APPROVED
By Bill Blake at 12:08 pm, Mar 13, 2025

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Structural Design Calculations

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Site No.: 4BV0382 - Machia Silo
Project: T-Mobile Equipment Upgrade
Client: J Lee Associates
Date: March 5, 2025

Synopsis:

The final T-Mobile antenna installation will consist of:

- Three (3) RFS APXVAALL24-43 antennas (1 per sector)
- Three (3) RFS APXVLL19P antennas (1 per sector)
- Three (3) Ericsson RRUS-4449 remote radio heads (RRHs)(1 per sector)
- Three (3) Ericsson RRUS-4460 RRHs (1 per sector)

Material Properties:

Structural steel yield stress, $F_{ys} := 36 \cdot ksi$

Steel yield stress (pipe), $F_{yp} := 35 \cdot ksi$

Modulus of elasticity of steel, $E_s := 29 \cdot 10^6 \cdot psi$

Steel unit weight, $\gamma_s := 490 \cdot pcf$

Concrete unit weight, $\gamma_{conc} := 150 \cdot pcf$

Loads:

Environmental Loads:

Wind Load:

Exposure category,	C	(ASCE 7-10 Sec 26.7.3)
Risk Category,	Category II	(ASCE 7-10 Table 1.5-1)
Basic Wind Velocity,	$V_w := 115$ mph	(ASCE 7-10)
Antenna Height,	$Height := 55ft$	
Exposure coefficient,	$K_z = 1.11$	(ASCE 7-10 Table 29.3-1)
Wind Directionality Factor,	$K_d := 0.9$	(ASCE 7-10 Table 26.6-1)
Velocity wind pressure,	$q_z := .00256 \cdot V_w^2 \cdot K_z \cdot K_d \cdot psf = 33.85 \cdot psf$	(ASCE 7-10 Sec. 27.3.2)
Gust response factor,	$G_r := 0.85$	(ASCE 7-10 Sec. 26.9.1)
Force coeff: Flat,	$C_f := 1.4$	(ASCE 7-10 Fig. 29.5-1)
Round	$C_r := .85$	
Wind Load factor,	$LF := .6$	(ASCE 7-10 Sect 2.4)
Wind load pressure,	$WL_f := q_z \cdot G_r \cdot C_f = 40.28 \cdot psf$	(ASCE 7-10 C26.5-1)
Radial ice thickness,	$t_{ice} := .75 \cdot in$	
Density of ice,	$\gamma_{ice} := 56 \cdot pcf$	

Equipment Loads:

Antennas

APXVAALL24-43:

Width, $w_{a1} := 24 \cdot in$

Depth, $t_{a1} := 8.7 \cdot in$

Length, $l_{a1} := 96 \cdot in$

Weight, $W_{a1} := 155 \cdot lb$

Position 2:

Width, $w_{a2} := 0 \cdot in$

Depth, $t_{a2} := 0 \cdot in$

Length, $l_{a2} := 0 \cdot in$

Weight, $W_{a2} := 0 \cdot lb$

Position 3:

Width, $w_{a3} := 0 \cdot in$

Depth, $t_{a3} := 0 \cdot in$

Length, $l_{a3} := 0 \cdot in$

Weight, $W_{a3} := 0 \cdot lb$

APXLLP19P:

Width, $w_{a4} := 11.3 \cdot in$

Depth, $t_{a4} := 4.6 \cdot in$

Length, $l_{a4} := 75.8 \cdot in$

Weight, $W_{a4} := 50 \cdot lb$

RRHs

RRUS-4449:

Width, $w_{r1} := 13.2 \cdot in$

Depth, $t_{r1} := 10.4 \cdot in$

Length, $l_{r1} := 14.9 \cdot in$

Weight, $W_{r1} := 74 \cdot lb$

Position 2:

Width, $w_{r2} := 0 \cdot in$

Depth, $t_{r2} := 0 \cdot in$

Length, $l_{r2} := 0 \cdot in$

Weight, $W_{r2} := 0 \cdot lb$

Position 3:

Width, $w_{r3} := 0 \cdot in$

Depth, $t_{r3} := 0 \cdot in$

Length, $l_{r3} := 0 \cdot in$

Weight, $W_{r3} := 0 \cdot lb$

RRUS-4460:

Width, $w_{r4} := 15.7 \cdot in$

Depth, $t_{r4} := 12.1 \cdot in$

Length, $l_{r4} := 19.6 \cdot in$

Weight, $W_{r4} := 109 \cdot lb$

Weight of antennas/RRHs:

$$W_1 := W_{a1} + W_{r1} = 229\,lb$$

$$W_2 := W_{a2} + W_{r2} = 0$$

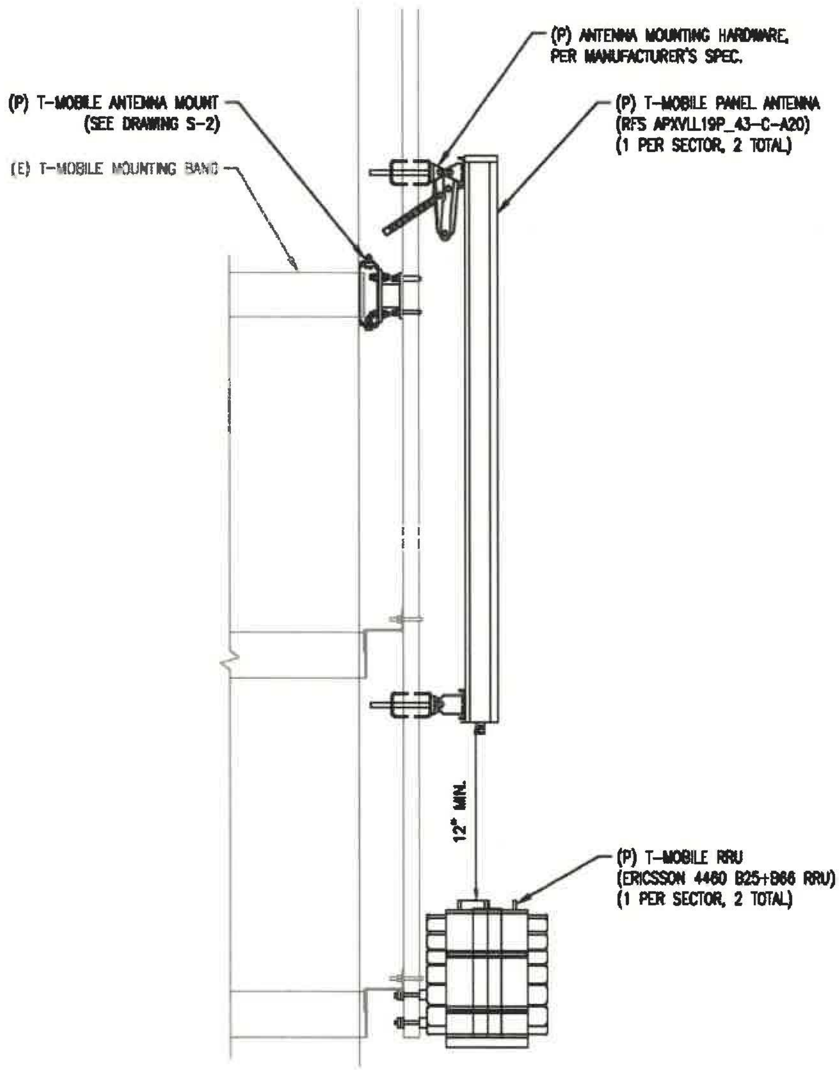
$$W_3 := W_{a3} + W_{r3} = 0$$

$$W_4 := W_{a4} + W_{r4} = 159\,lb$$

$$W_{ar} := \sum W = 388\,lb$$

Analysis

Fig 1 - Propopsed Mount (from drawings)



Antenna (APXLLP19P)

Width, $w_{a4} = 11.3 \cdot in$

Depth, $t_{a4} = 4.6 \cdot in$

Length, $l_{a4} = 75.8 \cdot in$

Weight, $W_{a4} = 50\,lb$

RRH (RRUS-4460)

Width, $w_{r4} = 15.7 \cdot in$

Depth, $t_{r4} = 12.1 \cdot in$

Length, $l_{r4} = 19.6 \cdot in$

Weight, $W_{r4} = 109\,lb$

Pipe

Diameter, $\phi_p := 2.375 \cdot in$

Length, $l_p := 10.25 \cdot ft$

Weight, $w_p := 3.65 \cdot plf$

Weight of ice:

$$W_{ant\_ice} := \left[\left[\left[w_{a1} + (2 \cdot t_{ice})\right] \cdot \left[t_{a1} + (2 \cdot t_{ice})\right] \cdot \left[l_{a1} + (2 \cdot t_{ice})\right]\right] - w_{a1} \cdot t_{a1} \cdot l_{a1}\right] \cdot \gamma_{ice} = 172.24\,lb$$

$$W_{rrh\_ice} := \left[\left[\left[w_{r1} + (2 \cdot t_{ice})\right] \cdot \left[t_{r1} + (2 \cdot t_{ice})\right] \cdot \left[l_{r1} + (2 \cdot t_{ice})\right]\right] - w_{r1} \cdot t_{r1} \cdot l_{r1}\right] \cdot \gamma_{ice} = 26.68\,lb$$

Analysis:

According to drawings by Arial Spectrum dated 8/17/09, the existing concrete silo was approximately 18' diameter, and 55' tall (to rim). Subsequent to 2009, the silo was extended 10' and Verizon installed one (1) sector of antennas at approximately 65' rad center. The thickness of the concrete walls is not known, but previous experience with similar silos would indicate that the walls are constructed of radial 30"Hx11"Wx3" concrete blocks, and are reinforced with pairs of 1/2" diameter steel tension bands, spaced approximately 30" o.c.

Check proposed mounts for T-Mobile equipment:

Side Wind Loading:

Effective depth of equipment, $D_{eff} := w_{a1} + 4 \cdot in + \phi_p = 2.53\,ft$ (use width of antenna due to skew)

Effective length of equipment, $L_{eff} := l_{a1} + 12 \cdot in + l_{r1} = 10.24\,ft$

Wind force on equipment, $P_{wind\_eq} := D_{eff} \cdot L_{eff} \cdot WL_f \cdot LF = 626.48\,lb$

Weight of pipe, brackets, $W_{misc} := 50 \cdot lb$

Distance of antennas from wall, $d_1 := 12 \cdot in$

Number of mounts, $n_s := 3$

Mount separation, $d_2 := 4 \cdot ft$

Moment at each mount, $M := \dfrac{P_{wind\_eq} \cdot d_1}{n_s} = 208.83\,ft \cdot lb$

Number of bolts per mount plate, $n_b := 4$

Spacing of bolts, $s_{bolt} := 9 \cdot in$

Maximum tensile force on bolt, $T_{bolt\_side} := \dfrac{\dfrac{M}{s_{bolt}}}{\dfrac{n_b}{2}} = 139.22\,lb$

Front Wind Loading:

Effective width of equipment, $W_{eff} := \max(w_{a1}, w_{r1}) = 2\,ft$

Effective length of equipment, $L_{eff} = 10.24\,ft$

Wind force on equipment, $P_{wind\_eq} := W_{eff} \cdot L_{eff} \cdot WL_f \cdot LF = 495\,lb$

Weight of pipe, brackets, $W_{misc} = 50\,lb$

Distance from top of antenna to top mount, $d_3 := 1.25 \cdot ft$

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Number of mounts, $n_s = 3$

Mount separation, $d_2 = 4\,ft$

Gravity load from equipment, $P_{g\_eq} := W_{ant\_ice} + W_{rrh\_ice} + W_{a1} + W_{r1} + W_{misc} = 477.93\,lb$

Mount Reactions:

Top, $$R_t := \frac{P_{wind\_eq} \cdot \left[(d_2 \cdot 2) - \left(\frac{L_{eff}}{2} - d_3 \right) \right] + P_{g\_eq} \cdot d_1}{d_2 \cdot 2} = 315.23\,lb$$

Bottom, $R_b := P_{wind\_eq} - R_t = 179.77\,lb$

Number of bolts per mount plate, $n_b := 4$

Maximum tensile force on bolt, $T_{bolt\_front} := \dfrac{\max(R_t, R_b)}{n_b} = 78.81\,lb$

Maximum tensile force on bolt (from either side or front loading), $T_{bolt} := \max(T_{bolt\_front}, T_{bolt\_side}) = 139.22\,lb$ **OK by inspection**

Check Silo

Number of sections, $N := 5$ (Silo will be subdivided into $N = 5$ sections for analysis)

Index, $i := 1 .. N$

Diameter at top, Diameter at bottom, Wall thickness (ave), Height of section,

$$D_{t\_od} := \begin{pmatrix} 216 \\ 216 \\ 216 \\ 216 \\ 216 \end{pmatrix} \cdot in \quad D_{b\_od} := \begin{pmatrix} 216 \\ 216 \\ 216 \\ 216 \\ 216 \end{pmatrix} \cdot in \quad t_{wall} := \begin{pmatrix} 3 \\ 3 \\ 3 \\ 3 \\ 3 \end{pmatrix} \cdot in \quad h_{sec} := \begin{pmatrix} 15 \\ 15 \\ 15 \\ 15 \\ 15 \end{pmatrix} \cdot ft$$

Inner dia. at top, $D_{t\_id_i} := D_{t\_od_i} - 2 \cdot t_{wall_i}$ Inner dia. at bottom, $D_{b\_id_i} := D_{b\_od_i} - 2 \cdot t_{wall_i}$

$$D_{t\_id} = \begin{pmatrix} 17.5 \\ 17.5 \\ 17.5 \\ 17.5 \\ 17.5 \end{pmatrix} ft \quad D_{b\_id} = \begin{pmatrix} 17.5 \\ 17.5 \\ 17.5 \\ 17.5 \\ 17.5 \end{pmatrix} ft$$

Approx. silo weight,

$$W_i := \left[\frac{\pi \cdot \frac{\left[\left(D_{b\_od_i}\right)^2 - \left[D_{b\_od_i} - 2\cdot\left(t_{wall_i}\right)\right]^2\right]}{4} + \pi \cdot \frac{\left[\left(D_{t\_od_i}\right)^2 - \left(D_{t\_od_i} - 2\cdot t_{wall_i}\right)^2\right]}{4}}{2}\right] \cdot h_{sec_i} \cdot \gamma_{conc}$$

$$\sum W = 156.83 \cdot kip$$

Total height, $H_{silo} := \sum h_{sec} = 75\,ft$

Wind load:

Height, $H_{silo} = 75\,ft$ AGL

Basic wind velocity, $V_w = 115$ mph

Wind directionality coeff., $K_d := .9$

Gust Responce Factor, $G_r := 0.85$

Force coeff., $C_f = 1.4$ Flat

$C_r := 0.75$ Round

Wind Load factor, $LF = 0.6$

$$h_{sec} = \begin{pmatrix} 15 \\ 15 \\ 15 \\ 15 \\ 15 \end{pmatrix} ft$$

Exposure coefficient, $K_z := \begin{pmatrix} 1.19 \\ 1.13 \\ 1.06 \\ .98 \\ .85 \end{pmatrix}$ (ASCE 7-10 Table 29.3-1)

Velocity wind pressure, $q := .00256 \cdot V_w^{\,2} \cdot K_z \cdot K_d \cdot psf$

Wind load pressure on stack, $WL_{stack} := q \cdot C_r \cdot G_r$

$$q = \begin{pmatrix} 36.26 \\ 34.43 \\ 32.3 \\ 29.86 \\ 25.9 \end{pmatrix} \cdot psf \qquad WL_{stack} = \begin{pmatrix} 23.12 \\ 21.95 \\ 20.59 \\ 19.04 \\ 16.51 \end{pmatrix} \cdot psf$$

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Average width of each section, $D_{ave} := \dfrac{D_{t\_od} + D_{b\_od}}{2}$ $D_{ave} = \begin{pmatrix} 18 \\ 18 \\ 18 \\ 18 \\ 18 \end{pmatrix} ft$

Linear wind load on each section, $w_i := D_{ave_i} \cdot WL_{stack_i}$ $w = \begin{pmatrix} 416.08 \\ 395.1 \\ 370.63 \\ 342.65 \\ 297.2 \end{pmatrix} \cdot plf$ (Input to Enercalc)

Calculate loads from carrier equipment:

Centerline height of T-Mobile antennas: $h_1 := Height = 55\,ft$

Exposure Coeff for equipment on silo, $K_{z\_e} := 1.09$

Wind load pressures on equipment, $WL_{eq} := .00256 \cdot V_w^2 \cdot K_{z\_e} \cdot K_d \cdot C_f \cdot psf = 46.5 \cdot psf$

Wind load on T-Mo antennas, $P_1 := 2 \cdot (D_{eff} \cdot L_{eff} \cdot WL_{eq}) = 2410.84\,lb$ (Input to Enercalc)

Centerline of Verizon antennas, $h_2 := 65 \cdot ft$

Wiind load on Verizon antennas, $P_2 := (D_{eff} \cdot L_{eff} \cdot WL_{eq}) = 1205.42\,lb$ (Input to Enercalc)

Cumulative moments on each section, $M_{tot\_sec} := \begin{pmatrix} 32 \\ 139 \\ 306 \\ 458 \\ 780 \end{pmatrix} \cdot ft \cdot kip$ (from Enercalc output)

Weight of T-Mobile equip, $W_1 := 2W_{ar} = 776\,lb$

Weight of Verizon equip, $W_2 := \dfrac{W_1}{2} = 388\,lb$

Weight of misc hardware (brackets, , bands, jumpers, etc...), $P_{misc} := 800 \cdot lb$

Dead load of equipment on ech section $W_{eq\_sec} := \begin{pmatrix} W_1 + W_2 + P_{misc} \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} = \begin{pmatrix} 1964 \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix} \text{lb}$

Total masonry dead load per section, $W_{tot\_sec} := W = \begin{pmatrix} 31.37 \\ 31.37 \\ 31.37 \\ 31.37 \\ 31.37 \end{pmatrix} \cdot \text{kip}$

Cumulative Weight

Cumulative dead load on each section, $DL(W_{tot\_sec} + W_{eq\_sec}) = \begin{pmatrix} 33.33 \\ 64.7 \\ 96.06 \\ 127.43 \\ 158.8 \end{pmatrix} \cdot \text{kip}$

Approximate moment at stack base due to wind, $M_o := M_{tot\_sec_N} = 780 \cdot \text{ft} \cdot \text{kip}$

Resisting moment due to self-weight of stack and equipment, $M_r := \left(DL(W_{tot\_sec})_N\right) \cdot \frac{D_{b\_od_N}}{2} = 1411.51 \, \text{ft} \cdot \text{kip}$

Factor of safety, $FS := 1.5$

$$\text{FactorOfSafetyCheck} := \begin{array}{|l} \text{"OK"} \quad \text{if} \quad FS \le \frac{M_r}{M_o} \\ \text{"NG"} \quad \text{otherwise} \end{array}$$

FactorOfSafetyCheck = "OK"

Conclusion:

Based on the results of the analysis, the proposed T-Mobile Equipment Upgrade installation is structurally sound, as designed and depicted on plans by this office. The analysis was conducted in accordance with the Vermont 2015 Fire & Building Safety Code, and ASCE 7-10.

References:

1. American Society of Civil Engineers (2010), Minimum Design Loads for Buildings and Other Structures (7-10), American Society of Civil Engineers, New York, NY
2. Vermont 2015 Fire & Building Safety Code (IBC 2015)