Lecture Note of Naval Architectural Calculation

Ship Stability

Ch. 12 Deterministic Damage Stability

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Ch. 12 Deterministic Damage Stability

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1. Introduction to Deterministic Damage Stability

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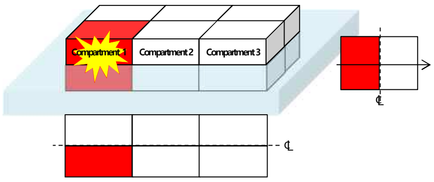
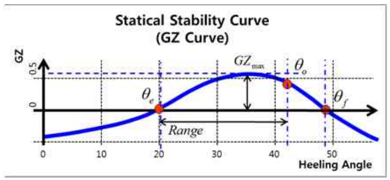


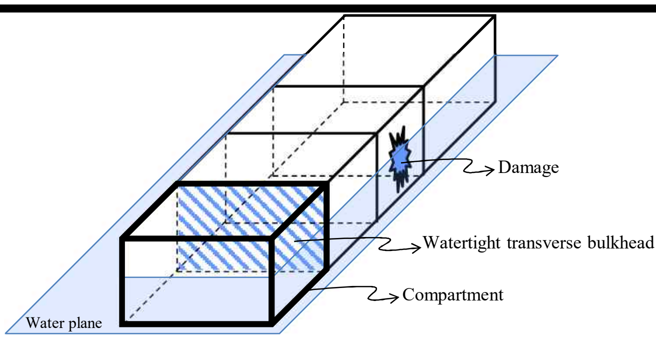


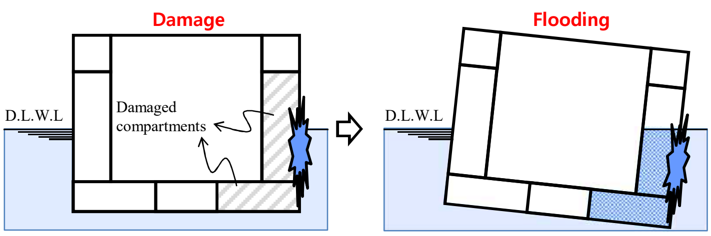
How to measure the ship's stability in a damaged condition?

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**

Definition of Damage and Flooding





* D.L.W.L: Design Load Water Line

Procedures of Calculation of Deterministic Damage Stability

- ☑ Step 1: Determination of international regulations to be applied according to ship type
- ☑ Step 2: Assumption of the according to ship length
- ☑ Step 3: Assumption of the
- ☑ Step 4: Assumption of the for each compartment
- ☑ Step 5: Evaluation of the required damage stability of international regulations

Step 1: International Regulations for Damage Stability According to Ship Type

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

1: International Convention on Load Lines
2: International Convention for the Prevention of Marine Pollution from Ships
3: International Bulk Chemical Code
4: International Gas Carrier Code
5: Safety Of Life At Sea
6: Freeboard type for a ship which carries liquid cargo (e.g., Tanker). Its freeboard is smaller than that of Type B.
7: Freeboard type for a ship which carries dry cargo (e.g., Container ship, passenger ship).

Step 2 & 3: Location and Extent of Damage in International Regulations - MARPOL, IBC, IGC

Location of damage

Regulation		MARPOL	IBC	IGC
Draft		For any operating draft reflecting loading conditions		
Location of Damage in Lengthwise	Anywhere	L_f>225m	Type 1[1)] Any L_f Type 2[1)] L_f>150m Type 3[1)] L_f>225m	Type 1G[2)], Type 2PG[2)] Any L_f Type 2G[2)] L_f>150m Type 3G[2)] L_f≥125m
	Anywhere (Engine room: 1 compartment)	150m<L_f <225m	Type 2 ≤150m Type 3 125m<L_f <225m	Type 2G L_f≤150m
	Anywhere (Engine room: exception)	L_f≤150m	Type 3 L_f<125m	L_f<125m Type 3G

Extent of damage

Regulation				MARPOL	IBC	IGC
Extent of Damage	Side Damage	Longitudinal Extent		$L_f^{2/3}/3$ or 14.5m, whichever is the lesser		
		Transverse Extent		B/5 or 11.5m, whichever is the lesser		
		Vertical Extent		No limit		
	Bottom Damage	Longitudinal Extent	FP'~0.3L_f	$L_f^{2/3}/3$ or 14.5m, whichever is the lesser		
			0.3L_f~Aft	$L_f^{2/3}/3$ or 5.0m, whichever is the lesser		L_f/10 or 5.0m, whichever is the lesser
		Transverse Extent	FP'~0.3L_f	B/6 or 10.0m, whichever is the lesser		
			0.3L_f~Aft	B/6 or 5.0m, whichever is the lesser		
		Vertical Extent		B/15 or 6.0m, whichever is the lesser		B/15 or 2m, whichever is the lesser
	➡ bottom raking damage[3)], Reg. 28 of MARPOL 73/78 - Longitudinal Extent: 20,000ton ≤ DWT ≤ 75,000ton : 0.4L_f from FP' 75,000ton ≤ DWT : 0.6L_f from FP' - Transverse Extent: 20,000ton ≤ DWT : B/3 anywhere - Vertical Extent: 20,000ton ≤ DWT : breach of outer hull[4)]					

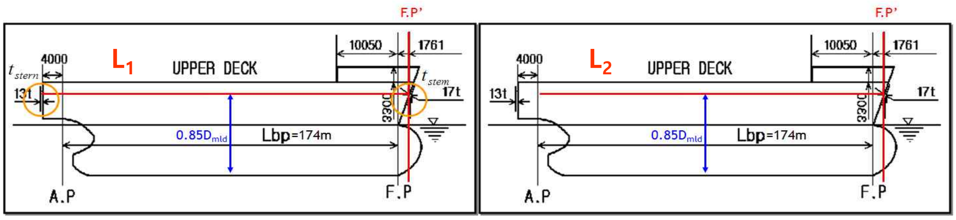
1) Type 1, Type 2, Type 3: Classification of chemical tanker according to the danger of the loaded cargo. The ship which carries most dangerous cargo is classified into Type 1.
2) Type 1G, Type 2G, Type 2PG, Type 3G: Classification of gas carrier according to the danger of the loaded cargo. The ship which carries most dangerous cargo is classified into Type 1G.
3) The bottom raking damage is only considered in MARPOL
4) The outer shell is only damaged in the vertical direction.

[Reference] Definition of Freeboard Length (L_f)

Freeboard Length (L_f)*:

(a) The length shall be taken as 96% of the total length on a waterline at 85% of the least moulded depth measured from the top of the keel (L_1), or as the length from the fore side of the stem to the axis of the rudder stock on that waterline (L_2), if that be greater.

(b) For ships without a rudder stock, the length (L) is to be taken as 96% of the waterline at 85% of the least molded depth.



$$\boxed{L_f = \max(L_1, L_2)}$$

Step 2 & 3: Location and Extent of Damage in International Regulations - ICLL

Location of damage

Regulation		ICLL
Draft		Summer load line
Location of damage in lengthwise	Anywhere (Engine room: 1 compartment)	L_f>150m Ship type A: 1 compartment / B-60: 1 compartment / B-100: 2 compartments
	Anywhere (Engine room: exception)	100m<L_f≤150m Ship type B-60: 1 compartment / B-100: 2 compartments

Extent of damage

Regulation			ICLL
Extent of Damage	Side Damage	Longitudinal Extent	Type A: 1 compartment Type B-60: 1 compartment Type B-100: 2 compartments
		Transverse Extent	1/5 or 11.5m, whichever is the lesser
		Vertical Extent	No limit

Damage assumptions

(a) The vertical extent of damage in all cases is assumed to be from the base line upwards without limit.

(b) The transverse extent of damage is equal to one-fifth (1/5) or 11.5 m, whichever is the lesser of breadth inboard from the side of the ship perpendicularly to the center line at the level of the summer load water line.

(c) No main transverse bulkhead is damaged.

Step 4: Permeability of Compartment (1/2)

When the ship is flooding, how to calculate the actual amount of flooding water?

The compartment of the ship already contains cargo, machinery, liquids, accommodations, or any other equipment or material. To consider this characteristics, the concept of permeability is introduced.

The permeability (μ) of a space is

.

Permeability of each general compartment

Spaces	MARPOL	IBC	IGC	ICLL
Appropriated to stores	0.60			0.95
Occupied by accommodation	0.95			0.95
Occupied by machinery	0.85			0.95
Void spaces	0.95			0.95
Intended for liquids	0 to 0.95*			0.95

* The permeability of partially filled compartments should be consistent with the amount of liquid carried in the compartment.

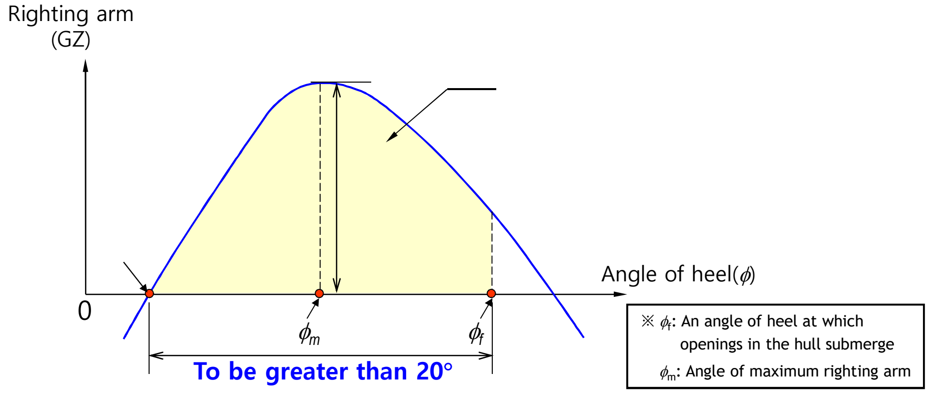
Step 4: Permeability of Compartment (2/2)

Permeability of each cargo compartment

Spaces	Permeability at draft d_s	Permeability at draft d_p	Permeability at draft d_l
Dry cargo spaces	**0.70**	**0.80**	**0.95**
Container cargo spaces	**0.70**	**0.80**	**0.95**
Ro-Ro spaces	**0.90**	**0.90**	**0.95**
Cargo liquids	**0.70**	**0.80**	**0.95**
Timber cargo in holds	**0.35**	**0.70**	**0.95**

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

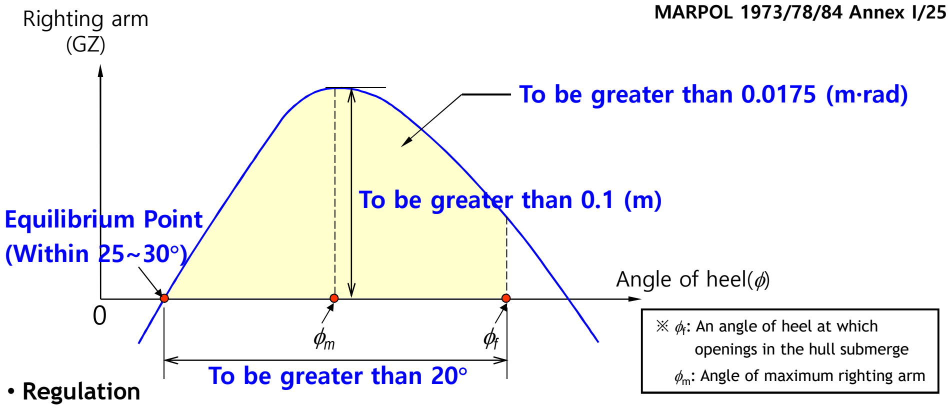
Step 5: Evaluation of the Required Damage Stability



Regulations	MARPOL	IBC	IGC	ICLL
Equilibrium point (angle of heel)	**Below 25° or 30°**		**Below 30°**	**Below 15° or 17°**
Maximum righting arm (GZ_{max})	**Over 0.1 m within the 20° range**			
Flooding angle (ϕ_f)	**Over 20° from the equilibrium point**			
Area under the curve within this range	**Over 0.0175 m·rad**			

Step 5: Evaluation of the Required Damage Stability - MARPOL Regulation for Damage Stability

MARPOL 1973/78/84 Annex I/25

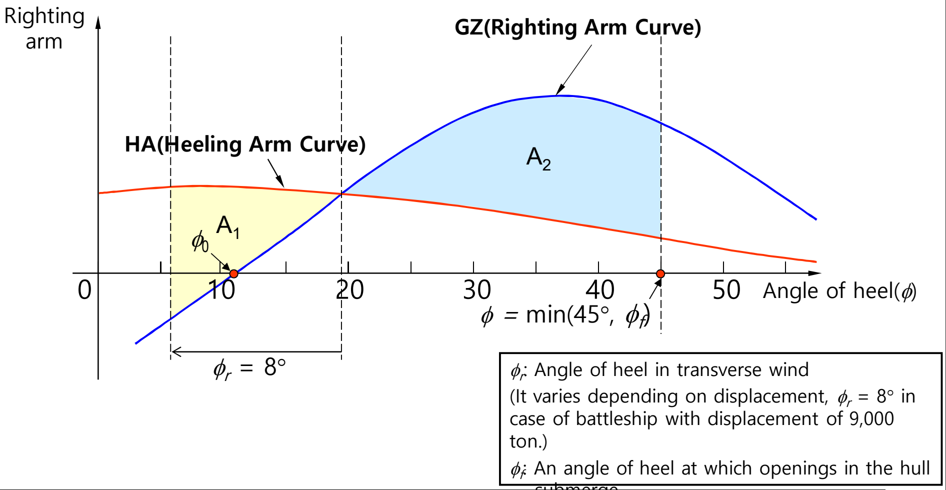


- **Regulation**
  - (a) The final waterline shall be below the lower edge of any opening through which progressive flooding may take place.
  - (b) The angle of heel due to unsymmetrical flooding shall not exceed 25 degrees, provided that this angle may be increased up to 30 degrees if no deck edge immersion occurs.
  - (c) The statical stability curve has at least a range of 20 degrees beyond the position of equilibrium in association with a maximum residual righting arm of at least 0.1 meter within the 20 degrees range
  - (d) The area under the curve within this range shall not be less than 0.0175 meter-radians.

Step 5: Evaluation of the Required Damage Stability - Damage Stability Criteria in Battleship*

- **Regulation**

ϕ_0(Initial Angle of Heel) $\leq$ 15°, $A_2 \geq 1.4 \cdot A_1$

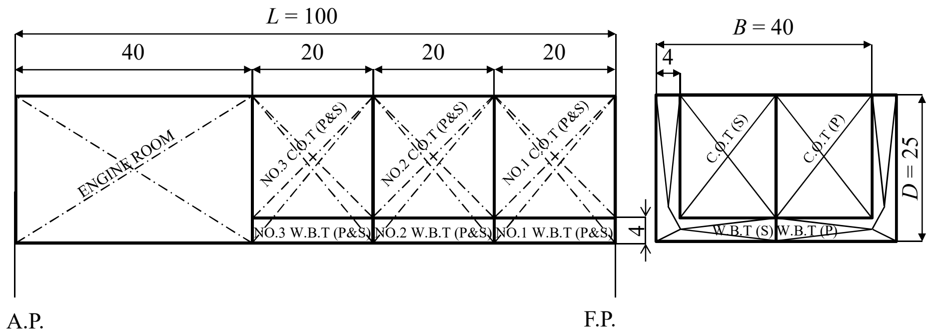


* Surko, S.W., "An Assessment of Current Warship Damaged Stability Criteria", Naval Engineers Journal, 1994

2. Example of Evaluation of Damage Stability According to the Deterministic Method for a Box-Shaped Ship

Principal Characteristics of the Box-Shaped Ship

☑ **Principal dimensions**
- **Ship type: Tanker**
- **Length B.P: 100m**
- **Breadth, molded: 40.0m**
- **Summer draft, molded (Scantling draft): 14.5m**
- **Deadweight: 50,000ton**



Applied Rules and Loading Conditions

Ship Type	Freeboard Type	Deterministic Damage Stability				Probabilistic Damage Stability
		ICLL[1]	MARPOL[2]	IBC[3]	IGC[4]	SOLAS[5]
Oil Tankers	A	O	O			
	B		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

☑ **International rules to be applied: MARPOL**

☑ **Loading conditions to be calculated**

- **All loading conditions should be evaluated.**
- **Here, we will evaluated the damage stability for the homogeneous scantling draft condition only.**

Hydrostatic values for the homogeneous scantling draft condition

Condition	Displacement	Draft	Trim	GoM	KGo
Homo. Scant. Draft (S.G.=0.810)	59,450	14.5	0.0	7.47	8.98

Step 1: International Regulations for Damage Stability According to Ship Type

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

1: International Convention on Load Lines
2: International Convention for the Prevention of Marine Pollution from Ships
3: International Bulk Chemical Code
4: International Gas Carrier Code
5: Safety Of Life At Sea
6: Freeboard type for a ship which carries liquid cargo (e.g., Tanker). Its freeboard is smaller than that of Type B.
7: Freeboard type for a ship which carries dry cargo (e.g., Container ship, passenger ship).

Step 2 & 3: Location and Extent of Damage in International Regulations - MARPOL, IBC, IGC

Location of damage

Regulation		MARPOL	IBC	IGC
Draft		For any operating draft reflecting loading conditions		
Location of Damage in Lengthwise	Anywhere	L_f>225m	Type 1[1] Any L_f Type 2[1] L_f>150m Type 3[1] L_f>225m	Type 1G[2], Type 2PG[2] Any L_f Type 2G[2] L_f>150m Type 3G[2] L_f≥125m
	Anywhere (Engine room: 1 compartment)	150m<L_f<225m	Type 2 ≤150m Type 3 125m<L_f<225m	Type 2G L_f≤150m
	Anywhere (Engine room: exception)	L_f≤150m	Type 3 L_f<125m	L_f<125m Type 3G

Extent of damage

Regulation				MARPOL	IBC	IGC
Extent of Damage	Side Damage	Longitudinal Extent		$L_f^{2/3}/3$ or 14.5m, whichever is the lesser		
		Transverse Extent		B/5 or 11.5m, whichever is the lesser		
		Vertical Extent		No limit		
	Bottom Damage	Longitudinal Extent	FP'~0.3L_f	$L_f^{2/3}/3$ or 14.5m, whichever is the lesser		
			0.3L_f~Aft	$L_f^{2/3}/3$ or 5.0m, whichever is the lesser		L_f/10 or 5.0m, whichever is the lesser
		Transverse Extent	FP'~0.3L_f	B/6 or 10.0m, whichever is the lesser		
			0.3L_f~Aft	B/6 or 5.0m, whichever is the lesser		
		Vertical Extent		B/15 or 6.0m, whichever is the lesser		B/15 or 2m, whichever is the lesser

➨ bottom raking damage[3], Reg. 28 of MARPOL 73/78
- Longitudinal Extent: 20,000ton ≤ DWT ≤ 75,000ton : 0.4L_f from FP'
  75,000ton ≤ DWT : 0.6L_f from FP'
- Transverse Extent: 20,000ton ≤ DWT : B/3 anywhere
- Vertical Extent: 20,000ton ≤ DWT : breach of outer hull[4]

1) Type 1, Type 2, Type 3: Classification of chemical tanker according to the danger of the loaded cargo. The ship which carries most dangerous cargo is classified into Type 1.
2) Type 1G, Type 2G, Type 2PG, Type 3G: Classification of gas carrier according to the danger of the loaded cargo. The ship which carries most dangerous cargo is classified into Type 1G.
3) The bottom raking damage is only considered in MARPOL
4) The outer shell is only damaged in the vertical direction.

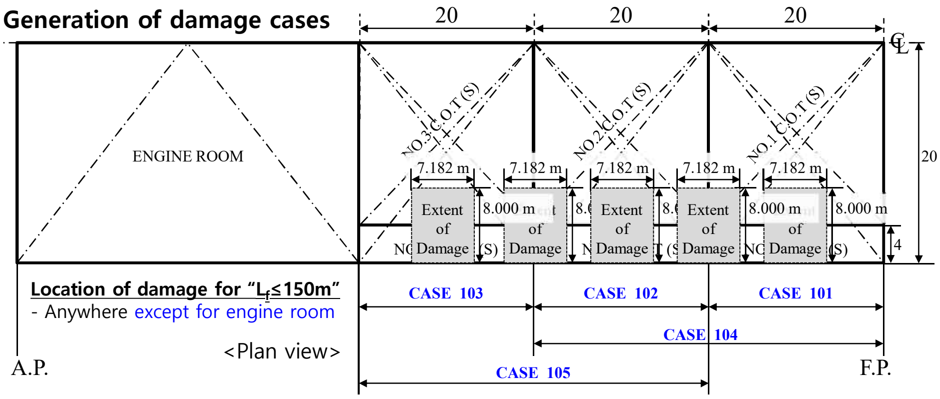
Step 2 & 3: Location and Extent of Damage in International Regulations - Case 1: Side Damage

Assumption of Extent of Damage (Side Damage)

Regulation	MARPOL	
Extent of Side Damage	Requirements	**Calculation results**
Longitudinal Extent	$L_f^{2/3}/3$ or 14.5m, whichever is the lesser	**7.182m**
Transverse Extent	B/5 or 11.5m, whichever is the lesser	**8.0m**
Vertical Extent	No limit (Infinite from baseline)	**No limit (Infinite from baseline)**

Step 2 & 3: Location and Extent of Damage in International Regulations - Case 1: Side Damage

Generation of damage cases



Location of damage for "$L_f \leq 150$m"
- Anywhere except for engine room

<Plan view>

Damage Case	No. 1 C.O.T(S)	No. 1 W.B.T(S)	No. 2 C.O.T(S)	No. 2 W.B.T(S)	No. 3 C.O.T(S)	No. 3 W.B.T(S)
101	Damaged	Damaged				
102			Damaged	Damaged		
103					Damaged	Damaged
104	Damaged	Damaged	Damaged	Damaged		
105			Damaged	Damaged	Damaged	Damaged

Step 4: Permeability of Compartment - Case 1: Side Damage

Spaces	MARPOL	IBC	IGC	ICLL
Appropriated to stores		0.60		0.95
Occupied by accommodation		0.95		0.95
Occupied by machinery		0.85		0.95
Void spaces		0.95		0.95
Intended for liquids		0 to 0.95*		0.95

All damage cases for side damage

Damage Case	No. 1 C.O.T(S)	No. 1 W.B.T(S)	No. 2 C.O.T(S)	No. 2 W.B.T(S)	No. 3 C.O.T(S)	No. 3 W.B.T(S)
101	Damaged	Damaged				
102			Damaged	Damaged		
103					Damaged	Damaged
104	Damaged	Damaged	Damaged	Damaged		
105			Damaged	Damaged	Damaged	Damaged

Information on the damaged compartments of the damage case "101"

	Permeability	Volume	XG (From AP)	YG (From Centerline)	ZG (From Baseline)
No. 1 C.O.T(S)	0.95	3,373.0	90.0	8.0	14.5
No. 1 W.B.T(S)	0.95	2,388.0	90.0	13.0	5.0

Step 5: Evaluation of the Required Damage Stability - Case 1: Side Damage

Evaluation results for the damage case “101” according to MARPOL

Regulations	Requirements	Calculation results	Satisfaction
Equilibrium point	**Below 25° or 30°**	**1.878°**	**O**
Maximum righting arm(GZ_{max})	**Over 0.1 m within the 20° range**	**2.652 m**	**O**
Flooding angle(ϕ_f)	**Over 20° from the equilibrium point**	**24.475°**	**O**
Area under the curve within this range	**Over 0.0175 m·rad**	**0.446 m·rad**	**O**

Step 2 & 3: Location and Extent of Damage in International Regulations - Case 2: Bottom Damage

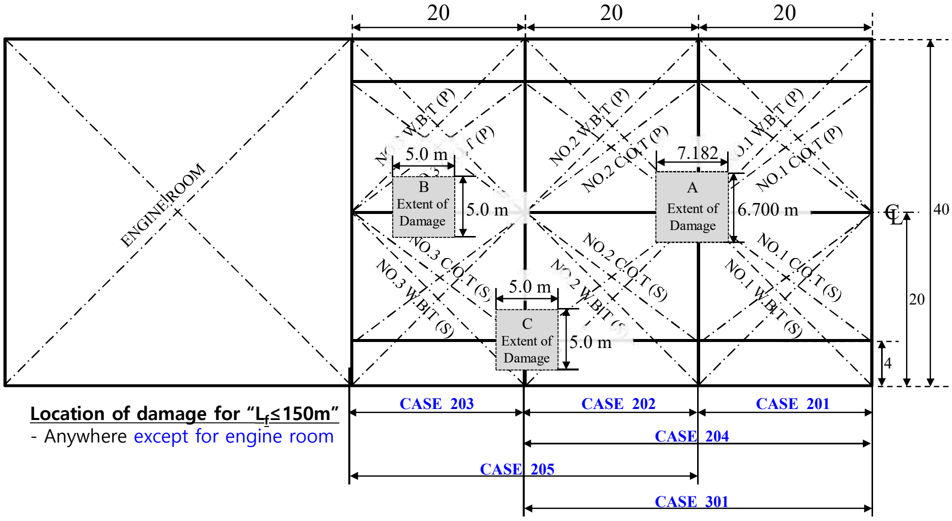
Assumption of Extent of Damage (Bottom Damage)

Regulation				MARPOL	IBC	IGC
Extent of Damage	Side Damage	Longitudinal Extent		$L_f^{2/3}/3$ or 14.5m, whichever is the lesser		
		Transverse Extent		B/5 or 11.5m, whichever is the lesser		
		Vertical Extent		No limit		
	Bottom Damage	Longitudinal Extent	FP'~0.3L_f	$L_f^{2/3}/3$ or 14.5m, whichever is the lesser		
			0.3L_f~Aft	$L_f^{2/3}/3$ or 5.0m, whichever is the lesser		$L_f/10$ or 5.0m, whichever is the lesser
		Transverse Extent	FP'~0.3L_f	B/6 or 10.0m, whichever is the lesser		
			0.3L_f~Aft	B/6 or 5.0m, whichever is the lesser		
		Vertical Extent		B/15 or 6.0m, whichever is the lesser		B/15 or 2m, whichever is the lesser

➡ bottom raking damage[3], Reg. 28 of MARPOL 73/78
- Longitudinal Extent: 20,000ton ≤ DWT ≤ 75,000ton : 0.4L_f from FP'
  75,000ton ≤ DWT : 0.6L_f from FP'
- Transverse Extent: 20,000ton ≤ DWT : B/3 anywhere
- Vertical Extent: 20,000ton ≤ DWT : breach of outer hull[4]

Regulation	Reg. 25, Annex I of MARPOL 73/78				Reg. 28, Annex I of MARPOL 73/78	
Extent of Damage	Bottom damage				Bottom raking damage	
	FP'~0.3L_f		0.3L_f~Aft			
	Requirements	**Calculation results**	Requirements	**Calculation results**	Requirements for DWT≤75,000ton	**Calculation results**
Longitudinal Extent	$L_f^{2/3}/3$ or 14.5m, whichever is the lesser	**7.182m**	$L_f^{2/3}/3$ or 5.0m, whichever is the lesser	**5.0m**	0.4L_f from FP'	**40.0m**
Transverse Extent	B/6 or 10.0m, whichever is the lesser	**6.7m**	B/6 or 5.0m, whichever is the lesser	**5.0m**	B/3 anywhere	**13.0m**
Vertical Extent	B/15 or 6.0m, whichever is the lesser	**2.7m**	B/15 or 6.0m, whichever is the lesser	**2.7m**	breach of outer hull	**breach of outer hull**

Step 2 & 3: Location and Extent of Damage in International Regulations - Case 2: Bottom Damage



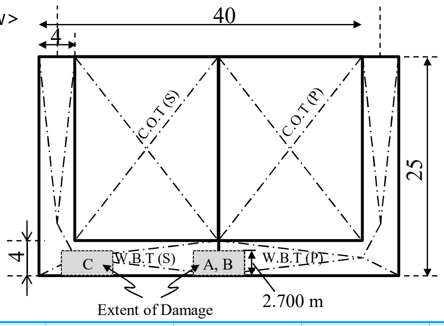
Location of damage for "$L_f \leq 150$m"

- Anywhere except for engine room

<Plan view>

Step 2 & 3: Location and Extent of Damage in International Regulations - Case 2: Bottom Damage

<Section view>



Damage Case	No. 1 W.B.T(S)	No. 1 W.B.T(P)	No. 2 W.B.T(S)	No. 2 W.B.T(P)	No. 3 W.B.T(S)	No. 3 W.B.T(P)
201	Damaged	Damaged				
202			Damaged	Damaged		
203					Damaged	Damaged
204	Damaged	Damaged	Damaged	Damaged		
205			Damaged	Damaged	Damaged	Damaged
206	Damaged					
207			Damaged			
208					Damaged	
209	Damaged		Damaged			
210			Damaged		Damaged	
301 (bottom raking damage)	Damaged	Damaged	Damaged	Damaged		
302 (bottom raking damage)	Damaged		Damaged			

Step 4: Permeability of Compartment
- Case 2: Bottom Damage

Spaces	MARPOL	IBC	IGC	ICLL
Appropriated to stores	0.60			0.95
Occupied by accommodation	0.95			0.95
Occupied by machinery	0.85			0.95
Void spaces	0.95			0.95
Intended for liquids	0 to 0.95*			0.95

All damage cases for bottom damage

Damage Case	No. 1 W.B.T(S)	No. 1 W.B.T(P)	No. 2 W.B.T(S)	No. 2 W.B.T(P)	No. 3 W.B.T(S)	No. 3 W.B.T(P)
201	Damaged	Damaged				
202			Damaged	Damaged		
203					Damaged	Damaged
204	Damaged	Damaged	Damaged	Damaged		
205			Damaged	Damaged	Damaged	Damaged
206	Damaged					
207			Damaged			
208					Damaged	
209	Damaged		Damaged			
210			Damaged		Damaged	
301 (bottom raking damage)	Damaged	Damaged	Damaged	Damaged		
302 (bottom raking damage)	Damaged		Damaged			

Information on the damaged compartments of the damage case "201"

	Permeability	Volume	XG (From AP)	YG (From Centerline)	ZG (From Baseline)
No. 1 W.B.T(P)	0.95	2,388.0	90.0	-13.0	5.0
No. 1 W.B.T(S)	0.95	2,388.0	90.0	13.0	5.0

Step 5: Evaluation of the Required Damage Stability
- Case 2: Bottom Damage

Evaluation results for the damage case "201" according to MARPOL

Regulations	Requirements	Calculation results	Satisfaction
Equilibrium point	**Below 25° or 30°**	?	O or X ?
Maximum righting arm(GZ_{max})	**Over 0.1 m within the 20° range**	?	O or X ?
Flooding angle(ϕ_f)	**Over 20° from the equilibrium point**	?	O or X ?
Area under the curve within this range	**Over 0.0175 m·rad**	?	O or X ?