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BALLASTING TOOLS
THE INDUSTRY STANDARD

Presented by the Tent Rental Division (TRD)

Tent Rental Division

ATA

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OUR SPEAKERS

Vincent Blouin

Associate Professor of Architecture and Materials Science and Engineering, Clemson University

Michael Tharpe

TRD Chairman & National Sales Manager Rainier Industries

Nick Deninno

TRD Steering Committee and COO of B&R Innovations, LLC, Founder of the Block And Roll® Tent Ballast system

Non-Engineered Ballasting Tool Overview and Demonstration

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TIMELINE

2008 – The Tent Rental Division started seeking groups to work on a ballasting tool

2010 – Clemson University began the Ballasting Study to develop the Ballasting Tool

2012 – The original Ballasting Tool was completed and introduced to the TRD members

2014 – The TRD Board carried the Ballasting Tool further to include Non-Engineered products

2016 – Clemson University was contracted to work on the Non-Engineered Ballasting Tool (the university closed due to Covid for 2020-2022)

2022 – The Non-Engineered Ballasting Tool was completed

Non-Engineered Ballasting Tool Overview and Demonstration

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WHY WE NEED THIS TOOL

Tent Rental Division

ARA American Rental Association

Non-Engineered Ballasting Tool Overview and Demonstration

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WHY WE NEED THIS TOOL

Tent Rental Division

ARA American Rental Association

Non-Engineered Ballasting Tool Overview and Demonstration

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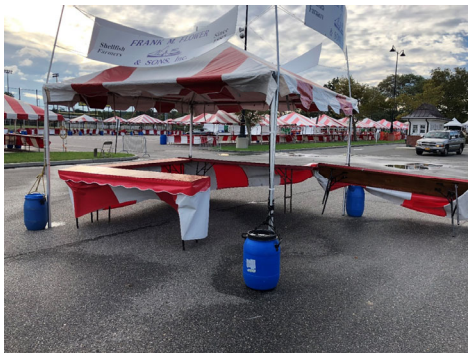

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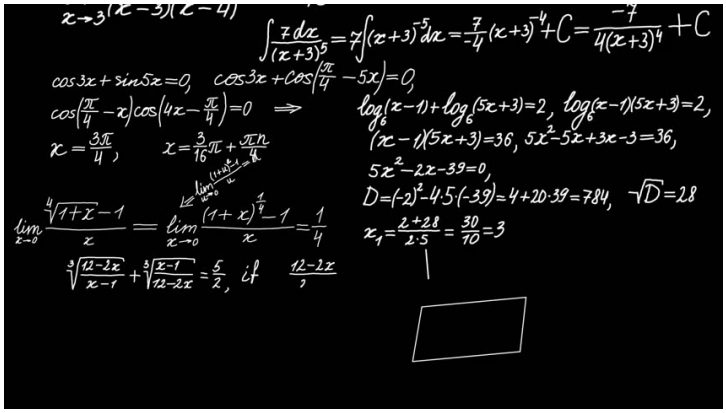
THE NUTS AND BOLTS

WITH VINCENT



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Outline

- Coefficient of Friction – Experimental setup
- Description of Tent and Ballast Configurations
- Tent Failure Modes
- Calculation of Wind Loads
- Ballast failure modes
- Calculation of Ballast Weights
- Parametric Studies
- Limitations and future work

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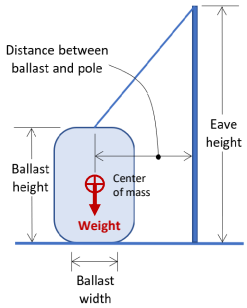
Coefficient of Friction of Ballasts

Holding power depends on many parameters:

1. Weight and weight distribution
2. Shape and size
3. Coefficient of friction
   - Ballast material
   - Ground surface
   - Modifier



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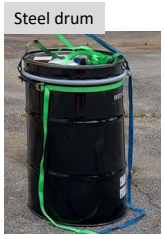
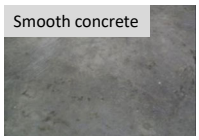
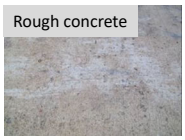
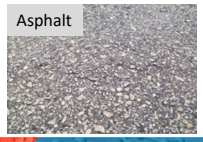
Ballasts

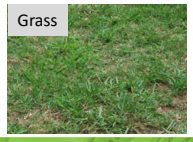


Ground surfaces









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Modifiers

Steel plate

Weight plate

Plywood

Rubber mat

Neoprene mat

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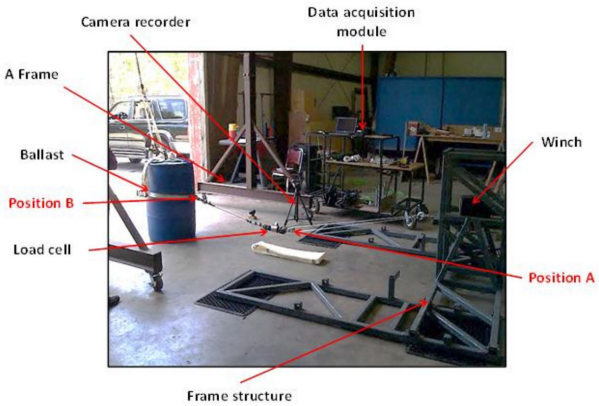
Experimental Setup



Load cells

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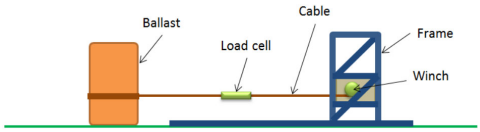
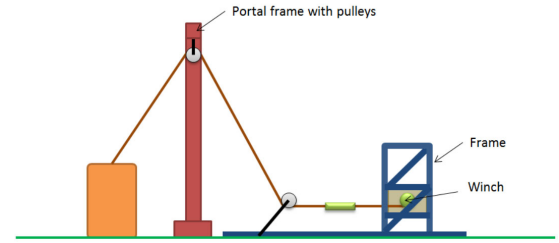
Experimental Setup





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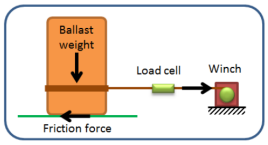
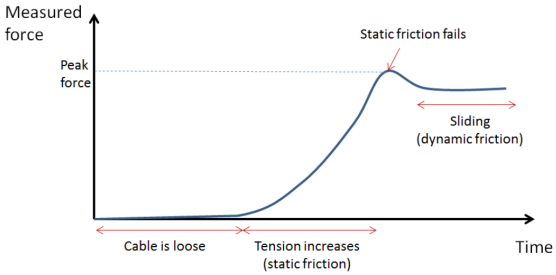
Experimental Setup





$$\mu = \frac{\text{Peak force}}{\text{Ballast weight}}$$

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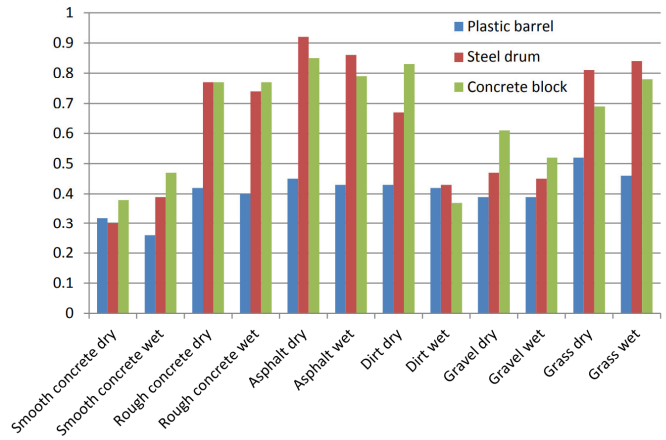
Coefficients of Friction - Ballasts



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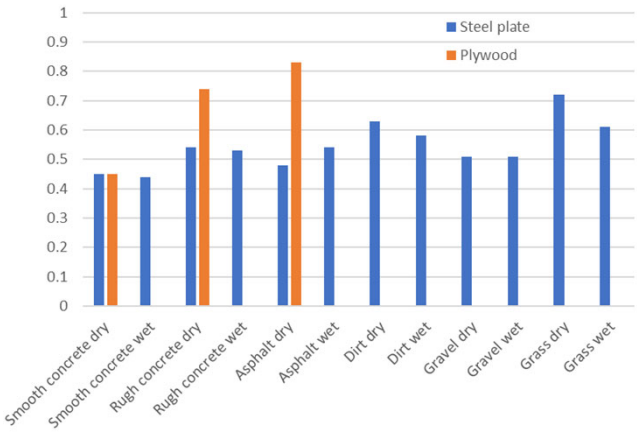
Coefficients of Friction - Modifiers



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Parametric Definition of Frame Tents

Parameter	Description, Options, Assumptions
Length (ft)	Dimension parallel to roof ridge
Width (ft)	Dimension perpendicular to roof ridge
Roof type	Gable, Hip, Pyramid
Ridge length (ft)	If gable roof: ridge length is equal to tent length If hip roof: ridge length defines the lengthwise roof pitch If pyramid roof: ridge length is zero
Roof height (ft)	Vertical distance between eave and roof highest point. Defines the widthwise roof pitch
Eave height (ft)	Height of uprights
Valance height (ft)	The valance is assumed to be rigidly secured to the frame
Enclosure	Open: Only roof, no side walls are present Enclosed: One or more side walls
# intermediate posts in length	The bay width is assumed to be uniform along the length. One ballast per intermediate post
# intermediate posts in width	The bay width is assumed to be uniform along the width. One ballast per intermediate post
# ballasts per corner posts	One, two, three

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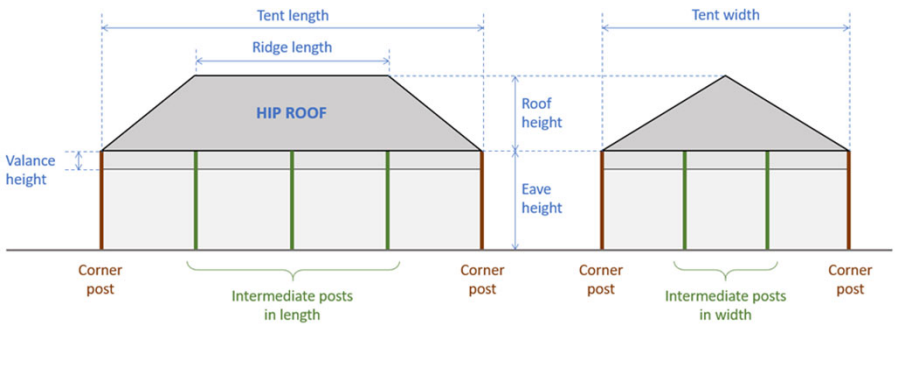
Parametric Definition of Frame Tents



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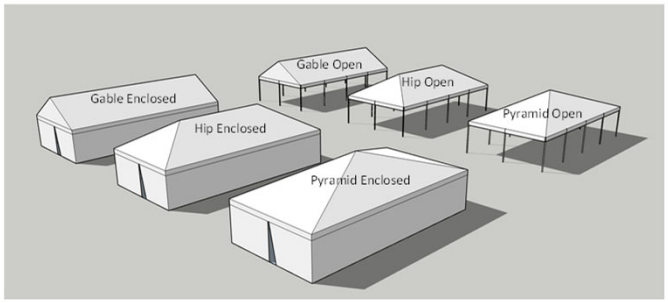

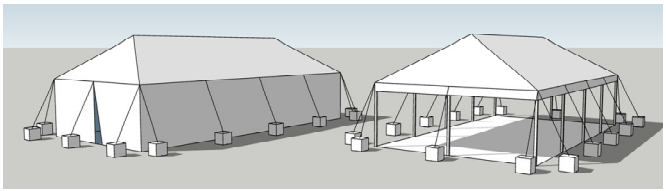

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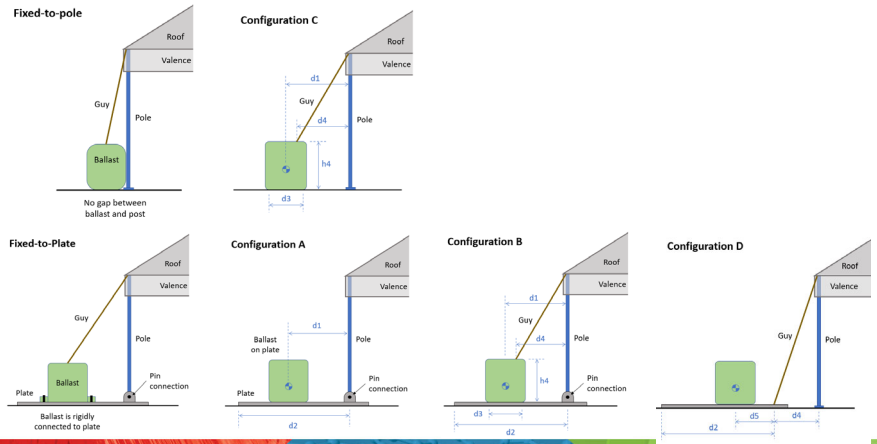
Ballast Configurations



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Site Parameters

Parameter	Description, Options, Assumption
Wind speed (mph)	Unobstructed wind speed Wind direction is irrelevant since both wind directions (i.e., parallel and perpendicular to roof ridge) are considered in wind load calculations. All other wind directions are assumed to induce smaller loads than the two main wind directions
Wind exposure	Fully-exposed: unobstructed areas Partially-exposed: open terrain with scattered obstructions having heights generally less than 30 ft Sheltered: urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.
Ground surface	Smooth concrete, rough concrete, asphalt, gravel, dirt, grass Based on experimental measurements, rain does not decrease significantly the friction coefficient of these ground surfaces

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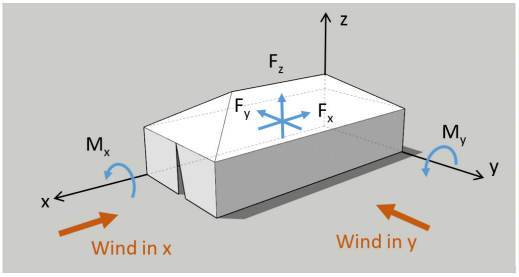
Definition of Wind Loads



X-axis is parallel to the ridge
Y-axis is perpendicular to the ridge

Two wind directions are considered:
Wind in x
Wind in y

All other wind directions are assumed to induce smaller loads than those of the two main wind directions.

Five wind loads induced by the two wind directions:
F_x – force in the negative x-direction due to wind in x
F_y – force in the negative y-direction due to wind in y
F_z – force in the positive z-direction due to wind in x or y, whichever leads to the greatest value
M_x – overturn moment about the x-axis due to wind in y, must be positive for overturn to occur
M_y – overturn moment about the y-axis due to wind in x, must be negative for overturn to occur

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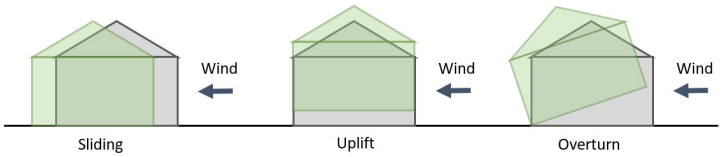
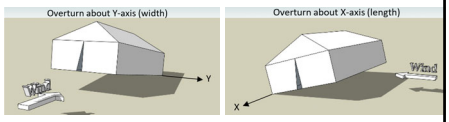
Tent Failure Modes



Sliding: Horizonal wind forces push the tent horizontally. Ballasts and pole footings slide on the ground.

Uplift: Vertical wind forces lift the entire tent as a whole. The ballasts are then pulled upward.

Overturn: The tent rotates about the leeward axis. This movement assumes that the tent frame is rigid and strong enough to resist buckling and collapse.



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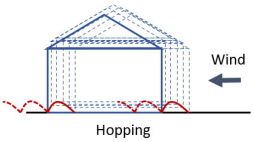
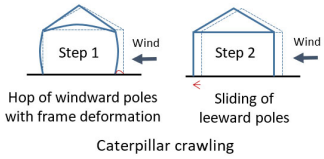
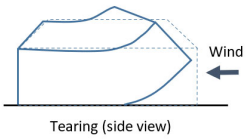
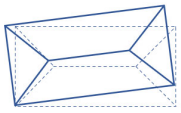
Tent Failure Modes

Less detrimental or similar failure modes









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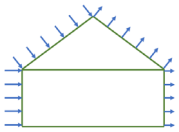
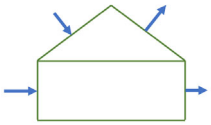
Wind Loads

Step 1
Surface pressures are calculated as prescribed by standard ASCE 7-10 *Minimum Design Loads for Buildings and Other Structures* by American Society of Civil Engineers



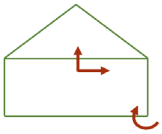
Surface pressures applied on all surfaces

Step 2
Surface pressures are converted to **surface forces** and center of force of each surface is calculated



Surface forces applied at center of force of each surface

Step 3
Surface forces are aggregated to calculate wind loads: **Total forces and moment** applied on tent



Total forces and moment

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Calculation of Wind Loads by ASCE 7-10

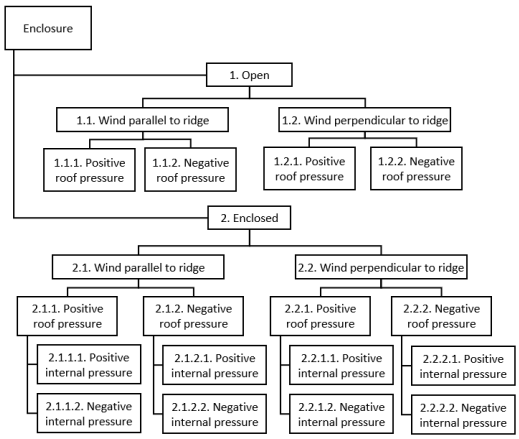
Two enclosures:
1. Open
2. Enclosed

Two wind directions:
1. Parallel to the ridge
2. Perpendicular to the ridge

Two roof pressures:
1. Positive
2. Negative

Two internal pressures (for enclosed):
1. Positive
2. Negative.

Total: 12 wind load cases
4 for open tents and 8 for enclosed tents



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Calculation of Wind Loads by ASCE 7-10

The tent includes eight different surfaces (i.e., four surfaces for the roof and four surfaces for the sides or valance). A different surface pressure is calculated for each surface for each of the 12 cases of Figure 19. The ASCE standard prescribes the surface pressure as:

$$p = q(z)\, G\, C_p - q(h)\, C_{pi} \quad (1)$$

where

- p is the surface pressure (lb/ft^2),
- $q(z)$ is the velocity pressure applied on walls or roof surfaces evaluated at height z according to Eq. (2) shown below (lb/ft^2),
- $q(h)$ is the velocity pressure applied on walls or roof surfaces evaluated at the mean roof height, h, according to Eq. (2) shown below (lb/ft^2),
- G is the gust-effect factor,
- C_p is the external pressure coefficient,
- C_{pi} is the internal pressure coefficient.

The velocity pressure evaluated at height z is:

$$q(z) = 0.00256\, K_z\, K_{zt}\, V^2 \quad (2)$$

where

- K_z is the velocity pressure exposure coefficient,
- K_{zt} is the topographic factor,
- V is the basic wind speed (mph).

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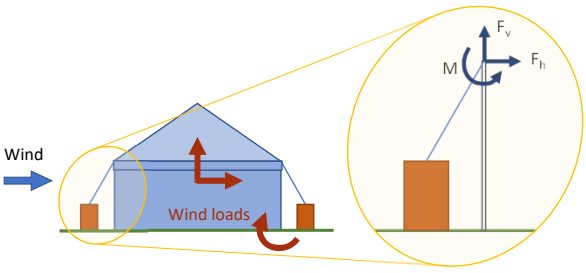
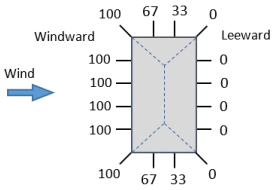
From Wind Loads to Ballast System Loads

- Wind loads are distributed to all contributing ballasts.
- Not all ballasts contribute to resisting the wind loads.



Example:
50% of all ballasts contribute to resisting



Once we know which ballasts contribute to resisting each failure mode, the required weight of the most loaded ballast can be calculated.

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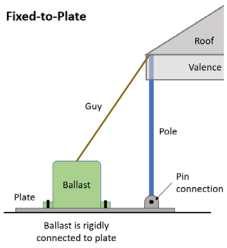
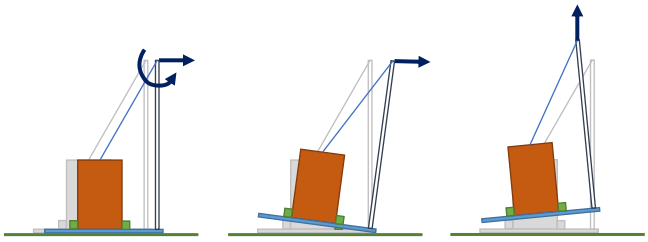
Ballast Failure Modes – Fixed-to-Plate Configuration



3 failure modes:
- Sliding
- Tilting
- Uplift



Sliding due to horizontal forces and moment (both directions)

Forward tilt due to horizontal force

Uplift due to vertical force

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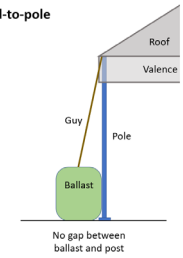
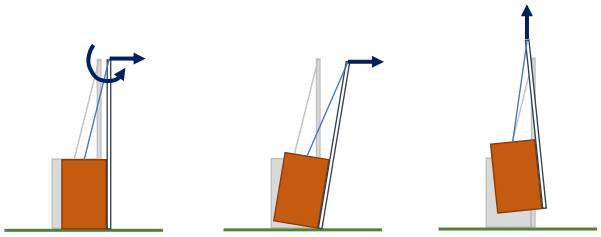
Ballast Failure Modes – Fixed-to-Pole Configuration



3 failure modes:
- Sliding
- Tilting
- Uplift



Sliding due to horizontal forces and moment (both dir.)

Forward tilt due to horizontal force

Uplift due to vertical force

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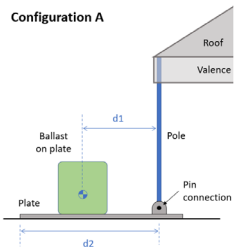
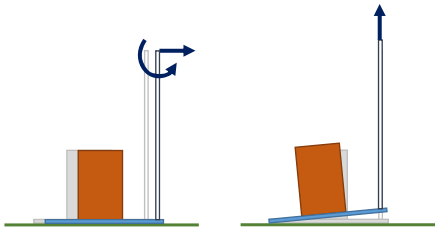
Ballast Failure Modes – Configuration A



2 failure modes:
- Sliding
- Uplift



Sliding of the plate due to horizontal forces and moment (both directions)

Uplift due to vertical force

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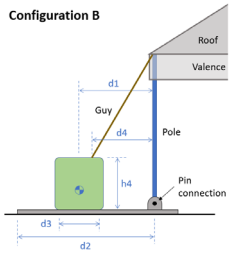
Ballast Failure Modes – Configuration B



4 failure modes:
- Sliding with plate
- Sliding on plate
- Tilting
- Uplift

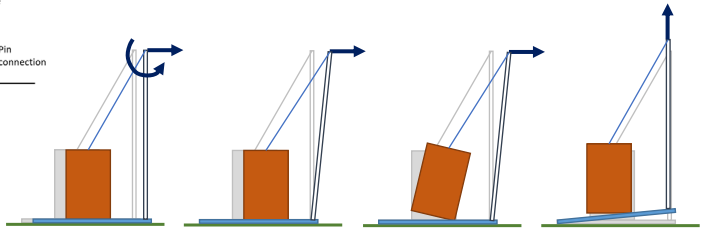


Plate sliding due to horizontal forces and moment

Ballast sliding due to horizontal force

Ballast tilting due to horizontal force

Uplift due to vertical force

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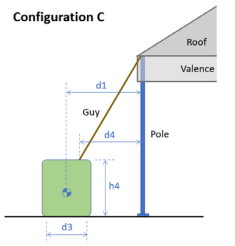
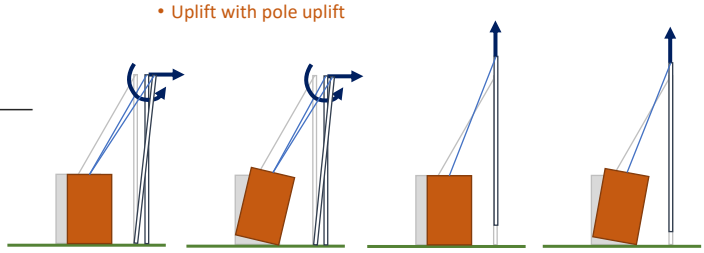
Ballast Failure Modes – Configuration C



4 failure modes:
- Sliding
- Tilting
- Sliding with pole uplift
- Uplift with pole uplift



Sliding due to horizontal forces and/or moment

Ballast tilting due to horizontal forces and/or moment

Ballast sliding due to Vertical force

Ballast tilting due to vertical force

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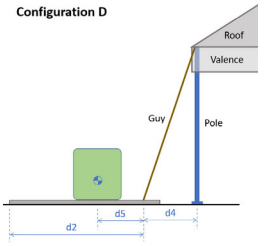
Ballast Failure Modes – Configuration D



4 failure modes:
- Sliding with plate
- Tilting with plate
- Sliding with plate with pole uplift
- Uplift with plate with pole uplift

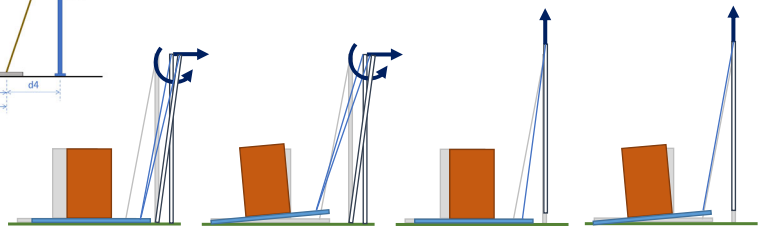


Plate sliding due to horizontal forces and/or moment

Plate tilting due to horizontal forces and/or moment

Plate sliding due to vertical force

Plate tilting due to vertical force

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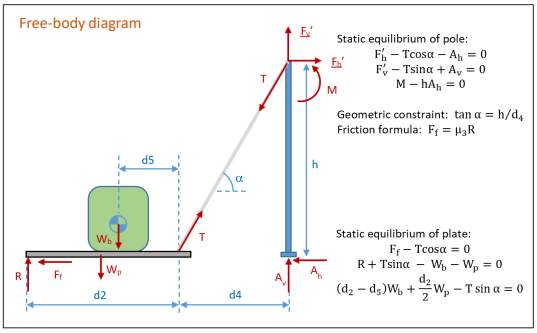
Calculation of Ballast Weight – Configuration D

Free-body diagram



Static equilibrium of pole:

$$F_h' - T\cos\alpha - A_h = 0$$
$$F_v' - T\sin\alpha + A_v = 0$$
$$M - hA_h = 0$$

Geometric constraint: $\tan\alpha = h/d_4$

Friction formula: $F_f = \mu_3 R$

Static equilibrium of plate:

$$F_f - T\cos\alpha = 0$$
$$R + T\sin\alpha - W_b - W_p = 0$$
$$(d_2 - d_5)W_b + \frac{d_2}{2}W_p - T\sin\alpha = 0$$

Failure mode 1:

$$W_{s1} = \max\left\{\frac{2F_{v1} - d_2 W_p}{2(d_2 - d_5)} + W_p, F_{v1}\left(1 + \frac{1}{\mu_3 \tan\alpha}\right)\right\}$$

Failure mode 2:

$$W_{s2} = \max\left\{\frac{2F_{h2}\tan\alpha - d_2 W_p}{2(d_2 - d_5)} + W_p, F_{h2}\left(\tan\alpha + \frac{1}{\mu_3}\right)\right\}$$

Failure mode 3:

$$W_{s3} = \max\left\{\frac{2F_{h3}\tan\alpha - d_2 W_p}{2(d_2 - d_5)} + W_p, F_{h3}\left(\tan\alpha + \frac{1}{\mu_3}\right)\right\}$$

Failure mode 4:

$$W_{s4} = \max\left\{\frac{2F_{v4} - d_2 W_p}{2(d_2 - d_5)} + W_p, F_{v4}\left(1 + \frac{1}{\mu_3 \tan\alpha}\right)\right\}$$

$$W_s = \max\{W_{s1}, W_{s2}, W_{s3}, W_{s4}\}$$

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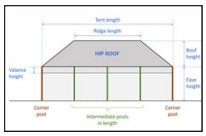
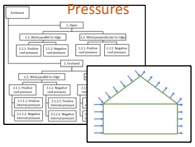
Overview of Complete Process

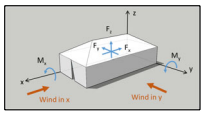
Define Wind Speed, Site, Tent



Calculate Surface Pressures

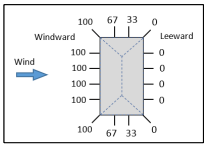


Calculate Wind Loads

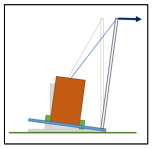


Consider Tent Failure Modes

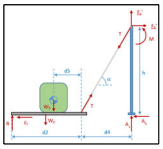
Identify Contributing Ballasts



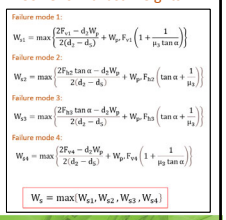
Consider Ballast Failure Modes



Static Equilibrium Equations



Solve for Ballast Weights



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Results - Parametric Studies

- Effect of wind speed
- Effect of tent length and width
- Effect of ballast configuration
- Effect of wind exposure
- Effect of ground surface and ballast type
- Effect of parameters of configuration A
- Effect of parameters of configuration B
- Effect of parameters of configuration C
- Effect of parameters of configuration D

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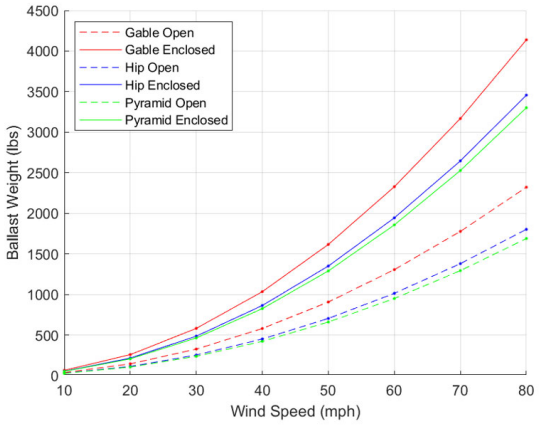
Effect of Wind Speed

Length	40′
Width	20′
Eave height	8′
Roof type	-
Roof height	6′
Valance height	1′
Number of intermediate posts in length	3
Number of intermediate posts in width	1
Number of ballasts per corner post	1
Ballast configuration	Fixed-to-pole
Ground surface	Asphalt
Ballast type	Concrete block
Wind speed	10 to 80 mph



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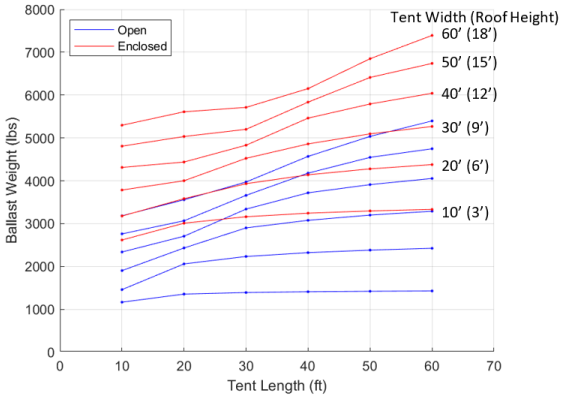
Effect of Tent length and Width

Length	10′ to 60′
Width	10′ to 60′
Eave height	8′
Roof type	Gable
Roof pitch	7.2/12
Valance height	1′
Number of intermediate posts in length	-
Number of intermediate posts in width	-
Number of ballasts per corner post	1
Ballast configuration	Fixed-to-pole
Ground surface	Asphalt
Ballast type	Concrete block
Wind speed	20 mph



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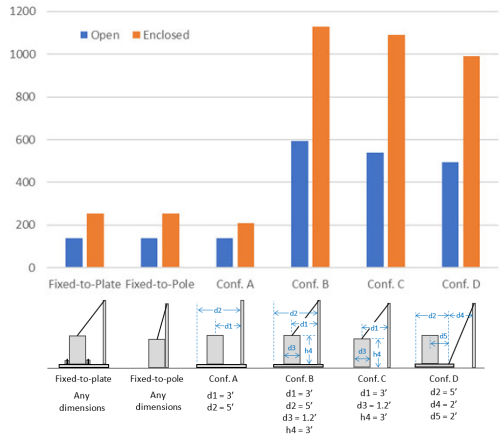
Effect of Tent length and Width

Length	40′
Width	20′
Eave height	8′
Roof type	Gable
Roof height	6′
Valance height	1′
Number of intermediate posts in length	3
Number of intermediate posts in width	1
Number of ballasts per corner post	1
Ballast configuration	-
Ground surface	Asphalt
Ballast type	Concrete block
Wind speed	20 mph



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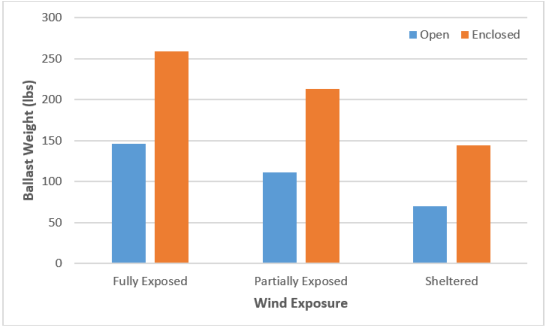
Effect of Wind Exposure

Length	40′
Width	20′
Eave height	8′
Roof type	Gable
Roof height	6′
Valance height	1′
Number of intermediate posts in length	3
Number of intermediate posts in width	1
Number of ballasts per corner post	1
Ballast configuration	Fixed-to-pole
Ground surface	Asphalt
Ballast type	Concrete block
Wind speed	20 mph



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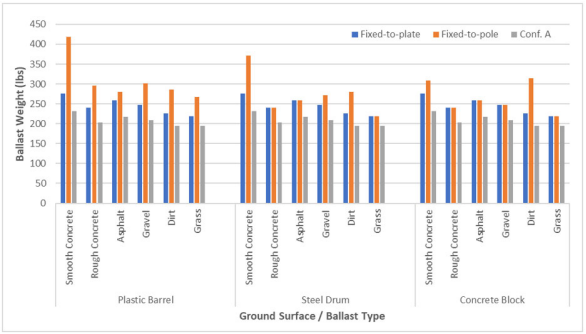
Effect of Ground Surface and Ballast Type

Length	40′
Width	20′
Eave height	8′
Roof type	Gable
Roof height	6′
Valance height	1′
Number of intermediate posts in length	3
Number of intermediate posts in width	1
Number of ballasts per corner post	1
Ballast configuration	-
Ground surface	-
Ballast type	-
Wind speed	20 mph



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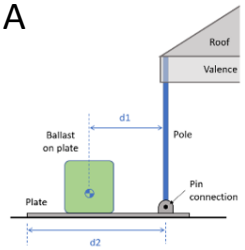
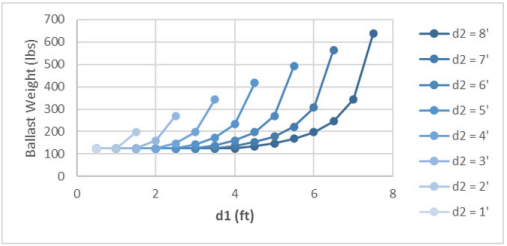
Effect of Parameters of Configuration A

Length	40′
Width	20′
Eave height	8′
Roof type	Gable
Roof height	6′
Valance height	1′
Number of intermediate posts in length	3
Number of intermediate posts in width	1
Number of ballasts per corner post	1
Ballast configuration	Conf. A
Ground surface	Asphalt
Ballast type	Concrete block
Wind speed	20 mph





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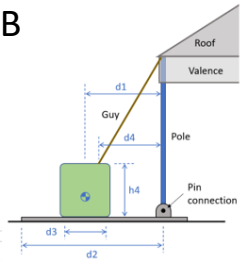
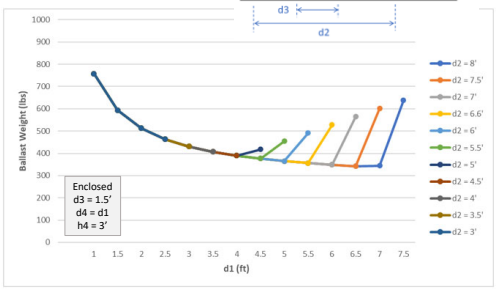
Effect of Parameters of Configuration B

Length	40′
Width	20′
Eave height	8′
Roof type	Gable
Roof height	6′
Valance height	1′
Number of intermediate posts in length	3
Number of intermediate posts in width	1
Number of ballasts per corner post	1
Ballast configuration	Conf. B
Ground surface	Asphalt
Ballast type	Concrete block
Wind speed	20 mph





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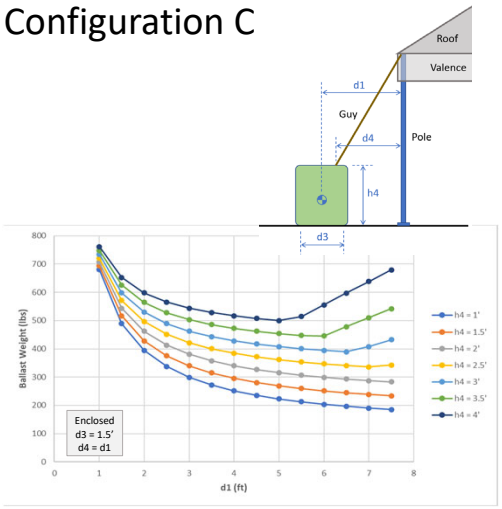
Effect of Parameters of Configuration C

Length	40′
Width	20′
Eave height	8′
Roof type	Gable
Roof height	6′
Valance height	1′
Number of intermediate posts in length	3
Number of intermediate posts in width	1
Number of ballasts per corner post	1
Ballast configuration	Conf. C
Ground surface	Asphalt
Ballast type	Concrete block
Wind speed	20 mph



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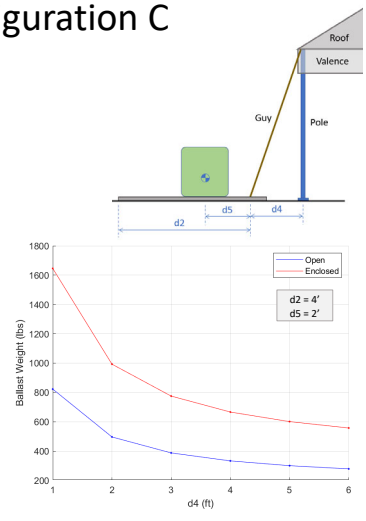
Effect of Parameters of Configuration C

Length	40′
Width	20′
Eave height	8′
Roof type	Gable
Roof height	6′
Valance height	1′
Number of intermediate posts in length	3
Number of intermediate posts in width	1
Number of ballasts per corner post	1
Ballast configuration	Conf. D
Ground surface	Asphalt
Ballast type	Concrete block
Wind speed	20 mph



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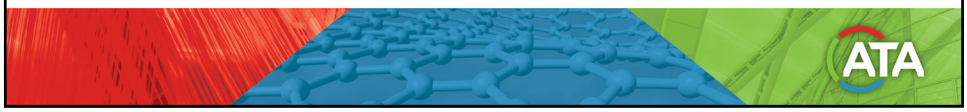
Limitations and Future Work

(1) Distribution of contributing ballasts should be validated using field testing or wind tunnel testing for the various types of tents and various frame stiffness properties.

(2) Include friction coefficients for surface modifiers

(3) The effect of guy line pretention is not considered in this study (assumed negligible). However, its effect on weight transfer from ballast to upright is not completely understood.

(4) Several simplifying (yet conservative) assumptions were used with statically indeterminate ballast systems. These assumptions should be validated. Likely to be challenging because of nonlinear behavior of highly flexible materials, presence of friction, and load path redundancy.



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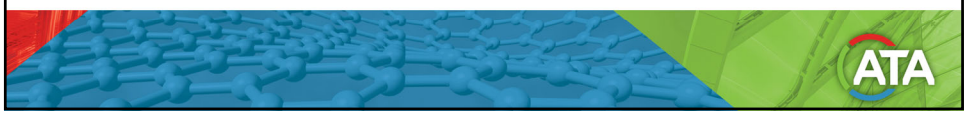
LIVE DEMO



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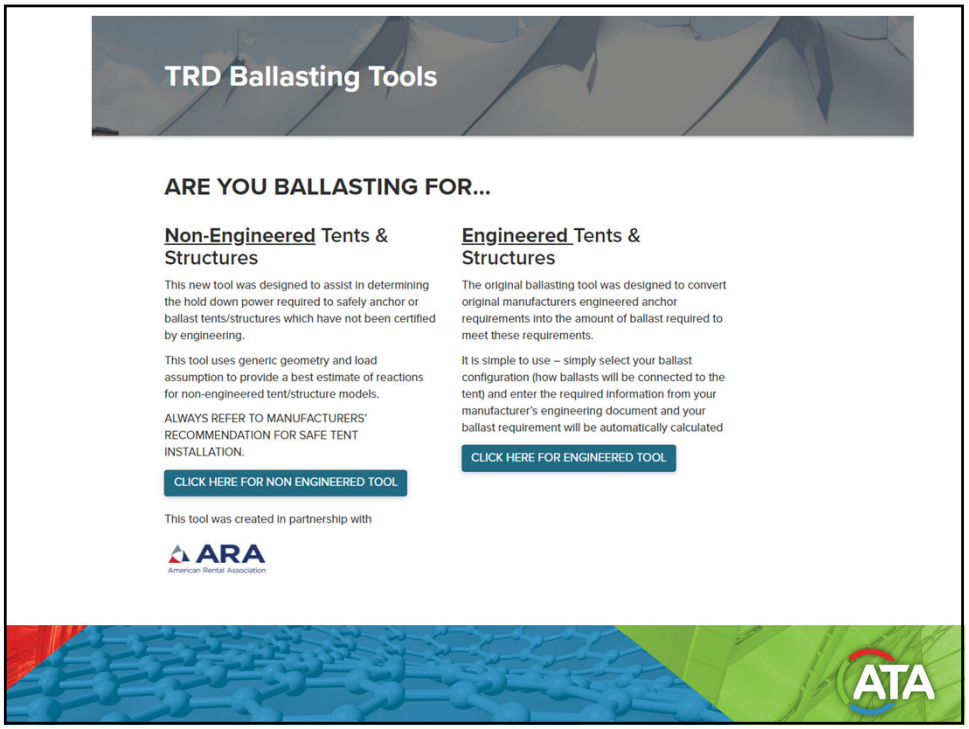
TRD Ballasting Tools
ARE YOU BALLASTING FOR...
Non-Engineered Tents & Structures
This new tool was designed to assist in determining the hold down power required to safely anchor or ballast tents/structures which have not been certified by engineering.
This tool uses generic geometry and load assumption to provide a best estimate of reactions for non-engineered tent/structure models.
ALWAYS REFER TO MANUFACTURERS' RECOMMENDATION FOR SAFE TENT INSTALLATION.
CLICK HERE FOR NON ENGINEERED TOOL
This tool was created in partnership with
ARA
American Rental Association
Engineered Tents & Structures
The original ballasting tool was designed to convert original manufacturers engineered anchor requirements into the amount of ballast required to meet these requirements.
It is simple to use – simply select your ballast configuration (how ballasts will be connected to the tent) and enter the required information from your manufacturer's engineering document and your ballast requirement will be automatically calculated
CLICK HERE FOR ENGINEERED TOOL
ATA

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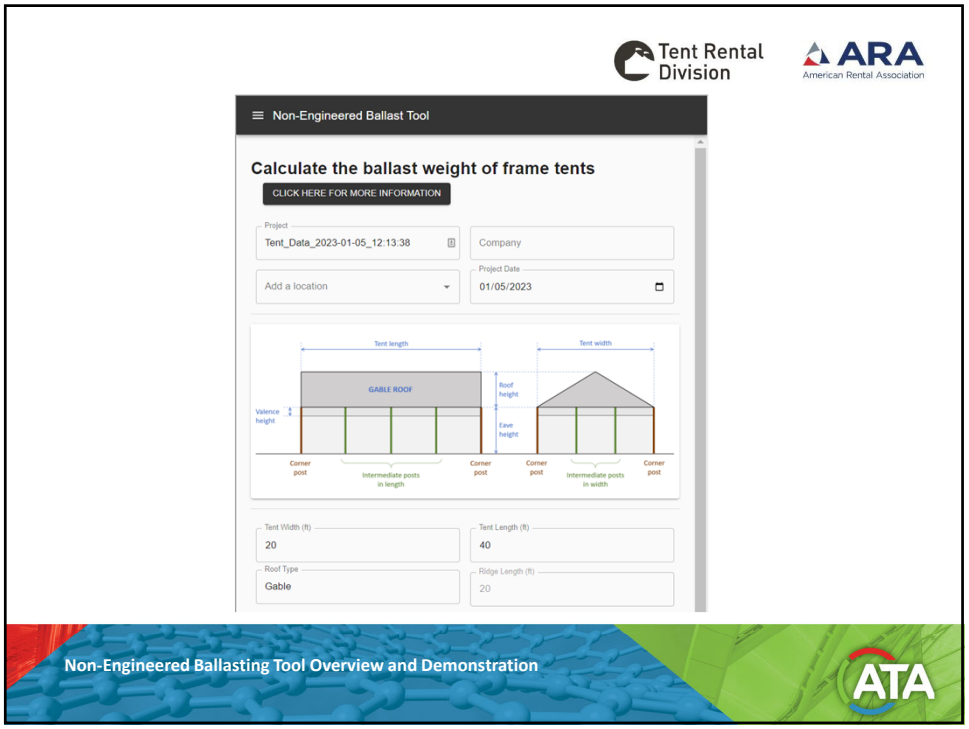
Tent Rental Division
ARA
American Rental Association
Non-Engineered Ballast Tool
Calculate the ballast weight of frame tents
CLICK HERE FOR MORE INFORMATION
Project
Tent_Data_2023-01-05_12:13:38
Company
Add a location
Project Date
01/05/2023
Tent length
Tent width
GABLE ROOF
Roof height
Valence height
Eave height
Corner post
Intermediate posts in length
Intermediate posts in width
Tent Width (ft)
20
Tent Length (ft)
40
Roof Type
Gable
Ridge Length (ft)
20
Non-Engineered Ballasting Tool Overview and Demonstration
ATA

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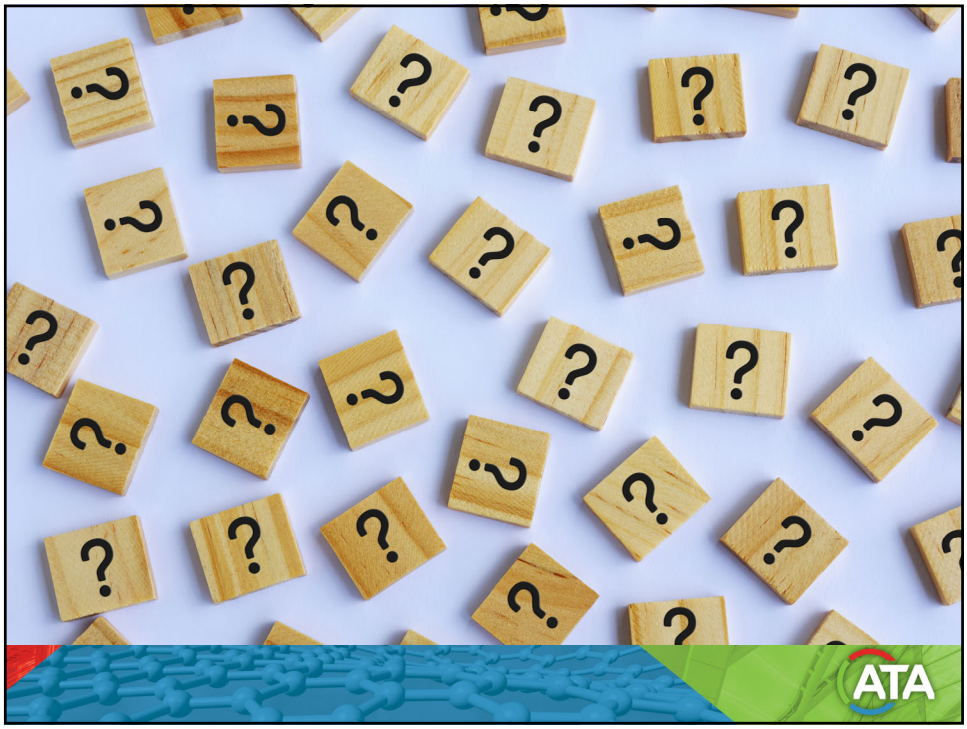

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THANK YOU!

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