7 단 면 검 토

7.1. 시공성

(☞ 강.설 4.3.3.2.3)

검토내용

횡방향 휨응력 상부플랜지		
	$f_l \le 0.6F_{yf}$	*(강.설 4.3-108)*
압축플랜지		
Open-flange	$f_{bu} + f_l \le \Phi_f R_h F_{yc}$	*(강.설 4.3-132)*
	$f_{bu} + f_l/3 \le \Phi_f F_{nc}$	*(강.설 4.3-133)*
(for slender web)	$f_{bu} \le \Phi_f F_{crw}$	*(강.설 4.3-134)*
Box-flange	$f_{bu} \le \Phi_f F_{nc}$	*(강.설 4.3-247)*
(for slender web)	$f_{bu} \le \Phi_f F_{crw}$	*(강.설 4.3-248)*
인장플랜지		
Open-flange	$f_{bu} + f_l \le \Phi_f R_h F_{yt}$	*(강.설 4.3-135)*
Box-flange	$f_{bu} \le \Phi_f R_h F_{yf} \Delta$	*(강.설 4.3-249)*
웨브		
	$V_{ui} \le \Phi_v V_n$	*(강.설 4.3-137)*

7.1.1. 횡방향 휨응력 상부플랜지 검토

(☞ 강.설 4.3.3.1.1.6)

$$\boxed{f_\ell \le 0.6F_{yf}}$$

f_ℓ 산정

Case		f_ℓ
Compression flange	$L_b \le 1.2L_p\sqrt{(C_bR_bF_{yc} / f_{bu})}$	$f_{\ell 1}$
	Otherwise	$\dfrac{0.85}{1-f_{bu}/F_{cr}} \cdot f_{\ell 1} \ \ge\ f_{\ell 1}$
Tension flange		$f_{\ell 1}$

여기서,

L_b = 비지지길이

L_p = 1.0 * r_t * $\sqrt{(E/F_{yc})}$ 소성거동을 보장하는 비지지길이의 한계 (☞ 강.설 4.3.3.1.8.2(3))

C_b = 모멘트 보정계수, taken as 1.0 (☞ 강.설 4.3.3.1.8.2(3))

= 1.0 if $f_{mid}/f_2 > 1$

= 1.0 If $f_2 = 0$

= $1.75-1.05f_1$ Otherwise

R_b = 1.0 for constructibility (A.C.6.10.1.10.2) (☞ 강.설 4.3.3.1.1.10(2))

f_{l1} = flange lateral bending stress throughout the unbraced length

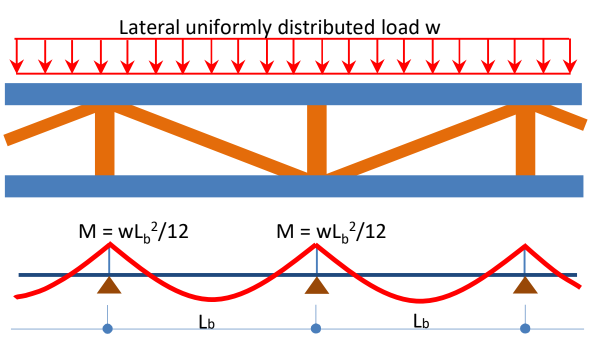
= $(1.25M_{lw} + 1.25M_{lo} + 1.5M_{lf} + 1.5M_{lc}) / S_\ell$

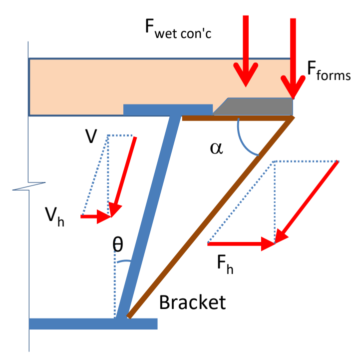
M_{lw} = flange lateral bending moment due to horizontal component of web shear in web

M_{lo} = flange lateral bending moment due to deck overhang wet concrete load

M_{lf} = flange lateral bending moment due to deck overhang forms load

M_{lc} = flange lateral bending moment due to curvature





■ Moment due to horizontal component of web shear

M_{lw} = $w*L_b^2/12$

w = $V_h = \Delta_v*\tan\Phi$

Δv = $[A1*75kN/m^3 + (A_c + A_s)*25kN/m^3]/2$

A1, A_c, A_s = Sectional area of steel girder, bottom concrete and deck slab

■ Moment due to overhang wet concrete loading

M_{lo} = $w*L_b^2/12$

w = $F_h = 0.5*F_{con}/\tan\alpha$

F_{con} = $t_s*b*25kN/m^3$

b, ts = cantilever and thickness of deck slab

- Moment due to overhang form loads

M_{lf} = $w*L_b^2/12$

w = $0.5*F_{forms}/\tan\alpha$

F_{forms} = 3.0 kN/m (assumed)

- Moment due to curvature

M_{lc} = $ML_b^2/(NRD)$

N = a constant taken as 12

R = girder radius

D = web depth

- 웨브 공칭휨좌굴강도

$$F_{cr} = \frac{C_b R_b \pi^2 E}{(L_b/r_t)^2}$$

$$r_t = \frac{b_{fc}}{\sqrt{(12(1 + D_c t_w/3/b_{fc}/t_{fc}))}}$$

f_{bu} = largest values of compressive stress in the flange

S_l = $t_{top}b_{top}^2/6$ section modulus of top flange about a vertical axis through the web

7.1.2. 플랜지 응력 검토

	압축플랜지		인장플랜지	
Open flange	$\mathbf{f_{bu} + f_l \le \phi_f R_h F_{yc}}$	*(강.설 4.3-132)*	$\mathbf{f_{bu} + f_l \le \phi_f R_h F_{yt}}$	*(강.설 4.3-135)*
	$\mathbf{f_{bu} + f_l/3 \le \phi_f F_{nc}}$	*(강.설 4.3-133)*		
	$\mathbf{f_{bu} \le \phi_f F_{crw}}$ (slender web)	*(강.설 4.3-134)*		
Box flange	$\mathbf{f_{bu} \le \phi_f F_{nc}}$	*(강.설 4.3-247)*	$\mathbf{f_{bu} \le \phi_f R_h F_{yf} \Delta}$	*(강.설 4.3-249)*
	$\mathbf{f_{bu} \le \phi_f F_{crw}}$ (slender web)	*(강.설 4.3-248)*		

1) 플랜지 응력

$$f_{bu} = \frac{1.25\cdot(DC_1 + DC_2)}{S_{steel}} + \frac{1.25\cdot DC_3}{S_{bot\_con}}$$

■ Φ_f, Φ_v = 1.0: 휨, 전단에 대한 강도저항계수

■ R_h = 하이브리드 계수 **(☞ 강.설 4.3.3.1.1.10(1))**

Case	$\mathbf{R_h}$
$F_{yw} \ge F_{yf}$	1.0
Otherwise	$[12+\beta(3\rho - \rho^3)]/(12 + 2\beta)$

ρ = $\min(F_{yw}/f_n\ ;\ 1.0)$

f_n = $\max(F_{yf},\ f_{bu})$

β = $2D_n t_w/A_{fn}$

D_n = 단면의 탄성중립축으로 부터 양플린지 안쪽 면까지의 거리 중 큰값

A_{fn} = 플랜지 단면적과 D_n 방향에 위치한 플랜지 덮개판 면적의 합

2) F_{nc} 산정 (Nominal flexural resistance of compression flange)

Case	$\mathbf{F_{nc}}$	
Open flange (OF)	$F_{nc} = \mathrm{Min}\ (F_{nc\_LB}\ ,\ F_{nc\_LTB})$	**(☞ 강.설 4.3.3.1.8.2)**
Box flange (BF)	$F_{nc} = F_{cb}\sqrt{[(1 - (f_v / \Phi_v / F_{cv})^2]}$	**(☞ 강.설 4.3.3.2.8.2)**

■ F_{nc_LB} (국부좌굴강도) 산정 **(☞ 강.설 4.3.3.1.8.2(2))**

Case	$\mathbf{F_{nc\_LB}}$
$\lambda_f \le \lambda_{pf}$	$R_b R_h F_{yc}$
Otherwise	$[1 - (1 - F_{yr}/R_h/F_{yc})\ (\lambda_f - \lambda_{pf})/(\lambda_{rf} - \lambda_{pf})]\ R_b R_h F_{yc}$

R_b = 1.0 for checking constructibility

F_{yr} = $\max\ [\min\ (0.7F_{yc}\ ,\ F_{yw})]\ ,\ 0.5F_{yc}]$

λ_f = $b_{fc}/2t_{fc}$

λ_{pf} = $0.38\sqrt{(E/F_{yc})}$

λ_{rf} = $0.56\sqrt{(E/F_{yr})}$

■ F_{nc_LTB} (횡비틀림좌굴강도) 산정 **(☞ 강.설 4.3.3.1.8.2(3))**

Case	$\mathbf{F_{nc\_LTB}}$

$L_b \le L_p$	$R_b R_h F_{yc}$
$L_p < L_b \le L_r$	$C_b[1 - (1-F_{yr}/R_h/F_{yc}) (L_b-L_p)/(L_r-L_p)]\ R_b R_h F_{yc} \le R_b R_h F_{yc}$
$L_b > L_r$	$F_{cr} \le R_b R_h F_{yc}$

L_b = unbraced length

L_p = $1.0 r_t \sqrt{(E/F_{yc})}$

L_r = $\pi r_t \sqrt{(E/F_{yr})}$

F_{cr} = $\dfrac{C_b R_b \pi^2 E}{(L_b / r_t)^2}$

■ Calculation of F_{cb} (☞ 강.설 4.3.3.2.8.2(2))

Case	$\mathbf{F_{cb}}$
$\lambda_f \le \lambda_p$	$R_b R_h F_{yc} \Delta$
$\lambda_p < \lambda_f \le \lambda_r$	$R_b R_h F_{yc}[\Delta - (\Delta - (\Delta - 0.3)/R_h) (\lambda_f - \lambda_p)/(\lambda_r - \lambda_p)]$
$\lambda_r < \lambda_f$	$0.9 E R_b k/\lambda_f^2$

λ_f = b_{fc} / t_{fc} if 종리브 없음

λ_f = w / t_{fc} if 종리브 있음

λ_r = $0.95 \sqrt{(Ek / (\Delta - 0.3) / F_{yc})}$

λ_p = $0.57 \sqrt{(Ek / \Delta / F_{yc})}$

Δ = $\sqrt{(1 - (f_v / F_{yc})^2)}$

f_v = $T / (2A_0\ t_f)$

T = 계수하중에 의한 내부토크

A_0 = 박스거더 단면의 폐합단면적

w = 압축플랜지의 종방향보강재 폭 또는 웨브로부터 가장 가까운 종방향보강재까지의 거리 중 큰 값

■ Calculation of F_{cv} (☞ 강.설 4.3.3.2.8.2(2))

Case	$\mathbf{F_{cv}}$
$\lambda_f \le 1.12\sqrt{(Ek_s/F_{yc})}$	$0.58 F_{yc}$
$1.12\sqrt{(Ek_s/F_{yc})} < \lambda_f \le 1.40(Ek_s/F_{yc})$	$0.65\sqrt{(F_{yc} E k_s)}/\lambda_f$
$\lambda_f > 1.40\sqrt{(Ek_s/F_{yc})}$	$0.9 E k_s/\lambda_f^2$

■ Calculation of k, k_s - Plate-buckling coefficient

Case		**k**	$\mathbf{k_s}$
종리브 없음		4.0	5.34
종리브 있음	n = 1	$1.0 \le [8 I_s/(w t_{fc}^3)]^{1/3} \le 4.0$	$\dfrac{5.34 + 2.84(I_s/w/t_{fc}^3)^{1/3}}{(n + 1)^2} \le 5.34$
	n = 2	$1.0 \le [0.894 I_s/(w t_{fc}^3)]^{1/3} \le 4.0$	

n = 등간격인 종방향보강재의 수

I_s = 종리브 단면2차모멘트

4) Checking web Bend-Buckling Resistance for slender web

(강.설 4.3.3.1.1.9)

$\boxed{f_{bu} \le \Phi_f F_{crw}}$

(For section with compact or noncompact web, this equation shall not be checked)

■ Section classification

Case	Section
$\frac{2D_c}{t_w} \le 5.7\sqrt{(E/F_{yc})}$	Compact or non-compact Wel
$\frac{2D_c}{t_w} > 5.7\sqrt{(E/F_{yc})}$	Slender Web

여기서,

$F_{crw} = \frac{0.9Ek}{(D/t_w)^2} \le$ smaller ($R_h F_{yc}$ and $F_{yw}/0.7$)

■ Calculation of k - bend-buckling coefficient

→ For the unstiffened web $k = 9/(D_c/D)^2$

→ For one longitudinal stiffener *(A. 6.10.1.9 & 강.설 4.3.3.1.1.9)*

Case	k
- 양쪽단이 압축 경우	7.2
- Otherwise	
$d_s/D_c \ge 0.4$	$5.17/(d_s/D)^2 \ge 9/(D_c/D)^2$
$d_s/D_c < 0.4$	$11.64/[(D_c-d_s)/D]^2$

D_c = 탄성범위 내에서 웨브의 압축 측 높이

= YU1 - t_{top} for Positive moment; YL2s - t_{bot} for Negative moment

d_s = 수평보강재 중심선과 압축플랜지 안쪽면사이의 거리

In this case, the values d_s is taken as 0.2D

→ For two longitudinal stiffener, k is calculated by equations proposed in below papers

Kim, Byung Jun, et al. "Web bend-buckling strength of plate girders with two longitudinal web stiffeners." Structural Engineering and Mechanics 69.4 (2019): 383-397.

Case	k
$\Psi \ge \cdot$ - $d_{sc} / D_c < 0.4$	$247.8\ (d_{sc} / D_c)^{1.8}\ (1 - \Psi)^{2.7}$
- $d_{sc} / D_c \ge 0.4$	$4.82\ (D_c / d_{sc})^{2.5}\ (1 - \Psi)^{2.7}$
$\Psi < -1.0$	$247.8\ (1 - \Psi)^{0.32}$

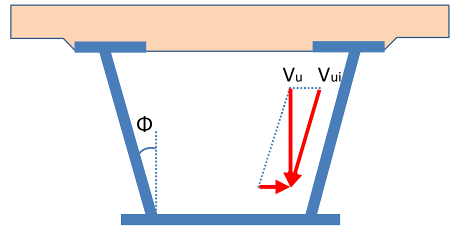
d_{sc} = distance between the center of the two longitudinal stiffeners and the inner surface of the compression flange

Ψ = f_t / f_c : stress ratio in the web panel

In this case, the distances between the first and second stiffener to the inner surface of the compression flange are taken as 0.14D and 0.36D, thus, d_{sc} would be 0.25D

7.1.3. Web checking

$$V_{ui} \le \Phi_v V_{cr}$$



V_{ui} = $V_u/\cos\Phi$

V_u = 경사진 웨브 1개에 작용하는 계수하중에 의한 전단력

Φ = 연직축에 대한 웨브의 경사각

V_{cr} = CV_p

V_p = $0.58F_{yw}Dt_w$

■ Ratio of shear buckling resistance (C) 산정

Case	C	
$D/t_w \le 1.12\sqrt{(Ek/F_{yw})}$	1.0	(1)
$1.12\sqrt{(Ek/F_{yw})} < D/t_w \le 1.40\sqrt{(Ek/F_{yw})}$	$1.12/(D/t_w)\sqrt{(Ek/F_{yw})}$	(2)
$D/t_w > 1.40\sqrt{(Ek/F_{yw})}$	$1.57(Ek/F_{yw})/(D/t_w)^2$	(3)

■ Calculation of k - shear-buckling ccoefficient

Case	k
Unstiffened web	5.0
Stiffened web	$5+5/(d_0/D)^2$

■ Classification of stiffened web and unstiffened web

(☞ 강.설 4.3.3.1.9.1(3))

Case	Classification
수직보강재 간격 $d_0 \le 3D$ and 수평보강재 없음	Stiffened web
수직보강재 간격 $d_0 \le 1.5D$ and 수평보강재 있음	Stiffened web
Otherwise	unstiffened web