Ship Stability

Ch. 13 Probabilistic Damage Stability

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Myung-Il Roh

Department of Naval Architecture and Ocean Engineering
Seoul National University

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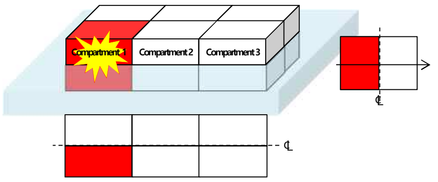
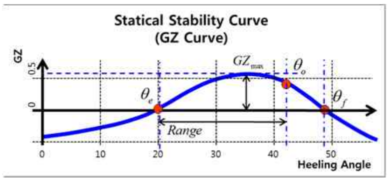
Ch. 13 Probabilistic Damage Stability (Subdivision and Damage Stability, SDS)

1. Introduction to Subdivision and Damage Stability

Two Methods to Measure the Ship's Damage Stability





How to measure the ship's stability in a damaged condition?

Deterministic Method : Calculation of survivability of a ship based on the position, stability, and inclination in damaged conditions

Probabilistic Method : Calculation of survivability of a ship based on the probability of damage

Probabilistic Method

The probability of damage "p_i" that a compartment or group of compartments may be flooded at the level of the subdivision draft ( )

The probability of survival "s_i" after flooding in a given damage condition.

The attained subdivision index "A" is the summation of the probability of all damage cases.

$$A = p_1 \times s_1 + p_2 \times s_2 + p_3 \times s_3 + \cdots p_i \times s_i$$
$$= \sum p_i \times s_i$$

Ship Types for Subdivision & Damage Stability

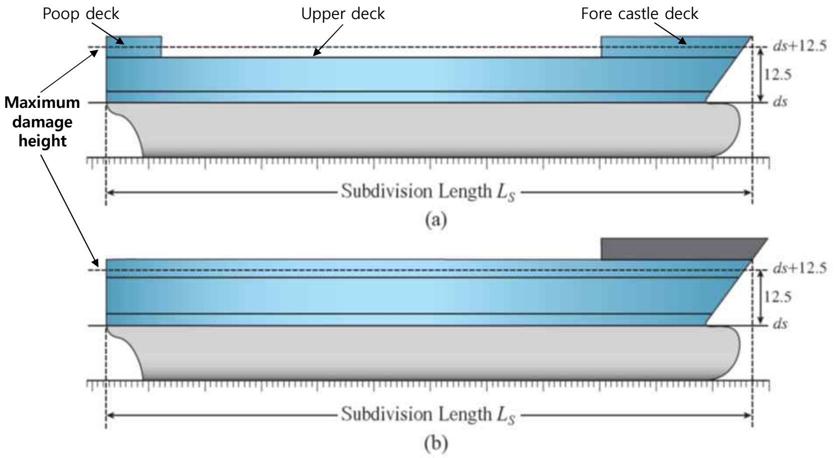
☑ Bulk carriers, Container carriers, Ro-Ro ships having over 80m in length

☑ Passenger ships of any length

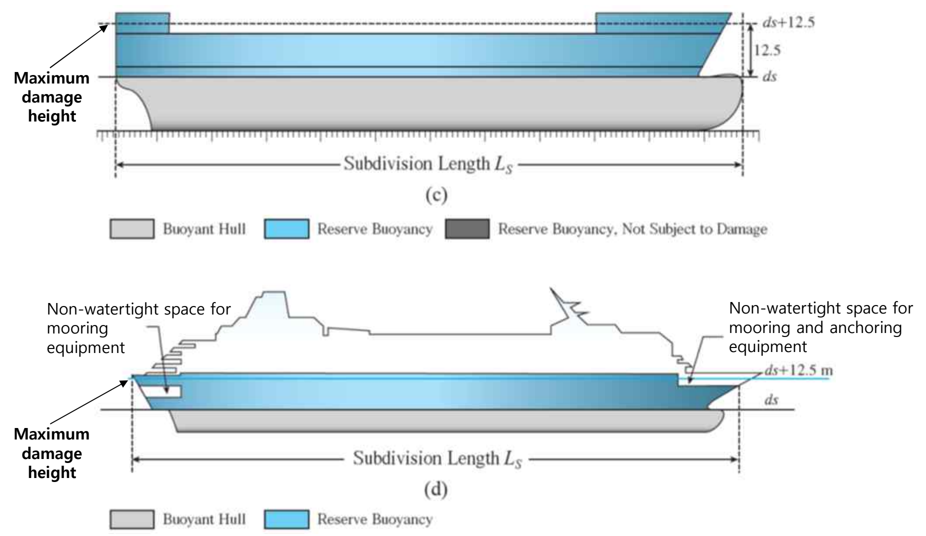
Ship Type	Freeboard Type	Deterministic Damage Stability				Probabilistic Damage Stability
		ICLL[1]	MARPOL[2]	IBC[3]	IGC[4]	SOLAS[5]
Oil Tankers	A[6]	O	O			
	B[7]		O			
Chemical Tankers	A	O		O		
Gas Carriers	B				O	
Bulk Carriers	B					O
	B-60	O				
	B-100	O				
Container Carriers Ro-Ro Ships Passenger Ships	B					O

Definition of Subdivision Length (L_s) (1/2)

☑ The greatest projected molded length of that part of the ship at or below deck or decks limiting the vertical extent of flooding with the ship (12.5m) at the deepest subdivision load line



Definition of Subdivision Length (L_s) (2/2)



Required Subdivision Index (R)

- ☑ The regulation for subdivision & damage stability are intended to provide ships with a minimum standard of subdivision.
- ☑ The degree of subdivision to be provided is to be determined by the required subdivision index R.
- ☑ The index, a function of the subdivision length (L_s), is defined as follows.
  - for cargo ships over 100m in L_S:

$$R = 1 - \frac{128}{L_s + 152}$$

  - for cargo ships of 80m in L_S and upwards, but not exceeding 100m in length L_S:

    where R_0 is the value R as calculated in accordance with the formula relevant to ships over 100 m in L_S.
  - for passenger ships

    where, $N=N_1+2N_2$, N_1: number of persons for whom lifeboats are provided, N_2: number of persons (including officers and crew) the ship is permitted to carry in excess of N_1

Attained Subdivision Index (A)

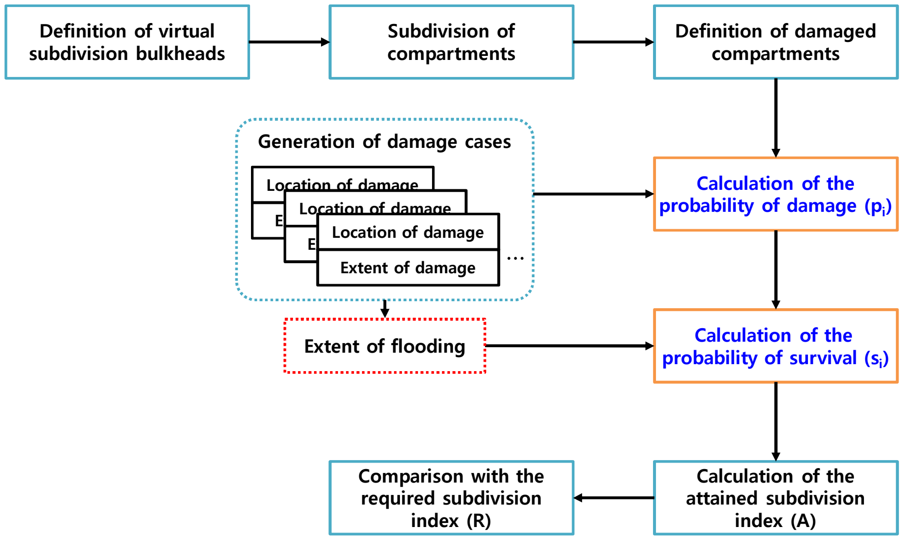
'he attained subdivision index A, calculated in accordance with his regulation, is to be not less than the required subdivision ndex R.

$$\text{Where } A = 0.4A_s + 0.4A_p + 0.2A_l$$

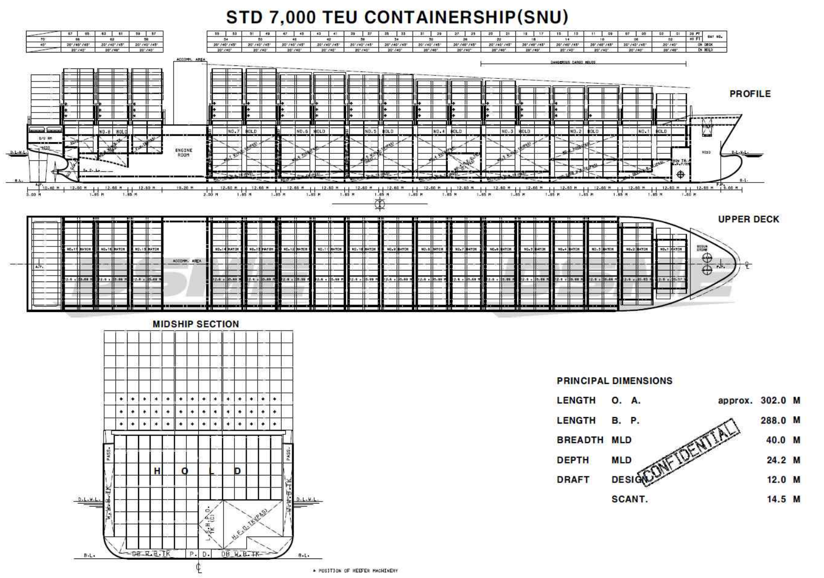
☑ The attained subdivision index A is to be calculated for the ship by the following formula.

Where,
i: Represents each compartment or group of compartments under consideration.
p_i: Accounts for the probability that only the compartment or group of compartments under consideration may be flooded, disregarding any horizontal subdivision, p_i is independent of the draft but includes the factor r.
s_i: Accounts for the probability of survival after flooding the compartment or group of compartments under consideration, including the effects of any horizontal subdivision, s_i is dependent on the draft and includes the factor v.

Overall Procedures to Evaluate the Probabilistic Damage Stability



[Example] 7,000TEU Container Ship - General Arrangement



[Example] 7,000TEU Container Ship
- Trim & Stability Calculation

NO	CONDITION	DISPL(T)	DEQ.	DA	DF	TRIM	GoM(M)	KG(M)	LB(M)	MAX S.F(T)	MAX B.M(T-M)
1	LIGHTSHIP COND.(NOT SEA GOING)	27710	4.12	6.53	1.56	4.97	15.65	16.00	354	4860	336289
2	BALLAST DEP.COND.	59255	7.86	9.62	5.99	3.64	9.84	11.76	279	-3547	158464
3	BALLAST ARR.COND.	51667	7.00	8.92	4.97	3.96	10.90	12.03	296	2868	188817
4	HOMO.SCANT.DEP.COND.(8mt/TEU, 6502 TEU)	117444	13.90	13.92	13.88	0.05	1.01	17.42	444	5899	273134
5	HOMO.SCANT.ARR.COND.(8mt/TEU, 6502 TEU)	109856	13.17	13.40	12.89	0.51	0.56	17.94	477	6638	332143
6	HOMO.SCANT.DEP.COND.(10mt/TEU, 6022 TEU)	123760	14.50	14.59	14.40	0.18	1.02	17.42	365	5905	248580
7	HOMO.SCANT.ARR.COND.(10mt/TEU, 6022 TEU)	116323	13.80	14.11	13.41	0.70	0.56	17.91	394	6647	294847
8	HOMO.SCANT.DEP.COND.(12mt/TEU, 5614 TEU)	123717	14.50	14.55	14.44	0.11	0.94	17.47	260	5270	232305
9	HOMO.SCANT.ARR.COND.(12mt/TEU, 5614 TEU)	118085	13.97	14.37	13.48	0.89	0.61	17.87	284	5562	245546
10	HOMO.SCANT.DEP.COND.(14mt/TEU, 5302 TEU)	123740	14.50	14.71	14.25	0.45	0.92	17.53	244	5042	217406
11	HOMO.SCANT.ARR.COND.(14mt/TEU, 5302 TEU)	120038	14.15	14.21	14.08	0.13	0.58				
16	HOMO.DES.DEP.COND.(8mt/TEU, 6054 TEU)	98112	12.00	12.21	11.77	0.43	0.94	17.73	416	5301	297074
17	HOMO.DES.ARR.COND.(8mt/TEU, 6054 TEU)	94131	11.60	11.76	11.41	0.35	0.59	18.17	420	5710	307761
18	HOMO.DES.DEP.COND.(10mt/TEU, 5390 TEU)	98062	12.00	12.17	11.81	0.36	0.56	17.71	299	5646	327391
19	HOMO.DES.ARR.COND.(10mt/TEU, 5390 TEU)	93552	11.54	12.00	11.01	0.99	0.79	17.82	320	5855	310951
20	HOMO.DES.DEP.COND.(12mt/TEU, 4886 TEU)	98040	12.00	12.41	11.52	0.89	0.69	17.82	233	5378	306050
21	HOMO.DES.ARR.COND.(12mt/TEU, 4886 TEU)	93706	11.56	11.70	11.40	0.30	0.67	17.92	228	6023	347568
22	HOMO.DES.DEP.COND.(14mt/TEU, 4350 TEU)	98027	12.00	12.41	11.52	0.89	1.43	17.28	188	4933	262228
23	HOMO.DES.ARR.COND.(14mt/TEU, 4350 TEU)	92390	11.42	11.83	10.96	0.87	1.08	17.78	194	5506	297030
24	HOMO.DES.DEP.COND.(16mt/TEU, 3818 TEU)	98215	12.01	12.16	11.85	0.31	2.40	16.26	180	4384	208479
25	HOMO.DES.ARR.COND.(16mt/TEU, 3818 TEU)	90627	11.24	11.57	10.87	0.70	2.11	16.79	194	4965	255419
26	HOMO.DES.DEP.COND.(18mt/TEU, 3386 TEU)	98075	12.00	12.25	11.72	0.53	3.40	15.27	183	4829	256143

In accordance with IACS UR S1, the commercial ship's loading conditions which should be calculated are as follows.

- Lightship condition
- Ballast condition
- Homogeneous loading condition
- Special condition required by the Owner

[Example] 7,000TEU Container Ship
- Trim & Stability Calculation

NO	CONDITION	DISPL(T)	DEQ.	DA	DF	TRIM	GoM(M)	KG(M)	LB(M)	MAX S.F(T)	MAX B.M(T-M)
1	LIGHTSHIP COND.(NOT SEA GOING)	27710	4.12	6.53	1.56	4.97	15.65	16.00	354	4860	336289
2	BALLAST DEP.COND.	59255	7.86	9.62	5.99	3.64	9.84	11.76	279	-3547	158464
3	BALLAST ARR.COND.	51667	7.00	8.92	4.97	3.96	10.90	12.03	296	2868	188817
4	HOMO.SCANT.DEP.COND.(8mt/TEU, 6502 TEU)	117444	13.90	13.92	13.88	0.05	1.01	17.42	444	5899	273134
5	HOMO.SCANT.ARR.COND.(8mt/TEU, 6502 TEU)	109856	13.17	13.40	12.89	0.51	0.56	17.94	477	6638	332143
6	HOMO.SCANT.DEP.COND.(10mt/TEU, 6022 TEU)	123760	14.50	14.59	14.40	0.18	1.02	17.42	365	5905	248580
7	HOMO.SCANT.ARR.COND.(10mt/TEU, 6022 TEU)	116323	13.80	14.11	13.41	0.70	0.56	17.91	394	6647	294847
8	HOMO.SCANT.DEP.COND.(12mt/TEU, 5614 TEU)	123717	14.50	14.55	14.44	0.11	0.94	17.47	260	5270	232305
9	HOMO.SCANT.ARR.COND.(12mt/TEU, 5614 TEU)	118085	13.97	14.37	13.48	0.89	0.61	17.87	284	5562	245546
10	HOMO.SCANT.DEP.COND.(14mt/TEU, 5302 TEU)	123740	14.50	14.71	14.25	0.45	0.92	17.53	244	5042	217406
11	HOMO.SCANT.ARR.COND.(14mt/TEU, 5302 TEU)	120038	14.15	14.21	14.08	0.13	0.58	17.85	243	5716	250760
12	HOMO.SCANT.DEP.COND.(16mt/TEU, 4918 TEU)	123726	14.50	14.74	14.21	0.52	0.93	17.51	197	5603	248925
13	HOMO.SCANT.ARR.COND.(16mt/TEU, 4918 TEU)	118410	14.00	14.20	13.75	0.45	0.56	17.87	202	6390	291851
14	HOMO.SCANT.DEP.COND.(18mt/TEU, 4566 TEU)	123748	14.50	14.55	14.44	0.12	0.92				
16	HOMO.DES.DEP.COND.(8mt/TEU, 6054 TEU)	98112	12.00	12.21	11.77	0.43	0.94	17.73	416	5301	297074
17	HOMO.DES.ARR.COND.(8mt/TEU, 6054 TEU)	94131	11.60	11.76	11.41	0.35	0.59	18.17	420	5710	307761
18	HOMO.DES.DEP.COND.(10mt/TEU, 5390 TEU)	98062	12.00	12.17	11.81	0.36	0.56	17.71	299	5646	327391
19	HOMO.DES.ARR.COND.(10mt/TEU, 5390 TEU)	93552	11.54	12.00	11.01	0.99	0.79	17.82	320	5855	310951
20	HOMO.DES.DEP.COND.(12mt/TEU, 4886 TEU)	98040	12.00	12.41	11.52	0.89	0.69	17.82	233	5378	306050
21	HOMO.DES.ARR.COND.(12mt/TEU, 4886 TEU)	93706	11.56	11.70	11.40	0.30	0.67	17.92	228	6023	347568
22	HOMO.DES.DEP.COND.(14mt/TEU, 4350 TEU)	98027	12.00	12.41	11.52	0.89	1.43	17.28	188	4933	262228
23	HOMO.DES.ARR.COND.(14mt/TEU, 4350 TEU)	92390	11.42	11.83	10.96	0.87	1.08	17.78	194	5506	297030
24	HOMO.DES.DEP.COND.(16mt/TEU, 3818 TEU)	98215	12.01	12.16	11.85	0.31	2.40	16.26	180	4384	208479
25	HOMO.DES.ARR.COND.(16mt/TEU, 3818 TEU)	90627	11.24	11.57	10.87	0.70	2.11	16.79	194	4965	255419
26	HOMO.DES.DEP.COND.(18mt/TEU, 3386 TEU)	98075	12.00	12.25	11.72	0.53	3.40	15.27	183	4829	256143
27	HOMO.DES.ARR.COND.(18mt/TEU, 3386 TEU)	90487	11.22	11.66	10.73	0.93	3.20	15.72	197	5417	307122
28	DRY DOCKING COND.(NOT SEA GOING)	37083	5.28	5.26	5.30	-0.04	12.01	14.67	247	6553	465644

All the loading conditions should satisfy intact stability criteria, which is well known as "IMO Res. A.749(18)".

[Example] 7,000TEU Container Ship
- Trim & Stability Calculation

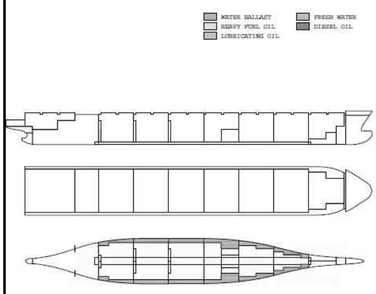
NO	CONDITION	DISPL(T) / KG(M)	DEQ. / LB(M)	DA	DF / MAX S.F(T)	TRIM	GoM(M) / MAX B.M(T-M)
1	LIGHTSHIP COND.(NOT SEA GOING)	27710	4.12	6.53	1.56	4.97	15.65
		16.00	354		4860		336289
2	BALLAST DEP.COND.	59255	7.86	9.62	5.99	3.64	9.84
		11.76	279		-3547		158464
3	BALLAST ARR.COND.	51667	7.00	8.92	4.97	3.96	10.90
		12.03	296		2868		188817
4	HOMO.SCANT.DEP.COND.(8mt/TEU, 6502 TEU)	117444	13.90	13.92	13.88	0.05	1.01
		17.42	444		5899		273134
5	HOMO.SCANT.ARR.COND.(8mt/TEU, 6502 TEU)	109856	13.17	13.40	12.89	0.51	0.56
		17.94	477		6638		332143
6	HOMO.SCANT.DEP.COND.(10mt/TEU, 6022 TEU)	123760	14.50	14.59	14.40	0.18	1.02
		17.42	365		5905		248580
7	HOMO.SCANT.ARR.COND.(10mt/TEU, 6022 TEU)	116323	13.80	14.11	13.41	0.70	0.56
		17.91	394		6647		294847
8	HOMO.SCANT.DEP.COND.(12mt/TEU, 5614 TEU)	123717	14.50	14.55	14.44	0.11	0.94
		17.47	260		5270		232305
9	HOMO.SCANT.ARR.COND.(12mt/TEU, 5614 TEU)	118085	13.97	14.37	13.48	0.89	0.61
		17.87	284		5562		245546
10	HOMO.SCANT.DEP.COND.(14mt/TEU, 5302 TEU)	123740	14.50	14.71	14.25	0.45	0.92
		17.53	244		5042		217406
11	HOMO.SCANT.ARR.COND.(14mt/TEU, 5302 TEU)	120038	14.15	14.21	14.08	0.13	0.58
		17.85	243		5716		250760
12	HOMO.SCANT.DEP.COND.(16mt/TEU, 4918 TEU)	123726	14.50	14.74	14.21	0.52	0.93
		17.51	197		5603		248925
13	HOMO.SCANT.ARR.COND.(16mt/TEU, 4918 TEU)	118410	14.00	14.20	13.75	0.45	0.56
		17.87	202		6390		291851
14	HOMO.SCANT.DEP.COND.(18mt/TEU, 4566 TEU)	123748	14.50	14.55	14.44	0.12	0.92
		17.35	187		5208		219448
15	HOMO.SCANT.ARR.COND.(18mt/TEU, 4566 TEU)	118503	14.01	14.23	13.73	0.50	0.59
		17.70	198		5719		242532

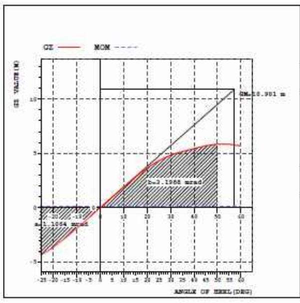
NO	CONDITION	DISPL(T) / KG(M)	DEQ. / LB(M)	DA	DF / MAX S.F(T)	TRIM	GoM(M) / MAX B.M(T-M)
16	HOMO.DES.DEP.COND.(8mt/TEU, 6054 TEU)	98112	12.00	12.21	11.77	0.43	0.94
		17.73	416		5301		297074
17	HOMO.DES.ARR.COND.(8mt/TEU, 6054 TEU)	94131	11.60	11.76	11.41	0.35	0.59
		18.17	420		5710		307761
18	HOMO.DES.DEP.COND.(10mt/TEU, 5390 TEU)	98062	12.00	12.17	11.81	0.36	0.56
		17.71	299		5646		327391
19	HOMO.DES.ARR.COND.(10mt/TEU, 5390 TEU)	93552	11.54	12.00	11.01	0.99	0.79
		17.82	320		5855		310951
20	HOMO.DES.DEP.COND.(12mt/TEU, 4886 TEU)	98040	12.00	12.41	11.52	0.89	0.69
		17.82	233		5378		306050
21	HOMO.DES.ARR.COND.(12mt/TEU, 4886 TEU)	93706	11.56	11.70	11.40	0.30	0.67
		17.92	228		6023		347568
22	HOMO.DES.DEP.COND.(14mt/TEU, 4350 TEU)	98027	12.00	12.41	11.52	0.89	1.43
		17.28	188		4933		262228
23	HOMO.DES.ARR.COND.(14mt/TEU, 4350 TEU)	92390	11.42	11.83	10.96	0.87	1.08
		17.78	194		5506		297030
24	HOMO.DES.DEP.COND.(16mt/TEU, 3818 TEU)	98215	12.01	12.16	11.85	0.31	2.40
		16.26	180		4384		208479
25	HOMO.DES.ARR.COND.(16mt/TEU, 3818 TEU)	90627	11.24	11.57	10.87	0.70	2.11
		16.79	194		4965		255419
26	HOMO.DES.DEP.COND.(18mt/TEU, 3386 TEU)	98075	12.00	12.25	11.72	0.53	3.40
		15.27	183		4829		256143
27	HOMO.DES.ARR.COND.(18mt/TEU, 3386 TEU)	90487	11.22	11.66	10.73	0.93	3.20
		15.72	197		5417		307122
28	DRY DOCKING COND.(NOT SEA GOING)	37083	5.28	5.26	5.30	-0.04	12.01
		14.67	247		6553		465644

[Example] 7,000TEU Container Ship
- Trim & Stability Calculation: Ballast Arrival Condition

(IMO Res.A-749(18))

NO	CONDITION	DISPL(T) / KG(M)	DEQ. / LB(M)	DA	DF / MAX S.F(T)	TRIM	GoM(M) / MAX B.M(T-M)
3	BALLAST ARR.COND.	51667	7.00	8.92	4.97	3.96	10.90
		12.03	296		2868		188817





DISPLACEMENT	51667	MT
KGO=KG+GGO	12.167	M
FLOODING ANGLE	40.000	DEG
AREA UNDER GZ CURVE		
	RESULT	CRITERIA.
0 UP TO 30	1.402	0.055 M-RAD
0 UP TO FLOODING ANG.	2.302	0.090 M-RAD
30 UP TO FLOODING ANG.	0.901	0.030 M-RAD
LEVER AFTER F.S. CORR.		
GZ AT 30 DEG	5.863	0.200 M
HEEL DUE TO WIND	0.4	16.00 DEG
GOM	10.901	0.150 M
WEATHER CRITERIA	2.893	1.000
ANGLE OF MAX GZ	52.0	25.00 DEG

[Example] 7,000TEU Container Ship
- Trim & Stability Calculation

NO	CONDITION	DISPL(T)	DEQ.	DA	DF	TRIM	GoM(M)
		KG(M)	LB(M)	MAX S.F(T)		MAX B.M(T-M)	
1	LIGHTSHIP COND.(NOT SEA GOING)	27710	4.12	6.53	1.56	4.97	15.65
		16.00	354	4860		336289	
2	BALLAST DEP.COND.	59255	7.86	9.62	5.99	3.64	9.84
		11.76	279	-3547		158464	
3	BALLAST ARR.COND.	51667	7.00	8.92	4.97	3.96	10.90
		12.03	296	2868		188817	
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		17.42	444	5899		273134	
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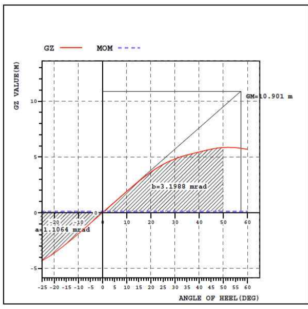
		17.94	477	6638		332143	
6	HOMO.SCANT.DEP.COND.(10mt/TEU, 6022 TEU)	123760	14.50	14.59	14.40	0.18	1.02
		17.42	365	5905		248580	
7	HOMO.SCANT.ARR.COND.(10mt/TEU, 6022 TEU)	116323	13.80	14.11	13.41	0.70	0.56
		17.91	394	6647		294847	
8	HOMO.SCANT.DEP.COND.(12mt/TEU, 5614 TEU)	123717	14.50	14.55	14.44	0.11	0.94
		17.47	260	5270		232305	
9	HOMO.SCANT.ARR.COND.(12mt/TEU, 5614 TEU)	118085	13.97	14.37	13.48	0.89	0.61
		17.87	284	5562		245546	
10	HOMO.SCANT.DEP.COND.(14mt/TEU, 5302 TEU)	123740	14.50	14.71	14.25	0.45	0.92
		17.53	244	5042		217406	
11	HOMO.SCANT.ARR.COND.(14mt/TEU, 5302 TEU)	120038	14.15	14.21	14.08	0.13	0.58
		17.85	243	5716		250760	
12	HOMO.SCANT.DEP.COND.(16mt/TEU, 4918 TEU)	123726	14.50	14.74	14.21	0.52	0.93
		17.51	197	5603		248925	
13	HOMO.SCANT.ARR.COND.(16mt/TEU, 4918 TEU)	118410	14.00	14.20	13.75	0.45	0.56
		17.87	202	6390		291851	
14	HOMO.SCANT.DEP.COND.(18mt/TEU, 4566 TEU)	123748	14.50	14.55	14.44	0.12	0.92
		17.35	187	5208		219448	
15	HOMO.SCANT.ARR.COND.(18mt/TEU, 4566 TEU)	118503	14.01	14.23	13.73	0.50	0.59
		17.70	198	5719		242532	

NO	CONDITION	DISPL(T)	DEQ.	DA	DF	TRIM	GoM(M)
		KG(M)	LB(M)	MAX S.F(T)		MAX B.M(T-M)	
16	HOMO.DES.DEP.COND.(8mt/TEU, 6054 TEU)	98112	12.00	12.21	11.77	0.43	0.94
		17.73	416	5301		297074	
17	HOMO.DES.ARR.COND.(8mt/TEU, 6054 TEU)	94131	11.60	11.76	11.41	0.35	0.59
		18.17	420	5710		307761	
18	HOMO.DES.DEP.COND.(10mt/TEU, 5390 TEU)	98062	12.00	12.17	11.81	0.36	0.56
		17.71	299	5646		327391	
19	HOMO.DES.ARR.COND.(10mt/TEU, 5390 TEU)	93552	11.54	12.00	11.01	0.99	0.79
		17.82	320	5855		310951	
20	HOMO.DES.DEP.COND.(12mt/TEU, 4886 TEU)	98040	12.00	12.41	11.52	0.89	0.69
		17.82	233	5378		306050	
21	HOMO.DES.ARR.COND.(12mt/TEU, 4886 TEU)	93706	11.56	11.70	11.40	0.30	0.67
		17.92	228	6023		347568	
22	HOMO.DES.DEP.COND.(14mt/TEU, 4350 TEU)	98027	12.00	12.41	11.52	0.89	1.43
		17.28	188	4933		262228	
23	HOMO.DES.ARR.COND.(14mt/TEU, 4350 TEU)	92390	11.42	11.83	10.96	0.87	1.08
		17.78	194	5506		297030	
24	HOMO.DES.DEP.COND.(16mt/TEU, 3818 TEU)	98215	12.01	12.16	11.85	0.31	2.40
		16.26	180	4384		208479	
25	HOMO.DES.ARR.COND.(16mt/TEU, 3818 TEU)	90627	11.24	11.57	10.87	0.70	2.11
		16.79	194	4965		255419	
26	HOMO.DES.DEP.COND.(18mt/TEU, 3386 TEU)	98075	12.00	12.25	11.72	0.53	3.40
		15.27	183	4829		256143	
27	HOMO.DES.ARR.COND.(18mt/TEU, 3386 TEU)	90487	11.22	11.66	10.73	0.93	3.20
		15.72	197	5417		307122	
28	DRY DOCKING COND.(NOT SEA GOING)	37083	5.28	5.26	5.30	-0.04	12.01
		14.67	247	6553		465644	

[Example] 7,000TEU Container Ship
- Trim & Stability Calculation: Homogeneous Scantling Arrival Condition (14mt/TEU, 5,302 TEU)

(IMO Res.A-749(18))

NO	CONDITION	DISPL(T)	DEQ.	DA	DF	TRIM	GoM(M)
11	HOMO.SCANT.ARR.COND.(14mt/TEU, 5302 TEU)	120038	14.15	14.21	14.08	0.13	0.58
		17.85	243	5716		250760	



DISPLACEMENT	51667	MT
KGO=KG+GGO	12.167	M
FLOODING ANGLE	40.000	DEG
AREA UNDER GZ CURVE		
	RESULT	CRITERIA.
0 UP TO 30	1.402	0.055 M-RAD
0 UP TO FLOODING ANG.	2.302	0.090 M-RAD
30 UP TO FLOODING ANG.	0.901	0.030 M-RAD
LEVER AFTER F.S. CORR.		
GZ AT 30 DEG	5.863	0.200 M
HEEL DUE TO WIND	0.4	16.00 DEG
GOM	10.901	0.150 M
WEATHER CRITERIA	2.891	1.000
ANGLE OF MAX GZ	52.0	25.00 DEG

[Example] 7,000TEU Container Ship
- Damage Stability Calculation (Subdivision and Damage Stability) (1/4)

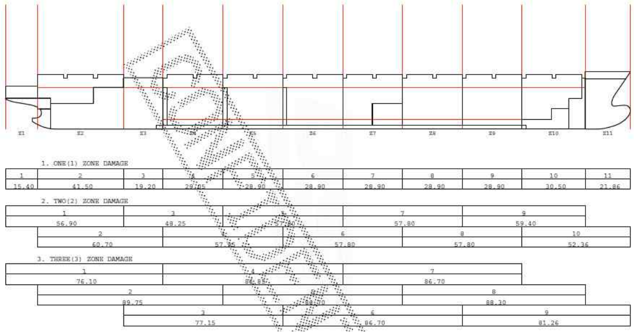
1. Input

- Intact Condition

INITIAL CONDITIONS

INTACT		DL	DP	DS
DRAFT	m	7.00	11.50	14.50
TRIM	m	3.92	0.00	0.00
GOM	m	4.00	0.50	0.50

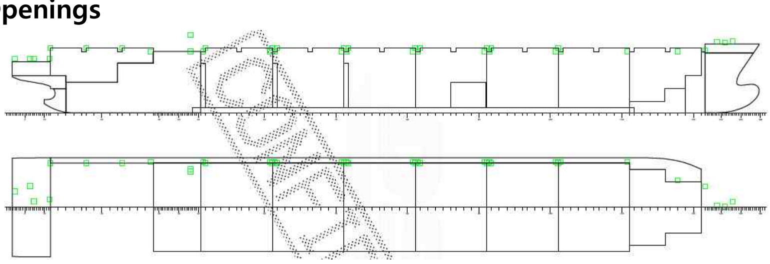
- Subdivision and Damage Length (Zone)



[Example] 7,000TEU Container Ship
- Damage Stability Calculation (Subdivision and Damage Stability) (2/4)

1. Input

- Openings



NAME	TYPE	FR	DX m	Y m	Z m	CONN. ROOM	OPENING DESCRIPTION
OP24	UNPROTECTED	46	0.000	15.325	31.480	ER	ACCOMMO. DOOR (B-DK)
OP25	UNPROTECTED	13	0.000	17.845	26.200	HOLD8	NO17 HATCH COAMING-AFT
OP26	UNPROTECTED	18	0.000	17.845	26.200	HOLD8	NO16 HATCH COAMING-AFT
OP27	UNPROTECTED	23	0.000	17.845	26.200	HOLD8	NO15 HATCH COAMING-AFT
OP28	UNPROTECTED	52	0.000	17.845	26.200	HOLD7	NO14 HATCH COAMING-AFT
OP29	UNPROTECTED	61	0.000	17.845	26.200	HOLD7	NO13 HATCH COAMING-FWD
OP30	UNPROTECTED	62	0.000	17.845	26.200	HOLD6	NO12 HATCH COAMING-AFT
OP31	UNPROTECTED	71	0.000	17.845	26.200	HOLD6	NO11 HATCH COAMING-FWD
OP32	UNPROTECTED	72	0.000	17.845	26.200	HOLD5	NO10 HATCH COAMING-AFT
OP33	UNPROTECTED	81	0.000	17.845	26.200	HOLD5	NO9 HATCH COAMING-FWD
OP34	UNPROTECTED	82	0.000	17.845	26.200	HOLD4	NO8 HATCH COAMING-AFT
OP35	UNPROTECTED	91	0.000	17.845	26.200	HOLD4	NO7 HATCH COAMING-FWD
OP36	UNPROTECTED	92	0.000	17.845	26.200	HOLD3	NO6 HATCH COAMING-AFT
OP37	UNPROTECTED	101	0.000	17.845	26.200	HOLD3	NO5 HATCH COAMING-FWD
OP01	WEATHERTIGH	-5	-0.100	6.385	21.900	VOID04	AIR PIPE,VOID-AFT
OP02	WEATHERTIGH	4	0.500	2.385	21.900	SGRM	ROPE HATCH
OP03	WEATHERTIGH	2	0.630	8.565	21.900	SGRM	MAINTENANCE HATCH for S/G RM
OP04	WEATHERTIGH	12	0.360	3.205	21.900	VOID04	AIR PIPE,VOID-FWD
OP05	WEATHERTIGH	26	2.150	18.279	24.661	FWP	AIR PIPE,FWT
OP06	WEATHERTIGH	46	0.000	14.485	24.818	ER	ACCOMMO.DOOR(UPPER DK)
OP07	WEATHERTIGH	51	1.000	18.329	24.722	B07WP	AIR PIPE, NO7 WWBT-AFT
OP08	WEATHERTIGH	60	2.150	18.329	24.722	B07WP	AIR PIPE, NO7 WWBT-FWD
OP09	WEATHERTIGH	61	1.000	18.329	24.722	B06WP	AIR PIPE, NO6 WWBT-AFT
OP10	WEATHERTIGH	70	2.150	18.329	24.722	B06WP	AIR PIPE, NO6 WWBT-FWD
OP11	WEATHERTIGH	71	1.000	18.329	24.722	B05WP	AIR PIPE, NO5 WWBT-AFT
OP12	WEATHERTIGH	80	2.150	18.329	24.722	B05WS	AIR PIPE, NO5 WWBT-FWD
OP13	WEATHERTIGH	81	1.000	18.329	24.722	B04WP	AIR PIPE, NO4 WWBT-AFT
OP14	WEATHERTIGH	90	2.150	18.329	24.722	B04WP	AIR PIPE, NO4 WWBT-FWD
OP15	WEATHERTIGH	91	1.000	18.329	24.722	B03WP	AIR PIPE, NO3 WWBT-AFT
OP16	WEATHERTIGH	100	2.150	18.329	24.722	B03WP	AIR PIPE, NO3 WWBT-FWD
OP17	WEATHERTIGH	101	1.000	18.329	24.722	B02WP	AIR PIPE, NO2 WWBT-AFT
OP18	WEATHERTIGH	110	2.150	18.329	24.722	B02WP	AIR PIPE, NO2 WWBT-FWD
OP19	WEATHERTIGH	118	0.000	10.885	24.722	B01P	AIR PIPE, NO1 WBT
OP20	WEATHERTIGH	122	0.000	8.365	25.175	BOSUN	DOOR to BOSUN STR
OP21	WEATHERTIGH	128	0.000	0.700	28.603	BOSUN	MAINTENANCE HATCH for BOSUN STR
OP22	WEATHERTIGH	132	0.000	0.257	28.367	VOID01	AIR VENT, FWD VOID
OP23	WEATHERTIGH	136	0.000	2.250	28.721	BOSUN	AIR VENT, BOSUN STR

[Example] 7,000TEU Container Ship
- Damage Stability Calculation (Subdivision and Damage Stability) (3/4)

ıtput

eria:

DAMAGES	W coeff.	W*P*V*S
1 - ZONE DAMAGES		
DL	0.40	0.17097
PL	0.40	0.17246
LL	0.20	0.10289
2 - ZONE DAMAGES		
DL	0.40	0.07440
PL	0.40	0.12610
LL	0.20	0.08681
3 - ZONE DAMAGES		
DL	0.40	0.00199
PL	0.40	0.00455
LL	0.20	0.00993
A-INDEX TOTAL		0.75011

Required subdivision index R = 0.71807

Attained subdivision index A = 0.75011

$$A_s, A_p, A_l \geq 0.5R \quad \text{: for cargo ships}$$

$$\geq 0.9R \quad \text{: for passenger ships}$$

(SOLAS Chapter II-1)

Where,
R: required subdivision index
A: attained subdivision index
A_s, A_p, A_l: attained subdivision index calculated at deepest subdivision draft (d_s), partial subdivision draft (d_p), and light service draft (d_l)

Definitions of three draft

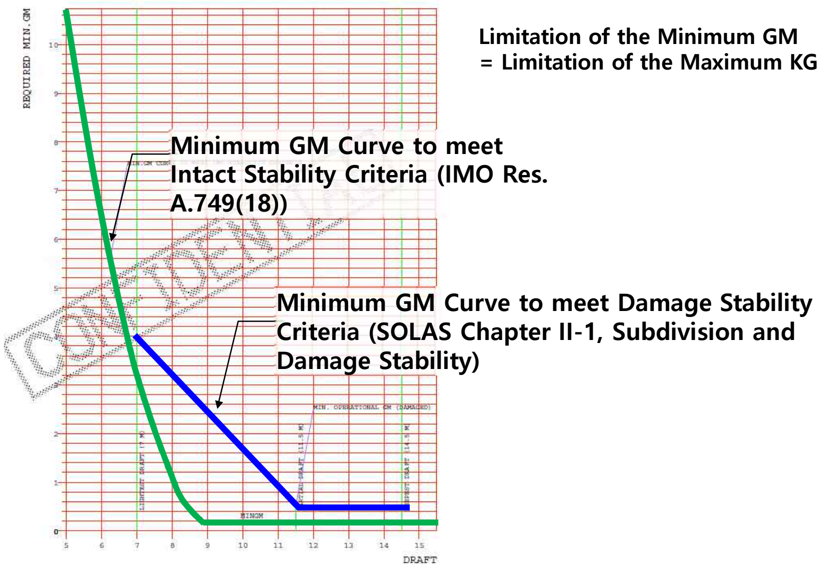
Light service draft (d_l): the service draft corresponding to the lightest anticipated loading and associated tankage, including, however, such ballast as may be necessary for stability and/or immersion. Passenger ships should include the full complement of passengers and crew on board.

Partial subdivision draft (d_p): the light service draft plus **60% of the difference between the light service draft and the deepest subdivision draft**.

Deepest subdivision draft (d_s): the waterline which corresponds to the **summer load line draft** of the ship

(SOLAS Chapter II-1)
Criteria
Where,
R: required subdivision index
A: attained subdivision index

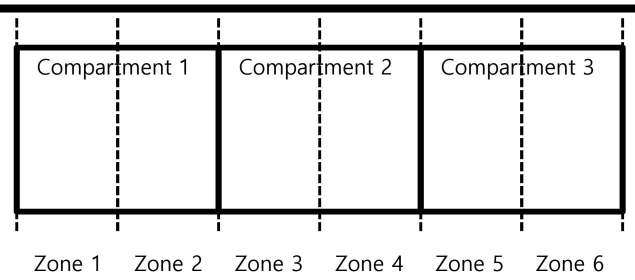
[Example] 7,000TEU Container Ship - Allowable Minimum GM Curve



Limitation of the Minimum GM
= Limitation of the Maximum KG

2. Definition of Virtual Subdivision Bulkheads

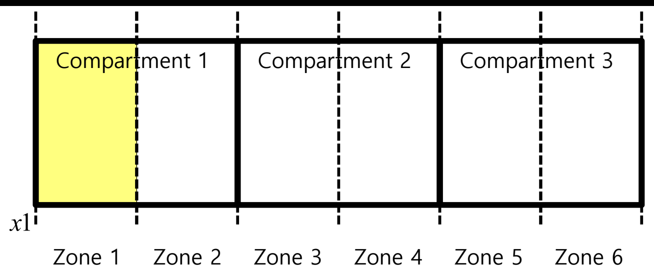
Definition of Virtual Subdivision Bulkheads - Compartment vs. Zone



Compartment – an onboard space within watertight boundaries.
➡ of the ship.

Zone – a longitudinal interval of the ship within the subdivision length.
➡ for calculation of the probability of damage "p_i".

Definition of Virtual Subdivision Bulkheads - One Zone Damage Case vs. Multi Zone Damage Case



Only one zone is damaged, this case is called "one zone damage case".
Two adjacent zones are damaged, this case is called "two zone damage case".

$x1$ = the distance from the aft terminal to the aft end of the zone in question.
$x2$ = the distance from the aft terminal to the forward end of the zone in question.

Example) One zone damage case: (Zone 1), (Zone 2), ...
Two zone damage case: (Zone 1, Zone 2), (Zone 2, Zone 3), ...

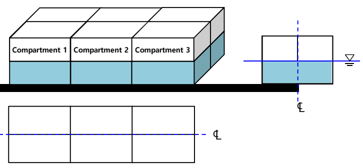
And, the length of damage in this case can be expressed by x1 and x2.

x_1 and x_2 represent the terminals of the compartment or group of compartments.

* Compartment: Onboard space within watertight boundaries.
* Zone: Longitudinal interval of the ship within the subdivision length.

3. Probability of Damage (p_i)

Probability of Damage



$$A = \sum p_i \times s_i$$

A: Subdivision index
p_i: Probability of damage
s_i: Probability of survival

What is the factor "p_i"?

: that a compartment or group of compartments **may be flooded** at the level of the **deepest subdivision draft "ds"**, that is, scantling draft.

: Related to the generation of "Damage Case"

➡ Dependent on the **geometry of the ship**
(Watertight arrangement and principal dimensions of the ship)

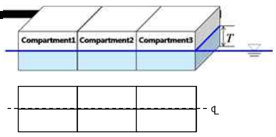
p: The probability of damage in the longitudinal subdivision
r: The probability of damage in the transverse subdivision

➡ Not dependent on the **draft**. Thus, we use the **deepest subdivision draft "ds"**

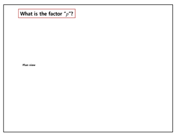
Probability of Damage in Longitudinal Subdivision (p)

Consideration of the Probability Related to the Longitudinal Subdivision

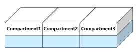
$p_i = p \cdot r$



: **Probability of damage in the** **subdivision**



: The **factor "p"** is dependent on the **length of damage ($x2 - x1$)** and the **subdivision length "L_s"** of a ship.



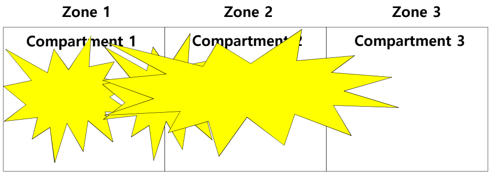
✓ What we consider in this part is " ". **Each end of the damage length is "$x1$" (left) and "$x2$" (right)** and we can calculate the probability of damage by this **length** $(x2 - x1)$.

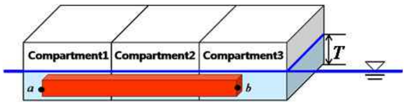
* The damage length is represented by the non-dimensional damage length in the SOLAS regulation:

[Example] Box-Shaped Ship - Damage Zone

$p_i = p \cdot r$

What is the "damage zone"?





: terminal of the zones

- ✓ **Damage zone** is a within the subdivision length.
- ✓ In general, the zones are placed in accordance with the watertight arrangement. However, **the zones can be placed in accordance with the virtual subdivision**.
- ✓ For this example, we place the zones in accordance with the compartments (the watertight arrangement).

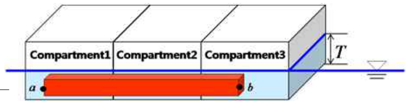
[Example] Box-Shaped Ship - Two Zones Damage Case (1/2)

Probability that "a" is located in zone 1

$$\frac{1}{3}$$

How can we obtain the value of "p" when two adjacent zones are damaged?

[Example] Box-Shaped Ship
- Three Zones Damage Case (1/3)

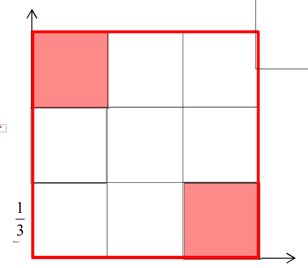


Probability that "a" is located in zone 1

$$\frac{1}{3}$$

How can we obtain the value of "p" when three zones are damaged?

[Example] Box-Shaped Ship - Three Zones Damage Case (3/3)



Representation in terms of "p"

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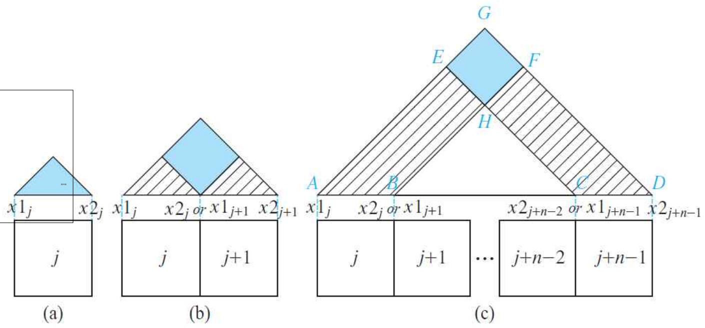
[Reference] Recurrence Formula for Three or More Adjacent Zones Damage Case

Three zones damage case:

$$p_6 = p(x_1, x_4) - p(x_1, x_3) - p(x_2, x_4) + p(x_2, x_3)$$



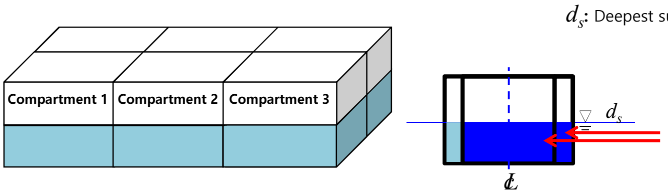
Probability of Damage in Transverse Subdivision (r)

Consideration of the Probability Related to the Transverse Subdivision (1/2)

$p_i = p \cdot r$

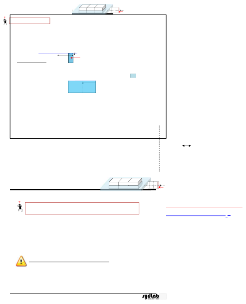
Is there only longitudinal subdivision to consider "p_i"?

d_s: Deepest subdivision draft



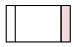
No!

- We have to consider the probability related to the **transverse subdivision and penetration**.
- The probability of damage in transverse subdivision and penetration is represented by the **factor "r"**.
- The factor "r" is determined **after deciding the longitudinal damage case**.

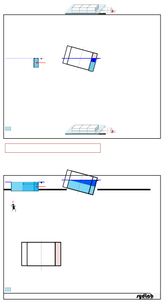


: Probability of damage in the **subdivision**

$$r = r(x1, x2, b, k, L_s)$$

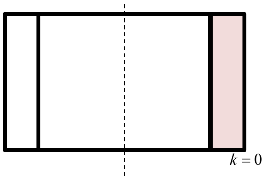


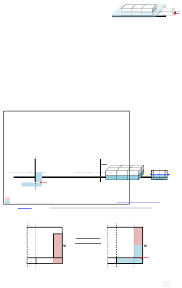
: The **factor** "r" is dependent on the **penetration depth** "b" and the **number of a particular longitudinal bulkhead** "k".
Where, **"k" is counted from shell towards the centerline**. And



Range of the Factor "b" Towards the Centerline (2/4)

Why the factor "b" is only considered to extend to $B/2$?



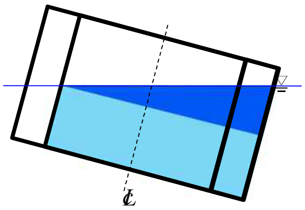


Range of the Factor "b" Towards the Centerline (4/4)

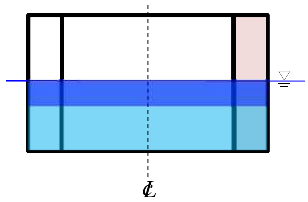
$$r = r(x1, x2, b, k, L_s)$$

Why the factor "b" is only considered to extend to $B/2$?

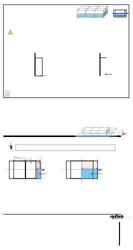
It is the most severe damage case because the factor "b" is considered to extent to B/2.



What if the factor "b" is considered to extent to B?



Because the result calculated for one side of the ship causes **more severe result** than for both side of the ship, the factor "b" is only considered to extend to B/2.



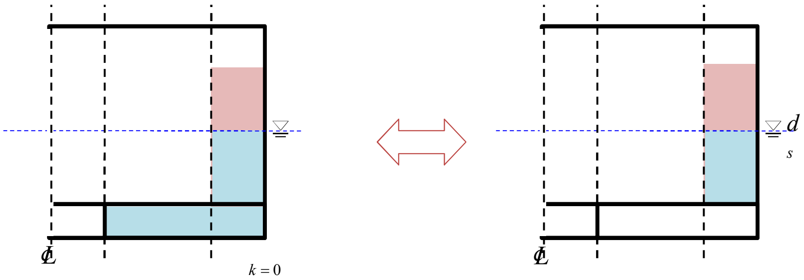
Vertical Extent
- “Lesser Extent”

The flooding always extends to baseline?

No!

If a lesser extent of damage will give a more severe result, such extent is to be assumed.

Example) $k=1$



“ extent”

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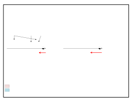
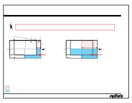
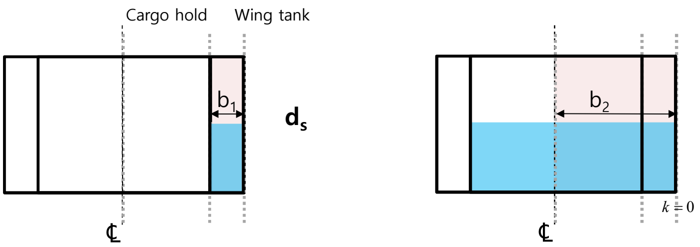




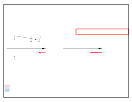
Assume that we calculate the value of r in the port side.

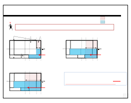
How can we obtain the value of "r" for a box-shaped ship?



k=1: $b=b_1$
(wing tank(P))

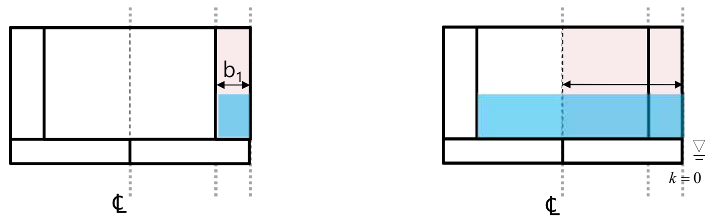
k=2: $b=b_2=B/2$
(wing tank(P)+cargo hold)





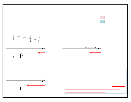
Assume that we calculate the value of *r* in the port side.

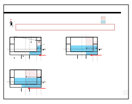
How can we obtain the value of "*r*" for a box-shaped ship?



k=1: b=b_1
(wing tank(P))

k=2: b=b_2=B/2
(wing tank(P)+cargo hold)



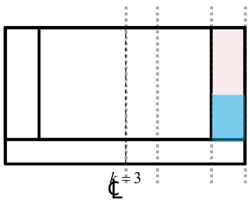


Case 4) Two Longitudinal Bulkheads
(2 Wing Tanks+1 Cargo Hold+2 Double Bottom Tanks+Pipe Duct)

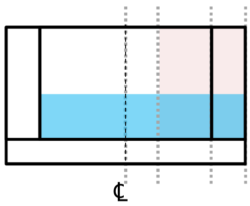
Assume that we calculate the value of r in the port side.

How can we obtain the value of "r" for a box-shaped ship?

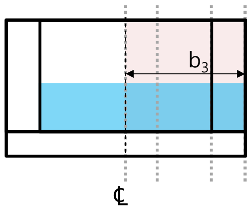
*** Lesser extent damage cases**



k=1: $b=b_1$
(wing tank(P))



k=2: $b=b_2$
(wing tank(P)+cargo hold)



k=3: $b=b_3=B/2$
(wing tank(P)+cargo hold)

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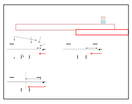
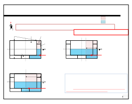
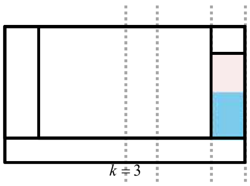
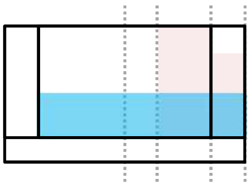
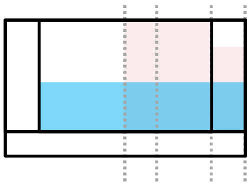




Case 4) Two Longitudinal Bulkheads
(2 Wing Tanks+1 Cargo Hold+2 Double Bottom Tanks+Pipe Duct+Passageway)







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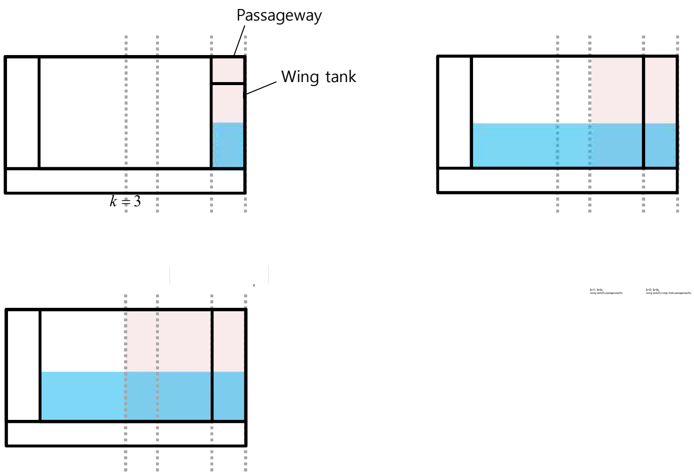
Case 4) Two Longitudinal Bulkheads
(2 Wing Tanks+1 Cargo Hold+2 Double Bottom Tanks+Pipe Duct+Passageway)

Assume that we calculate the value of r in the port side.

How can we obtain the value of "r" for a box-shaped ship?



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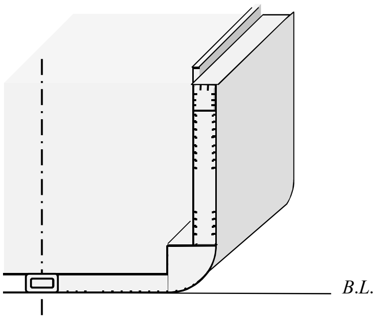
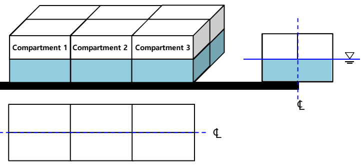
[Example] 7,000 TEU Container Carrier
- One Zone Damage: Z8

How can we obtain the values of “r“?



Probability of Survival (1/2)



$$A = \sum p_i \times s_i$$

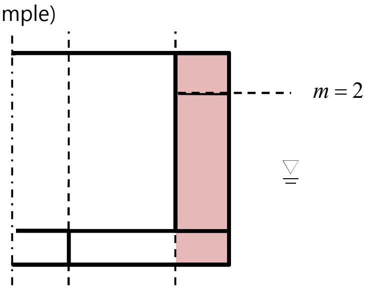
actor "s_i" is the after flooding in a given
e condition.

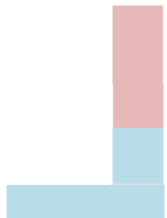
➡ Dependent on the **"initial draft (d_s, d_p, d_l)"**

Consideration of Horizontal Subdivision in Flooding Stage - Factor "v_m"

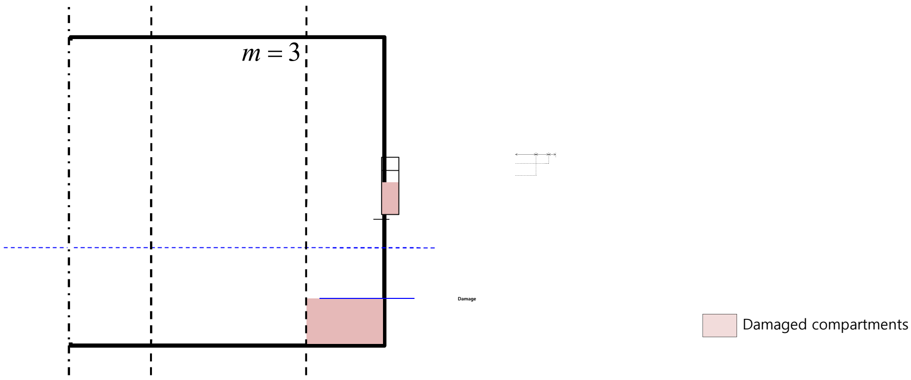
Where "m" represents each **horizontal boundary** counted upwards from the waterline **under consideration**.

Example)





Consideration of Horizontal Subdivision in Flooding Stage - Factor "v_m": Stage 1) Damage (Initial Condition) (1/4)



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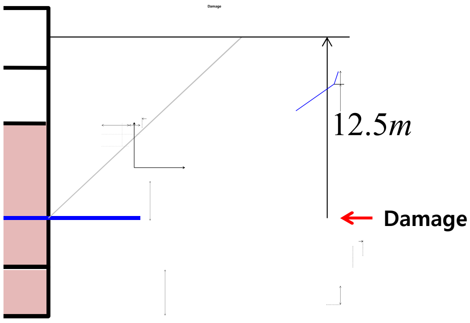
However, **the horizontal subdivision line located lower can be flooded easier than that located higher**. Therefore, the interpolation line between zero and one is modified as shown in following figure.

(Example)

Damage

Consideration of Horizontal Subdivision in Flooding Stage - Factor "v_m": Stage 1) Damage (Initial Condition) (3/4)



Consideration of Horizontal Subdivision in Flooding Stage - Factor “v_m”: Stage 2) Flooding up to m=1

The factor “v_m” is dependent on the **geometry of the watertight arrangement (decks) “H_m”** of the ship and **the draft of the initial loading condition** (d: d_s, d_p, d_l).

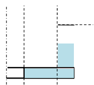
Where ,

The maximum possible vertical extent of damage is d+12.5m.
Then, the factor “H_m” equals 1.

Example) k=1, m=1

$$s_i = v_1 \cdot s_{\min 1}$$

Stage 2) Flooding up to m=1



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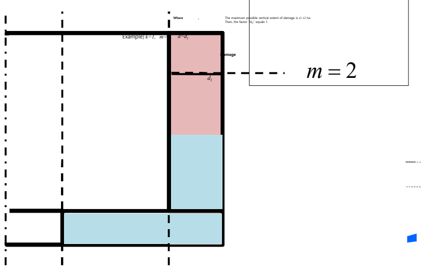
Where ,

The maximum possible vertical extent of damage is d+12.5m.
Then, the factor “H_m” equals 1.

Example) k=1, m=2

Consideration of Horizontal Subdivision in Flooding Stage - Factor "v_m": Stage 4) Flooding up to m=3



Attained Subdivision Index "A"
- Check of the Attained Index "A"

Producing an index A requires the calculation of various damage scenarios defined by the extent of damage and the initial loading conditions of the ship before damage.

Three loading conditions are to be considered and the result weighted as follows:

$$A_s, A_p, A_l \geq 0.5R \quad \text{: for cargo ships}$$
$$\geq 0.9R \quad \text{: for passenger ships}$$

Where the indices "s", "p", and "l" represent the three loading conditions and the factor to be multiplied to the index indicates **how the index A from each loading condition is weighted**.

We can assume that the meaning of the weight factors 0.4, 0.4, and 0.2. In the ship's lifecycle, the lightship condition is rarely exist.

Normally, the loading condition is performed between the scantling draft and design draft. Thus, the weight factor considers this cruising condition.

Definitions of three draft

Light service draft(dl): the service draft corresponding to the lightest anticipated loading and associated tankage, including, however, such ballast as may be necessary for stability and/or immersion. Passenger ships should include the full complement of passengers and crew on board.

Partial subdivision draft(dp): the light service draft plus **60% of the difference between the light service draft and the deepest subdivision draft**.

Deepest subdivision draft(ds): the waterline which corresponds to the **summer load line draft** of the ship

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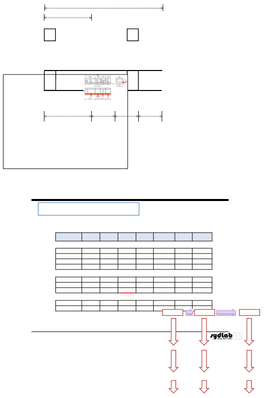
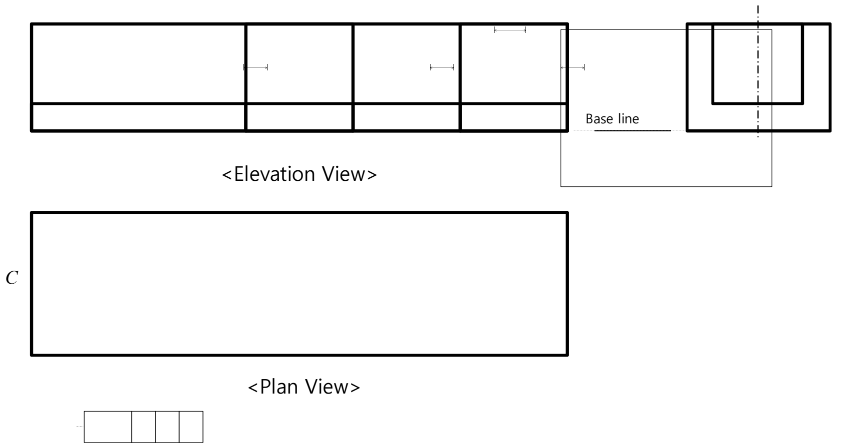
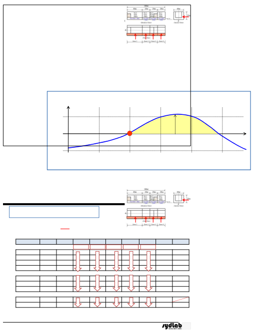


Assumption of Subdivision Zone



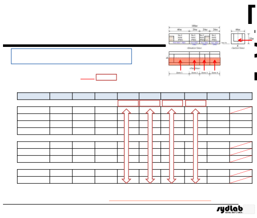


[Case 1] Calculation of Probability of Survival (s_i)

$$s_i = s_i(\theta_e, \theta_v, GZ_{\max}, Range)$$

Typical GZ curve in damage condition

θ_e: The equilibrium angle of heel in any stage of flooding, in degrees
GZ_{max}: The maximum positive righting lever, in meters
Range: The range of positive righting arms, in degrees, measured from the angle θ_e



[Case 2] Calculation of Probability of Damage (p_i)

Calculation Condition
: Scantling Draft (18.0m), b=20.0 Cause
Bigger

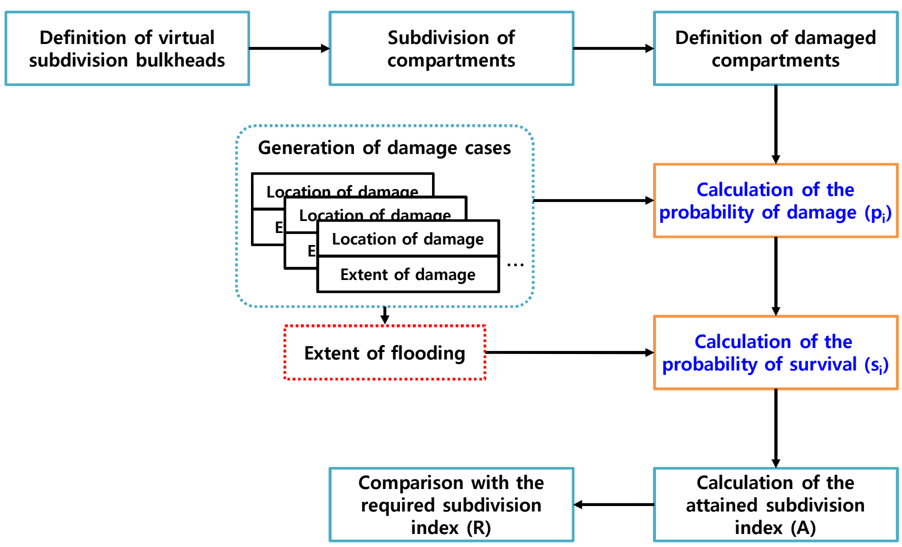
DAMAGES	x_1	x_2	Damage Length	J	p	r	p_i
<1 zone damage>					Effect	Effect	Effect
1.2.1	0	40	40	0.4000	[illegible]	[illegible]	[illegible]
2.2.1	40	60	20	0.2000	[illegible]	[illegible]	[illegible]
3.2.1	60	80	20	0.2000	[illegible]	[illegible]	[illegible]
4.2.1	80	100	20	0.2000	[illegible]	[illegible]	[illegible]
<2 zone damage>					Bigger	Bigger	Bigger
1-2.2.1	0	60	60	0.6000	[illegible]	[illegible]	[illegible]
2-3.2.1	40	80	40	0.4000	[illegible]	[illegible]	[illegible]
3-4.2.1	60	100	40	0.4000	[illegible]	[illegible]	[illegible]
<3 zone damage>							
1-3.2.1	0	80	80	0.8000	[illegible]	[illegible]	[illegible]
2-4.2.1	40	100	60	0.6000	[illegible]	[illegible]	[illegible]

J: Non-dimensional damage length $J = \frac{|x_2 - x_1|}{Ls}$

[Case 2] Calculation of
Probability of Survival (s_i)

6. Summary

Overall Procedures to Evaluate the Probabilistic Damage Stability



Comparison Between the Deterministic and Probabilistic Damage Stability

Items	Deterministic Damage Stability		Probabilistic Damage Stability
	ICLL[1]	MARPOL[2]	SOLAS
Ships			
Definition of damaged compartments	Define the compartments as same with actual compartments		**Define virtual damage compartments after subdividing the compartments by using virtual subdivision bulkheads**
Assumption of extent of damage	Assume the extent of damage with actual compartments as a basis		**Assume the extent of damage with the virtual damage compartments as a basis**
Generation of damage cases	Generate a damage case per one or two compartments	Generate a damage case per two compartments	**Generate a damage case for each extent of damage**
Draft under consideration	The deepest subdivision draft (d_s)	All drafts to be applied in the intact stability calculation	**The deepest subdivision draft (d_s), the partial subdivision draft (d_p), the light service draft (d_l)**
Evaluation of damage stability	All damage cases should satisfy each criterion for the regulation of damage stability.		

1: International Convention on Load Lines
2: International Convention for the Prevention of Marine Pollution from Ships