•서울대학교 조선해양공학과 학부4학년 “창의적 선박설계” 강의 교재

Midship Rule Scantling
(선체 중앙부 구조부재 설계)

2008.6

서울대학교 조선해양공학과

이규열

선박의 기본설계 과정

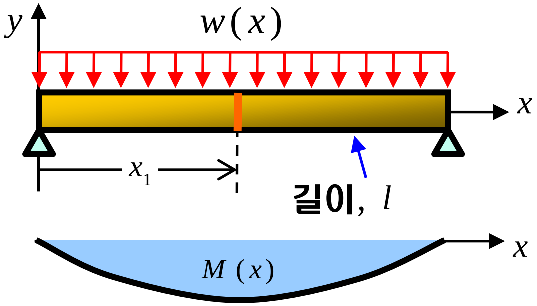
상선

- 선주 요구조건
- 유사 실적선 자료 조사
- 주요치수 결정
- 경하중량 추정
- 저항, 마력 추정
- 주기관 선정
- 프로펠러 주요치수 결정
- Rudder 주요치수 결정
- 선형설계
- 개략 일반배치도 작성
- 구획 배치 및 선박계산
- 구조 설계

James M. Gere, "Mechanics of Materials 6th Edition", Thomson, ch5. Stress in Beams

[요약] 선체 구조 설계
Part 1. Longitudinal Strength

① 재료역학 (Beam Theory)



weight, w
$w = w(x)$

⇩

Shear force, Q
$Q(x) = \int w(x)dx$

⇩

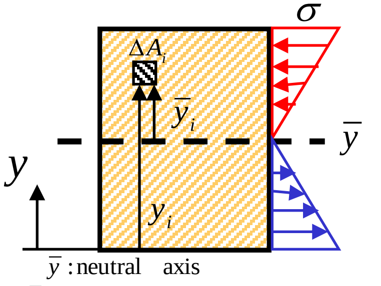
Bending Moment, M
$M(x) = \int Q(x)dx$

보의 단면에 작용하는 응력, σ

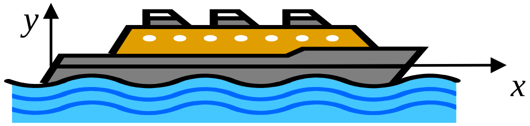
$$\sigma = \frac{M}{I_{\bar{y}} / \bar{y}_i} = \frac{M}{Z}$$

$,(I_{\bar{y}}$: moment of inertia from $\bar{y})$
$,(z$: section modulus$)$

<보의 단면>



② Longitudinal strength



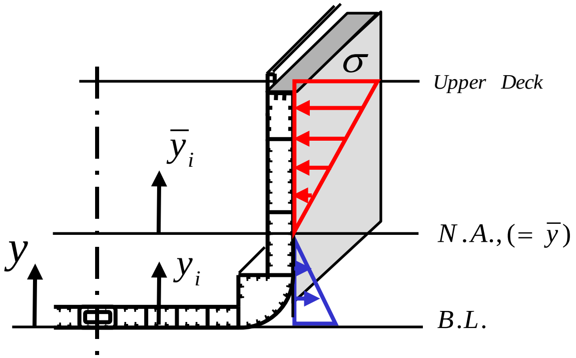
: 선박을 길이방향의 얇은 두께의 속이 빈 Section Beam으로 가정
→ Beam Theory **적용**

선박의 Midship section**에 작용하는 응력,** σ

$$\boxed{\sigma_{act.}} = \frac{\overset{\text{SWBM}}{\boxed{M_s}} + \overset{\text{VWBM}}{\boxed{M_w}}}{\boxed{I_{ship,N.A}} / \bar{y}_i} = \frac{M}{Z}$$

$,(I_{ship,N.A.}$: moment of inertia from N.A. of Midship section$)$

<Midship section>



③Allowable stress (허용 응력), σ_l

$$\sigma_{act.} \le \sigma_l$$

Mild steel의 yield stress:
$\sigma_y = 235\ [N/mm^2]$

Allowable stress by Rule:
$\sigma_l = 175\ f_1\ [N/mm^2]$

④ Midship section 전체의 Moment of inertia, $I_{ship,N.A.}$는 어떻게 구하나?

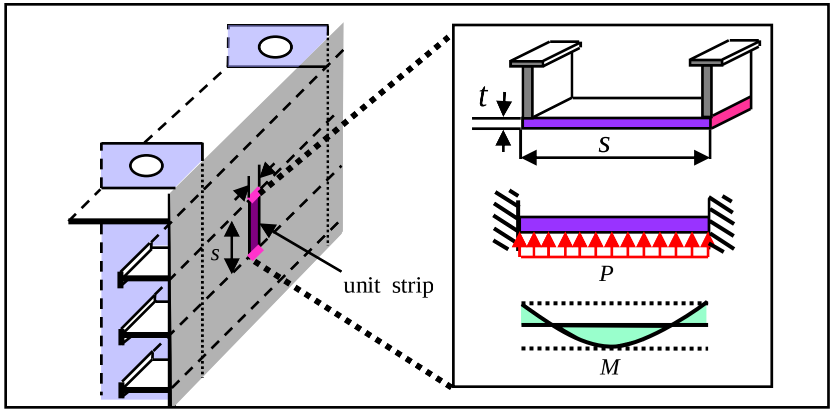
→ $\sigma_{act.} \le \sigma_l$ **를 만족하는** $I_{ship,N.A.}$**를 구하기 위해 부재의 배치, 치수를 결정하는 업무가 중앙단면 구조 설계임**

Part2. Local Scantling (⑤)

Part3. $\sigma_{act.} \le \sigma_l$ **를 만족 하도록 추가 적인 치수 증가(⑥)**

[요약] 선체 구조 설계
Part 2. Local scantling (⑤)

Plate(⑤-1)



✓ Assumption

- Longi.로 양단이 고정 지지된 Beam
- Beam이 균일 분포 하중을 받음
- Plastic 범위까지 확대해서 사용함

Design Load, p

Allowable Stress, σ

✓ Required thickness

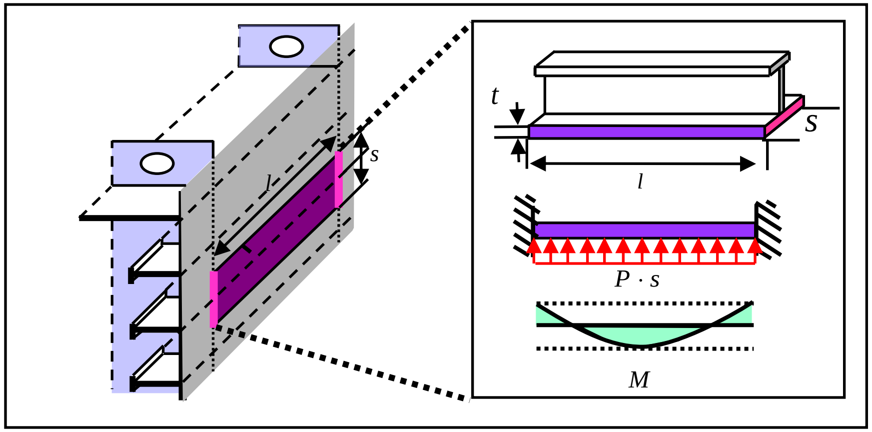
$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$$

✓Minimum thickness (추정식)

예) Bottom plating

$$t = 5.0 + \frac{0.04L_1}{\sqrt{f_1}} + t_k \quad (mm)$$

Longitudinals(⑤-2)



✓ Assumption

- Web frame로 양단이 고정 지지된 Beam (판을 포함한 단면을 사용)
- Beam이 균일 분포 하중을 받음
- Elastic 범위까지 사용함

Design Load, p

Allowable Stress, σ

✓Required section modulus of longitudinals

$$Z = \frac{83 l^2 \cdot s \cdot p \cdot w_k}{12 \cdot \sigma} \ (cm^3)$$

Required section modulus를 만족하는 Longi.를 Table 에서 찾아 Longi.의 치수 선정

a	b	t_1	t_2	r_1	r_2	A	I	Z
mm						cm^2	cm^4	cm^3
… 300 400 400 …	90 100 100	13 11.5 13	17 16 18	19 24 24	9.5 12 12	52.67 61.09 68.59	17600 34200 36700	743 1120 1230

✓Minimum thickness of web and flange (추정식)

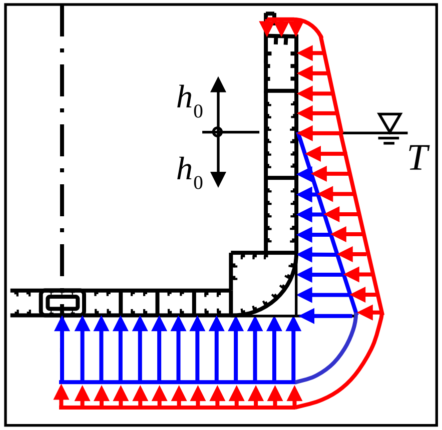
예) Bottom longitudinals

$$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm) \quad , t_2 = \frac{h}{g} + t_k \ (mm) \quad , \max(t_1, t_2)$$

[요약] 선체 구조 설계
Part 2. Local scantling(⑤)

Design Load, p

✓ Sea pressure

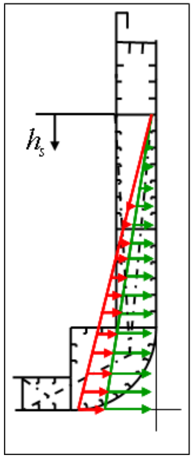


$$P = \underbrace{10\,h_0}_{\text{Static Pressure}} + \underbrace{p_{dp}}_{\text{Dynamic Pressure}}$$

$$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2(T-z)$$

자세한 수식은 Pt.3 Ch.1 Sec.4 C200 참고

✓ Liquid Cargo Tank



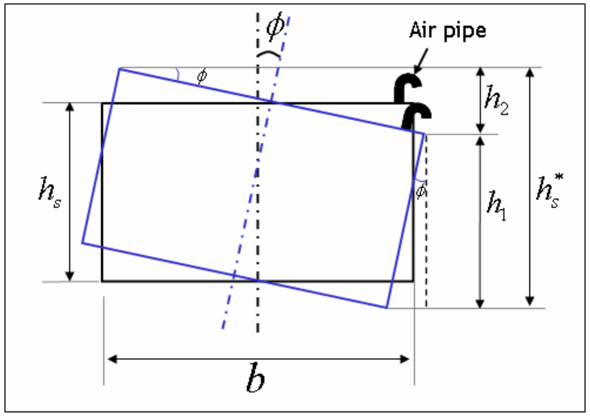
P_1: Vertical Acceleration을 고려

$$P_1 = \underbrace{\rho g_0 h_s}_{\text{Static Pressure}} + \underbrace{0.5\rho a_v h_s}_{\text{Dynamic Pressure}}$$

$$p = \rho(g_0 + 0.5a_v)h_s$$

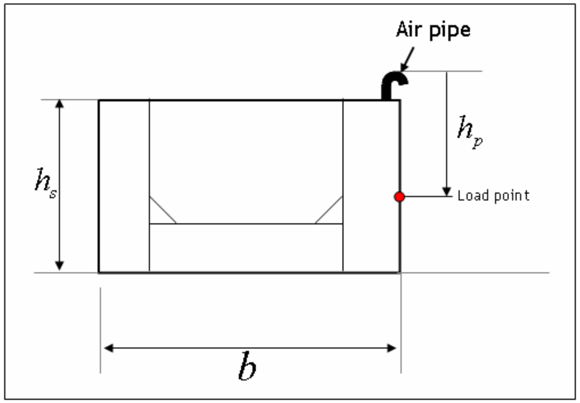
h_s : virtical distance in m from load point to top of tank

P_2: Rolling Motion을 고려



$$p_2 = \rho g_0[0.67(h_s + \phi b) - 0.12\sqrt{H\phi b_t}\,]$$

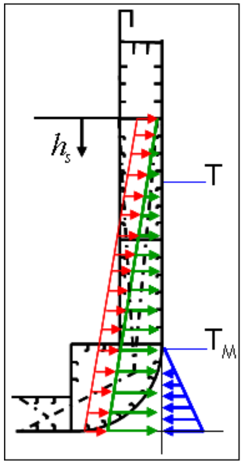
P_4 :Tank overflow를 고려



$$p = \underbrace{0.67\rho g_0 h_p}_{\text{Overflow로 인한 Pressure drop}} + \underbrace{\Delta P_{dyn}}_{\text{Calculated Pressure drop}}$$

Generally, 25kN/m²

P_5 :Tank Test를 고려



Tank의 Leakage 여부를 Test 하기 위해 over-pressure를 가함

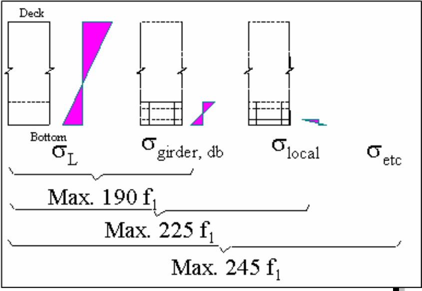
$$p = \rho g_0 h_s - 10h_b + p_o$$

$$p_o = \rho g_0 \times 2.5$$
$$= 10 \times 2.5$$
$$= 25kN/m^2$$

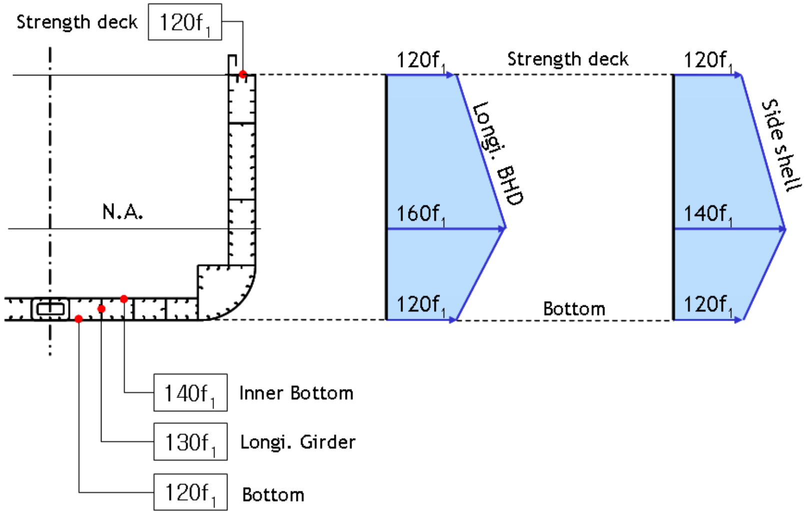
h_b : virtical distance in m from load point tominimum design draught

[요약] 선체 구조 설계
Part 2. Local scantling(⑤)

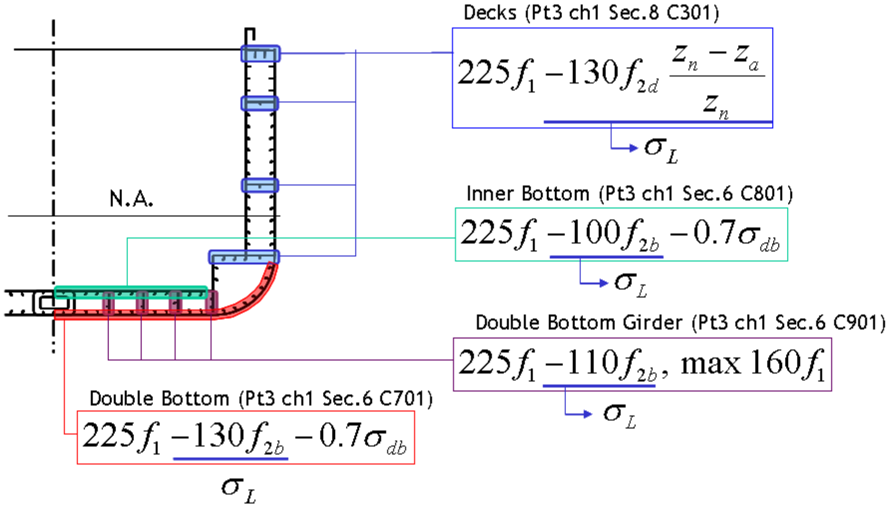
Allowable stress, σ



✓ Longitudinally stiffened Plates



✓ Longitudinal Stiffeners



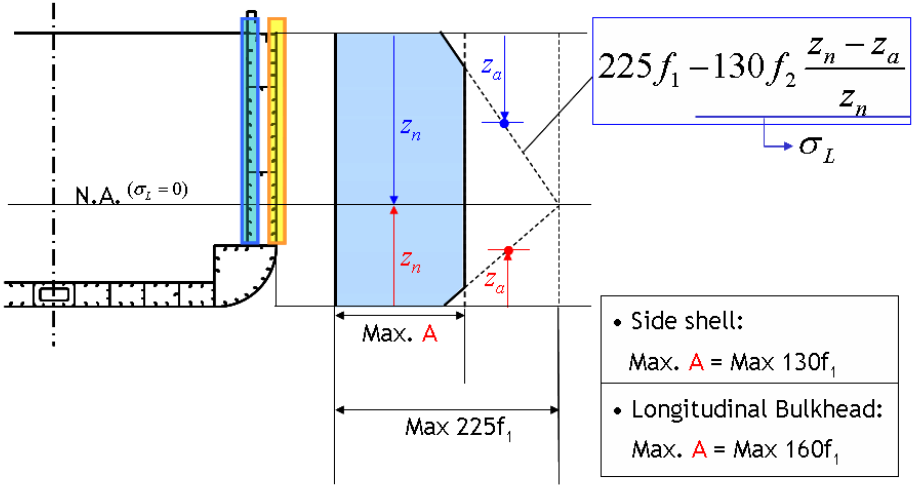
✓ Stress factor, $f_{2b,d}$

$$f_{2b,d} = \frac{5.7(M_S + M_W)}{Z_{b,d}}$$

Midship section modulus at bottom or deck as built

→ 기준선의 $Z_{b,,d}$로 가정!

Iteration을 통해, 가정한 단면계수 값과 계산된 단면계수 값이 일치하도록 전체 중앙 단면 계수를 계산



- Side shell:
  Max. A = Max $130f_1$
- Longitudinal Bulkhead:
  Max. A = Max $160f_1$

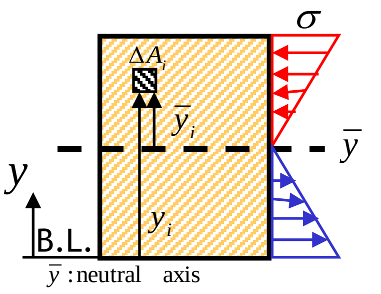
[요약] 선체 구조 설계
Part 2. Local scantling(⑤)

✓ 재료역학(⑤-3)

보의 단면에 작용하는 응력,

$$\sigma = \frac{M}{I_{\bar{y}}/\bar{y}_i} = \frac{M}{z}$$

<보의 단면>



1) Neutral Axis, $\bar{y}$ 구하기

$$\bar{y} = \frac{B.L.\text{을 기준으로한, 단면적의 1차 모멘트}}{\text{부재의 총 단면적}} = \frac{\sum y_i \cdot \Delta A_i}{\sum \Delta A_i}$$

2) Base line (y=0)을 기준으로 한, 단면적의 Moment of inertia, $I_{y=0}$ 구하기

$$I_{y=0} = \sum y_i^{2} \cdot \Delta A_i$$

3) Neutral Axis, $\bar{y}$를 기준으로 한, 단면의 Moment of Inertia, $I_{\bar{y}}$ 구하기

$$I_{\bar{y}} = I_{y=0} \underline{- \bar{y}^{2} \cdot A} \quad ,\left(A = \sum \Delta A_i\right)$$

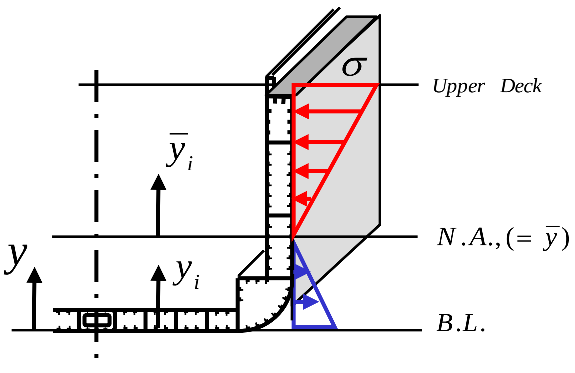
평행축 정리를 이용한 기준 축 이동

✓ 선박의 Midship Section (⑤-4)

선박의 Midship section에 작용하는 응력,

$$\sigma_{act.} = \frac{M_s + M_w}{I_{ship,N.A.}/\bar{y}_i}$$

<Midship section>



Midship section의 각 부재 들에 대해 치수를 결정

1) 전체 Midship section의 Neutral Axis 구하기

$$N.A. = \bar{y} = \frac{\sum y_i \cdot \Delta A_i}{\sum \Delta A_i}$$

$N.A.$: Base line에서 Neutral Axis까지의 높이(cm)

ΔA_i: 각 부재의 단면적

2) Base line을 기준으로 한, Midship 전체의 Moment of inertia, $I_{ship,B.L.}$ 구하기

$$I_{ship,B.L.} = \sum y_i^{2} \cdot \Delta A_i$$

y_i : Base line 으로 부터 각 부재의 면적 중심까지의 거리

ΔA_i: 각 부재의 단면적

3) $N.A.$ 를 기준으로 한 Midship 전체의 Moment of Inertia $I_{ship,N.A.}$ 구하기

$$I_{ship,N.A.} = I_{ship,B.L.} \underline{- (N.A.)^{2} \cdot \sum \Delta A_i}$$

평행축 정리를 이용한 기준 축 이동

[요약] 선체 구조 설계
Part3. $\sigma \le \sigma_l$를 만족 하도록 추가적인 치수 증가[⑥]

Class Rule에 따른 Local Scantling으로 구한 중앙단면의 section modulus(z) 와 선체에 작용하는 응력 (σ)를 구함

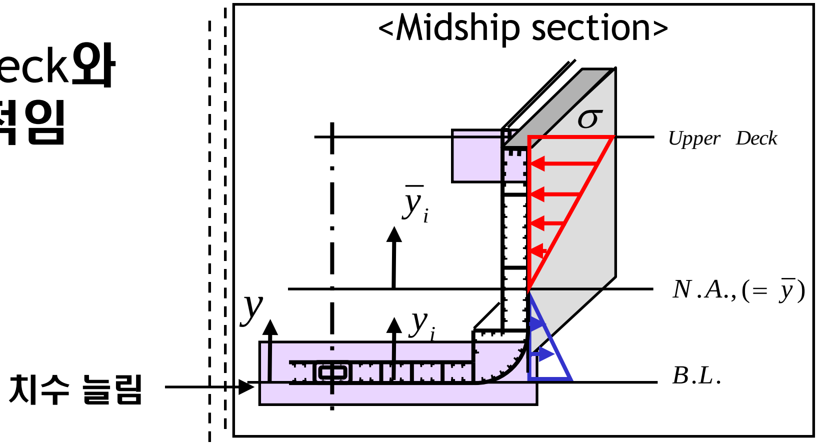
$$\sigma_{act.} = \frac{M_s + M_w}{I_{ship,N.A.} / \bar{y}_i} = \frac{M}{z}$$

$\sigma_{act.} \le \sigma_l$를 만족 하도록 I값을 증가 시킴

$$\sigma_l = 175\, f_1 \ [N/mm^2]$$

✓ I값을 늘리기 위해서는 y값이 큰 deck와 Bottom의 부재를 늘리는 것이 효율적임

→ Dcck와 Bottom의 Plates, Longitudinals의 치수를 늘림



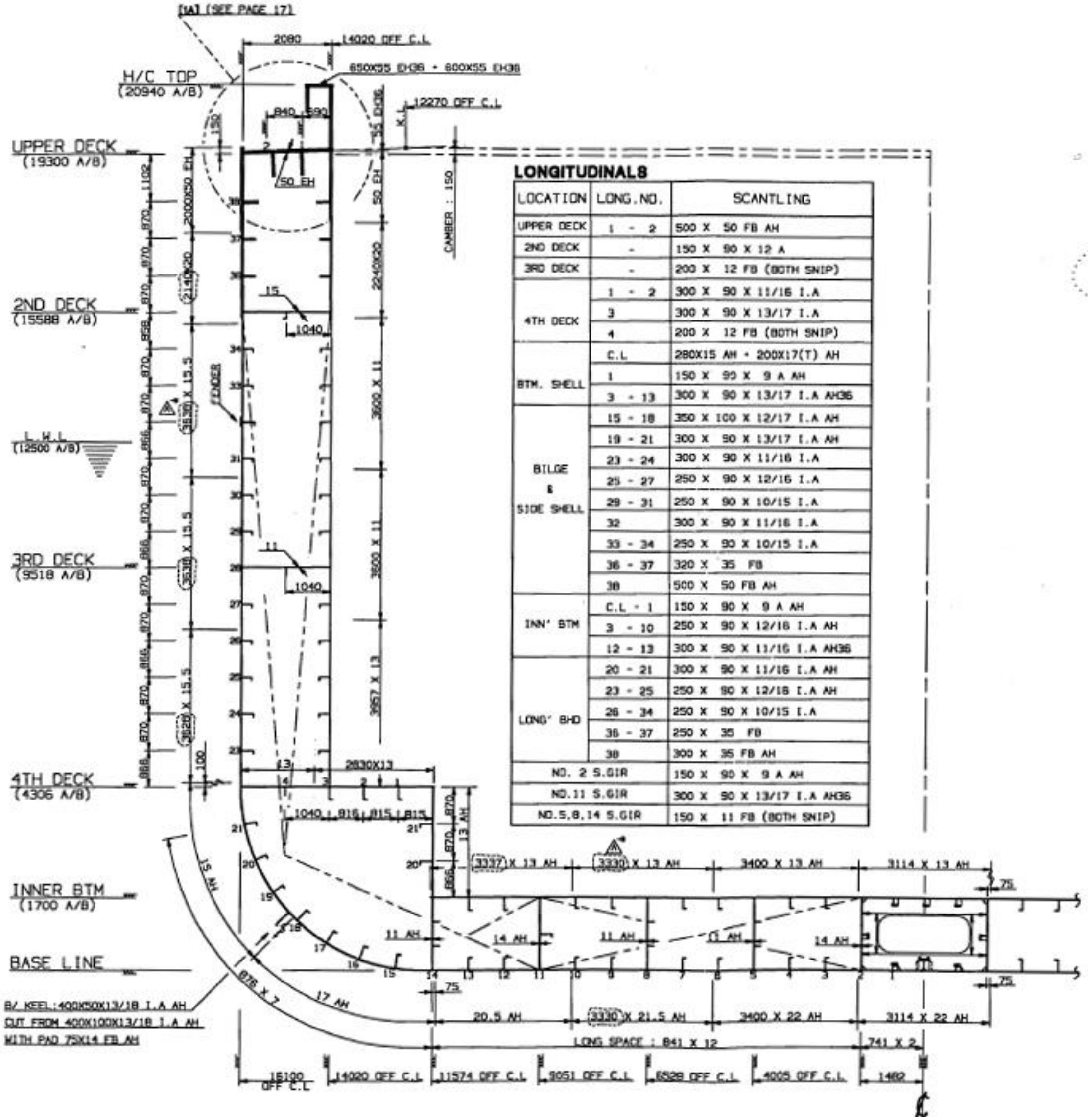
Contents

1. General
2. Materials
3. Longitudinal Strength
4. Design Load
5. Local Scantling
6. Buckling (추가 예정)
7. Fatigue (추가 예정)

1. General

1.1 선체 중앙단면도
1.2 Stress transmission
1.3 Rule length and block coefficient
1.4 판 두께 선택기준, Grouping of longitudinal stiffener

1.1 Midship section for 3,700 TEU Containership



LONGITUDINALS

LOCATION	LONG.NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

1.2 Stress transmission

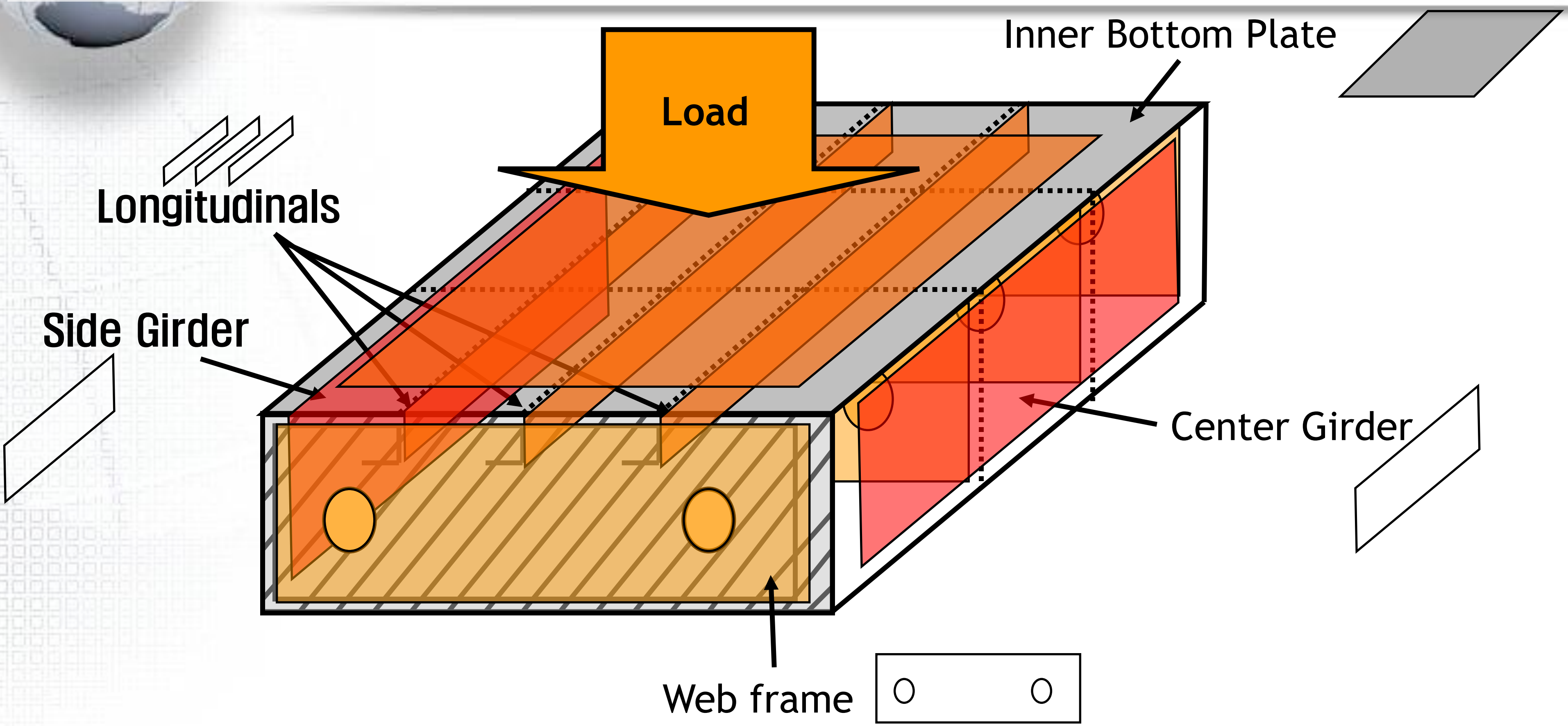


Plate → Longi. → Web frame → Girder

→ : Stress Transmission

1.3 Rule length and block coefficient

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.1 101

이규열, 창의적 선박설계 강의노트 12장 선체 구조설계 p.9

1) Rule length (L)

: Rule Scantling시 사용하는 선박의 길이

$$\boxed{0.96 \cdot LWL < L < 0.97 \cdot LWL}$$

- Distance on <u>the summer load waterline (LWL)</u> from the fore side of the stem to the axis of the rudder stock
- Not to be taken less than 96%, and need not be taken greater than 97%, of the extreme length on the summer load waterline (L_{WL})

ex)

LBP	LWL	0.96·LWL	0.97 ·LWL	L
250	261	250.56	253.17	250.56
250	258	247.68	250.26	250.00
250	255	244.80	247.35	247.35

2) Block coefficient (C_B)

- To be calculated based on rule length

1.4 판 두께 선택기준, Grouping of longitudinal stiffner

이규열, 창의적 선박설계 강의노트 12장 선체 구조설계 p.11

1) 판 두께 선택 기준

→ **계산에서 나온 값을 그대로 판의 두께로 사용하는 것이 아니라 생산되고 있는 판의 두께로 선정한다.**

1) 0.5 mm **간격으로**
2) 0.25 mm **이상** : 0.5 mm
3) 0.25 mm **미만** : 0.00 mm

ex) 15.75 mm → 16.0 mm
15.74 mm → 15.5 mm

---

2) Grouping of longitudinal stiffner

- Average value but not to be taken less than 90% of the largest individual requirement. (DNV)

ex) 100, 90, 80, 70, 60 **치수를 갖는** 5**개의** longi**의 평균 치수는** 80×5 **이다.**
그러나 최대 100×90% = 90**보다 작으므로** 90 ×5 **를 배치 하여야 한다.**

2. Materials

- 2.1 Material factor
- 2.2 Material classes
- 2.3 Corrosion Addition (tk , tc)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2

이규열, 창의적 선박설계 강의노트 12장 선체 구조설계 p.9,10

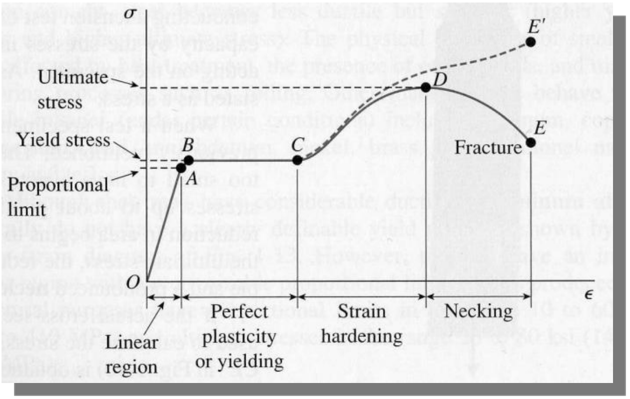
DSME, “**선박구조설계**” 1-8 , 2005.8

2.1 Material Factors

- The material factor f_1 included in the various formulae for scantlings and in expressions giving allowable stresses.

Material Designation	Yield Stress (N/mm²)	$\frac{\sigma}{\sigma_{NV-NS}}$	Material Factor
NV-NS	235	235/235 = 1.00	1.00
NV-27	265	265/235 = 1.13	1.08
NV-32	315	315/235 = 1.34	1.28
NV-36	355	355/235 = 1.51	1.39
NV-40	390	390/235 = 1.65	1.43

*NV-NS : Normal Strength Steel(Mild Steel)



*Yield Stress(**항복응력**, σ_y) [N/mm²] or [Mpa]: Hook’s law**성립하는 탄성영역을 넘어서 소성영역이 시작되는 지점**

2.2 Material Classes

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2
이규열, 창의적 선박설계 강의노트 12장 선체 구조설계 p.9,10
DSME, "선박구조설계" 2-16 선급강재 steel grade 비교표 , 2005.8

- In order to distinguish between the material grade requirements for different hull parts, various material classes are applied as defined in Table.

Thickness (mm)	Class				
	I	II	III	IV	V
$t \leq 15$	A/AH	A/AH	A/AH	A/AH	D/DH
$15 < t \leq 20$	A/AH	A/AH	A/AH	B/AH	E/DH
$20 < t \leq 25$	A/AH	A/AH	B/AH	D/DH	E/EH
$25 < t \leq 30$	A/AH	A/AH	D/DH	E/DH	E/EH
$30 < t \leq 35$	A/AH	B/AH	D/DH	E/EH	E/EH
$35 < t \leq 40$	A/AH	B/AH	D/DH	E/EH	E/EH
$40 < t \leq 50$	B/AH	D/DH	E/EH	E/EH	E/EH

Steel Grade별 가격

08.05.30기준

Grade	$/ton
A	$1,340
AH36	$1,384
…	…
E	$1,425
EH36	$1,502

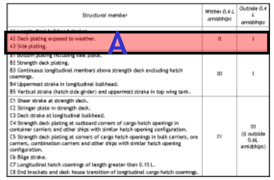
✓ Steel Grade 에 따라, 첨가되는 화학원소 성분이 다르다.

✓ Steel Grade 표기가 A,B,D,E 순으로 갈수록 탈산(Deoxidation) 및 열처리과정을 거친다.

➔ 장점: 재료의 연성, 취성이 좋아짐
단점: 가격이 비쌈

*A: 'A' grade 'Normal strength Steel'
AH: 'A' grade 'High tensile steel'

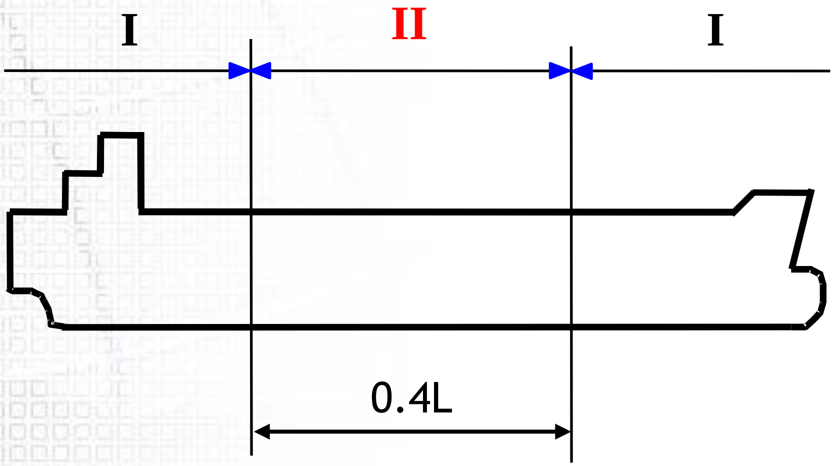
2.2 Material Classes
– Typical Example (1)

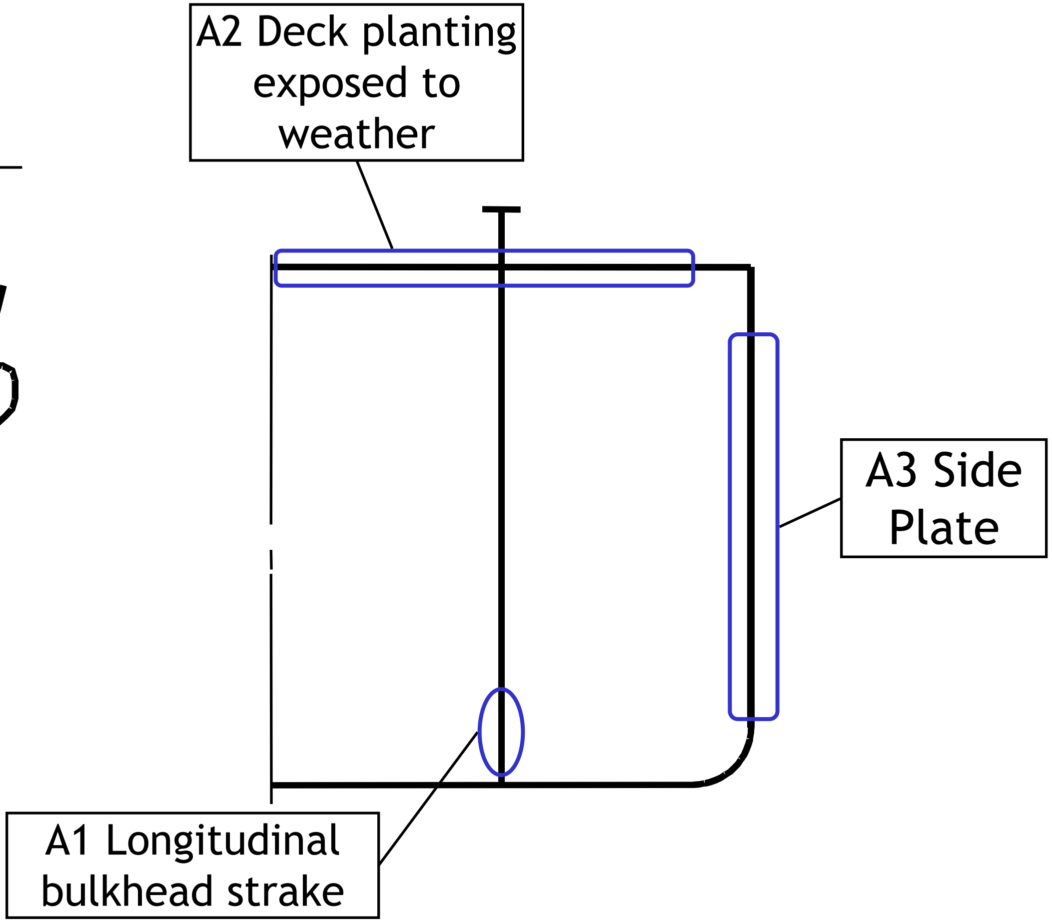


Structural member	Within 0.4 L amidships	Outside 0.4 L amidships
A1 Longitudinal bulkhead strakes. A2 Deck plating exposed to weather. A3 Side plating.	II	I
B1 Bottom plating including keel plate. B2 Strength deck plating. B3 Continuous longitudinal members above strength deck excluding hatch coamings. B4 Uppermost strake in longitudinal bulkhead. B5 Vertical strake (hatch side girder) and uppermost strake in top wing tank.	III	I
C1 Sheer strake at strength deck. C2 Stringer plate in strength deck. C3 Deck strake at longitudinal bulkhead. C4 Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configuration. C5 Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers, combination carriers and other ships with similar hatch opening configuration. C6 Bilge strake. C7 Longitudinal hatch coamings of length greater than 0.15 L. C8 End brackets and deck house transition of longitudinal cargo hatch coamings.	IV	III (II outside 0.6L amidships)

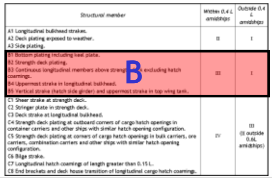
Structural member	*0.4 L*	*Outside 0.4 L*
A1 Longitudinal bulkhead strakes. A2 Deck plating exposed to weather. A3 Side plating.	II	I

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2 Table B2





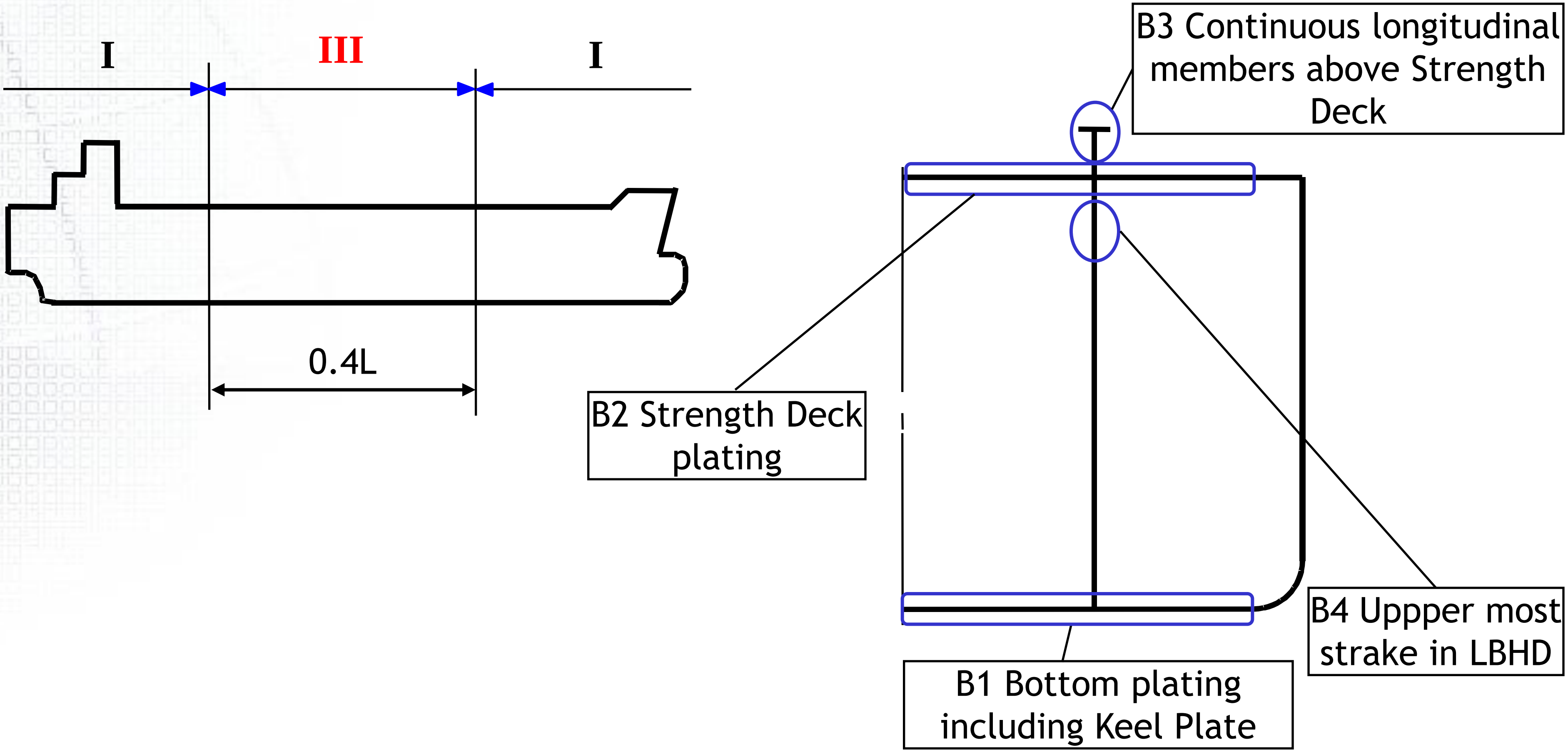
2.2 Material Classes – Typical Example (2)



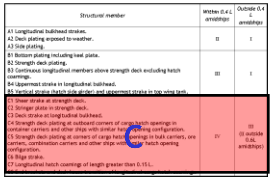
Structural member	Within 0.4 L amidships	Outside 0.4 L amidships
A1 Longitudinal bulkhead strakes. A2 Deck plating exposed to weather. A3 Side plating.	II	I
B1 Bottom plating including keel plate. B2 Strength deck plating. B3 Continuous longitudinal members above strengt B k excluding hatch coamings. B4 Uppermost strake in longitudinal bulkhead. B5 Vertical strake (hatch side girder) and uppermost strake in top wing tank.	III	I
C1 Sheer strake at strength deck. C2 Stringer plate in strength deck. C3 Deck strake at longitudinal bulkhead. C4 Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configuration. C5 Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers, combination carriers and other ships with similar hatch opening configuration. C6 Bilge strake. C7 Longitudinal hatch coamings of length greater than 0.15 L. C8 End brackets and deck house transition of longitudinal cargo hatch coamings.	IV	III (II outside 0.6L amidships)

Structural member	*0.4 L*	*Outside 0.4 L*
B1 Bottom plating including keel plate. B2 Strength deck plating. B3 Continuous longitudinal members above strength deck B4 Uppermost strake in longitudinal bulkhead.	III	I

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2 Table B2



2.2 Material Classes – Typical Example (3)



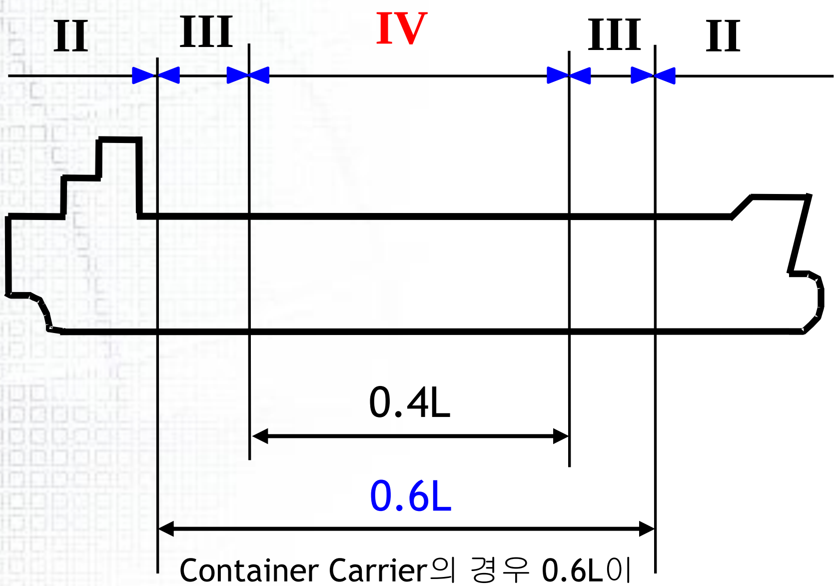
Structural member	Within 0.4 L amidships	Outside 0.4 L amidships
A1 Longitudinal bulkhead strakes. A2 Deck plating exposed to weather. A3 Side plating.	II	I
B1 Bottom plating including keel plate. B2 Strength deck plating. B3 Continuous longitudinal members above strength deck excluding hatch coamings. B4 Uppermost strake in longitudinal bulkhead. B5 Vertical strake (hatch side girder) and uppermost strake in top wing tank.	III	I
C1 Sheer strake at strength deck. C2 Stringer plate in strength deck. C3 Deck strake at longitudinal bulkhead. C4 Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configuration. C5 Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers, combination carriers and other ships with similar hatch opening configuration. C6 Bilge strake. C7 Longitudinal hatch coamings of length greater than 0.15 L.	IV	III (II outside 0.6L amidships)

C

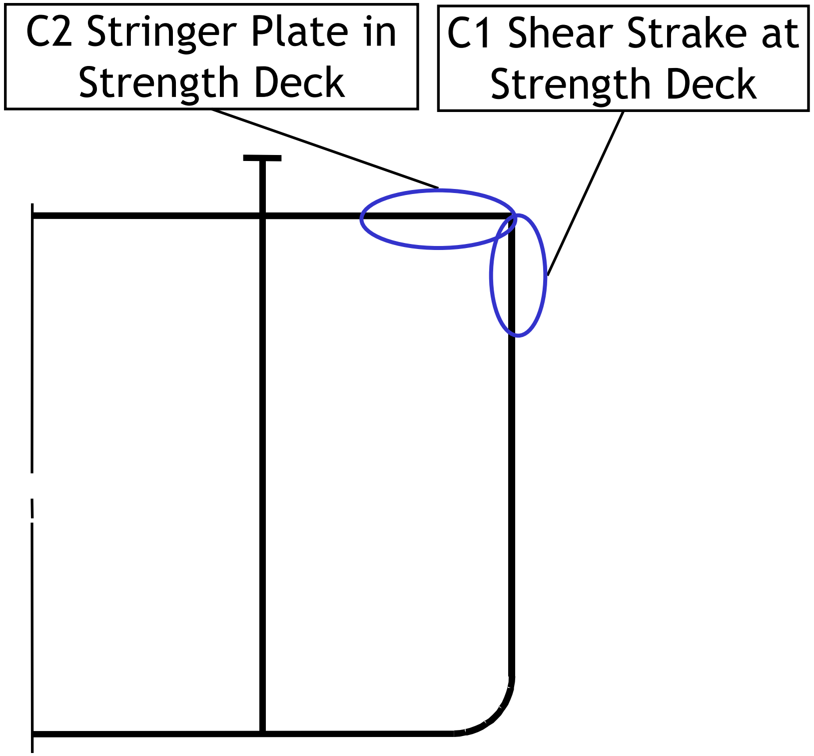
Structural member	*0.4 L*	*Outside 0.4 L*
C1 Sheer strake at strength deck. C2 Stringer plate in strength deck	IV	III (II outside 0.6L amidships)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2 Table B2

E/EH ← **When L> 250 m**



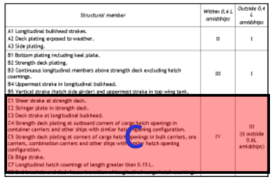
Container Carrier의 경우 0.6L이 Cargo Region으로 바뀜



C2 Stringer Plate in Strength Deck

C1 Shear Strake at Strength Deck

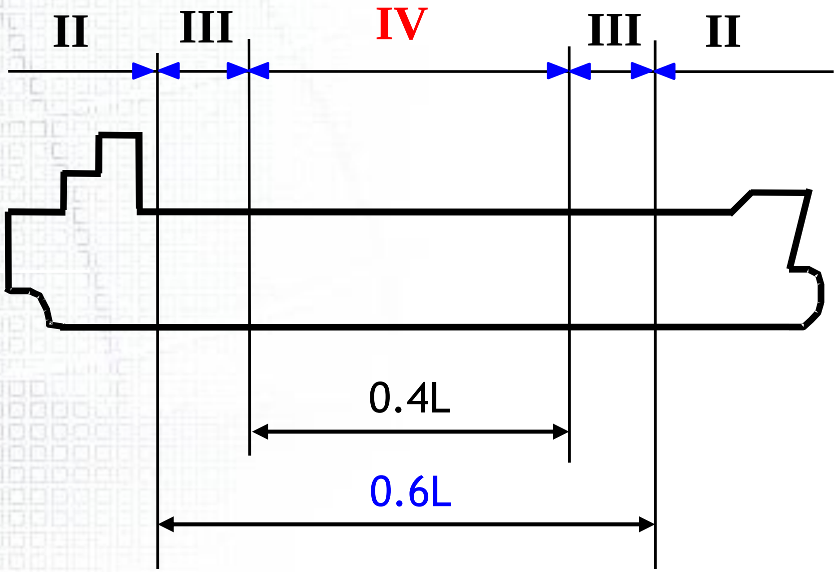
2.2 Material Classes
– Typical Example (4)

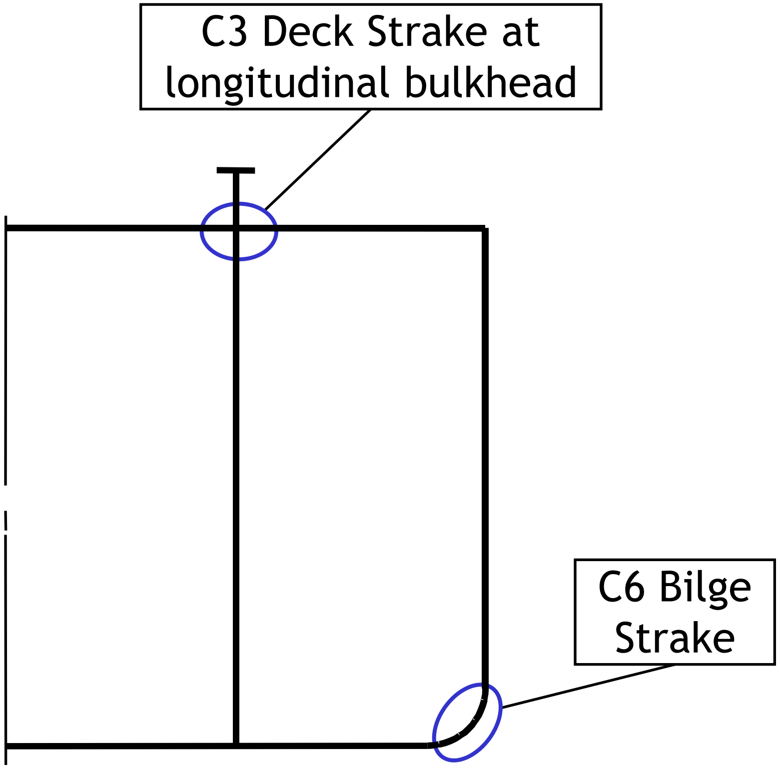


Structural member	Within 0.4 *L* amidships	Outside 0.4 *L* amidships
A1 Longitudinal bulkhead strakes. A2 Deck plating exposed to weather. A3 Side plating.	II	I
B1 Bottom plating including keel plate. B2 Strength deck plating. B3 Continuous longitudinal members above strength deck excluding hatch coamings. B4 Uppermost strake in longitudinal bulkhead. B5 Vertical strake (hatch side girder) and uppermost strake in top wing tank.	III	I
C1 Sheer strake at strength deck. C2 Stringer plate in strength deck. C3 Deck strake at longitudinal bulkhead. C4 Strength deck plating at outboard corners of cargo hatch openings in container carriers and other ships with similar hatch opening configuration. C5 Strength deck plating at corners of cargo hatch openings in bulk carriers, ore carriers, combination carriers and other ships with similar hatch opening configuration. C6 Bilge strake. C7 Longitudinal hatch coamings of length greater than 0.15 L.	IV	III (II outside 0.6L amidships)

Structural member	*0.4 L*	*Outside 0.4 L*
C3 Deck strake at longitudinal bulkhead. C6 Bilge strake.	IV	III (II outside 0.6L amidships)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2 Table B2





DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2
DSME, “선박구조설계” 2-10 부식 , 2005.8

2.3 Corrosion Addition (t_k , t_c)

- In tanks for cargo oil and or water ballast the scantlings of the steel structures shall be increased by corrosion additions.

→ **각 선급에서는 실제 운항하는 선박의 정기 검사를 통해 얻어진 자료를 바탕으로 각 구역별로** Corrosion Margin(0.5~3mm)**을 고려한 설계를 규정함** **(DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.2 Table D1, D2 참조)**

ex) Bottom plate thickness

$$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + \boxed{t_k} \ (mm)$$

Corrosion Addition을 **더해줌**

* **부식**(Corrosion):**금속재료가 사용 환경 중의 물질과 반응해서 금속이온 또는 비금속 화합물이 되어 소모되어 가는 현상**

3. Longitudinal Strength

3.1 Still water shear forces, Q_S
Wave Shear force, Q_W

3.2 Still water bending moments, M_S
Wave Bending moment, M_W

3.3 Total Shear force and bending moment
3.4 Section Modulus
3.5 Stress $\leq$ Allowable Stress

3. Longitudinal Strength (종강도)

- Longitudinal Strength :
  배 길이 방향으로 발생하는 shear force**와** bending moment**에 견디는 선체구조의 강도**

- **방법** : **선체를 얇은 두께의 속이 빈** section beam**으로 가정하고**, hull weight **및** cargo**는 아래로**, buoyancy**는 위로 작용하는** loading**으로 보고 순수한** beam theory**에 따라 선체길이 방향의** shear force **및** bending moment**를 계산한다**.
  - **외부 조건** : Hydrostatic, wave, wind, temperature **등**
  - **내부 조건** : Cargo Loading, Lightship weight, Tank/Hold Arrangement

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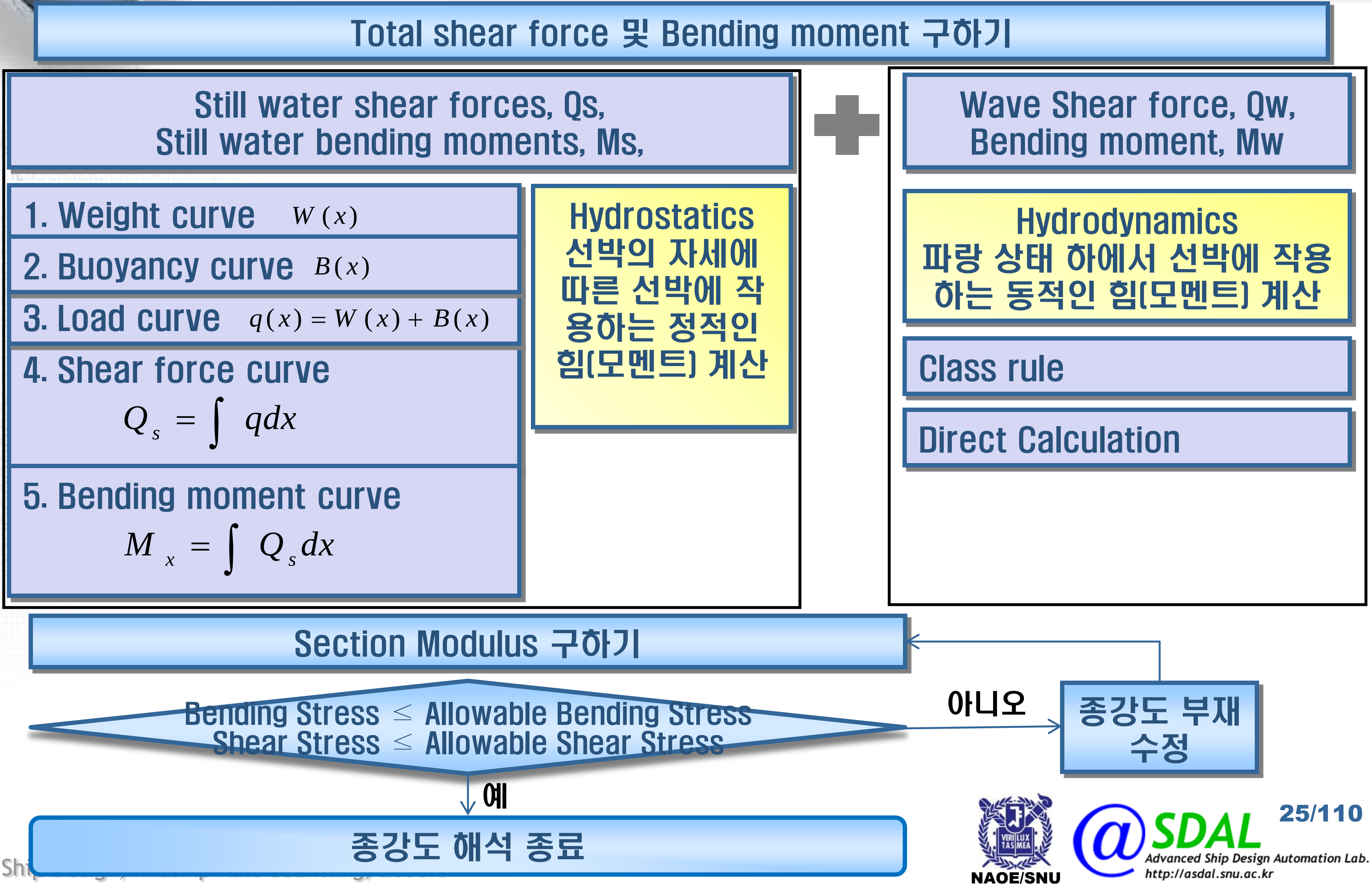
- **종강도 설계의 목적**
  - **파에 의한 외부적인 하중 조건과 화물 및 선체 자중에 의한 내부적인 하중 조건에 의해 발생되는 길이 방향의** shear force**와** bending moment **계산**
  - **주어진 설계하중을 충분히 만족시킬 수 있는 최소 횡단면을 배 길이 방향에 따라 결정**

3. Longitudinal Strength (종강도)



Total shear force 및 Bending moment 구하기

Still water shear forces, Qs,
Still water bending moments, Ms,

1. Weight curve $W(x)$
2. Buoyancy curve $B(x)$
3. Load curve $q(x) = W(x) + B(x)$
4. Shear force curve

$$Q_s = \int qdx$$

5. Bending moment curve

$$M_x = \int Q_s dx$$

Hydrostatics
선박의 자세에 따른 선박에 작용하는 정적인 힘(모멘트) 계산

+

Wave Shear force, Qw,
Bending moment, Mw

Hydrodynamics
파랑 상태 하에서 선박에 작용하는 동적인 힘(모멘트) 계산

Class rule

Direct Calculation

Section Modulus 구하기

Bending Stress $\leq$ Allowable Bending Stress
Shear Stress $\leq$ Allowable Shear Stress

아니오

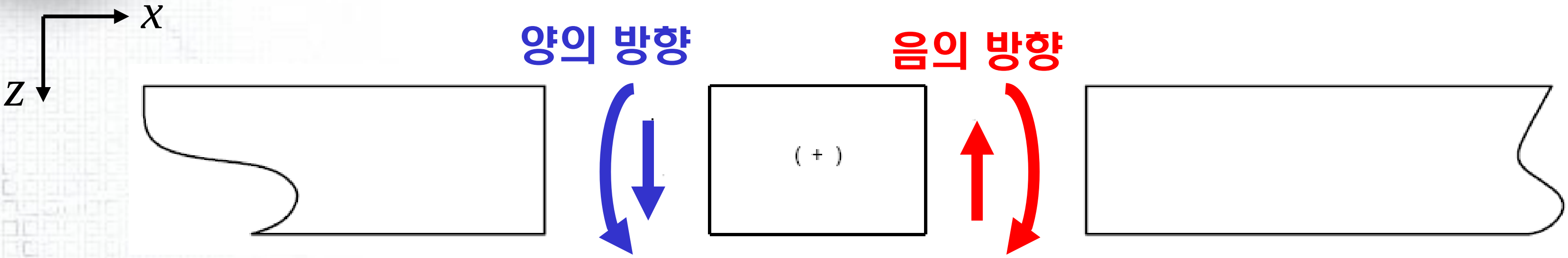
종강도 부재 수정

예

종강도 해석 종료

3. Longitudinal Strength <부호규약>

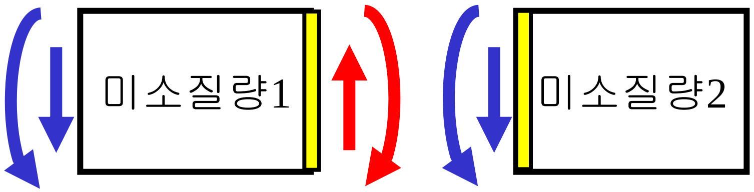
- Shear force와 Bending moment의 부호



Shear force와 Bending moment의 부호는 좌표축에 따라 정해진다.

Shear force : 아래 방향이 양, Bending moment : 반시계방향이 양

- 자유물체도의 각 면에서 서로 다른 방향의 shear force 및 bending moment가 작용하는 이유



미소질량 1, 2가 서로 붙어서 같은 면(노란색 면)을 공유한다고 하자.

미소질량들의 왼쪽에 양의 방향의 shear force와 bending moment가 작용한다고 정의하면,

미소질량 2에 의해 노란색 면이 양의 방향으로 shear force와 bending moment를 받는다.

물체는 평형상태(알짜힘과 모멘트가 0)에 있으므로 미소질량 1의 오른쪽 면에서 음의 방향의 shear force와 bending moment가 작용해야 한다.

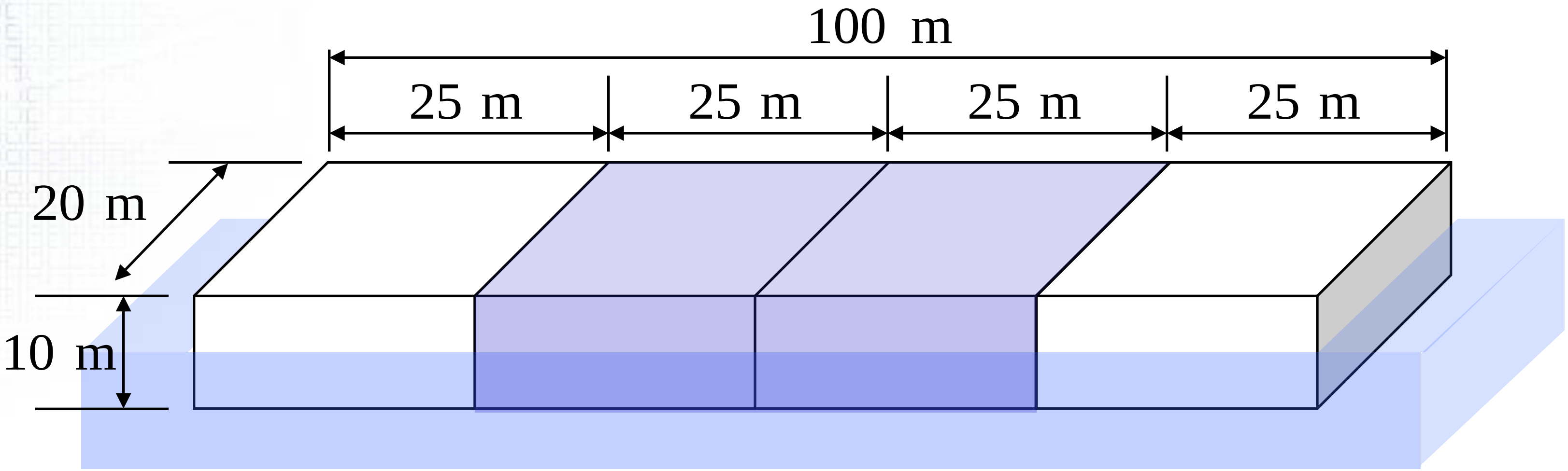
3. Longitudinal Strength
(예제) (1)

1. Weight curve (W)
2. Buoyancy curve (B)
3. Load curve q = W – B
4. Shear force curve
5. Bending moment curve

예제) **정수**(still water) **중에** Barge**가 떠 있으며 그 제원 및 자중은 다음과 같다.**

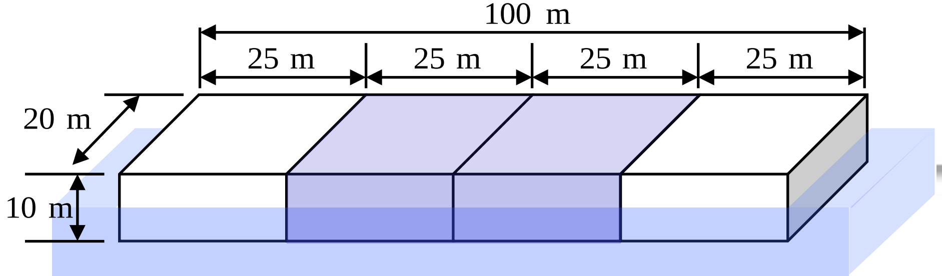
- L x B x D = 100m x 20m x 10m
- **자중** : 2,000 ton

중앙의 2**개** hold**에 청수를 가득 채웠을 때 다음 물음에 답하여라.**

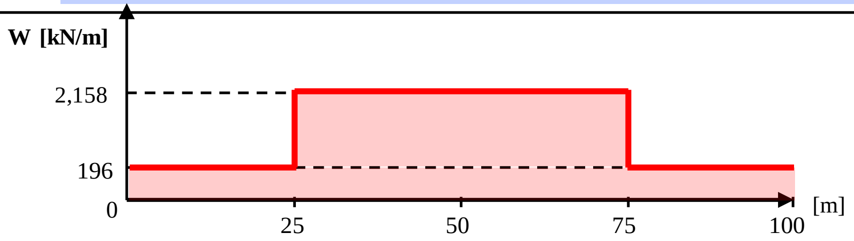


3. Longitudinal Strength

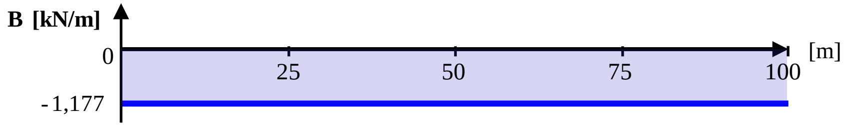
(예제) (2)



(1) Weight curve, $w(x)$

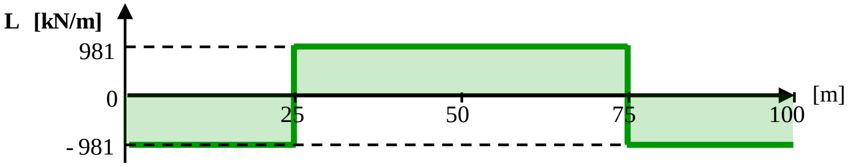


(2) Buoyancy curve, $B(x)$



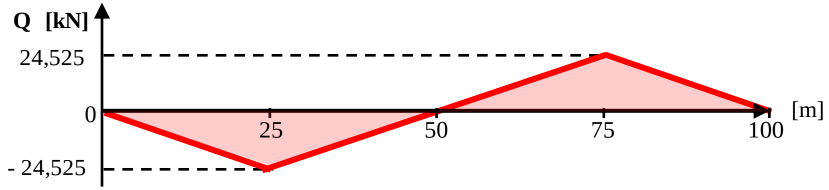
(3) Load curve, $q(x)$

$$q(x) = W(x) + B(x)$$



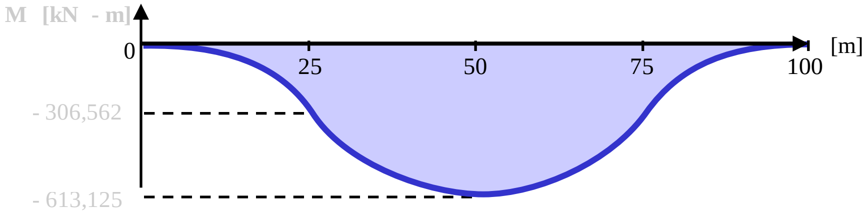
(4) Shear force curve

$$Q_s = \int q\,dx$$



(5) Bending moment curve

$$M_x = \int Q_s\,dx$$



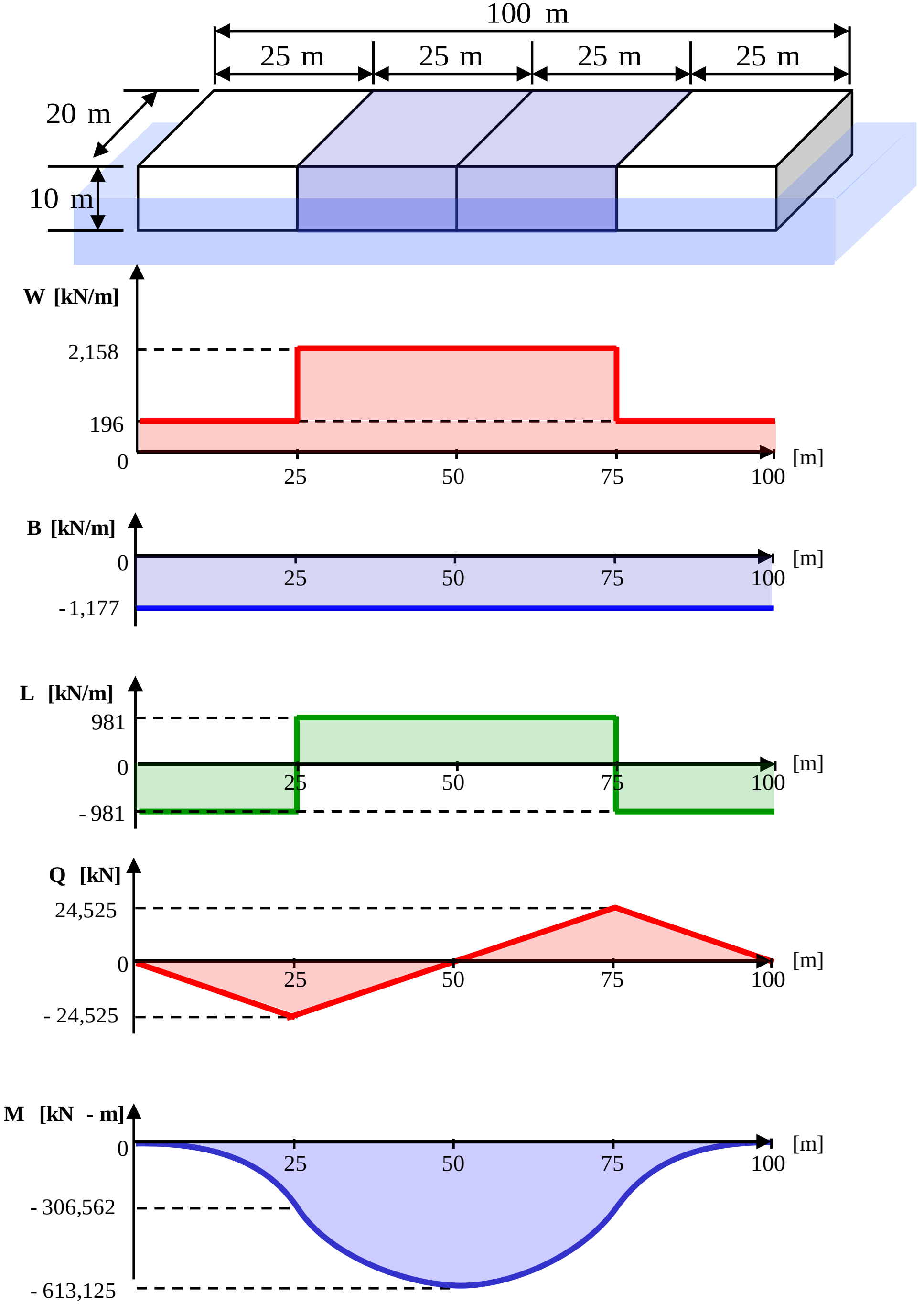
3. Longitudinal Strength
(예제) (3)

(6) Barge의 midship allowable stress,σ_l가 175(N/mm^2)일 때, Barge에 요구되는 최소 Section modulus는?

$$M = 613{,}125 \ (\mathrm{kN-m})$$
$$= 613{,}125 \times 10^6 \ (\mathrm{N-mm})$$

$$\sigma_l = \frac{M}{Z} \Rightarrow Z = \frac{M}{\sigma_l}$$

$$Z = \frac{M}{\sigma_l} = \frac{613{,}125 \times 10^6 [N - mm]}{175 \ [N/mm^2]}$$
$$= \underline{3.5 \ [m^3]} //$$



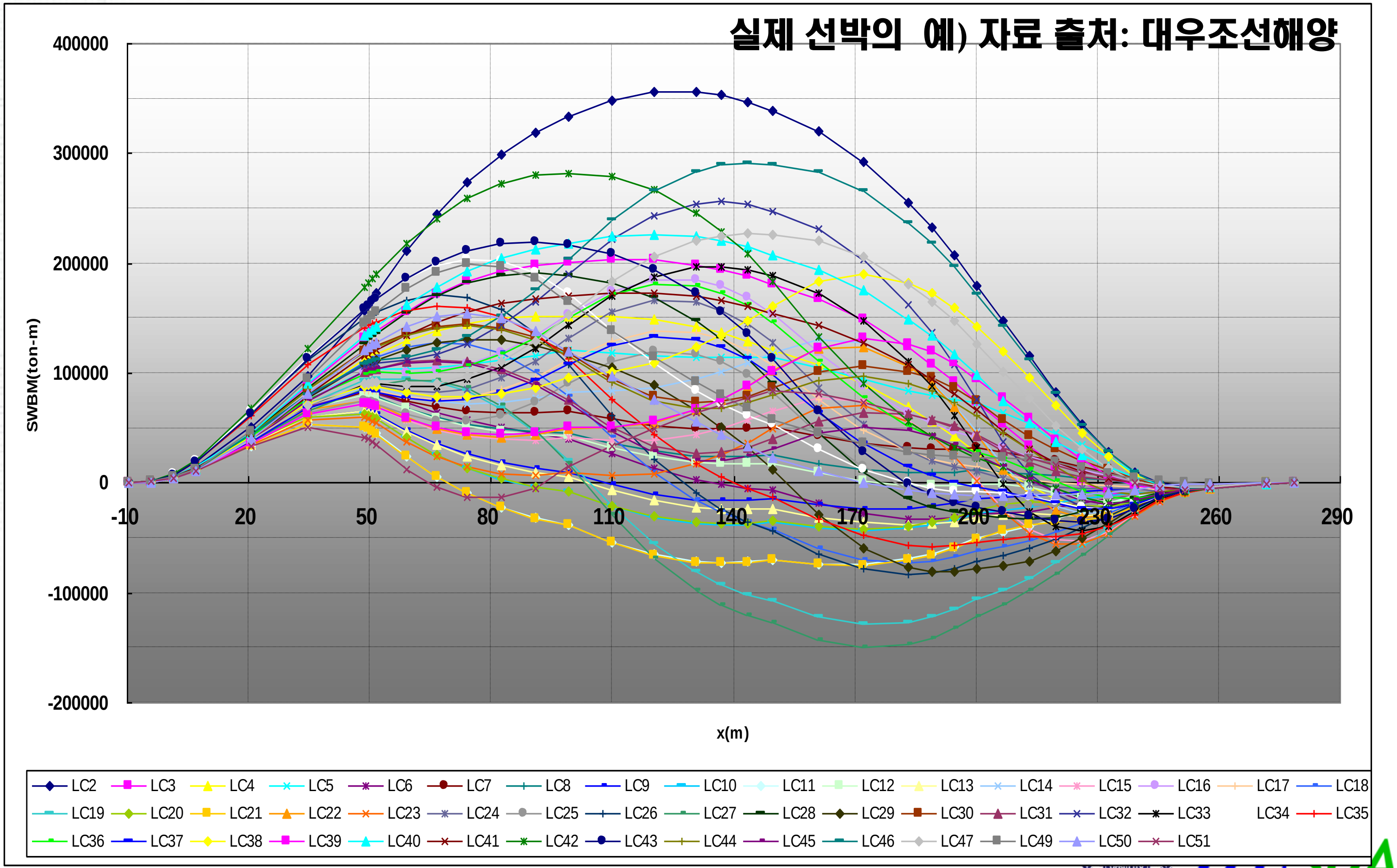
3.1 Bending moment curve
(예제) 실제 선박의 예

1. Weight curve (W)
2. Buoyancy curve (B)
3. Load curve q = W – B
4. Shear force curve
5. Bending moment curve

Hydrostatics
선박의 자세에 따른 선박에 작용하는 정적인 힘(모멘트) 계산

5. Bending moment curve

- DnV rule의 Pt3 Ch.1 Sec.5의 102에 명시된 Design Cargo, Ballast loading condition 등에 따라 still water shear force(Qs), still water bending moment(Ms)가 계산 됨


실제 선박의 예) 자료 출처: 대우조선해양

3.1 Minimum Still water shear forces, Q_S, Minimum Virtical wave shear force, Q_W

- Still water shear force는 다음 값보다 작지 않아야 한다. (Pt 3 Ch1 Sec. 5 B107)

$$\boxed{Q_S = k_{sq} Q_{SO} \ (kN)}$$

$$Q_{SO} = 5\frac{M_{SO}}{L} \ (kN)$$

k_{sq} = 0 at A.P. and F.P.
= 1.0 between 0.15 L and 0.3 L from A.P.
= 0.8 between 0.4 L and 0.6 L from A.P.
= 1.0 between 0.7 L and 0.85 L from A.P.

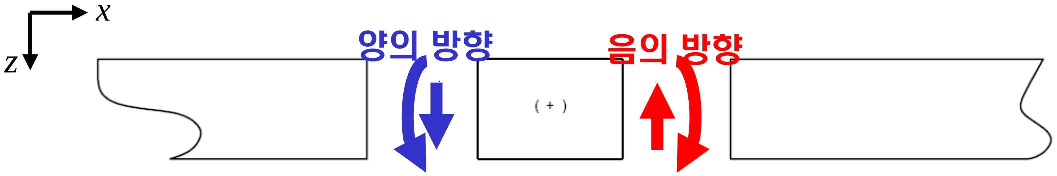
$M_{SO} = -0.065 C_{WU} L^2 B(C_B + 0.7)$ (kNm) in sagging
$= C_{WU} L^2 B(0.1225 - 0.015 C_B)$ (kNm) in hogging

- vertical wave shear forces에 대한 rule 값 (Pt 3 Ch1 Sec. 5 B203)

양의 shear force : $\boxed{Q_{WP} = 0.3\beta k_{wqp} C_W LB(C_B + 0.7)}$

음의 shear force : $\boxed{Q_{WN} = -0.3\beta k_{wqn} C_W LB(C_B + 0.7)}$

β : 운항상태와 관련된 계수
k_{wqp} , k_{wqn} : 길이방향의 위치에 따른 계수
C_W : wave coefficient



DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.5

Minimum Still water bending moments, M_S MinimumVirtical wave bending moment, M_W

- 중앙 단면에서의 still water bending moment는 다음의 값보다 작지 않아야 한다.

$$\boxed{M_S = M_{SO}\ (kNm)}$$

$$M_{SO} = \underline{-0.065}\,C_{WU} L^2 B(C_B + 0.7) \quad \text{(kNm) in sagging}$$

$$= C_{WU} L^2 B(0.1225 - 0.015 C_B) \quad \text{(kNm) in hogging}$$

wave coefficient, for unrestricted service.

- 중앙단면에서의 vertical wave bending moment는 다음의 값보다 작지 않아야 한다.

$$\boxed{M_w = M_{WO}\quad (kNm)}$$

$$M_{WO} = \underline{-0.11}\,\alpha C_W L^2 B(C_B + 0.7) \quad \text{(kNm) in sagging}$$

$$= 0.19\,\alpha C_W L^2 B C_B \quad \text{(kNm) in hogging}$$

L	C_W
$L \le 100$	$0.0792 \cdot L$
$100 < L < 300$	$10.75 - [(300 - L)/100]^{3/2}$
$300 \le L \le 350$	10.75
$L > 350$	$10.75 - [(L - 350)/150]^{3/2}$

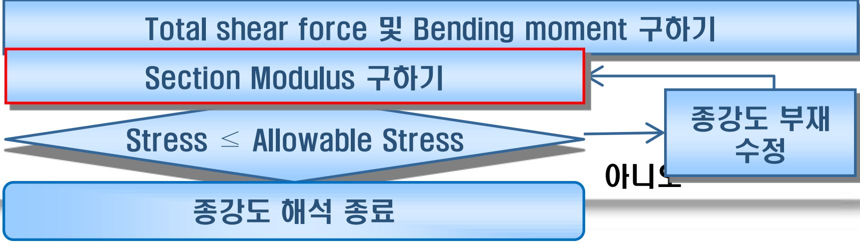
$\alpha = 1.0$ for seagoing condition

$= 0.5$ for harbour and sheltered water conditions (enclosed fjords, lakes, rivers)

C_W : wave coefficient

C_B : block coefficient, not be taken less than 0.6

3.4 Minimum Section Modulus



DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.5

- Transverse neutral axis**에 대한 중앙단면의** section modulus**는 다음의 값보다 작지 않아야 한다.**

$$Z_O = \frac{C_{WO}}{f_1} L^2 B (C_B + 0.7)$$

C_{WO} : wave coefficient

L	C_W
$L < 300$	$10.75 - [(300 - L)/100]^{3/2}$
$300 \le L \le 350$	10.75
$L > 350$	$10.75 - [(L - 350)/150]^{3/2}$

f_1 = material factor

C_B is in this case not to be taken less than 0.60.

- Cargo and ballast conditions**에서의** neutral axis**에 대한** section modulus requirements

$$Z_O = \frac{|M_S + M_W|}{\sigma_l} 10^3 (cm^3)$$

$\sigma_l = 175\ f_1 N/mm^2$ within 0.4 L amidship

$= 125\ f_1 N/mm^2$ within 0.1 L from A.P. or F.P.

DSME, Dnv Rule 해설서, 1991.8

$$M_{SO} = \underline{-0.065}\, C_{WU} L^2 B (C_B + 0.7)$$

$$M_{WO} = \underline{-0.11}\alpha C_W L^2 B (C_B + 0.7)$$

Stress factor, f_2 (f_{2b}, f_{2d}) 유도

Z_O : mild steel(f1 = 1.0) **사용시** Rule midship section modulus

Pt.3 Sh.1 Sec5 C302

$$f_2 = \frac{Z_O}{Z_A}$$

$$Z_O = \frac{C_{WO}}{f_1} L^2 B (C_b + 0.7) \qquad (cm^3)$$

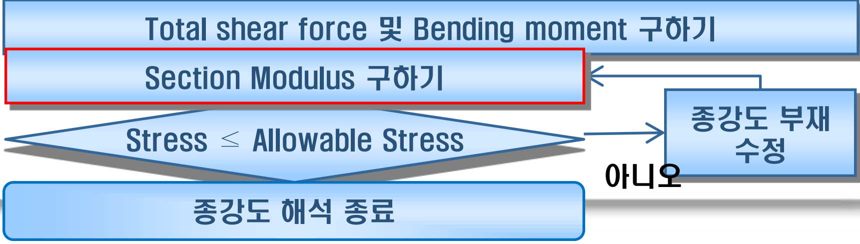
Z_A : Actual midship section modulus (cm^3)

$$f_2 = \frac{C_{WO} L^2 B (C_b + 0.7)}{Z_A} = \boxed{\frac{1}{0.175}} \frac{\boxed{0.175} \cdot C_{WO} L^2 B (C_b + 0.7)}{Z_A}$$

$$= \boxed{5.7} \times \frac{\boxed{0.065} \cdot C_{WO} L^2 B (C_b + 0.7) + \boxed{0.11} \cdot C_{WO} L^2 B (C_b + 0.7)}{Z_A}$$

$$\boxed{\therefore\ f_2 = 5.7 \times \frac{(M_S + M_W)}{Z_A}} \ , \left(\begin{aligned} M_S &= 0.065 \cdot C_{WO} L^2 B (C_b + 0.7) \\ M_W &= 0.11 \cdot C_{WO} L^2 B (C_b + 0.7) \end{aligned} \right)$$

3.4 Miminum midship moment of inertia, I_{ship}

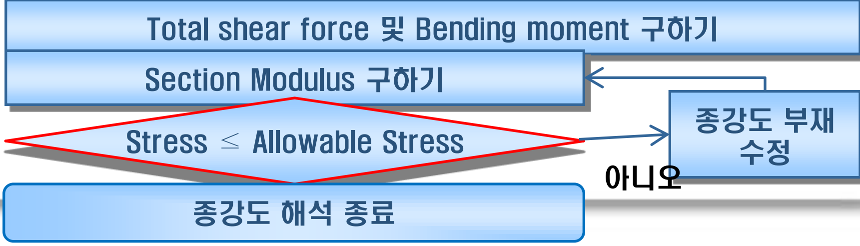


DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.5

- transverse neutral axis**에 대한 중앙단면의** moment of inertia**는 다음의 값보다 작지 않아야 한다.**

$$I_{ship} = 3C_W L^3 B(C_B + 0.7) \quad (cm^4)$$

3.5 Stress ≤ Allowable Stress – Bending Stress and Allowable Bending Stress


Total shear force 및 Bending moment 구하기

Section Modulus 구하기

Stress ≤ Allowable Stress

아니오

종강도 부재 수정

종강도 해석 종료

- **선체 각 단면에 발생하는** Bending stress**는 다음 식으로 얻어지며, 그 값이** allowable hull girder bending stress σ_l**을 초과하지 않도록 각** longitudinal members**의 치수를 적절히 조정하여야 한다.**

$$\boxed{\sigma_{act.} = \frac{M_S + M_W}{Z} 10^3 \quad (kg/cm^2)}$$

$$\boxed{\sigma_{act.} \le \sigma_l}$$

$\sigma_l = 175\ f_1 N/mm^2$ within 0.4 L amidship

$= 125\ f_1 N/mm^2$ within 0.1 L from A.P. or F.P.

4. Design Load

4.1 ship motion and acceleration

4.2 Combined Acceleration

4.3 Design Probability Level

4.4 Load point

4.5 Pressure & Force

a) Sea Pressure
b) Liquid Tank Pressure
c) Dry Cargo Pressure
d) Sloshing
e) Heavy Units
f) Flooding Pressure
g) Slamming & Bow Impact

[복습] 6자유도 선박의 운동방정식

창의적선박설계 강의자료 “Ship Motion and Wave Load” 참고

$$\mathbf{M}\ddot{\mathbf{x}} = \underline{\mathbf{F}_{Gravity} + \mathbf{F}_{static}} + \underline{\mathbf{F}_{F.K} + \mathbf{F}_{D}} + \underline{\mathbf{F}_{R}}$$

Linearization

$\mathbf{F}_{\text{Restoring}}$ $(= -\mathbf{C}\mathbf{x})$

$\mathbf{F}_{\text{exciting}}$

$\mathbf{F}_{R} = -\mathbf{A}\ddot{\mathbf{x}} - \mathbf{B}\dot{\mathbf{x}}$

$$\mathbf{M}\ddot{\mathbf{x}} = -\mathbf{C}\mathbf{x} + \mathbf{F}_{exciting} - \mathbf{A}\ddot{\mathbf{x}} - \mathbf{B}\dot{\mathbf{x}}$$

$$\underline{(\mathbf{M} + \mathbf{A})\ddot{\mathbf{x}} + \mathbf{B}\dot{\mathbf{x}} + \mathbf{C}\mathbf{x} = \mathbf{F}_{exciting}}$$

6자유도 선박의 운동 방정식

✓ 선박의 운동 방정식 풀이

Given : 단면의 Added mass
및 Damping Coefficient,
Wave exciting force

Strip Method

Find : 6자유도 가속도, 속도, 변위

✓ 선박에 작용하는 SWBM 및 VWBM 계산

- SWBM : Still Water Bending Moment
- VWBM : Vertical Water Bending Moment

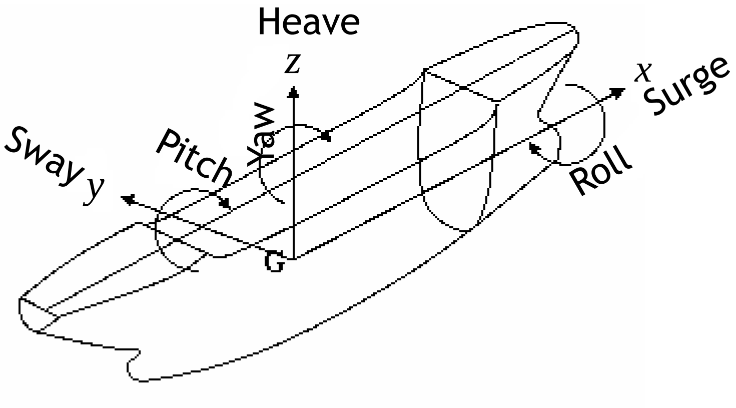
✓ Local Scantling

- Pd: dynamic pressure

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4

4.1 Ship Motion and Acceleration에대한 경험식

Common Acceleration Parameter	$a_0 = \frac{3C_w}{L} + C_v C_{v1}$
Surge Acceleration	$a_x = 0.2 g_0 a_0 \sqrt{C_b}$
Combined Sway/Yaw Acceleration	$a_y = 0.3 g_0 a_0$
Heave Acceleration	$a_z = 0.7 g_0 \frac{a_0}{\sqrt{C_b}}$
Tangential Roll Acceleration	$a_r = \phi \left(\frac{2\pi}{T_r} \right)^2 R_r$
Tangential Pitch Acceleration	$a_p = \theta \left(\frac{2\pi}{T_p} \right)^2 R_p$



- A common Acceleration Parameter, a_0

$$\boxed{a_0 = \frac{3C_W}{L} + C_V C_{V1}}$$

$C_V = \frac{\sqrt{L}}{50}$, maximum 0.2

$C_{V1} = \frac{V}{\sqrt{L}}$, minimum 0.8

C_W = Wave coefficien t

L	C_W
$L \le 100$	$0.0792 \cdot L$
$100 < L < 300$	$10.75 - [(300 - L)/100]^{3/2}$
$300 \le L \le 350$	10.75
$L > 350$	$10.75 - [(L - 350)/150]^{3/2}$

4.1 Ship Motions and Accelerations
– Roll angle & Roll Period

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4

✓ Roll angle

$$\phi = \frac{50c}{B+75} \quad \text{(rad)}$$

$c = (1.25 - 0.025\,T_R)\,k$
k = 1.2 for ships without bilge keel
= 1.0 for ships with bilge keel
= 0.8 for ships with active roll damping facilities
T_R = as defined in 402, not to be taken greater than 30.

✓ Roll Period

$$T_R = \frac{2k_r}{\sqrt{GM}} \quad \text{(s)}$$

k_r= 0.39B for ships with even transverse distribution of mass
=0.35B for tankers in ballast
=0.25B for ships loaded with ore between longitudinal bulkheads
GM= 0.07B in general
= 0.12B for tankers and bulk carriers

✓ Pitch angle

$$\theta = 0.25\,\frac{a_0}{C_B} \quad \text{(rad)}$$

$$a_0 = \frac{3C_W}{L} + C_V C_{V1}$$

✓ Pitch Period

$$T_P = 1.8\sqrt{\frac{L}{g_0}} \quad \text{(s)}$$

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4 B600

4.2 Combined Acceleration – Vertical Acceleration, a_v

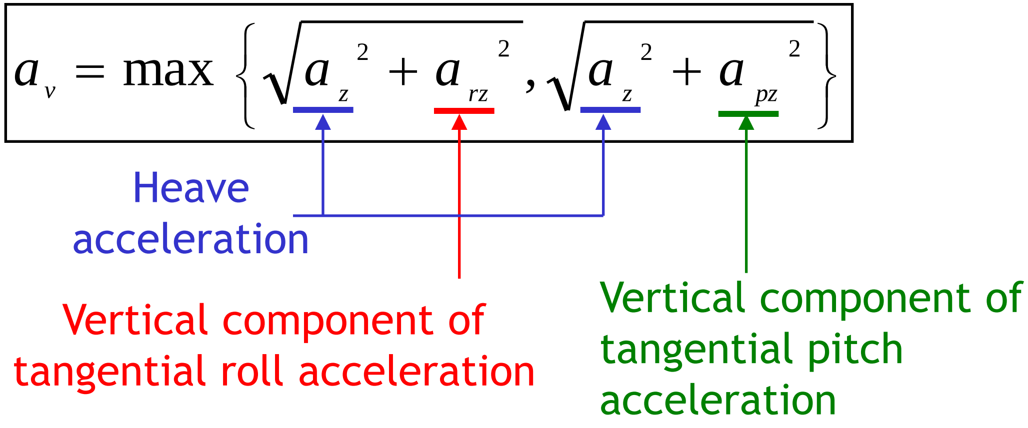
✓ Heave, Pitch & Roll Motion의 수직방향 가속도 성분들에 대한 연성 효과

$$\boxed{a_v = \frac{k_v g_o a_o}{C_b}}$$

K_v = Acceleration distribution factor along the length of vessel

= 0.7 between 0.3L and 0.6L from A.P.

a_0 = Common Acceleration Parameter

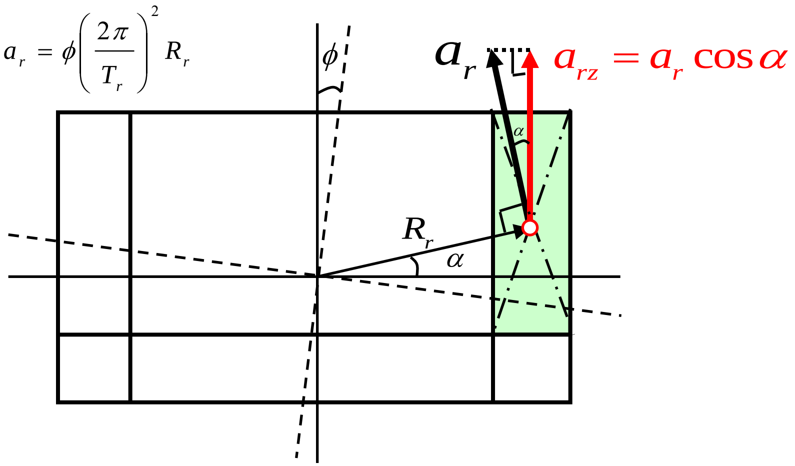


$$a_v = \max\left\{\sqrt{a_z^2 + a_{rz}^2}, \sqrt{a_z^2 + a_{pz}^2}\right\}$$

Heave acceleration

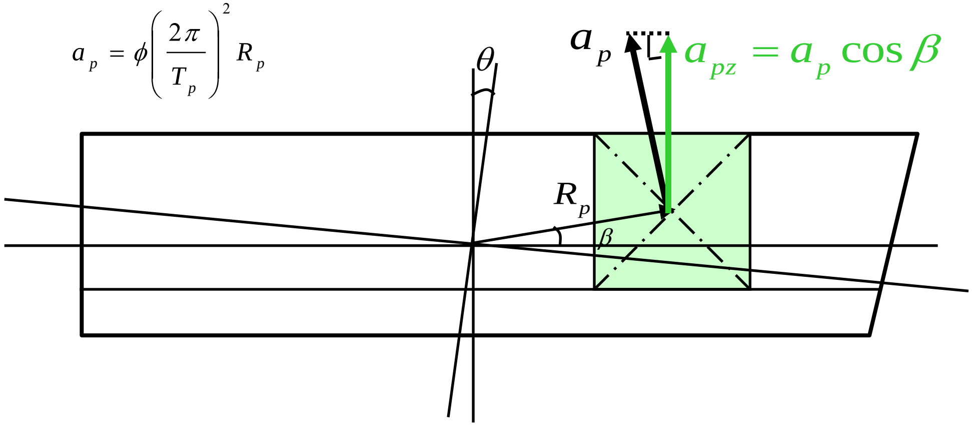
Vertical component of tangential roll acceleration

Vertical component of tangential pitch acceleration



$$a_r = \phi\left(\frac{2\pi}{T_r}\right)^2 R_r$$

$$a_{rz} = a_r \cos\alpha$$



$$a_p = \phi\left(\frac{2\pi}{T_p}\right)^2 R_p$$

$$a_{pz} = a_p \cos\beta$$

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4 B700

4.2 Combined Acceleration – Transverse Acceleration, a_t

✓ Sway, Yaw & Roll Motion의 폭 방향 가속도 성분들에 대한 연성 효과

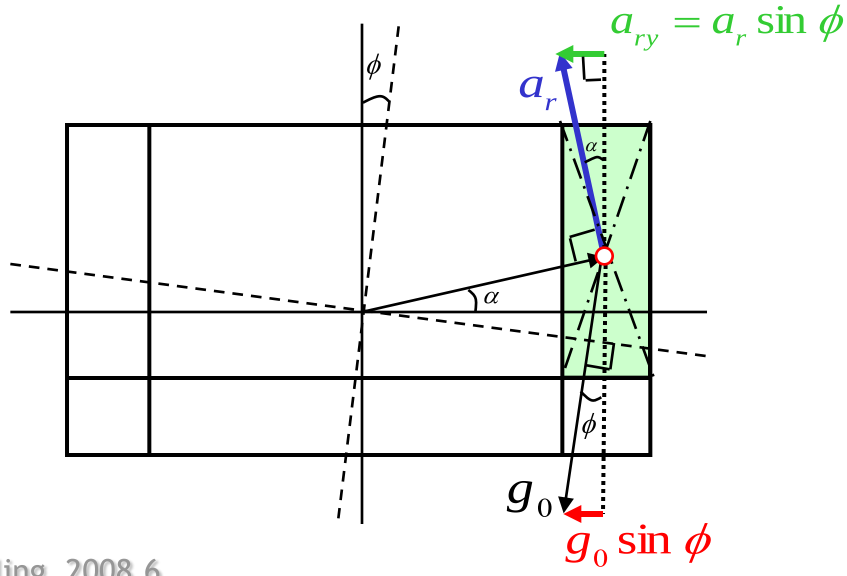
$$\boxed{a_t = \sqrt{\underbrace{a_y^{\,2}}_{} + (\underbrace{g_o \sin\phi}_{} + \underbrace{a_{ry}}_{})^2}}$$

Combined Sway & yaw acceleration

$a_y = 0.3 g_0 a_0$

Transverse component of acceleration of gravity by roll angle

Transverse component of the tangential roll acceleration



DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4 B800

4.2 Combined Acceleration
– Longitudinal Acceleration, a_l

✓ Surge & Pitch Motion의 길이방향 가속도 성분들에 대한 연성 효과

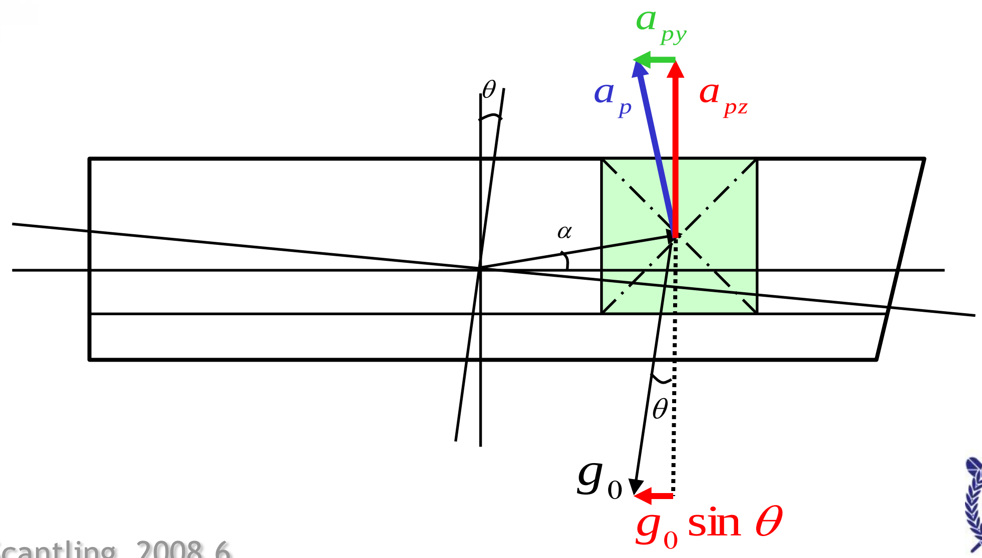
$$a_l = \sqrt{a_x{}^2 + (g_o \sin\theta + a_{px})^2}$$

$$a_x = 0.2 g_0 a_0 \sqrt{C_b}$$

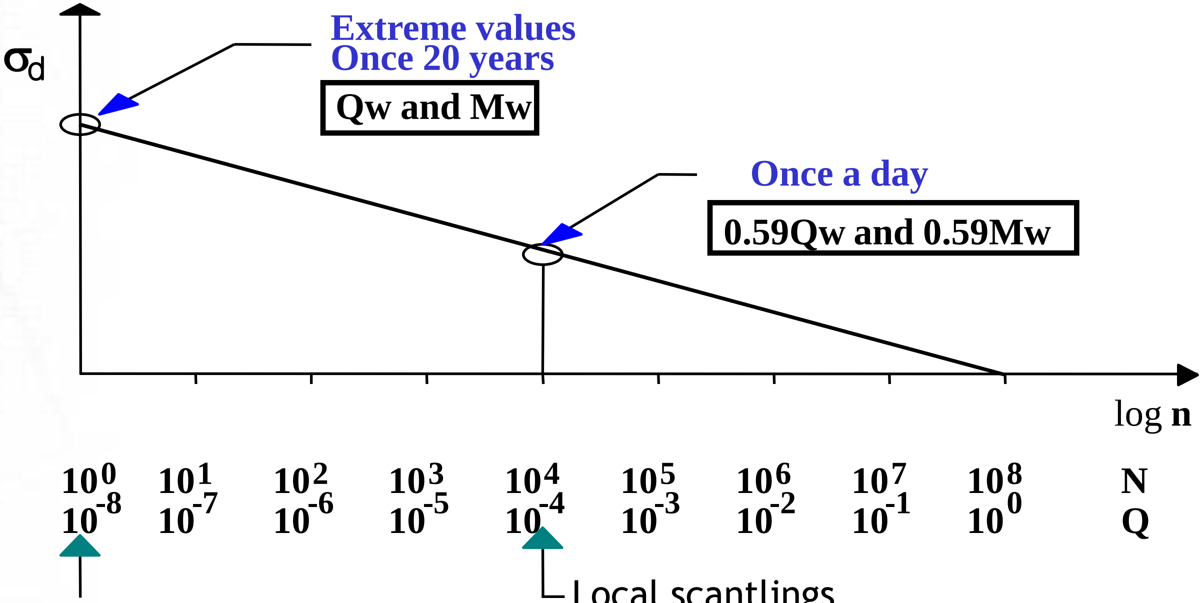
Combined Sway & yaw acceleration

Longitudinal component of acceleration of gravity by Pitch angle

Longitudinal component of the Pitch acceleration



4.3 Design Probability Level



Hull girder strength
Buckling strength
Local strength of container supports

Local scantlings
Fatigue strength

✓ 선박이 일생(20년 기준)동안 항해 중에 만나는 파의 개수: 약 10^8개
→20년 만에 한번 조우하는 extreme 파(10^{-8}확률)에 대하여 선박이 견딜 수 있도록 설계함. (Extreme condition)
(Ship motion, Acceleration은 Extreme value로 주어짐)

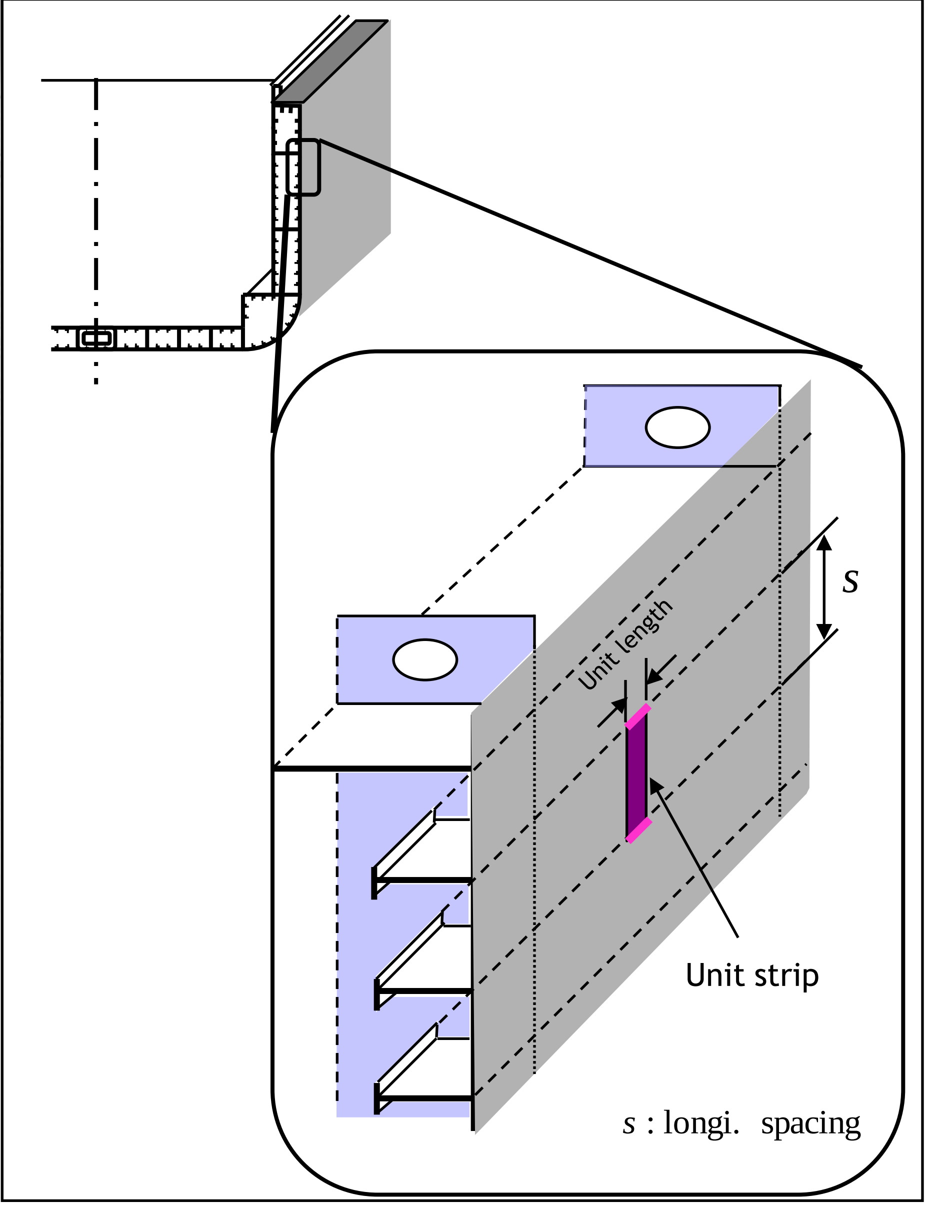
✓ Design pressure의 경우, 10^{-4} 수준으로 낮추어진 값을 사용(Reduction Value = 0.5 × Extreme value)

예) Liquid Tank Pressure: Vertical Acceleration를 고려한 Pressure, P_1

$$p_1 = \rho\left(g_o + \underline{0.5a_v}\right)h_s$$

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4 A 202

4.4 Load point – Horizontally stiffened plate



✓ Load point의 Pressure 값을 Unit strip의 Uniform load로 가정함

✓ Load point 결정법

1. General

: Longi. spacing (s)의 Midpoint

2. Seam & butt

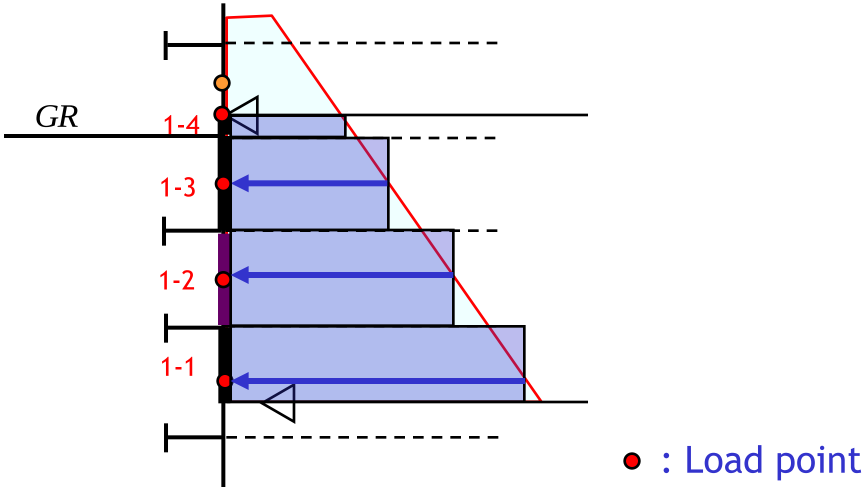
1) Longi. spacing (s)의 Midpoint를 포함하는 경우,

: Longi. span (s)의 Midpoint

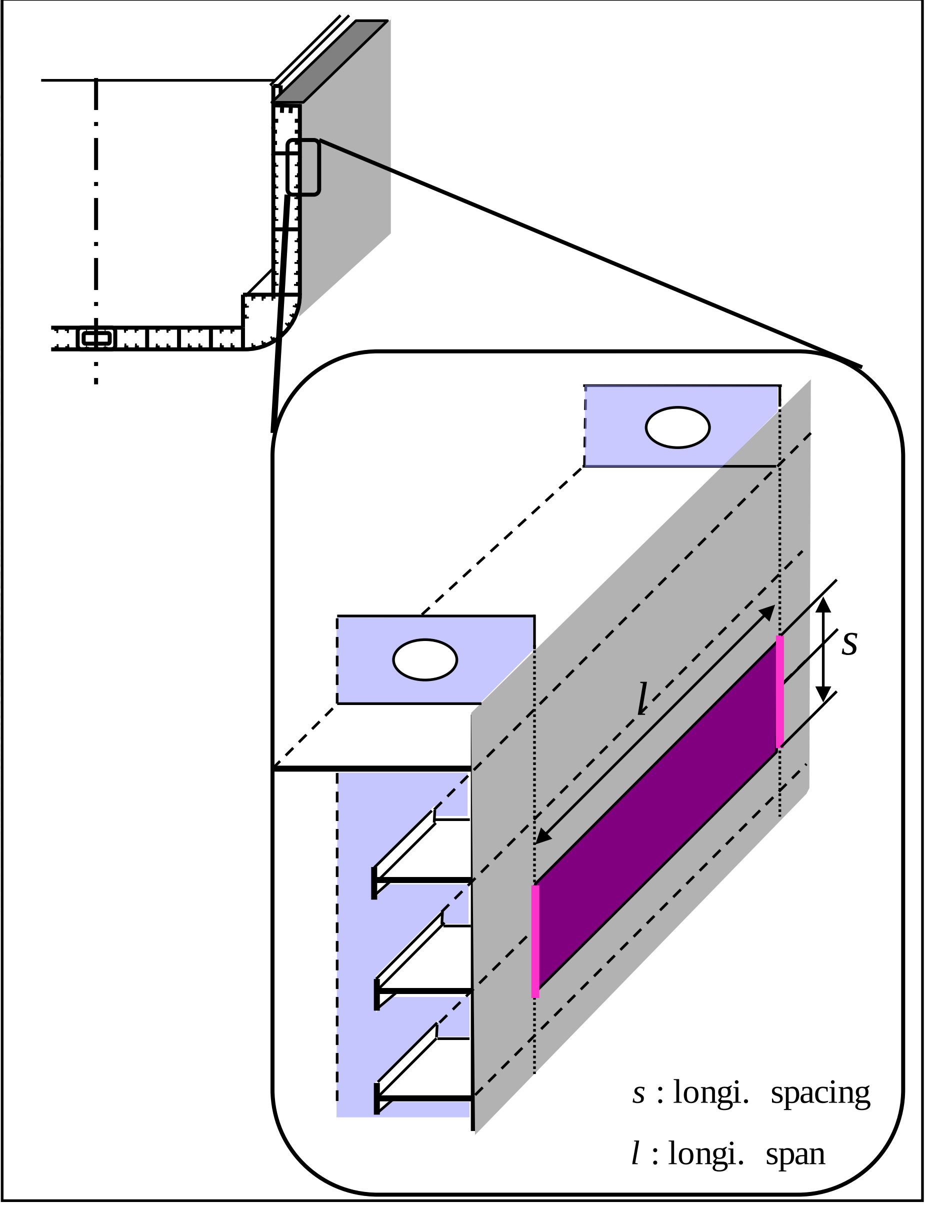
2) Longi. spacing (s)의 Midpoint를 포함하는 않은 경우,

: Midpoint에서 가까운 값(Seam & butt line)

✓ side plate에 작용하는 Sea pressure의 Load point



4.4 Load point
– Longitudinal stiffeners



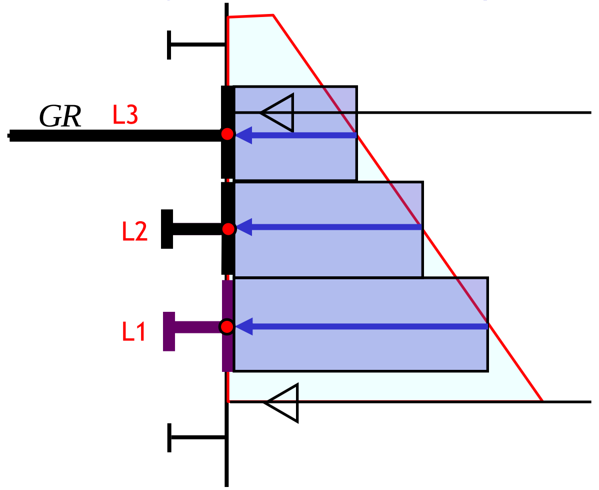
✓ Load point의 Pressure 값을 Unit strip의 Uniform load로 가정함

✓ Load point 결정법

1. General

: Longi. span (l)의 Midpoint

✓ side Longi.에 작용하는 Sea pressure의 Load point



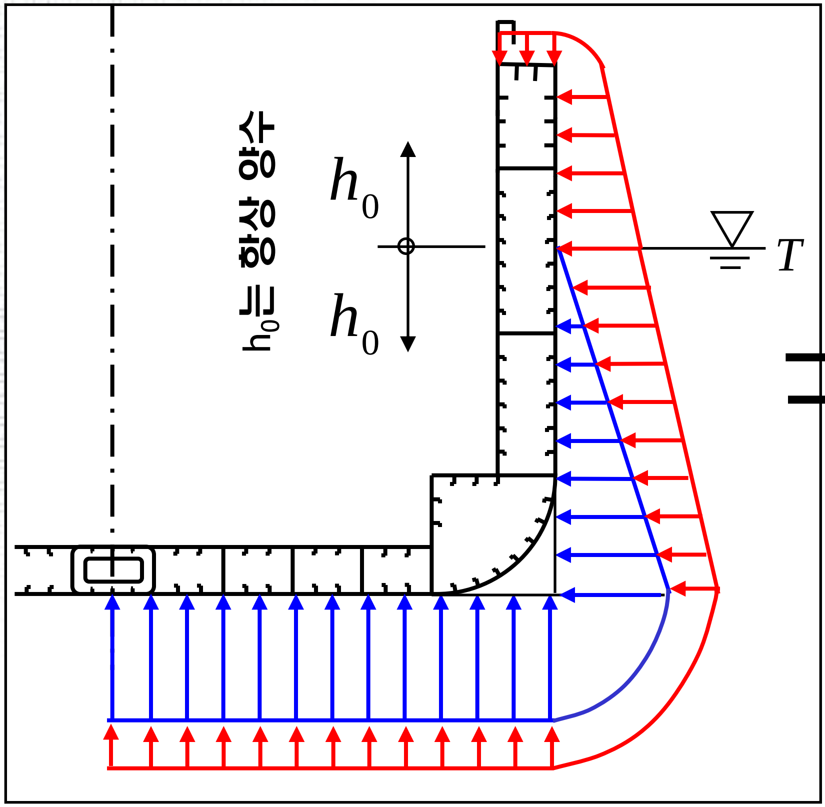
● : Load point

4.5 Pressure and Force

a) Sea Pressure

✓ sea pressures = static sea pressure + dynamic sea pressure

$$P = P_s + P_d$$



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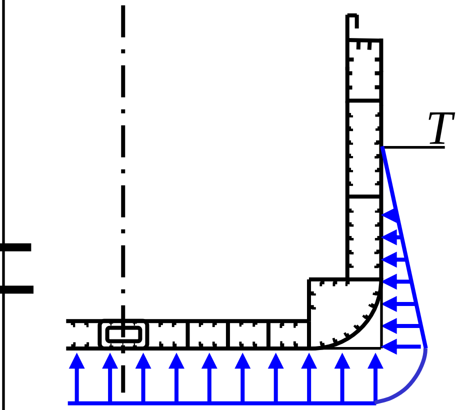
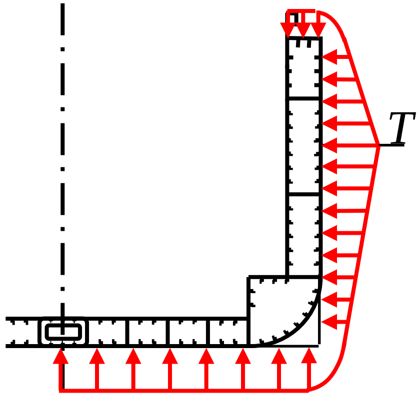


$$P_s = \rho g h_0 = 10 h_0$$

Static Sea Pressure

+



$$P_d = p_{dp}$$

Dynamic Sea Pressure

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4 C 300

DSME, “선박구조설계” 5-3, 2005.8

4.5 Pressure and Force
b) Liquid Tank Pressure (1)

- 액체로 가득찬 Tank의 압력(kN/m2)은 다음 식 중에서 구해 지는 값 중 가장 큰 것을 취한다.

$$p_1 = \rho\left(g_o + 0.5a_v\right)h_s$$

$$p_2 = \rho\, g_o\left[0.67\left(h_s + \phi\, b\right) - 0.12\sqrt{H\; b_t\, \phi}\right]$$

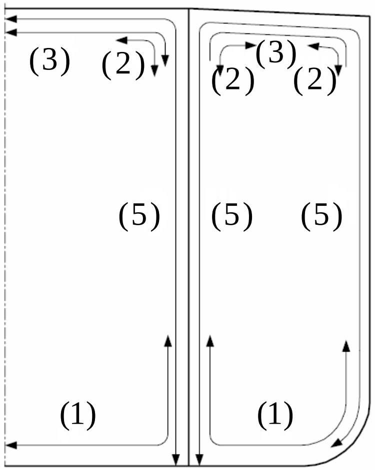
$$p_3 = \rho\, g_o\left[0.67\left(h_s + \theta\, l\right) - 0.12\sqrt{H\; l_t\, \theta}\right]$$

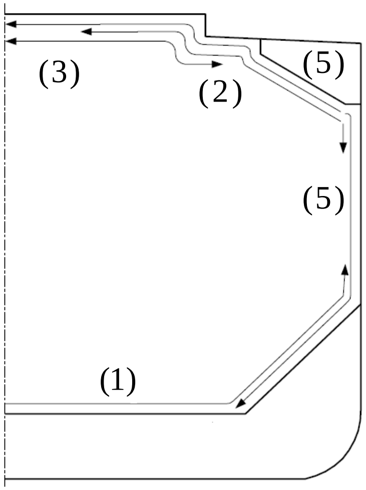
$$p_4 = 0.67\left(\rho\, g_o h_p + \Delta P_{dyn}\right)$$

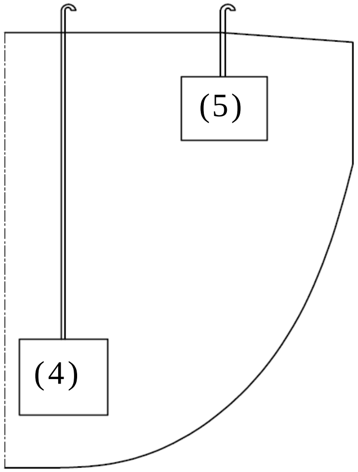
$$p_5 = \rho\, g_o h_s + p_o$$

P_1: Vertical Acceleration 고려
P_2: Rolling 고려
P_3: Pitching 고려
P_4: Overflow 고려
P_5: Tank Test 고려

- 위치 별로 가장 큰 영향을 받는 Pressure가 다름





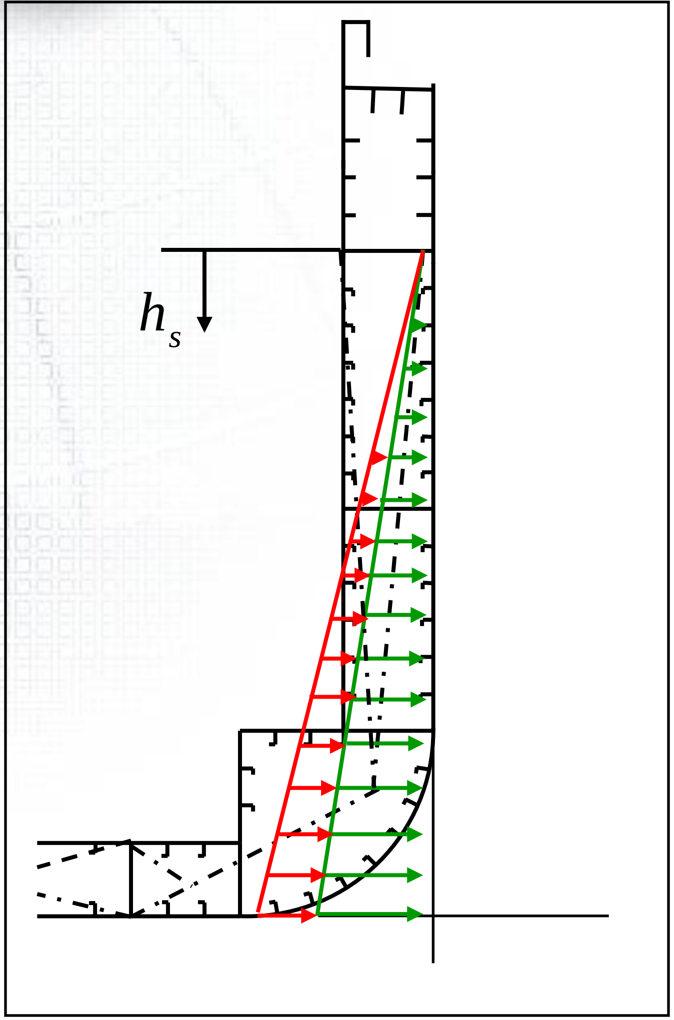


4.5 Pressure and Force
b) Liquid Tank Pressure (2)

$$p_1 = \rho\,(g_o + 0.5a_v)\,h_s$$
$$p_2 = \rho\, g_o \left[0.67\,(h_s + \phi\, b) - 0.12\sqrt{H\, b_t\, \phi}\right]$$
$$p_3 = \rho\, g_o \left[0.67\,(h_s + \theta\, l) - 0.12\sqrt{H\, l_t\, \theta}\right]$$
$$p_4 = 0.67\,(\rho\, g_o h_p + \Delta P_{dyn})$$
$$p_5 = \rho\, g_o h_s + p_o$$

P_1: Vertical Acceleration 고려
P_2: Rolling 고려
P_3: Pitching 고려
P_4: Overflow 고려
P_5: Tank Test 고려

✓ Vertical Acceleration을 고려한 Design Pressure, P_1 (General)



$$P_1 = \underline{\rho g_0 h_s} + \underline{0.5\rho a_v h_s}$$

Static Pressure

Dynamic Pressure

Probility Level에 의해 10^{-4}확률로 낮추어진 값을 사용

(reduction value=0.5×extreme value)

$$\boxed{p = \rho(g_0 + 0.5a_v)h_s}$$

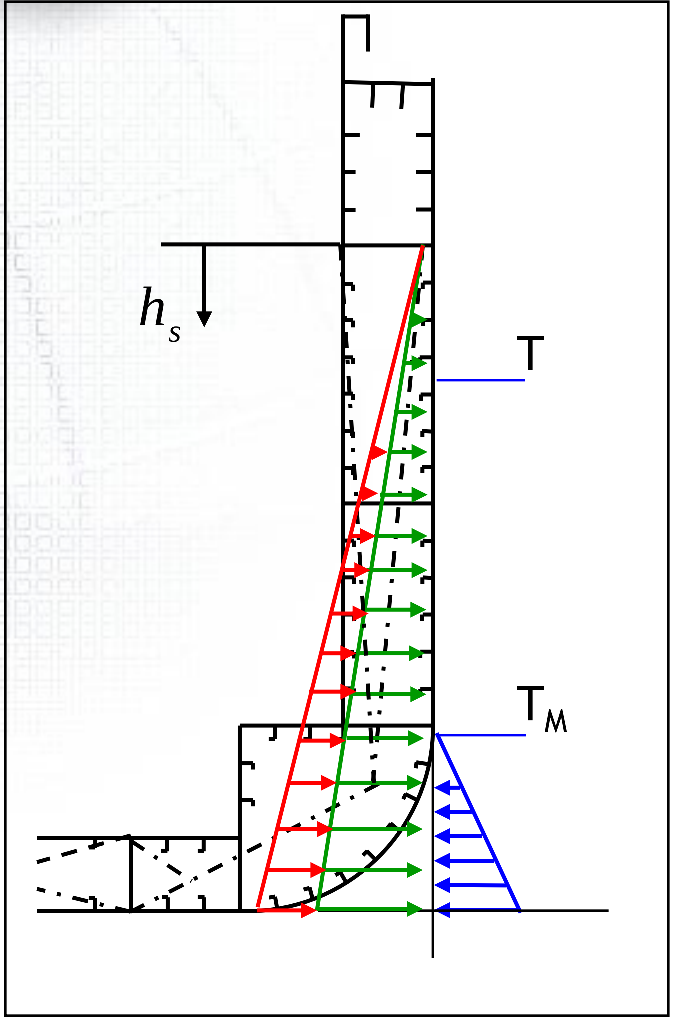
h_s : virtical distance in m from load point to top of tank

4.5 Pressure and Force
b) Liquid Tank Pressure (3)

$$p_1 = \rho\,(g_o + 0.5a_v)\,h_s$$
$$p_2 = \rho\, g_o \left[0.67\,(h_s + \phi\, b) - 0.12\sqrt{H\, b_t\, \phi}\,\right]$$
$$p_3 = \rho\, g_o \left[0.67\,(h_s + \theta\, l) - 0.12\sqrt{H\, l_t\, \theta}\,\right]$$
$$p_4 = 0.67\,(\rho\, g_o h_p + \Delta P_{dyn})$$
$$p_5 = \rho\, g_o h_s + p_o$$

P_1: Vertical Acceleration 고려
P_2: Rolling 고려
P_3: Pitching 고려
P_4: Overflow 고려
P_5: Tank Test 고려

✓ Vertical Acceleration을 고려한 Design Pressure, P_1 (Side shell)



Side shell의 경우, Sea pressure에 의한 영향이 존재함

$$P = \underbrace{\rho g_0 h_s}_{\text{Static Pressure}} + \underbrace{0.5\rho a_v h_s}_{\text{Dynamic Pressure}} \underbrace{- 10\, h_b}_{\text{sea pressure}}$$

Pressure 고려 시, 가장 Sevier한 경우를 고려함
Side shell 에 작용하는 Liquid cargo pressure가 가장 큰 경우는 Sea pressure에 의한 영향이 최소일 때, 즉, 흘수가 최소일 때(T_M)이다.

$$\boxed{p = \rho(g_0 + 0.5a_v)h_s - 10\, h_b}$$

h_b : virtical distance in m from load point to minimum design draught

T_M = 2 + 0.02 L for Tanker (IMO RULE)
= 0.35T for Dry cargo

4.5 Pressure and Force
b) Liquid Tank Pressure (4)

$$p_1 = \rho\,(g_o + 0.5a_v)\,h_s$$

$$p_2 = \rho\, g_o \left[0.67\,(h_s + \phi\, b) - 0.12\sqrt{H\; b_t\, \phi}\,\right]$$

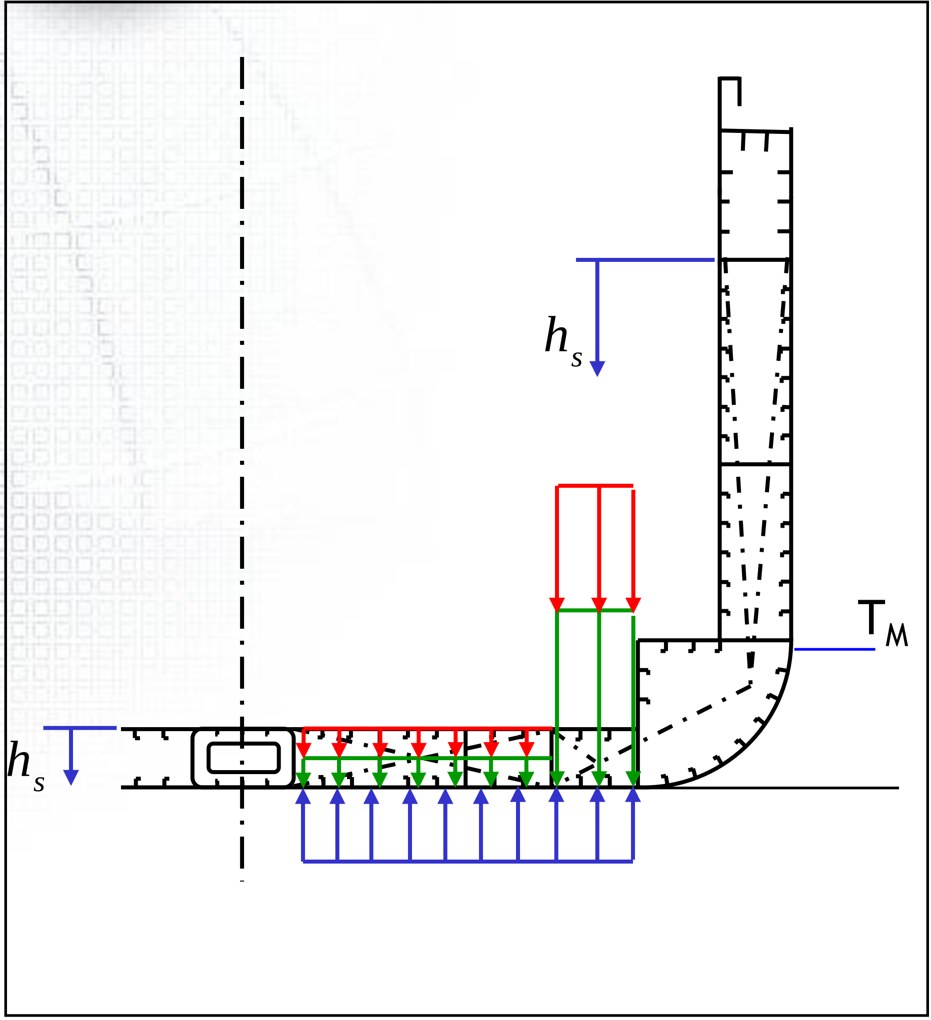
$$p_3 = \rho\, g_o \left[0.67\,(h_s + \theta\, l) - 0.12\sqrt{H\; l_t\, \theta}\,\right]$$

$$p_4 = 0.67\,(\rho\, g_o h_p + \Delta P_{dyn})$$

$$p_5 = \rho\, g_o h_s + p_o$$

P_1: Vertical Acceleration 고려
P_2: Rolling 고려
P_3: Pitching 고려
P_4: Overflow 고려
P_5: Tank Test 고려

Vertical Acceleration을 고려한 Design Pressure, P_1 (Bottom Shell)



$$P = \underbrace{\rho g_0 h_s}_{\text{Static Pressure}} + \underbrace{0.5\rho a_v h_s}_{\text{Dynamic Pressure}} - \underbrace{10T_M}_{\text{sea pressure}}$$

Pressure 고려 시, 가장 Sevier한 경우를 고려함
Bottom에 작용하는 Liquid cargo pressure가 가장 큰 경우는 Sea pressure에 의한 영향이 최소일 때, 즉, 흘수가 최소일 때(T_M)이다.

$$\boxed{p = \rho(g_0 + 0.5a_v)h_s - 10T_M}$$

$T_M = 2 + 0.02\,L$ for Tanker (IMO RULE)
$\quad = 0.35T$ for Dry cargo

4.5 Pressure and Force
b) Liquid Tank Pressure (5)

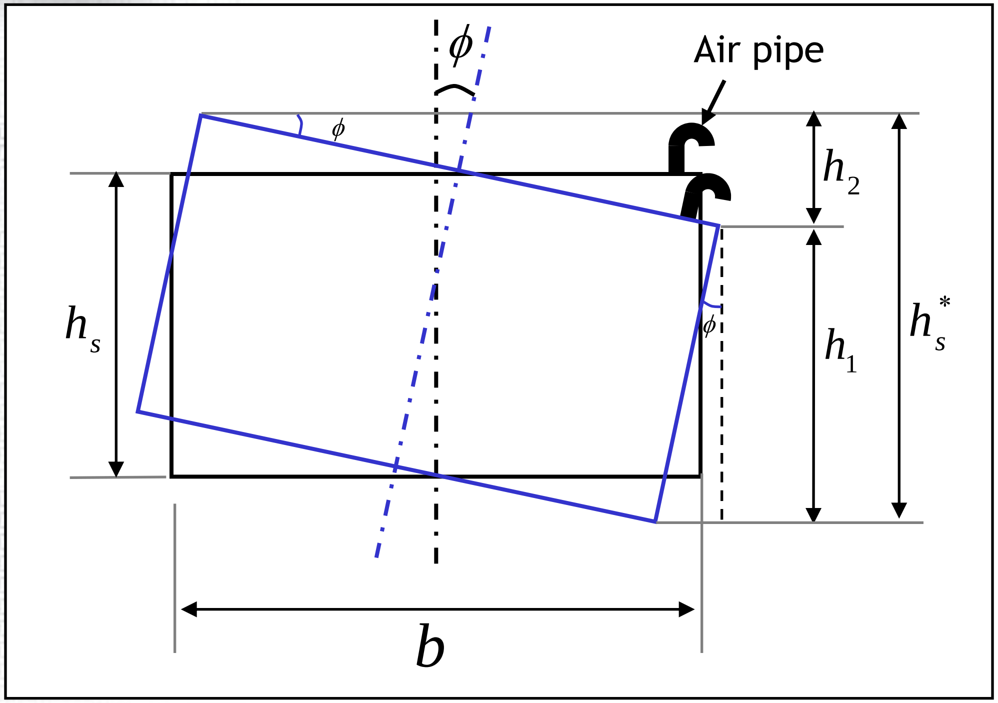
$$p_1 = \rho\left(g_o + 0.5a_v\right)h_s$$
$$p_2 = \rho\, g_o\left[0.67\left(h_s + \phi\, b\right) - 0.12\sqrt{H\, b_t\, \phi}\,\right]$$
$$p_3 = \rho\, g_o\left[0.67\left(h_s + \theta\, l\right) - 0.12\sqrt{H\, l_t\, \theta}\,\right]$$
$$p_4 = 0.67\left(\rho\, g_o h_p + \Delta P_{dyn}\right)$$
$$p_5 = \rho\, g_o h_s + p_o$$

P_1: Vertical Acceleration 고려
P_2: Rolling 고려
P_3: Pitching 고려
P_4: Overflow 고려
P_5: Tank Test 고려

Rolling Motion을 고려한 Design Pressure, P_2

DSME, 선박구조설계 5-3

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4



Rolling시 더 큰 Static pressure가 작용함

$\phi \ll 1$ 이라 가정

$$h_1 = h_s \cos\phi \approx h_s$$
$$h_2 = b \sin\phi \approx b\phi$$
$$\therefore\ h_s^* = h_1 + h_2$$
$$= \underline{\left(h_s + b\phi\right)}$$

$$\boxed{p_2 = \rho g_0[\underline{0.67}\,(h_s + \phi b) \underline{- 0.12\sqrt{H\phi b_t}}\,]}$$

선박의 Rolling시 Cargo가 Overflow에 의한 Pressure drop을 고려하여 실제 수두의 2/3(=0.67)를 취함

실제 Tank가 Full로 채워지지 않고, 약 98%만 채워진다. 이를(약 2%) 고려함

4.5 Pressure and Force
b) Liquid Tank Pressure (6)

$$p_1 = \rho \left(g_o + 0.5 a_v\right) h_s$$

$$p_2 = \rho\, g_o \left[0.67 \left(h_s + \phi\, b\right) - 0.12 \sqrt{H\ b_t\, \phi}\ \right]$$

$$p_3 = \rho\, g_o \left[0.67 \left(h_s + \theta\, l\right) - 0.12 \sqrt{H\ l_t\, \theta}\ \right]$$

$$p_4 = 0.67 \left(\rho\, g_o h_p + \Delta P_{dyn}\right)$$

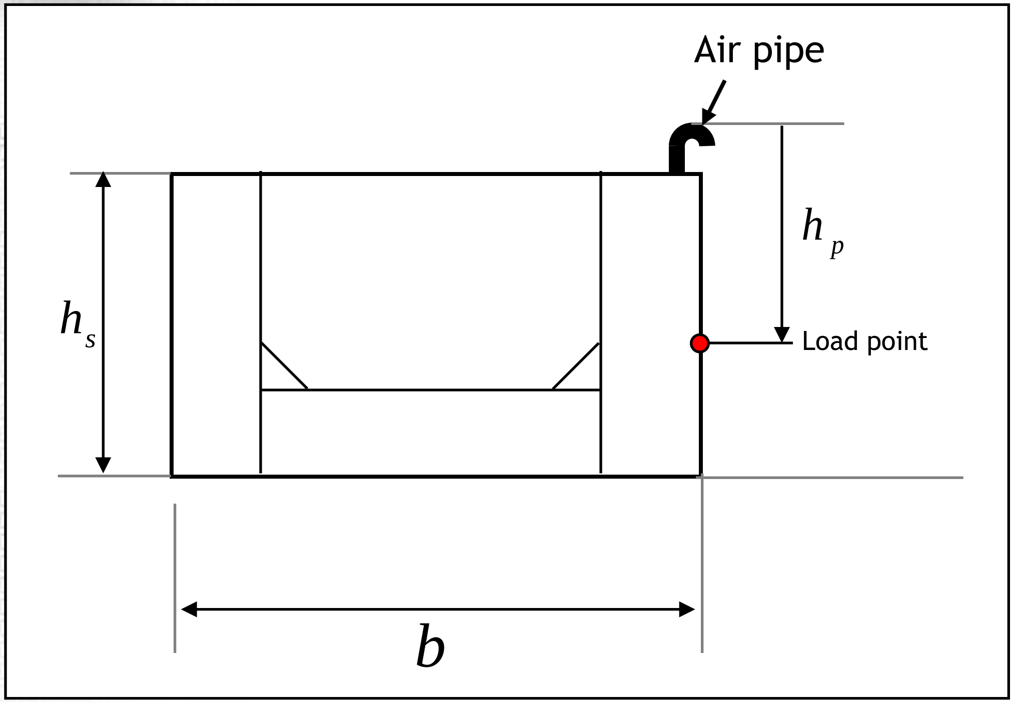
$$p_5 = \rho\, g_o h_s + p_o$$

P_1: Vertical Acceleration 고려
P_2: Rolling 고려
P_3: Pitching 고려
P_4: Overflow 고려
P_5: Tank Test 고려

DSME, “선박구조설계” 5-3

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4

Tank overflow를 고려한 Design Pressure, P_4



Tank overflow시 Air pipe까지 물이 차게 되므로, Static pressure계산시 h_p를 사용함

h_p = vertical distance in m from the load point to the top of air pipe

$$\boxed{p = \underline{0.67}\,\rho g_0 h_p + \underline{\Delta P_{dyn}}}$$

Calculated Pressure drop

Generally, 25kN/m^2

선박의 Rolling시 Cargo가 Overflow되어 Pressure drop현상을 고려하여 실제 수두의 2/3(=0.67)를 취함

4.5 Pressure and Force
b) Liquid Tank Pressure (7)

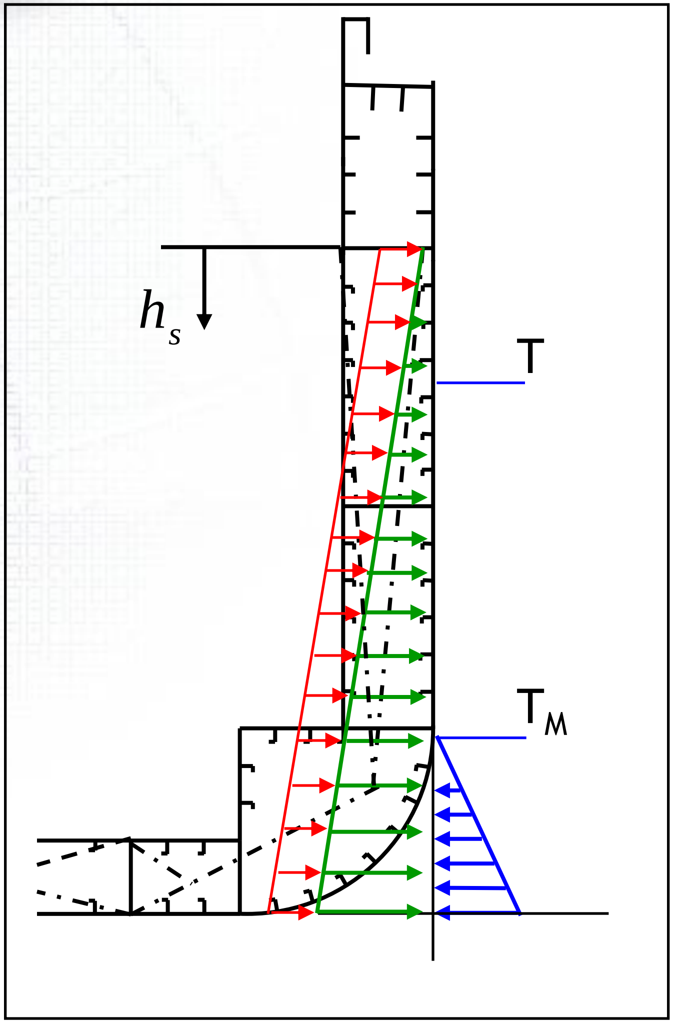
$$p_1 = \rho\left(g_o + 0.5a_v\right)h_s$$
$$p_2 = \rho\, g_o\left[0.67\left(h_s + \phi\, b\right) - 0.12\sqrt{H\ b_t\ \phi}\right]$$
$$p_3 = \rho\, g_o\left[0.67\left(h_s + \theta\, l\right) - 0.12\sqrt{H\ l_t\ \theta}\right]$$
$$p_4 = 0.67\left(\rho\, g_o h_p + \Delta P_{dyn}\right)$$
$$p_5 = \rho\, g_o h_s + p_o$$

P_1: Vertical Acceleration 고려
P_2: Rolling 고려
P_3: Pitching 고려
P_4: Overflow 고려
P_5: Tank Test 고려

Tank Test를 고려한 Design Pressure, P_5

DSME, 선박구조설계 5-3

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.4



Tank Test (Tank의 Leakage **여부를** Test**함) 시**, Tank height + 2.5m**에 해당하는 수두를 가지도록** over-pressure**를 가함**

$$\boxed{p = \rho g_0 h_s - 10\, h_b + \underline{p_o}}$$

$$p_o = \rho g_0 \times 2.5$$
$$= 10 \times 2.5$$
$$= 25\, kN / m^2$$

h_b : virtical distance in m from load point to minimum design draught

5. Local Scantling

5.1 Stress Factor
5.2 allowable stress
5.3 Plate의 required thickness 식 유도
5.4 Longitudianls의 required section modulus 식 유도

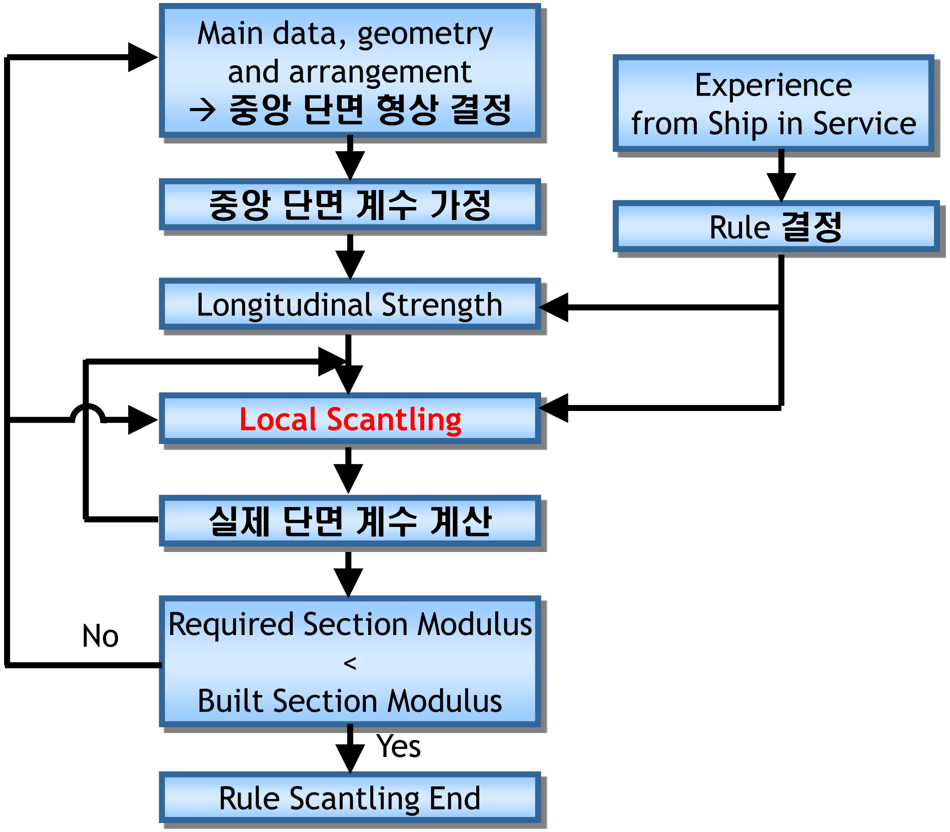
이규열,"창의적 선박설계" 선체 구조설계 p.15

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6,7,8,9,10

5. Local Scantling

→ **선체 구조가** Hydrostatic, Hydrodynamic force**에 의한 외력을 견디도록 부재 치수 결정**

→**해당 선박이 선급** Rule**및 구조역학적 강도에 만족하도록 설계하는 과정을** Local Scantling**이라 함.**

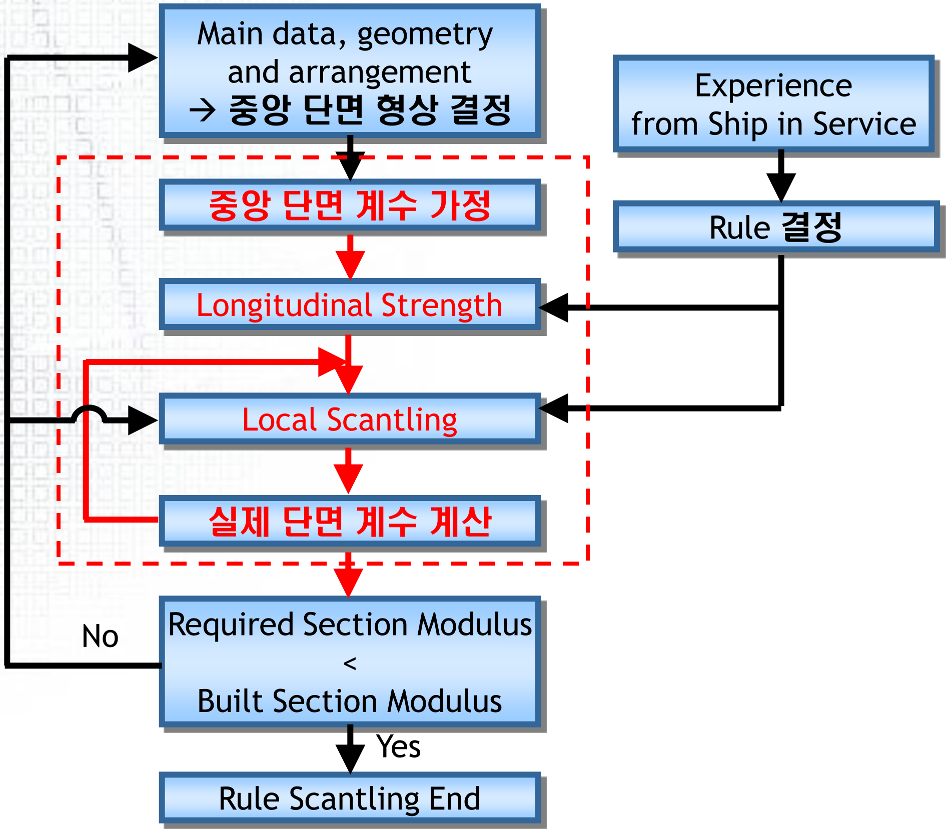


DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6 c800

창의적 선박설계 12장 선체 구조설계 p. 26

5.1 Stress factor

✓부재 치수 결정(Local scantling)시 Iteration 이 필요한 이유


Main data, geometry and arrangement
→ 중앙 단면 형상 결정

Experience from Ship in Service

중앙 단면 계수 가정

Rule 결정

Longitudinal Strength

Local Scantling

실제 단면 계수 계산

Required Section Modulus < Built Section Modulus

No

Yes

Rule Scantling End

ex) Inner bottom Longitudinals

$$Z = \frac{83 l^2 s p w_k}{\sigma} \ (cm^3)$$

$$\sigma = 225 f_1 - 100 f_{2b} - 0.7 \sigma_{db}$$

the largest design SWBM (kN·m)

rule VWBM in (kN·m)

$$f_{2b,2d} = \frac{5.7 (M_S + M_W)}{Z_{b,d}}$$

midship section modulus (cm^3) at bottom or deck as built

갑판(deck)과 선저(bottom)에서의 선체 단면 계수가 필요한데, 부재 치수를 결정한 후에야 알 수 있음. ← 가정!

Iteration을 통해, 가정한 단면계수 값과 계산된 단면계수 값이 일치하도록 전체 중앙 단면 계수를 계산

Local Strength & Allowable Stresses

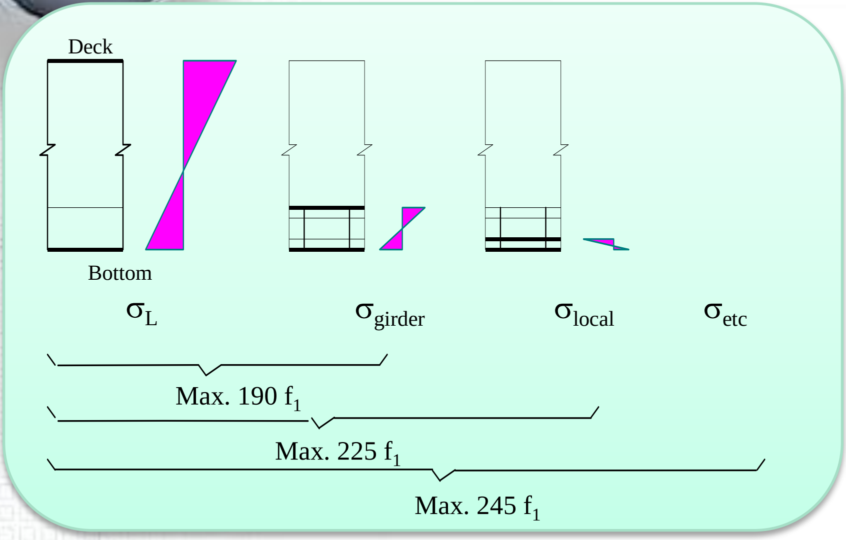


그림 설명

$\sigma_L, \sigma_{girder}, \sigma_{local}$ 을 합한 총 Stress가 225f_1을 넘지 말아야 한다.*

·실제 현업에서는 구조해석을 통해 σ_{girder} (Double Bottom Stress라고도 함)를 구하는데, 여기에 수 계산을 통하여 얻은 다른 두 개의 Stress를 합하여 기준 값을 만족하는지 체크한다. 출처 : 조선소 구조설계 전문가

Load -> Stress 연관성 (개념도)

1) 선박전체의 Hogging or Sagging

↓

σ_L

2) Cargo Load

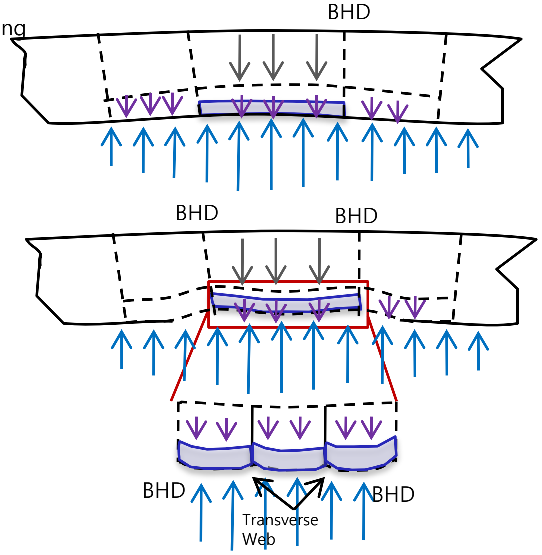
↓

σ_{girder}

3) Ballasting Load

↓

σ_{local}



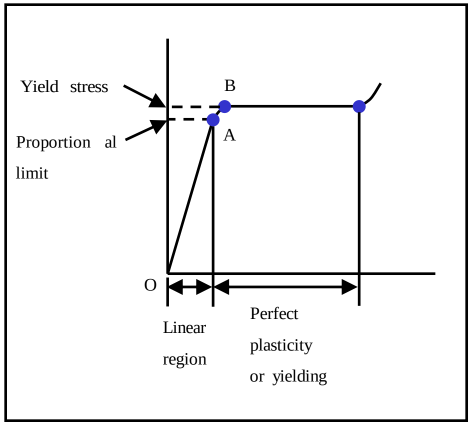
그림에서 계수 값 설명 (Yield Stress 값 235와 차이?)

245 f_1 : Maximum Yield Stress

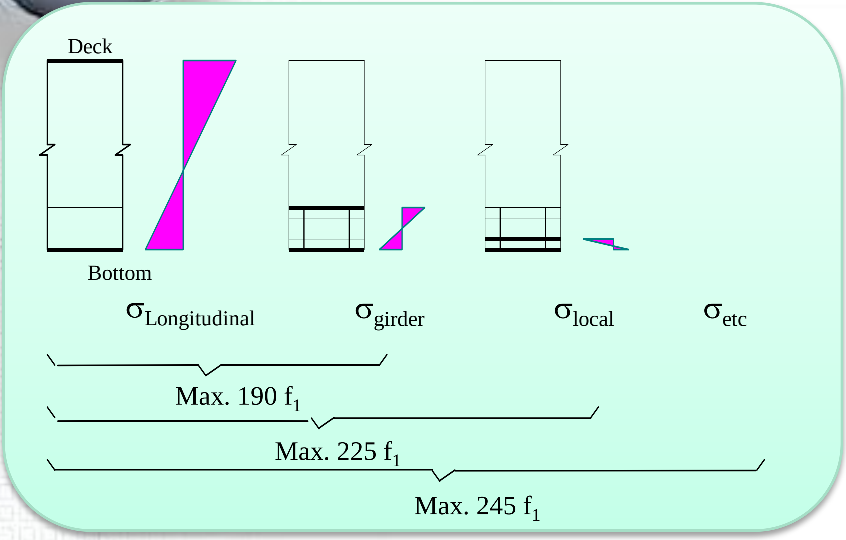
235f_1: Proportional limit

225 f_1 : Plate의 영향 고려하여 Maximum Yield Stress 보다 작은 값 사용

결국 etc의 영향을 제외하면 225 f_1 를 Yield Stress처럼 사용한다는 뜻



Local Strength & Allowable Stresses



그림의 또 다른 의미 해석

종강도에 관련된 부재의 Local Allowable Stress는 Rule에서 요구하는 대로 구해야 함.

Double Bottom Longitudinal 식의 경우,

$$Z = \frac{83 l^2 s p w_k}{\sigma} \quad (cm^3)$$

p 는 Local Pressure이므로

종강도에 해당하는 $100 f_{2b}$ 와 Double Bottom Girder에 해당하는 $0.7\sigma_{db}$ 을 제외한 값을 사용한다

(이 그림과 계수들이 일치하지는 않음)

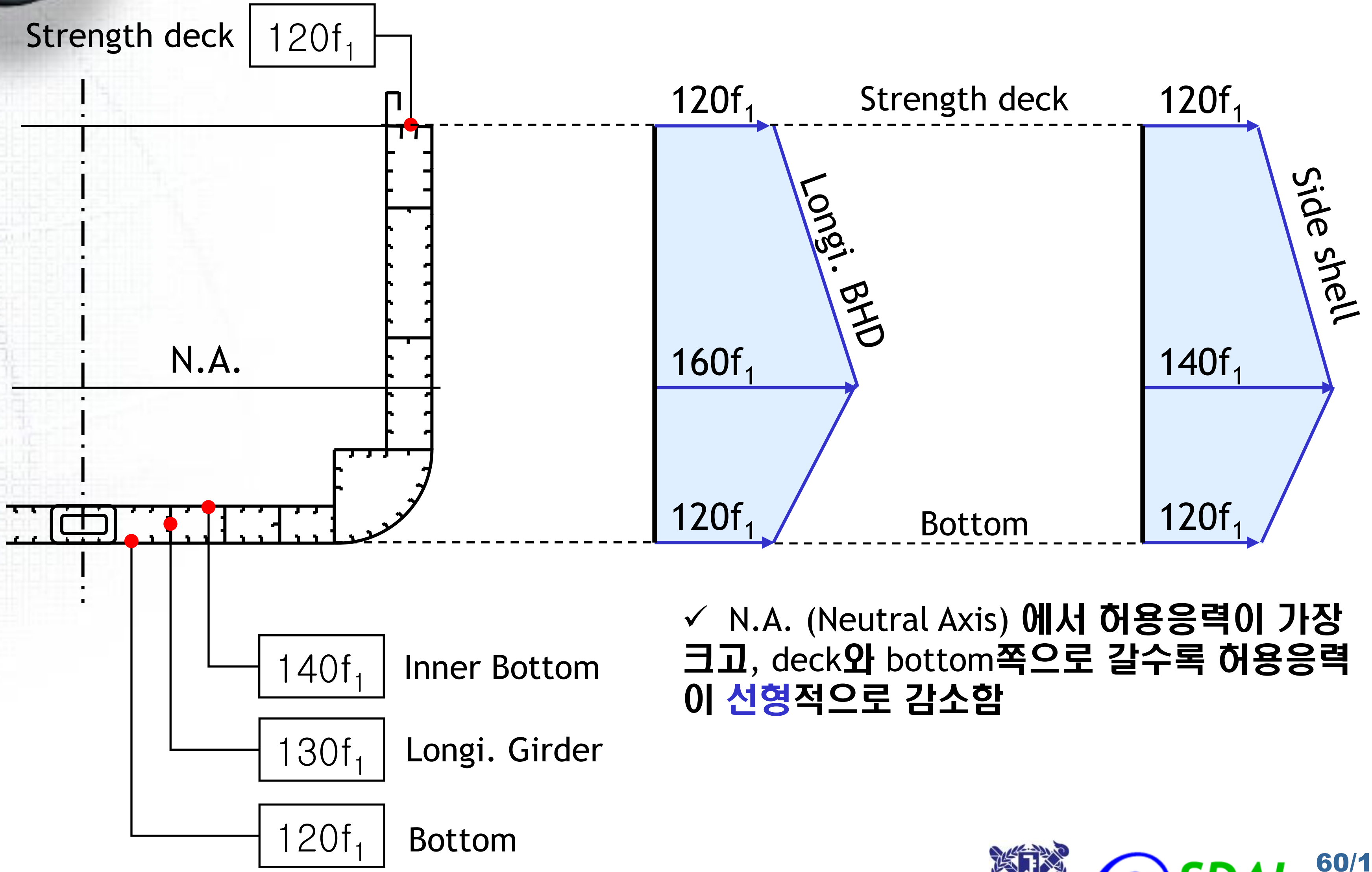
$$\sigma = 225 f_1 - 100 f_{2b} - 0.7\sigma_{db}$$

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6 c800

5.2 Allowable Stresses
– Longitudinally stiffened Plates

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6,7,8,9

DSME, Dnv Rule 해설서, 1991.8

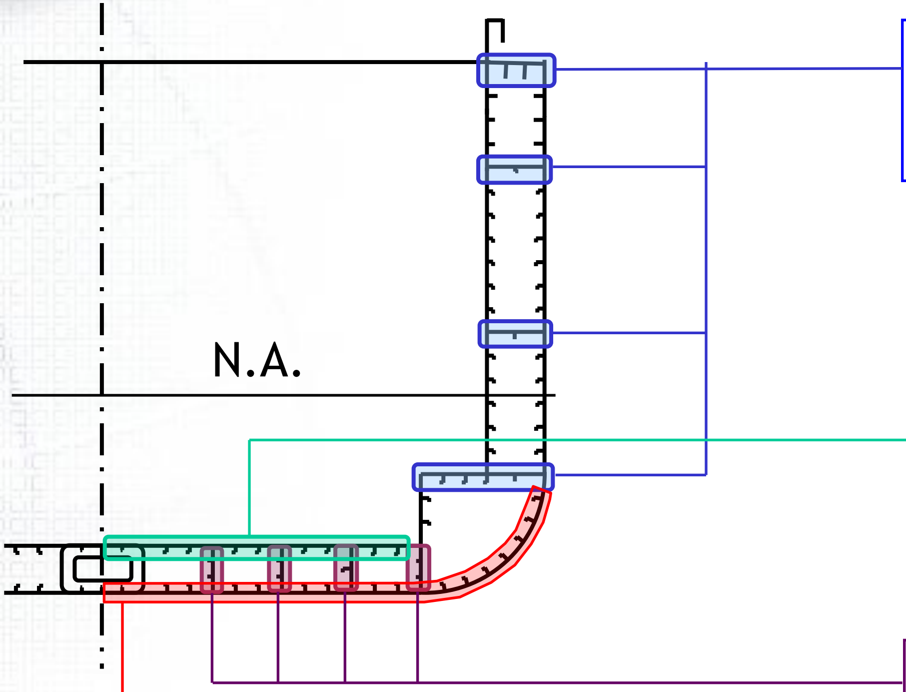


- ✓ N.A. (Neutral Axis) 에서 허용응력이 가장 크고, deck와 bottom쪽으로 갈수록 허용응력이 선형적으로 감소함

5.2 Allowable Stresses
– Longitudinal Stiffeners (1)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6,7,8,9

DSME, Dnv Rule 해설서, 1991.8



Decks (Pt3 ch1 Sec.8 C301)

$$225 f_1 - \underbrace{130 f_{2d} \frac{z_n - z_a}{z_n}}_{\sigma_L}$$

Inner Bottom (Pt3 ch1 Sec.6 C801)

$$225 f_1 - \underbrace{100 f_{2b}}_{\sigma_L} - 0.7\sigma_{db}$$

Double Bottom Girder (Pt3 ch1 Sec.6 C901)

$$225 f_1 - \underbrace{110 f_{2b}}_{\sigma_L}, \ \max \ 160 f_1$$

Double Bottom (Pt3 ch1 Sec.6 C701)

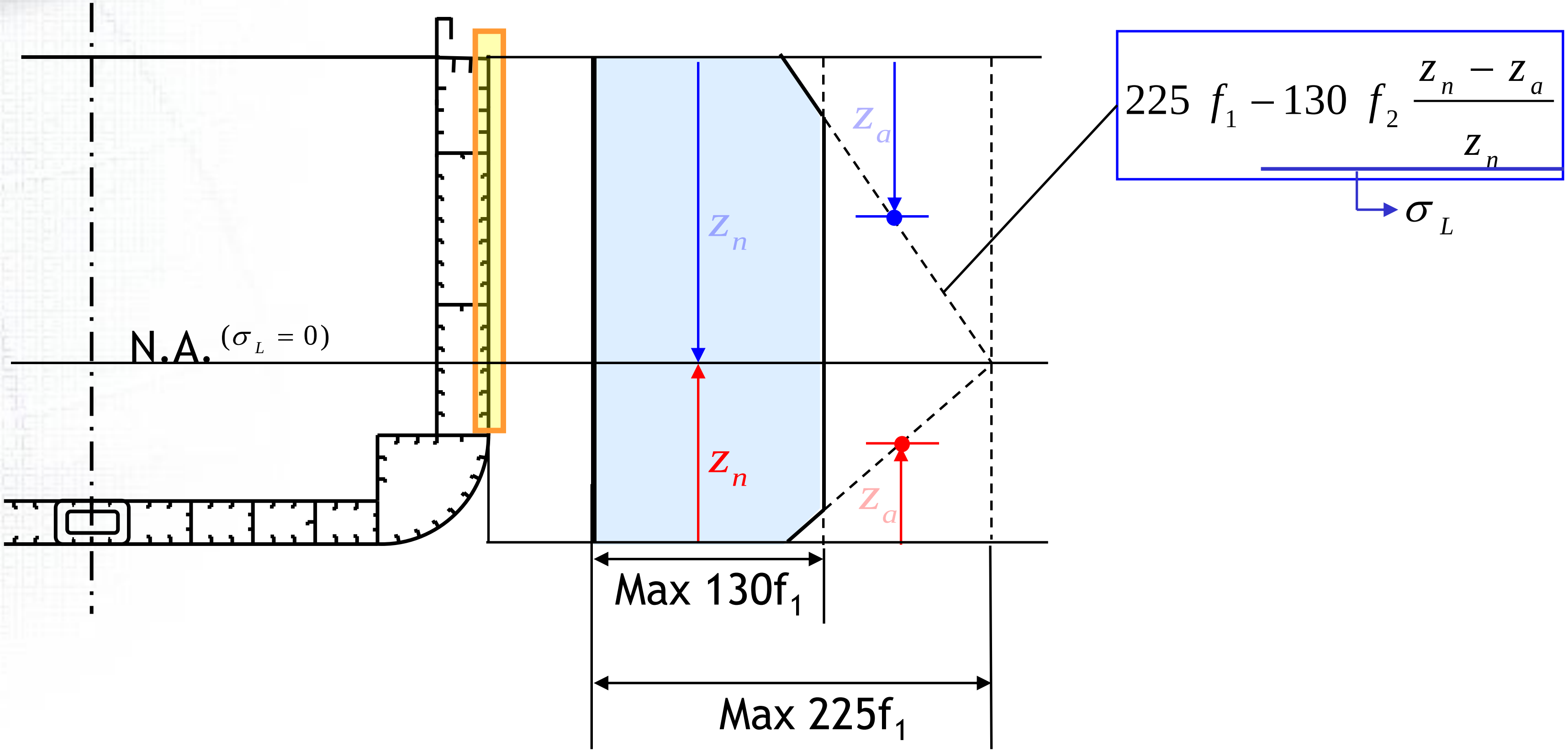
$$225 f_1 - \underbrace{130 f_{2b}}_{\sigma_L} - 0.7\sigma_{db}$$

5.2 Allowable Stresses
– Longitudinal Stiffeners (1)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6,7,8,9

DSME, Dnv Rule 해설서, 1991.8

Side shell (Pt3 ch1 Sec.7 C301)



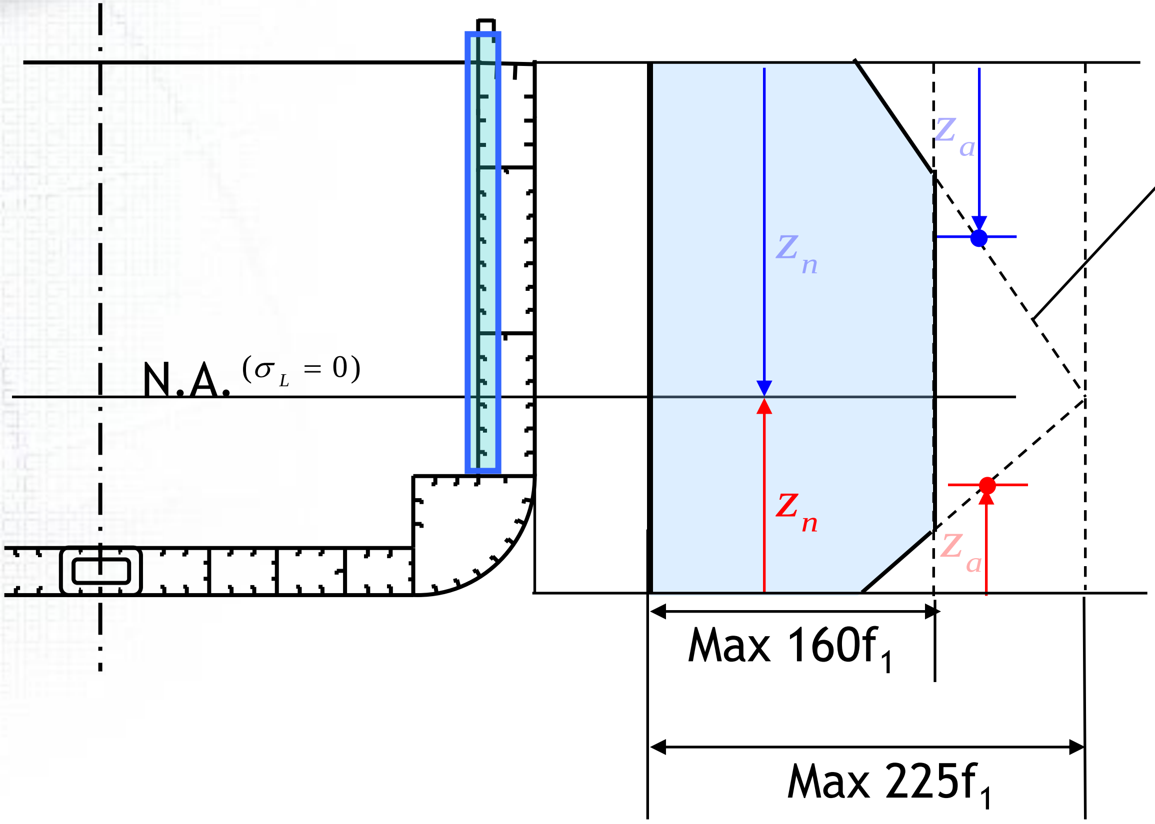
$$\underbrace{225\,f_1 - 130\,f_2\,\frac{z_n - z_a}{z_n}}_{\sigma_L}$$

5.2 Allowable Stresses
– Longitudinal Stiffeners (1)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6,7,8,9

DSME, Dnv Rule 해설서, 1991.8

Longitudinal Bulkhead (Pt3 ch1 Sec.9 C201)



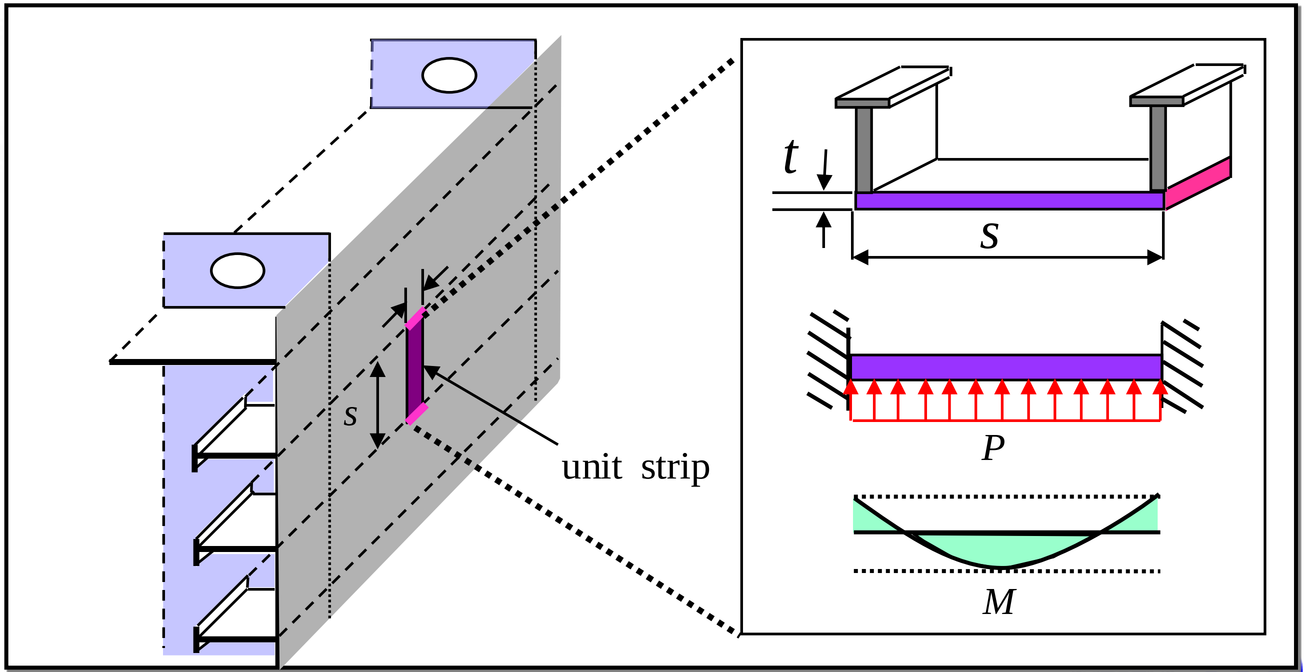
$$\underline{225\ f_1 - 130\ f_2 \frac{z_n - z_a}{z_n}} \rightarrow \sigma_L$$

5.3 Plate의 required thickness 식 유도

가정1. Longitudinals or Girder**로 양단이 지지된** Unit Strip Plate**를 잘라내어** Span ’s’ , Thickness ‘t’**인** Beam**으로 가정**

가정2. Beam**이 받는 하중은 균일 분포 하중으로 가정**
(Load point**에서의** Pressure**를 분포하중으로 가정**)

가정3. Plate**는** Plastic **범위까지 확대하여 고려함**
(Elastic**범위에 비해 큰** allowable stress**값 사용**)



5.3 Plate의 required thickness 식 유도

James M. Gere, Mechanics of Materials 6th Edition, Thomson, p. 440~449
이규열,"창의적 선박설계" 12장 선체 구조설계 p.17
DSME, "선박구조설계" 7 Local Scantling 7-3

Plastic moment(M_p)

$$M_p = \frac{ps^2}{16}$$

Plastic section modulus(Z_p)

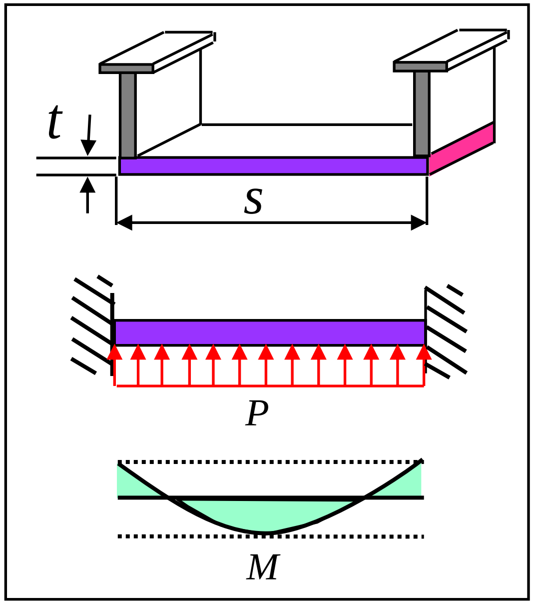
$$Z_p = \frac{1 \cdot t^2}{4} = \frac{t^2}{4}$$

Cf) Eastic moment(M)

$$M = \frac{ps^2}{12}$$

Elastic section modulus(Z)

$$Z = \frac{1 \cdot t^2}{6} = \frac{t^2}{6}$$



$$\sigma = \frac{M_p}{Z_p} = \frac{ps^2}{16} \cdot \frac{4}{t^2} = \frac{ps^2}{4t^2} \Rightarrow t^2 = \frac{ps^2}{4\sqrt{\sigma}} \Rightarrow t = \frac{s\sqrt{p}}{2\sqrt{\sigma}}$$

Considering different units $t(mm),\ s(m),\ p(kN/m^2),\ \sigma(N/mm^2)$

$$\boxed{t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)}$$

k_a = correction factor for aspect ratio of plate field

[증명] 탄성영역에서 양단고정보의 처짐, 전단력, 모멘트

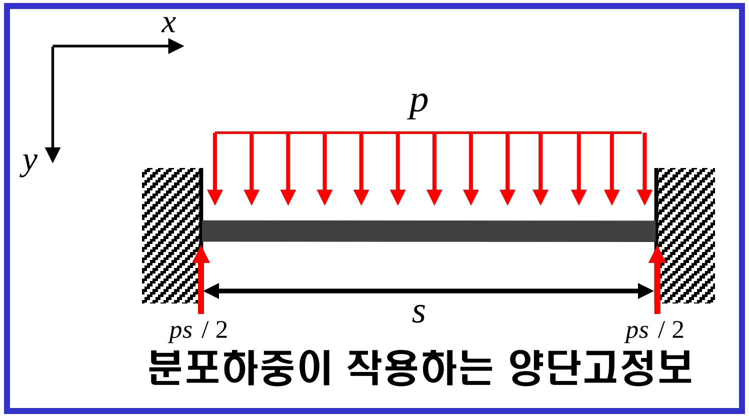
$$EI\cdot y = -\frac{1}{24}p\cdot x^4+\frac{1}{6}c_1x^3+\frac{1}{2}c_2x^2+c_3x+c_4 \qquad (1)$$

$$EI\frac{dy}{dx} = -\frac{1}{6}p\cdot x^3+\frac{1}{2}c_1x^2+c_2x+c_3 \qquad (2)$$

$$EI\frac{d^2y}{dx^2} = -M(x) = -\frac{1}{2}p\cdot x^2+c_1x+c_2 \qquad (3)$$

$$EI\frac{d^3y}{dx^3} = -V(x) = -p\cdot x+c_1 \qquad (4)$$

$$EI\frac{d^4y}{dx^4} = f(x) = p \qquad (5)$$



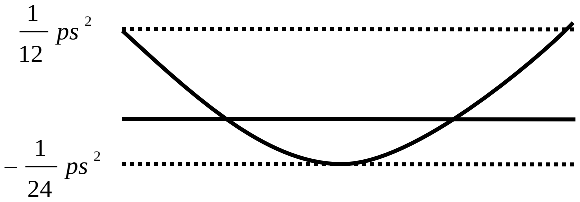
분포하중이 작용하는 양단고정보

$$\therefore M(x)=\frac{1}{2}p\cdot x^2-\frac{1}{2}ps\cdot x+\frac{1}{12}ps^2$$

$$M(0)=\frac{1}{12}ps^2$$

$$M\left(\frac{s}{2}\right)=\frac{1}{2}p\cdot\left(\frac{s}{2}\right)^2-\frac{1}{2}ps\cdot\frac{s}{2}+\frac{1}{12}ps^2=\left(\frac{1}{8}-\frac{1}{4}+\frac{1}{12}\right)ps^2=-\frac{1}{24}ps^2$$

$$M(s)=\frac{1}{2}p\cdot s^2-\frac{1}{2}ps\cdot s+\frac{1}{12}ps^2=\frac{1}{12}ps^2$$



모멘트 분포도

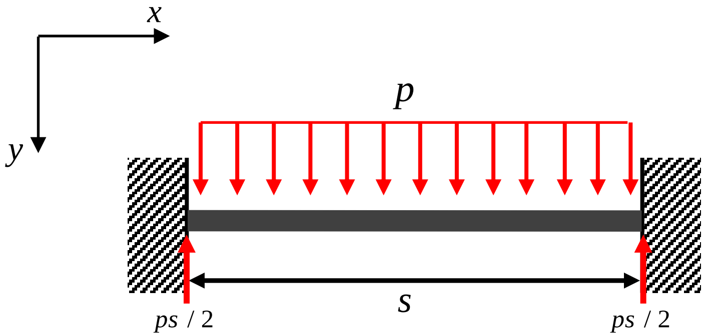
5.3 Plate의 required thickness 식 유도 – Plastic Moment, M_p (3)

분포하중이 커질 때 보는 다음과 같이 상태가 바뀐다.

1) 보의 전체가 탄성 영역(p_0)

2) 보의 양 끝단에 소성힌지 발생($p_0+\Delta p$)

3) 보의 중앙부에 소성힌지 발생
(붕괴점, point of collapse)($p_0+\Delta p'$)



분포하중이 작용하는 양단고정보

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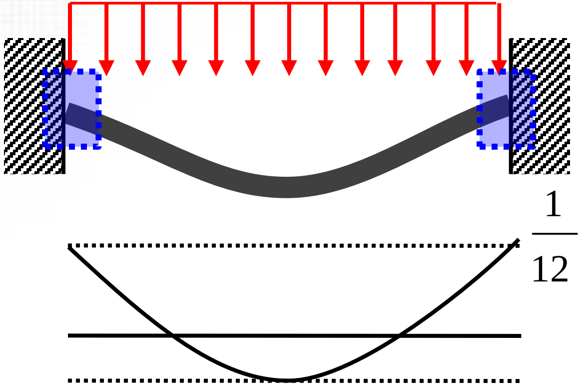
2) 보의 양 끝단에 소성힌지 발생($p_0+\Delta p$)

$$p = p_0 + \Delta p$$



모멘트 분포도

▨ : 소성힌지가 되어,
소성 모멘트 M_P가 작용하는 부분

$$\frac{1}{12} ps^2 = \frac{1}{12}(p_0 + \Delta p)s^2 = M_p$$

$$-\frac{1}{24} ps^2 = -\frac{1}{24}(p_0 + \Delta p)s^2$$

P가 더 커져도, 양 끝단의 모멘트는 Mp로 유지됨.

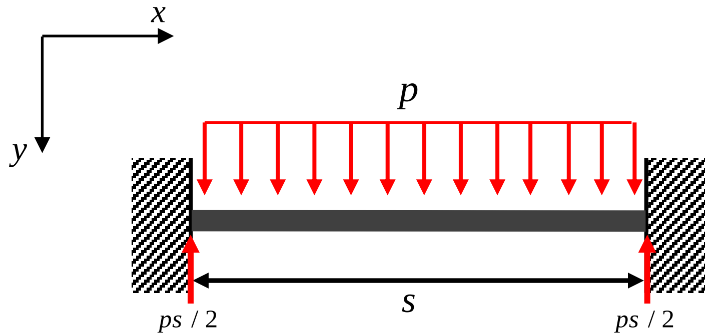
5.3 Plate의 required thickness 식 유도 – Plastic Moment, M_p (4)

분포하중이 커질 때 보는 다음과 같이 상태가 바뀐다.

1) 보의 전체가 탄성 영역(p_0)

2) 보의 양 끝단에 소성힌지 발생($p_0+\Delta p$)

3) 보의 중앙부에 소성힌지 발생 (붕괴점, point of collapse)($p_0+\Delta p'$)



분포하중이 작용하는 양단고정보

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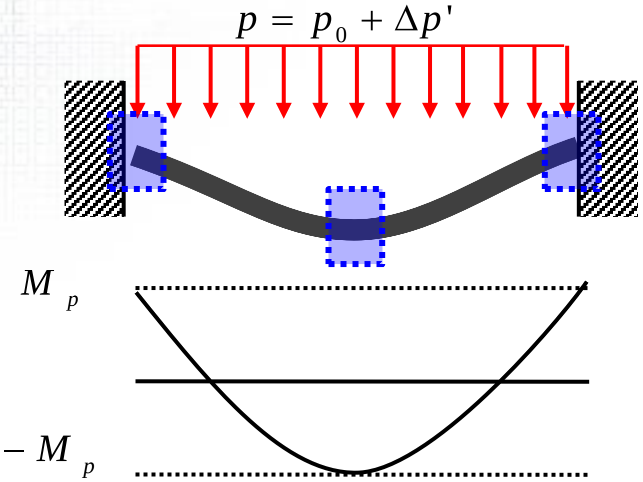
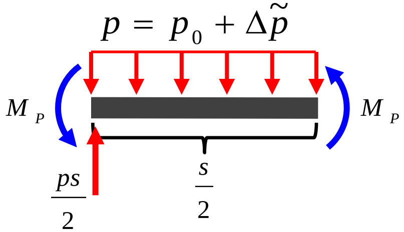
3) 보의 중앙부에 소성힌지 발생(붕괴점, point of collapse)($p_0+\Delta p'$)



x=0부터 s/2까지 자유물체도를 도시하면,



왼쪽 끝단에서의 모멘트 평형으로부터,

$$M_P - \int_0^{s/2} p\cdot x\,dx + M_P = I\ddot{\theta} = 0$$

$$2M_P = \int_0^{s/2} p\cdot x\,dx = \frac{1}{2}px^2\Big|_{x=0}^{x=s/2} = \frac{ps^2}{8}$$

$$\boxed{\therefore M_P = \frac{pl^2}{16}}$$

5.3 Plate의 required thickness 식 유도
– Plastic Section modulus, Z_p

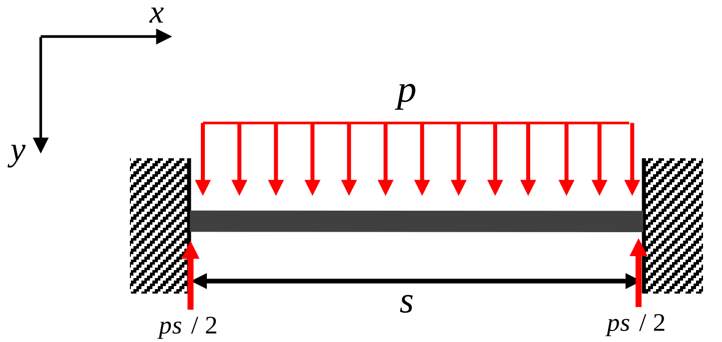
$$M_p = -\int_A \sigma y dA = -\int_{A_1} (-\sigma_y) y dA - \int_{A_2} \sigma_y y dA$$

$$= \sigma_y \int_{A_1} y dA + \sigma_y \int_{A_2} y dA$$

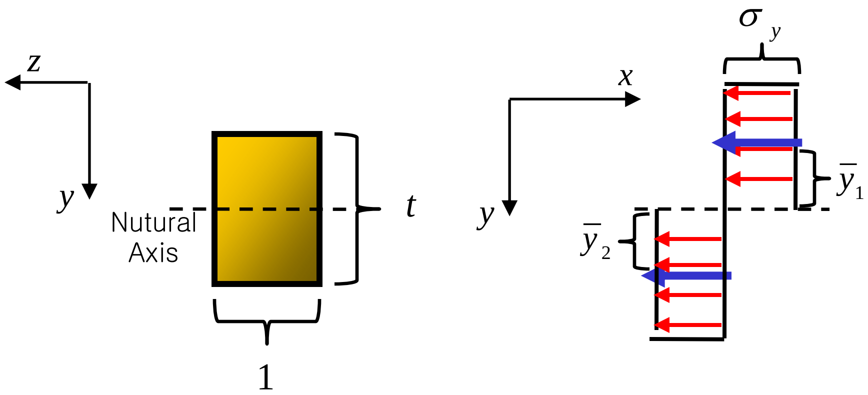
$$= \sigma_y \underbrace{\frac{A(\bar{y}_1 + \bar{y}_2)}{2}}_{Z_p}$$

$$Z_p = \frac{A(\bar{y}_1 + \bar{y}_2)}{2} = \frac{t(t/4 + t/4)}{2} = \frac{t^2}{4}$$

$$\boxed{Z_p = \frac{t^2}{4}}$$



분포하중이 작용하는 양단고정보

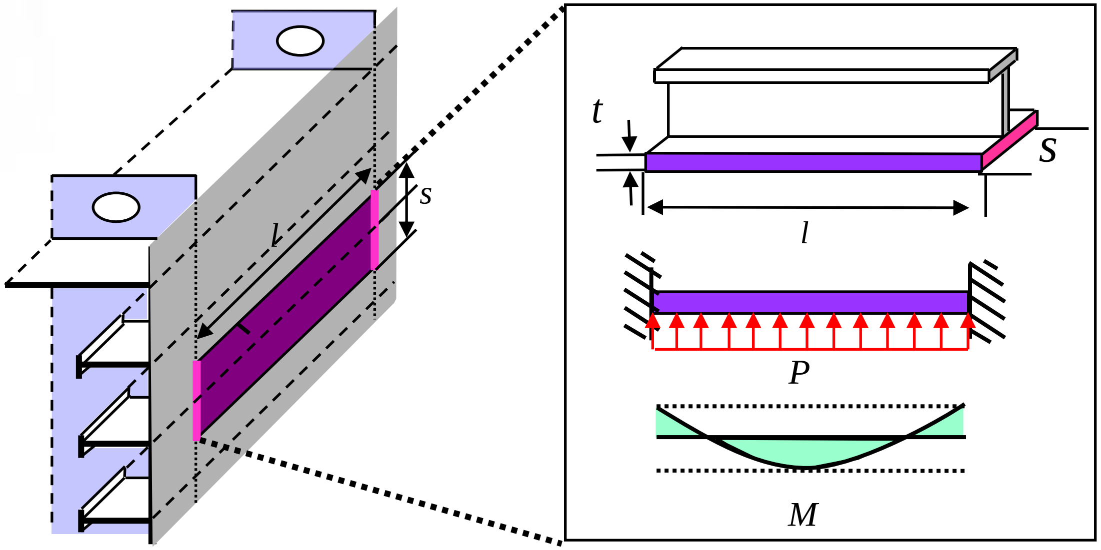


5.4 Stiffener의 부재 치수 결정식 유도

가정1. Stiffener가 설치된 하부의 plate까지 잘라내어
Span 'l'인 Beam으로 가정

가정2. Beam이 받는 하중은 균일 분포 하중으로 가정
(Load point에서의 Pressure를 분포하중으로 가정)

가정3. Stiffener는 Elastic 범위까지 고려함
(하중이 제거되었을 시, 원래 위치로 돌아옴.)



Stiffener의 부재 치수 결정식 유도

James M. Gere, Mechanics of Materials 6th Edition, Thomson, p. 440~449
이규열,"창의적 선박설계" 12장 선체 구조설계 p.17
DSME, "선박구조설계" 7 Local Scantling 7-3

Eastic moment(M)

$$M = \frac{ps \cdot l^2}{12}$$

Rearranging formula for thickness

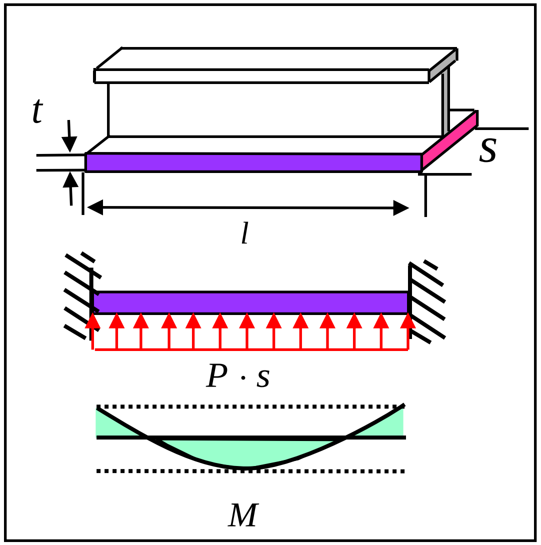
$$\sigma = \frac{M}{Z} \Rightarrow \sigma = \frac{p \cdot s \cdot l^2}{12} \cdot \frac{1}{Z}$$

$$\Rightarrow Z = \frac{p \cdot s \cdot l^2}{12\sigma}$$

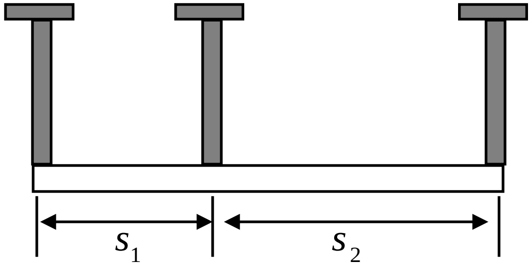
Considering different units

$$p(kN/m^2),\ s(m),\ l(m),\ \sigma(N/mm^2)$$

$$\boxed{Z = \frac{83 l^2 \cdot s \cdot p \cdot w_k}{12\sigma} \quad (cm^3)}$$



Stiffener spacing이 다른 경우 -> 평균값 사용.



$$s = \frac{s_1 + s_2}{2}$$

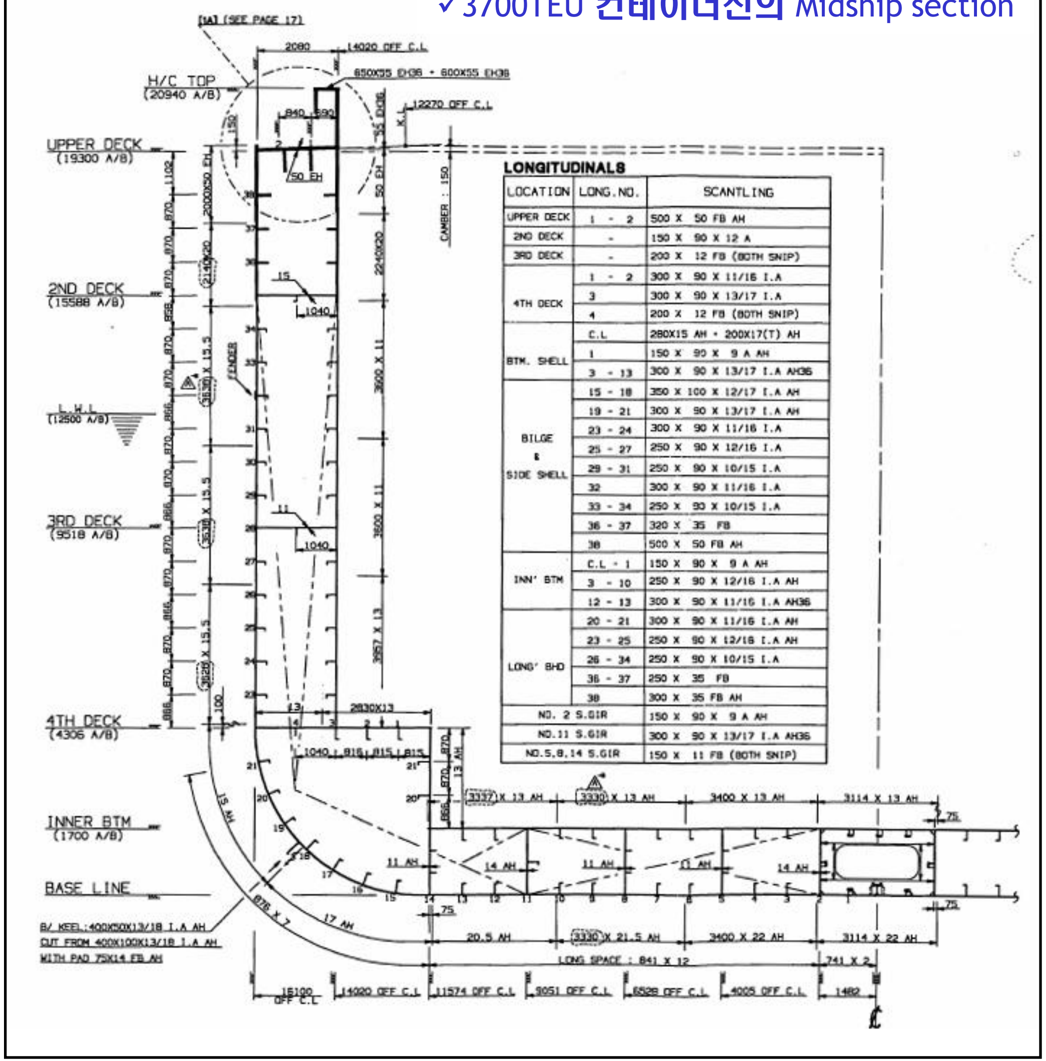
Midship Scantling 예제

✓ 설계선의 주요 제원은 2006년 선박설계 콘테스트 4100TEU급 컨테이너선의 주요 제원 사용

✓ :중앙단면 부재 배치, Longi spacing, Seam line 은 2006년 선박설계 콘테스트 3700TEU 컨테이너선(기준선)의 Midship section과 동일하게 사용

설계선의 주요 제원	
LOA(m)	259.64
LBP(m)	247.64
L_scant(m)	245.11318
B(m)	32.2
D(m)	19.3
Td(m)	11
Ts(m)	12.6
Vs(knt)	24.5
C_b	0.6563

✓3700TEU 컨테이너선의 Midship section



LONGITUDINALS

LOCATION	LONG.NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

Midship Scantling 예제
- 목차

Outer bottom & Bilge plate

Outer bottom Longitudinals

Inner bottom plate

Inner bottom Longitudinals

Side shell plate

Side shell Longitudinals

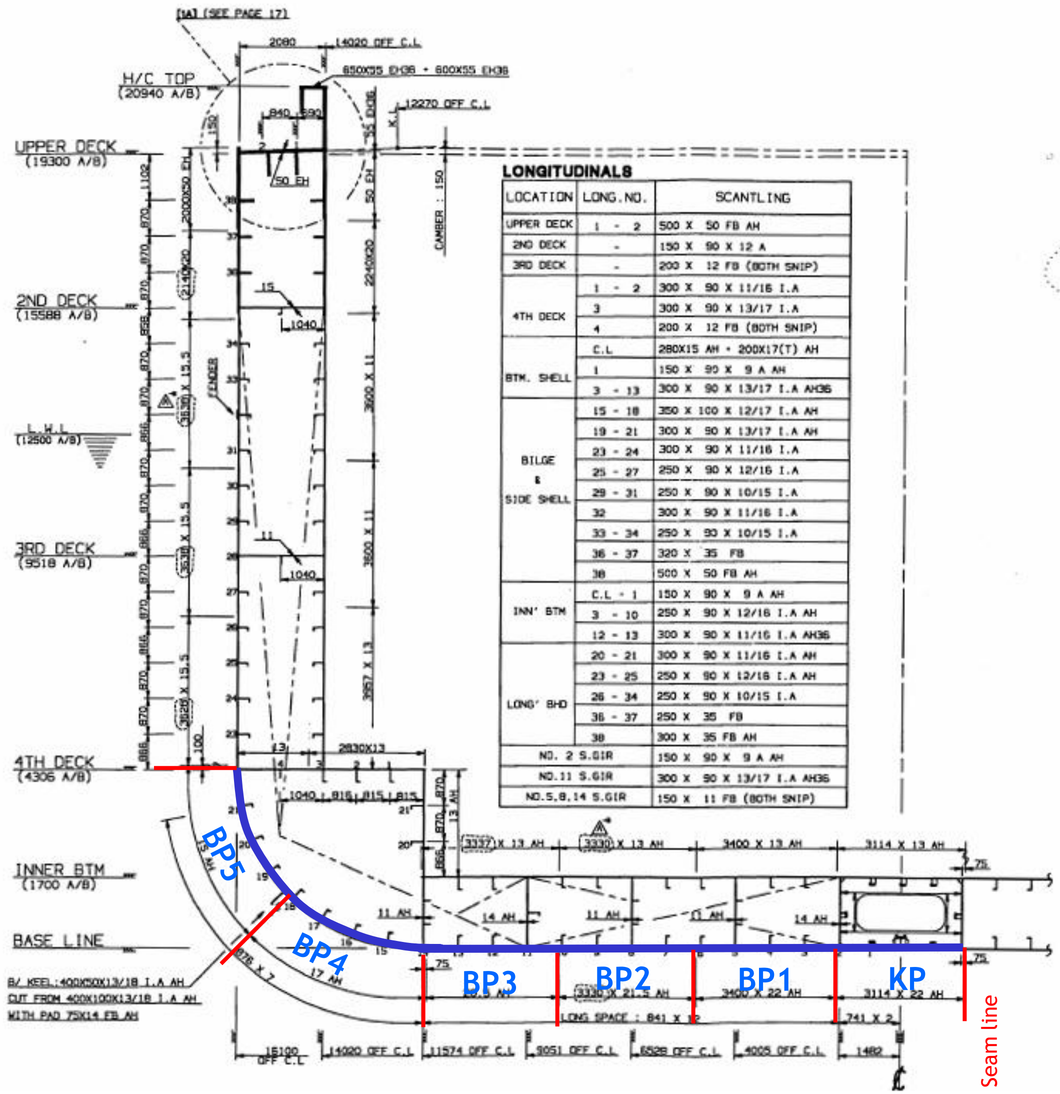
deck plate

deck Longitudinals

Longitudinal bulkhead plate

Longitudinal bulkhead Longitudinals

Outer Bottom & Bilge plate

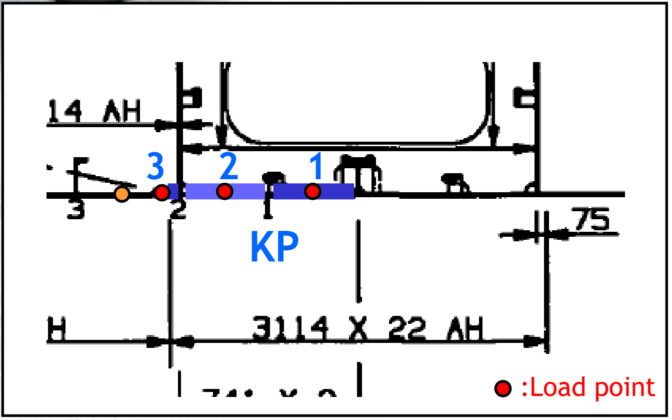


LONGITUDINALS

LOCATION	LONG. NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

KP : Keel plate, BPn: n-th Outer Bottom plate

Keel Plate (KP) (1)



- ✓ Keel plate는 3개의 Unit strip으로 구성

- ✓ Unit strip의 Load point:
  1,2, : Midpoint
  3: Midpoint와 가장 가까운 지점

- ✓ 3개의 Unit strip에 대해 각각 Plate 두께를 계산하고, 가장 큰 값을 Keel plate 의 두께로 사용한다.

- ✓KP의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

✓ Design Load

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6 Table B1

Structure	Load Type	$p\ (kN/m^2)$
Outer bottom	Sea pressure	$p_1 = 10T + p_{dp}$

: Keel plate의 경우 Sea pressure만이 Design Load로 작용함

①

Keel Plate의 Unit strip 1에 대한 Design Load, P

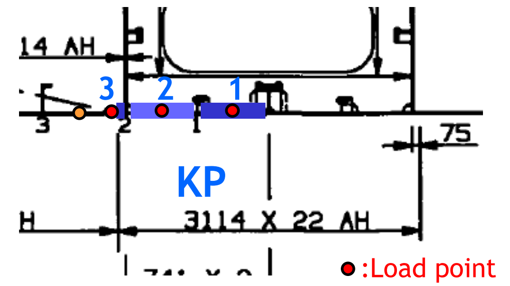
p1	pdp	pl	ks		2	0.2L~0.7L form A.P. ks=2
			Cw		10.343	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			kf	f	6.7	f=waterline에서 선박 측면 상단의 수직거리 (최대 0.8*Cw)
					6.7	
					28.33795639	$p_l = (k_s C_W + k_f)(0.8 + 0.15V/\sqrt{L})$
		y			8.05	중심선으로부터 하중지점까지의 수평거리, 최소 B/4(m)=8.05
		z			0	선저(Baseline)으로 부터 하중지점까지의 수직거리, 최대 T(m)
					23.355	$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2(T-z)\ (kN/m^2)$
					149.355	$p_1 = 10T + p_{dp}$

Unit strip2, Unit strip3 도 동일한 Flow로 구함

Unit strip2 : p1 = 149.355(kN/m^2)

Unit strip3 : p1 = 149.355(kN/m^2)

Keel Plate (KP) (2)



②

✓ Required Thickness

$$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$$

✓ Allowable stress for Bottom Plate

$$\sigma = 120 \ f_1$$

Keel Plate의 Unit strip 1에 대한 Required Thickness

t_1	p	149.355	Maximum Design Load
	ka	1.0	$k_a = (1.1 - 0.25 s/l)^2$,s/l= 0.4 이하 ka는 최대 1.0
	s	0.741	stiffener spacing in m
	f1	1.28	Material factor = 1.28 for NV-32
	σ	153.6	$\sigma = 120 \ f_1$
	tk	1.5	Corrosion addition
		13.04	$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$

Unit strip2, Unit strip3 도 동일한 Flow로 구함

Unit strip2 : t_1 = 13.04 (mm)

Unit strip3 : t_1 = 14.603(mm)

③

✓ Minimum Thickness

$$t_2 = 7.0 + \frac{0.05 L_1}{\sqrt{f_1}} + t_k \ (mm)$$

t_2	L1	245.11	Min (L, 300) (m)
	f1	1.28	Material factor = 1.28 for NV-32
	tk	1.5	Corrosion addition
		19.33	$t_2 = 7.0 + \frac{0.05 L_1}{\sqrt{f_1}} + t_k \ (mm)$

Unit strip 1,2,3에 모두 적용됨

cf) Minimum Breadth

$$b = 800 + 5L \ (mm)$$

b	Rule	2025.566	
	Arr.	3154	배치 상의 Keel plate 폭

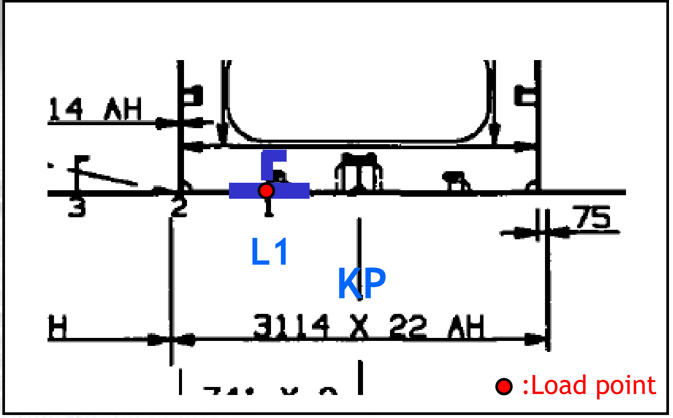
→ Rule을 만족함

④	$t = \max(t_1, t_2) \ [mm]$
Unit strip 1	19.33
Unit strip 2	19.33
Unit Strip 3	19.33

⑤ Unit strip의 두께 중 가장 큰 값을 Keel plate의 두께로 정함

$$t = 19.33 \approx 19.5 \ [mm]$$

Longitudinals at Keel Plate (L1)(1)



✓Load point: Midpoint

✓L_1의 Material은 **기준선과 동일한** NV-32를 **사용한다**.(f_1=1.28)

✓ Design Load

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6 Table B1

Structure	**Load Type**	$p\ (kN/m^2)$
Outer bottom	Sea pressure	$p_1 = 10T + p_{dp}$

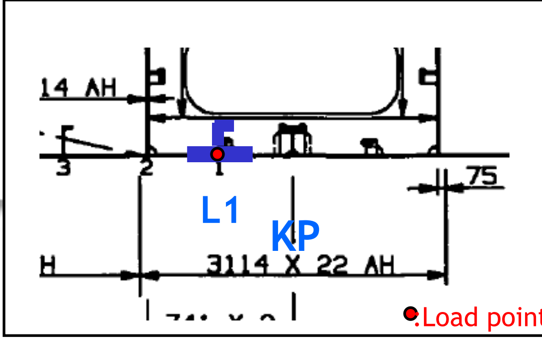
: Keel plate**의 경우** Sea pressure**만이** Design Load**로 작용함**

①

L1 **에 대한** Design Load P

p_1	pdp	pl	ks		2	0.2L~0.7L form A.P. ks=2
			Cw		10.343	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			kf	f	6.7	f=waterline에서 선박 측면 상단의 수직거리 (최대 0.8*Cw)
					6.7	
					28.33795639	$p_l = (k_s C_W + k_f)(0.8 + 0.15V/\sqrt{L})$
		y			8.05	중심선으로부터 하중지점까지의 수평거리, 최소 B/4(m)=8.05
		z			0	선저(Baseline)으로 부터 하중지점까지의 수직거리, 최대 T(m)
					23.355	$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2(T-z)\ (kN/m^2)$
					149.355	$p_1 = 10T + p_{dp}$

Longitudinals at Keel Plate (L1)(2)



②

✓ Required Section Modulus

$$Z = \frac{83 l^2 s p w_k}{\sigma} \quad (cm^3)$$

✓ Allowable stress

$$\sigma = 225 f_1 - 130 f_{2b} - 0.7\sigma_{db}$$

Z	le		2.96	Web frame 간격(3.16m) - 0.2 m(braket)
	s		0.741	stiffener spacing in m
	p		149.355	Maximum Design Load
	wk	tkw	1.0	Corrosion addition
		tkf	1.0	Corrosion addition
			1.15	$1 + 0.05(t_{kw} + t_{kf})$ for flanged section
	σ	f1	1.28	Material factor = 1.28 for NV-32
		f2b	1.04	3700TEU의 section Modulus로 구한 값임
		σdb	25.6	$20f_1$ in general
			134.88	$\sigma = 225 f_1 - 130 f_{2b} - 0.7\sigma_{db}$
	744.91			$Z = \frac{83 l^2 s p w_k}{\sigma} \ (cm^3)$

③

✓ Minimum Thickness of Web and Flange

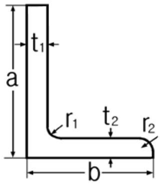
$$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm), \quad t_2 = \frac{h}{g} + t_k \ (mm)$$

t1	k	4.9022	0.02 L_1
	f1	1.28	Material factor = 1.28 for NV-32
	tk	1.0	Corrosion addition
	10.83		$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm)$
t2	h	400	Profile height in m
	g	70	70 for flanged profile webs
	tk	1.0	Corrosion addition
	7.21		$t_2 = \frac{h}{g} + t_k \ (mm)$

$$t = \max(t_1, t_2) = t_1$$

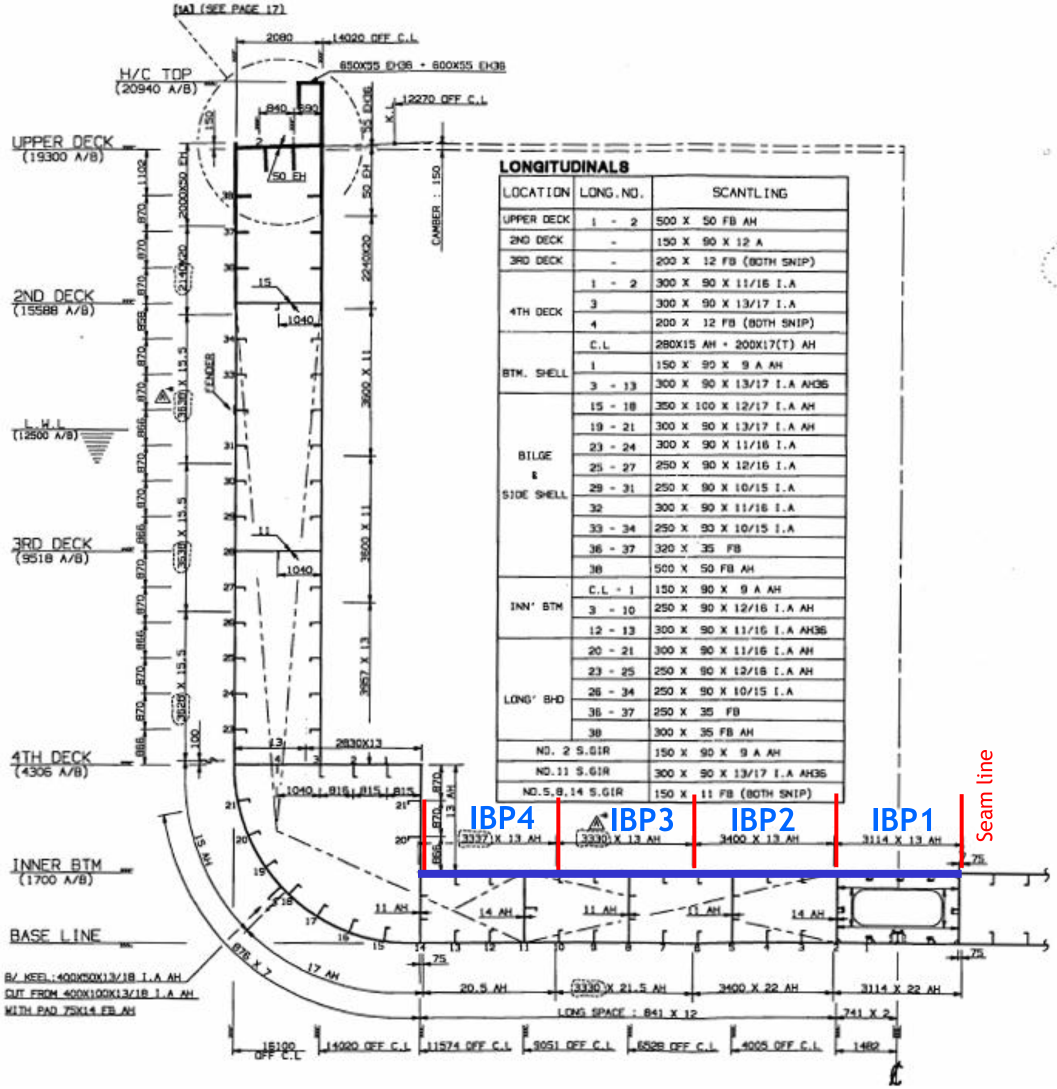
④ Required section modulus를 만족하는 Longi.를 Table 에서 찾아 Longi.의 치수 선정

"조선설계편람", 제 4판 (일본어), 일본관서조선협회, 1996
이규열, "창의적 선박설계", 선체 구조설계, p22~25



a	b	t_1	t_2	r_1	r_2	A	I	Z
mm						cm^2	cm^4	cm^3
400	100	11.5	16	24	12	61.09	34,200	1,120

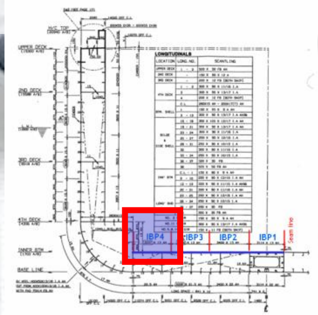
Inner Bottom plate

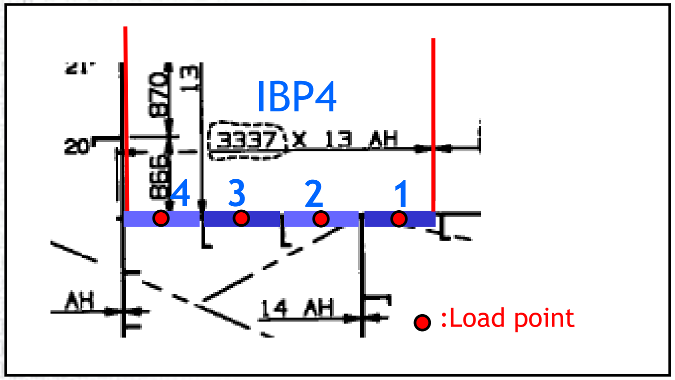


LONGITUDINALS

LOCATION	LONG.NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

Inner Bottom Plate (IBP4) (1)





- ✓ IBP4는 4개의 Unit strip으로 구성
- ✓ Unit strip의 Load point:
  1,2,3,4 : Midpoint

✓ 4개의 Unit strip에 대해 각각 Plate 두께를 계산하고, 가장 큰 값을 IBP4 의 두께로 사용한다.

✓IBP의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

✓ Design Load

Structure	Load Type	
Inner bottom	Dry cargo in cargo holds	$p_4 = \rho(g_0 + 0.5a_V)H_C$
Inner Bottom, floors and girders	Pressure on tank boundary in double bottom	$p_{13} = 0.67(10\,h_p + \Delta p_{dyn})$ $p_{14} = 10\,h_s + p_0$
	Minimum pressure	$p_{15} = 10\,T$

① LBP4의 Unit strip 1에 대한 Design Load, P

✓ Dry cargo in cargo holds

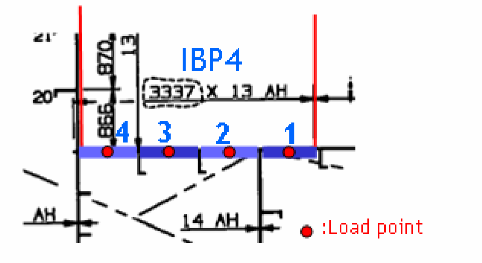
컨테이너의 경우 Plate에 네 꼭지점에 집중하중으로 작용함 (분포하중x)
컨테이너는 가벼운 화물에 속하므로, Local scantling시
고려 하지 않아도 무방함 (조선소 구조 전문가 의견)

✓ Tank의 overflow 고려

p_{13}	Δp_{dyn}	25	25 in general
	hp	14.648	Air pipe에서 Load point까지의 거리 (air pipe의 위치는 second deck에서 0.76m 높은 곳을 잡음)
		114.89	$P_4 = 0.67(\rho g_0 h_p + \Delta P_{dyn})$

Unit strip2,3,4,5도 위 값과 동일

Inner Bottom Plate (IBP4) (2)



① LBP4**의** Unit strip 1**에 대한** Design Load, P

✓ Tank**의** Static pressure**고려**

p14	hs	0	Tank top에서 Unit strip 1까지의 거리는 0
	p0	15	15 in ballast hold of dry cargo vessels
		15	$p_{14} = 10\,h_s + p_0$

Unit strip2,3,4 **도 동일한** Flow**로 구함**

Unit strip2 : $p_{14} = 153.88(kN/m^{2})$
Unit strip3 : $p_{14} = 153.88(kN/m^{2})$
Unit strip4 : $p_{14} = 153.88(kN/m^{2})$

$h_s = 13.88\ m$
,(Tanktop**이** Unit strip1**과 다름**)

✓Bottom plate **손상으로 인한 침수 고려**

p15	**126**	$p_{15} = 10\,T$

Unit strip2,3,4,5**도 위 값과 동일**

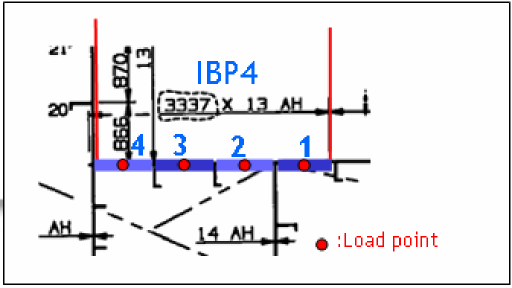
p_{13}~p_{15}**중 가장 큰 값을 Pressure 로 취한다**

$$p = \max(\ p_{13}, p_{14}, p_{15}\ )$$

$$[kN/m^{2}]$$

Unit strip1 : $p = p_{15} = 126$
Unit strip2 : $p = p_{14} = 153.88$
Unit strip3 : $p = p_{14} = 153.88$
Unit strip4 : $p = p_{14} = 153.88$

Inner Bottom Plate (IBP4) (1)



②

✓ Required Thickness

$$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$$

✓ Allowable stress for Bottom Plate

$$\sigma = 140 \ f_1$$

Keel Plate의 Unit strip 1에 대한 Required Thickness

t_1	p	126	Maximum Design Load
	ka	1.0	$k_a = (1.1 - 0.25 s / l)^2$,s/l= 0.4 이하 ka는 최대 1.0
	s	0.841	stiffener spacing in m
	f1	1.28	Material factor = 1.28 for NV-32
	σ	179.2	$\sigma = 140 \ f_1$
	tk	1	Corrosion addition
		12.14	$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$

Unit strip2,3,4도 동일한 Flow로 구함

Unit strip2 : t_1 = 13.31 (mm)

Unit strip3 : t_1 = 13.31(mm)

Unit strip4 : t_1 = 13.31(mm)

③

✓ Minimum Thickness

$$t_2 = t_0 + \frac{0.03 L_1}{\sqrt{f_1}} + t_k \ (mm)$$

t_2	t_0	5.0	5.0 in general
	L1	245.11	Min (L, 300) (m)
	f1	1.28	Material factor = 1.28 for NV-32
	tk	1	Corrosion addition
		12.50	

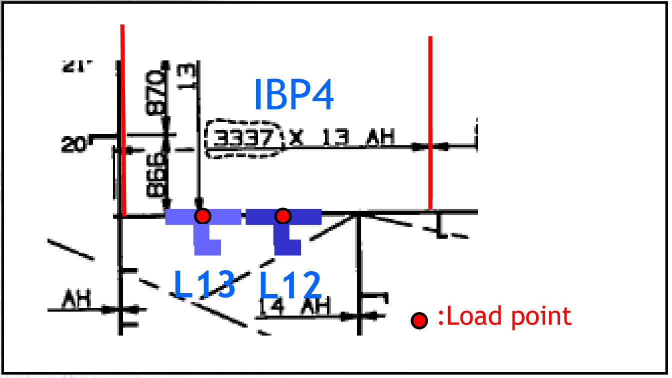
Unit strip 1,2,3,4에 모두 적용됨

④	$t = \max(t_1, t_2) \ [mm]$
Unit strip 1	12.50
Unit strip 2	13.31
Unit Strip 3	13.31

⑤ Unit strip의 두께 중 가장 큰 값을 Keel plate의 두께로 정함

$$t = 13.31 \approx 13.5 \ [mm]$$

Longitudinals at Inner Bottom (L12)(1)



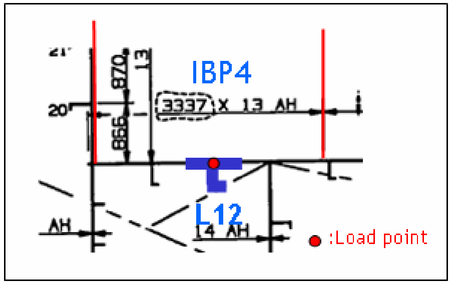
✓Load point: Midpoint

✓L_{12} ,L_{13} 의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

✓ Design Load

Structure	Load Type	
Inner bottom	Dry cargo in cargo holds	$p_4 = \rho(g_0 + 0.5a_V)H_C$
Inner Bottom, floors and girders	Pressure on tank boundary in double bottom	$p_{13} = 0.67(10h_p + \Delta p_{dyn})$ $p_{14} = 10h_s + p_0$
	Minimum pressure	$p_{15} = 10T$

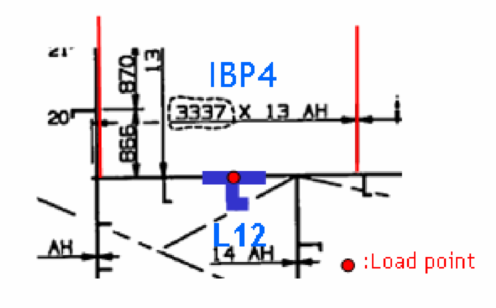
① L14에 대한 Design Load, P



Longitudinals at Inner Bottom의 Design Load는 Inner Bottom plate의 값과 동일함

L14 : p = p_{14} =153.88

Longitudinals at Inner bottom [L12][2]



②

✓ Required Section Modulus

$$Z = \frac{83 l^2 s p w_k}{\sigma} \ (cm^3)$$

✓ Allowable stress

$$\sigma = 225 \ f_1 - 100 \ f_{2b} - 0.7 \sigma_{db}$$

Z	le		2.96	Web frame 간격(3.16m) - 0.2 m (braket)
	s		0.841	stiffener spacing in m
	p		153.88	Maximum Design Load
	wk	tkw	1.0	Corrosion addition
		tkf	1.0	Corrosion addition
			1.1	$1 + 0.05(t_{kw} + t_{kf})$ for flanged section
	σ	f1	1.28	Material factor = 1.28 for NV-32
		f2b	1.04	3700TEU의 section Modulus로 구한 값임
		σdb	25.6	$20f_1$ in general
			166.08	$\sigma = 225 \ f_1 - 100 \ f_{2b} - 0.7\sigma_{db}$
	623.33			$Z = \frac{83 l^2 s p w_k}{\sigma} \ (cm^3)$

③

✓ Minimum Thickness of Web and Flange

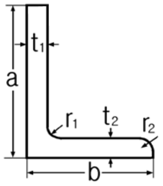
$$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm), \quad t_2 = \frac{h}{g} + t_k \ (mm)$$

t1	k	4.9022	$0.02 L_1$
	f1	1.28	Material factor = 1.28 for NV-32
	tk	1.0	Corrosion addition
	10.33		$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm)$
t2	h	300	Profile height in m
	g	70	70 for flanged profile webs
	tk	1.0	Corrosion addition
	5.29		$t_2 = \frac{h}{g} + t_k \ (mm)$

$$t = \max(t_1, t_2) = t_1$$

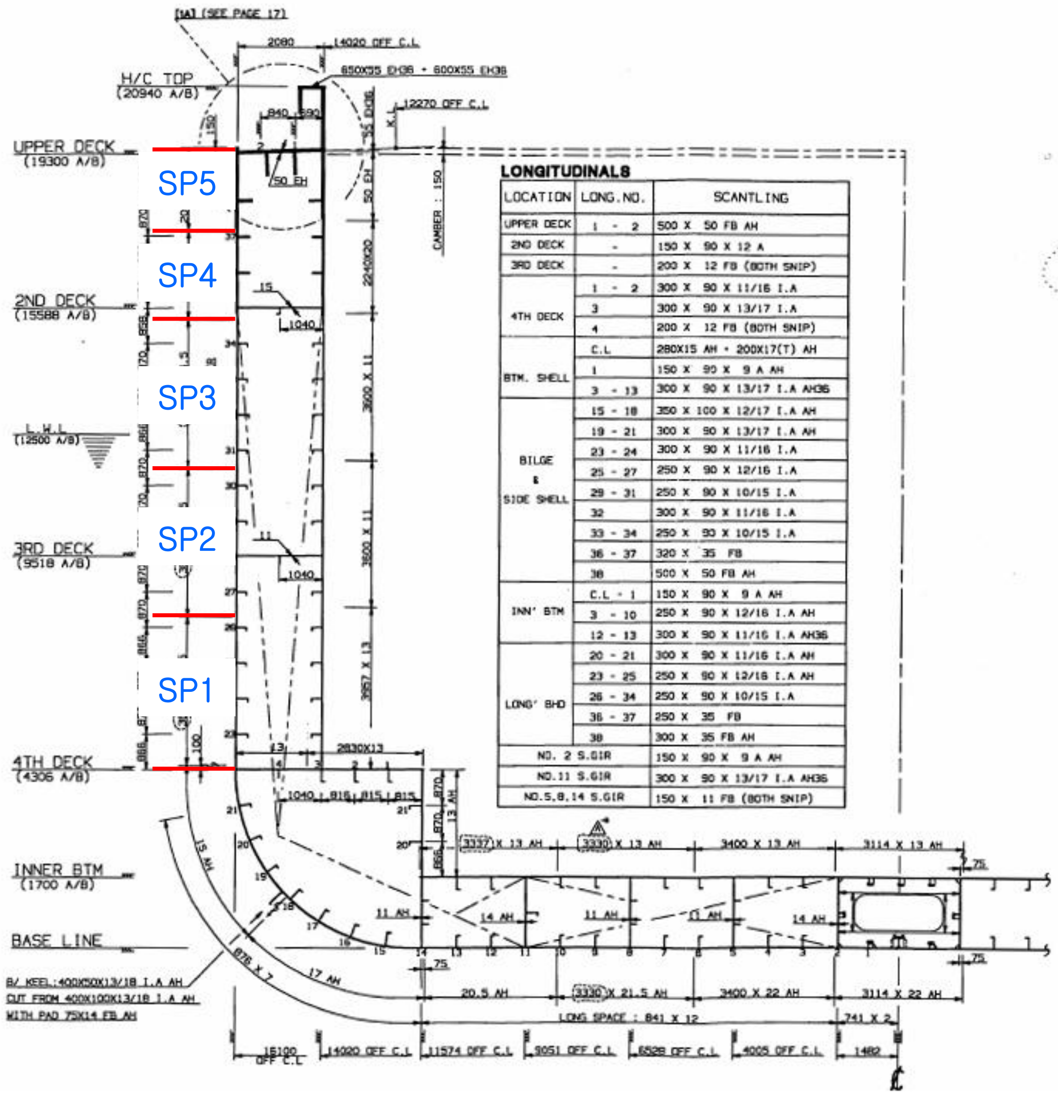
④ Required section modulus를 만족하는 Longi.를 Table 에서 찾아 Longi.의 치수 선정

"조선설계편람", 제 4판 (일본어), 일본관서조선협회, 1996
이규열, "창의적 선박설계", 선체 구조설계, p22~25



a	b	t_1	t_2	r_1	r_2	A	I	Z
mm						cm^2	cm^4	cm^3
300	90	11	16	19	9.5	46.22	16,400	681

Side shell plate

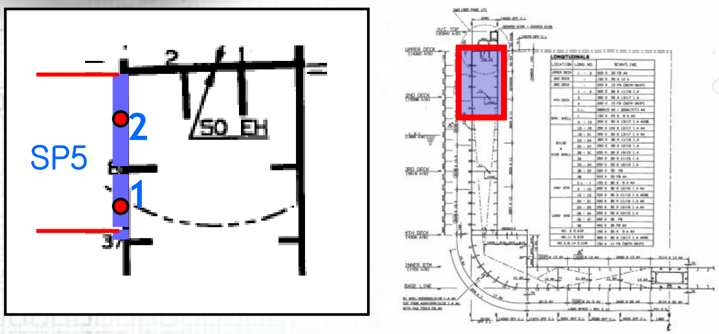


LONGITUDINALS

LOCATION	LONG.NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

- SP : Side shell Plate

Side shell plate (1)
(Design Load & Load Point)



● :Load point

✓ SP5(Shear strake at strength deck)는 2개의 strip으로 구성

✓ Unit strip의 Load point:
1,2, : Midpoint

✓ 2개의 Unit strip에 대해 각각 Plate 두께를 계산하고, 가장 큰 값을 SP5 의 두께로 사용한다.

✓SP5의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

✓ SP5는 side plate이면서, strength deck의 shear strake이므로, side plating과 strength deck plating을 함께 고려. (DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.7 C202)

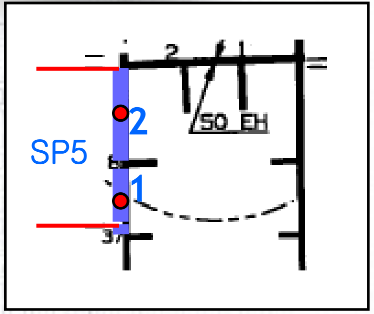
$$t = \frac{t_1 + t_2}{2} \quad (mm)$$

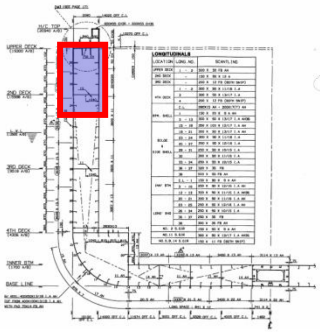
✓t1 : required side plating in mm

✓t2 : strength deck plating in mm

- ✓t2 shall not be taken less than t1.

Side shell plate (2)
(SP5 – Side plating)





● :Load point

- ✓ SP5(Shear strake at strength deck)는 2개의 strip으로 구성
- ✓ Unit strip의 Load point:
  1,2, : Midpoint
- ✓ 2개의 Unit strip에 대해 각각 Plate 두께를 계산하고, 가장 큰 값을 SP5 의 두께로 사용한다.
- ✓SP5의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.7 Table B1

Structure	Load Type	$p\ (kN/m^2)$
External	Sea pressure above summer load waterline	$p_2 = p_{dp} - (4+0.2k_s)h_0$

: SP5의 경우 Sea pressure만이 Design Load로 작용함

①

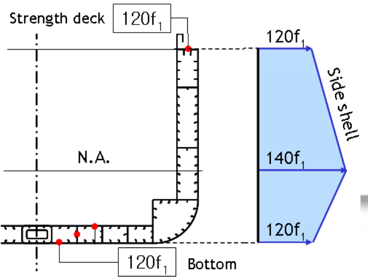
SP5의 Unit strip 1에 대한 Design Load P

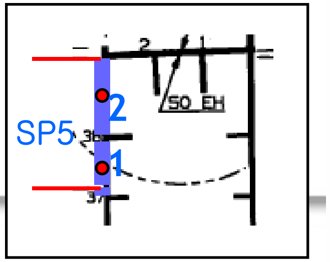
p2	pdp	pl	ks		2	0.2L~0.7L form A.P. ks=2
			Cw		10.343	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			kf	f	6.7	f = waterline에서 선박 측면 상단의 수직거리 (최대 0.8*Cw)
					6.7	
					28.33795639	$p_l = (k_s C_W + k_f)(0.8 + 0.15V/\sqrt{L})$
		y			16.1	중심선으로부터 하중지점까지의 수평거리, 최소 B/4(m) = 8.05
		z			12.6	선저(Baseline)으로 부터 하중지점까지의 수직거리, 최대 T(m)
					48.613	$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2(T-z)\ (kN/m^2)$
	h0				5.163	Waterline에서 load point까지의 수직 거리
					25.896	$p_2 = p_{dp} - (4+0.2k_s)h_0$

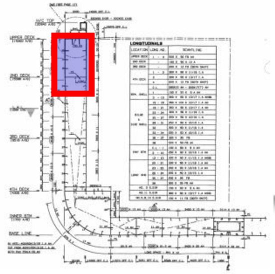
Unit strip2도 동일한 Flow로 구함

Unit strip2 : p2 = 21.558(kN/m^2)

Side shell plate (3) (SP5 – Side plating)







●:Load point

②

✓ Required Thickness

$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$$

✓ Allowable stress for Side shell Plate

$\sigma = 140\ f_1$ at N.A.

σshall be reduced linearly.

SP5의 Unit strip 1에 대한 Required Thickness

t_{1_1}	p	25.896	Maximum Design Load
	ka	1.0	$k_a = (1.1 - 0.25 s / l)^2$, s/l= 0.4 이하 ka는 최대 1.0
	s	0.87	stiffener spacing in m
	f1	1.28	Material factor = 1.28 for NV-32
	sigma	157.431	N.A(140f1)~ deck(140f1), 선형적으로 감소
	tk	3	Corrosion addition
		8.575	$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$

Unit strip2도 동일한 Flow로 구함

Unit strip2 : t_1 = 9.993 (mm)

③ ✓ Minimum Thickness

$$t = 5.0 + \frac{kL_1}{\sqrt{f_1}} + t_k \ (mm)$$

t_{1_2}	k	0.03	Min (L, 300) (m)
	L1	245.11	Min (L, 300) (m)
	f1	1.28	Material factor = 1.28 for NV-32
	tk	3	Corrosion addition
		14. 5	$t = 5.0 + \frac{kL_1}{\sqrt{f_1}} + t_k \ (mm)$

Unit strip 1,2에 모두 적용됨

cf) Minimum Breadth

$$b = 800 + 5L\,(mm)$$

b	Rule	2025.566	
	Arr.	3154	배치 상의 Keel plate 폭

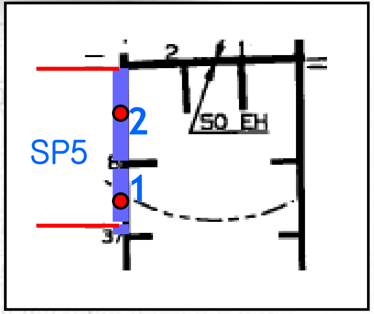
→ Rule을 만족함

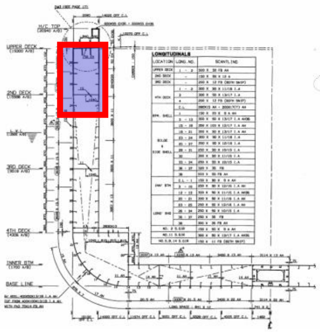
④	$t_1 = \max(t_{1\_1}, t_{1\_2})$ [mm]
Unit strip 1	14.5
Unit strip 2	14.5

⑤ Unit strip의 두께 중 가장 큰 값을 SP5의 두께로 정함

$$t_1 = 14.5$$

Side shell plate (4)
(SP5 – Strength deck plating)





● :Load point

- ✓ SP5(Shear strake at strength deck)는 2개의 strip으로 구성
- ✓ Unit strip의 Load point:
  1,2, : Midpoint
- ✓ 2개의 Unit strip에 대해 각각 Plate 두께를 계산하고, 가장 큰 값을 SP5 의 두께로 사용한다.
- ✓SP5의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.7 Table B1

Structure	Load Type	$p \ (kN/m^2)$
Weather deck	Sea pressure	$p_1 = a(p_{dp} - (4 + 0.2k_s)h_0)$

: SP5의 경우 Sea pressure만이 Design Load로 작용함

①

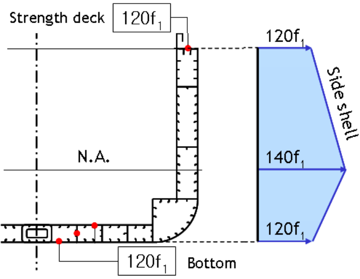
SP5의 Unit strip 1에 대한 Design Load P

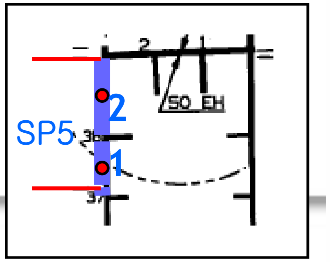
p1	pdp	pl	ks		2	0.2L~0.7L form A.P. ks=2
			Cw		10.343	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			kf	f	6.7	f = waterline에서 선박 측면 상단의 수직거리 (최대 0.8*Cw)
					6.7	
					28.33795639	$p_l = (k_s C_W + k_f)(0.8 + 0.15V/\sqrt{L})$
		y			16.1	중심선으로부터 하중지점까지의 수평거리, 최소 B/4(m) = 8.05
		z			12.6	선저(Baseline)으로 부터 하중지점까지의 수직거리, 최대 T(m)
					48.613	$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2(T-z) \ (kN/m^2)$
	a				0.8	FP, deckhouse front 앞쪽으로 0.15L: 1.0, 그 외 : 0.8
	h0				6.7	Waterline at T에서 deck까지의 수직 거리
					15.743	$p_1 = a(p_{dp} - (4 + 0.2k_s)h_0)$

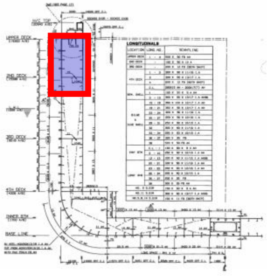
Unit strip2도 동일한 Flow로 구함

Unit strip2 : p1 =15.743(kN/m^2)

Side shell plate (5)
(SP5 – Strength deck plating)







●:Load point

②

✓ Required Thickness

$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \quad (mm)$$

✓ Allowable stress for Side shell Plate

$\sigma = 140 \ f_1$ at N.A.

σshall be reduced linearly.

SP5의 Unit strip 1에 대한 Required Thickness

t2_1	p	15.743	Maximum Design Load
	ka	1.0	$k_a = (1.1 - 0.25 s / l)^2$, s/l= 0.4 이하 ka는 최대 1.0
	s	0.87	stiffener spacing in m
	f1	1.28	Material factor = 1.28 for NV-32
	sigma	153.6	120f1
	tk	3	Corrosion addition
		7.401	$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$

Unit strip2도 동일한 Flow로 구함

Unit strip2 : t_{1_1} =8.574 (mm)

③

✓ Minimum Thickness

$$t = t_0 + \frac{kL_1}{\sqrt{f_1}} + t_k \quad (mm)$$

t_{2_2}	t0	5.5	5.5 for unsheathed weather and cargo deck
	k	0.02	0.02 in vessels with single continuous deck
	L1	245.11	Min (L, 300) (m)
	f1	1.28	Material factor = 1.28 for NV-32
	tk	3	Corrosion addition
		12.883	$t = t_0 + \frac{kL_1}{\sqrt{f_1}} + t_k \ (mm)$

Unit strip 1,2에 모두 적용됨

cf) Minimum Breadth

$$b = 800 + 5L\,(mm)$$

b	Rule	2025.566	
	Arr.	3154	배치 상의 Keel plate 폭

→ Rule을 만족함

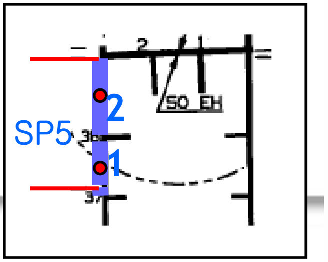
④	$t_2 = \max(t_{2\_1}, t_{2\_2}) \quad [mm]$
Unit strip 1	12.883
Unit strip 2	12.883

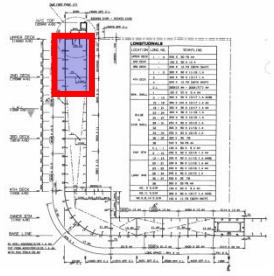
⑤ Unit strip의 두께 중 가장 큰 값을 SP5의 두께로 정함

$$t_2 = 12.883 \approx 13.0$$

0.25 단위로 반올림

Side shell plate (6) (SP5 – Shear strake at strength deck)





●:Load point

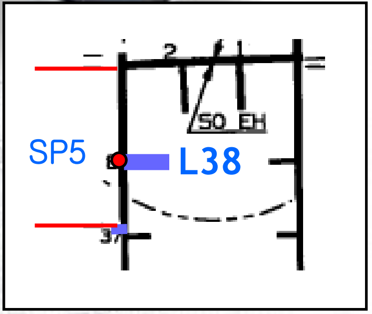
- ✓ Shear strake at strength deck

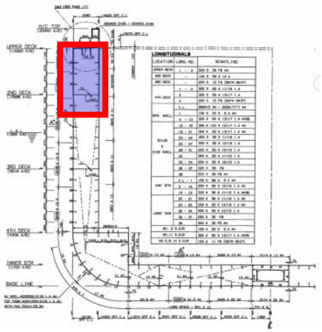
$$t = \frac{t_1 + t_2}{2} \quad (mm)$$

- ✓t1 : required side plating in mm $t_1 = 14.5$
- ✓t2 : strength deck plating in mm $t_2 = 13.0$
  - ✓t2 shall not be taken less than t1. $\therefore t_2 = 14.5$

$$\therefore t = \frac{t_1 + t_2}{2} = \frac{14.5 + 14.5}{2} = 14.5 \quad (mm)$$

Longitudinals at Side shell plate (1) (L38 – Side structure)





● :Load point

✓Load point: Midpoint

✓L_{38}의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

✓ L_{38}은 side structure에서의 longitudinals와 deck structure에서의 longitudinals를 고려한다.

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.7 Table B1

Structure	Load Type	$p\ (kN/m^2)$
External	Sea pressure above summer load waterline	$p_2 = p_{dp} - (4 + 0.2k_s)h_0$

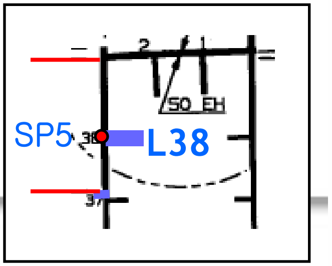
: L_{38}의 경우 Sea pressure만이 Design Load로 작용함

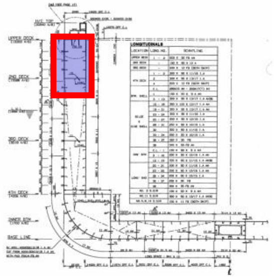
①

SP5의 L_{38}에 대한 Design Load P

p2	pdp	pl	ks		2	0.2L~0.7L form A.P. ks=2
			Cw		10.343	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			kf	f	6.7	f = waterline에서 선박 측면 상단의 수직거리 (최대 0.8*Cw)
					6.7	
					28.33795639	$p_l = (k_s C_W + k_f)(0.8 + 0.15V/\sqrt{L})$
		y			16.1	중심선으로부터 하중지점까지의 수평거리, 최소 B/4(m) = 8.05
		z			12.6	선저(Baseline)으로 부터 하중지점까지의 수직거리, 최대 T(m)
					48.613	$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2(T - z)\ (kN/m^2)$
	h0				5.598	Waterline에서 load point까지의 수직 거리
					23.982	$p_2 = p_{dp} - (4 + 0.2k_s)h_0$

Longitudinals at Side shell plate (2)
(L38 – Side structure)




●:Load point

②

✓ Required Section Modulus

$$Z = \frac{83 l^2 s p w_k}{\sigma} \ (cm^3)$$

✓ Allowable stress

$$\sigma = 225 f_1 - 130 f_2 \frac{z_n - z_a}{z_n}$$

Z_1	le		2.96	Web frame 간격(3.16m) - 0.2 m(braket)
	s		0.986	= (0.87+1.102)/2, stiffener spacing in m
	p		23.95194	Maximum Design Load
	wk	tkw	3	Corrosion addition
		tkf	3	Corrosion addition
			1.3	$1 + 0.05(t_{kw} + t_{kf})$ for flanged section
	σ	f1	1.28	Material factor = 1.28 for NV-32
		f2	1.19	f2=f2d, 3700TEU의 section Modulus로 구한 값임
		zn	10.272	=19.3 - 9.028, neutral axis부터 deck까지의 거리
		za	1.102	deck부터 load point까지의 거리
			150.383	$\sigma = 225 f_1 - 130 f_2 \frac{z_n - z_a}{z_n}$
	148.651			$Z = \frac{83 l^2 s p w_k}{\sigma} \ (cm^3)$

③

✓ Minimum Thickness of Web and Flange

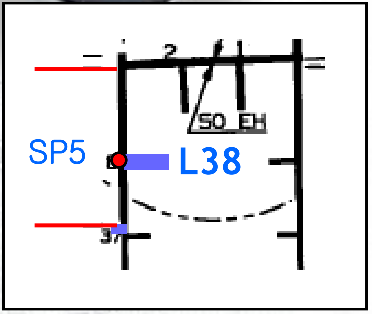
$$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm), \quad t_2 = \frac{h}{g} + t_k \ (mm)$$

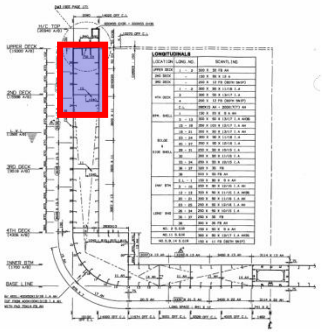
t1_1	k	4.9022	0.02 L_1
	f1	1.28	Material factor = 1.28 for NV-32
	tk	3	Corrosion addition
	12.33		$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm)$
t1_2	h	200	Profile height in m
	g	20	20 for plat bar profile
	tk	3	Corrosion addition
	13		$t_2 = \frac{h}{g} + t_k \ (mm)$

$$t = \max(t_1, t_2) = t_2$$

$$\therefore Z_1 = 148.651 \ cm^3, \quad t_1 = 13 \ mm$$

Longitudinals at Side shell plate (3)
(L38 – Deck structure)





● :Load point

✓Load point: Midpoint

✓L_{38}의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

✓ L_{38}은 side structure에서의 longitudinals와 deck structure에서의 longitudinals를 고려한다.

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.7 Table B1

Structure	Load Type	$p\ (kN/m^2)$
Weather deck	Sea pressure	$p_1 = a(p_{dp} - (4 + 0.2k_s)h_0)$

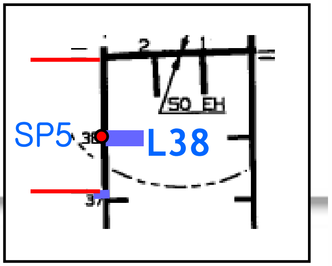
: L38의 경우 Sea pressure만이 Design Load로 작용함

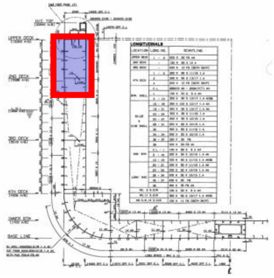
①

SP5의 L_{38}에 대한 Design Load P

<table>
<tr><td rowspan="11">p1</td><td rowspan="8">pdp</td><td rowspan="5">pl</td><td>ks</td><td colspan="2">2</td><td>0.2L~0.7L form A.P. ks=2</td></tr>
<tr><td>Cw</td><td colspan="2">10.343</td><td>100 < L < 300,   10.75 - [(300-L)/100]^(3/2)</td></tr>
<tr><td rowspan="2">kf</td><td>f</td><td>6.7</td><td rowspan="2">f = waterline에서 선박 측면 상단의 수직거리
(최대 0.8*Cw)</td></tr>
<tr><td colspan="2">6.7</td></tr>
<tr><td colspan="3">28.33795639</td><td>$p_l = (k_s C_W + k_f)(0.8 + 0.15 V/\sqrt{L})$</td></tr>
<tr><td>y</td><td colspan="3">16.1</td><td>중심선으로부터 하중지점까지의 수평거리, 최소 B/4(m) = 8.05</td></tr>
<tr><td>z</td><td colspan="3">12.6</td><td>선저(Baseline)으로 부터 하중지점까지의 수직거리, 최대 T(m)</td></tr>
<tr><td colspan="4">48.613</td><td>$p_{dp} = p_l + 135 \frac{y}{B+75} - 1.2(T - z)\ (kN/m^2)$</td></tr>
<tr><td>a</td><td colspan="4">0.8</td><td>FP, deckhouse front 앞쪽으로 0.15L: 1.0, 그 외 : 0.8</td></tr>
<tr><td>h0</td><td colspan="4">6.7</td><td>Waterline at T에서 deck까지의 수직 거리</td></tr>
<tr><td colspan="5">15.307</td><td>$p_1 = a(p_{dp} - (4 + 0.2k_s)h_0)$</td></tr>
</table>

Longitudinals at Side shell plate (4)
(L38 – Deck structure)





●:Load point

②

✓ Required Section Modulus

$$Z = \frac{83 l^2 s p w_k}{\sigma} \quad (cm^3)$$

✓ Allowable stress

$$\sigma = 225\, f_1 - 130\, f_{2d} \frac{z_n - z_a}{z_n}$$

Z_2	le		2.96	Web frame 간격(3.16m) - 0.2 m(braket)
	s		0.986	= (0.87+1.102)/2, stiffener spacing in m
	p		15.307	Maximum Design Load
	wk	tkw	3	Corrosion addition
		tkf	3	Corrosion addition
			1.3	$1 + 0.05(t_{kw} + t_{kf})$ for flanged section
	σ	f1	1.28	Material factor = 1.28 for NV-32
		f2d	1.19	3700TEU의 section Modulus로 구한 값임
		zn	10.272	=19.3 - 9.028, neutral axis부터 deck까지의 거리
		za	1.102	deck부터 load point까지의 거리
			150.383	$\sigma = 225\, f_1 - 130\, f_{2d} \frac{z_n - z_a}{z_n}$
			94.877	$Z = \frac{83 l^2 s p w_k}{\sigma} \quad (cm^3)$

③

✓ Minimum Thickness of Web and Flange

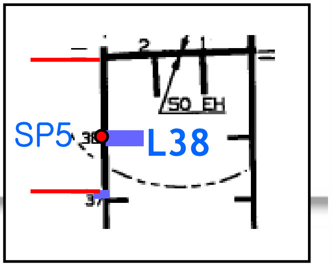
$$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm), \quad t_2 = \frac{h}{g} + t_k \ (mm)$$

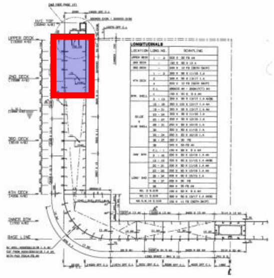
t2_1	k	4.9022	0.02 L_1
	f1	1.28	Material factor = 1.28 for NV-32
	tk	3	Corrosion addition
	12.33		$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm)$
t2_2	h	200	Profile height in m
	g	20	20 for plat bar profile
	tk	3	Corrosion addition
	13		$t_2 = \frac{h}{g} + t_k \ (mm)$

$$t = \max(t_1, t_2) = t_2$$

$$\therefore Z_2 = 94.877 \ cm^3, \quad t_2 = 13 \ mm$$

Longitudinals at Side shell plate (5)
(L38 – Side structure & Deck structure)





●:Load point

- ✓ Side structure : $Z_1 = 148.651\ cm^3,\ t_1 = 13\ mm$
- ✓ Deck structure : $Z_2 = 94.877\ cm^3,\ t_2 = 13\ mm$
- ✓ Side structure & Deck structure

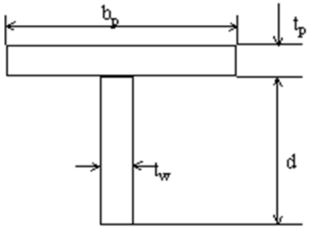
$$Z = \max(Z_1, Z_2) = Z_1 = 148.651\ cm^3$$

$$t = \max(t_1, t_2) = 13\ mm$$

④ Required section modulus**를 만족하는** Longi.**를** Table **에서 찾아** Longi.**의 치수 선정**

판을 포함한 소형 평강재의 단면계수

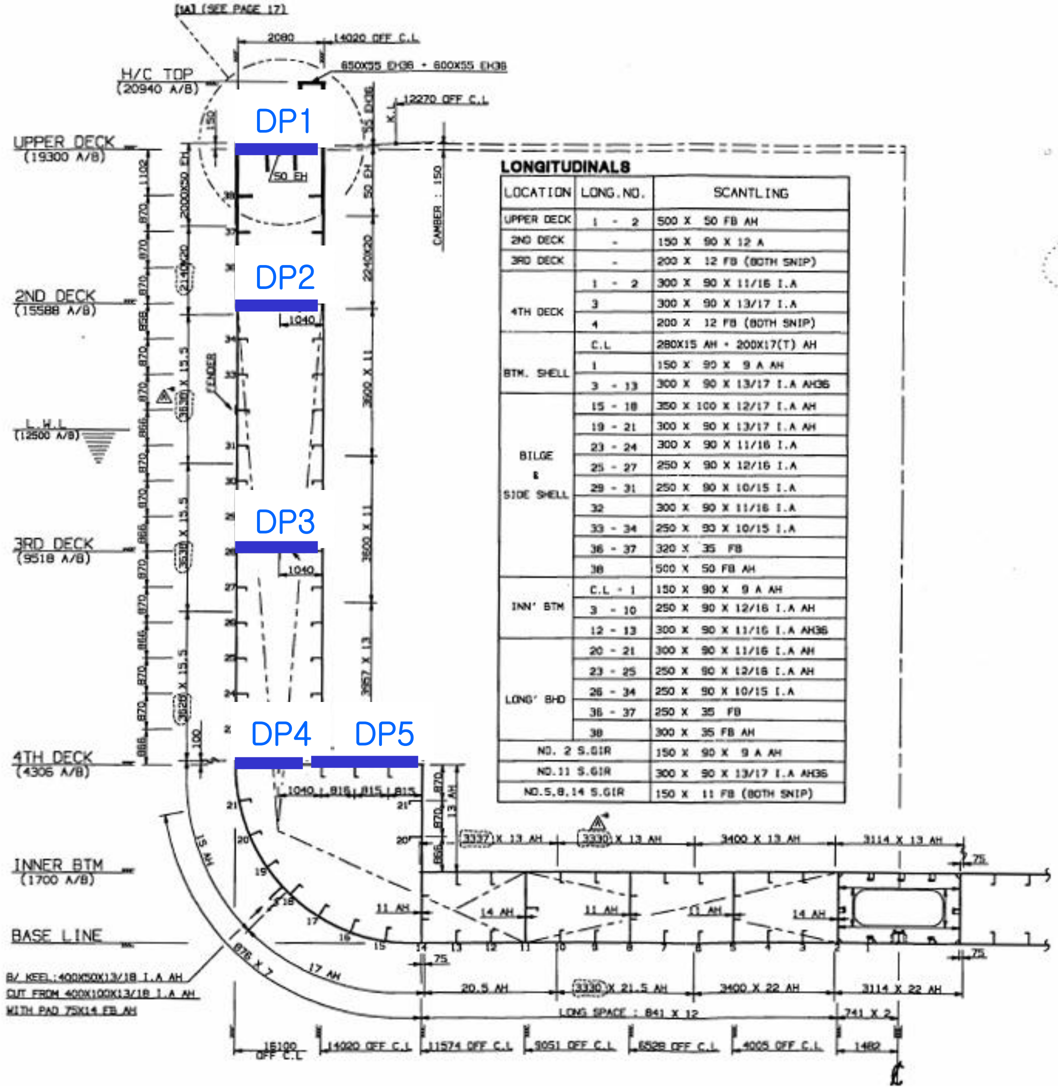
d \ tw		6	9	11	12.7	14
150	A	9	13.5	16.5	19.1	21
	Z	44.7	65.2	78.3	89.1	97.2
	I	614	856	1000	1120	1200



판을 포함한 대형 평강재의 단면계수

d \ tw		16	19	22	25.4	28	32	35	38
200	A	32	38	44	50.8	56	64	70	76
	Z	215	259	305	359	401	469	521	576
	I	3900	4730	5600	6640	7460	8790	9830	10900

Deck plate

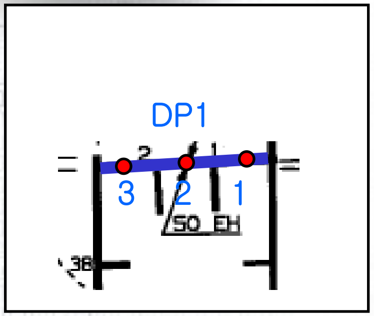


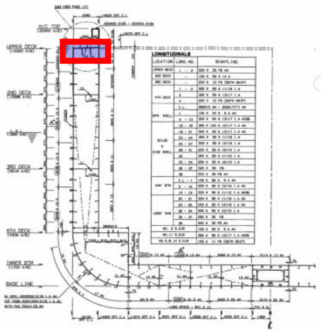
LONGITUDINALS

LOCATION	LONG. NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

- DP : Deck Plate

Deck plate (1)





● :Load point

- ✓ DP1은 3개의 strip으로 구성

- ✓ Unit strip의 Load point:
  1,2,3 : Midpoint

- ✓ 3개의 Unit strip에 대해 각각 Plate 두께를 계산하고, 가장 큰 값을 DP1의 두께로 사용한다.

- ✓DP1의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.7 Table B1

Structure	Load Type	$p\ (kN/m^2)$
Weather deck	Sea pressure	$p_1 = a(p_{dp} - (4 + 0.2k_s)h_0)$

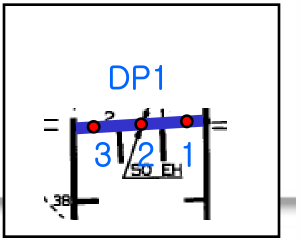
: DP1의 경우 Sea pressure만이 Design Load로 작용함

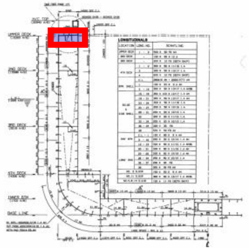
①

DP1의 Unit strip$_3$에 대한 Design Load P

p1	pdp	pl	ks		2	0.2L~0.7L form A.P. ks=2
			Cw		10.343	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			kf	f	6.7	f = waterline에서 선박 측면 상단의 수직거리 (최대 0.8*Cw)
					6.7	
					28.33795639	$p_l = (k_s C_W + k_f)(0.8 + 0.15V/\sqrt{L})$
		y			15.825	중심선으로부터 하중지점까지의 수평거리, 최소 B/4(m) = 8.05
		z			12.6	선저(Baseline)으로 부터 하중지점까지의 수직거리, 최대 T(m)
					48.267	$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2(T - z)\ (kN/m^2)$
	a				0.8	FP, deckhouse front 앞쪽으로 0.15L: 1.0, 그 외 : 0.8
	h0				6.7	Waterline at T에서 deck까지의 수직 거리
					16.853	$p_1 = a(p_{dp} - (4 + 0.2k_s)h_0)$

Deck plate (2)





● :Load point

②

✓ Required Thickness

$$t = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$$

✓ Allowable stress for Side shell Plate

$\sigma = 140 \ f_1$ at N.A.

σshall be reduced linearly.

DP1의 Unit strip 3에 대한 Required Thickness

t_1	p	16.853	Maximum Design Load
	ka	1.0	$k_a = (1.1 - 0.25 s / l)^2$, s/l= 0.4 이하 ka는 최대 1.0
	s	0.765	= (0.69 + 0.84)/2, stiffener spacing in m
	f1	1.28	Material factor = 1.28 for NV-32
	sigma	153.6	120f1
	tk	3	Corrosion addition
		6.611	$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$

Unit strip1, 2도 동일한 Flow로 구함

Unit strip1 : t_1 = 6.45 (mm)

Unit strip2 : t_1 = 6.535 (mm)

③ ✓ Minimum Thickness

$$t = t_0 + \frac{k L_1}{\sqrt{f_1}} + t_k \ (mm)$$

t_2	t0	5.5	5.5 for unsheathed weather and cargo deck
	k	0.02	0.02 in vessels with single continuous deck
	L1	245.11	Min (L, 300) (m)
	f1	1.28	Material factor = 1.28 for NV-32
	tk	3	Corrosion addition
		12.883	$t = t_0 + \frac{k L_1}{\sqrt{f_1}} + t_k \ (mm)$

Unit strip 1,2에 모두 적용됨

cf) Minimum Breadth

$$b = 800 + 5L \ (mm)$$

b	Rule	2025.566	
	Arr.	3154	배치 상의 Keel plate 폭

→ Rule을 만족함

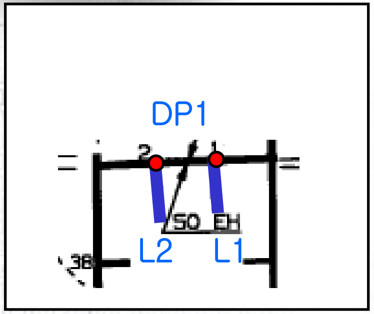
④	$t_2 = \max(t_{2\_1}, t_{2\_2}) \ [mm]$
Unit strip 1	12.883
Unit strip 2	12.883

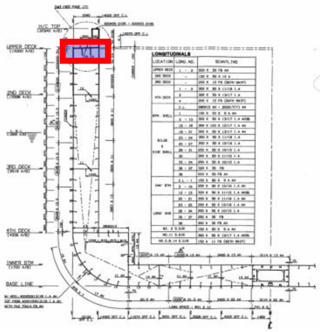
⑤ Unit strip의 두께 중 가장 큰 값을 DP1의 두께로 정함

$$t_2 = 12.883 \approx 13.0$$

0.25 단위로 반올림

Longitudinals at Deck plate (1)





● :Load point

✓Load point: Midpoint

✓L_1, L_2의 Material은 기준선과 동일한 NV-32를 사용한다.(f_1=1.28)

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.7 Table B1

Structure	Load Type	$p\ (kN/m^2)$
Weather deck	Sea pressure	$p_1 = a(p_{dp} - (4+0.2k_s)h_0)$

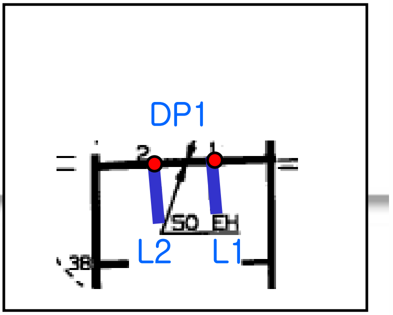
: L_1, L_2의 경우 Sea pressure만이 Design Load로 작용함

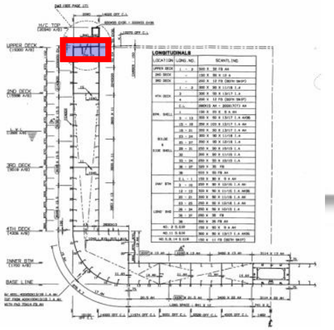
①

SP5의 L_2에 대한 Design Load P

p1	pdp	pl	ks		2	0.2L~0.7L form A.P. ks=2
			Cw		10.343	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			kf	f	6.7	f = waterline에서 선박 측면 상단의 수직거리 (최대 0.8*Cw)
					6.7	
					28.33795639	$p_l = (k_s C_W + k_f)(0.8 + 0.15V/\sqrt{L})$
		y			15.55	중심선으로부터 하중지점까지의 수평거리, 최소 B/4(m) = 8.05
		z			12.6	선저(Baseline)으로 부터 하중지점까지의 수직거리, 최대 T(m)
					47.921	$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2(T-z)\ (kN/m^2)$
	a				0.8	FP, deckhouse front 앞쪽으로 0.15L: 1.0, 그 외 : 0.8
	h0				6.7	Waterline at T에서 deck까지의 수직 거리
					16.576	$p_1 = a(p_{dp} - (4+0.2k_s)h_0)$

Longitudinals at Deck plate (2)





● :Load point

②

✓ Required Section Modulus

$$Z = \frac{83 l^2 s p w_k}{\sigma} \quad (cm^3)$$

✓ Allowable stress

$$\sigma = 225 f_1 - 130 f_{2d} \frac{z_n - z_a}{z_n}$$

Z	le		2.96	Web frame 간격(3.16m) - 0.2 m(braket)
	s		0.695	= (0.550 + 0.840)/2, stiffener spacing in m
	p		16.576	Maximum Design Load
	wk	tkw	3	Corrosion addition
		tkf	3	Corrosion addition
			1.3	
	σ	f1	1.28	Material factor = 1.28 for NV-32
		f2d	1.19	3700TEU의 section Modulus로 구한 값임
		zn	10.272	=19.3 - 9.028, neutral axis부터 deck까지의 거리
		za	0	deck부터 load point까지의 거리
			150.383	
			72.422	$1 + 0.05(t_{kw} + t_{kf})$ for flanged section

③

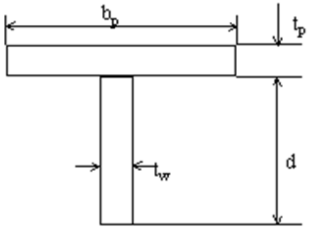
✓ Minimum Thickness of Web and Flange

$$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm), \quad t_2 = \frac{h}{g} + t_k \ (mm)$$

t1	k	4.9022	0.02 L_1
	f1	1.28	Material factor = 1.28 for NV-32
	tk	3	Corrosion addition
	12.33		$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm)$
t2_2	h	150	Profile height in m
	g	20	20 for plat bar profile
	tk	3	Corrosion addition
	10.5		$t_2 = \frac{h}{g} + t_k \ (mm)$

$$t = \max(t_1, t_2) = t_1$$

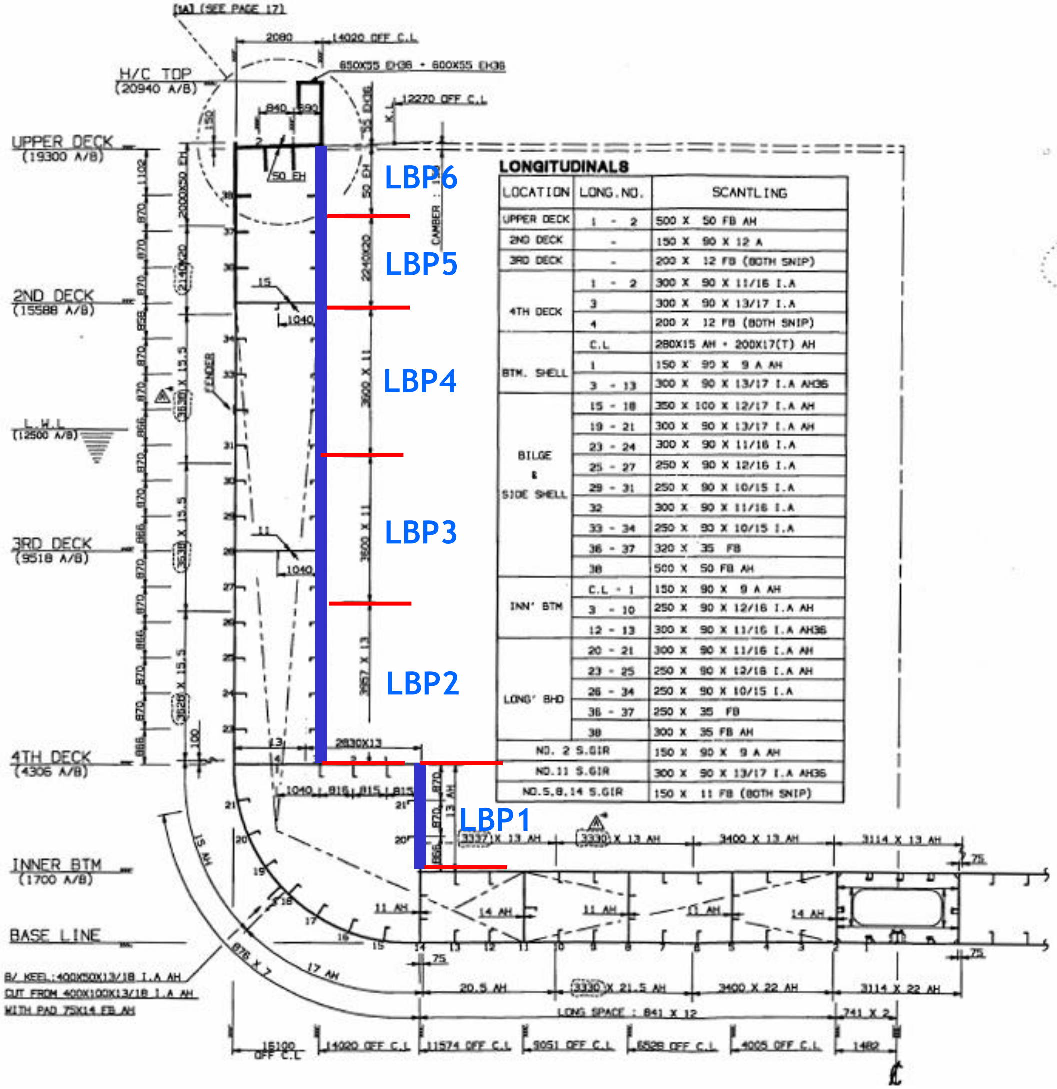
④ Required section modulus를 만족하는 Longi.를 Table 에서 찾아 Longi.의 치수 선정



판을 포함한 소형 평강재의 단면계수

d \ tw		6	9	11	12.7	14
150	A	9	13.5	16.5	19.1	21
	Z	44.7	65.2	78.3	89.1	97.2
	I	614	856	1000	1120	1200

Longitudinal Bulkhead plate

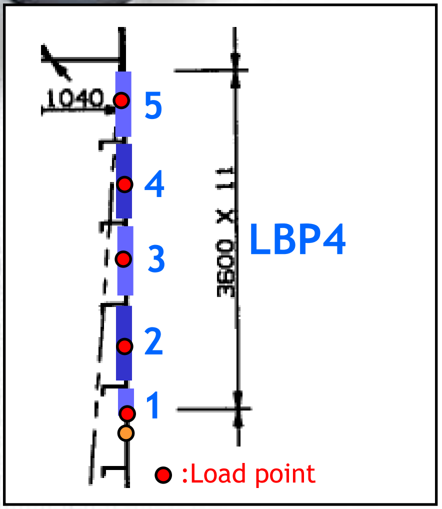


LONGITUDINALS

LOCATION	LONG. NO.	SCANTLING
UPPER DECK	1 - 2	500 X 50 FB AH
2ND DECK	-	150 X 90 X 12 A
3RD DECK	-	200 X 12 FB (BOTH SNIP)
4TH DECK	1 - 2	300 X 90 X 11/16 I.A
	3	300 X 90 X 13/17 I.A
	4	200 X 12 FB (BOTH SNIP)
BTM. SHELL	C.L	280X15 AH + 200X17(T) AH
	1	150 X 90 X 9 A AH
	3 - 13	300 X 90 X 13/17 I.A AH36
BILGE & SIDE SHELL	15 - 18	350 X 100 X 12/17 I.A AH
	19 - 21	300 X 90 X 13/17 I.A AH
	23 - 24	300 X 90 X 11/16 I.A
	25 - 27	250 X 90 X 12/16 I.A
	29 - 31	250 X 90 X 10/15 I.A
	32	300 X 90 X 11/16 I.A
	33 - 34	250 X 90 X 10/15 I.A
	36 - 37	320 X 35 FB
	38	500 X 50 FB AH
INN' BTM	C.L - 1	150 X 90 X 9 A AH
	3 - 10	250 X 90 X 12/16 I.A AH
	12 - 13	300 X 90 X 11/16 I.A AH36
LONG' BHD	20 - 21	300 X 90 X 11/16 I.A AH
	23 - 25	250 X 90 X 12/16 I.A AH
	26 - 34	250 X 90 X 10/15 I.A
	36 - 37	250 X 35 FB
	38	300 X 35 FB AH
NO. 2 S.GIR		150 X 90 X 9 A AH
NO.11 S.GIR		300 X 90 X 13/17 I.A AH36
NO.5,8,14 S.GIR		150 X 11 FB (BOTH SNIP)

LBP : Longitudinal Bulkhead Plate

Longitudinal Bulkhead plate (LBP4) (1)



✓LBP4은 5개의 Unit strip으로 구성

✓ Unit strip의 Load point:
1: Midpoint와 가장 가까운 지점
2,3,4,5 : Midpoint

✓ 5개의 Unit strip에 대해 각각 Plate 두께를 계산하고, 가장 큰 값을 LBP4 의 두께로 사용한다.

✓LBP4의 Material은 기준선과 동일한 NV-NS를 사용한다.(f_1=1.00)

✓ Design Load

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6 Table B1

Structure	Load Type	$p\ (kN/m^2)$
Watertight bulkheads	Sea pressure when flooded or general dry cargo minimum	$p_1 = 10 h_b$
Tank bulkheads in general		$P_3 = \rho(g_0 + 0.5a_V)\cdot h_s$ $P_4 = 0.67(\rho g_0 h_p + \Delta P_{dyn})$ $P_5 = \rho g_0 h_s + p_0$

① LBP4의 Unit strip 1에 대한 Design Load, P

선박 손상시 Sea pressure에 의한 영향 고려, P1

p1	h_b	3.725	선박손상 시 Second Deck 까지 잠긴다고 가정
	37.25		$p_1 = 10 h_b$

Unit strip2,3,4,5도 동일한 Flow로 구함

Unit strip2 : p1 = 30.31(kN/m^2)

Unit strip3 : p1 = 21.63(kN/m^2)

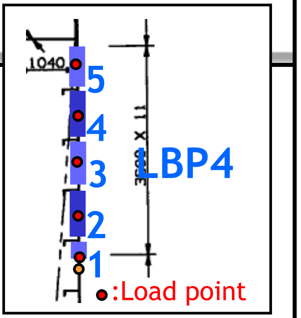
Unit strip4 : p1 = 12.93(kN/m^2)

Unit strip5 : p1 = 4.29(kN/m^2)

뒷장 이어서..

Longitudinal Bulkhead plate (LBP4) (2)

① LBP4의 Unit strip 1에 대한 Design Load, P



virtical accelation을 고려, P_3

p3	av	a0	Cw	10.34	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			Cv	0.2	$C_V = \sqrt{L} / 50$, max 0.2
			Cv1	1.56	$C_{V1} = V / \sqrt{L}$, max 0.8
				0.4396	$a_0 = 3C_W \cdot / L + C_V C_{V1}$
		kv		0.7	0.7 between 0.3L and 0.6L from A.P.
				4.599	$a_v = k_v g_0 a_0 / C_B$
	hb			3.725	선박손상 시 Second Deck 까지 잠긴다고 가정
				46.24	$p_3 = \rho(g_0 + 0.5a_v)h_s - 10h_b$

Unit strip2,3,4,5도 동일한 Flow로 구함

Unit strip2 : p2 = 30.31(kN/m$^{2)}$

Unit strip3 : p2 = 21.63(kN/m$^{2)}$

Unit strip4 : p2 = 12.93(kN/m$^{2)}$

Unit strip5 : p2 = 4.29(kN/m$^{2)}$

Tank Overflow 를 고려, P_4

p4	Δpdyn	25	25 in general
	hp	4.485	Air pipe에서 Load point까지의 거리 (air pipe의 위치는 second deck에서 0.76m 높은 곳을 잡음)
		46.97	$P_4 = 0.67(\rho g_0 h_p + \Delta P_{dyn})$

Unit strip2,3,4,5도 동일한 Flow로 구함

Unit strip2 : p4 = 42.29(kN/m$^{2)}$

Unit strip3 : p4 = 36.44(kN/m$^{2)}$

Unit strip4 : p4 = 30.58(kN/m$^{2)}$

Unit strip5 : p4 = 24.76(kN/m$^{2)}$

Tank Test 를 고려, P_5

p5	P_0	25	25 in general
	Hs	3.725	Air pipe에서 Load point까지의 거리 (air pipe의 위치는 second deck에서 0.76m 높은 곳을 잡음)
		52.46	$P_5 = \rho g_0 h_s + p_0$

Unit strip2,3,4,5도 동일한 Flow로 구함

Unit strip2 : p5 = 45.48(kN/m$^{2)}$

Unit strip3 : p5 = 36.75(kN/m$^{2)}$

Unit strip4 : p5 = 28.00(kN/m$^{2)}$

Unit strip5 : p5 = 19.31(kN/m$^{2)}$

p_1~p_5중 가장 큰 값을 Pressure 로 취한다

$$p = \max(p_1, p_3, p_4, p_5)$$

$$[kN / m^2]$$

Unit strip1 : p = p_5 = 52.46

Unit strip2 : p = p_5 =45.48

Unit strip3 : p = p_5 =36.74

Unit strip4 : p = p_4 = 30.58

Unit strip5 : p = p_4 24.76

Longitudinal Bulkhead plate (LBP4) (2)

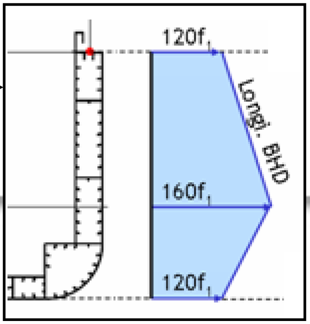
②

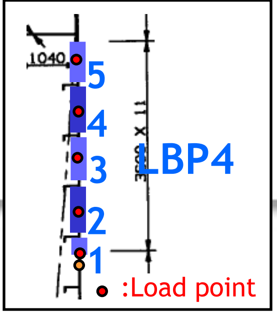
✓ Required Thickness

$$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$$

✓ Allowable stress for Bottom Plate

그림 참조





Keel Plate**의** Unit strip 1**에 대한** Required Thickness

t_1	p	52.46	Maximum Design Load
	ka	1.0	$k_a = (1.1 - 0.25 s/l)^2$,s/l= 0.4 이하 ka는 최대 1.0
	s	0.87	stiffener spacing in m
	f1	1	Material factor = 1.00 for NV-NS
	σ	134.48	
	tk	3	Corrosion addition
		11.59	$t_1 = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma}} + t_k \ (mm)$

Unit strip2,3,4,5**도 동일한** Flow**로 구함**

Unit strip2 : t1 = 10.99 (mm)

Unit strip3 : t1 = 10.26 (mm)

Unit strip4 : t1 = 9.67 (mm)

Unit strip5 : t1 = 8.96 (mm)

③

✓ Minimum Thickness

$$t_2 = 5.0 + \frac{k \cdot L_1}{\sqrt{f_1}} + t_k \ (mm)$$

t_2	L1	245.11	Min (L, 300) (m)
	f1	1.00	Material factor = 1.00 for NV-NS
	Tk	3	Corrosion addition
	k	0.01	0.01 for other bulkheads
		8	$t_2 = 5.0 + \frac{k \cdot L_1}{\sqrt{f_1}} + t_k \ (mm)$

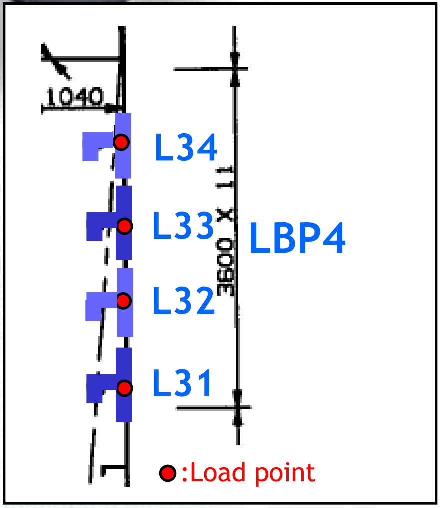
Unit strip 1,2,3,4,5**에 모두 적용됨**

④	$t = \max(t_1, t_2) \ [mm]$
Unit strip 1	11.59
Unit strip 2	10.99
Unit Strip 3	10.26
Unit Strip 4	9.67
Unit Strip 5	8.96

⑤ Unit strip**의 두께 중 가장 큰 값을** LBP4 **의 두께로 정함**

$$t = 11.59 \approx 11.5 \ [mm]$$

Longitudinals at Longitudinal Bulkhead plate (LBP4) (1)



✓Load point: Midpoint

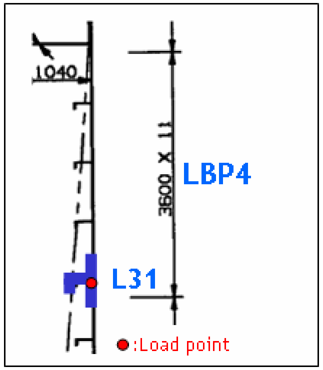
✓LBP4의 Material은 기준선과 동일한 NV-NS를 사용한다.(f_1=1.00)

✓ Design Load

DnV Rules, Jan. 2004,Pt.3 Ch.1 Sec.6 Table B1

Structure	Load Type	$p\ \ (kN/m^2)$
Watertight bulkheads	Sea pressure when flooded or general dry cargo minimum	$p_1 = 10\,h_b$
Tank bulkheads in general		$P_3 = \rho(g_0 + 0.5a_V)\cdot h_s$ $P_4 = 0.67(\rho g_0 h_p + \Delta P_{dyn})$ $P_5 = \rho g_0 h_s + p_0$

① L31 에 대한 Design Load, P

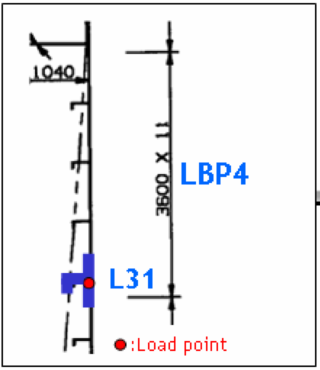


선박 손상시 Sea pressure에 의한 영향 고려, P1

p1	hb	3.464	선박손상 시 Second Deck 까지 잠긴다고 가정
	34.64		$p_1 = 10\,h_b$

뒷장 이어서..

Longitudinal Bulkhead plate (LBP4) (2)



① L31 **에 대한** Design Load, P

virtical accelation을 고려, P_3

p3	av	a0	Cw	10.34	100 < L < 300, 10.75 - [(300-L)/100]^(3/2)
			Cv	0.2	$C_V = \sqrt{L}/50$, max 0.2
			Cv1	1.56	$C_{V1} = V/\sqrt{L}$, max 0.8
				0.4396	$a_0 = 3C_W \cdot / L + C_V C_{V1}$
		kv		0.7	0.7 between 0.3L and 0.6L from A.P.
				4.599	$a_v = k_v g_0 a_0 / C_B$
	hb			3.464	선박손상 시 Second Deck 까지 잠긴다고 가정
				43.00	$p_3 = \rho(g_0 + 0.5a_v)h_s - 10h_b$

Tank Overflow 를 고려, P_4

p4	Δpdyn	25	25 in general
	hp	4.224	Air pipe에서 Load point까지의 거리 (air pipe의 위치는 second deck에서 0.76m 높은 곳을 잡음)
		45.21	$P_4 = 0.67(\rho g_0 h_p + \Delta P_{dyn})$

Tank Test 를 고려, P_5

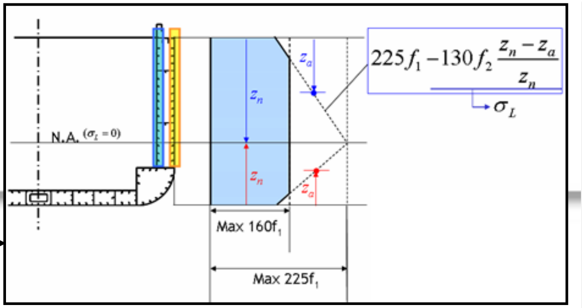
p5	P0	25	25 in general
	Hs	3.464	Air pipe에서 Load point까지의 거리 (air pipe의 위치는 second deck에서 0.76m 높은 곳을 잡음)
		49.83	$P_5 = \rho g_0 h_s + p_0$

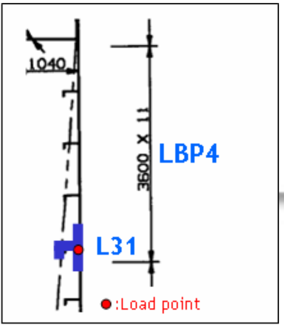
p_1~p_5중 가장 큰 값을 Pressure 로 취한다

$$p = \max(p_1, p_3, p_4, p_5) \ [kN/m^2]$$

$$p = p_5 = 49.83$$

Longitudinal Bulkhead plate (LBP4) (3)





②

✓ Required Section Modulus

$$Z = \frac{83 l^2 s p w_k}{\sigma} \quad (cm^3)$$

✓ Allowable stress

$$\sigma = 225 f_1 - 130 f_2 \frac{z_n - z_a}{z_n}$$

Z	le		2.96	Web frame 간격(3.16m) - 0.2 m(braket)
	s		0.87	stiffener spacing in m
	p		49.83	Maximum Design Load
	wk	tkw	1.5	Corrosion addition
		tkf	1.5	Corrosion addition
			1.15	$1 + 0.05(t_{kw} + t_{kf})$ for flanged section
	σ		160	
			226.08	$Z = \frac{83 l^2 s p w_k}{\sigma} \quad (cm^3)$

③

✓ Minimum Thickness of Web and Flange

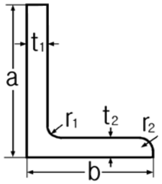
$$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm), \quad t_2 = \frac{h}{g} + t_k \ (mm)$$

t$_1$	k	4.9022	0.01L$_1$
	f1	1.00	Material factor = 1.00 for NV-NS
	tk	1.5	Corrosion addition
	8.95		$t_1 = 5.0 + \frac{k}{\sqrt{f_1}} + t_k \ (mm)$
t$_2$	h	340	Profile height in m
	g	70	70 for flanged profile webs
	tk	1.5	Corrosion addition
	4.36		$t_2 = \frac{h}{g} + t_k \ (mm)$

$$t = \max(t_1, t_2) = t_1$$

④ Required section modulus를 만족하는 Longi.를 Table 에서 찾아 Longi.의 치수 선정

"조선설계편람", 제 4판 (일본어), 일본관서조선협회, 1996
이규열, "창의적 선박설계", 선체 구조설계, p22~25



a	b	t$_1$	t$_2$	r$_1$	r$_2$	A	I	Z
mm						cm^2	cm^4	cm^3
200	90	9	14	14	7	29.66	5,870	340