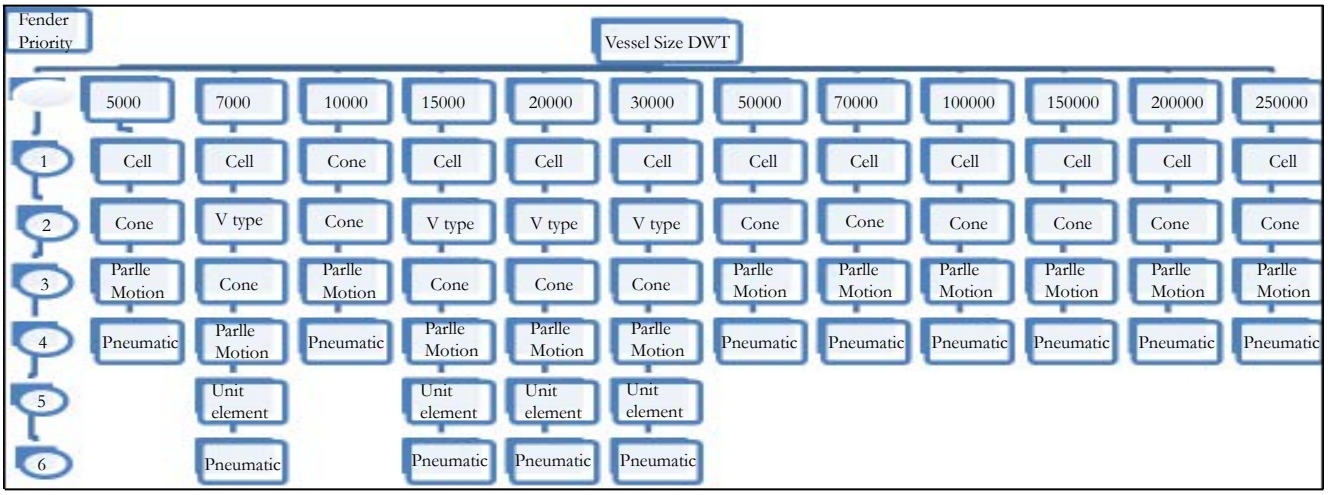


Figure 10. Suitability Matrix for Sheltered – Difficult Condition (IS).

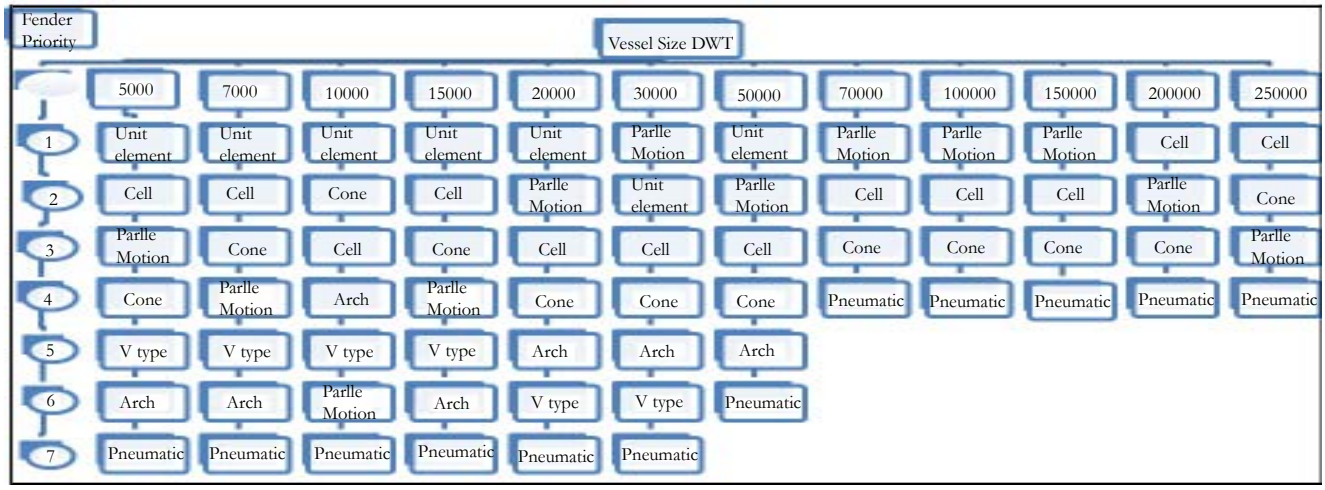


Figure 11. Suitability Matrix for Sheltered – Favorable Condition (IS).

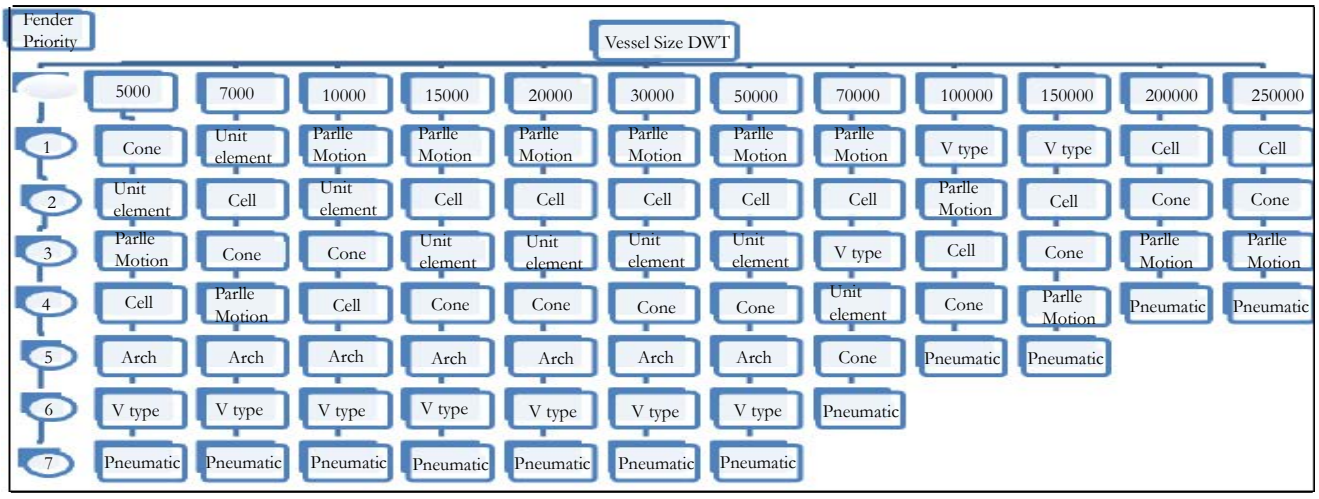


Figure 12. Suitability Matrix for Navigation Difficult – Exposed Condition (BS).

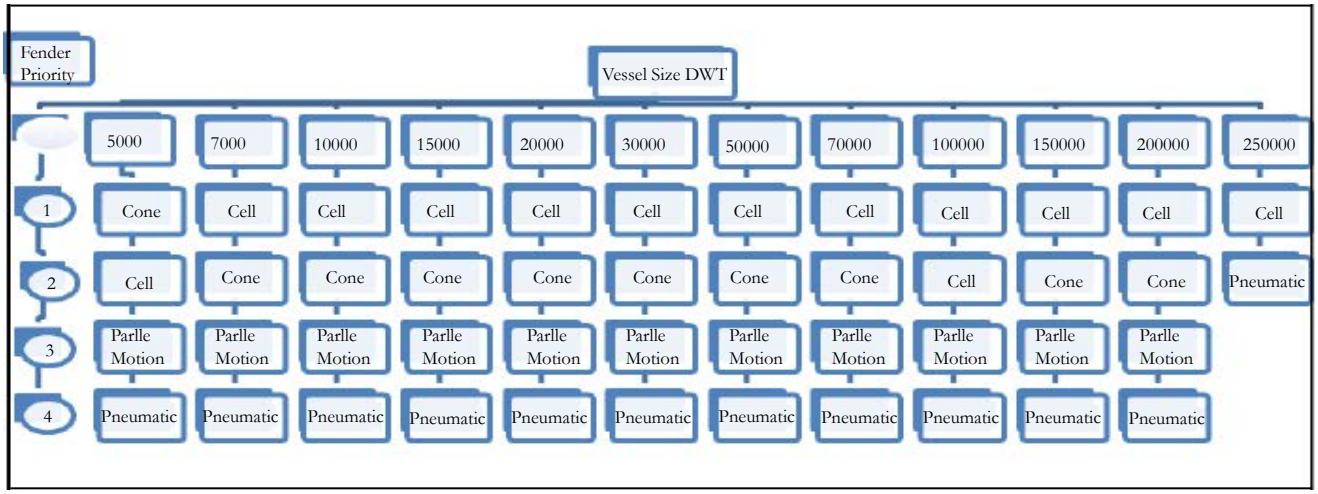


Figure 13. Suitability Matrix for Good Berthing – Exposed Condition (BS).

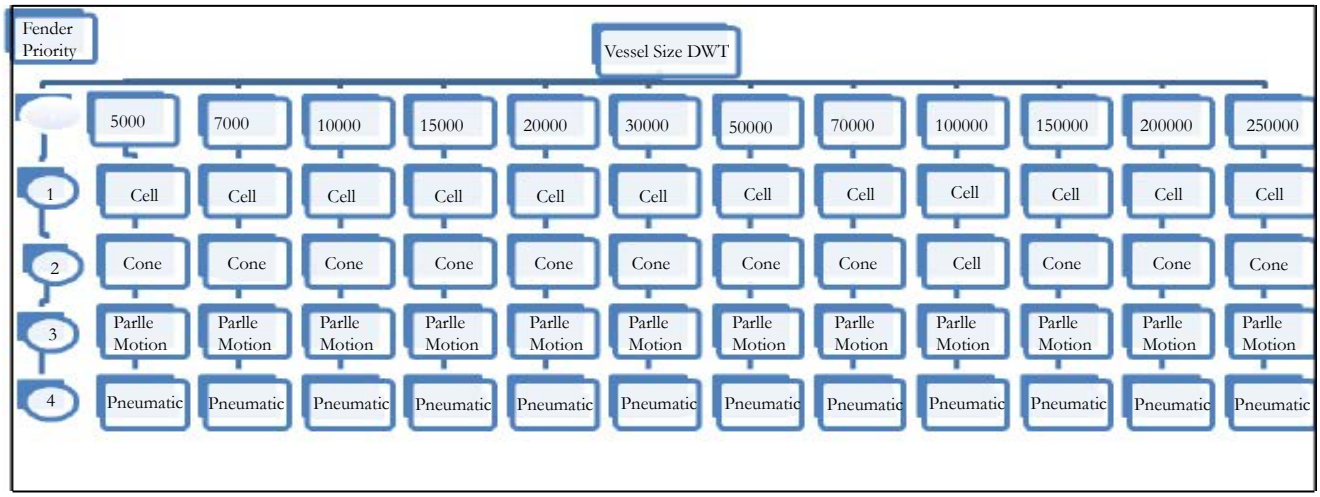


Figure 14. Suitability Matrix for Easy Berthing– Exposed Condition (BS).

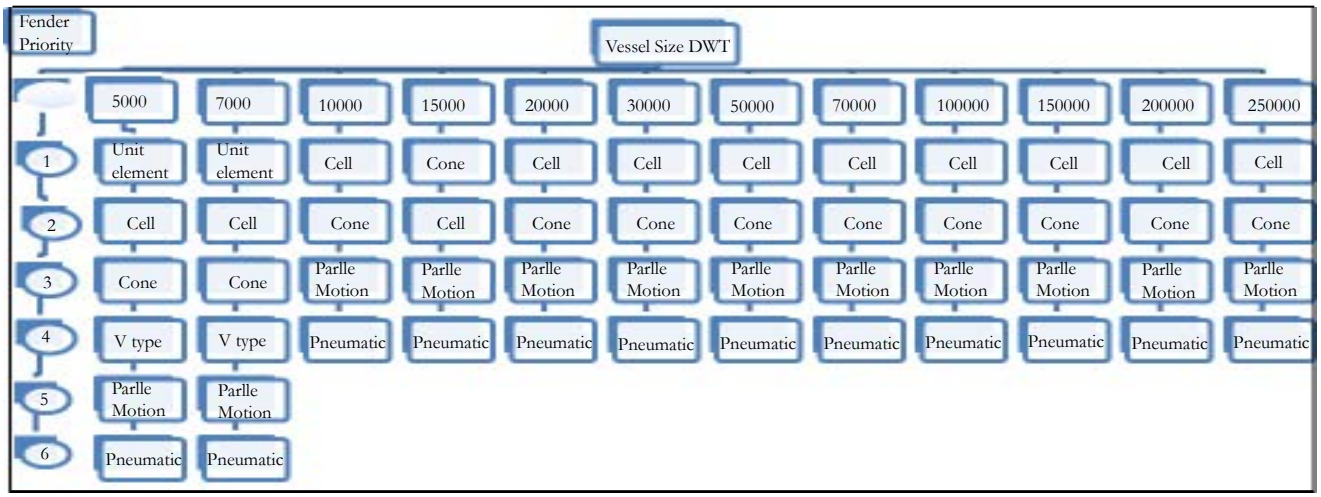


Figure 15. Suitability Matrix for Difficult Berthing – Sheltered Condition (BS).

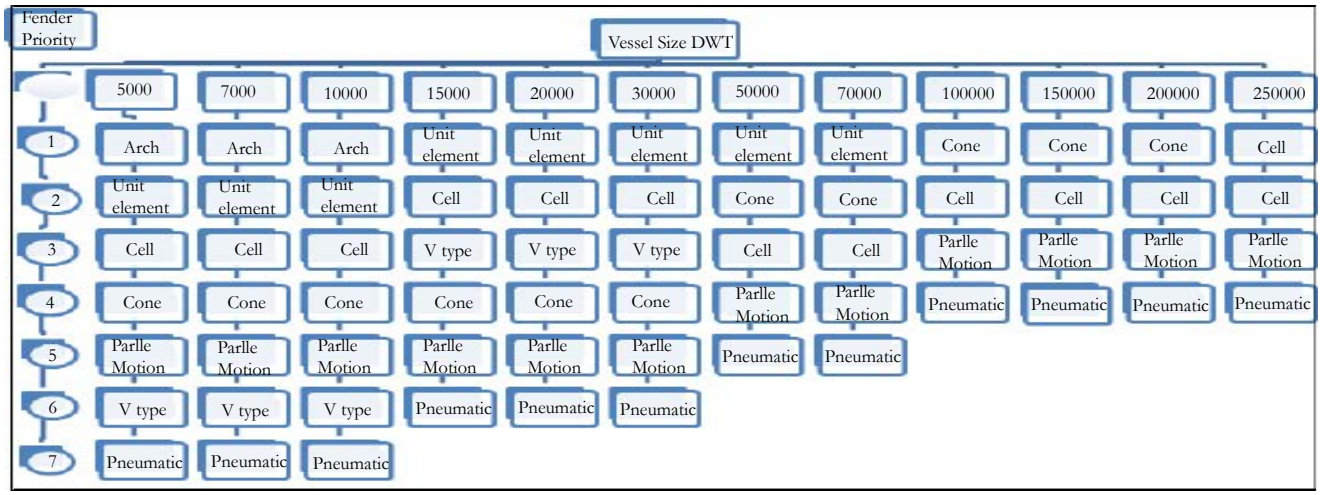
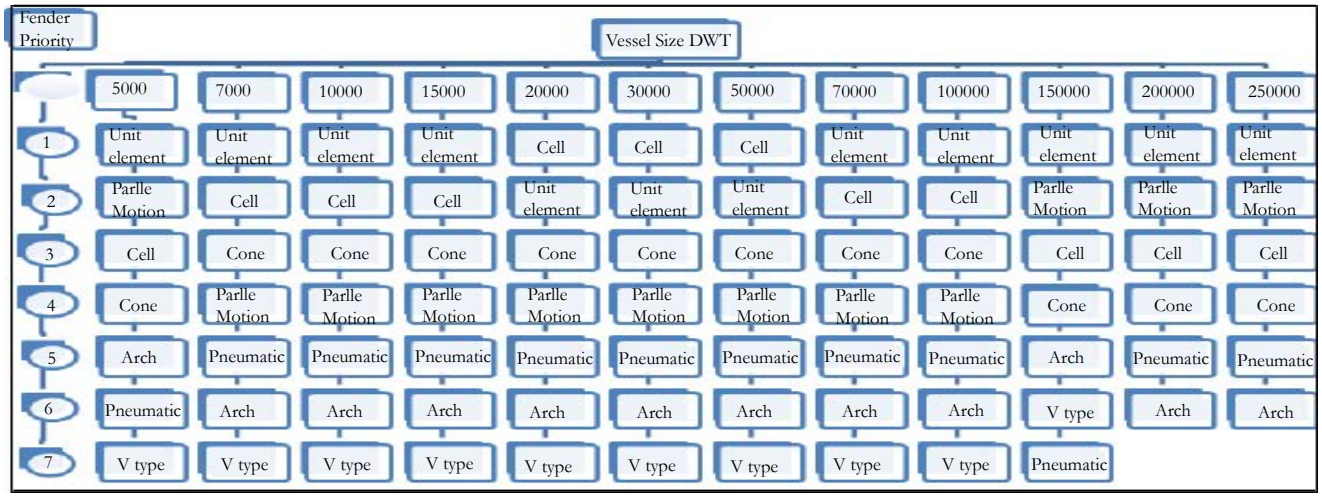


Figure 16. Suitability Matrix for Good Berthing – Sheltered Condition (BS).



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