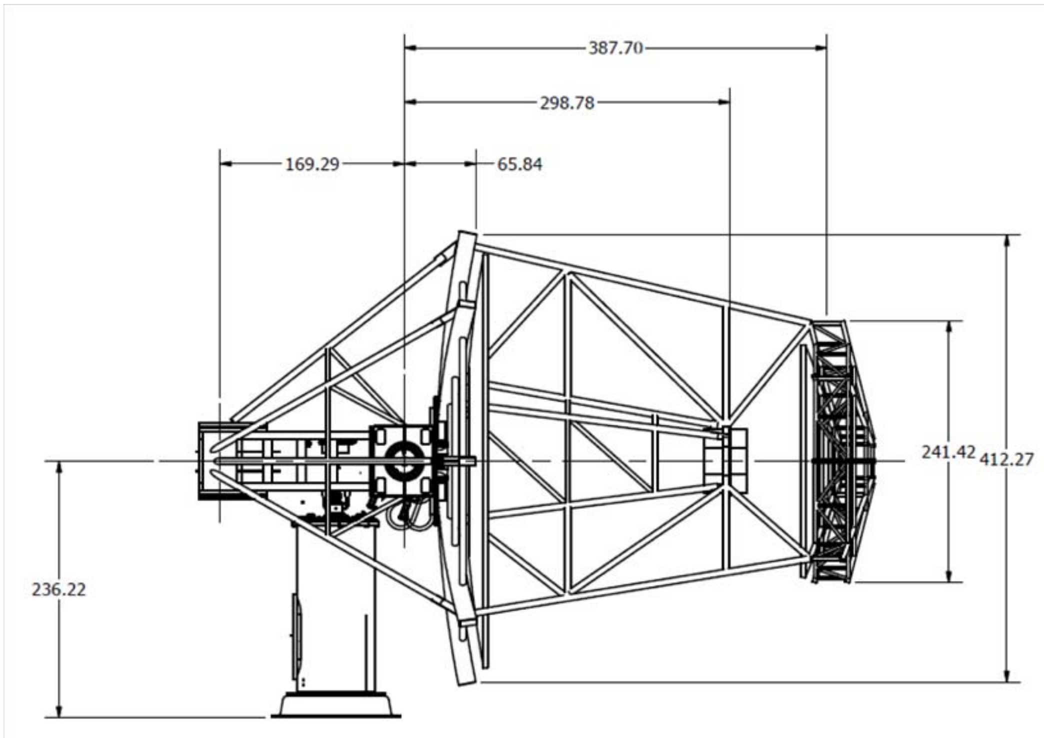
1.0 Define Material and Geometric Inputs used in the calculations
2.0 Calculation of the angular velocity and accelerations
3.0 Calculate the CounterWeight needed
4.0 Calculate approximate mass moments of inertia about the elevaton and azimuth axis
5.0 Calculate the wind torques and forces as a function of velocity, and elevation/azimuth angles
6.0 Calculate the wind torques at the park positions under maximum wind conditions
7.0 Calculate Foundation Strength



1.0 Inputs

Weight of components

$Wp := 7.1ton$ Weight of primary structure and mirrors

$Ws := 3.2ton$ Weight of secondary structure and mirrors

$Wc := 1ton$ Weight of Camera

$Wpositioner := 12.6ton$ Weight of Positioner

$Wyoke := 6ton$ Weight of yoke

Number of Mirrors

$Np := 48$ Number of Primary Mirrors

$Ns := 24$ Number of Secondary Mirrors

Define Geometry of Telescope

$Ls := 387in$ Distance from elevation axis to secondary

$Lc := 298in$ Distance from elevation axis to camera

$Lp := 65in$ Distance from elevation axis to primary

$Lcw := 169in$ Distance from elevation axis to CW

$Ds := 241in$ Diameter of Secondary

$Dp := 412in$ Diameter of Primary

$tp := 18in$ Thickness of Primary Structure

$ts := 36in$ Thickness of Secondary Structure

$Acamera := 0.6m$ Length of camera along optical axis

$Bcamera := 1.1m$ Diameter of camera

$HeightEL := 6m$ Height of the elevation axis above the ground

$Hcw := 48in$ Height of CW

Wind Velocities and Park Positions

$Vmax := 50\frac{km}{hr}$ Max 10 minute afveragewind speed

$Vmax = 31.07 \cdot mph$

$Vop := 36\frac{km}{hr}$ Operational 10 minute average wind speed

$Vop = 22.37 \cdot mph$

$Vsurvival := 120\frac{km}{hr}$ Survival 10 minute average wind speed

$Vsurvival = 74.56 \cdot mph$

$Vibc := 90mph$

$Vibc = 144.84 \cdot \frac{km}{hr}$

Design wind speed of International Building Code IBC-2009 and ASCE7-05
Veritas was designed to 34m/s (76mph) based on the 1997 Uniform Building Code which was the precursor to the IBC

$\alpha park1 := 15deg$

$\alpha park2 := 35deg$

$Zo := 30ft$ — Reference height for wind velocity

Bearing Friction Torques

$TfrictionEL := 15.3kN \cdot m$ — Bearing friction torque on elevation axis

$TfrictionAZ := 21.4kN \cdot m$ — Bearing friction torque on Azimuth axis

Seismic Loads

$Ss := 0.276$ $S1 := 0.075$ — From VERITAS foundation design documents

Soil Site Class D assumed

$Fa := 1.6$ $Fv := 2.4$ — Tables 11.4-1 and 11.4-2 Site Coefficients

$SDS := \frac{2}{3} \cdot Fa \cdot Ss$ $SDS = 0.29$

$SD1 := \frac{2}{3} \cdot Fv \cdot S1$ $SD1 = 0.12$ — Design Spectral Response

$To := 0.2 \cdot \frac{SD1}{SDS}$ $To = 0.08$

$Ts := \frac{SD1}{SDS}$ $Ts = 0.41$

$TL := 6$

$Sa := .4 \cdot SDS$ $Sa = 0.12$

2.0 Calculate the angular velocity and accelerations needed to meet the CTA specifications

According to CTA Level B Sub-System Performance Requirememtns Section 4.7 the telescope must be able to reach any point in the sky above 30 deg elevation within 90 seconds.

Assumption that both axis can rotate simultaniously.

The elevation axis has a range of 0 deg to 91 deg so to meet the requirement it must rotate from 30 deg to 90 deg in 90 seconds. The azimuth axis has a range of +/-270 degree. To meet the requirement it must rotate a maximum of 360 deg in 90 seconds.

2.1 Azimuth Axis

$\theta max := 180deg$

$\omega max := 4.0\frac{deg}{s}$

$\alpha Az := 0.1\frac{deg}{s^2}$

$ta := \frac{\omega max}{\alpha Az}$ $\quad ta = 40.00\,s$ $\quad$ Time for acceleration to maximum angular velocity

$\theta a := \frac{1}{2}\alpha Az \cdot ta^2$ $\quad \theta a = 80.00\cdot deg$ $\quad$ Angle during acceleration period

Defined maximum angular motion

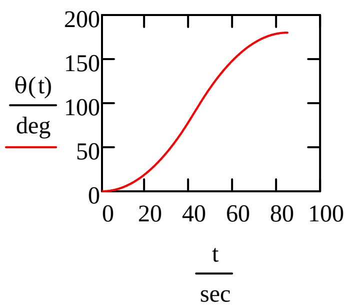
$tc := \frac{\theta max - 2\cdot\theta a}{\omega max}$ $\quad tc = 5.00\,s$ $\quad$ Time of constant angular velocity

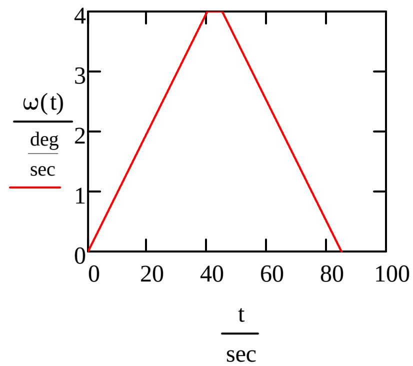
$tmax := 2\cdot ta + tc$ $\quad tmax = 85.00\,s$ $\quad$ Time required to achieve θmax

$t := 0.0sec, 0.1sec .. tmax$

$$\omega(t) := \begin{cases} (\alpha Az\cdot t) & \text{if } t \le ta \\ \omega max & \text{if } t > ta \\ [\omega max - \alpha Az\cdot(t - ta - tc)] & \text{if } t > ta + tc \end{cases}$$

$$\theta(t) := \begin{cases} \left(\frac{1}{2}\alpha Az\cdot t^2\right) & \text{if } t \le ta \\ [\theta a + \omega max\cdot(t - ta)] & \text{if } t \ge ta \wedge t \le tc + ta \\ \left[[\omega max\cdot(t - tc - ta)] - \frac{1}{2}\cdot\alpha Az\cdot(t - tc - ta)^2 + \theta a + \omega max\cdot tc\right] & \text{if } t > ta + tc \end{cases}$$





2.2 Elevation Axis

$\theta max := 90deg$

$\omega max := 2\frac{deg}{s}$

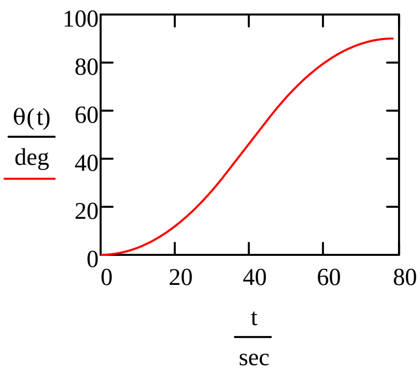
$\alpha El := 0.06\frac{deg}{s^2}$

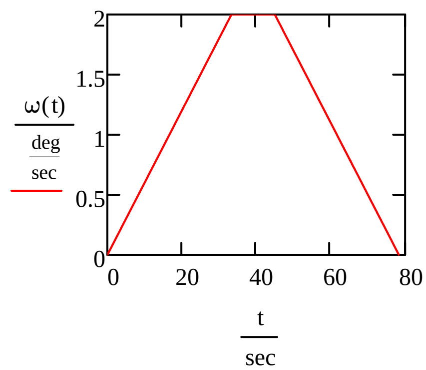
$ta := \frac{\omega max}{\alpha El}$	$ta = 33.33\,s$	Time for acceleration to maximum angular velocity
$\theta a := \frac{1}{2}\alpha El\cdot ta^2$	$\theta a = 33.33\cdot deg$	Angle during acceleration period
		Defined maximum angular motion
$tc := \frac{\theta max - 2\cdot\theta a}{\omega max}$	$tc = 11.67\,s$	Time of constant angular velocity
$tmax := 2\cdot ta + tc$	$tmax = 78.33\,s$	Time required to achieve θmax

$t := 0.0sec, 0.1sec\,..\,tmax$

$$\omega(t) := \begin{cases} (\alpha El\cdot t) & \text{if } t \le ta \\ \omega max & \text{if } t > ta \\ [\omega max - \alpha El\cdot(t - ta - tc)] & \text{if } t > ta + tc \end{cases}$$

$$\theta(t) := \begin{cases} \left(\frac{1}{2}\alpha El \cdot t^2\right) & \text{if } t \le ta \\ [\theta a + \omega max \cdot (t - ta)] & \text{if } t \ge ta \wedge t \le tc + ta \\ \left[[\omega max \cdot (t - tc - ta)] - \frac{1}{2} \cdot \alpha El \cdot (t - tc - ta)^2 + \theta a + \omega max \cdot tc\right] & \text{if } t > ta + tc \end{cases}$$





3.0 Calculate CW

$$Wcw := \frac{Ws \cdot Ls + Wc \cdot Lc + Wp \cdot Lp}{Lcw}$$

$Wcw = 11.8 \cdot ton$ Weight of counterweight

$Mcw := Wcw \cdot g \cdot Lcw$ $Mcw = 333 \cdot ft \cdot kip$ Moment of Counterweight

$Wtotal := Wcw + Ws + Wc + Wp$ Total weight of OSS

$Wtotal = 23.1 \cdot ton$

4.0 Calculate Inertias and Moments about elevation and Azimuth axis

$Is := Ws \cdot Ls^2$

$Is = 280501.43\, m^{2.00} \cdot kg$ Mass moment of inertia of secondary about elevation axis

$Ms := Ws \cdot g \cdot Ls$

$Ms = 279840.82 \cdot N \cdot m$

$Ic := Wc \cdot Lc^2$

$Ic = 51975\, m^2 \cdot kg$ Mass moment of inertia of camera about elevation axis

$Mc := Wc \cdot g \cdot Lc$

$Mc = 67338.96 \cdot N \cdot m$

$Ip := Wp \cdot Lp^2$

$Ip = 17556.92\, m^{2.00} \cdot kg$ Mass moment of inertia of primary about elevation axis

$Mp := Wp \cdot g \cdot Lp$

$Mp = 104285.00 \cdot N \cdot m$

$Icw(LCW) := \frac{Ws \cdot Ls + Wc \cdot Lc + Wp \cdot Lp}{LCW} \cdot LCW^2$

$Icw(Lcw) = 197616.69 \cdot kg \cdot m^2$

$Itotal(LCW) := Is + Ic + Ip + Icw(LCW)$

$Itotal(Lcw) = 547650\, m^2 \cdot kg$

Calculate the Inertia Torques

$\alpha ElMin := 0.06 \frac{deg}{s^2}$ Minimum Angular Velocity

$\alpha ElMax := .66 \frac{deg}{s^2}$ Maximum Angular Velocity

$TorqueInertiaMinEl := Itotal(Lcw) \cdot \alpha ElMin$

$TorqueInertiaMinEl = 423 \cdot lbf \cdot ft$

$TorqueInertiaMaxEl := Itotal(Lcw) \cdot \alpha ElMax$

$TorqueInertiaMaxEl = 4653 \cdot lbf \cdot ft$

TorqueInertiaMaxEl = 6.31·kN·m

Assume that the inertia about the azimuth axis is the same as the elevation axis

$\alpha AzMin := 0.1 \frac{deg}{s^2}$

$\alpha AzMax := 2 \frac{deg}{s^2}$

TorqueInertiaMinAz := Itotal(Lcw)·αAzMin

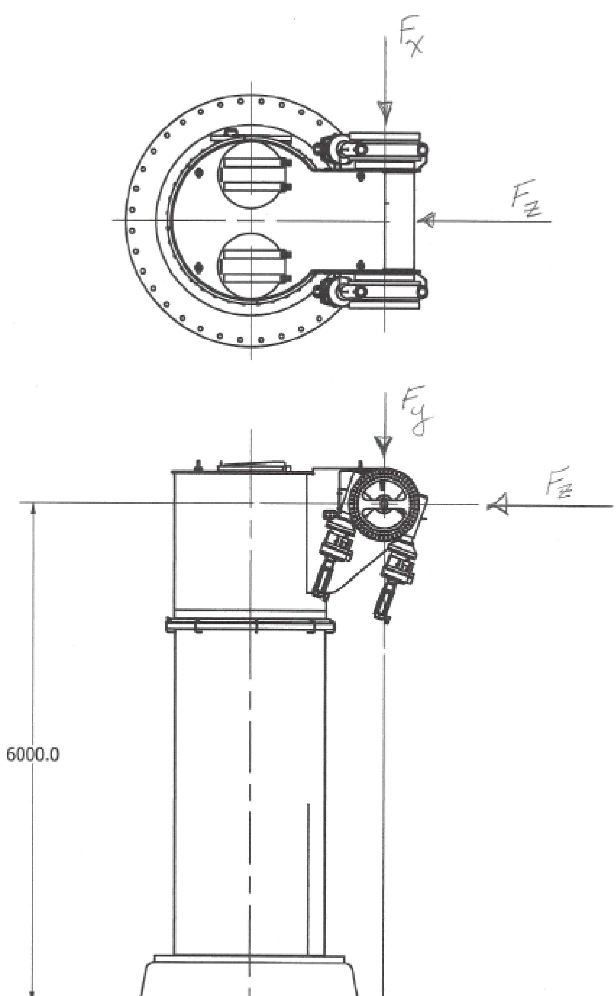
TorqueInertiaMinAz = 705·lbf·ft

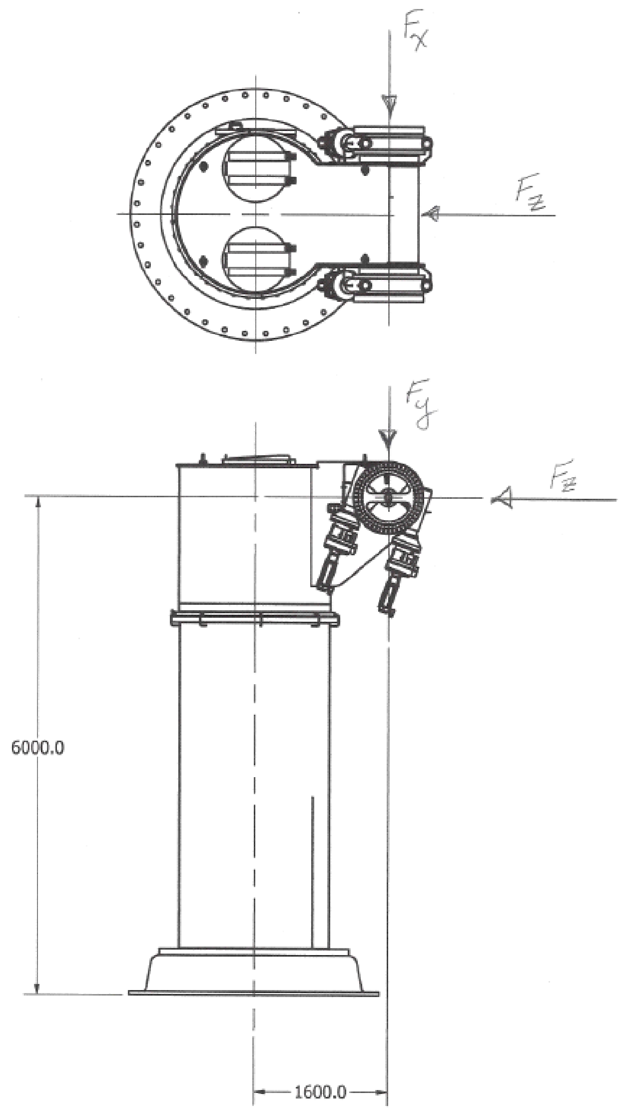
TorqueInertiaMaxAz := Itotal(Lcw)·αAzMax

TorqueInertiaMaxAz = 14·kip·ft

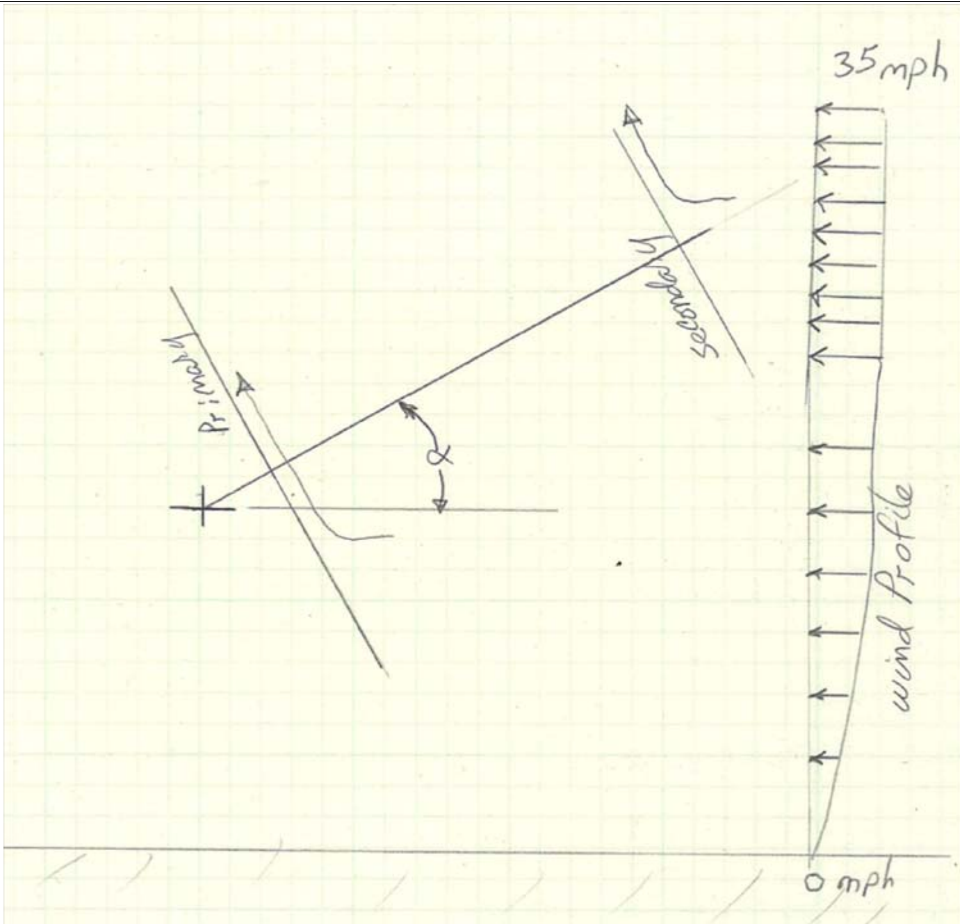
TorqueInertiaMaxAz = 19.12·kN·m

5.0 Calculate Torques and Forces Due to Wind
Assume each mirror is a flat plate at an angle to the wind





5.1 Define the Velocity Profile



Wind

Calculate the height to points on the primary/secondary as a function of the elevation angle and radial position on the mirror

$$hPrim(\alpha, rp) := HeightEL + Lp \cdot \sin(\alpha) + rp \cdot \cos(\alpha)$$

$$hSec(\alpha, rs) := HeightEL + Ls \cdot \sin(\alpha) + rs \cdot \cos(\alpha)$$

Calculate the wind torque assuming a smooth solid surface, no vortex shedding or drag
Ignore the curvature of the primary/secondary dishes and treat as flat plates

$$\rho air := 1.07 \frac{kg}{m^3}$$

Density at sea level 1.16

$$\alpha := 0deg, .1deg .. 90deg$$

$$Zref := 30ft$$

$Zo := .5ft$

Define the velocity profile.

$$VelPrim(\alpha, rp, Velocity) := \begin{cases} Velocity \cdot \dfrac{\ln\left(\dfrac{hPrim(\alpha, rp)}{Zo}\right)}{\ln\left(\dfrac{Zref}{Zo}\right)} & \text{if } hPrim(\alpha, rp) < Zref \\ Velocity & \text{otherwise} \end{cases}$$

$$VelSec(\alpha, rs, Velocity) := \begin{cases} Velocity \cdot \dfrac{\ln\left(\dfrac{hSec(\alpha, rs)}{Zo}\right)}{\ln\left(\dfrac{Zref}{Zo}\right)} & \text{if } hSec(\alpha, rs) < Zref \\ Velocity & \text{otherwise} \end{cases}$$

$$VelH(h, Velocity) := \begin{cases} Velocity \cdot \dfrac{\ln\left(\dfrac{h}{Zo}\right)}{\ln\left(\dfrac{Zref}{Zo}\right)} & \text{if } h < Zref \\ Velocity & \text{otherwise} \end{cases}$$

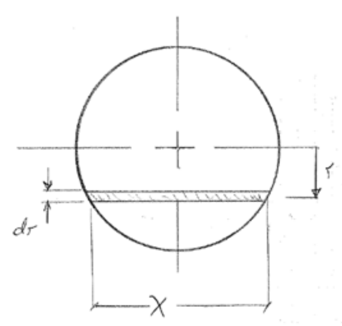
Calculate the vertical and horizontal force on the primary and secondary. Assume a conservative shape factor of 1.6

$Cd := 1.6$

$$XPrim(rp) := 2 \cdot \sqrt{\left(\frac{Dp}{2}\right)^2 - rp^2}$$

$$XSec(rs) := 2 \cdot \sqrt{\left(\frac{Ds}{2}\right)^2 - rs^2}$$

Length of differential strip wind is acting on for integration



5.2 Elevation Axis Torques

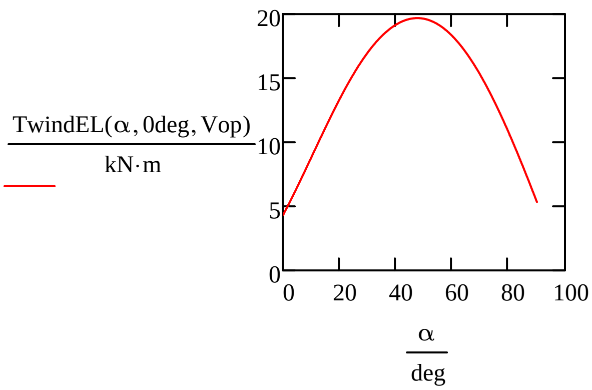
Calculate the Wind Forces and Torques

$$TwindEL(\alpha,\beta,Velocity) := \int_{-\frac{Dp}{2}}^{\frac{Dp}{2}} \frac{Cd\cdot\rho air\cdot(VelPrim(\alpha,rp,Velocity)\cdot\cos(\beta))^2}{2}\cdot XPrim(rp)\cdot\cos(\alpha)\cdot(Lp\cdot\sin(\alpha)+rp\cdot\cos(\alpha))\,drp\ ...$$

$$+\int_{-\frac{Ds}{2}}^{\frac{Ds}{2}} \frac{Cd\cdot\rho air\cdot(VelSec(\alpha,rs,Velocity)\cdot\cos(\beta))^2}{2}\cdot XSec(rs)\cdot\cos(\alpha)\cdot(Ls\cdot\sin(\alpha)+rs\cdot\cos(\alpha))\,drs\ ...$$

$$+\frac{Cd\cdot\rho air\cdot\left(VelPrim\left(\alpha,\frac{Dp}{2},Velocity\right)\cdot\cos(\beta)\right)^2}{2}\cdot(tp\cdot Dp)\cdot\sin(\alpha)\cdot\left(Lp\cdot\sin(\alpha)-\frac{Dp}{2}\cdot\cos(\alpha)\right)\ ...$$

$$+\frac{Cd\cdot\rho air\cdot\left(VelSec\left(\alpha,\frac{Ds}{2},Velocity\right)\cdot\cos(\beta)\right)^2}{2}\cdot(ts\cdot Ds)\cdot\sin(\alpha)\cdot\left(Ls\cdot\sin(\alpha)-\frac{Ds}{2}\cdot\cos(\alpha)\right)$$



$TVopEL(\alpha,\beta) := TwindEL(\alpha,\beta,Vop)$

$\alpha := 10deg$ $\beta := 0deg$

Given

$0deg < \alpha < 90deg$

$0deg < \beta < 90deg$

$$\begin{pmatrix}\alpha\\ \beta\end{pmatrix} := \text{Maximize}(\text{TVopEL}, \alpha, \beta)$$

$\alpha\text{maxEL} := \alpha$ $\alpha\text{maxEL} = 47.64\cdot\text{deg}$

$\beta\text{maxEL} := \beta$ $\beta\text{maxEL} = 0.00\cdot\text{deg}$

$\text{TwindMaxEL}(\text{Velocity}) := \text{TwindEL}(\alpha\text{maxEL}, \beta\text{maxEL}, \text{Velocity})$

$\text{TwindMaxEL}(\text{Vop}) = 14.5\cdot\text{kip}\cdot\text{ft}$ $\text{TwindMaxEL}(\text{Vop}) = 19.67\cdot\text{kN}\cdot\text{m}$

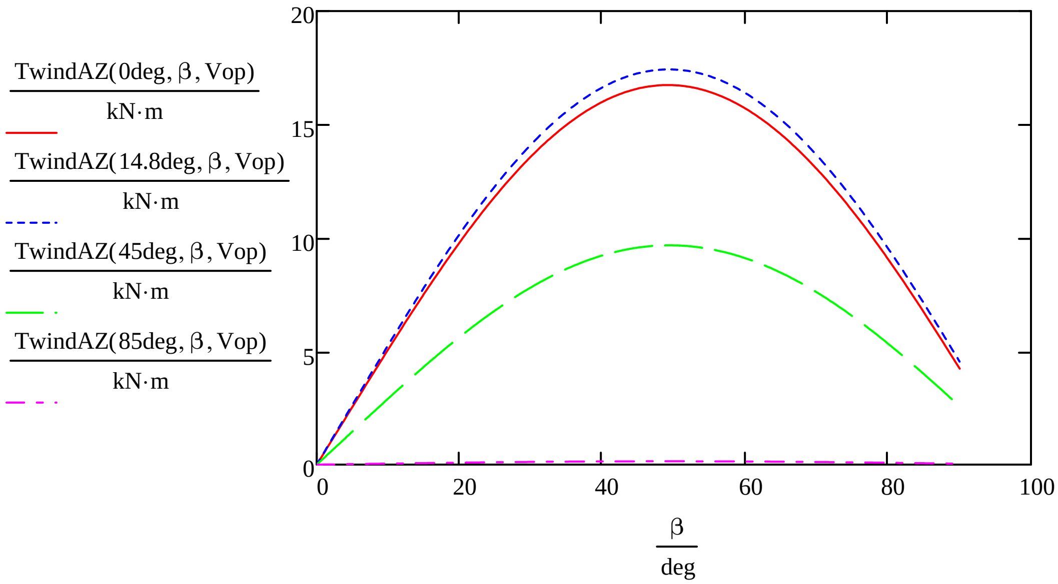
5.3 Calculate the wind torques about the Azimuth Axis

Calculate the height to points on the primary/secondary as a function of the elevation angle and radial position on the mirror

When β=0deg then the wind is along the optical axis

$$\text{TwindAZ}(\alpha, \beta, \text{Velocity}) := \int_{\frac{-\text{Dp}}{2}}^{\frac{\text{Dp}}{2}} \frac{\text{Cd}\cdot\rho\text{air}\cdot\text{VelPrim}(\alpha, \text{rp}, \text{Velocity})^2}{2}\cdot\text{XPrim}(\text{rp})\cdot\cos(\beta)\cdot\cos(\alpha)\cdot(\text{Lp}\cdot\cos(\alpha) - \text{rp}\cdot\sin(\alpha))\cdot\sin(\beta)\,d\text{rp} \ldots$$
$$+ \int_{\frac{-\text{Ds}}{2}}^{\frac{\text{Ds}}{2}} \frac{\text{Cd}\cdot\rho\text{air}\cdot\text{VelSec}(\alpha, \text{rs}, \text{Velocity})^2}{2}\cdot\text{XSec}(\text{rs})\cdot\cos(\beta)\cdot\cos(\alpha)\cdot[(\text{Ls}\cdot\cos(\alpha) - \text{rs}\cdot\sin(\alpha))\cdot\sin(\beta)]\,d\text{rs} \ldots$$
$$+ \int_{\frac{-\text{Dp}}{2}}^{\frac{\text{Dp}}{2}} \frac{\text{Cd}\cdot\rho\text{air}\cdot\text{VelPrim}(\alpha, \text{rp}, \text{Velocity})^2}{2}\cdot\text{tp}\cdot\sin(\beta)\cdot(\text{Lp}\cdot\cos(\alpha) - \text{rp}\cdot\sin(\alpha))\cdot\sin(\beta)\cdot\cos(\alpha)\,d\text{rp} \ldots$$
$$+ \int_{\frac{-\text{Ds}}{2}}^{\frac{\text{Ds}}{2}} \frac{\text{Cd}\cdot\rho\text{air}\cdot\text{VelSec}(\alpha, \text{rs}, \text{Velocity})^2}{2}\cdot\text{ts}\cdot\sin(\beta)\cdot(\text{Ls}\cdot\cos(\alpha) - \text{rs}\cdot\sin(\alpha))\cdot\sin(\beta)\cdot\cos(\alpha)\,d\text{rs}$$

$\beta := 0.0\text{deg}, 0.2\text{deg} .. 90\text{deg}$ Azimuth Angle



$TVopAZ(\alpha,\beta) := TwindAZ(\alpha,\beta,Vop)$

$\alpha := 10deg$ $\beta := 0deg$

Given

$0deg < \alpha < 90deg$

$0deg < \beta < 90deg$

$\begin{pmatrix}\alpha \\ \beta\end{pmatrix} := Maximize(TVopAZ,\alpha,\beta)$

$\alpha maxAZ := \alpha$ $\alpha maxAZ = 10.13\cdot deg$

$\beta maxAZ := \beta$ $\beta maxAZ = 49.27\cdot deg$

$TwindMaxAZ(Velocity) := TwindAZ(\alpha maxAZ,\beta maxAZ,Velocity)$

$TwindMaxAZ(Vop) = 13.0\cdot kip\cdot ft$ $TwindMaxAZ(Vop) = 17.61\cdot kN\cdot m$

5.4 Calculate the Force in the X Direction Due to Wind

$$\mathrm{FwindX}(\alpha,\beta,\mathrm{Velocity}) := \int_{\frac{-Dp}{2}}^{\frac{Dp}{2}} \frac{Cd\cdot\rho air\cdot \mathrm{VelPrim}(\alpha,rp,\mathrm{Velocity})^2}{2}\cdot \mathrm{XPrim}(rp)\cdot\cos(\beta)\cdot\sin(\beta)\cdot\cos(\alpha)\,drp\ \ldots$$
$$+\int_{\frac{-Ds}{2}}^{\frac{Ds}{2}} \frac{Cd\cdot\rho air\cdot \mathrm{VelSec}(\alpha,rs,\mathrm{Velocity})^2}{2}\cdot \mathrm{XSec}(rs)\cdot\cos(\beta)\cdot\sin(\beta)\cdot\cos(\alpha)\,drs\ \ldots$$
$$+\int_{\frac{-Dp}{2}}^{\frac{Dp}{2}} \frac{Cd\cdot\rho air\cdot \mathrm{VelPrim}(\alpha,rp,\mathrm{Velocity})^2}{2}\cdot tp\cdot\sin(\beta)\cdot\sin(\beta)\cdot\cos(\alpha)\,drp\ \ldots$$
$$+\int_{\frac{-Ds}{2}}^{\frac{Ds}{2}} \frac{Cd\cdot\rho air\cdot \mathrm{VelSec}(\alpha,rs,\mathrm{Velocity})^2}{2}\cdot ts\cdot\sin(\beta)\cdot\sin(\beta)\cdot\cos(\alpha)\,drs$$

$$\mathrm{FpMirrorX}(\alpha,\beta,h,\mathrm{Velocity}) := Cd\cdot\rho air\cdot\frac{\mathrm{VelH}(h,\mathrm{Velocity})^2}{2}\cdot\frac{\left(\pi\cdot Dp^2\right)}{4Np}\cdot\cos(\beta)\cdot\cos(\alpha)\cdot\sin(\beta) + Cd\cdot\rho air\cdot\frac{\mathrm{VelH}(h,\mathrm{Velocity})^2}{2}\cdot\frac{Dp\cdot tp}{Np}\cdot\sin(\beta)$$

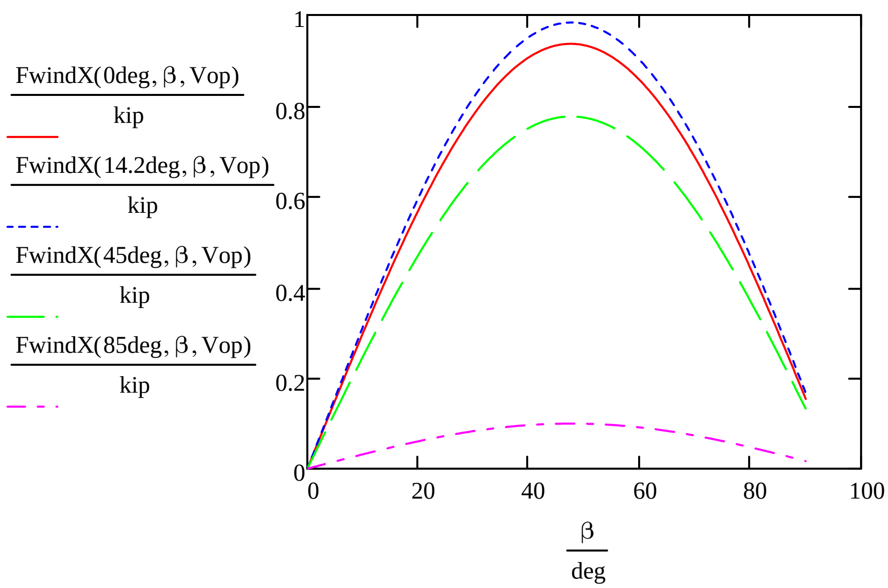
$$\mathrm{FsMirrorX}(\alpha,\beta,h,\mathrm{Velocity}) := Cd\cdot\rho air\cdot\frac{\mathrm{VelH}(h,\mathrm{Velocity})^2}{2}\cdot\frac{\left(\pi\cdot Ds^2\right)}{4Ns}\cdot\cos(\beta)\cdot\cos(\alpha)\cdot\sin(\beta) + Cd\cdot\rho air\cdot\frac{\mathrm{VelH}(h,\mathrm{Velocity})^2}{2}\cdot\frac{Ds\cdot ts}{Ns}\cdot\sin(\beta)\cdot$$

$$\mathrm{FpwindX}(\alpha,\beta,\mathrm{Velocity}) := \frac{1}{Np}\cdot\left(\begin{array}{l}\displaystyle\int_{\frac{-Dp}{2}}^{\frac{Dp}{2}} \frac{Cd\cdot\rho air\cdot \mathrm{VelPrim}(\alpha,rp,\mathrm{Velocity})^2}{2}\cdot \mathrm{XPrim}(rp)\cdot\cos(\beta)\cdot\sin(\beta)\cdot\cos(\alpha)\,drp\ \ldots\\ \displaystyle+\int_{\frac{-Dp}{2}}^{\frac{Dp}{2}} \frac{Cd\cdot\rho air\cdot \mathrm{VelPrim}(\alpha,rp,\mathrm{Velocity})^2}{2}\cdot tp\cdot\sin(\beta)\cdot\sin(\beta)\cdot\cos(\alpha)\,drp\end{array}\right)$$

$$FswindX(\alpha,\beta,Velocity) := \frac{1}{Ns}\cdot\left(\int_{\frac{-Ds}{2}}^{\frac{Ds}{2}} \frac{Cd\cdot\rho air\cdot VelSec(\alpha,rs,Velocity)^2}{2}\cdot XSec(rs)\cdot\cos(\beta)\cdot\sin(\beta)\cdot\cos(\alpha)\,drs\ ... \\ + \int_{\frac{-Ds}{2}}^{\frac{Ds}{2}} \frac{Cd\cdot\rho air\cdot VelSec(\alpha,rs,Velocity)^2}{2}\cdot ts\cdot\sin(\beta)\cdot\sin(\beta)\cdot\cos(\alpha)\,drs\right)$$

$\beta := 0.0deg, 0.2deg .. 90deg$

Azimuth Angle



$FVopX(\alpha,\beta) := FwindX(\alpha,\beta,Vop)$

$\alpha := 10deg$ $\beta := 0deg$

Given

$0deg < \alpha < 90deg$

$0deg < \beta < 90deg$

$$\begin{pmatrix} \alpha \\ \beta \end{pmatrix} := \text{Maximize}(\text{FVopX}, \alpha, \beta)$$

$\alpha\text{maxEL} := \alpha$ $\qquad$ $\alpha\text{maxEL} = 14.19 \cdot \text{deg}$

$\beta\text{maxEL} := \beta$ $\qquad$ $\beta\text{maxEL} = 47.66 \cdot \text{deg}$

$$\text{FwindMaxX}(\text{Velocity}) := \text{FwindX}(\alpha\text{maxEL}, \beta\text{maxEL}, \text{Velocity})$$

$\text{FwindMaxX}(\text{Vop}) = 1.0 \cdot \text{kip}$ $\qquad$ $\text{FwindMaxX}(\text{Vop}) = 4.37 \cdot \text{kN}$

5.5 Calculate the Force in the Z Direction Due to Wind

$$\text{FwindZ}(\alpha, \beta, \text{Velocity}) := \int_{\frac{-\text{Dp}}{2}}^{\frac{\text{Dp}}{2}} \frac{\text{Cd} \cdot \rho\text{air} \cdot \text{VelPrim}(\alpha, \text{rp}, \text{Velocity})^2}{2} \cdot \text{XPrim}(\text{rp}) \cdot \cos(\beta) \cdot \cos(\beta) \cdot \cos(\alpha)\, d\text{rp} \ldots$$
$$+ \int_{\frac{-\text{Ds}}{2}}^{\frac{\text{Ds}}{2}} \frac{\text{Cd} \cdot \rho\text{air} \cdot (\text{VelSec}(\alpha, \text{rs}, \text{Velocity}))^2}{2} \cdot \text{XSec}(\text{rs}) \cdot \cos(\alpha) \cdot \cos(\beta) \cdot \cos(\beta)\, d\text{rs} \ldots$$
$$+ \frac{\text{Cd} \cdot \rho\text{air} \cdot \left(\text{VelPrim}\left(\alpha, \frac{\text{Dp}}{2}, \text{Velocity}\right)\right)^2}{2} \cdot (\text{tp} \cdot \text{Dp}) \cdot \sin(\alpha) \cdot \cos(\beta) \cdot \cos(\beta) \ldots$$
$$+ \frac{\text{Cd} \cdot \rho\text{air} \cdot \left(\text{VelSec}\left(\alpha, \frac{\text{Ds}}{2}, \text{Velocity}\right)\right)^2}{2} \cdot (\text{ts} \cdot \text{Ds}) \cdot \sin(\alpha) \cdot \cos(\beta) \cdot \cos(\beta)$$

$$\text{FpMirrorZ}(\alpha, \beta, h, \text{Velocity}) := \text{Cd} \cdot \rho\text{air} \cdot \frac{\text{VelH}(h, \text{Velocity})^2}{2} \cdot \frac{\left(\pi \cdot \text{Dp}^2\right)}{4\text{Np}} \cdot \cos(\beta) \cdot \cos(\alpha) \cdot \cos(\beta)$$

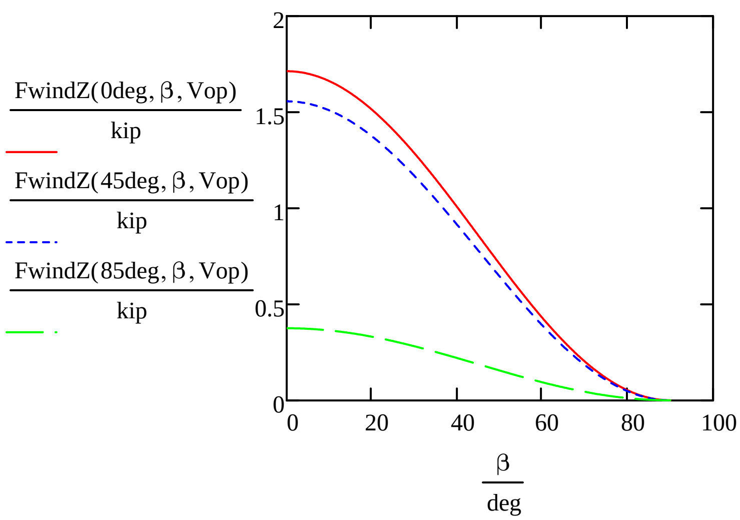
$$\text{FsMirrorZ}(\alpha, \beta, h, \text{Velocity}) := \text{Cd} \cdot \rho\text{air} \cdot \frac{\text{VelH}(h, \text{Velocity})^2}{2} \cdot \frac{\left(\pi \cdot \text{Ds}^2\right)}{4\text{Ns}} \cdot \cos(\beta) \cdot \cos(\alpha) \cdot \cos(\beta)$$

$$FpwindZ(\alpha,\beta,Velocity) := \frac{1}{Np}\cdot\left[\int_{\frac{-Dp}{2}}^{\frac{Dp}{2}} \frac{Cd\cdot\rho air\cdot VelPrim(\alpha,rp,Velocity)^2}{2}\cdot XPrim(rp)\cdot\cos(\beta)\cdot\cos(\beta)\cdot\cos(\alpha)\,drp \ldots + \frac{Cd\cdot\rho air\cdot\left(VelPrim\left(\alpha,\frac{Dp}{2},Velocity\right)\right)^2}{2}\cdot(tp\cdot Dp)\cdot\sin(\alpha)\cdot\cos(\beta)\cdot\cos(\beta)\right]$$

$$FswindZ(\alpha,\beta,Velocity) := \frac{1}{Ns}\cdot\left[\int_{\frac{-Ds}{2}}^{\frac{Ds}{2}} \frac{Cd\cdot\rho air\cdot(VelSec(\alpha,rs,Velocity))^2}{2}\cdot XSec(rs)\cdot\cos(\alpha)\cdot\cos(\beta)\cdot\cos(\beta)\,drs \ldots + \frac{Cd\cdot\rho air\cdot\left(VelSec\left(\alpha,\frac{Ds}{2},Velocity\right)\right)^2}{2}\cdot(ts\cdot Ds)\cdot\sin(\alpha)\cdot\cos(\beta)\cdot\cos(\beta)\right]$$

$\beta := 0.0deg, 0.2deg .. 90deg$

Azimuth Angle



Calculate the Maximum Force in Z

Initial Guess

$\alpha := 10deg$ $\beta := 10deg$

$FwindMaxZ(\alpha, \beta) := FwindZ(\alpha, \beta, Vop)$

$\begin{pmatrix} \alpha \\ \beta \end{pmatrix} := Maximize(FwindMaxZ, \alpha, \beta)$

$\alpha FZmax := \alpha$ $\alpha FZmax = 17.81 \cdot deg$

$\beta FZmax := \beta$ $\beta FZmax = -0.00 \cdot deg$

$FwindMaxZ(Velocity) := FwindZ(\alpha FZmax, \beta FZmax, Velocity)$

$FwindMaxZ(Vop) = 1.8 \cdot kip$ $FwindMaxZ(Vop) = 8.22 \cdot kN$

6.0 Calculate Torques and ForcesFor All Wind Velocities

6.1 Tracking Wind Velocity 36km/hr

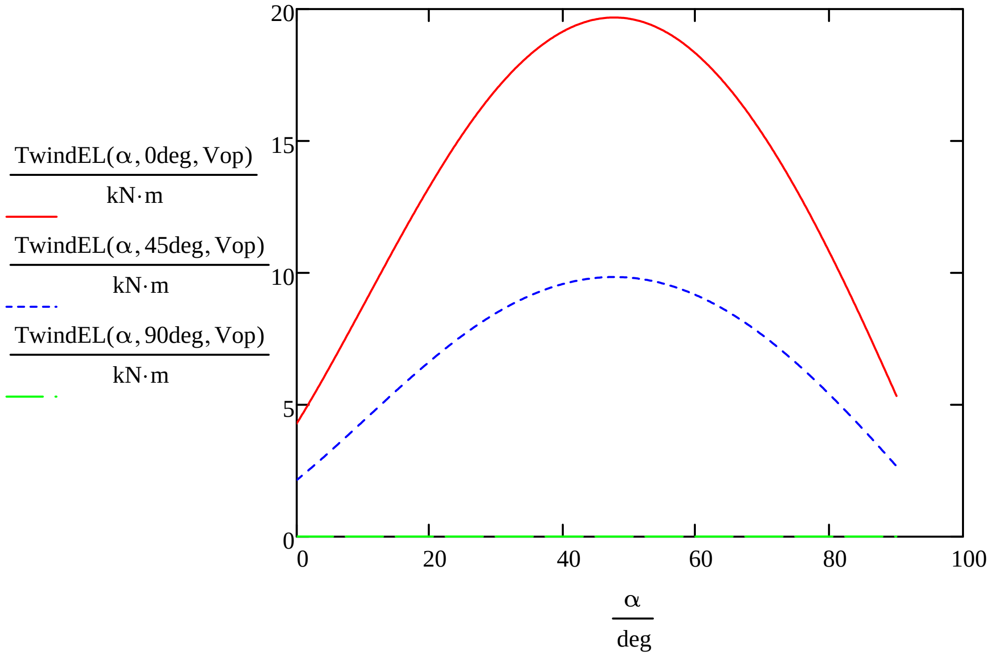
Elevation Torque

$TwindMaxEL(Vop) = 19.67 \cdot kN \cdot m$ $TwindMaxEL(Vop) = 14.51 \cdot kip \cdot ft$

$TmaxEL := TwindMaxEL(Vop) + TfrictionEL + TorqueInertiaMaxEl$

$TmaxEL = 41.28 \cdot kN \cdot m$ $TmaxEL = 30.45 \cdot kip \cdot ft$

$\alpha := 0deg, 0.2deg .. 90deg$



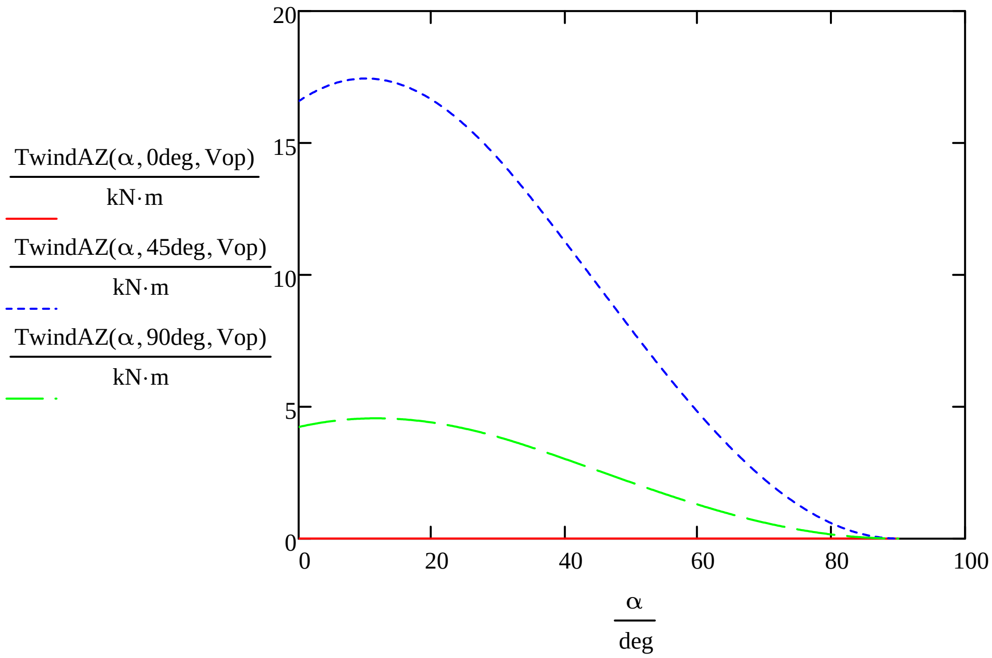
Azimuth Torque

$TwindMaxAZ(Vop) = 17.61 \cdot kN \cdot m$ $\quad$ $TwindMaxAZ(Vop) = 12.99 \cdot kip \cdot ft$

$TmaxAZ := TwindMaxAZ(Vop) + TfrictionAZ + TorqueInertiaMaxAz$

$TmaxAZ = 58.12 \cdot kN \cdot m$ $\quad$ $TmaxAZ = 42.87 \cdot kip \cdot ft$

$\alpha := 0deg, 0.2deg .. 90deg$



FwindMaxX(Vop) = 4374.18 N   FwindMaxX(Vop) = 0.98·kip

FwindMaxZ(Vop) = 8215.08 N   FwindMaxZ(Vibc) = 29.90·kip

yn := −9ft

Primary mirror wind loads

FpMirrorX(0deg, 0deg, yn + 19.7ft, Vibc) = 0.00·kip   FpMirrorZ(0deg, 0deg, yn + 19.7ft, Vop) = 0.02·kip

FpwindX(35deg, 90deg, Vibc) = 0.02·kip   FpwindZ(0deg, 0deg, Vop) = 0.03·kip

Secondary mirror wind loads

FsMirrorX(35deg, 90deg, yn + 19.7ft, Vibc) = 0.03·kip   FsMirrorZ(35deg, 90deg, yn + 19.7ft, Vibc) = 0.00·kip

FswindX(35deg, 90deg, Vibc) = 0.06·kip   FswindZ(0deg, 0deg, Vop) = 0.02·kip

6.2 Slewing Wind Velocity 50km/hr

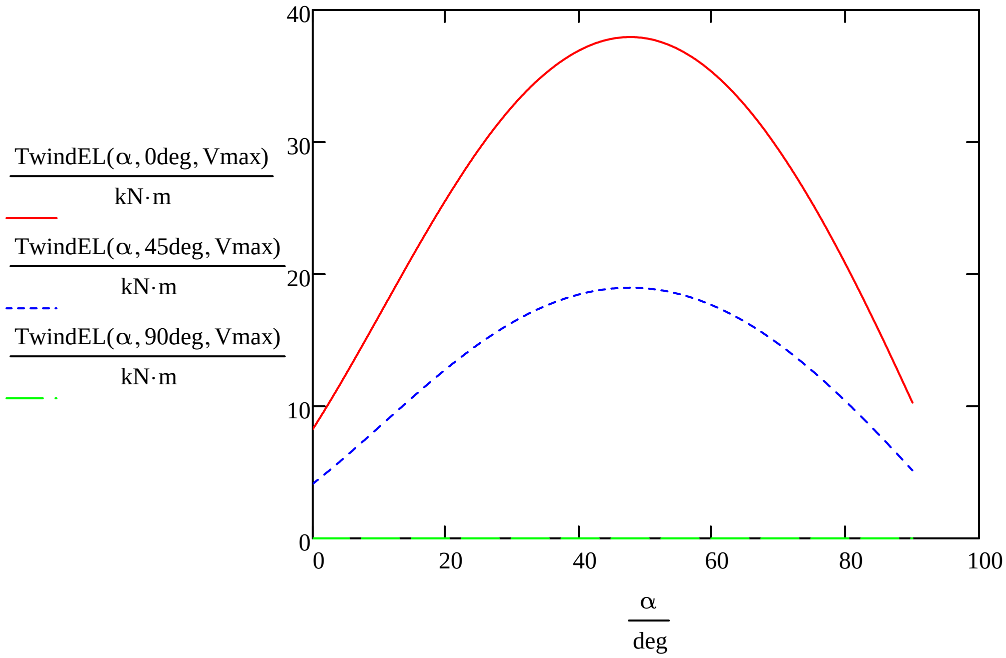
Elevation Torque

$TwindMaxEL(Vmax) = 37.95 \cdot kN \cdot m$ $\quad$ $TwindMaxEL(Vmax) = 27.99 \cdot kip \cdot ft$

$TmaxEL := TwindMaxEL(Vmax) + TfrictionEL + TorqueInertiaMaxEl$

$TmaxEL = 59.56 \cdot kN \cdot m$ $\quad$ $TmaxEL = 43.93 \cdot kip \cdot ft$

$\alpha := 0deg, 0.2deg .. 90deg$



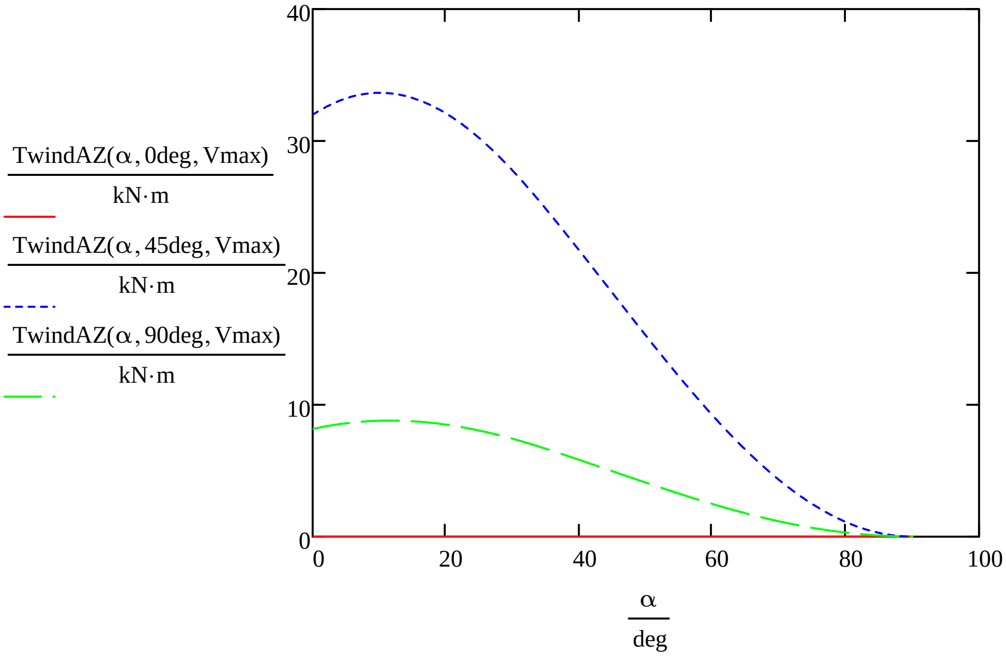
Azimuth Torque

$TwindMaxAZ(Vmax) = 33.97 \cdot kN \cdot m$ $\quad$ $TwindMaxAZ(Vmax) = 25.05 \cdot kip \cdot ft$

$TmaxAZ := TwindMaxAZ(Vmax) + TfrictionAZ + TorqueInertiaMaxAz$

$TmaxAZ = 74.48 \cdot kN \cdot m$ $\quad$ $TmaxAZ = 54.94 \cdot kip \cdot ft$

$\alpha := 0deg, 0.2deg .. 90deg$



FwindMaxX(Vmax) = 8437.85 N   FwindMaxX(Vmax) = 1.90·kip

FwindMaxZ(Vmax) = 15846.99 N   FwindMaxZ(Vmax) = 3.56·kip

6.3 CTA Survival Wind Velocity 120km/hr

Under survival wind conditions the telescope will not translate so the inertia and friction torques are not considered

Elevation Torque

TwindMaxEL(Vsurvival) = 218.61·kN·m   TwindMaxEL(Vsurvival) = 161.24·kip·ft

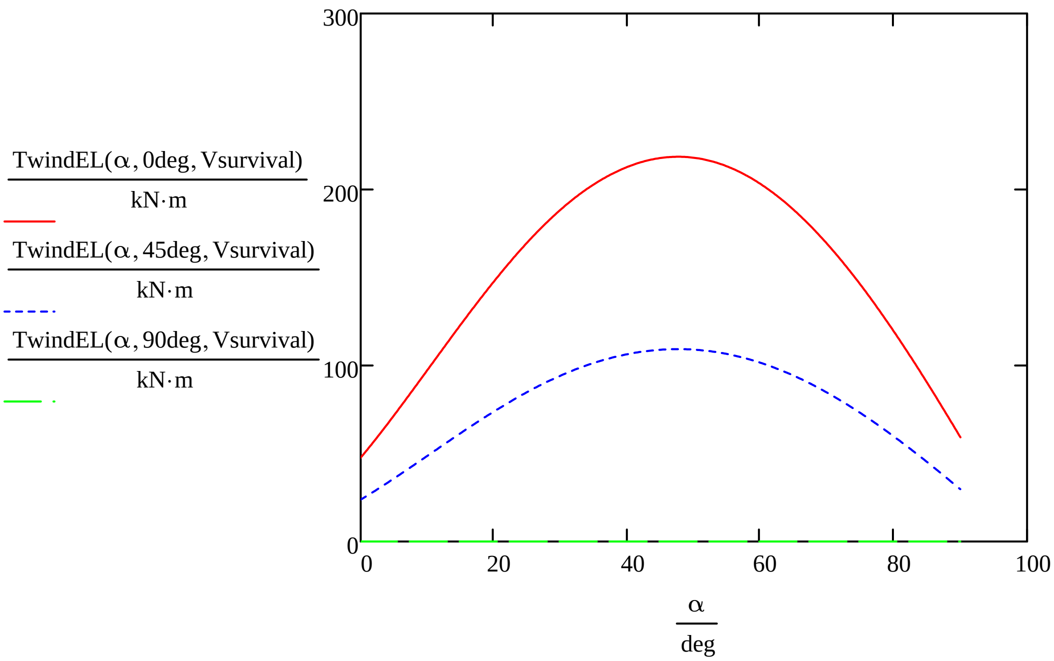
TELpark1 := TwindEL(αpark1, 0deg, Vsurvival)   Elevation Axis wind torque at the Park Position 1

TELpark1 = 123.17·kN·m   TELpark1 = 90.84·kip·ft

TELpark2 := TwindEL(αpark2, 0deg, Vsurvival)   Elevation Axis wind torque at the Park Position 2

TELpark2 = 202.92·kN·m   TELpark2 = 149.67·kip·ft

$\alpha := 0deg, 0.2deg .. 90deg$



Azimuth Torque

$TwindMaxAZ(Vsurvival) = 195.64 \cdot kN \cdot m$ $TwindMaxAZ(Vsurvival) = 144.30 \cdot kip \cdot ft$

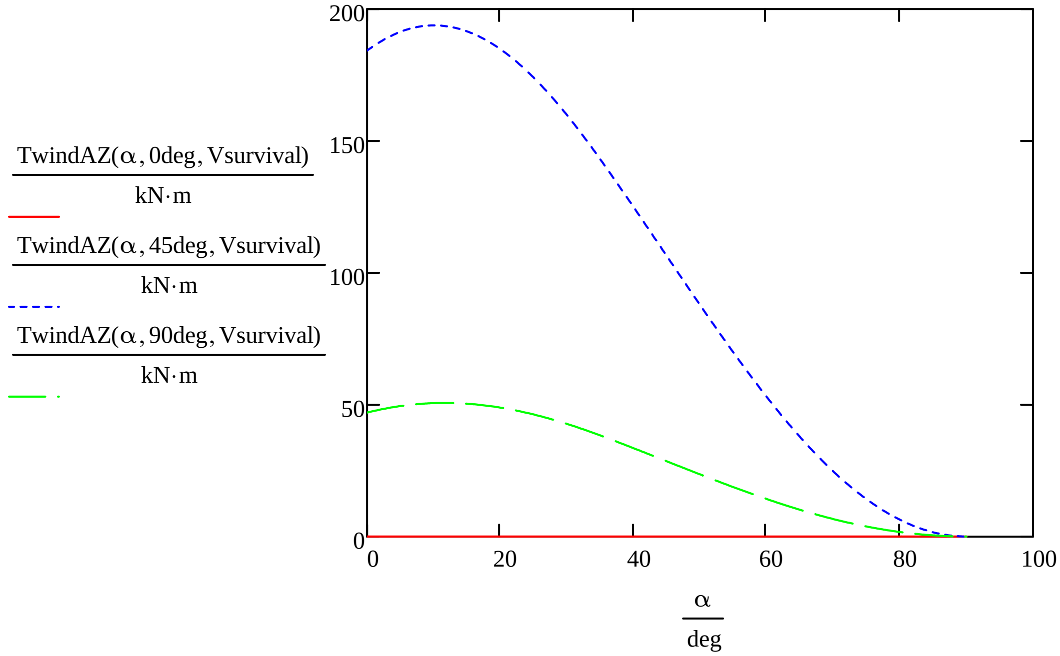
$TAZpark1 := TwindAZ(\alpha park1, 45deg, Vsurvival)$ Azimuth Axis wind torque at the Park Position 1

$TAZpark1 = 191.49 \cdot kN \cdot m$ $TAZpark1 = 141.24 \cdot kip \cdot ft$

$TAZpark2 := TwindEL(\alpha park2, 45deg, Vsurvival)$ Azimuth Axis wind torque at the Park Position 2

$TAZpark2 = 101.46 \cdot kN \cdot m$ $TAZpark2 = 74.83 \cdot kip \cdot ft$

$\alpha := 0deg, 0.2deg .. 90deg$



6.4 IBC Survival Wind Velocity 90mph

Under survival wind conditions the telescope will not translate so the inertia and friction torques are not considered

Elevation Torque

$TwindMaxEL(Vibc) = 318.48 \cdot kN \cdot m$ $TwindMaxEL(Vibc) = 234.90 \cdot kip \cdot ft$

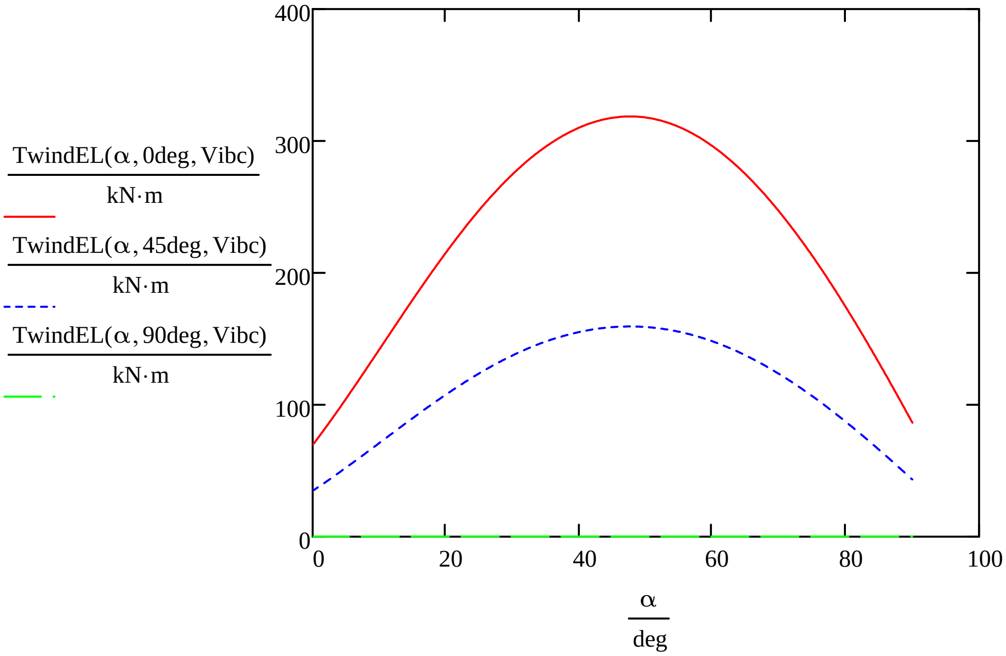
$TELpark1 := TwindEL(35deg, 0deg, Vibc)$ Elevation Axis wind torque at the Park Position 1

$TELpark1 = 295.63 \cdot kN \cdot m$ $TELpark1 = 218.05 \cdot kip \cdot ft$

$TELpark2 := TwindEL(\alpha park2, 0deg, Vibc)$ Elevation Axis wind torque at the Park Position 2

$TELpark2 = 295.63 \cdot kN \cdot m$ $TELpark2 = 218.05 \cdot kip \cdot ft$

$\alpha := 0deg, 0.2deg .. 90deg$



Azimuth Torque

TwindMaxAZ(Vibc) = 285.03·kN·m   TwindMaxAZ(Vibc) = 210.23·kip·ft

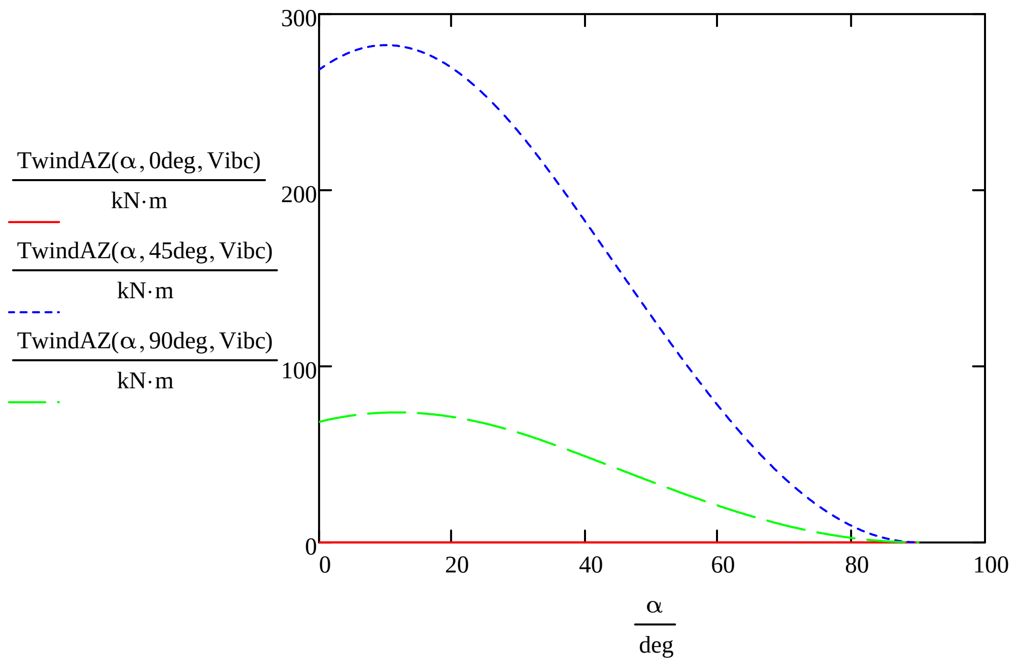
TAZpark1 := TwindAZ(−15deg, 0deg, Vibc)   Azimuth Axis wind torque at the Park Position 1

TAZpark1 = 0.00·kN·m   TAZpark1 = 0.00·kip·ft

TAZpark2 := TwindEL(αpark2, 45deg, Vibc)   Azimuth Axis wind torque at the Park Position 2

TAZpark2 = 147.82·kN·m   TAZpark2 = 109.02·kip·ft

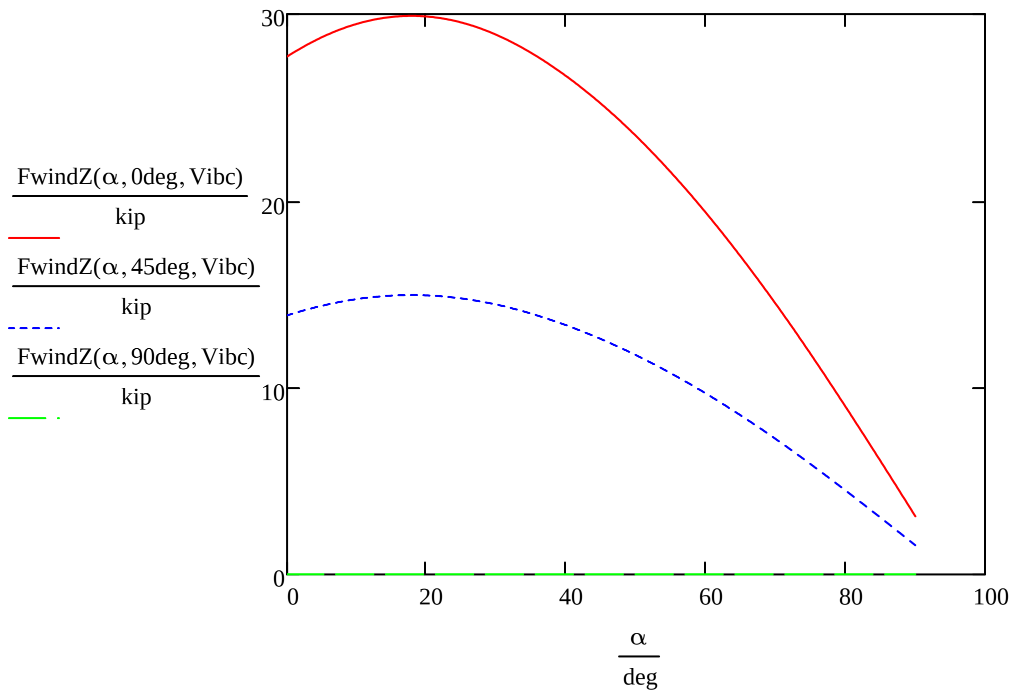
α := 0deg, 0.2deg .. 90deg



Force in Z direction

$FwindZ(35deg, 0deg, Vibc) = 124.13 \cdot kN$ $\quad$ $FwindZ(35deg, 0deg, Vibc) = 27.91 \cdot kip$

$FwindMaxZ(Vibc) = 132.98 \cdot kN$ $\quad$ $FwindMaxZ(Vibc) = 29.90 \cdot kip$



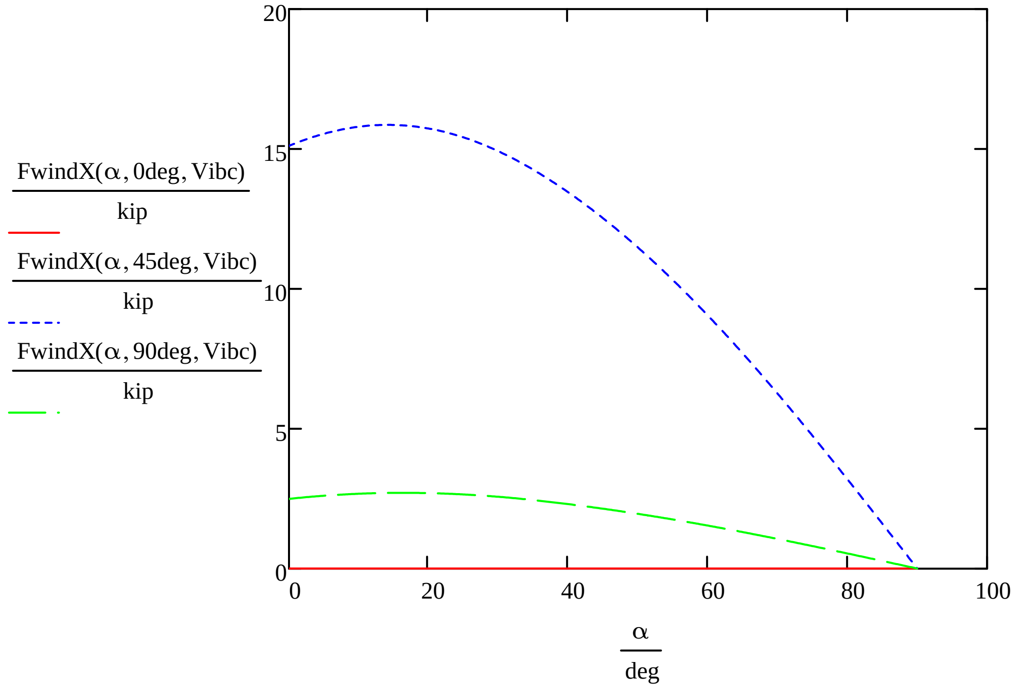
Force in X Direction

$\text{FwindX}(35\text{deg}, 47.6\text{deg}, \text{Vibc}) = 63.64 \cdot \text{kN}$

$\text{FwindX}(35\text{deg}, 47.6\text{deg}, \text{Vibc}) = 14.31 \cdot \text{kip}$

$\text{FwindMaxX}(\text{Vibc}) = 70.81 \cdot \text{kN}$

$\text{FwindMaxX}(\text{Vibc}) = 15.92 \cdot \text{kip}$



7.0 Calculate Concrete Foundation Strength at the 15degree park position

7.1 Inputs

$Wt := Wtotal + Wpositioner + Wyoke$ Total Weight of OSS, Counterweight and Positioner

$Wt = 41.72 \cdot ton$

$HeightEL = 6.00\,m$ Height of the elevation axis above the ground

$Lelevation := 1.6m$ Distance from elevation axis to centerline of tower/foundation

$qsoil := 3000 \frac{lbf}{ft^2}$

Define Concrete and Foundation Properties

$\phi f := 0.9$

$fc := 4ksi$ Strength of concrete

$fy := 60ksi$ Yield strength of steel reinforcement

$db := 25mm$ Diameter of reinforcement steel

$Ab := \frac{\pi \cdot db^2}{4}$

$Ab = 0.76 \cdot in^2$ Area of reinforcement bar

$nbars := 17$ Number of bars in cross section

$As := nbars \cdot Ab$ $As = 12.93 \cdot in^2$ Total steel area in cross section

$dflange := 2134mm$ Diameter of bolt circle on flange

$dbf := 1.25in$ Diameter of bolts on flange

$nfbolts := 24$ Number of flange bolts

$Df := 5m$ Diameter of foundation

$rf := \frac{Df}{2}$

$depth := 800mm$ Depth of Foundation

$d := 800mm - 75mm$ Depth of steel

$d = 28.54 \cdot in$

$r1 := \frac{dflange}{2}$

$Af := \frac{\pi \cdot Df^2}{4}$ Bearing Area of foundation

$PuFoundation := 150 \frac{lbf}{ft^3} \cdot Af \cdot depth$

$PuFoundation = 83.2 \cdot kip$

Define Concrete Breakout Strength of Bolts

$kc := 24$ Cast in place bolts -- D5.2.1

$\phi bt := 0.75$

$hef := 600mm$ Effective length of bolt in concrete

$Nb := kc \cdot \left(\frac{hef}{in}\right)^{1.5} \cdot \sqrt{\frac{fc}{psi}} \cdot lbf$

$Nb = 174.3 \cdot kip$

7.2 Calculate the Maximum Moment on Foundation

Survival Wind Loading -- at -15degree elevation angle and 0degree Azimuth

$Fz := FwindZ(15deg, 0deg, Vibc)$

$Fz = 132.73 \cdot kN$ $Fz = 29.84 \cdot kip$

$Fy := Wt \cdot g$

$Fx := FwindX(15deg, 0deg, Vibc)$

$Fx = 0.00 \cdot kip$

$Mx := TwindEL(15deg, 0deg, Vibc)$

$Mx = 132.35 \cdot kip \cdot ft$ Moment about the elevation axis

$My := TwindAZ(15deg, 0deg, Vibc)$

$My = 0.00 \cdot kip \cdot ft$ Moment about the azimuth axis

$Mu := 1.2Wtotal \cdot g \cdot Lelevation + 1.6Fz \cdot HeightEL + 1.6Mx + 1.2Wyoke \cdot g \cdot Lelevation$

$Mu = 1518.48 \cdot kip \cdot ft$ $Mu = 2058.79 \cdot kN \cdot m$

$Mu' := Wtotal \cdot g \cdot Lelevation + Fz \cdot HeightEL + Mx + Wyoke \cdot g \cdot Lelevation$

$Mu' = 1025.49 \cdot kip \cdot ft$

$Pu := 1.2 \cdot Fy + 1.2 \cdot PuFoundation$

$Pu = 199.98 \cdot kip$ $Pu = 889.57 \cdot kN$

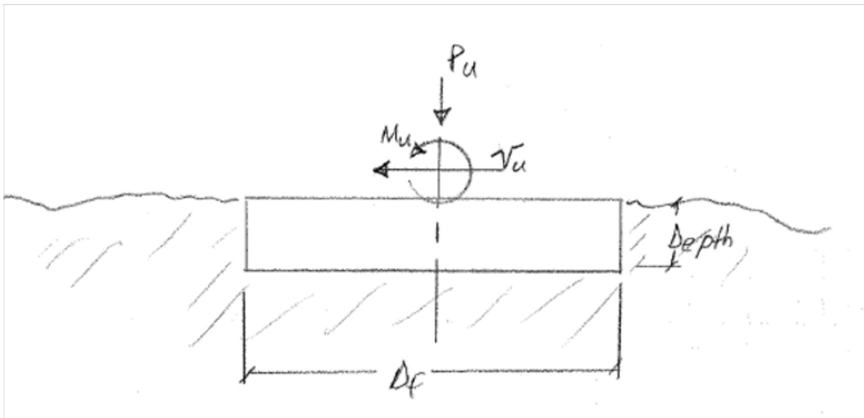
$Pu' := Fy + PuFoundation$

$Pu' = 166.65 \cdot kip$

$Vu := 1.6Fz$

$Vu' := Fz$

$e := \frac{Mu'}{Pu'}$ $\quad$ $e = 1.88\,m$ $\quad$ $e = 6.15\cdot ft$



7.3 Foundation Strength

7.3.1 Soil Pressure

Assume that soil is in compression under the entire foundation -- solve for the soil pressure

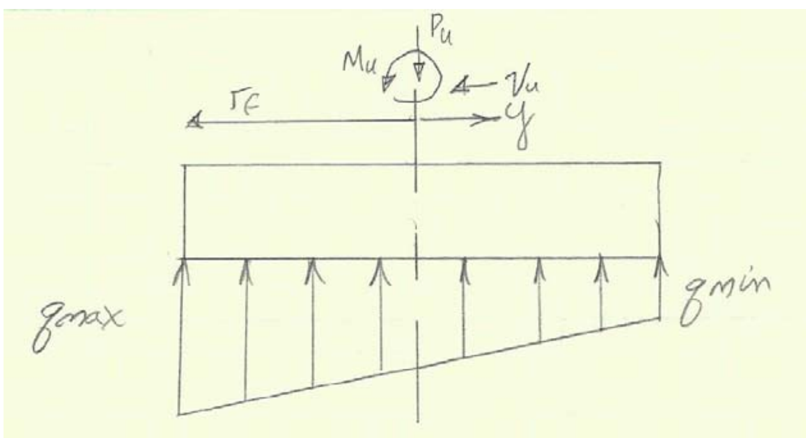
$If := \frac{\pi\cdot Df^4}{64}$

$qmax := \frac{Pu'}{Af} + \frac{Mu'\cdot\frac{Df}{2}}{If}$

$qmax = 3.15\cdot\frac{kip}{ft^2}$

$qmin := \frac{Pu'}{Af} - \frac{Mu'\cdot\frac{Df}{2}}{If}$

$qmin = -1577.76\cdot\frac{lbf}{ft^2}$

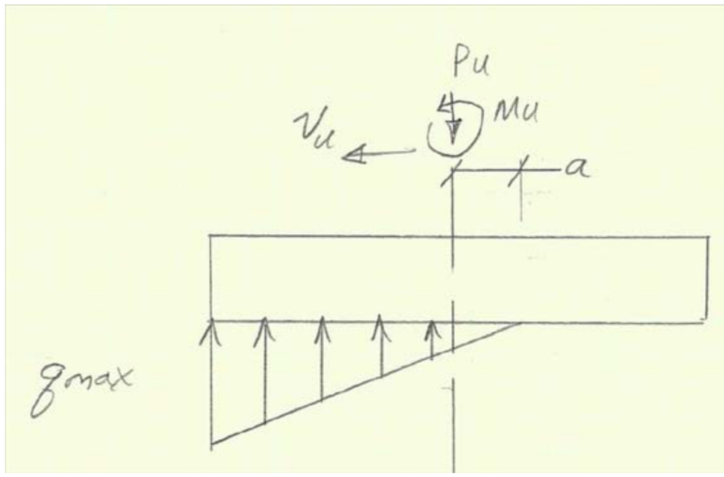


qmin is negative which is not possible -- assume a soil pressure distribution shown below. Solve for max soil pressure.

$e := \frac{Mu'}{Pu'}$ $e = 1.88\,m$ $e = 6.15 \cdot ft$

Initial Guess of max soil pressure and distribution

$qmax := 1 \frac{kip}{ft^2}$ $a := 1m$



Given

$$Pu' = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2}\, dy$$

$$Mu' = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot y\, dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := Find(qmax, a)$$

$qmax = 7.65 \cdot \frac{kip}{ft^2}$

An assumed soil strength value of 3kips/ft^2 is listed on the foundation drawings but the actual value is not known

$a = -1.01\,m$

7.3.2 Calculate Strength of Concrete bending using factored values .

Check strength of concrete in bending at flange mounting plate

$rd := r1$ Radius where max bending moment is checked.

Recalculate the soil pressure using Pu and Mu with load factors applied

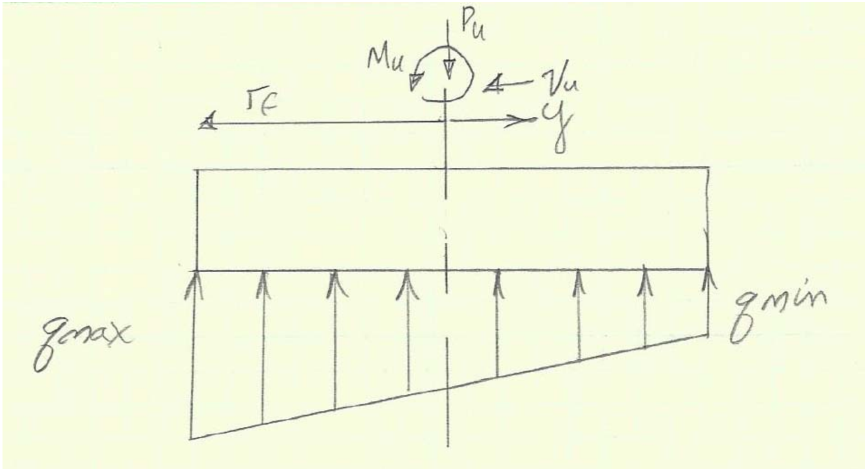
Calculate max soil pressure

$$qmax := \frac{Pu}{Af} + \frac{Mu \cdot \frac{Df}{2}}{If}$$

$$qmax = 4.5 \cdot \frac{kip}{ft^2}$$

$$qmin := \frac{Pu}{Af} - \frac{Mu \cdot \frac{Df}{2}}{If}$$

$$qmin = -2.56 \cdot \frac{kip}{ft^2}$$



qmin is negative which is not possible - assume a soil pressure distribution shown below. Solve for max soil pressure..

$$e := \frac{Mu}{Pu} \qquad e = 2.31\,m \qquad e = 7.59 \cdot ft$$

Initial Guess of soil pressure

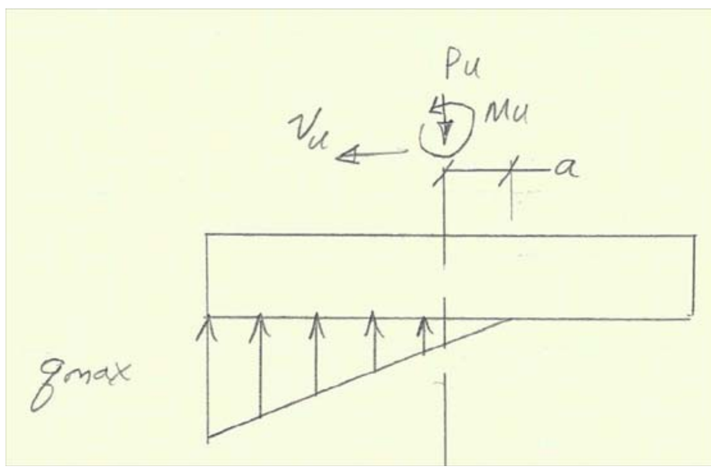
$$qmax := 18\frac{kip}{ft^2} \qquad a := -1m$$

Given

$$Pu = \int_{-a}^{rf} qmax \cdot \left(\frac{a + y}{a + rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2}\, dy$$

$$Mu = \int_{-a}^{rf} qmax \cdot \left(\frac{a + y}{a + rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot y\, dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := Find(qmax, a)$$



$$qmax = 55.23 \cdot \frac{kip}{ft^2}$$ Maximum soil pressure

$$a = -2.06\,m$$

Use the soil pressure calculated with load factors to find the moment in the concrete

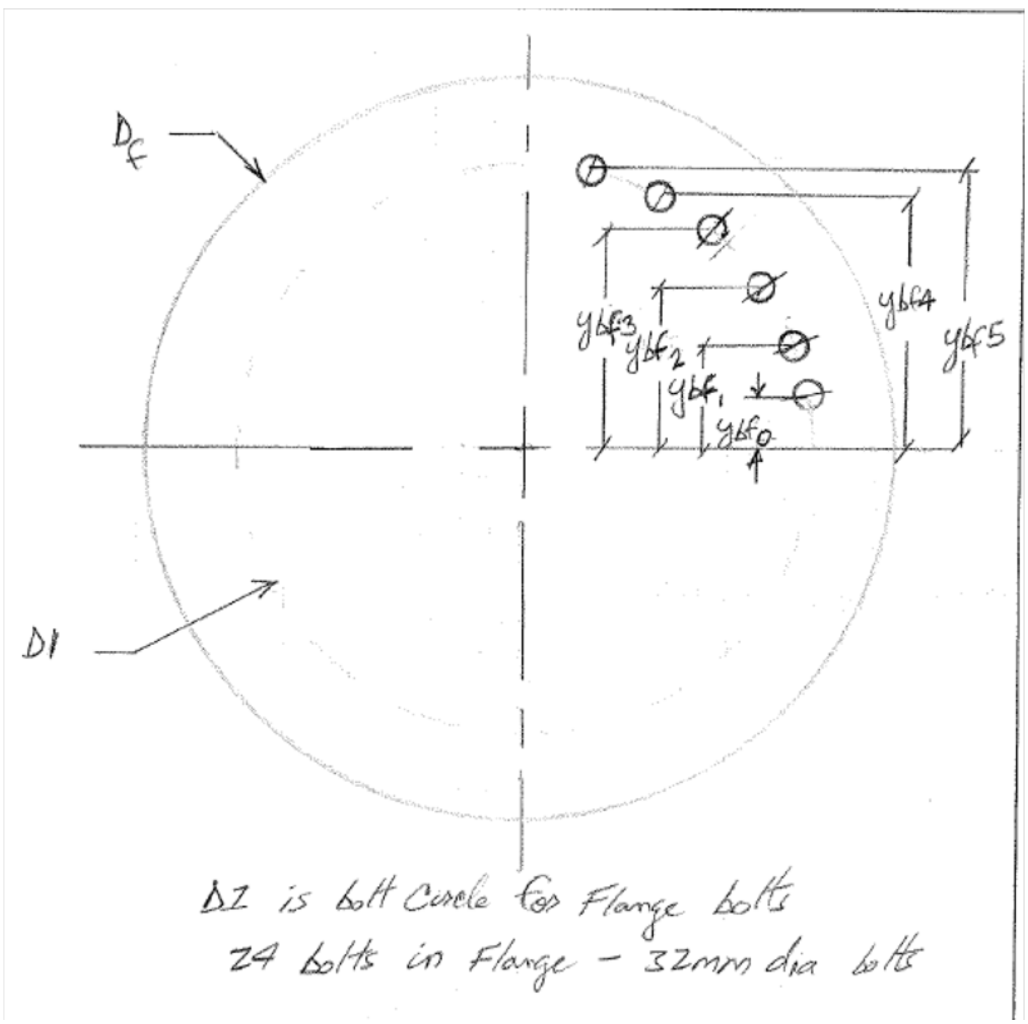
$$Muconcrete := \int_{rd}^{rf} (qmax) \cdot \left(\frac{a + y}{rf + a} \right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot (y - rd)\, dy$$

$Muconcrete = -2035.09 \cdot ft \cdot kip$ Internal moment in concrete

$$\phi Mn := \phi f \cdot fy \cdot As \cdot \left(d - \frac{As \cdot fy}{2 \cdot 0.85 \cdot fc \cdot Df} \right)$$

$\phi Mn = 1627.63 \cdot ft \cdot kip$ Greater than φMuconcrete so ok

7.3.3 Calculate the Forces in the Flange Bolts



Calculate distance to bolts

$$ybf_0 := \frac{dflange}{2} \cdot \sin\left(\frac{15deg}{2}\right)$$

$$ybf_1 := \frac{dflange}{2} \cdot \sin\left(15deg + \frac{15deg}{2}\right)$$

$$ybf_2 := \frac{dflange}{2} \cdot \sin\left(30deg + \frac{15deg}{2}\right)$$

$$ybf_3 := \frac{dflange}{2} \cdot \sin\left(45deg + \frac{15deg}{2}\right)$$

$$ybf_4 := \frac{dflange}{2} \cdot \sin\left(60deg + \frac{15deg}{2}\right)$$

$$ybf_5 := \frac{dflange}{2} \cdot \sin\left(75deg + \frac{15deg}{2}\right)$$

$$ybf = \begin{pmatrix} 139.27 \\ 408.32 \\ 649.55 \\ 846.51 \\ 985.78 \\ 1057.87 \end{pmatrix} \cdot mm \qquad ybf = \begin{pmatrix} 5.48 \\ 16.08 \\ 25.57 \\ 33.33 \\ 38.81 \\ 41.65 \end{pmatrix} \cdot in$$

$$Fbolt := \frac{Mu}{\left[\sum_{i=0}^{5} \left[4\left(ybf_i \cdot \frac{ybf_i}{ybf_5}\right)\right]\right]}$$

Factored forces in bolt

$$Fbolt = 35.84 \cdot kip$$

$dbf = 31.75 \cdot mm$ Diameter of flange bolts

$$Abf := \frac{\pi \cdot dbf^2}{4}$$

$Abf = 1.23 \cdot in^2$ Cross sectional area of flange bolts

$fybf := 36ksi$ Yield strength of flange bolt material -- specified on drawing but assumed.

$\phi b := 0.75$ Strength reduction factor for bolts

$$FbfStress := \frac{Fbolt}{Abf}$$

$FbfStress = 29.20 \cdot ksi$

$\phi Fnt := \phi b \cdot fybf$ $\phi Fnt = 27.00 \cdot ksi$ Allowable bolt stress in tension

$Fsbolt := \frac{Vu}{nfbolts \cdot Abf}$ $Fsbolt = 1.62 \cdot ksi$ Shear stress per bolt

$\phi Fns := \phi b \cdot .533 \cdot fybf$ $\phi Fns = 14.39 \cdot ksi$ Allowable bolt stress in Shear

$\frac{FbfStress}{\phi Fnt} + \frac{Fsbolt}{\phi Fns} = 1.19$ Greater than 1 so not ok.

7.3.4 Calculate Overturning and Sliding Safety Factors

$\frac{Pu' \cdot rf}{Mu' + Vu' \cdot depth} = 1.24$ Less than 1.5 so not ok

Check sliding assuming a coefficient of friction of 0.5

$\frac{Pu' \cdot 0.5}{Vu'} = 2.79$ Greater than 1.5 so ok

8. Foundation Strength at 35 degree Park Position and no support on secondary

8.1 Calculate the Maximum Moment on Foundation

Survival Wind Loading -- at 35degree elevation angle and 0degree Azimuth

$Fz := FwindZ(35deg, 0deg, Vibc)$

$Fz = 124.13 \cdot kN$ $Fz = 27.91 \cdot kip$

$Fy := Wt \cdot g$

$Fx := FwindX(35deg, 0deg, Vibc)$

$Fx = 0.00 \cdot kip$

$Mx := TwindEL(35deg, 0deg, Vibc)$

$Mx = 218.05 \cdot kip \cdot ft$ Moment about the elevation axis

$My := TwindAZ(35deg, 0deg, Vibc)$

$My = 0.00 \cdot kip \cdot ft$ Moment about the azimuth axis

$Mu := 1.2Wtotal \cdot g \cdot Lelevation + 1.6Fz \cdot HeightEL + 1.6Mx + 1.2Wyoke \cdot g \cdot Lelevation$

$Mu = 1594.70 \cdot kip \cdot ft$ $Mu = 2162.12 \cdot kN \cdot m$

$Mu' := Wtotal \cdot g \cdot Lelevation + Fz \cdot HeightEL + Mx + Wyoke \cdot g \cdot Lelevation$

$Mu' = 1073.12 \cdot kip \cdot ft$

$Pu := 1.2 \cdot Fy + 1.2 \cdot PuFoundation$

$Pu = 199.98 \cdot kip$ $Pu = 889.57 \cdot kN$

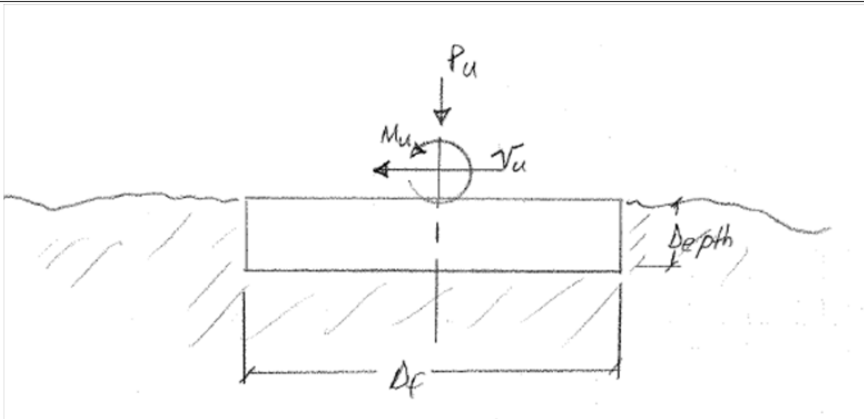
$Pu' := Fy + PuFoundation$

$Pu' = 166.65 \cdot kip$

$Vu := 1.6Fz$

$Vu' := Fz$

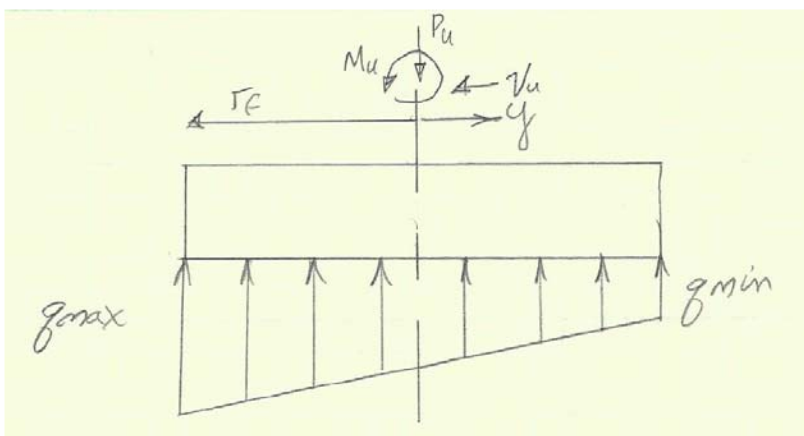
$e := \frac{Mu'}{Pu'}$ $e = 1.96\,m$ $e = 6.44 \cdot ft$



8.2 Soil Pressure

Assume that soil is in compression under the entire foundation -- solve for the soil pressure

$$If := \frac{\pi \cdot Df^4}{64}$$



$$qmax := \frac{Pu'}{Af} + \frac{Mu' \cdot \frac{Df}{2}}{If}$$

$$qmax = 3.26 \cdot \frac{kip}{ft^2}$$

$$qmin := \frac{Pu'}{Af} - \frac{Mu' \cdot \frac{Df}{2}}{If}$$

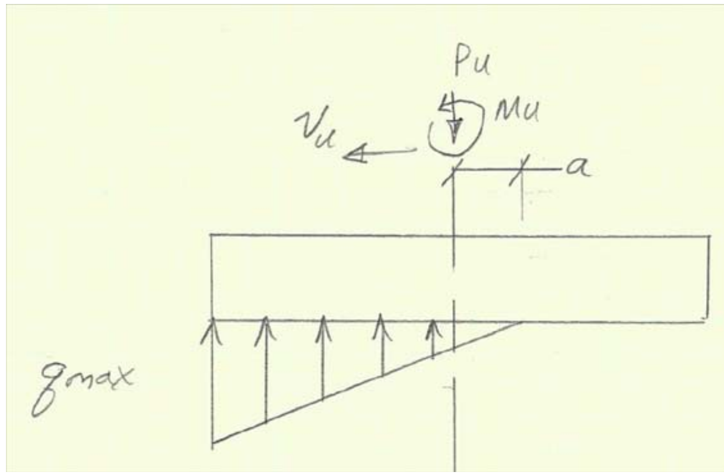
$$qmin = -1687.67 \cdot \frac{lbf}{ft^2}$$

qmin is negative which is not possible -- assume a soil pressure distribution shown below. Solve for max soil pressure.

$e := \frac{Mu'}{Pu'}$ $\quad e = 1.96\,m$ $\quad e = 6.44 \cdot ft$

Initial Guess of max soil pressure and distribution

$qmax := 1 \frac{kip}{ft^2}$ $a := 1m$



Given

$$Pu' = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2}\, dy$$

$$Mu' = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot y\, dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := Find(qmax, a)$$

$qmax = 9.54 \cdot \frac{kip}{ft^2}$

An assumed soil strength value of 3kips/ft^2 is listed on the foundation drawings but the actual value is not known

$a = -1.22\,m$

Calculate soil pressure using equivalent square foundation

$side := \sqrt{\frac{\pi \cdot Df^2}{4}}$ $side = 4.43\,m$ Dimension of square foundation

$e := \frac{Mu'}{Pu'}$ $e = 1.96\,m$

$\frac{side}{6} = 0.74\,m$ eccentricity greater than side/6

$$qmax := \frac{2 \cdot Pu'}{3side \cdot \left(\frac{side}{2} - e\right)}$$

$qmax = 9.21 \cdot ksf$

8.3. Calculate Strength of Concrete bending using factored values .

Check strength of concrete in bending at flange mounting plate

$rd := r1$ Radius where max bending moment is checked.

Recalculate the soil pressure using Pu and Mu with load factors applied

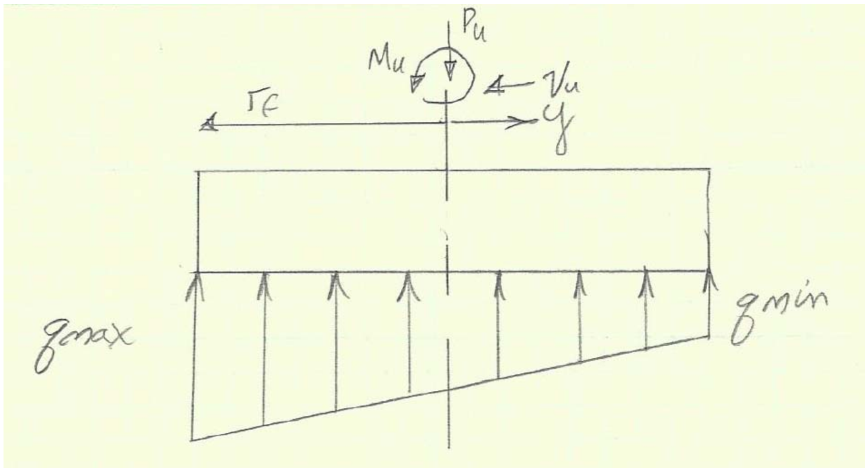
Calculate max soil pressure

$$qmax := \frac{Pu}{Af} + \frac{Mu \cdot \frac{Df}{2}}{If}$$

$$qmax = 4.6 \cdot \frac{kip}{ft^2}$$

$$qmin := \frac{Pu}{Af} - \frac{Mu \cdot \frac{Df}{2}}{If}$$

$$qmin = -2.73 \cdot \frac{kip}{ft^2}$$



qmin is negative which is not possible - assume a soil pressure distribution shown below. Solve for max soil pressure..

$$e := \frac{Mu}{Pu} \qquad e = 2.43\,m \qquad e = 7.97 \cdot ft$$

Initial Guess of soil pressure

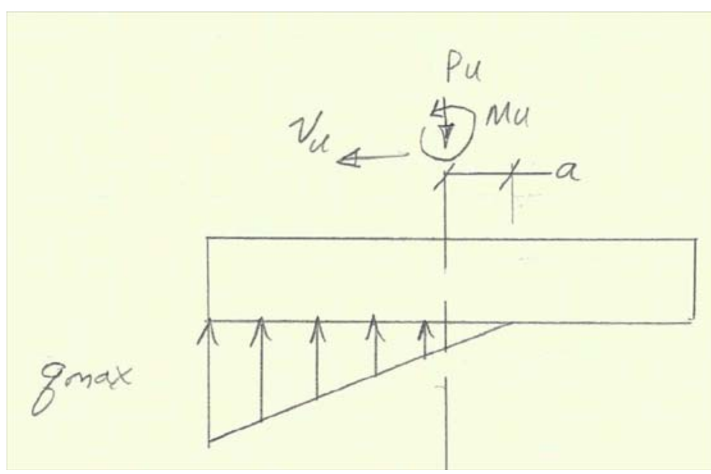
$$qmax := 18 \frac{kip}{ft^2} \qquad a := -1m$$

Given

$$Pu = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2}\, dy$$

$$Mu = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot y\, dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := Find(qmax, a)$$



$$qmax = 239.64 \cdot \frac{kip}{ft^2}$$ Maximum soil pressure

$a = -2.34\,m$

$rd := |a|$

Use the soil pressure calculated with load factors to find the moment in the concrete

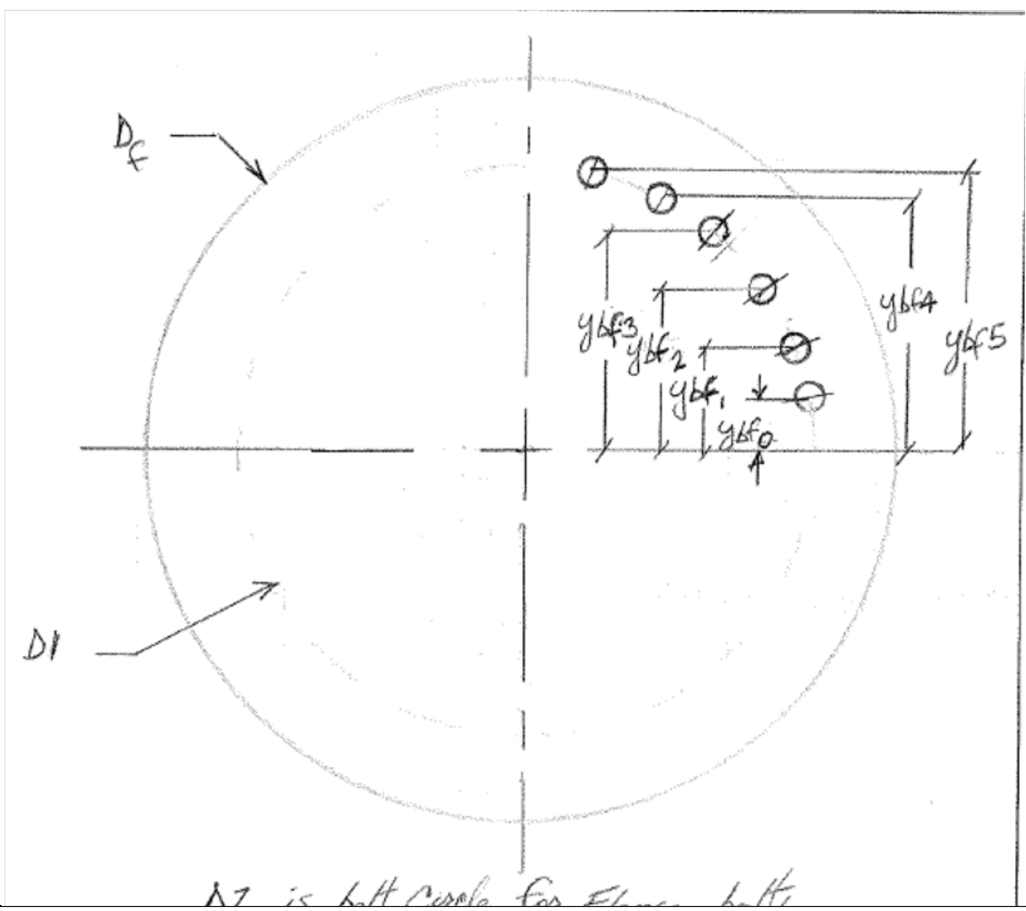
$$Muconcrete := \int_{rd}^{rf} (qmax)\cdot\left(\frac{a + y}{a + rf}\right)\cdot 2\cdot\sqrt{rf^2 - y^2}\cdot(y - rd)\,dy$$

$Muconcrete = 61.00\cdot ft\cdot kip$ Internal moment in concrete

$$\phi Mn := \phi f\cdot fy\cdot As\cdot\left(d - \frac{As\cdot fy}{2\cdot 0.85\cdot fc\cdot Df}\right)$$

$\phi Mn = 1627.63\cdot ft\cdot kip$ Greater than φMuconcrete so ok

8.4 Calculate the Forces in the Flange Bolts



24 bolts in Flange - 32mm dia bolts

Calculate distance to bolts

$$ybf_0 := \frac{dflange}{2}\cdot\sin\left(\frac{15deg}{2}\right)$$

$$ybf_1 := \frac{dflange}{2}\cdot\sin\left(15deg + \frac{15deg}{2}\right)$$

$$ybf_2 := \frac{dflange}{2}\cdot\sin\left(30deg + \frac{15deg}{2}\right)$$

$$ybf_3 := \frac{dflange}{2}\cdot\sin\left(45deg + \frac{15deg}{2}\right)$$

$$ybf_4 := \frac{dflange}{2}\cdot\sin\left(60deg + \frac{15deg}{2}\right)$$

$$ybf_5 := \frac{dflange}{2}\cdot\sin\left(75deg + \frac{15deg}{2}\right)$$

$$ybf = \begin{pmatrix} 139.27 \\ 408.32 \\ 649.55 \\ 846.51 \\ 985.78 \\ 1057.87 \end{pmatrix}\cdot mm \qquad ybf = \begin{pmatrix} 5.48 \\ 16.08 \\ 25.57 \\ 33.33 \\ 38.81 \\ 41.65 \end{pmatrix}\cdot in$$

$$Fbolt := \frac{Mu}{\left[\sum_{i=0}^{5}\left[4\left(ybf_i\cdot\frac{ybf_i}{ybf_5}\right)\right]\right]} - \frac{Pu}{24}$$ Factored forces in bolt

$$Fbolt = 29.30\cdot kip$$

$dbf = 31.75\cdot mm$ Diameter of flange bolts

$Abf := \frac{\pi\cdot dbf^2}{4}$ $Abf = 1.23\cdot in^2$ Cross sectional area of flange bolts

$fybf := 36ksi$ Yield strength of flange bolt material -- specified on drawing but assumed.

$\phi b := 0.75$ Strength reduction factor for bolts

$$FbfStress := \frac{Fbolt}{Abf}$$

$FbfStress = 23.88 \cdot ksi$

$\phi Fnt := \phi b \cdot fybf$ $\phi Fnt = 27.00 \cdot ksi$ Allowable bolt stress in tension

$Fsbolt := \frac{Vu}{nfbolts \cdot Abf}$ $Fsbolt = 1.52 \cdot ksi$ Shear stress per bolt

$\phi Fns := \phi b \cdot .533 \cdot fybf$ $\phi Fns = 14.39 \cdot ksi$ Allowable bolt stress in Shear

$\frac{FbfStress}{\phi Fnt} + \frac{Fsbolt}{\phi Fns} = 0.99$ Greater than 1 so not ok.

8.5 Calculate Overturning and Sliding Safety Factors

$\frac{Pu' \cdot rf}{Mu' + Vu' \cdot depth} = 1.19$ Less than 1.5 so not ok

Check sliding assuming a coefficient of friction of 0.5

$\frac{Pu' \cdot 0.5}{Vu'} = 2.99$ Greater than 1.5 so ok

9. Foundation Strength at 35 degree Park Position and no support on secondary Adding Concrete Blocks to increase Pu

Concrete blocks 3x3x3

$Wblock := 4kip$

$Nblock := 10$

9.1 Calculate the Maximum Moment on Foundation

Survival Wind Loading -- at 35degree elevation angle and 0degree Azimuth

$Fz := FwindZ(35deg, 0deg, Vibc)$

$Fz = 124.13 \cdot kN$ $Fz = 27.91 \cdot kip$

$Fy := Wt \cdot g$

$Fx := FwindX(35deg, 0deg, Vibc)$

$Fx = 0.00 \cdot kip$

$Mx := TwindEL(35deg, 0deg, Vibc)$

$Mx = 218.05 \cdot kip \cdot ft$ Moment about the elevation axis

$My := TwindAZ(35deg, 0deg, Vibc)$

$My = 0.00 \cdot kip \cdot ft$ Moment about the azimuth axis

$Mu := 1.2Wtotal \cdot g \cdot Lelevation + 1.6Fz \cdot HeightEL + 1.6Mx + 1.2Wyoke \cdot g \cdot Lelevation$

$Mu = 1594.70 \cdot kip \cdot ft$ $Mu = 2162.12 \cdot kN \cdot m$

$Mu' := Wtotal \cdot g \cdot Lelevation + Fz \cdot HeightEL + Mx + Wyoke \cdot g \cdot Lelevation$

$Mu' = 1073.12 \cdot kip \cdot ft$

$Pu := 1.2 \cdot Fy + 1.2 \cdot PuFoundation + 1.2 \cdot Nblock \cdot Wblock$

$Pu = 247.98 \cdot kip$ $Pu = 1103.08 \cdot kN$

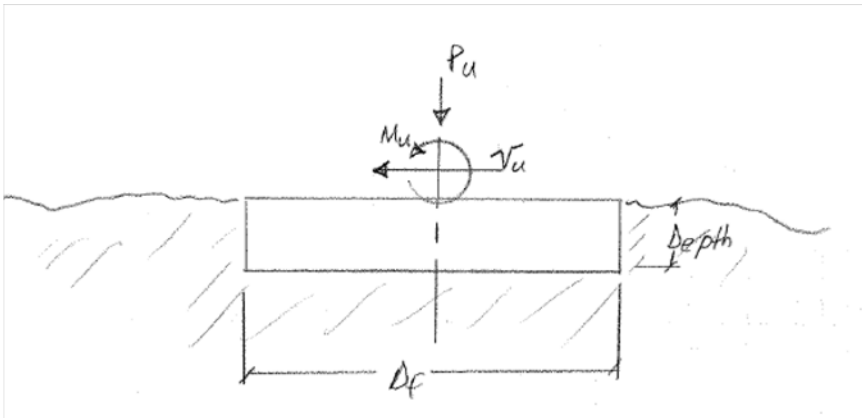
$Pu' := Fy + PuFoundation + Nblock \cdot Wblock$

$Pu' = 206.65 \cdot kip$

$Vu := 1.6Fz$

$Vu' := Fz$

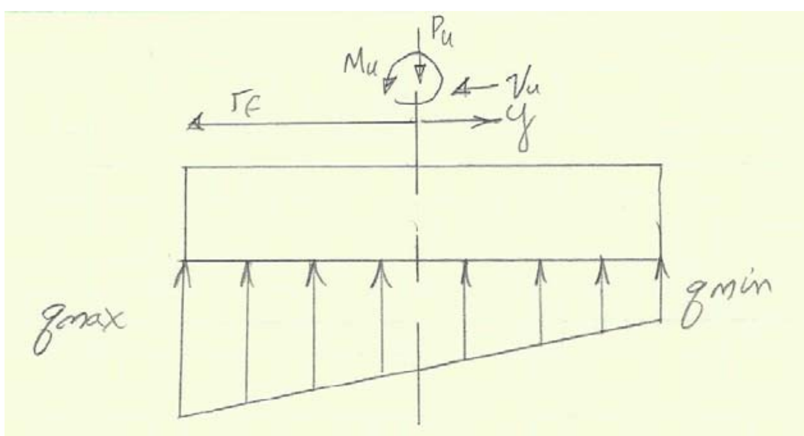
$e := \frac{Mu'}{Pu'}$ $e = 1.58\,m$ $e = 5.19 \cdot ft$



9.2 Soil Pressure

Assume that soil is in compression under the entire foundation -- solve for the soil pressure

$If := \frac{\pi \cdot Df^4}{64}$



$qmax := \frac{Pu'}{Af} + \frac{Mu' \cdot \frac{Df}{2}}{If}$

$qmax = 3.45 \cdot \frac{kip}{ft^2}$

$qmin := \frac{Pu'}{Af} - \frac{Mu' \cdot \frac{Df}{2}}{If}$

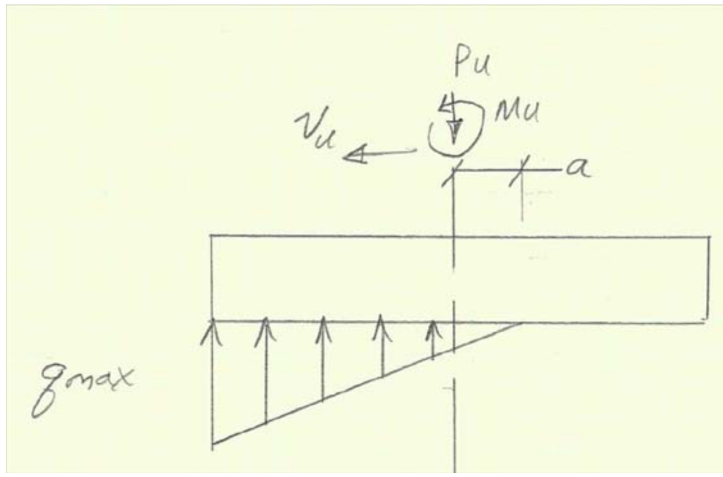
$qmin = -1498.41 \cdot \frac{lbf}{ft^2}$

qmin is negative which is not possible -- assume a soil pressure distribution shown below. Solve for max soil pressure.

$e := \frac{Mu'}{Pu'}$ $\qquad e = 1.58\,m$ $\qquad e = 5.19 \cdot ft$

Initial Guess of max soil pressure and distribution

$qmax := 4\,\frac{kip}{ft^2}$ $\qquad a := 1m$



Given

$$Pu' = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2}\, dy$$

$$Mu' = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot y\, dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := \text{Find}(qmax, a)$$

$qmax = 5.43 \cdot \frac{kip}{ft^2}$

An assumed soil strength value of 3kips/ft^2 is listed on the foundation drawings but the actual value is not known

$a = -0.28\,m$

Calculate soil pressure using equivalent square foundation

$side := \sqrt{\frac{\pi \cdot Df^2}{4}}$ $\qquad side = 4.43\,m$ $\qquad$ Dimension of square foundation

$e := \frac{Mu'}{Pu'}$ $\qquad e = 1.58\,m$

$\frac{side}{6} = 0.74\,m$ $\qquad$ eccentricity greater than side/6

$$qmax := \frac{2 \cdot Pu'}{3side \cdot \left(\frac{side}{2} - e\right)}$$

$qmax = 4.56 \cdot ksf$

9.3. Calculate Strength of Concrete bending using factored values .

Check strength of concrete in bending at flange mounting plate

$rd := r1$ Radius where max bending moment is checked.

Recalculate the soil pressure using Pu and Mu with load factors applied

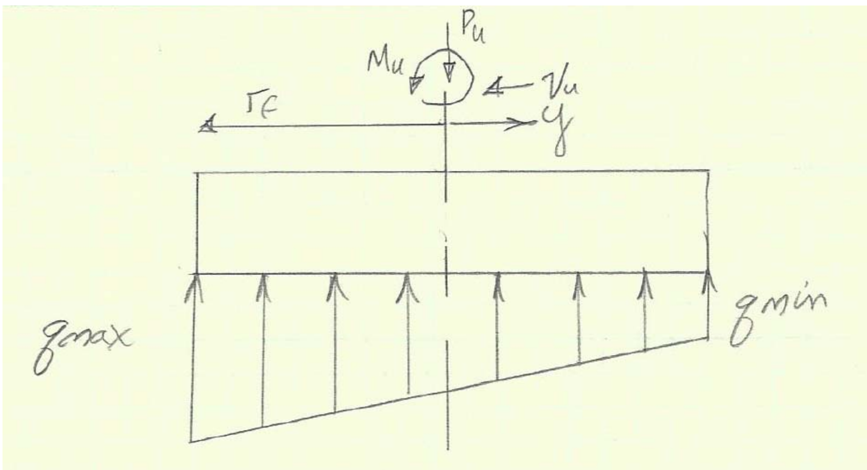
Calculate max soil pressure

$$qmax := \frac{Pu}{Af} + \frac{Mu \cdot \frac{Df}{2}}{If}$$

$$qmax = 4.9 \cdot \frac{kip}{ft^2}$$

$$qmin := \frac{Pu}{Af} - \frac{Mu \cdot \frac{Df}{2}}{If}$$

$$qmin = -2.51 \cdot \frac{kip}{ft^2}$$

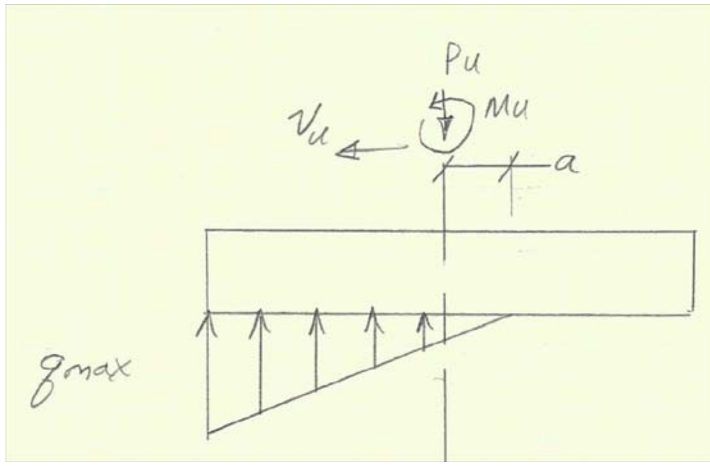


qmin is negative which is not possible - assume a soil pressure distribution shown below. Solve for max soil pressure..

$e := \frac{Mu}{Pu}$ $e = 1.96\, m$ $e = 6.43 \cdot ft$

Initial Guess of soil pressure

$qmax := 18 \frac{kip}{ft^2}$ $\quad$ $a := -1m$



Given

$$Pu = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2}\, dy$$

$$Mu = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot y\, dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := Find(qmax, a)$$

$qmax = 14.09 \cdot \frac{kip}{ft^2}$ Maximum soil pressure

$a = -1.22\, m$

$rd := |a|$

Use the soil pressure calculated with load factors to find the moment in the concrete

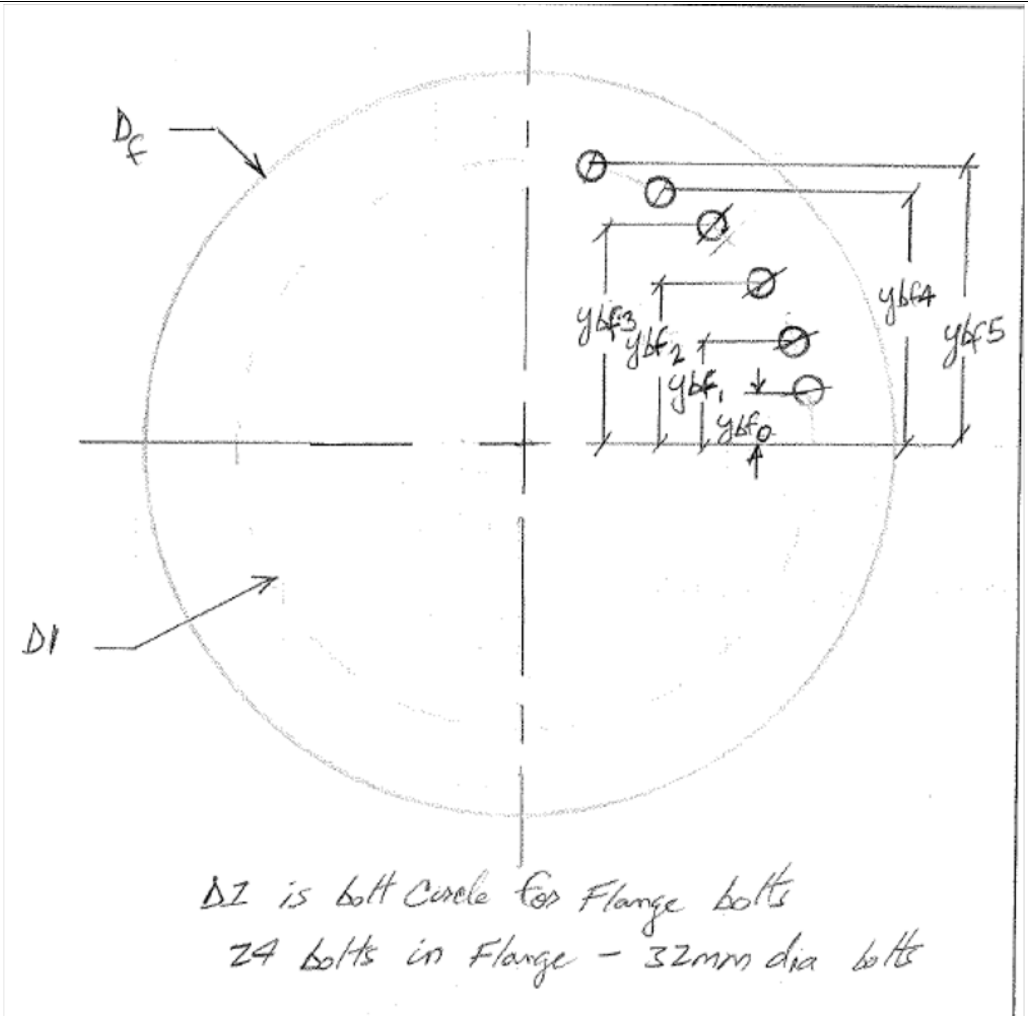
$$Muconcrete := \int_{rd}^{rf} (qmax) \cdot \left(\frac{a+y}{rf+a}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot (y - rd)\, dy$$

$Muconcrete = 604.93 \cdot ft \cdot kip$ Internal moment in concrete

$$\phi Mn := \phi f \cdot fy \cdot As \cdot \left(d - \frac{As \cdot fy}{2 \cdot 0.85 \cdot fc \cdot Df}\right)$$

$\phi Mn = 1627.63 \cdot ft \cdot kip$ Greater than φMuconcrete so ok

9.4 Calculate the Forces in the Flange Bolts



Calculate distance to bolts

$$ybf_0 := \frac{dflange}{2}\cdot\sin\left(\frac{15deg}{2}\right)$$

$$ybf_1 := \frac{dflange}{2}\cdot\sin\left(15deg + \frac{15deg}{2}\right)$$

$$ybf_2 := \frac{dflange}{2}\cdot\sin\left(30deg + \frac{15deg}{2}\right)$$

$$ybf_3 := \frac{dflange}{2}\cdot\sin\left(45deg + \frac{15deg}{2}\right)$$

$$ybf_4 := \frac{dflange}{2}\cdot\sin\left(60deg + \frac{15deg}{2}\right)$$

$$ybf_5 := \frac{dflange}{2}\cdot\sin\left(75deg + \frac{15deg}{2}\right)$$

$$ybf = \begin{pmatrix} 139.27 \\ 408.32 \\ 649.55 \\ 846.51 \\ 985.78 \\ 1057.87 \end{pmatrix}\cdot mm \qquad ybf = \begin{pmatrix} 5.48 \\ 16.08 \\ 25.57 \\ 33.33 \\ 38.81 \\ 41.65 \end{pmatrix}\cdot in$$

$$Fbolt := \frac{Mu}{\left[\sum_{i=0}^{5}\left[4\left(ybf_i\cdot\frac{ybf_i}{ybf_5}\right)\right]\right]} - \frac{Fy}{24}$$

Factored forces in bolt

$Fbolt = 34.16\cdot kip$

$dbf = 31.75\cdot mm$ — Diameter of flange bolts

$Abf := \frac{\pi\cdot dbf^2}{4}$ — $Abf = 1.23\cdot in^2$ — Cross sectional area of flange bolts

$fybf := 36ksi$ — Yield strength of flange bolt material -- specified on drawing but assumed.

$\phi b := 0.75$ — Strength reduction factor for bolts

$$FbfStress := \frac{Fbolt}{Abf}$$

$FbfStress = 27.84\cdot ksi$

$\phi Fnt := \phi b\cdot fybf$ — $\phi Fnt = 27.00\cdot ksi$ — Allowable bolt stress in tension

$Fsbolt := \frac{Vu}{nfbolts\cdot Abf}$ — $Fsbolt = 1.52\cdot ksi$ — Shear stress per bolt

$\phi Fns := \phi b\cdot .533\cdot fybf$ — $\phi Fns = 14.39\cdot ksi$ — Allowable bolt stress in Shear

$$\frac{FbfStress}{\phi Fnt} + \frac{Fsbolt}{\phi Fns} = 1.14$$

Greater than 1 so not ok.

9.5 Calculate Overturning and Sliding Safety Factors

$$\frac{Pu' \cdot rf}{Mu' + Vu' \cdot depth} = 1.48$$

Greater than 1.5 so ok

Check sliding assuming a coefficient of friction of 0.5

$$\frac{Pu' \cdot 0.5}{Vu'} = 3.70$$

Greater than 1.5 so ok

10. Foundation Strength at 35 degree Park Position and no support on secondary Determine the size of a new foundation needed and adding Hilti Anchor Bolts

$Df := 6m$ Diameter of foundation

$$rf := \frac{Df}{2}$$

$Af := \dfrac{\pi \cdot Df^2}{4}$ Bearing Area of foundation

$$PuFoundation := 150 \frac{lbf}{ft^3} \cdot Af \cdot depth$$

$$PuFoundation = 119.8 \cdot kip$$

10.1 Calculate the Maximum Moment on Foundation

Survival Wind Loading -- at 35degree elevation angle and 0degree Azimuth

$Fz := FwindZ(35deg, 0deg, Vibc)$

$Fz = 124.13 \cdot kN$ $Fz = 27.91 \cdot kip$

$Fy := Wt \cdot g$

$Fx := FwindX(35deg, 0deg, Vibc)$

$Fx = 0.00 \cdot kip$

$Mx := TwindEL(35deg, 0deg, Vibc)$

$Mx = 218.05 \cdot kip \cdot ft$ Moment about the elevation axis

$My := TwindAZ(35deg, 0deg, Vibc)$

$My = 0.00 \cdot kip \cdot ft$ Moment about the azimuth axis

$Mu := 1.2Wtotal \cdot g \cdot Lelevation + 1.6Fz \cdot HeightEL + 1.6Mx + 1.2Wyoke \cdot g \cdot Lelevation$

$Mu = 1594.70 \cdot kip \cdot ft$ $Mu = 2162.12 \cdot kN \cdot m$

$Mu' := Wtotal \cdot g \cdot Lelevation + Fz \cdot HeightEL + Mx + Wyoke \cdot g \cdot Lelevation$

$Mu' = 1073.12 \cdot kip \cdot ft$

$Pu := 1.2 \cdot Fy + 1.2 \cdot PuFoundation$

$Pu = 243.92 \cdot kip$ $Pu = 1084.99 \cdot kN$

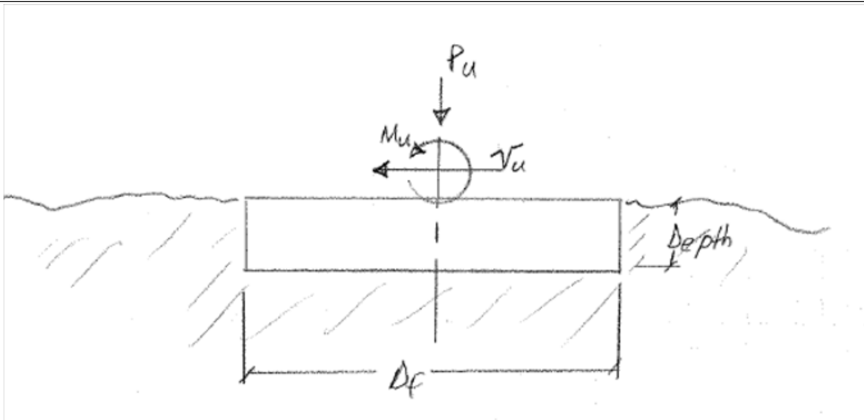
$Pu' := Fy + PuFoundation$

$Pu' = 203.26 \cdot kip$

$Vu := 1.6Fz$

$Vu' := Fz$

$e := \frac{Mu'}{Pu'}$ $e = 1.61\,m$ $e = 5.28 \cdot ft$



10.2 Soil Pressure

Assume that soil is in compression under the entire foundation -- solve for the soil pressure

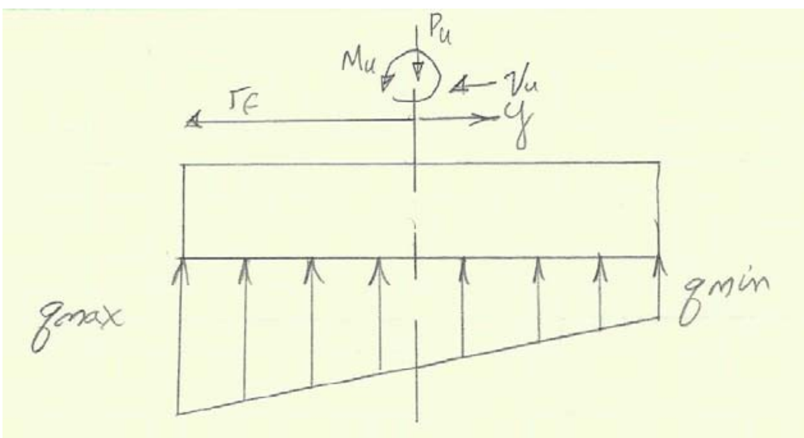
$$If := \frac{\pi \cdot Df^4}{64}$$

$$qmax := \frac{Pu'}{Af} + \frac{Mu' \cdot \frac{Df}{2}}{If}$$

$$qmax = 2.10 \cdot \frac{kip}{ft^2}$$

$$qmin := \frac{Pu'}{Af} - \frac{Mu' \cdot \frac{Df}{2}}{If}$$

$$qmin = -765.10 \cdot \frac{lbf}{ft^2}$$

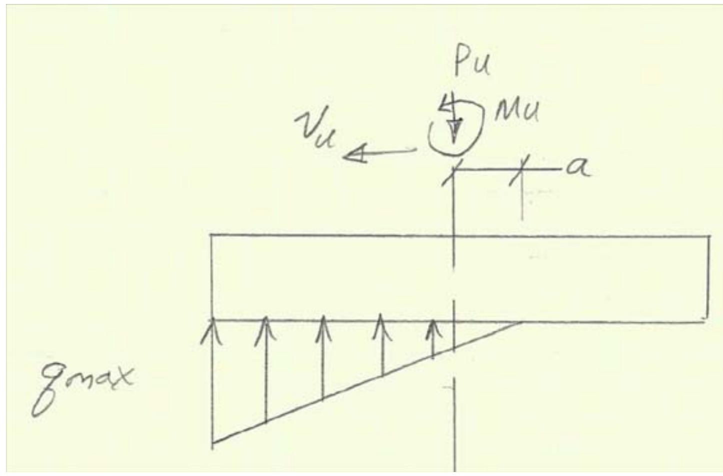


qmin is negative which is not possible -- assume a soil pressure distribution shown below. Solve for max soil pressure.

$$e := \frac{Mu'}{Pu'} \qquad e = 1.61\,m \qquad e = 5.28 \cdot ft$$

Initial Guess of max soil pressure and distribution

$qmax := 1\,\frac{kip}{ft^2}$ $\quad a := 1m$



Given

$$Pu' = \int_{-a}^{rf} qmax\cdot\left(\frac{a+y}{a+rf}\right)\cdot 2\cdot\sqrt{rf^2-y^2}\,dy$$

$$Mu' = \int_{-a}^{rf} qmax\cdot\left(\frac{a+y}{a+rf}\right)\cdot 2\cdot\sqrt{rf^2-y^2}\cdot y\,dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := Find(qmax, a)$$

$qmax = 2.65\cdot\frac{kip}{ft^2}$

An assumed soil strength value of 3kips/ft^2 is listed on the foundation drawings but the actual value is not known

$a = 0.41\,m$

Calculate soil pressure using equivalent square foundation

$side := \sqrt{\frac{\pi\cdot Df^2}{4}}$ $\quad side = 5.32\,m$ Dimension of square foundation

$e := \frac{Mu'}{Pu'}$ $\quad e = 1.61\,m$

$\frac{side}{6} = 0.89\,m$ eccentricity greater than side/6

$$qmax := \frac{2\cdot Pu'}{3side\cdot\left(\frac{side}{2} - e\right)}$$

$qmax = 2.26\cdot ksf$

10.3. Calculate Strength of Concrete bending using factored values .

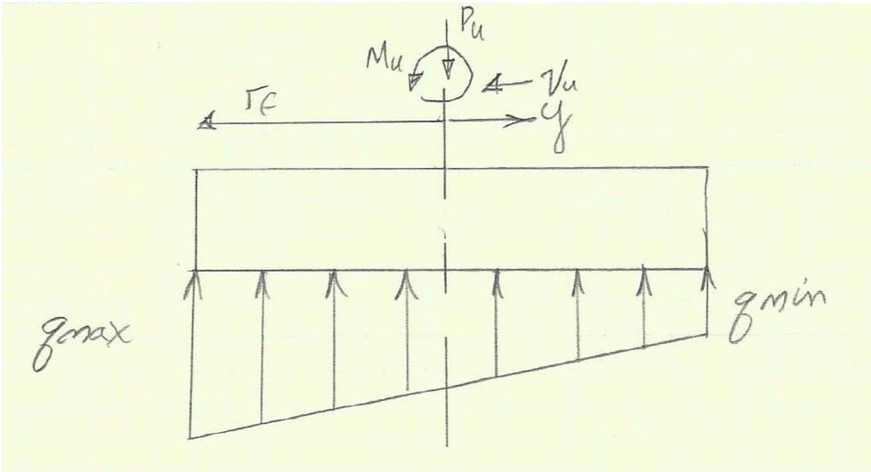
Check strength of concrete in bending at flange mounting plate

$rd := r1$ Radius where max bending moment is checked.

Recalculate the soil pressure using Pu and Mu with load factors applied

Calculate max soil pressure

$$qmax := \frac{Pu}{Af} + \frac{Mu \cdot \frac{Df}{2}}{If}$$



$$qmax = 2.9 \cdot \frac{kip}{ft^2}$$

$$qmin := \frac{Pu}{Af} - \frac{Mu \cdot \frac{Df}{2}}{If}$$

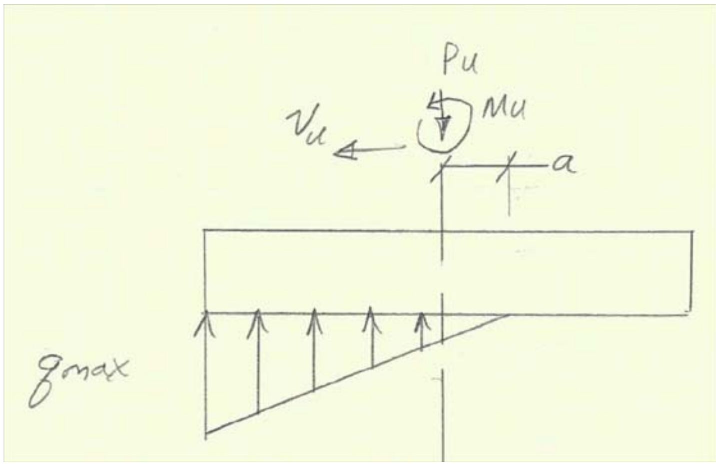
$$qmin = -1.33 \cdot \frac{kip}{ft^2}$$

qmin is negative which is not possible - assume a soil pressure distribution shown below. Solve for max soil pressure..

$$e := \frac{Mu}{Pu} \qquad e = 1.99\,m \qquad e = 6.54 \cdot ft$$

Initial Guess of soil pressure

$$qmax := 18 \frac{kip}{ft^2} \qquad a := -1m$$



Given

$$Pu = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2}\, dy$$

$$Mu = \int_{-a}^{rf} qmax \cdot \left(\frac{a+y}{a+rf}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2} \cdot y\, dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := Find(qmax, a)$$

$$qmax = 5.06 \cdot \frac{kip}{ft^2}$$ Maximum soil pressure

$a = -0.57\,m$

$rd := |a|$

Use the soil pressure calculated with load factors to find the moment in the concrete

$$Muconcrete := \int_{rd}^{rf} (qmax)\cdot\left(\frac{a+y}{rf+a}\right)\cdot 2\cdot\sqrt{rf^2 - y^2}\cdot(y - rd)\,dy$$

$Muconcrete = 1135.76\cdot ft\cdot kip$ Internal moment in concrete

$$\phi Mn := \phi f\cdot fy\cdot As\cdot\left(d - \frac{As\cdot fy}{2\cdot 0.85\cdot fc\cdot Df}\right)$$

$\phi Mn = 1633.26\cdot ft\cdot kip$ Greater than Muconcrete so ok

Calculate the shear strength of the concrete

$$Vuconcrete := \int_{rd}^{rf} (qmax)\cdot\left(\frac{a+y}{rf+a}\right)\cdot 2\cdot\sqrt{rf^2 - y^2}\,dy$$

$Vuconcrete = 243.92\cdot kip$

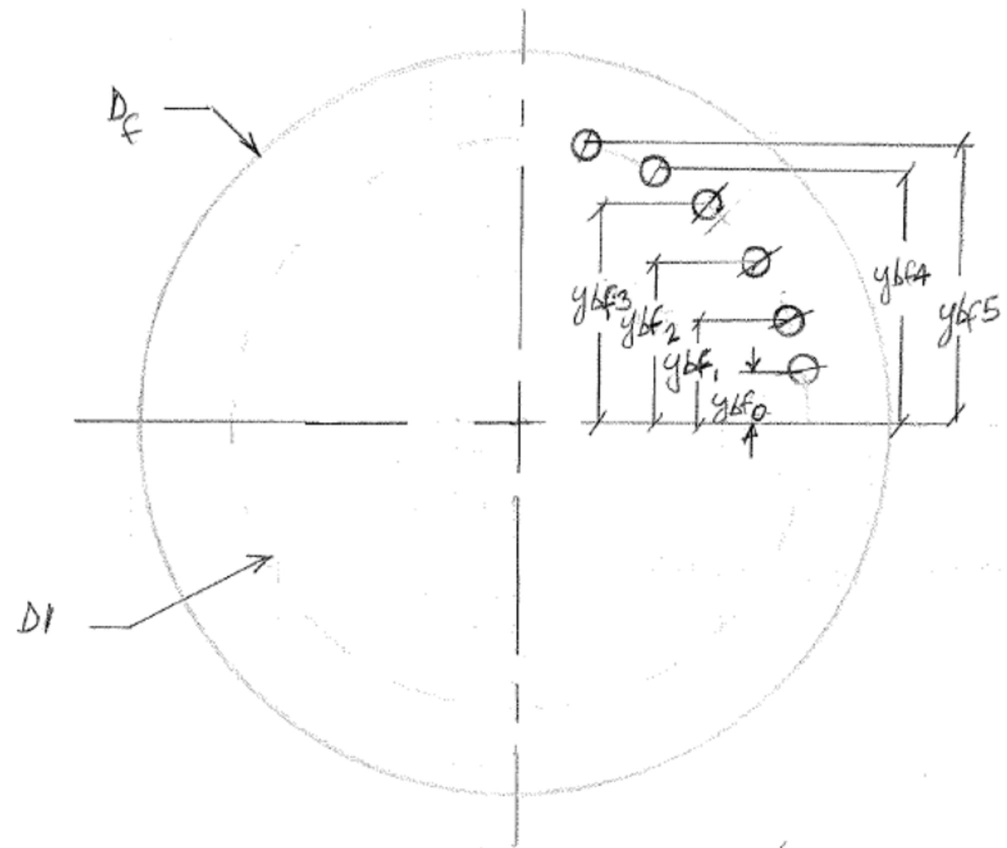
$\phi shear := 0.75$ Strength reduction factor for shear

$$\phi Vn := \phi shear\cdot 2\cdot\sqrt{\frac{fc}{psi}}\cdot\frac{Df\cdot depth}{in^2}\cdot lbf$$

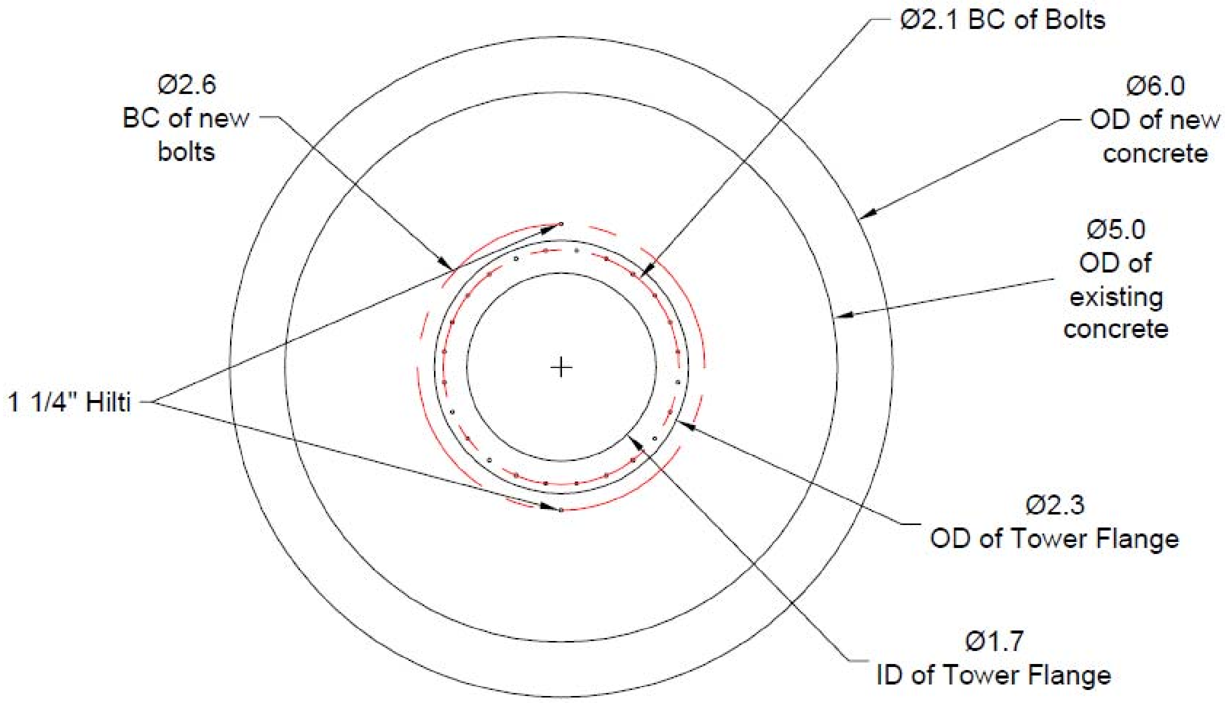
$\phi Vn = 705.82\cdot kip$

10.4 Calculate the Forces in the Flange Bolts

Add a Hiliti anchor that is directly south and north and therefore in-line with the park position and can resist the maximum moment. The Hilti anchor will be the same diameter as the existing bolts.



DI is bolt Circle for Flange bolts
24 bolts in Flange - 32mm dia bolts



$Df = 6.00\,m$ $\quad$ $Df = 236.22\cdot in$ $\quad$ Diameter of foundation

$dflange = 2.13\,m$ $\quad$ $dflange = 2.13\,m$ $\quad$ Diameter of bolt circle with existing anchor bolts

$dHilti := 2.6m$

Calculate distance to bolts

$$ybf_0 := \frac{dflange}{2}\cdot\sin\left(\frac{15deg}{2}\right)$$

$$ybf_1 := \frac{dflange}{2}\cdot\sin\left(15deg + \frac{15deg}{2}\right)$$

$$ybf_2 := \frac{dflange}{2}\cdot\sin\left(30deg + \frac{15deg}{2}\right)$$

$$ybf_3 := \frac{dflange}{2}\cdot\sin\left(45deg + \frac{15deg}{2}\right)$$

$$ybf_4 := \frac{dflange}{2}\cdot\sin\left(60deg + \frac{15deg}{2}\right)$$

$$ybf_5 := \frac{dflange}{2} \cdot \sin\left(75deg + \frac{15deg}{2}\right)$$

$$ybf_6 := \frac{dHilti}{2}$$ Distnace from NA to Hilti anchor

$$ybf = \begin{pmatrix} 139.27 \\ 408.32 \\ 649.55 \\ 846.51 \\ 985.78 \\ 1057.87 \\ 1300.00 \end{pmatrix} \cdot mm \qquad ybf = \begin{pmatrix} 5.48 \\ 16.08 \\ 25.57 \\ 33.33 \\ 38.81 \\ 41.65 \\ 51.18 \end{pmatrix} \cdot in$$

$$Fbolt := \frac{Mu}{\left[\sum_{i=0}^{5}\left[4\left(ybf_i \cdot \frac{ybf_i}{ybf_5}\right)\right] + 2 \cdot ybf_6 \cdot \frac{ybf_6}{ybf_5}\right]} - \frac{Pu}{24}$$ Factored forces in bolt

$Fbolt = 20.01 \cdot kip$ Maximum bolt force in existing anchor bolts

$$Fhilti := Fbolt \cdot \frac{ybf_6}{ybf_5}$$ $Fhilti = 24.59 \cdot kip$

$dbf = 31.75 \cdot mm$ Diameter of flange bolts

$$Abf := \frac{\pi \cdot dbf^2}{4}$$ $Abf = 1.23 \cdot in^2$ Cross sectional area of flange bolts

$fybf := 36ksi$ Yield strength of flange bolt material -- specified on drawing but assumed.

$\phi b := 0.75$ Strength reduction factor for bolts

$$FbfStress := \frac{Fbolt}{Abf}$$

$FbfStress = 16.30 \cdot ksi$

$\phi Fnt := \phi b \cdot fybf$ $\phi Fnt = 27.00 \cdot ksi$ Allowable bolt stress in tension

$Fsbolt := \frac{Vu}{nfbolts \cdot Abf}$ $Fsbolt = 1.52 \cdot ksi$ Shear stress per bolt

$\phi Fns := \phi b \cdot .533 \cdot fybf$ $\phi Fns = 14.39 \cdot ksi$ Allowable bolt stress in Shear

$\frac{FbfStress}{\phi Fnt} + \frac{Fsbolt}{\phi Fns} = 0.71$ Less than 1 so ok.

10.4.2 Calculate the bolt spacing needed for Hilit Anchor

$\frac{\pi \cdot dflange}{24} = 11.00 \cdot in$ Current spacing between anchor bolts

10.5 Calculate Overturning and Sliding Safety Factors

$\frac{Pu' \cdot rf}{Mu' + Vu' \cdot depth} = 1.75$ Greater than 1.5 so ok

Check sliding assuming a coefficient of friction of 0.5

$\frac{Pu' \cdot 0.5}{Vu'} = 3.64$ Greater than 1.5 so ok

10.6 Calculate the connection between the existing foundation concrete and the new concrete

$dbar := \frac{3}{4} in$ Diameter of reinforcement bar at joint

Use two bars

$Av := 2 \frac{\pi \cdot dbar^2}{4}$ Area of shear reinforcement bars

$fybar := 60ksi$ Yield strength of bars -- Grade 60

$\phi shear := 0.75$ Strength reduction factor for shear

$Df = 6.00\,m$ $Df = 19.69\cdot ft$ New concrete foundation diameter

$Dold := 5m$ $Dold = 16.40\cdot ft$ Existing concrete foundation diameter

$$Rold := \frac{Dold}{2}$$

$$Vnew := depth\cdot\frac{\pi}{4}\cdot\left(Df^2 - Dold^2\right)$$ Volume of new concrete needed

$Vnew = 9.04\cdot yd^3$ $Vnew = 6.91\cdot m^3$

$$WnewConcrete := Vnew\cdot 150\frac{lbf}{ft^3}$$

$WnewConcrete = 36.61\cdot kip$ Weight of new concrete

Calculate the shear at interface -- first calculate the distribution of the factored soil pressure on the bottom of the foundation

$rd := 1m$ Radius where shear is checked

Initial Guess of soil pressure

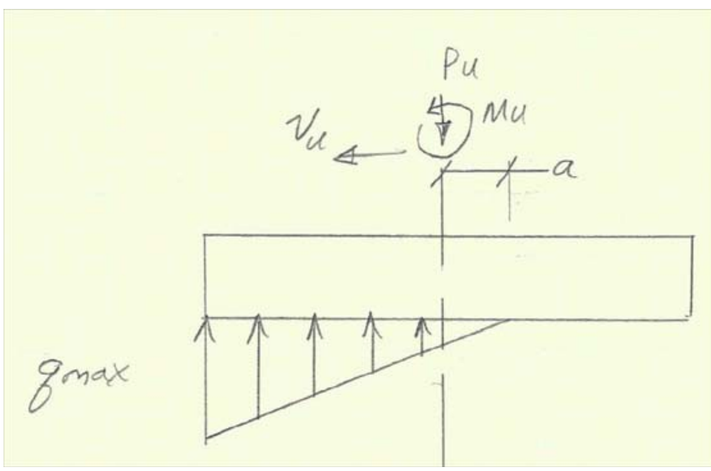
$$qmax := 5\frac{kip}{ft^2}$$ $a := -1m$

Given

$$Pu = \int_{-a}^{rf} qmax\cdot\left(\frac{a+y}{a+rf}\right)\cdot 2\cdot\sqrt{rf^2 - y^2}\,dy$$

$$Mu = \int_{-a}^{rf} qmax\cdot\left(\frac{a+y}{a+rf}\right)\cdot 2\cdot\sqrt{rf^2 - y^2}\cdot y\,dy$$

$$\begin{pmatrix} qmax \\ a \end{pmatrix} := Find(qmax, a)$$



$qmax = 5.06 \cdot \frac{kip}{ft^2}$ Maximum soil pressure

$a = -0.57\,m$

Use the soil pressure calculated with load factors to find the shear in the concrete

$rd := |a|$

$$Vjoint := \int_{rd}^{Rold} (qmax)\cdot\left(\frac{a+y}{rf+a}\right)\cdot 2\cdot\sqrt{rf^2-y^2}\cdot\left(1-\frac{\sqrt{Rold^2-y^2}}{\sqrt{rf^2-y^2}}\right)dy + \int_{rd}^{rf}(qmax)\cdot\left(\frac{a+y}{rf+a}\right)\cdot 2\cdot\sqrt{rf^2-y^2}\,dy$$

$Vjoint = 308.42\cdot kip$ Total shear force carried by the new concrete and transferred across joint

Carry shear across joint by shear friction.
μ is 0.6 for concrete placed agasinst hardened concrete that is not intentionally roughened

$\mu := 0.6$

$\phi Vn := \phi shear\cdot\mu\cdot Av\cdot fy$

$\phi Vn = 23.86\cdot kip$ Shear strength of shear friction joint

$Nshear := \frac{Vjoint}{\phi Vn}$ $Nshear = 12.93$ Number of radial rebars needed for shear transfer from new concrete to old.

Use 15 bars $Nshear := 15$

$\frac{180deg}{Nshear} = 12.00\cdot deg$ Angle spacing between bars.

$\frac{\pi\, Dold}{2}\cdot\frac{12deg}{180deg} = 20.61\cdot in$ Spacing around the circumference of bars

Development length of radial bars

$$ld := \frac{\frac{fy}{psi}}{25 \cdot \sqrt{\frac{fc}{psi}}} \cdot dbar$$

$$ld = 28.46 \cdot in$$

$$\frac{Df - Dold}{2} = 19.69 \cdot in$$

Greater than the thickness (Df-Dold)/2) of new concrete so use hooked bar

$$Ldh := \frac{\frac{0.02 \cdot fy}{psi}}{\sqrt{\frac{fc}{psi}}} \cdot dbar$$

$$Ldh = 14.23 \cdot in$$

Calculate the shear strength of the concrete and max shear in new concrete

$$Vunew := \int_{Rold}^{rf} (qmax) \cdot \left(\frac{a + y}{rf + a}\right) \cdot 2 \cdot \sqrt{rf^2 - y^2}\, dy$$

$$Vunew = 53.71 \cdot kip$$

$\phi shear := 0.75$ Strength reduction factor for shear

$$\phi Vn := \phi shear \cdot 2 \cdot \sqrt{\frac{fc}{psi}} \cdot \frac{\frac{(Df - Dold)}{2} \cdot depth}{in^2} \cdot lbf$$

$$\phi Vn = 58.82 \cdot kip$$

Calculate minimum circumferential reinforcement

$$Amin := 0.0018 \cdot depth \cdot \frac{(Df - Dold)}{2}$$

$Amin = 1.12 \cdot in^2$

Use #4 bars -- 3 on top and 3 on bottom

$$spacing := \frac{\frac{Df - Dold}{2} - 6in}{2}$$

$spacing = 6.84 \cdot in$

$d1 := Dold + 6in$	$d1 = 5.15\,m$	$d1 = 202.85 \cdot in$
$d2 := d1 + 2spacing$	$d2 = 5.50\,m$	$d2 = 216.54 \cdot in$
$d3 := d2 + 2spacing$	$d3 = 5.85\,m$	$d3 = 230.22 \cdot in$

$\cdot \cos(\alpha)\cdot \sin(\beta)$

$\cos(\alpha)\cdot \sin(\beta)$