WIND LOADING ON NON-BUILDING STRUCTURES

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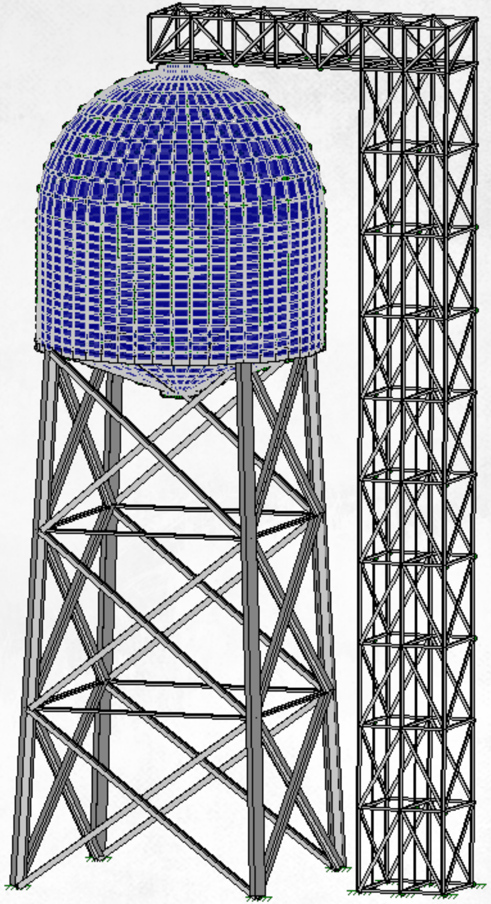
NON-BUILDING STRUCTURES IN RISA

3D | RISA-3D



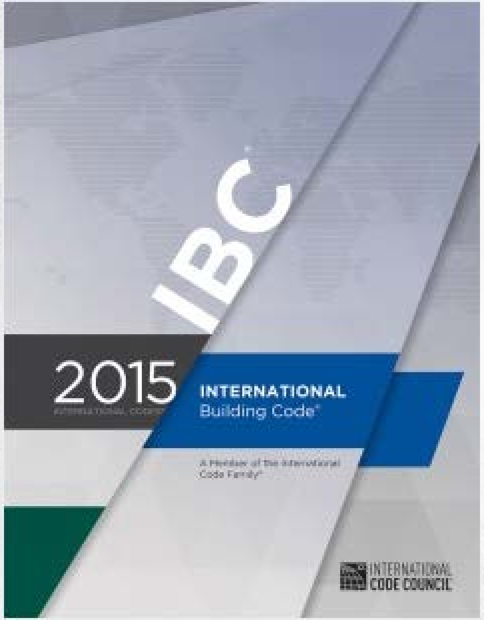
Today's Webinar Objectives

- Understanding the Code
- Applying Loads
    - Wind
    - Ice
- Interpreting Results

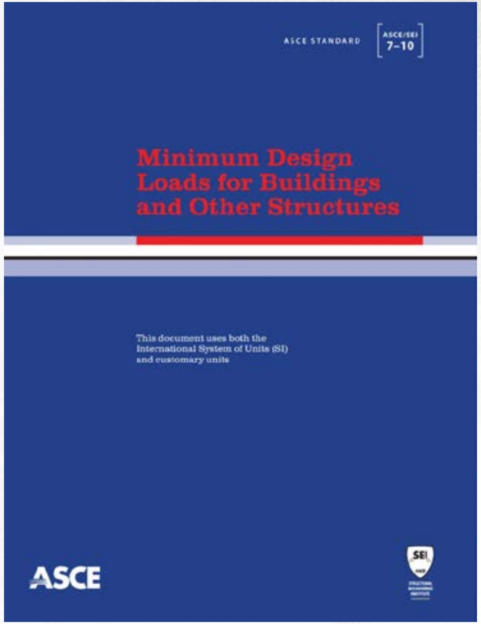
Let's Start Loading!

NON-BUILDING STRUCTURES IN RISA

Design per IBC 2015...



...which references ASCE 7-10



NON-BUILDING STRUCTURES IN RISA

Part 1: Wind Loading

NON-BUILDING STRUCTURES IN RISA

Chapter 26 – General Requirements

- Calculation of basic wind parameters:

  Risk Category

  V = Basic Wind Speed

  Kd = Wind Directionality Factor

  Exposure Category

  Kzt = Topographic Factor

  G = Gust Effect Factor

NON-BUILDING STRUCTURES IN RISA

Risk Category (Table 1.5-1)

Assume that tank holds hazardous chemicals at industrial site

~~Category IV: Essential Facilities~~

~~Category IV: Poses Substantial Hazard to Community~~

~~Category IV: Required for Essential Facilities to function~~

NON-BUILDING STRUCTURES IN RISA

Risk Category (Table 1.5-1)

Assume that tank holds hazardous chemicals at industrial site

~~Category III: Poses Substantial Risk to Human Life~~

~~Category III: Could Substantially Impact Day-to-Day Life~~

Category III/IV*: Hazardous Chemicals

*Determined by Jurisdiction Authorities

I = 1.00 (Table 1.5-2)

NON-BUILDING STRUCTURES IN RISA

Basic Wind Speed

Project Site: East St. Louis, Illinois 62201

V = 120 mph (Figure 26.5-1B)

Note: This is a Strength Design Level Wind (ASCE 7-10)

In ASCE 7-05 this would have been 90 mph

NON-BUILDING STRUCTURES IN RISA

Wind Directionality Factor (Table 26.6-1)

Separate Factors for Tank versus Tower and Tank Legs

Tank:	$K_d = 0.95$	(Round Tanks)
Tank Legs:	$K_d = 0.85$	(Lattice Framework)
Tower:	$K_d = 0.85$	(Lattice Framework)

NON-BUILDING STRUCTURES IN RISA

Exposure Category (Section 26.7.3)

- Exposure Category D: Water Surface for at least 1 mile
- Exposure Category B: Dense Buildings or Forests for at least ½ mile
- Exposure Category C: All Other Cases

NON-BUILDING STRUCTURES IN RISA

Site Photo (Worst Case Direction)

Therefore, Exposure Category C

NON-BUILDING STRUCTURES IN RISA

Topographic Factor (Section 26.8.2)

Levee along river is 10 feet high (H = 10 ft)

Levee on opposite bank is 1,500 ft away

Condition 1: No obstructions within distance 100*H

100*H = 1,000 ft < 1,500 ft

Therefore, Condition 1 is met

NON-BUILDING STRUCTURES IN RISA

Topographic Factor (Section 26.8.2)

Condition 2: No obstructions of at least half height within 2 miles

Levees are of equal height

1,500 ft < 2 miles

<u>Therefore, Condition 2 is not met</u>

<u>Therefore, $K_{zt} = 1.0$</u>

NON-BUILDING STRUCTURES IN RISA

Gust Effect Factor (Section 26.9)

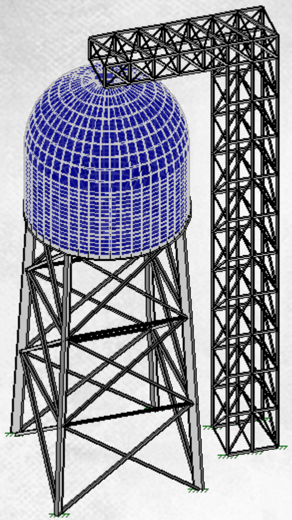
Requires determination if structure is Rigid or Flexible

Rigid:	$n \geq 1$ Hz	$T < 1$ sec
Flexible:	$n < 1$ Hz	$T \geq 1$ sec

NON-BUILDING STRUCTURES IN RISA

Gust Effect Factor (Section 26.9)

From Dynamic Analysis:



Tank and Legs: n = 8.4 Hz (Rigid) G = 0.85

Tower: 0.5 Hz < n < 0.77 Hz (Flexible)

NON-BUILDING STRUCTURES IN RISA

Gust Effect Factor (Section 26.9)

Gf = 1.272

$n_1 := 0.501 \cdot Hz$

$c := 0.2$ (Table 26.9-1)

$h := 97.5\ ft$

$z_{min} := 15\ ft$ (Table 26.9-1)

$z := \max(0.6 \cdot h, z_{min}) = 58.5\ ft$ (Section 26.9.4)

$I_z := c \cdot \left(\frac{33\ ft}{z}\right)^{\left(\frac{1}{6}\right)} = 0.182$ (Eqn 26.9-7)

$g_Q := 3.4$ (Section 26.9.5)

$B := 10\ ft$

$l := 500\ ft$ (Table 26.9-1)

$\varepsilon := \left(\frac{1}{3.0}\right)$ (Table 26.9-1)

$L_z := l \cdot \left(\frac{z}{33\ ft}\right)^{\varepsilon} = 605.133\ ft$ (Eqn 26.9-9)

$Q := \sqrt{\frac{1}{1+0.63 \cdot \left(\frac{B+h}{L_z}\right)^{0.63}}} = 0.908$ (Section 26.9-8)

$x := 2 \cdot (\ln(3600\ sec \cdot n_1)) = 14.995$

$g_R := \sqrt{x} + \frac{0.577}{\sqrt{x}} = 4.021$ (Eqn 26.9-11)

$\beta := 0.05$

$b_{bar} := 0.65$ (Table 26.9-1)

$\alpha := 9.5$ (Table 26.9-1)

$V := 120\ mph$ (Figure 26.5-1B)

$V_z := b_{bar} \cdot \left(\frac{z}{33\ ft}\right)^{\alpha} \cdot \left(\frac{88}{60}\right) \cdot V = 26334\ mph$ (Eqn 26.9-16)

$N_1 := \frac{n_1 \cdot L_z}{V_z} = 0.008$ (Eqn 26.9-14)

$R_n := \frac{7.47 \cdot N_1}{(1+10.3 \cdot N_1)^{\frac{5}{3}}} = 0.052$ (Eqn 26.9-13)

$\eta_h := 4.6 \cdot \frac{n_1 \cdot h}{V_z} = 0.006$ (Section 26.9.5)

$R_h := \frac{1}{\eta_h} - \frac{1}{2 \cdot \eta_h^2} \cdot (1 - e^{-2 \cdot \eta_h}) = 0.996$ (Section 26.9-15a)

$\eta_B := 4.6 \cdot \frac{n_1 \cdot B}{V_z} = 5.967 \cdot 10^{-4}$ (Section 26.9.5)

$R_B := \frac{1}{\eta_B} - \frac{1}{2 \cdot \eta_B^2} \cdot (1 - e^{-2 \cdot \eta_B}) = 1$ (Section 26.9-15a)

$L := B = 10\ ft$

$\eta_L := 15.4 \cdot \frac{n_1 \cdot L}{V_z} = 0.002$ (Section 26.9.5)

$R_L := \frac{1}{\eta_L} - \frac{1}{2 \cdot \eta_L^2} \cdot (1 - e^{-2 \cdot \eta_L}) = 0.999$ (Section 26.9-15a)

$R := \sqrt{\frac{1}{\beta} \cdot R_n \cdot R_h \cdot R_B \cdot (0.53 + 0.47 \cdot R_L)} = 1.012$ (Eqn 26.9-12)

$g_v := 3.4$ (Section 26.9.5)

$G_f := 0.925 \cdot \left(\frac{1+1.7 \cdot I_z \cdot \sqrt{g_Q^2 \cdot Q^2 + g_R^2 \cdot R^2}}{1+1.7 \cdot g_v \cdot I_z}\right) = 1.163$ (Eqn 26.9-10)

$n_1 := 0.773 \cdot Hz$

$c := 0.2$ (Table 26.9-1)

$h := 97.5\ ft$

$z_{min} := 15\ ft$ (Table 26.9-1)

$z := \max(0.6 \cdot h, z_{min}) = 58.5\ ft$ (Section 26.9.4)

$I_z := c \cdot \left(\frac{33\ ft}{z}\right)^{\left(\frac{1}{6}\right)} = 0.182$ (Eqn 26.9-7)

$g_Q := 3.4$ (Section 26.9.5)

$B := 10\ ft$

$l := 500\ ft$ (Table 26.9-1)

$\varepsilon := \left(\frac{1}{3.0}\right)$ (Table 26.9-1)

$L_z := l \cdot \left(\frac{z}{33\ ft}\right)^{\varepsilon} = 605.133\ ft$ (Eqn 26.9-9)

$Q := \sqrt{\frac{1}{1+0.63 \cdot \left(\frac{B+h}{L_z}\right)^{0.63}}} =$ [illegible] (Section 26.9-8)

$x := 2 \cdot (\ln(3600\ sec \cdot n_1)) = 15.862$

$g_R := \sqrt{x} + \frac{0.577}{\sqrt{x}} = 4.128$ (Eqn 26.9-11)

$\beta := 0.05$

$b_{bar} := 0.65$ (Table 26.9-1)

$\alpha := 9.5$ (Table 26.9-1)

$V := 120\ mph$ (Figure 26.5-1B)

$V_z := b_{bar} \cdot \left(\frac{z}{33\ ft}\right)^{\alpha} \cdot \left(\frac{88}{60}\right) \cdot V = 26334\ mph$ (Eqn 26.9-16)

$N_1 := \frac{n_1 \cdot L_z}{V_z} = 0.012$ (Eqn 26.9-14)

$R_n := \frac{7.47 \cdot N_1}{(1+10.3 \cdot N_1)^{\frac{5}{3}}} = 0.074$ (Eqn 26.9-13)

$\eta_h := 4.6 \cdot \frac{n_1 \cdot h}{V_z} = 0.009$ (Section 26.9.5)

$R_h := \frac{1}{\eta_h} - \frac{1}{2 \cdot \eta_h^2} \cdot (1 - e^{-2 \cdot \eta_h}) = 0.994$ (Section 26.9-15a)

$\eta_B := 4.6 \cdot \frac{n_1 \cdot B}{V_z} = 9.206 \cdot 10^{-4}$ (Section 26.9.5)

$R_B := \frac{1}{\eta_B} - \frac{1}{2 \cdot \eta_B^2} \cdot (1 - e^{-2 \cdot \eta_B}) = 0.999$ (Section 26.9-15a)

$L := B = 10\ ft$

$\eta_L := 15.4 \cdot \frac{n_1 \cdot L}{V_z} = 0.003$ (Section 26.9.5)

$R_L := \frac{1}{\eta_L} - \frac{1}{2 \cdot \eta_L^2} \cdot (1 - e^{-2 \cdot \eta_L}) = 0.998$ (Section 26.9-15a)

$R := \sqrt{\frac{1}{\beta} \cdot R_n \cdot R_h \cdot R_B \cdot (0.53 + 0.47 \cdot R_L)} = 1.215$ (Eqn 26.9-12)

$g_v := 3.4$ (Section 26.9.5)

$G_f := 0.925 \cdot \left(\frac{1+1.7 \cdot I_z \cdot \sqrt{g_Q^2 \cdot Q^2 + g_R^2 \cdot R^2}}{1+1.7 \cdot g_v \cdot I_z}\right) = 1.272$ (Eqn 26.9-10)

NON-BUILDING STRUCTURES IN RISA

Wind Concepts

Main Wind Force Resisting System

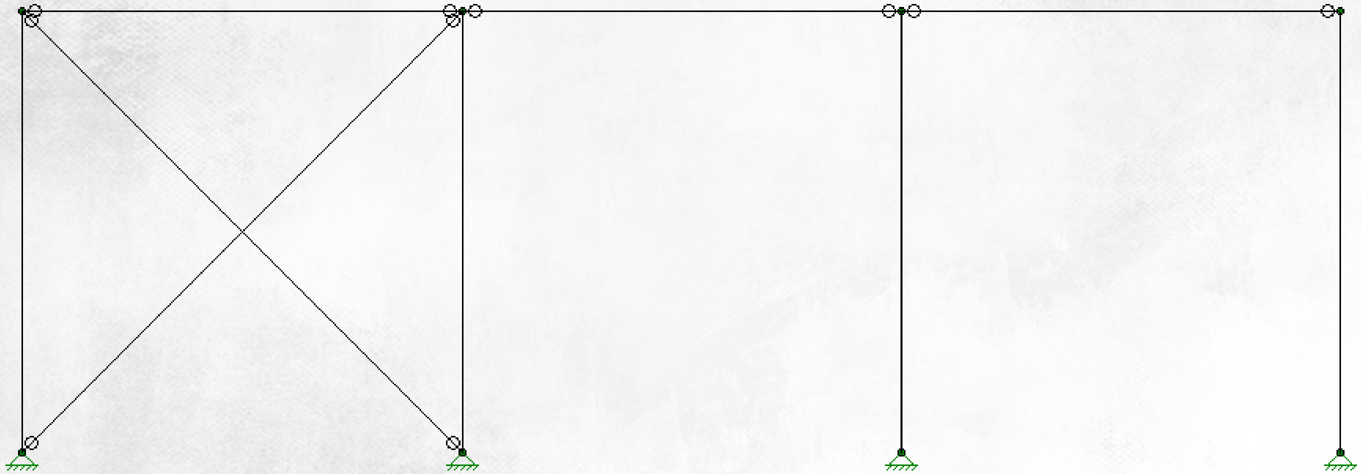
- Elements of the structure which are essential to keeping the entire structure from collapsing due to wind.

Components and Cladding

- Elements (Structural or Non-Structural) which transmit wind forces to the Main Wind Force Resisting System.
- Not essential for overall structural stability

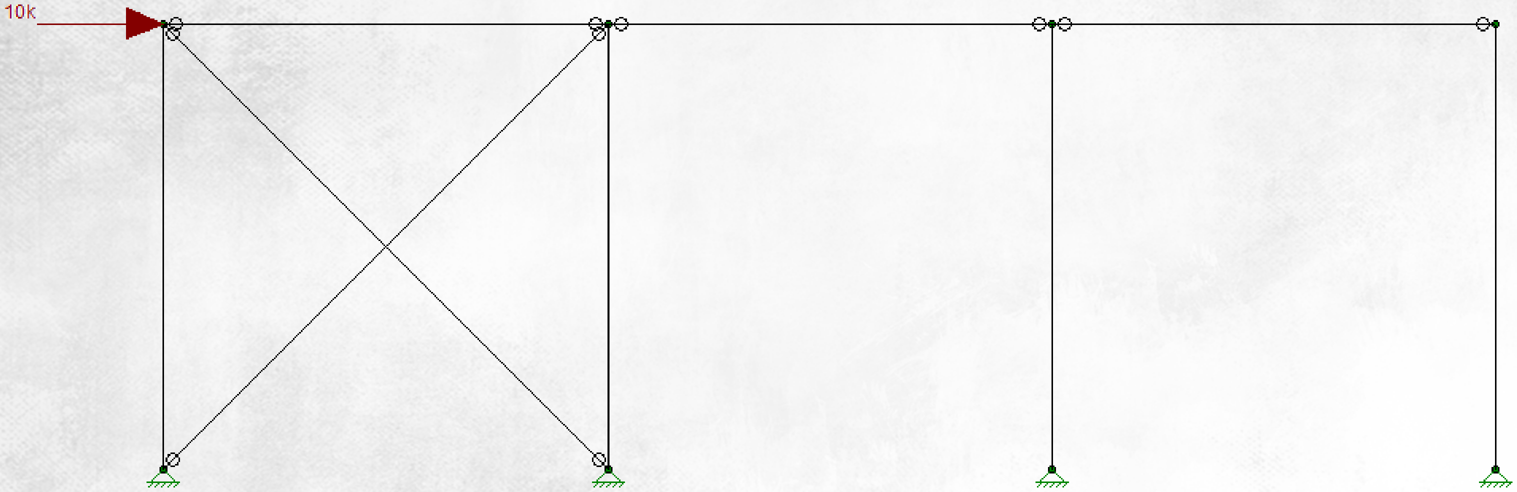
NON-BUILDING STRUCTURES IN RISA

Main Wind Force Resisting System



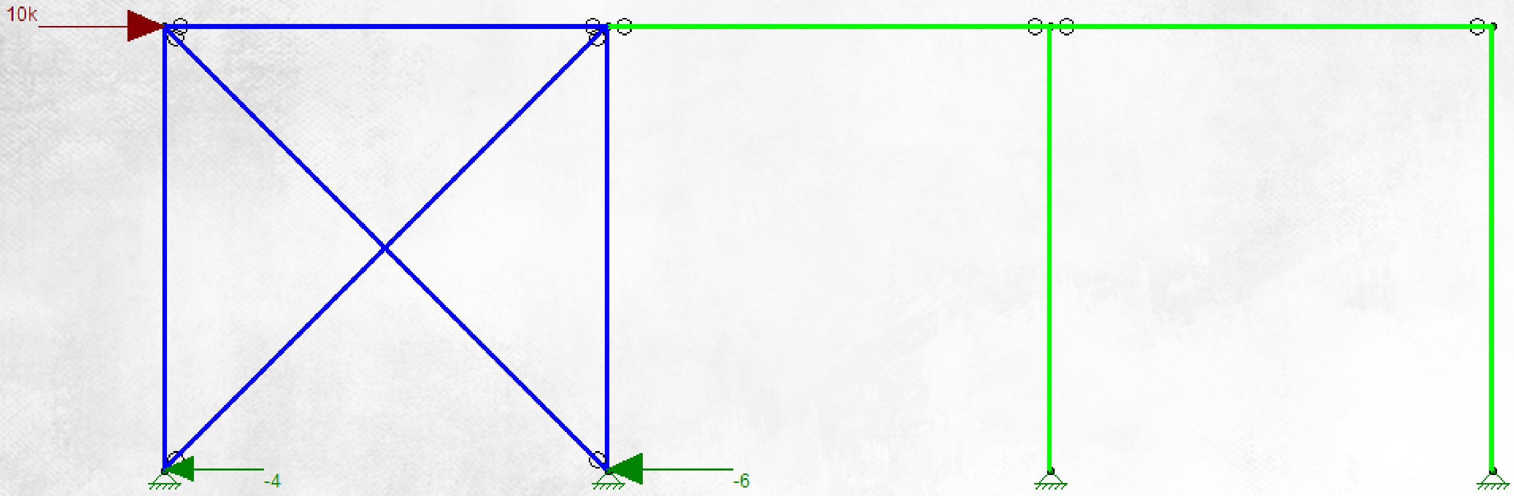
NON-BUILDING STRUCTURES IN RISA

Main Wind Force Resisting System



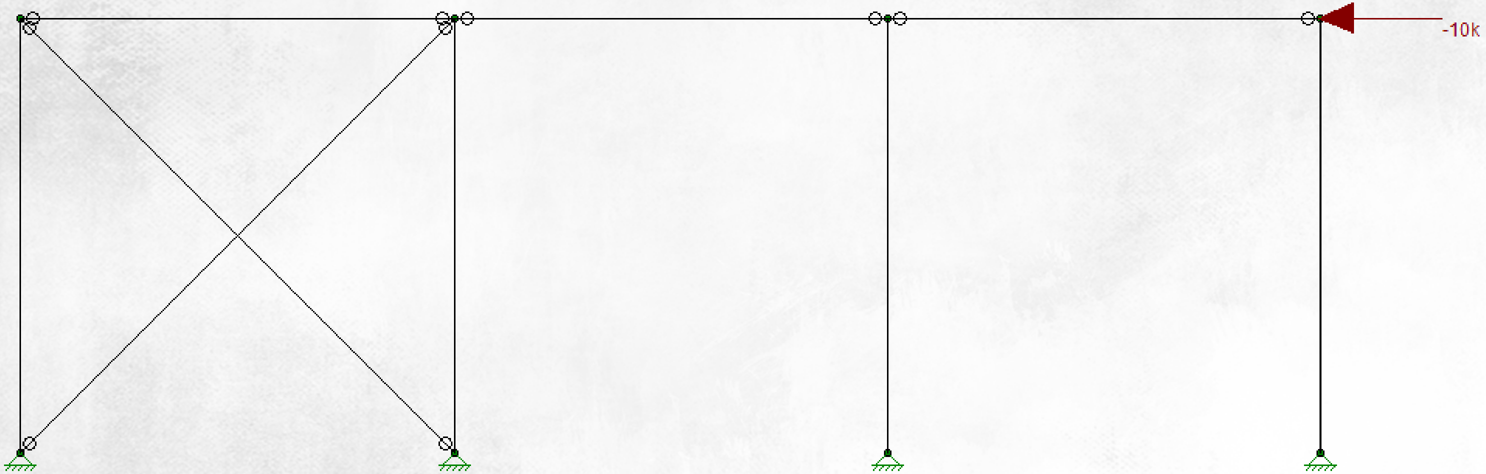
NON-BUILDING STRUCTURES IN RISA

Main Wind Force Resisting System



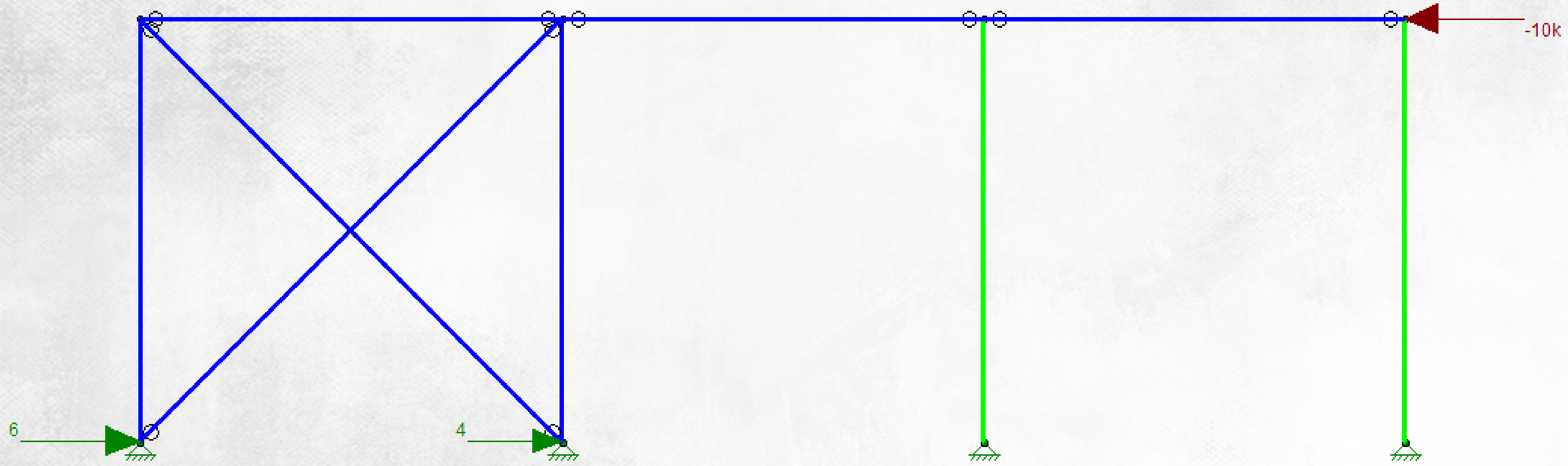
NON-BUILDING STRUCTURES IN RISA

Main Wind Force Resisting System



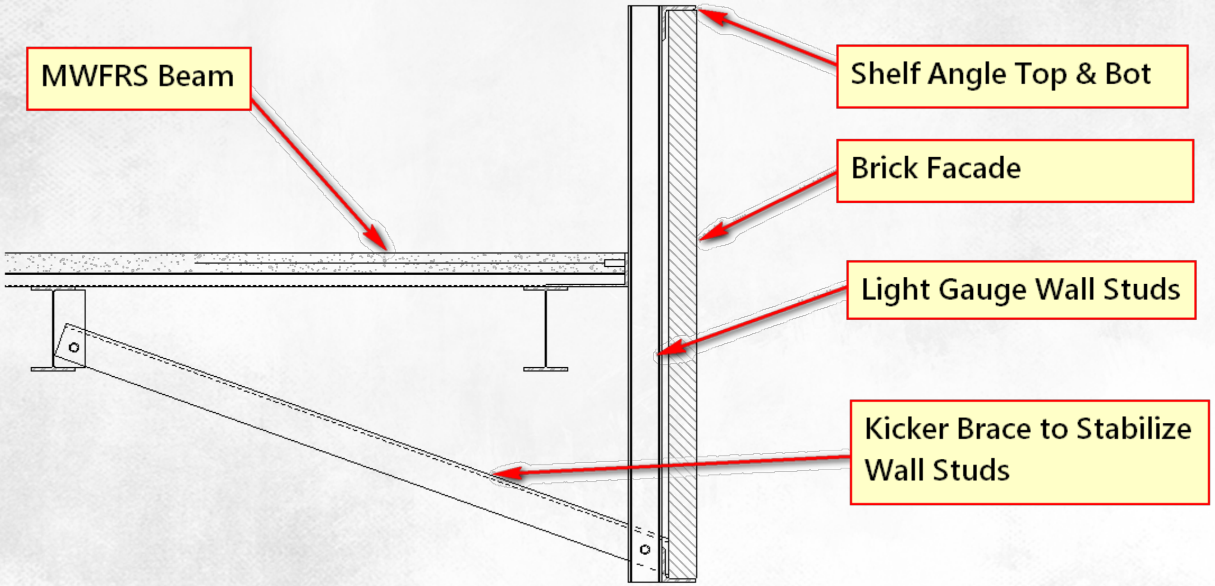
NON-BUILDING STRUCTURES IN RISA

Main Wind Force Resisting System



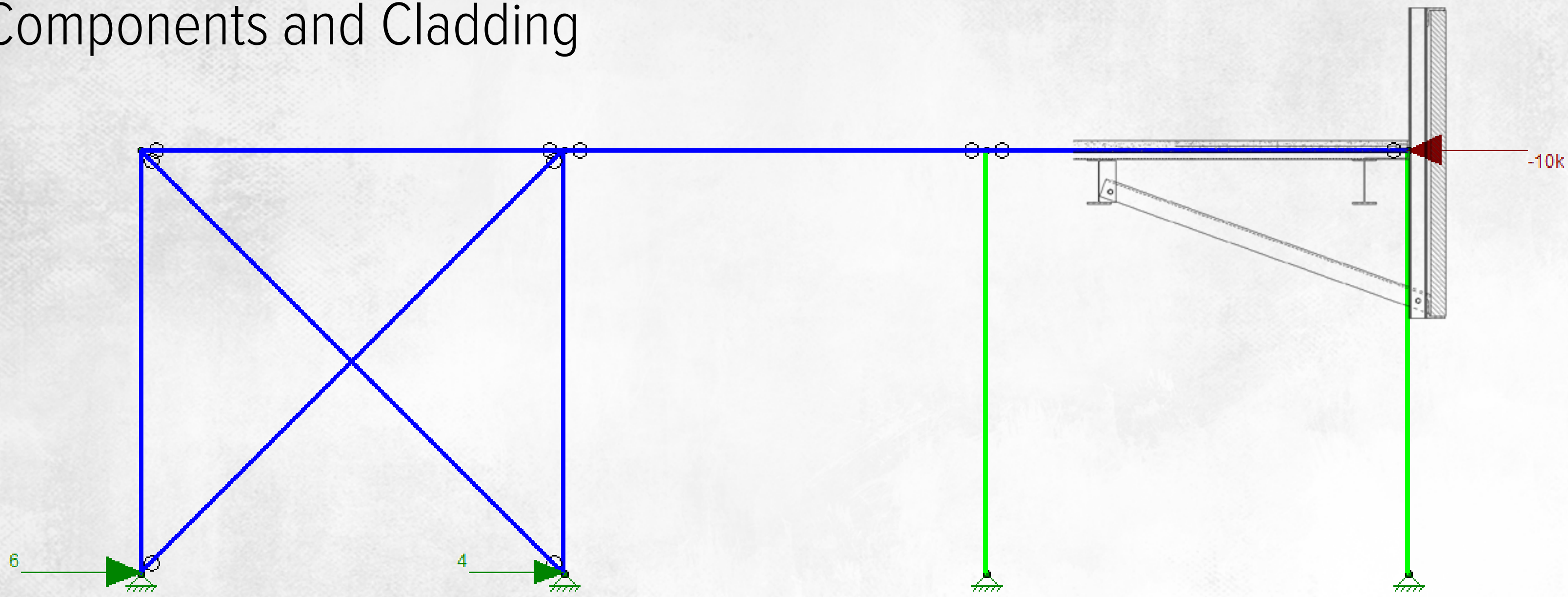
NON-BUILDING STRUCTURES IN RISA

Components and Cladding



NON-BUILDING STRUCTURES IN RISA

Components and Cladding

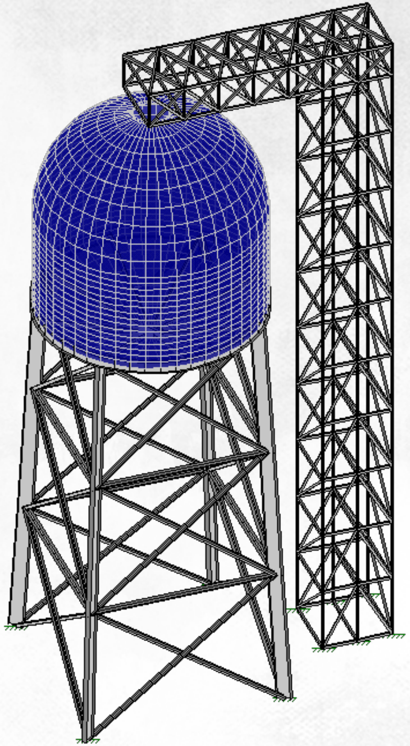


NON-BUILDING STRUCTURES IN RISA

Main Wind Force Resisting System

- No cladding or façade
- All elements contribute to overall stability

Therefore, no components and cladding



NON-BUILDING STRUCTURES IN RISA

ASCE 7-10 Main Wind Force Resisting System Chapters

~~Chapter 27: Buildings of All Heights~~

~~Chapter 28: Low Rise Buildings~~

Chapter 29: Roof Overhangs, Parapets, and Other Structures

NON-BUILDING STRUCTURES IN RISA

Chapter 29 Preconditions

- ✓ Regular-Shaped Structure
- ✓ No Special Response Characteristics
- ✓ No Channeling or Buffeting Effects at Site

NON-BUILDING STRUCTURES IN RISA

Velocity Pressure Exposure Coefficient

Height = 100 feet (approx)

Exposure Category C

$K_z = 1.26$ (Table 29.3-1)

NON-BUILDING STRUCTURES IN RISA

Velocity Pressure (Tank)

Kz = 1.26

Kzt = 1.00

Kd = 0.95

V = 120 mph

qz = 0.00256*Kz*Kzt*Kd*(V^2) = 44.1 psf

NON-BUILDING STRUCTURES IN RISA

Velocity Pressure (Tank Legs and Tower)

Kz = 1.26

Kzt = 1.00

Kd = 0.85

V = 120 mph

qz = 0.00256*Kz*Kzt*Kd*(V^2) = 39.5 psf

NON-BUILDING STRUCTURES IN RISA

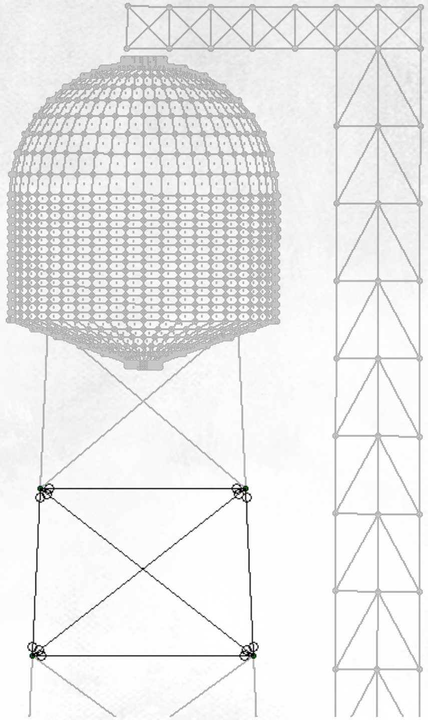
Force Coefficient (Tank Legs)

Trussed Tower (Figure 29.5-3)

ε = Ratio of Solid Area to Gross Area

ε = 88 sf / 509 sf = 0.17

$C_f = 4.0 * \varepsilon^2 - 5.9 * \varepsilon + 4.0 = 3.1$



NON-BUILDING STRUCTURES IN RISA

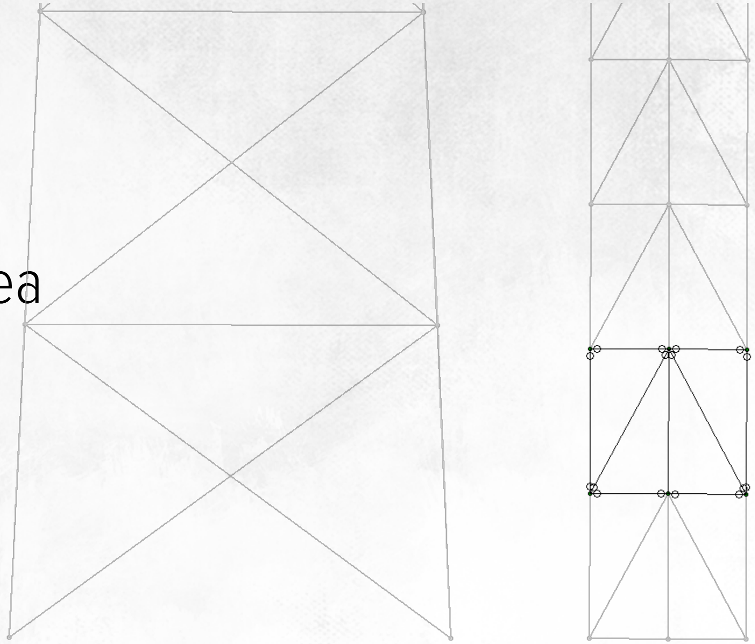
Force Coefficient (Tower)

Trussed Tower (Figure 29.5-3)

ε = Ratio of Solid Area to Gross Area

ε = 16.5 sf / 92.5 sf = 0.17

$C_f = 4.0*\varepsilon^2 - 5.9*\varepsilon + 4.0 = 3.1$



NON-BUILDING STRUCTURES IN RISA

Force Coefficient (Tank)

Tanks (Figure 29.5-1)

Assume Smooth h = 100 ft D = Diameter = 32 ft

D*(qz)^(1/2) = 213 > 2.5

h/D = 3.125

Cf = [0.1*(3.125 ft – 1 ft) / (7 ft – 1 ft)] + 0.5 = 0.54

NON-BUILDING STRUCTURES IN RISA

Design Wind Pressures

Tank Legs:	(39.5 psf)*(0.85)*(3.1/2) = 52 psf
Tower:	(39.5 psf)*(1.272)*(3.1/2) = 78 psf
Tank:	(44.1 psf)*(0.85)*(0.54) = 20.2 psf

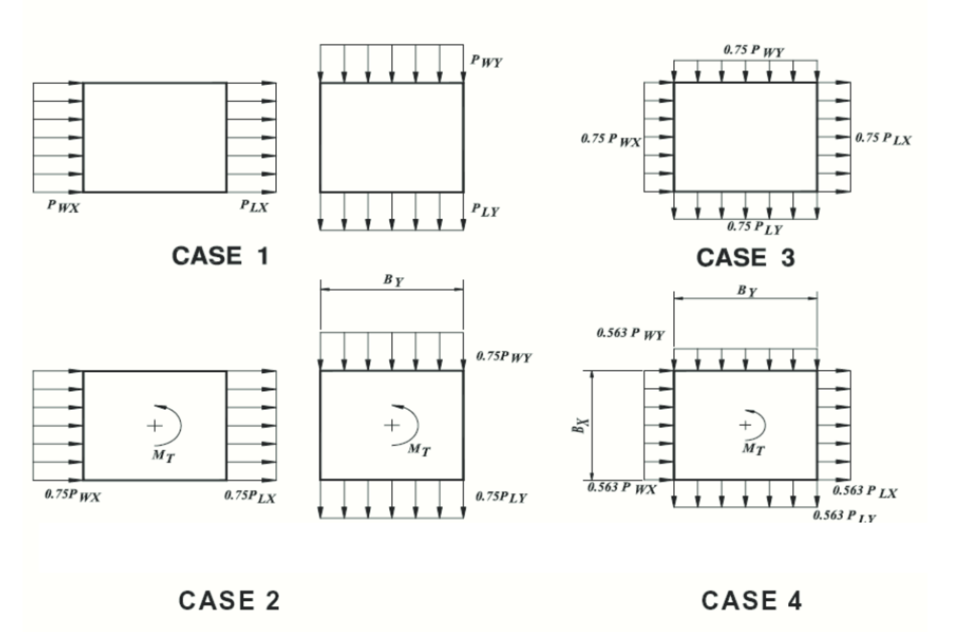
NON-BUILDING STRUCTURES IN RISA

Wind Load Cases

Straight Wind

Quartering Wind

Torsion



Images courtesy of American Society of Civil Engineers

NON-BUILDING STRUCTURES IN RISA

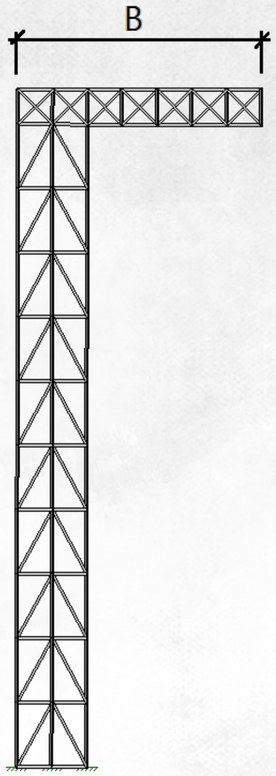
Wind Torsion (Tower)

There is no clear "B" dimension

Conservatively use the maximum width

$e = 0.15 * B = (0.15) * (35 \text{ ft}) = 5.25 \text{ ft}$

$M = F * e \qquad = F * 5.25 \text{ ft-lbs}$

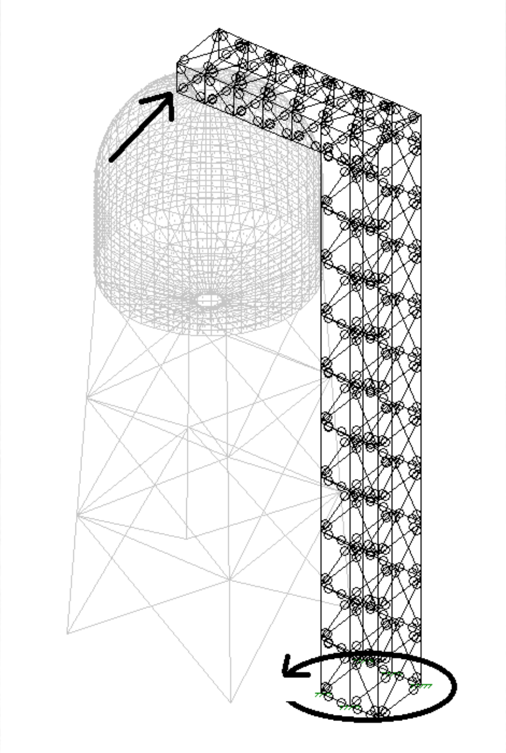


NON-BUILDING STRUCTURES IN RISA

Wind Torsion (Tower)

Conservatively Apply as a Point Load

$P = M / 30\ \text{ft} = 0.175*F$



NON-BUILDING STRUCTURES IN RISA

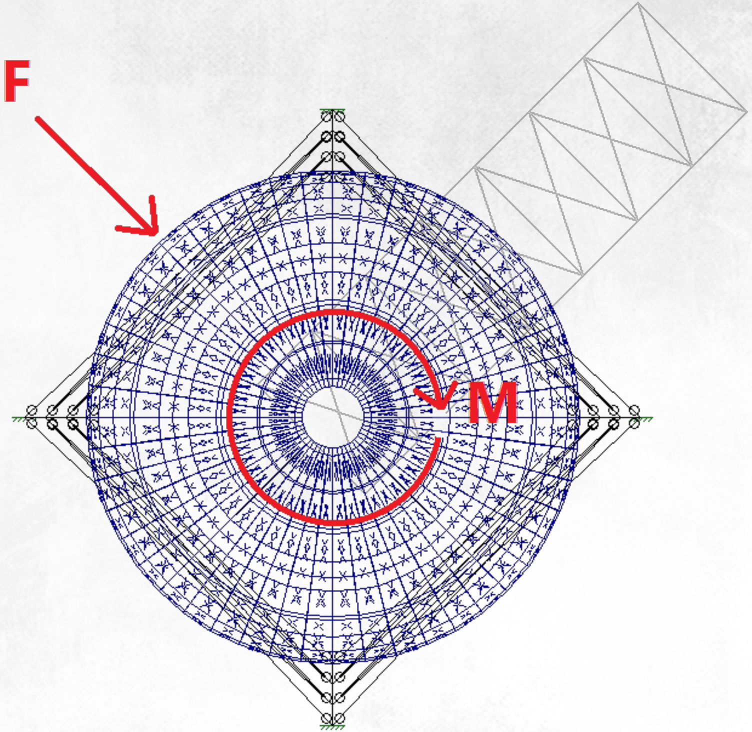
Wind Torsion (Tank)

e = 0.15*D = (0.15)*(32 ft) = 4.8 ft

M = F*e = F*4.8 ft-lbs

Apply as circumferential line load

w = (M / (D/2)) / (D*π) = 0.003*F lbs/ft



NON-BUILDING STRUCTURES IN RISA

Part 2: Ice Loading

NON-BUILDING STRUCTURES IN RISA

Chapter 10 – Atmospheric Icing

- Calculation of ice loading parameters:

  Risk Category

  t = Nominal Ice Thickness

  fz = Height Factor

  Kzt = Topographic Factor

  Vc = Concurrent Wind Speed

  Dc = Approximate Diameter of Member

NON-BUILDING STRUCTURES IN RISA

Risk Category

Already calculated as Category III

I = 1.25 (Table 1.5-2)

Nominal Ice Thickness

t = 1" (Figure 10-2)

NON-BUILDING STRUCTURES IN RISA

Height Factor

Conservatively take height (z) as 100 ft for everything

fz = (z/33)^0.1 = 1.12

Topographic Factor

Already calculated as 1.0

NON-BUILDING STRUCTURES IN RISA

Design Ice Thickness

td = 2.0*t*I*fz*(Kzt)^0.35 (Eqn 10.4-5)

td = 2.8”

Design Ice Density

γ = 56 pcf

NON-BUILDING STRUCTURES IN RISA

Concurrent Wind Speed

V = 40 mph (Figure 10-2)

Design Velocity Pressures

qz = 0.00256*Kz*Kzt*Kd*(V^2)

Tank: qz = 4.9 psf

Tank Legs and Tower: qz = 4.4 psf

NON-BUILDING STRUCTURES IN RISA

Concurrent Wind Speed

V = 40 mph (Figure 10-2)

Design Velocity Pressures

qz = 0.00256*Kz*Kzt*Kd*(V^2)

Tank: qz = 4.9 psf

Tank Legs and Tower: qz = 4.4 psf

NON-BUILDING STRUCTURES IN RISA

<u>Design Wind Pressures</u>

Tank Legs: $p = (4.4\ \text{psf})*(0.85)*(3.1/2) = 5.8\ \text{psf}$

Tower: $p = (4.4\ \text{psf})*(1.272)*(3.1/2) = 8.7\ \text{psf}$

Tank: $p = (4.9\ \text{psf})*(0.85)*(0.54) = 2.25\ \text{psf}$

NON-BUILDING STRUCTURES IN RISA

Approximate Member Diameter

Must be Hand Calculated for each member size

List of Shapes Susceptible to Icing:

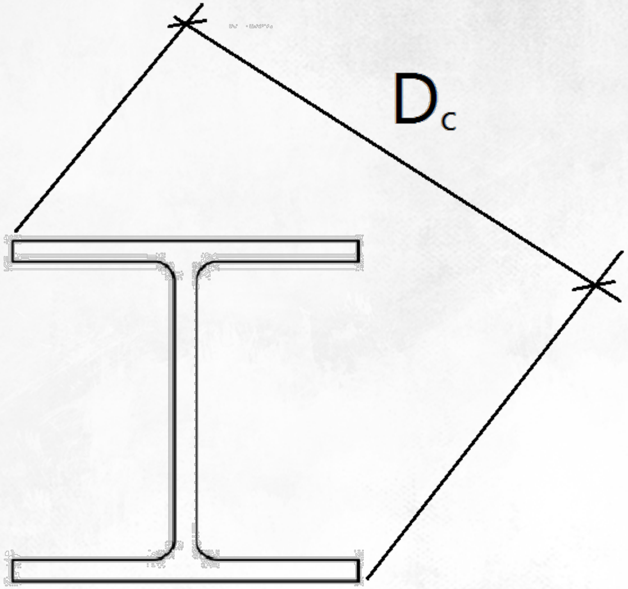
- W24x76
- LL6x6
- HSS4x4

NON-BUILDING STRUCTURES IN RISA

Approximate Member Diameter

W24x76

Dc = 25.5”



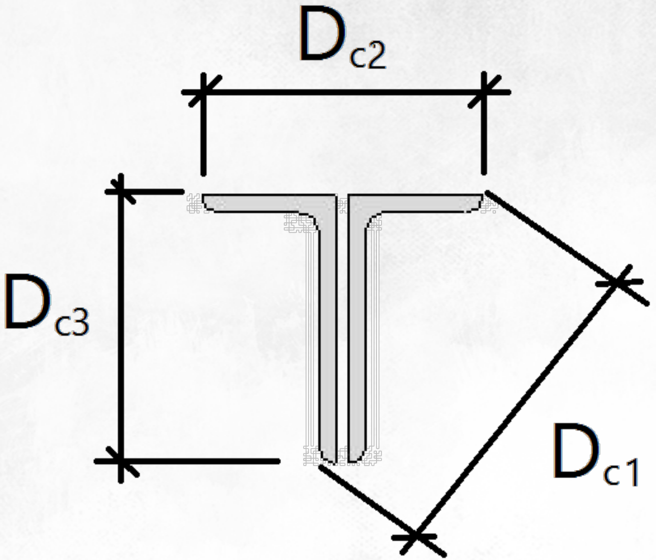
NON-BUILDING STRUCTURES IN RISA

Approximate Member Diameter

LL6x6

Dc = MAX[Dc1, Dc2, Dc3]

Dc = 12”

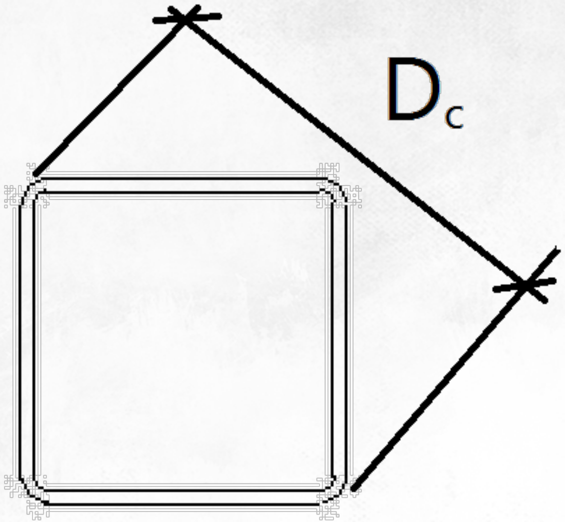


NON-BUILDING STRUCTURES IN RISA

Approximate Member Diameter

HSS4x4

Dc = 5.7”



NON-BUILDING STRUCTURES IN RISA

Ice Weight (Members)

$$w = \gamma^* \pi^* td^*(Dc+td)$$

W24x76:	96.8 lbs/ft
LL6x6:	50.6 lbs/ft
HSS4x4:	29.1 lbs/ft

Ice Weight (Tank)

$$w = \gamma^* \pi^* td \quad = 41 \text{ psf}$$

NON-BUILDING STRUCTURES IN RISA

Ice Wind (Members)

Conservatively assume that wind acts perpendicular to Dc dimension

w = p*(Dc+2*td)

W24x76:	15 lbs/ft
LL6x6:	8.5 lbs/ft
HSS4x4:	8.3 lbs/ft

Ice Wind (Tank)

Tank profile with and without ice is nearly identical (32’ versus 32.56’)

Therefore apply wind load the same as standard wind load

NON-BUILDING STRUCTURES IN RISA

Load Combinations

Design per AISC ASD

1. 1.0*D
2. 1.0*D + 1.0*L + 0.7*I
3. 1.0*D + 0.7*I +/- 0.7*Wi
4. 1.0*D +/- 0.6*W
5. 1.0*D + 0.75*L +/- 0.45*W
6. 0.6*D +/- 0.6*W
7. 0.6*DL + 0.7*I +/- 0.7*Wi

NON-BUILDING STRUCTURES IN RISA

Wind Loads (Expanded)

For each case where W is applied we need:

1.	WLX	Straight Wind in the X Direction
2.	WLZ	Straight Wind in the Z Direction
3.	0.75WLX + 0.75WLZ	Quartering Wind
4.	0.75WLX – 0.75WLZ	Opposite Quartering Wind
5.	0.75WLX + 0.75WLY	Eccentric Wind in the X Direction
6.	0.75WLX – 0.75WLY	Opposite Eccentric Wind in the X Direction
7.	0.75WLZ + 0.75WLY	Eccentric Wind in the Z Direction
8.	0.75WLZ – 0.75WLY	Opposite Eccentric Wind in the Z Direction
9.	0.563WLX + 0.563WLZ + 0.75WLY	Eccentric Quartering Wind
10.	0.563WLX - 0.563WLZ + 0.75WLY	Eccentric Opposite Quartering Wind
11.	0.563WLX + 0.563WLZ – 0.75WLY	Opposite Eccentric Quartering Wind
12.	0.563WLX - 0.563WLZ – 0.75WLY	Opposite Eccentric Opposite Quartering Wind

NON-BUILDING STRUCTURES IN RISA

Ice Wind Loads (Expanded)

It would be difficult to quantify eccentric torsion for the wind load.

Engineering Judgement: Effect would be negligible anyway

Therefore, for each case where Wi is applied we need:

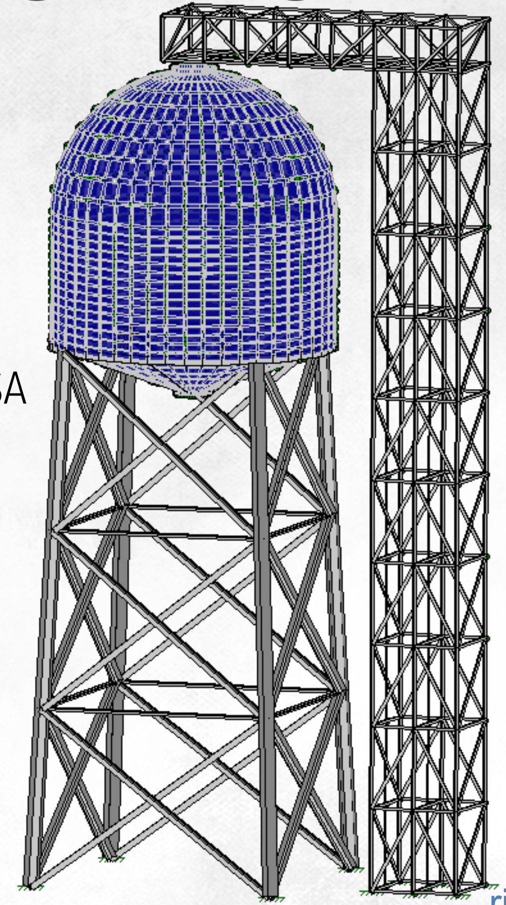
1.	WLX	Straight Wind in the X Direction
2.	WLZ	Straight Wind in the Z Direction
3.	0.75WLX + 0.75WLZ	Quartering Wind
4.	0.75WLX – 0.75WLZ	Opposite Quartering Wind

NON-BUILDING STRUCTURES IN RISA

3D | RISA-3D

Upcoming Webinar:

Part 3 of 3: Dynamic Loading on Non-Building Structures in RISA
3/2/2016



RISA

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QUESTIONS?

Please let us know if you have questions

- We will answer questions for the next 5 minutes
- Once the webinar is closed, we will post all Q&A's at **risa.com**
- For further information, contact us at **info@risa.com**