<u>Pickets:</u>

1) Traditional Vertical Pickets:

a) More forces at top.
b) Shear cone layers.
c) Snow fails in compression near the top surface.
d) Things to do:
   i) Use the firmest snow possible.
   ii) Use the longest and widest picket.
   iii) Completely bury the picket for both strength and protection from the suns solar energy.
   iv) Place picket just above the strongest layer of snow.
   v) Use multiple pickets when feasible.
   vi) On mild slopes , place the picket/s at a 15 degree angle up hill from the slope
   vii) On steep slopes, place the picket/s at a 45 degree angle up hill from the slope.

2) Horizontal Pickets:

a) Stronger than traditional pickets.
b) Watch for icy layers in the snow.
c) Discuss shear cones.
d) When using multiple pickets place them a minimum of 3 times the depth apart ***but avoid putting the pickets in front of each other.*** *If the pickets are placed in front of each other make sure the front picket will not be lifted out.*
e) Things to do:
   i) Bury as deep as possible.
   ii) Use the firmest snow possible.
   iii) In firm snow use the 24” picket instead of the 36” picket.
   iv) Attach to the center hole so the picket does not rotate.
   v) Make sure the trench is wide enough to backfill properly.

3) Sierra Pickets:

a) More than 20% stronger than horizontal placement.
b) Less sensitive to weak layer within the snow than in the horizontal configuration.
c) When using multiple pickets place them a minimum of 3 times the depth apart ***but avoid putting the pickets in front of each other.*** *If the pickets are placed in front of each other make sure the front picket will not be lifted out.*
d) Things to do:
   i) Use the firmest snow possible.
   ii) Bury as deep as possible.
   iii) Place Sierra picket/s perpendicular to the slope.
   iv) In firm snow use the 24” picket instead of the 36” picket.
   v) Make sure the trench is wide enough to backfill properly.

When using multiple tools make sure you equalize the anchors ***but do NOT use self-equalizing rigging!***

Ice Axe/s in place of Pickets:

1) **Horizontal:**
   a) Same thing applies as for the horizontal pickets.
   b) Girth-hitch a runner to the mid-point of the ice axe handle.
   c) Use a carabiner in the spiked end of the ice axe to prevent the runner from slipping off.

2) **Vertical:**
   a) Same thing applies has for the vertical pickets.
   b) The approximate pull out strength with the head of the ice axe buried approximately 12” below the snows surface; 900-1500 lbs.
   c) Strongest if girth-hitched to the mid-point of the ice axe handle.

3) **Horizontal + Vertical:**
   a) Stronger than the vertical and horizontal placements.
   b) Strongest if the horizontal axe is placed in front of the vertical axe and is located at the mid-point of the vertical axe.
   c) The approximate pull out strength with the head of the vertical ice axe buried approximately 12” below the snows surface; 1900 lbs.

For the most part pickets make a stronger anchor than ice axes!

Deadman:

1) Attach a length of webbing to the center of a pack, snow shovel, snowshoe, etc; with the most frontal area facing perpendicular to the slope.
   a) Things to do:
      i) Use the firmest snow possible.
      ii) Use multiple anchors when possible, when using multiple anchors place them a minimum of 3 times the depth apart.
      iii) Make sure your attachment point to the anchor will ***NOT*** cause the anchor to rotate.
      iv) Bury as deep as possible.
      v) Make sure the trench is wide enough to backfill properly.

Snow Bollards:

1) Make horseshoe-shape where the uphill side is the deepest and the downhill side is undisturbed snow.
2) Depending on the snow type the bollard should be 3-10 feet wide and a foot to 1-1/2 feet deep.
3) Pack the snow in and around the upper perimeter of the bollard and pad it with packs, clothing, ice axes, pickets, padding, or whatever you may have on hand to keep the rope from cutting into the sides of the bollard.
4) Use webbing when possible, it is less likely “when placed properly” to cut through the bollard than rope.
5) When constructing a snow bollard watch for ice layers, the rope can slip right through those layers with very little force.

Determining the amount of stress in a MSR snow picket.

First; determine the stress concentration factor from the drilled holes.

$r := .3125 \qquad c := .895 \qquad D := 1.5$

$$C_1 := 3.022 - 0.422 \frac{r}{c} + 3.556 \left(\frac{r}{c}\right)^2 \qquad C_2 := -0.569 + 2.664 \frac{r}{c} - 4.397 \left(\frac{r}{c}\right)^2$$

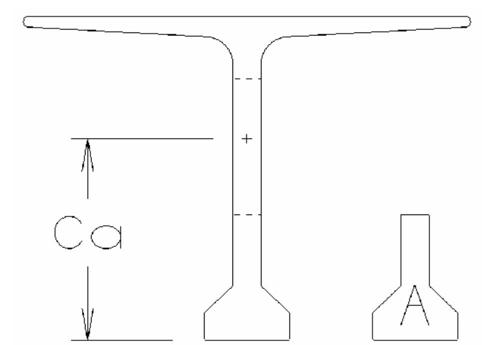
$$C_3 := 3.138 - 18.367 \frac{r}{c} + 28.093 \left(\frac{r}{c}\right)^2 \qquad C_4 := -3.591 + 16.125 \frac{r}{c} - 27.252 \left(\frac{r}{c}\right)^2$$

$$K := C_1 + C_2 \cdot \left(\frac{2 \cdot c}{D}\right) + C_3 \cdot \left(\frac{2 \cdot c}{D}\right)^2 + C_4 \cdot \left(\frac{2 \cdot c}{D}\right)^3 \qquad K = 1.132$$

Reference: Stress Concentration Factors, by Walter D. Pilkey

Second; determine the stress due to shear from the carabiner and the bending stress from the load applied. The moment of inertia, the distance from the extreme fibers to the axis of the centroid, and the area of the lower section of the picket was determined from a CAD system.

$I := .11533 \qquad C_a := .9343 \qquad A := .12142 \qquad P := 2100$



Shear Stress; $\tau := \frac{P}{A}$

Bending Stress from a 24" Picket;

$$\sigma_{24} := \frac{3 \cdot P \cdot C_a \cdot K}{I} \qquad \sigma_{24} = 57791.527$$

Bending Stress from a 36" Picket;

$$\sigma_{36} := \frac{4.5 \cdot P \cdot C_a \cdot K}{I} \qquad \sigma_{36} = 86687.29$$

Principal Stress from a 24" Picket;

$$\sigma_{p24} := \frac{\sigma_{24}}{2} + \sqrt{\left(\frac{\sigma_{24}}{2}\right)^2 + \tau^2}$$

$$\sigma_{p24} = 62572.074$$

Principal Stress from a 36" Picket;

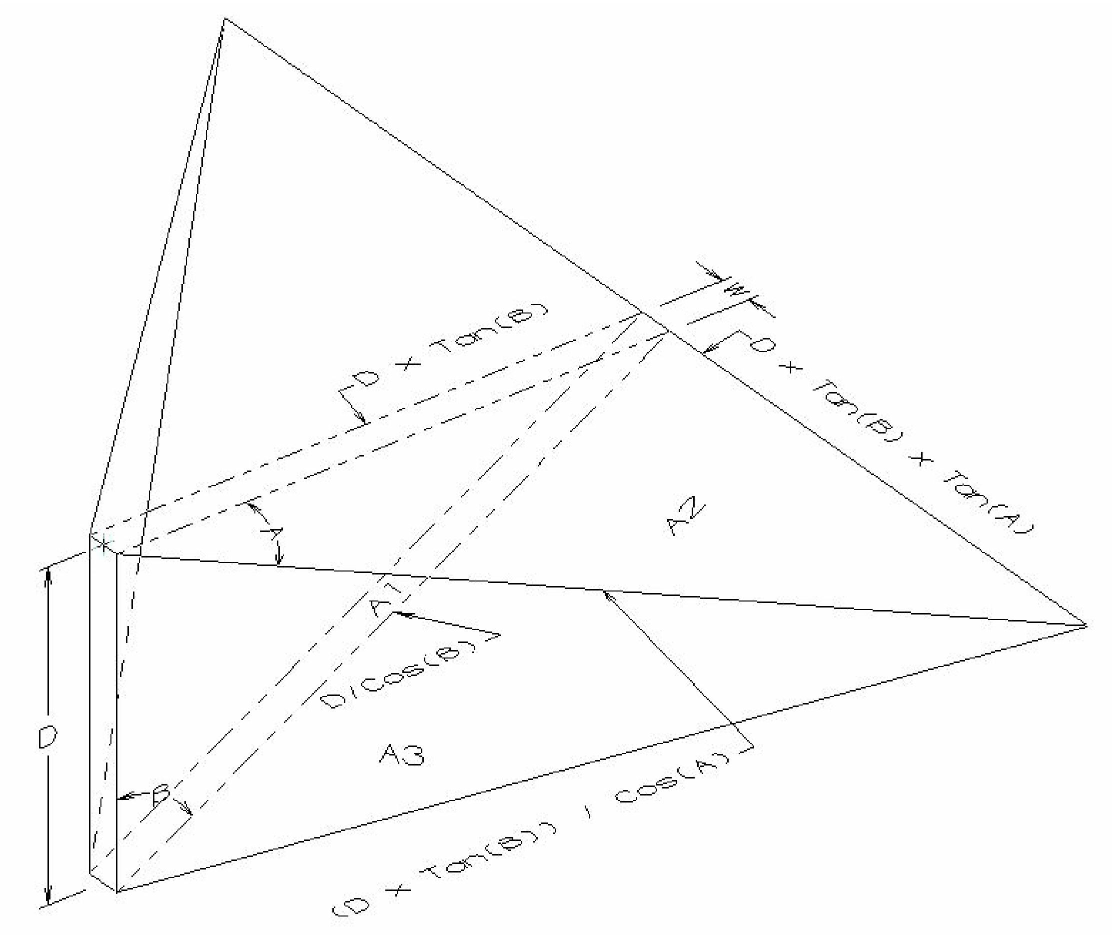
$$\sigma_{p36} := \frac{\sigma_{36}}{2} + \sqrt{\left(\frac{\sigma_{36}}{2}\right)^2 + \tau^2}$$

$$\sigma_{p36} = 90010.553$$

The 36" picket has 1.439 times more stress at the mid point than the 24" picket. A picket made from 2024-T6 aluminum has an ultimate stress of 68_ksi, in the example shown above the *36" picket would have failed* but not the 24" picket.

$$\Delta := \frac{\sigma_{p36}}{\sigma_{p24}} \qquad \Delta = 1.439$$

Total Snow Shear Area from Buried Object:



$$A_1 := \frac{W \cdot D}{\cos(B)}$$

$$A_2 := \frac{1}{2} \cdot \left(\frac{D}{\cos(B)} \right) \cdot (D \cdot \tan(B) \cdot \tan(A)) \quad \text{or} \quad A_2 := \frac{D^2 \cdot \tan(B) \cdot \tan(A)}{2 \cdot \cos(B)}$$

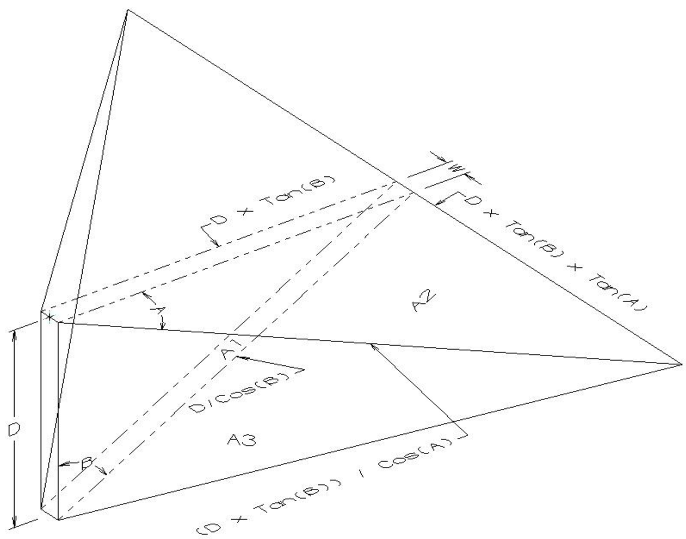
$$A_3 := \frac{1}{2} \cdot D \cdot \left(\frac{D \cdot \tan(B)}{\cos(A)} \right) \quad \text{or} \quad A_3 := \frac{D^2 \cdot \tan(B)}{2 \cdot \cos(A)}$$

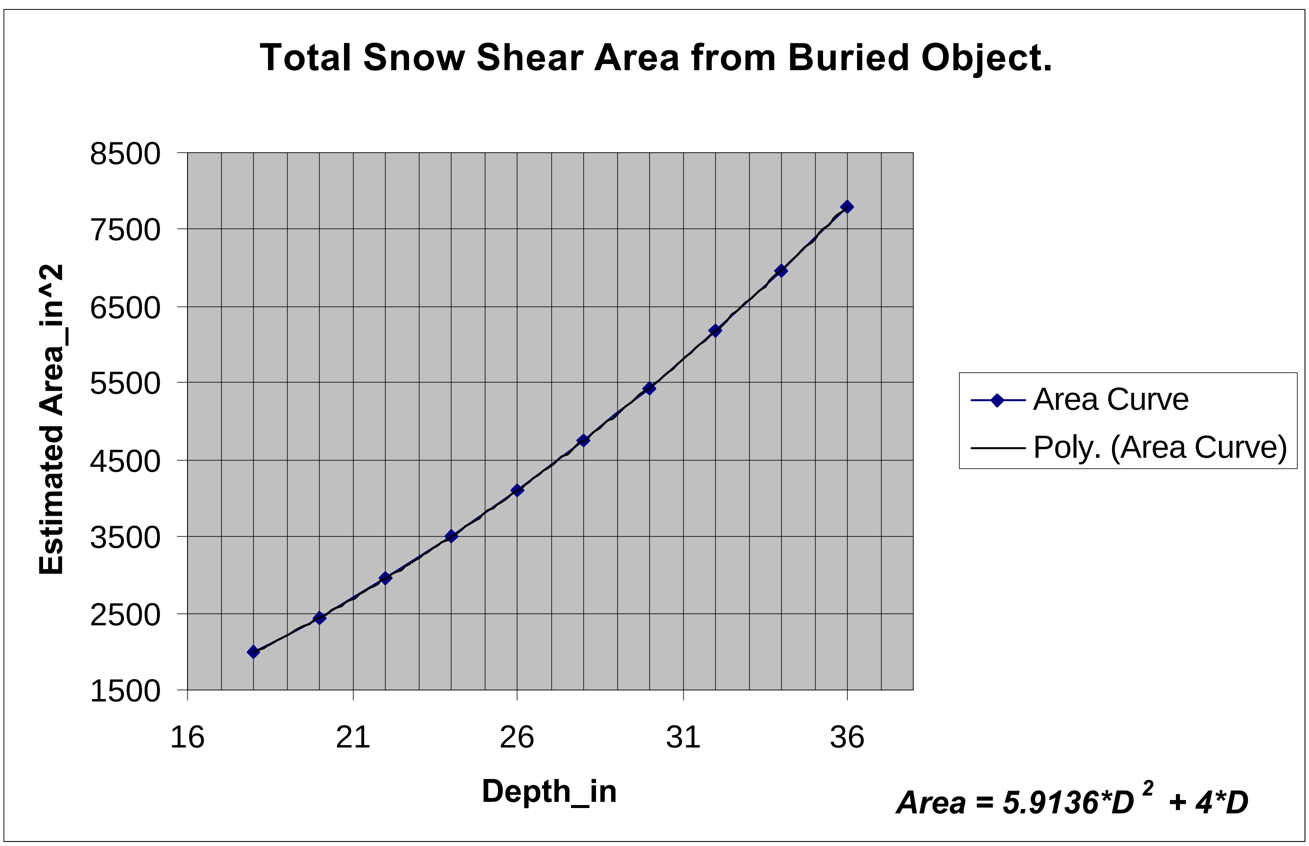
$$A_{total} := A_1 + 2 \cdot A_2 + 2 \cdot A_3 \quad \text{or} \quad A_{total} := \frac{D}{\cos(B)} \cdot \left(W + D \cdot \tan(B) \cdot \tan(A) + \frac{D \cdot \sin(B)}{\cos(A)} \right)$$

Analysis of Vertical Snow Shear Cones:

Vertical Picket	*Angles A & B were found by experimentation.*	
Width of Picket:	**Angle A:**	**Angle B:**
2	45	60

Depth of Object:	***Total Area:***
18	1988.004
20	2445.437
22	2950.178
24	3502.229
26	4101.588
28	4748.256
30	5442.232
32	6183.518
34	6972.112
36	7808.014





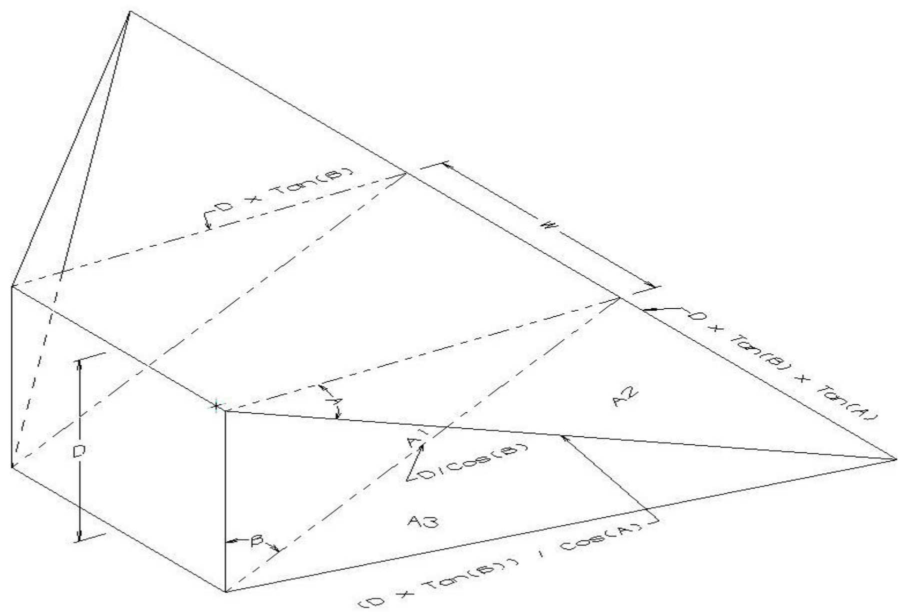
Analysis of Horizontal Snow Shear Cones:

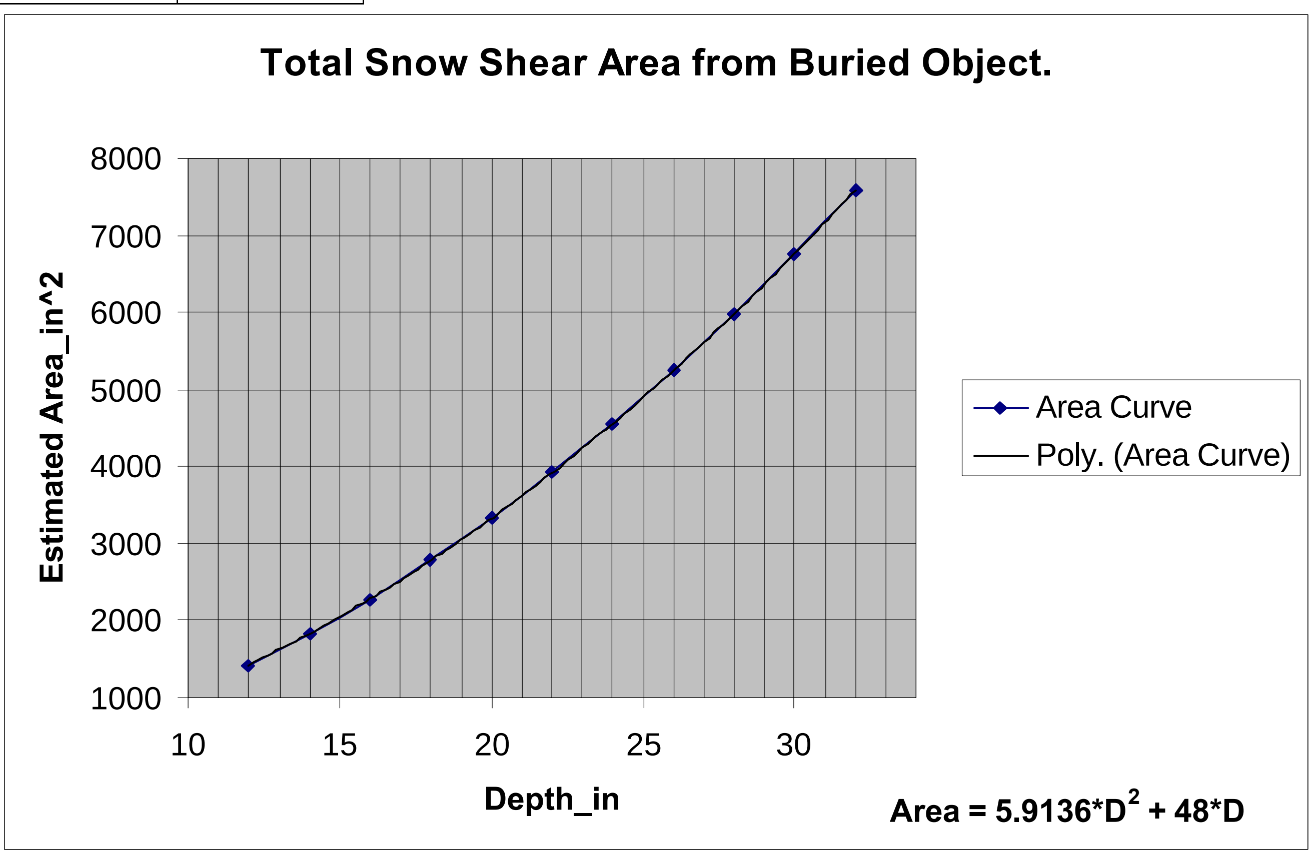
Horizontal Picket

Angles A & B were found by experimentation.

Width of Picket:	Angle A:	Angle B:
24	45	60

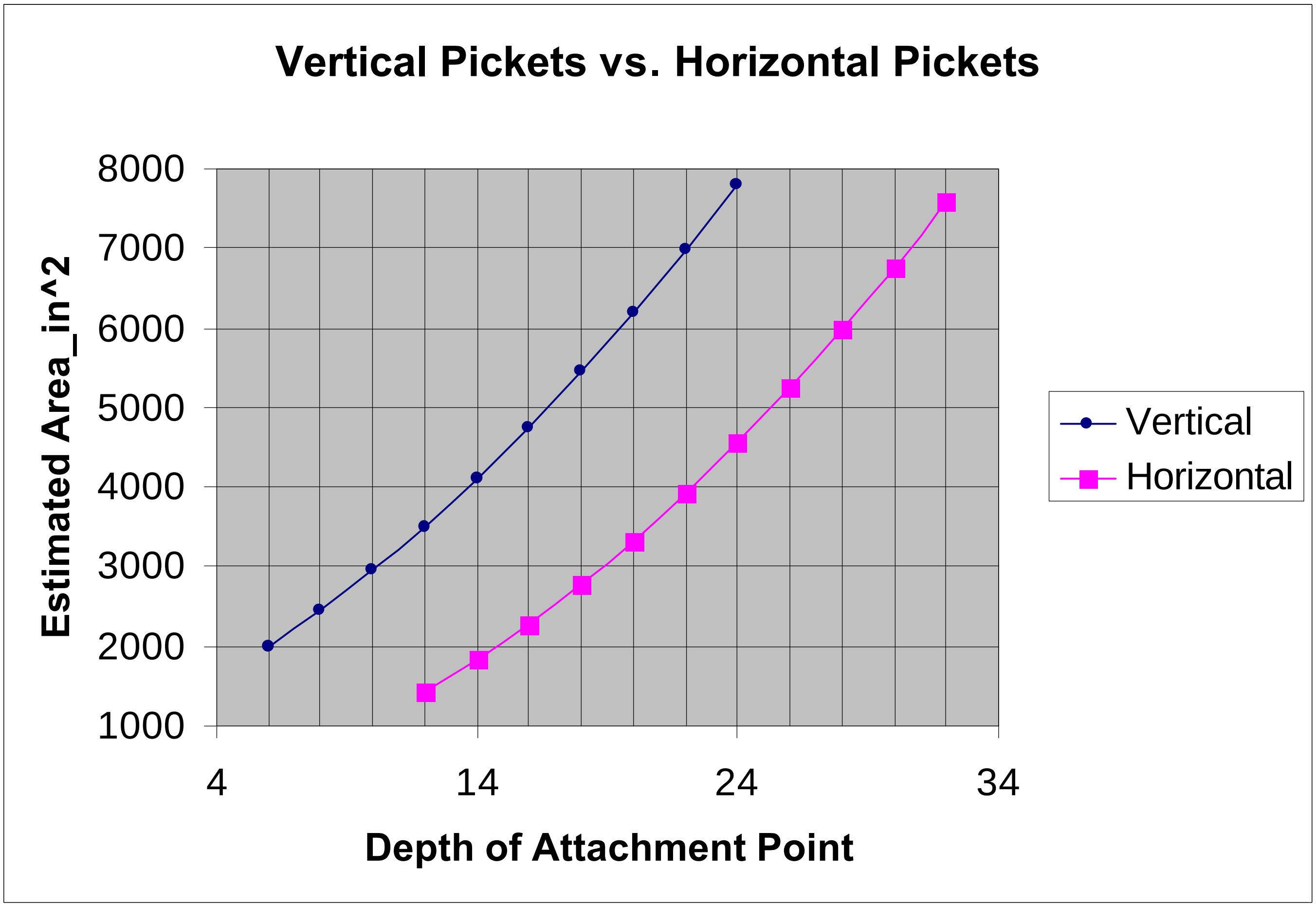
Depth of Object:	*Total Area:*
12	1427.557
14	1831.064
16	2281.879
18	2780.004
20	3325.437
22	3918.178
24	4558.229
26	5245.588
28	5980.256
30	6762.232
32	7591.518





Comparison of vertical pickets versus horizontal pickets.

In the chart below the pickets are being compared with the rope attached to the center hole of the picket and with the rope/attachment point at the same depth in the snow.



Force required to stop a fall on PMI 10mm Static Rope:

$$\frac{W\cdot h + W\cdot\delta - \left(\frac{a_1}{2\cdot L}\cdot\delta^2 + \frac{b_1}{3\cdot L^2}\cdot\delta^3\right)}{\frac{-b_1}{3\cdot L^2}} \;\Big|\; \begin{matrix}\text{simplify}\\ \text{collect},\delta\end{matrix} \rightarrow \delta^3 + \frac{3}{2}\cdot a_1\cdot\frac{L}{b_1}\cdot\delta^2 - 3\cdot W\cdot\frac{L^2}{b_1}\cdot\delta - 3\cdot W\cdot h\cdot\frac{L^2}{b_1}$$

$$\left(\delta - \frac{p}{3}\right)^3 + p\cdot\left(\delta - \frac{p}{3}\right)^2 + q\cdot\left(\delta - \frac{p}{3}\right) + r \;\Big|\; \begin{matrix}\text{simplify}\\ \text{collect},\delta\end{matrix} \rightarrow \delta^3 + \left(q - \frac{1}{3}\cdot p^2\right)\cdot\delta - \frac{1}{3}\cdot q\cdot p + r + \frac{2}{27}\cdot p^3$$

$$= \delta^3 + a\cdot\delta + b = 0$$

Weight	**Rope Length:**	**Distance of Fall:**	**Deflection Constants:**
$W := 200$	$L := 25$	$h := 10$	$a_1 := -220.6 \quad b_1 := 207010$

$$p := \frac{3\cdot a_1\cdot L}{2\cdot b_1} \qquad q := \frac{-3\cdot W\cdot L^2}{b_1} \qquad r := \frac{-3\cdot W\cdot h\cdot L^2}{b_1} \qquad a := \frac{1}{3}\cdot\left(3\cdot q - p^2\right) \qquad b := \frac{1}{27}\cdot\left(2\cdot p^3 - 9\cdot p\cdot q + 27\cdot r\right)$$

$$A := \sqrt[3]{\frac{-b}{2} + \sqrt{\frac{b^2}{4} + \frac{a^3}{27}}} \qquad B := \sqrt[3]{\frac{-b}{2} - \sqrt{\frac{b^2}{4} + \frac{a^3}{27}}} \qquad \delta := A + B \qquad \delta = 2.857$$

$$F := \frac{a_1}{L}\cdot\delta + \frac{b_1}{L^2}\cdot\delta^2 \qquad F = 2677.998\ \text{lbf} \quad \varepsilon$$

Note:
ε: To simplify these computations knot stretch was not included. If you want to get an approximation with a knot included, add 0.25*rope_length+1.5 to the rope length "L" variable and recalculate.

References:

Attaway, Steve; Predicting Rope Impact Forces using a Non-Linear Force Deflection.
Hudson; The Engineers Manual, John Wiley and Sons, NY, 1944

Force required to stop a fall on PMI 10.6mm Dynamic Rope:

$$\frac{W\cdot h + W\cdot\delta - \left(\frac{a_1}{2\cdot L}\cdot\delta^2 + \frac{b_1}{3\cdot L^2}\cdot\delta^3\right)}{\frac{-b_1}{3\cdot L^2}} \;\Big|\; \begin{matrix}\text{simplify}\\ \text{collect},\delta\end{matrix} \rightarrow \delta^3 + \frac{3}{2}\cdot a_1\cdot\frac{L}{b_1}\cdot\delta^2 - 3\cdot W\cdot\frac{L^2}{b_1}\cdot\delta - 3\cdot W\cdot h\cdot\frac{L^2}{b_1}$$

$$\left(\delta - \frac{p}{3}\right)^3 + p\cdot\left(\delta - \frac{p}{3}\right)^2 + q\cdot\left(\delta - \frac{p}{3}\right) + r \;\Big|\; \begin{matrix}\text{simplify}\\ \text{collect},\delta\end{matrix} \rightarrow \delta^3 + \left(q - \frac{1}{3}\cdot p^2\right)\cdot\delta - \frac{1}{3}\cdot q\cdot p + r + \frac{2}{27}\cdot p^3$$

$$= \delta^3 + a\cdot\delta + b = 0$$

Weight	**Rope Length:**	**Distance of Fall:**	**Deflection Constants:**
$W := 200$	$L := 25$	$h := 10$	$a_1 := -27.367$ $b_1 := 13243$

$p := \frac{3\cdot a_1\cdot L}{2\cdot b_1}$ $\quad q := \frac{-3\cdot W\cdot L^2}{b_1}$ $\quad r := \frac{-3\cdot W\cdot h\cdot L^2}{b_1}$ $\quad a := \frac{1}{3}\cdot\left(3\cdot q - p^2\right)$ $\quad b := \frac{1}{27}\cdot\left(2\cdot p^3 - 9\cdot p\cdot q + 27\cdot r\right)$

$A := \sqrt[3]{\frac{-b}{2} + \sqrt{\frac{b^2}{4} + \frac{a^3}{27}}}$ $\quad B := \sqrt[3]{\frac{-b}{2} - \sqrt{\frac{b^2}{4} + \frac{a^3}{27}}}$ $\quad \delta := A + B$ $\quad \delta = 7.991$

$F := \frac{a_1}{L}\cdot\delta + \frac{b_1}{L^2}\cdot\delta^2$ $\quad F = 1344.125\ \text{lbf}\ \ \varepsilon$

Note:
ε: To simplify these computations knot stretch was not included. If you want to get an approximation with a knot included, add 0.25*rope_length+1.5 to the rope length "L" variable and recalculate.

References:

Attaway, Steve; Predicting Rope Impact Forces using a Non-Linear Force Deflection.
Hudson; The Engineers Manual, John Wiley and Sons, NY, 1944