Design References

LRFD AASHTO LRFD Bridge Design Specifications, 9th Edition
MAST 2 Lateral Stability of Long Prestressed Concrete Beams - Part 2, PCI Journal, Jan-Feb 1993

SEATED ON TRANSPORT TO PROJECT SITE

Concrete Properties

Concrete Compressive Strength, $f_{c.trans}$ = 7.00 ksi
Unit Weight of Unreinforced Girder Concrete, w_c: 0.150 kcf
Correction Factor for Modulus of Elasticity, K_1 = 1.00
Concrete Density Modification Factor, λ = 1.00
Concrete Modulus of Elasticity, $E_{c.trans}$: **LRFD Eq. 5.4.2.4-1**

$$E_{c.trans} = 120000\,K_1\,w_c^2\,f_{c.trans}^{0.33}$$

$$= 120000(1.00)(0.150\text{ kcf})^2(7.00\text{ ksi})^{0.33}$$

$$= 5132\ \text{ksi}$$

Modulus of Rupture, $f_{r.trans}$ **LRFD 5.4.2.6**

$$f_{r.trans} = -0.24\ \lambda\sqrt{f_{c.trans}}$$

$$= -0.24(1.00)\sqrt{7.00\text{ ksi}}$$

$$= -0.635\ \text{ksi}$$

Prestress Force

Effective Prestress Force at Seating, $P_{eff.trans}$ = 1251.5 kips
CG of Strands at Midspan to Bottom of Girder, $y_{cgs.mid.trans}$ = 7.910 in
Camber, $\Delta_{camber.trans}$ = 2.920 in

Other Configuration Parameters

The girder is assumed to be transported to the project site bunked a distance a_{trans} from both girder ends
Bunking Locations from End of Girder, a_{trans} = 10.00 ft
Height from Roll Center to Bottom of Girder, $y_{seat.trans}$: 48.000 in
Height of Roll Center from Roadway, $h_{roll.trans}$ = 24.000 in
Bunking Tolerance from CL Girder to CL Support, $e_{bunk.trans}$ = 1.685 in
Hauling Rig Rotational Stiffness, $K_{\theta.\ trans}$ = 40500 kip-in/rad

Other Loading Parameters

Lateral Wind Force during Transport, $w_{wind.trans}$ = 0.000 klf

Vertical Wind Uplift Considered Negligible for Transport

Transport Impact, IM_{trans} = 0 %

Effective Weight of Girder at Transport to Project Site, $w_{DC.girder.trans}$:

$$w_{DC.girder.trans} = w_{DC.girder}\ (1 + IM_{trans})$$

= (0.876 klf) (1 + 0.00)

= 0.876 klf

Total Weight of Girder at Transport, $W_{girder.trans}$

$$W_{girder.trans} = w_{DC.girder.trans}\ L_{girder}$$

= (0.876 klf)(136.00 ft)

= 119.1 kips

Centrifugal Force

Maximum Superelevation, α_{trans}: 0.060 ft/ft

Minimum Turn Radius, $Radius_{trans}$: 1000.00 ft

Hauling Rig Velocity in Turn, Vel_{trans}: 0.000 mph

Centrifugal Effect, CE_{trans}:

$$CE_{trans} = \frac{Vel_{trans}^2}{g\ Radius_{trans}}\ w_{DC.girder.trans}$$

$$= \frac{(0.00 \text{ mph} / (3600 \text{ sec/hr} / 5280 \text{ feet/mile}))^2}{(32.2 \text{ ft/s}^2)(1{,}000.00 \text{ ft})}(0.876 \text{ klf})$$

= 0.000 klf

Girder Eccentricities

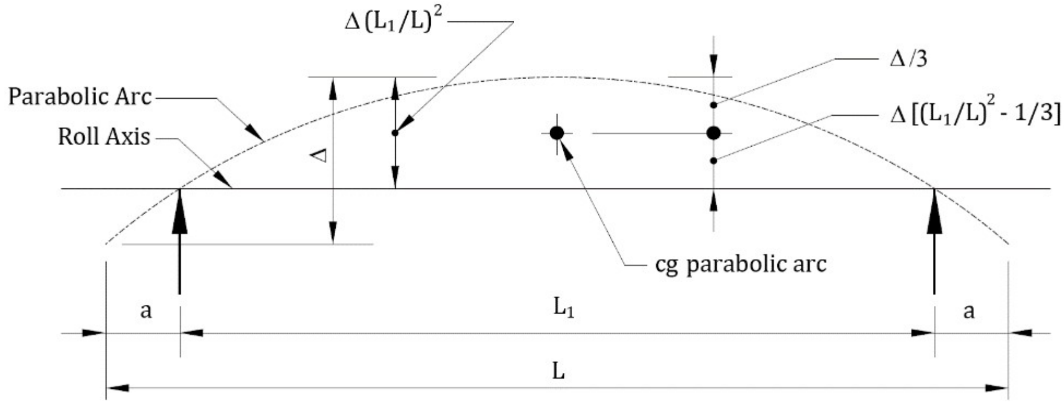
Total Lateral Deflection over Girder Length, $e_{i.total.trans}$: 2.700 in (Assumed Parabolic)

Eccentricity Reduction Factor, $offset_{trans}$:

$$L_{1.trans} = L_{girder} - 2\,a_{trans}$$

= 136.00 ft - 2(10.00 ft)

= 116.00 ft



Offset to centroid of a parabolically deflected girder from roll axis (used horizontally and vertically)

based on MAST 2 Figure B1, with generic variables

$$offset_{trans} = \left(\frac{L_{1.trans}}{L_{girder}}\right)^2 - \frac{1}{3}$$

$$= \left(\frac{116.00\text{ ft}}{136.00\text{ ft}}\right)^2 - \frac{1}{3}$$

= 0.394

Center of Mass Eccentricity Due to Lateral Deflection and Bunking Tolerance, $e_{i.trans}$:

$$e_{i.trans} = e_{i.total.trans}\,offset_{trans} + e_{bunk.trans}$$

= (2.700 in)(0.394) + 1.685 in

= 2.749 in

Distance from the Center of Mass of the Cambered Arc above Roll Axis, $y_{r.trans}$:

$$y_{r.trans} = y_{seat.trans} + y_b + offset_{trans}\,\Delta_{camber.trans}$$

= 48.000 in + 36.600 in + 0.394(2.920 in)

= 85.751 in

Mid-Height of Cambered Girder above Roll Axis, $y_{wind.trans}$:

$$y_{wind.trans} = \frac{h_{girder}}{2} + y_{seat.trans} + offset_{trans}\,\Delta_{camber.trans}$$

$$= \frac{72.000\text{ in}}{2} + 48.000\text{ in} + 0.394(2.920\text{ in})$$

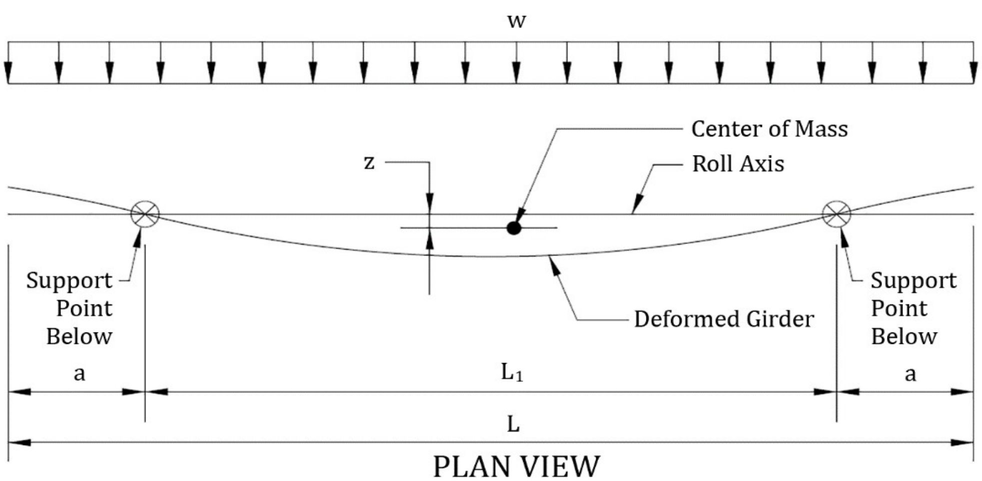
$$= 85.151\text{ in}$$

Center of Mass Eccentricity Due to Centrifugal Force, $z_{CE.trans}$:

$$z_{CE.trans} = \frac{CE_{trans}}{12\,E_{c.trans}\,I_y\,L_{girder}}\left(\frac{L_{1.trans}^5}{10} - a_{trans}^2\,L_{1.trans}^3 + 3\,a_{trans}^4\,L_{1.trans} + \frac{6}{5}\,a_{trans}^5\right)$$

$$= \left(\frac{(0.000\text{ klf})(12\text{ in/ft})^3}{(12)(5{,}132\text{ ksi})(37{,}634\text{ in}^4)(136.00\text{ ft})}\right)\left(\frac{(116.00\text{ ft})^5}{10} - (10.00\text{ ft})^2(116.00\text{ ft})^3 + 3(10.00\text{ ft})^4\,(116.00\text{ ft}) + \frac{6(10.00\text{ ft})^5}{5}\right)$$

$$= 0.000\text{ in}$$



Center of Mass Eccentricity Due to Wind Deflection, $z_{wind.trans}$:

$$z_{wind.trans} = \frac{w_{wind.trans}}{12\,E_{c.trans}\,I_y\,L_{girder}}\left(\frac{L_{1.trans}^5}{10} - a_{trans}^2\,L_{1.trans}^3 + 3\,a_{trans}^4\,L_{1.trans} + \frac{6}{5}\,a_{trans}^5\right)$$

$$= \left(\frac{(0.000\text{ klf})(12\text{ in/ft})^3}{(12)(5{,}132\text{ ksi})(37{,}634\text{ in}^4)(136.00\text{ ft})}\right)\left(\frac{(116.00\text{ ft})^5}{10} - 10.00\text{ ft})^2(116.00\text{ ft})^3 + 3(10.00\text{ ft})^4\,(116.00\text{ fl} + \frac{6(10.00\text{ ft})^5}{5}\right)$$

$$= 0.000\text{ in}$$

Total Center of Mass Eccentricity Due to Wind and CE, $z_{total.trans}$

$$z_{total.trans} = z_{wind.trans} + z_{CE.trans}$$

= 0.000 in + 0.000 in

= 0.000 in

Center of Mass Eccentricity Due to Girder Weight on Weak Axis, $z_{0.trans}$:

$$z_{0.trans} = \frac{w_{DC.girder.trans}}{12\,E_{c.trans}\,I_y\,L_{girder}}\left(\frac{L_{1.trans}^5}{10} - a_{trans}^2\,L_{1.trans}^3 + 3\,a_{trans}^4\,L_{1.trans} + \frac{6}{5}\,a_{trans}^5\right)$$

$$= \left(\frac{(0.876\text{ klf })(12\text{ in/ft})^3}{(12)(5{,}132\text{ ksi})(37{,}634\text{ in}^4\text{ })(136.00\text{ ft})}\right)$$

$$\left(\frac{(116.00\text{ ft})^5}{10} - 10.00\text{ ft})^2(116.00\text{ ft})^3 + 3(10.00\text{ ft})^4\,(116.00\text{ fl} + \frac{6(10.00\text{ ft})^5}{5}\right)$$

= 9.355 in

Check Stresses

Moment Due to Gravity Load, $M_{g.trans}$ at $x = a_{harp}$ from Girder End:

$$M_{g.trans} = \frac{w_{DC.girder.trans}\,L_{girder}}{2}\,(x - a_{trans}) - \frac{w_{DC.girder.trans}\,x^2}{2}$$

$$= \frac{(0.876\text{ klf})(136.00\text{ ft})}{2}\,(54.40\text{ ft} - 10.00\text{ ft}) - \frac{(0.876\text{ klf})(54.40\text{ ft})^2}{2}$$

= 1349 kip-ft = 16183 kip-in

Lateral Moment Due to Wind, $M_{wind.trans}$ at $x = a_{harp}$ from Girder End

$$M_{wind.trans} = \frac{w_{wind.trans}\,L_{girder}}{2}\,(x - a_{trans}) - \frac{w_{wind.trans}\,x^2}{2}$$

$$= \frac{(0.000\text{ klf})(136.00\text{ ft}}{2}\,(54.40\text{ ft} - 10.00\text{ ft}) - \frac{(0.000\text{ klf})(54.40\text{ ft})^2}{2}$$

= 0.0 kip-ft = 0 kip-in

Lateral Moment Due to Centrifugal Force, $M_{CE.trans}$ at $x = a_{harp}$ from Girder End:

$$M_{CE.trans} = \frac{CE_{trans}\,L_{girder}}{2}\,(x - a_{trans}) - \frac{CE_{trans}\,x^2}{2}$$

$$= \frac{(0.000\text{ klf})(136.00\text{ ft}}{2}\,(54.40\text{ ft} - 10.00\text{ ft}) - \frac{(0.000\text{ klf})(54.40\text{ ft})^2}{2}$$

= 0.0 kip-ft = 0 kip-in

Total Lateral Moment Due to Wind and CE, $M_{total.trans}$:

$$M_{total.trans} = M_{wind.trans} + M_{CE.trans}$$

= 0.0 kip-ft + 0.0 kip-ft

= 0.0 kip-ft = 0 kip-in

Overturning Moment Due to Wind and CE, $M_{ot.trans}$:

$$M_{ot.trans} = L_{girder}\,(w_{wind.trans}\,y_{wind.trans} + CE_{trans}\,y_{r.trans})$$

= (136.00 ft)((0.000 klf)(85.151 in) + (0.000 klf)(85.751 in))/(12in /ft)

= 0.0 kip-ft = 0 kip-in

Concrete Stresses in Girder:

$$f_{t.trans} = P_{eff.trans}\left(\frac{1}{A_{girder}} - \frac{y_b - y_{cgs.mid.trans}}{S_{x.t}}\right) + \frac{M_{g.trans}}{S_{x.t}} - \frac{M_{total.trans}}{S_{y.t}}$$

$$= 1{,}252\text{ kips}\left(\frac{1}{767.0\text{ in}^2} - \frac{36.600\text{ in} - 7.910\text{ in}}{15{,}421\text{ in}^3}\right) + \frac{16{,}183\text{ kip-in}}{15{,}421\text{ in}^3} - \frac{0\text{ kip-in}}{1{,}792\text{ in}^3}$$

= 0.353 ksi

$$f_{b.trans} = P_{eff.trans}\left(\frac{1}{A_{girder}} + \frac{y_b - y_{cgs.mid.trans}}{S_{x.b}}\right) - \frac{M_{g.trans}}{S_{x.b}} + \frac{M_{total.trans}}{S_{y.b}}$$

$$= 1{,}252\text{ kips}\left(\frac{1}{767.0\text{ in}^2} + \frac{36.600\text{ in} - 7.910\text{ in}}{14{,}915\text{ in}^3}\right) - \frac{16{,}183\text{ kip-in}}{14{,}915\text{ in}^3} + \frac{0\text{ kip-in}}{2{,}895\text{ in}^3}$$

= 2.954 ksi

$$\theta_{eq.trans} = \frac{K_{\theta.trans}\,\alpha_{trans} + W_{girder.trans}(z_{total.trans} + e_{i.trans}) + M_{ot.trans}}{K_{\theta.trans} - W_{girder.trans}(y_{r.trans} + z_{0.trans})}$$

$$= \frac{(40{,}500\text{ kip-in/rad})(0.06000\text{ rad}) + (119.1\text{ kip})(0.000\text{ in} + 2.749\text{ in}) + 0\text{ kip-in}}{40{,}500\text{ kip-in/rad} - (119.1\text{ kip})(85.751\text{ in} + 9.355\text{ in})}$$

= 0.09453 rad

$$f_{eq.t.trans} = f_{t.trans} - \frac{M_{g.trans}\,\theta_{eq.trans}}{S_{y.t}}$$

$$= 0.353\text{ ksi} - \frac{(16{,}183\text{ kip-in})(0.09453\text{ rad})}{1{,}792\text{ in}^3}$$

= -0.501 ksi

$$f_{eq.b.trans} = f_{b.trans} + \frac{M_{g.trans}\,\theta_{eq.trans}}{S_{y.b}}$$

$$= 2.954\text{ ksi} + \frac{(16{,}183\text{ kip-in})(0.09453\text{ rad})}{2{,}895\text{ in}^3}$$

= 3.482 ksi

	Critical	Allowable	**LRFD 5.9.2.3.2a**		
Compressive Stress:	3.482 ksi	$0.60\,f_{c.trans}$	= 0.60(7.00 ksi) =	4.20 ksi	OK
Tensile Stress:	-0.501 ksi	f_r	=	-0.635 ksi	OK

Check Factor of Safety Against Cracking

Lateral Moment to Cause Cracking :

$$M_{lat.trans} = (f_{t.trans} - f_{r.trans})S_{y.t}$$

= (0.353 ksi - (-0.635 ksi))(1,792 in³ /12 in/ft)

= 147.5 kip-ft

Tilt Angle at Cracking due to Lateral Deflection:

$$\theta_{cr.trans} = \frac{M_{lat.trans}}{M_{g.trans}}$$

$$= \frac{147.5 \text{ kip-ft}}{1{,}349 \text{ kip-ft}} = 0.10938 \text{ rad}$$

Factor of Safety Against Cracking:

$$FS_{cr.trans} = \frac{K_{\theta.trans}\,(\theta_{cr.trans} - \alpha_{trans})}{W_{girder.trans}\,[(y_{r.trans} + z_{0.trans})\,\theta_{cr.trans} + z_{total.trans} + e_{i.trans}] + M_{ot.trans}}$$

$$= \frac{(40{,}500 \text{ kip-in/rad})(0.10938 \text{ rad} - 0.06000 \text{ rad})}{(119.1 \text{ kip})[(85.751 \text{ in} + 9.355 \text{ in})(0.10938 \text{ rad}) + 0.000 \text{ in} + 2.749 \text{ in}] + 0 \text{ kip-in}}$$

= 1.276

Critical Factor of Safety Against Cracking:

$FS_{cr.trans} =$ 1.276 ≥ 1.000 OK

Check Factor of Safety Against Failure

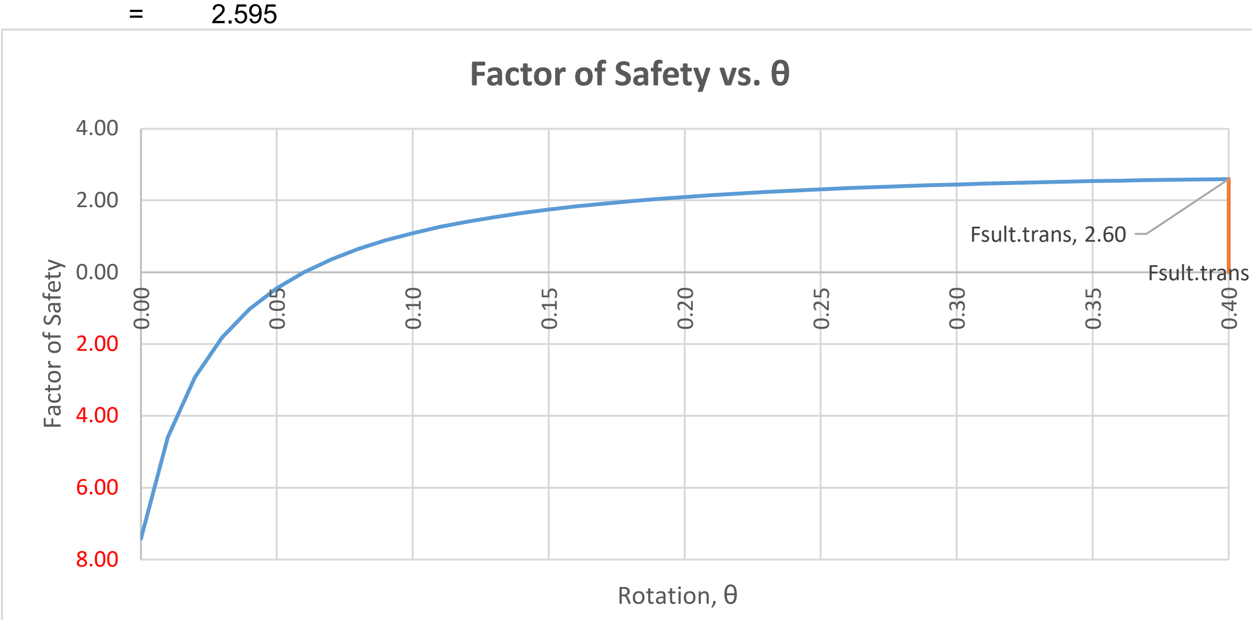
Factor of Safety Against Failure:

$$FS_{ult.trans}(\theta) = \frac{K_{\theta.trans}\,(\theta - \alpha_{trans})}{W_{girder.trans}[\,(z_{0.trans}\theta + z_{total.trans})(1 + 2.5\theta) + y_{r.trans}\theta + e_{i.trans}] + M_{ot.trans}}$$

Solution for Maximum Factor of Safety, $\theta_{max.ult.trans}$ = 0.40000 rad ≤ 0.4 rad

$$FS_{ult.trans} = \frac{(40{,}500 \text{ kip-in/rad})(0.40000 \text{ rad} - 0.06000 \text{ rad})}{(119.1 \text{ kip})\,[((9.355 \text{ in})(0.40000 \text{ rad}) + 0.000 \text{ in})\,(1 + 2.5(0.40000 \text{ rad})) + (85.751 \text{ in})(0.40000 \text{ rad}) + 2.749 \text{ in}] + 0 \text{ kip-in}}$$

= 2.595



Check Factor of Safety Against Failure for Critical Case

$$FS_{ult.trans} = \max(FS_{ult.trans}, FS_{cr.trans})$$

2.595 $<$ 1.500 OK

Check Factor of Safety Against Rollover (Cracked)

Overturning Moment from Wind and CE, $M_{roll.trans}$:

$$M_{roll.trans} = L_{girder}\,(w_{wind.trans} + CE_{trans})\,(h_{roll.trans} + z_{max.trans}\alpha_{trans})$$

= (136.00 ft)((0.000 klf + 0.000 klf)(24.000 in + (36.000 in)(0.06000 rad)))/(12in/ft)

= 0.0 kip-ft = 0 kip-in

Tilt Angle at Maximum Resisting Moment Arm, $\theta_{max.p.trans}$:

$$\theta_{max.p.trans} = \frac{W_{girder.trans}(z_{max.trans} - h_{roll.trans}\,\alpha_{trans}) + M_{roll.trans}}{K_{\theta.trans}} + \alpha_{trans}$$

$$= \frac{(119.1\text{ kip})(36.000\text{ in} - (24.000\text{ in})(0.06000\text{ rad})) + 0\text{ kip-in}}{40{,}500\text{ kip-in/rad}} + 0.06000\text{ rad}$$

= 0.16166 rad

Corresponding Center of Mass Eccentricity due to Tilt Angle, $z_{0.p.trans}$:

$$z_{0.p.trans} = z_{0.trans}\,(1 + 2.5\theta_{max.p.trans})$$

= (9.355 in)(1 + 2.5(0.16166 rad))

= 13.136 in

Factor of Safety:

$$FS_{roll.trans} = \frac{K_{\theta.trans}\,(\theta_{max.p.trans} - \alpha_{trans})}{W_{girder.trans}\left[(z_{0.p.trans} + y_{r.trans})\theta_{max.p.trans} + z_{total.trans}\,(1 + 2.5\,\theta_{max.p.trans}) + e_{i.trans}\right] + M_{ot.trans}}$$

$$= \frac{(40{,}500\text{ kip-in/rad})\,(0.162\text{ rad} - 0.06000\text{ rad})}{(119.1\text{ kip})[\,(13.136\text{ in} + 85.751\text{ in})(0.16166\text{ rad}) + (0.000\text{ in})(\,1 + 2.5(0.16166\text{ rad})) + 2.749\text{ in}\,] + 0\text{ kip-in}}$$

= 1.845

Factor of Safety against Rollover:

$FS_{roll.trans}$ = 1.845 ≥ 1.500 OK