Model for Estimating Limit-State Displacements of Two-Column Steel Bridge Piers

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Yield Limit-State

$$\Delta_y = \gamma_{sc}\gamma_{cb}\Delta'_y \tag{1}$$

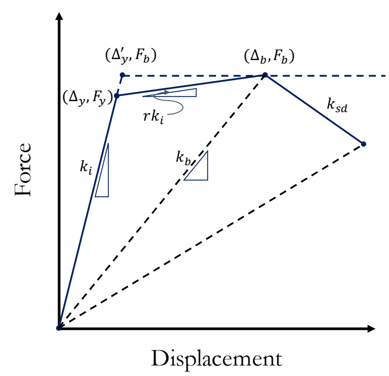
$$\gamma_{cb} = 1.05\left(\frac{1}{K_{rcb}}\right)^{0.92} \tag{2}$$

$$\gamma_{sc} = 1.88 - 0.01\left(\frac{D}{t}\right) \tag{3}$$

$$\Delta'_y = \frac{\phi_y L_c^2}{3} \tag{4}$$

$$\phi_y = \frac{2\epsilon_y}{D} \tag{5}$$

$$F_y = n_c\frac{f_y S}{L_c} \tag{6}$$



Figur 1: Idealized force versus displacement response.

Buckling Limit-State

$$\Delta_b = \gamma_{sc}\gamma_{cb}\Delta'_b \tag{7}$$

$$\gamma_{cb} = 0.65\left(\frac{1}{K_{rcb}}\right)^{0.58}\left(\frac{D}{t}\right)^{0.14} \tag{8}$$

$$\gamma_{sc} = 1.73 \tag{9}$$

$$\Delta'_b = \Delta_e + \Delta_p \tag{10}$$

$$\Delta_e = \frac{\phi'_y L_c^2}{3} \tag{11}$$

$$\phi'_y = \phi_y\left(\frac{M_p}{M_y}\right) \tag{12}$$

$$\Delta_p = L_p\left(\phi_b - \phi'_y\right)\left(L_c - \frac{L_p}{2}\right) \tag{13}$$

$$\phi_b = \frac{b_c\epsilon_b}{D} \tag{14}$$

$$b_c = 2.81 - 0.019\left(\frac{D}{t}\right) \tag{15}$$

$$\epsilon_b = 15\left(\frac{D}{t}\right)^{-2} \tag{16}$$

$$L_p = k_p L_c \tag{17}$$

$$k_p \approx 0.035 \tag{18}$$

$$F_b = F_y\left[1 + r\left(\frac{\Delta'_b}{\Delta'_y} - 1\right)\right] \leq \frac{M_p}{L_c} \tag{19}$$

$$r = 0.0136\left(\frac{D}{t}\right) + 0.004 f_y - 0.35 \tag{20}$$

Strength Degradation Rate

$$k_{sd} = 540\left(\frac{D}{t}\right)^{-1.3} - 0.18\left(\frac{P}{P_u}\right) - 11.3 \tag{21}$$

Displacement Corresponding to n% Strength Reduction

$$\Delta_{sd-n} = \Delta_b - \frac{F_b L_e\left(1 - 0.01n\right)}{100 k_{sd}} \tag{22}$$

Nomenclature

D	=	Column diameter
F_y	=	System force at yield limit-state
F_b	=	System force at local buckling limit-state
K_{rcb}	=	Cap beam relative stiffness
L_c	=	Column cantilever length
L_p	=	Plastic hinge length
M_p	=	Expected column maximum bending moment
M_y	=	Column yield moment
P	=	Column axial load
P_u	=	Column axial load capacity
S	=	Column section modulus
b_c	=	Dimensionless column curvature at local buckling
f_y	=	Yield strength of steel
k_p	=	Ratio of plastic hinge length to column cantilever length
k_{sd}	=	Column strength degradation rate, % reduction per unit drift
n	=	Strength reduction in terms of percentage of F_b
n_c	=	Number of columns
r	=	Column bi-linear factor
t	=	Column wall thickness
Δ_b	=	System displacement at column local buckling
Δ'_b	=	Single column displacement at column local buckling
Δ_e	=	Elastic component of column displacement
Δ_p	=	Plastic component of column displacement
Δ_{sd-n}	=	Displacement at n% strength reduction
Δ_y	=	System yield displacement
Δ'_y	=	Single column yield displacement
ϵ_y	=	Column yield strain
ϵ_b	=	Column strain at local buckling
γ_{sc}	=	Socket connection flexibility coefficient
γ_{cb}	=	Cab beam flexibility coefficient
ϕ_b	=	Column maximum curvature at local buckling
ϕ_y	=	Column yield curvature
ϕ'_y	=	Equivalent column yield curvature