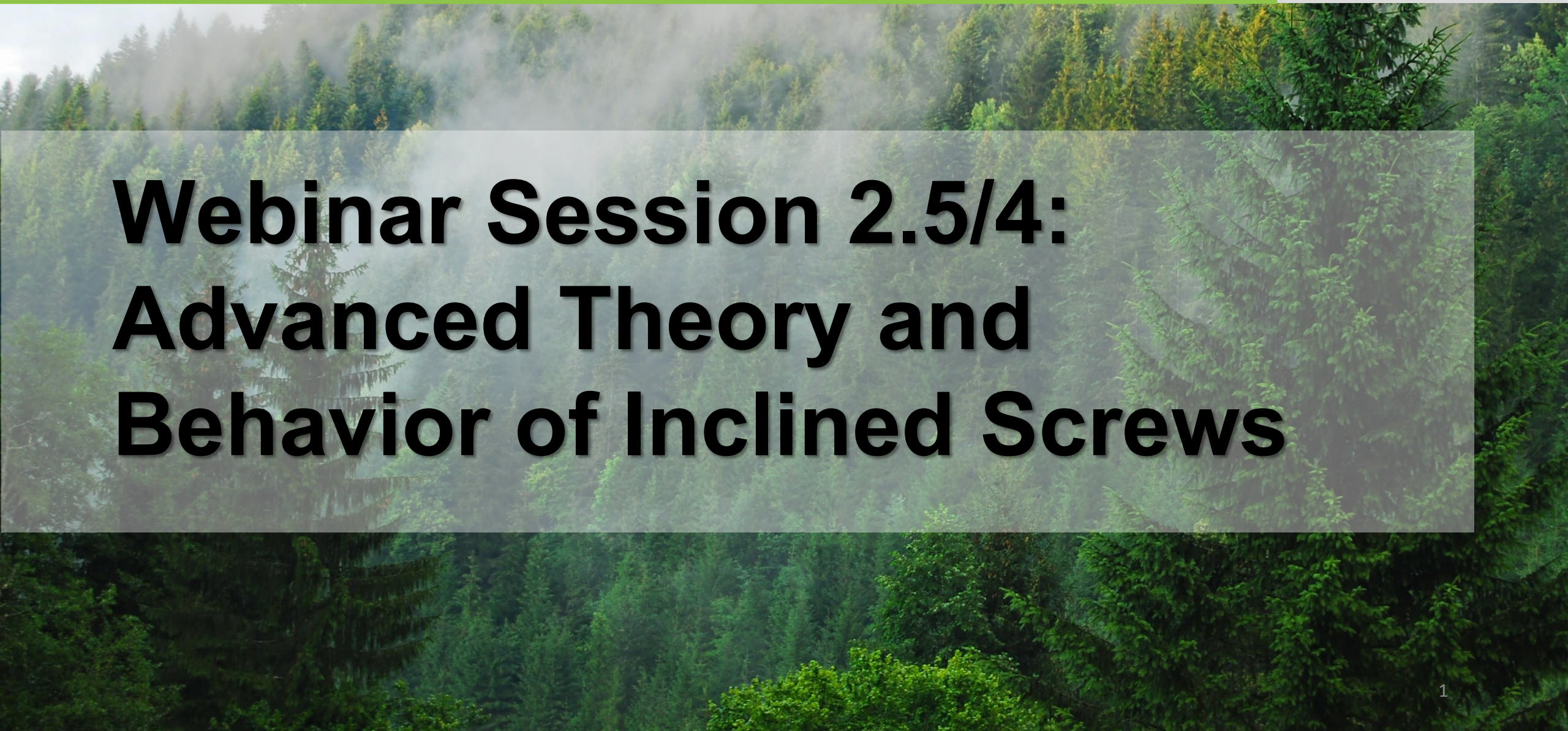


Webinar Session 2.5/4: Advanced Theory and Behavior of Inclined Screws

Keith Porter

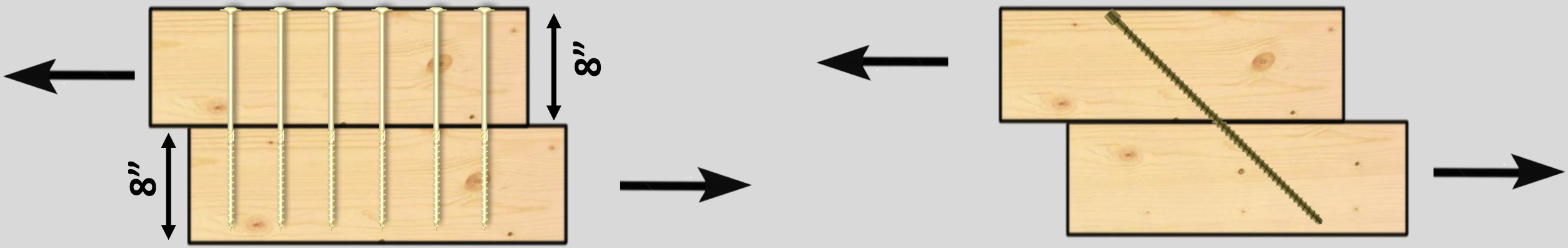
Dalhousie University
-B.Eng. in Civil Engineering

MyTiCon Timber Connectors
-Research and Development

Outline:

- **Theory of Inclined Screws**
  - Efficiency and penetration depth
- **Behavior of Inclined Screws**
  - Plastic and brittle behavior
- **Design Models**
  - Simplified Truss Model
  - Combined Loading Equation
  - Extended Johansen Theory

Advanced Theory and Behavior of Inclined Screws

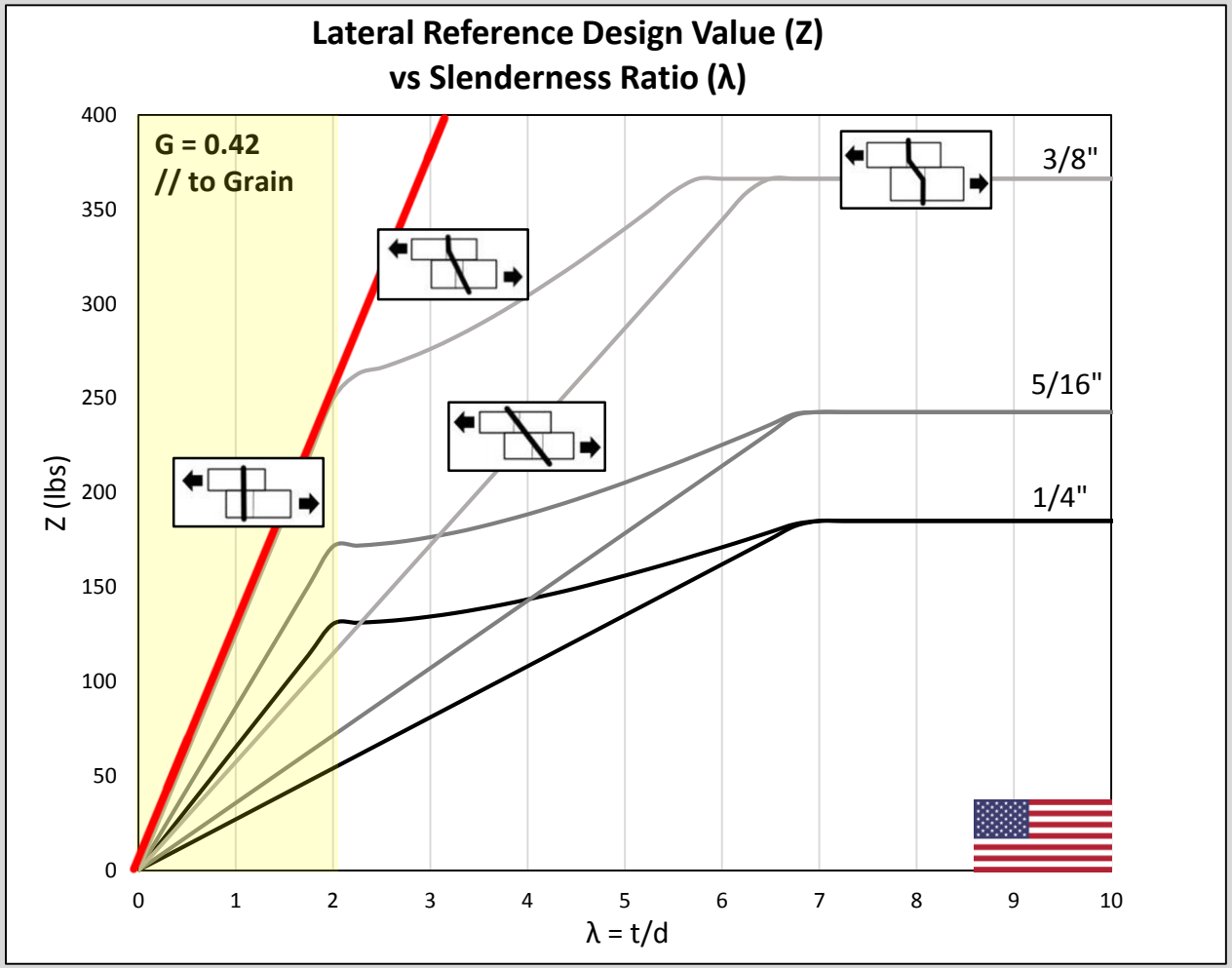


QTY = 6

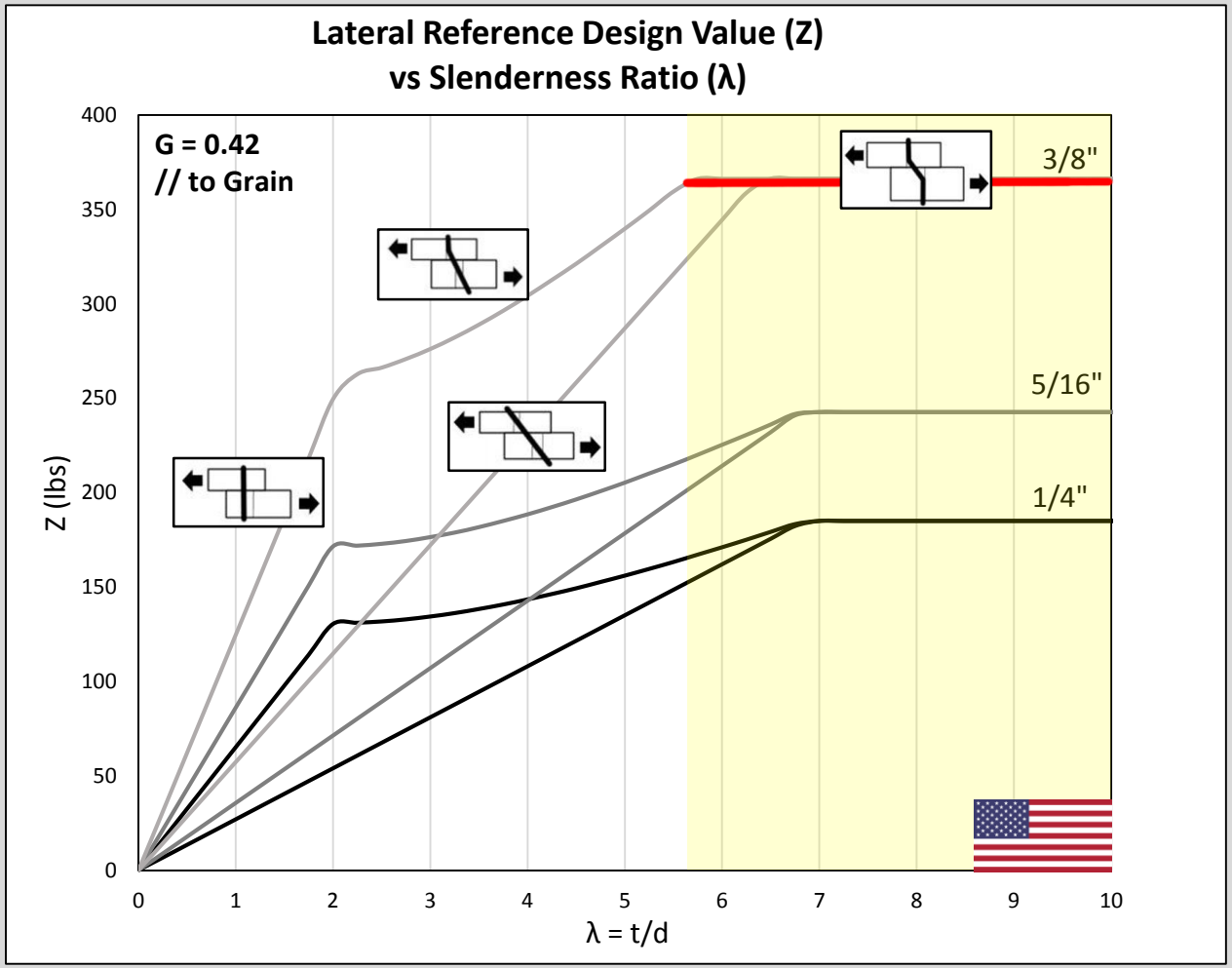
Z = 3,000 lbs

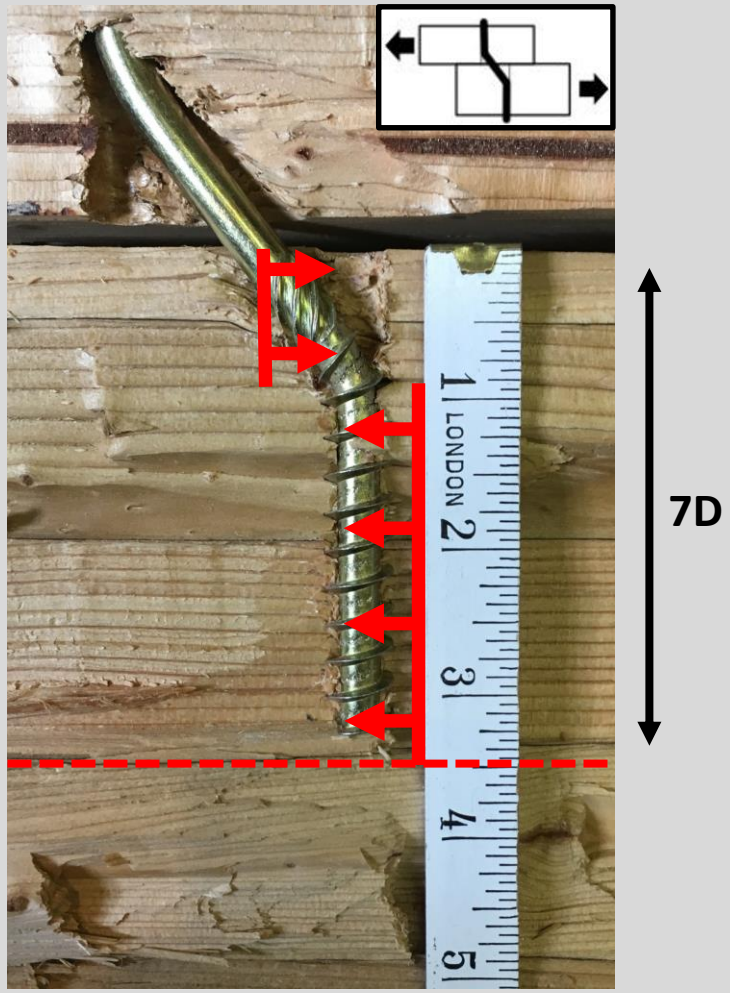
QTY = 1

Advanced Theory and Behavior of Inclined Screws

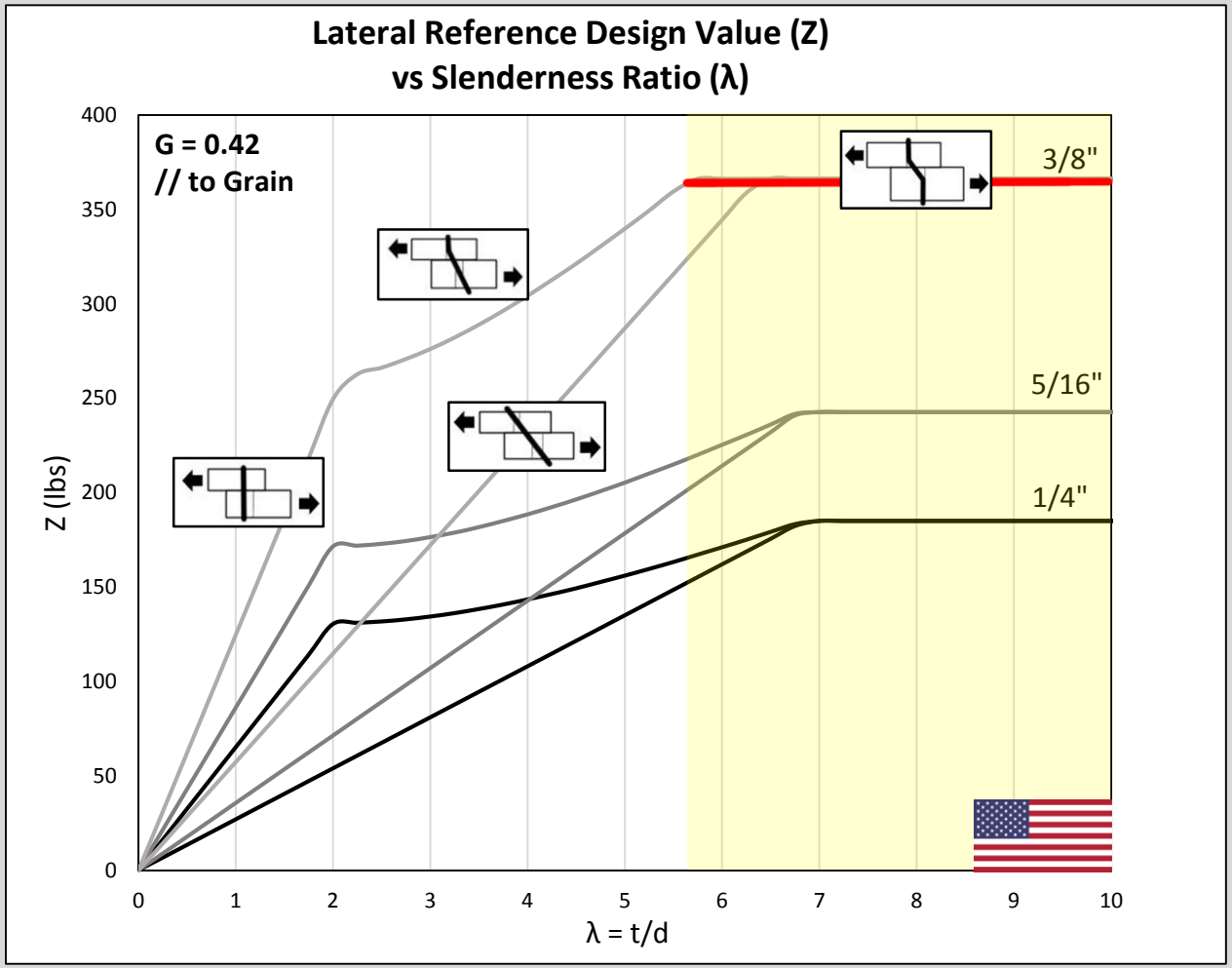


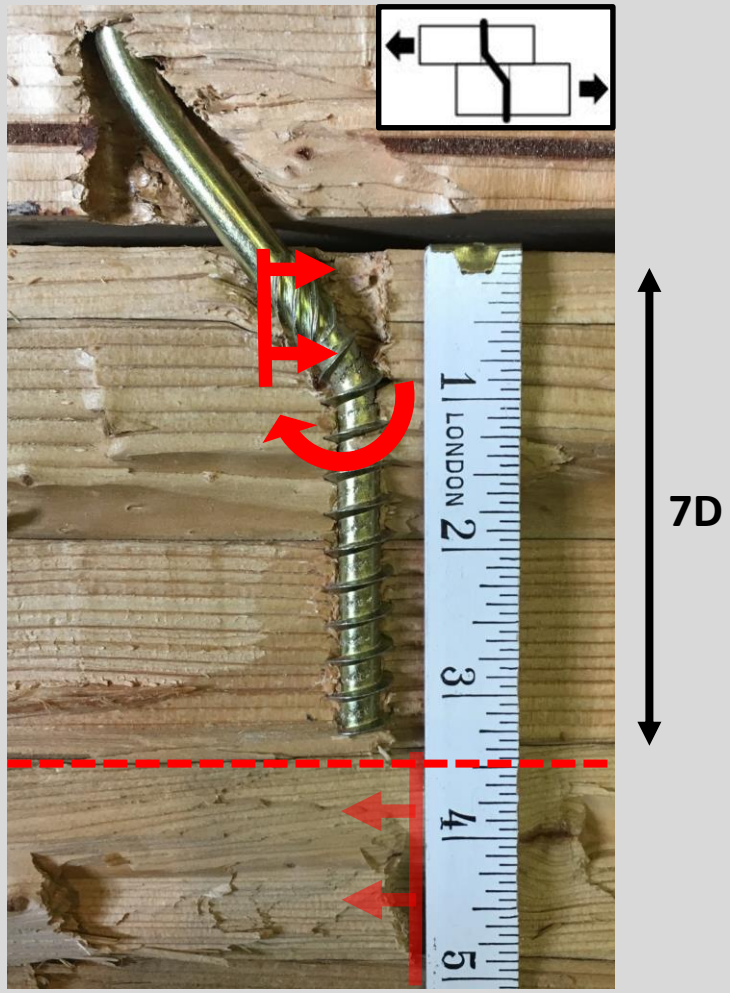
Webinar Session 2.5
Advanced Theory and Behavior of Inclined Screws



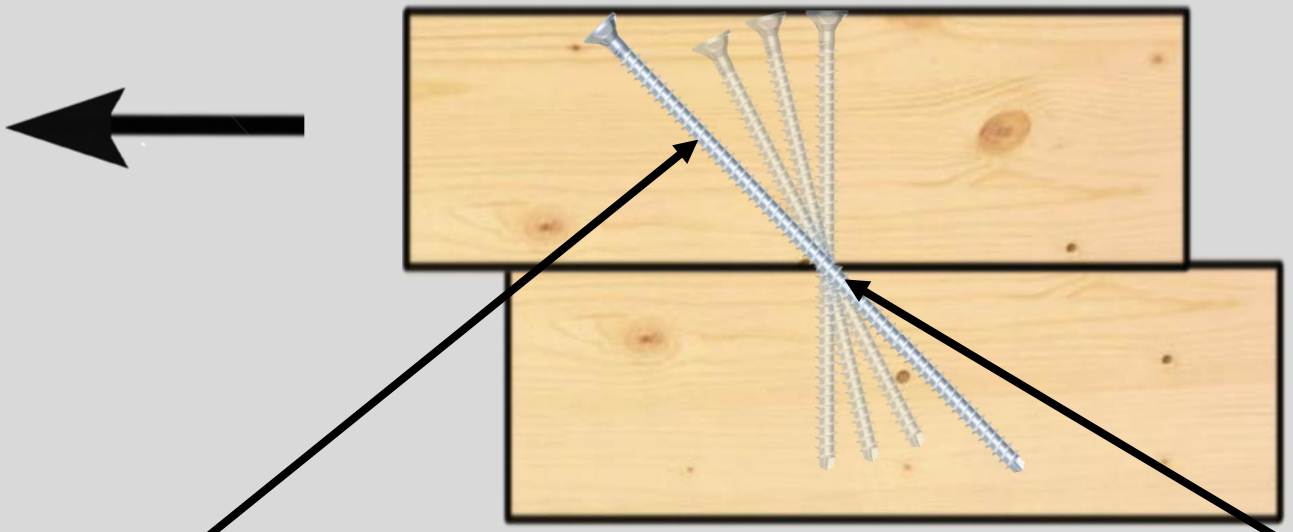


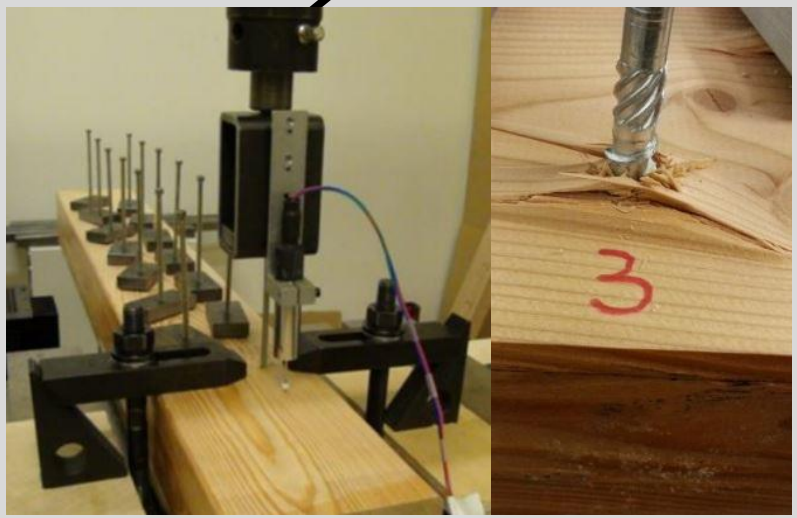
Webinar Session 2.5
Advanced Theory and Behavior of Inclined Screws

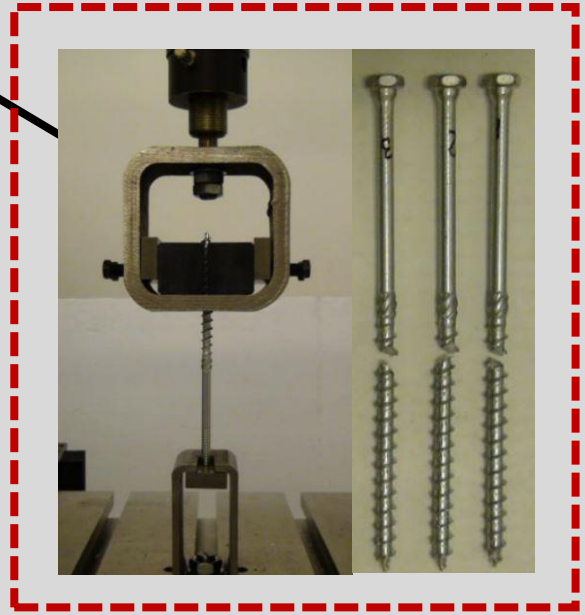




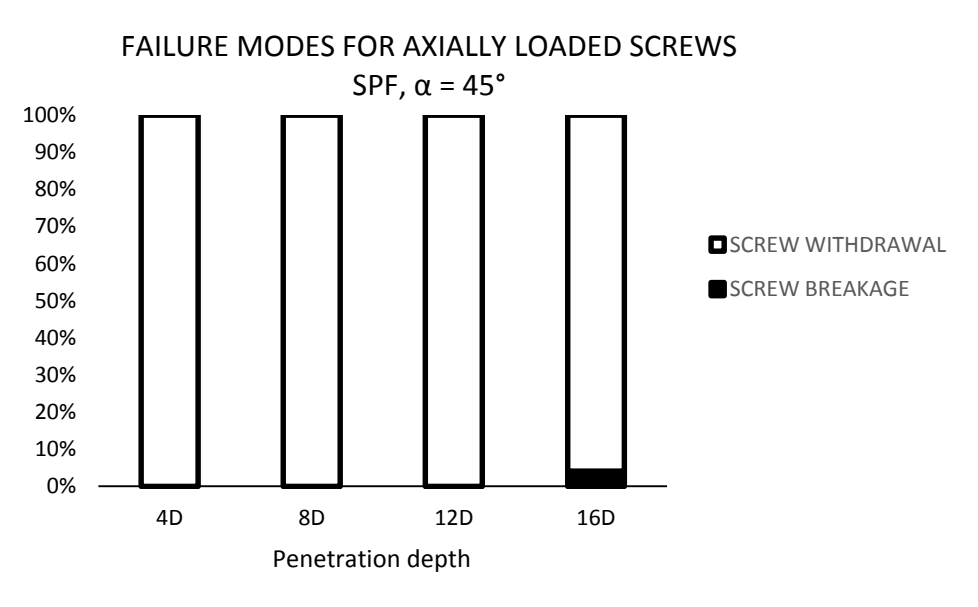
Advanced Theory and Behavior of Inclined Screws

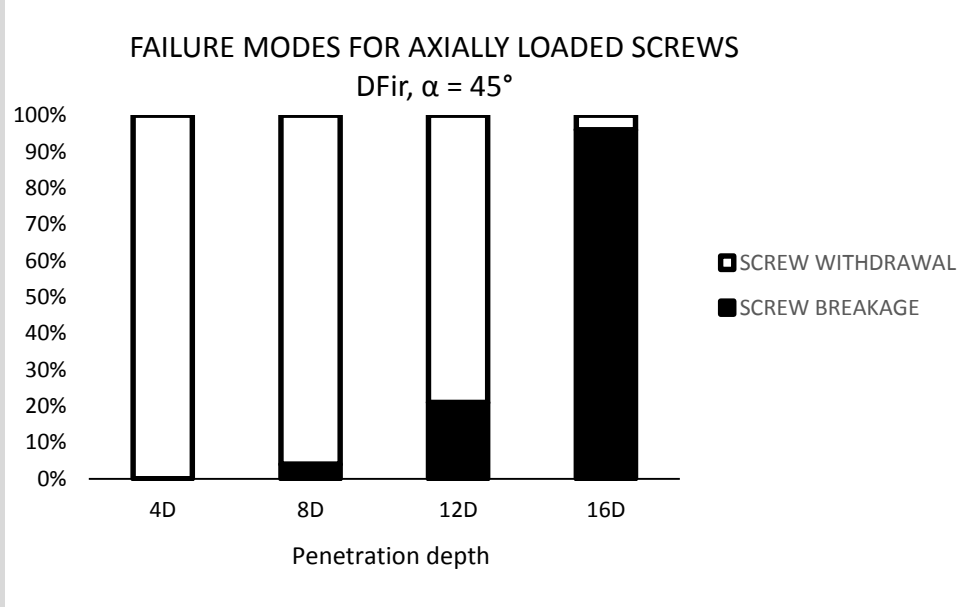




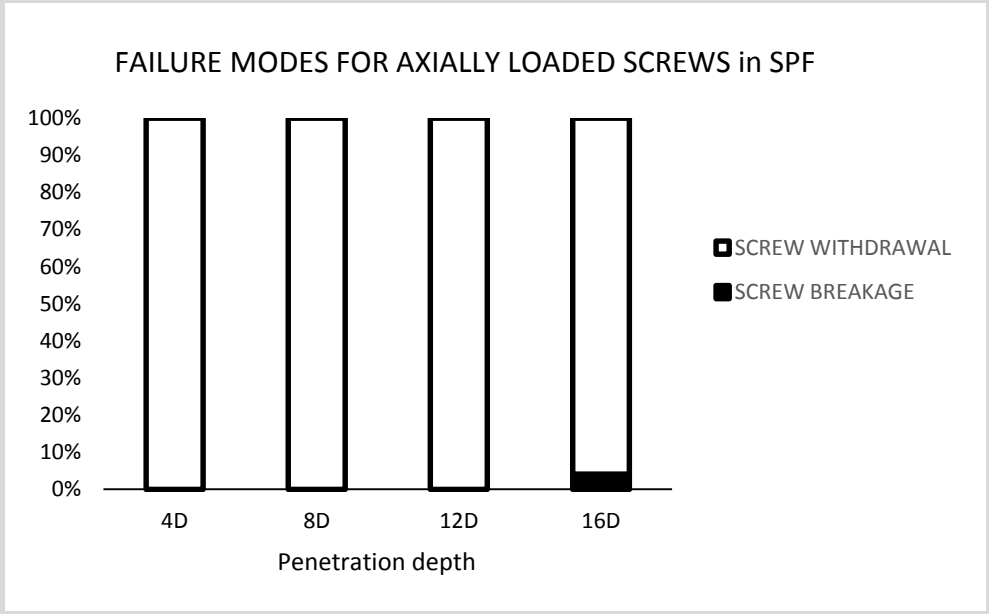


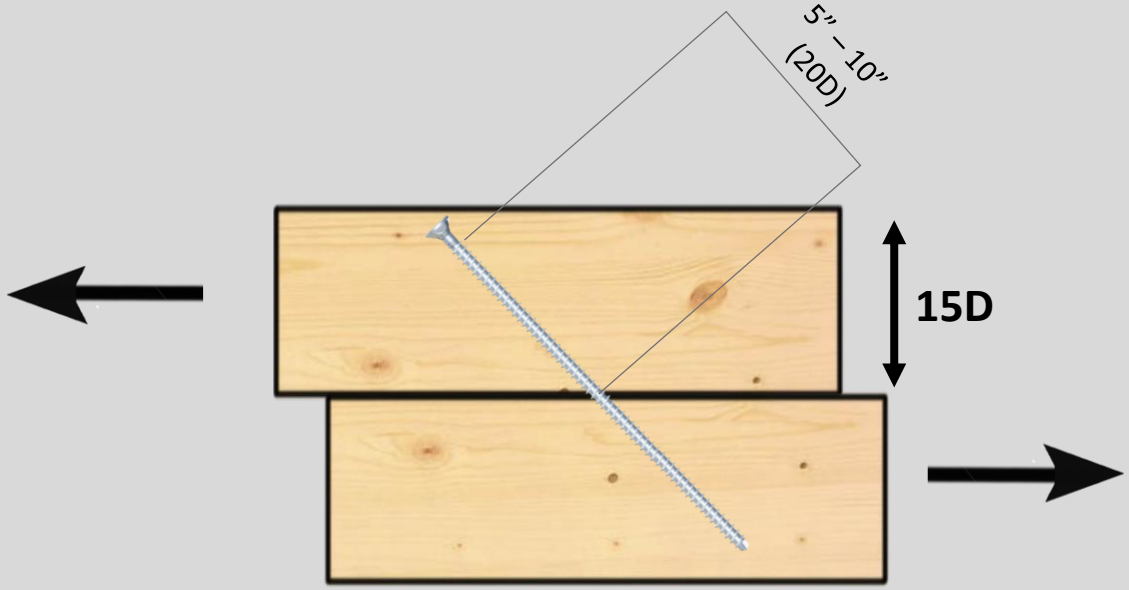
Advanced Theory and Behavior of Inclined Screws





Advanced Theory and Behavior of Inclined Screws

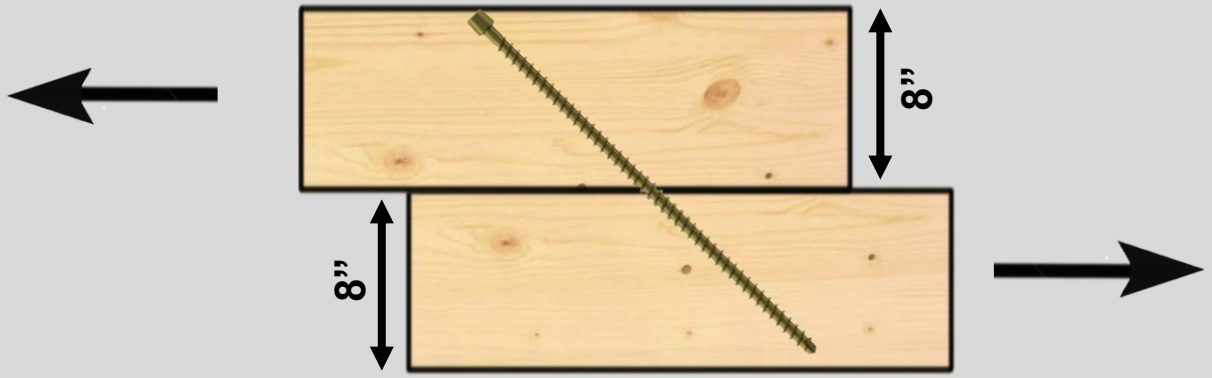




Advanced Theory and Behavior of Inclined Screws

D = 1-1/8”

D = ½”

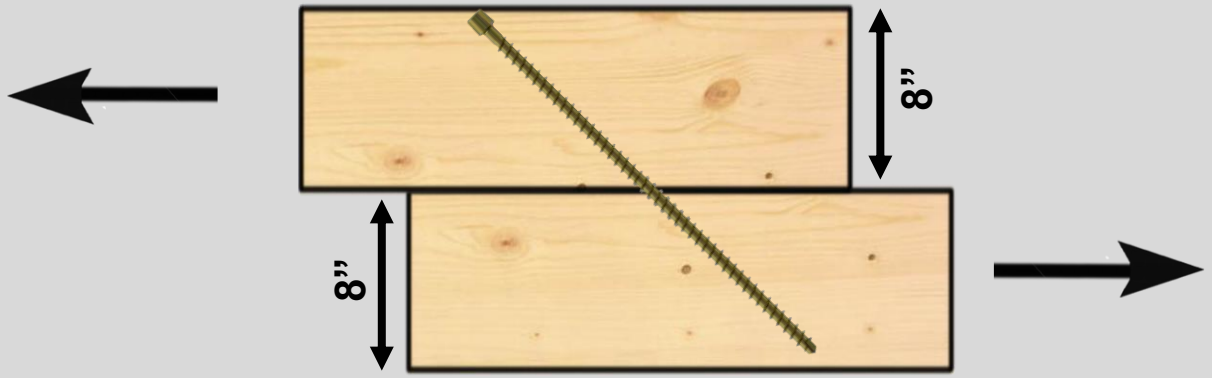


Z = 3,000 lbs

Advanced Theory and Behavior of Inclined Screws

D = 1-1/8”

D = ½”

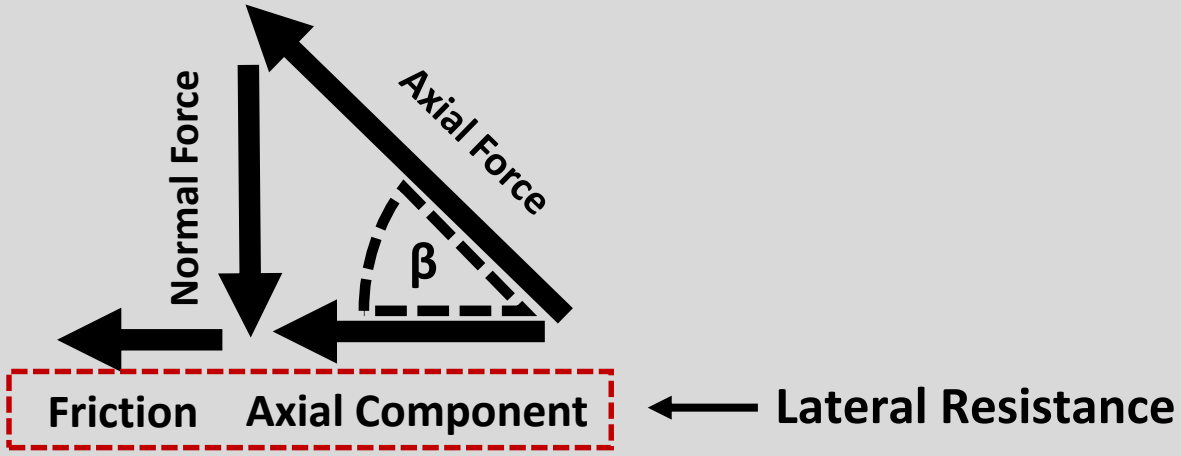


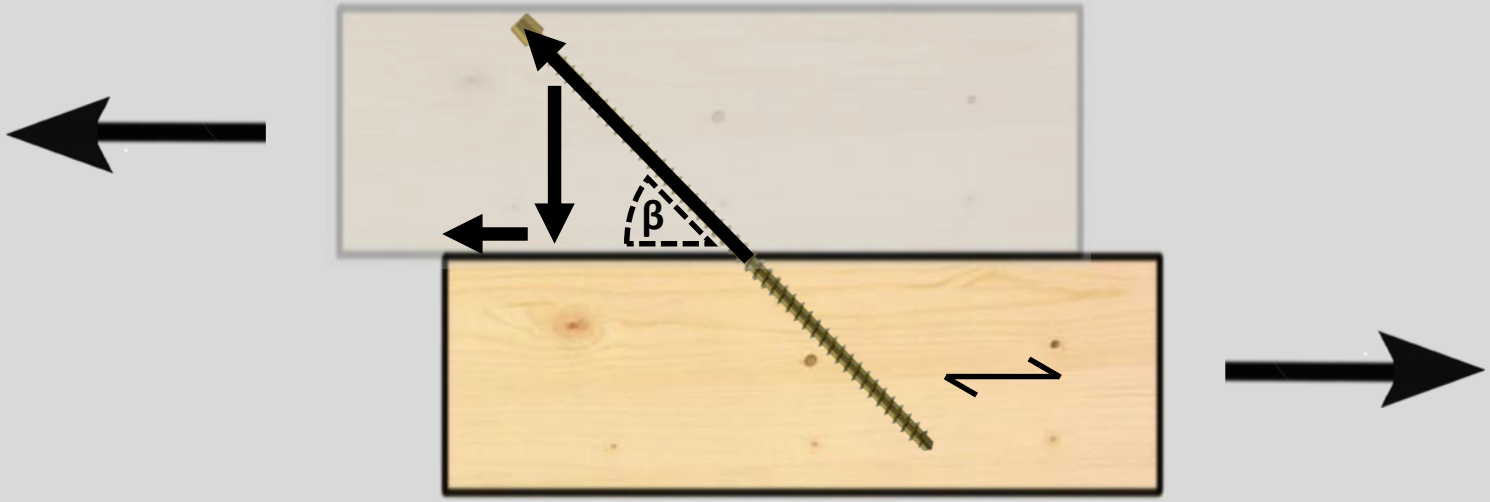
Z = 3,000 lbs

Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Simplified Truss Model

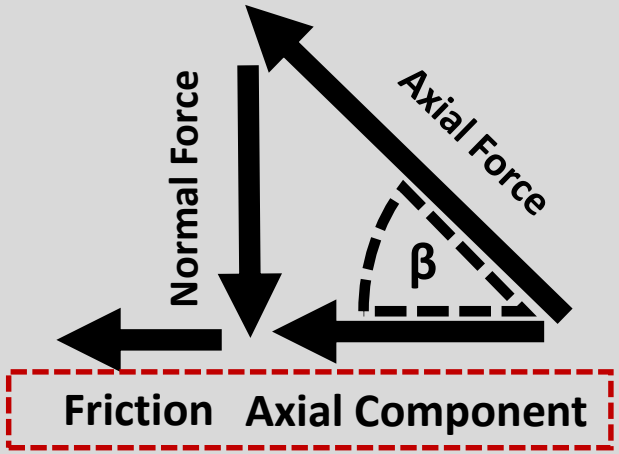




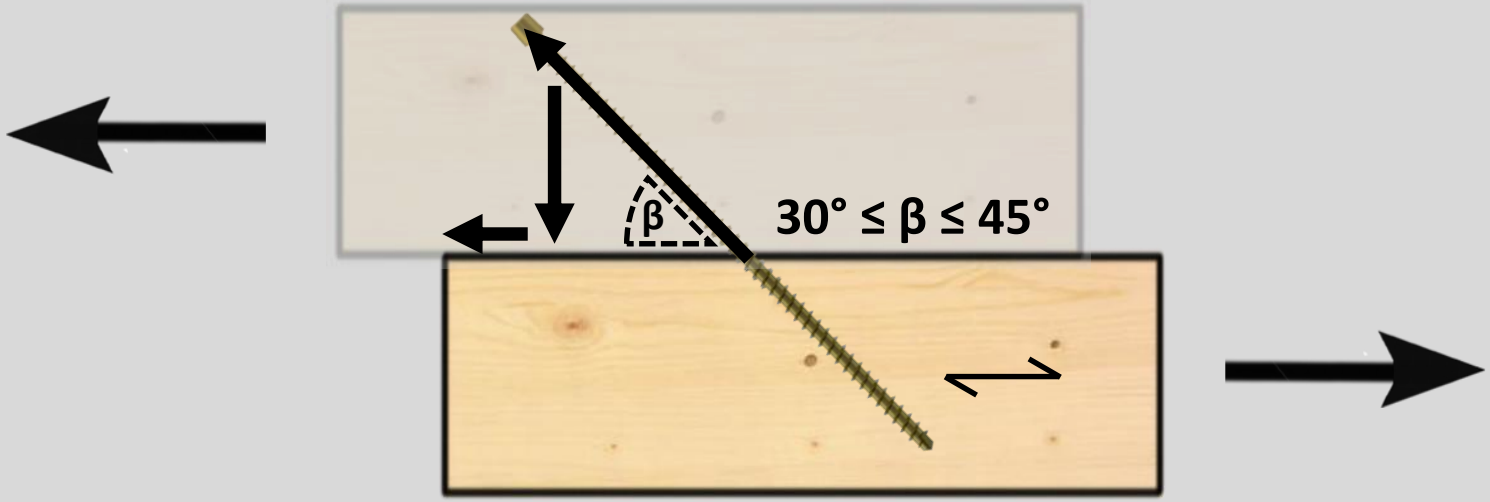
Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Simplified Truss Model



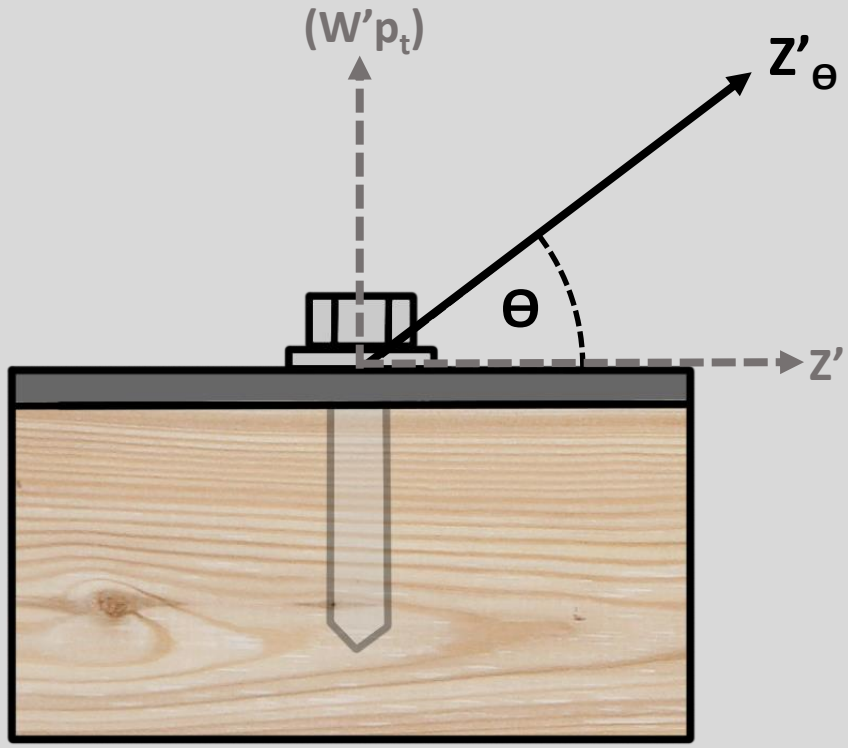
Lateral Resistance = $\begin{cases} \min[(W_\alpha' p_t), (T_a)] \cdot (\cos\beta + \mu \cdot \sin\beta) \\ \min[(P_{rw}), (\varphi T)] \cdot (\cos\beta + \mu \cdot \sin\beta) \end{cases}$



Advanced Theory and Behavior of Inclined Screws

Combined Loading Equation

$$Z'_{\theta} = \frac{(W'p_t)Z'}{(W'p_t)\cos^2\theta + Z'\sin^2\theta}$$



(McLain & Carroll, 1990)

Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Extended Johansen Theory

$$R_a = R_{ax,k} \cdot \sin\alpha + f_{h,1,k} \cdot s_1 \cdot d \cdot \cos\alpha$$

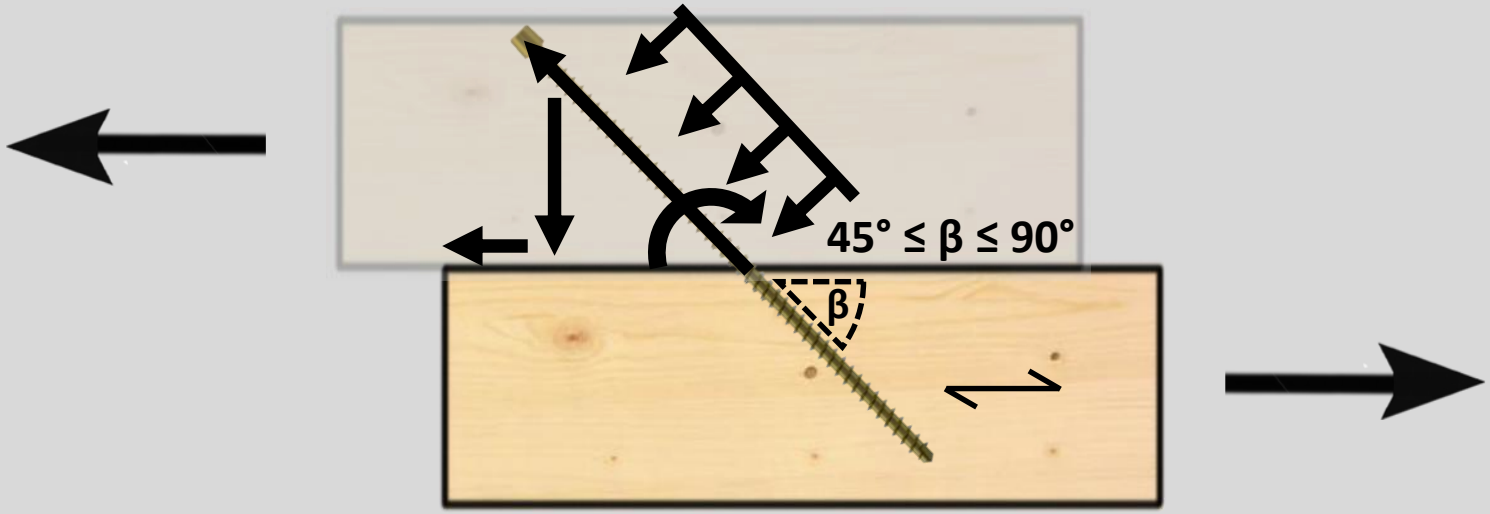
$$R_b = R_{ax,k} \cdot \sin\alpha + f_{h,2,k} \cdot s_2 \cdot d \cdot \cos\alpha$$

$$R_c = R_{ax,k} \cdot (\mu \cdot \cos\alpha + sen\,\alpha) + \frac{f_{h,1,k} \cdot s_1 \cdot d}{1+\beta} \cdot (1 - \mu \cdot \tan\alpha) \cdot \left[\sqrt{\beta + 2 \cdot \beta^2 \cdot \left(1 + \frac{s_2}{s_1} + \left(\frac{s_2}{s_1}\right)^2\right) + \beta^3 \cdot \left(\frac{s_2}{s_1}\right)^2} - \beta \cdot \left(1 + \frac{s_2}{s_1}\right)\right]$$

$$R_d = R_{ax,k} \cdot (\mu \cdot \cos\alpha + sen\,\alpha) + \frac{f_{h,1,k} \cdot s_1 \cdot d}{2+\beta} \cdot (1 - \mu \cdot \tan\alpha) \cdot \left[\sqrt{2 \cdot \beta \cdot (1+\beta) + \left(\frac{4 \cdot \beta \cdot (2+\beta) \cdot M_{y,k}}{f_{h,1,k} \cdot d \cdot s_1^2}\right)} - \beta\right]$$

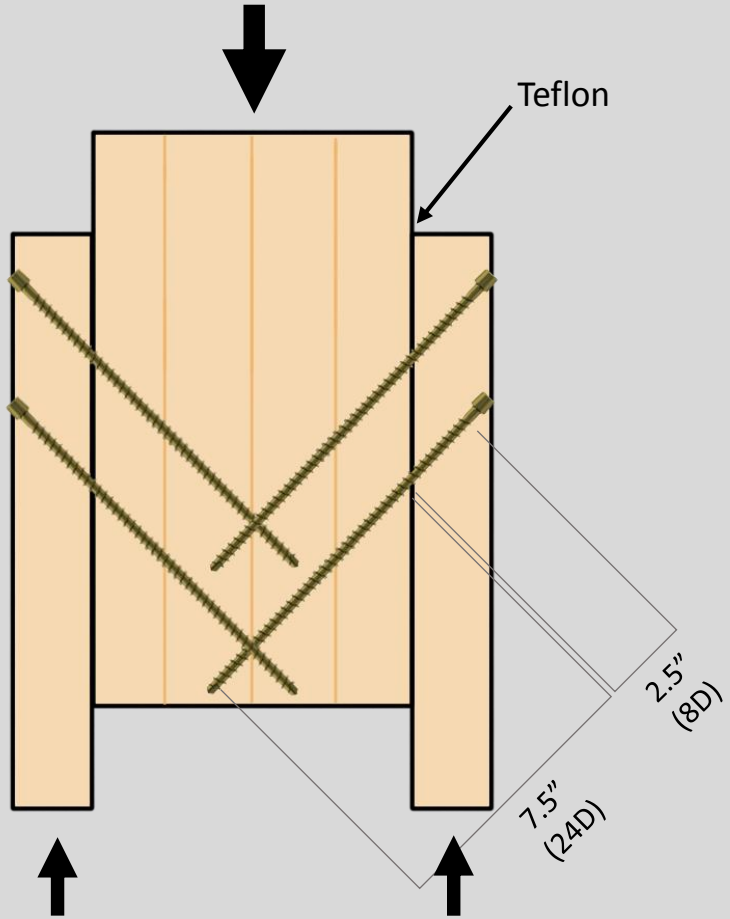
$$R_e = R_{ax,k} \cdot (\mu \cdot \cos\alpha + sen\,\alpha) + \frac{f_{h,1,k} \cdot s_2 \cdot d}{1+2 \cdot \beta} \cdot (1 - \mu \cdot \tan\alpha) \cdot \left[\sqrt{2 \cdot \beta^2 \cdot (1+\beta) + \left(\frac{4 \cdot \beta \cdot (1+2 \cdot \beta) \cdot M_{y,k}}{f_{h,1,k} \cdot d \cdot s_2^2}\right)} - \beta\right]$$

$$R_f = R_{ax,k} \cdot (\mu \cdot \cos\alpha + sen\,\alpha) + (1 - \mu \cdot \tan\alpha) \cdot \sqrt{\frac{2 \cdot \beta}{1+\beta}} \cdot \sqrt{2 \cdot M_{y,k} \cdot f_{h,1,k} \cdot d \cdot \cos^2\alpha}$$

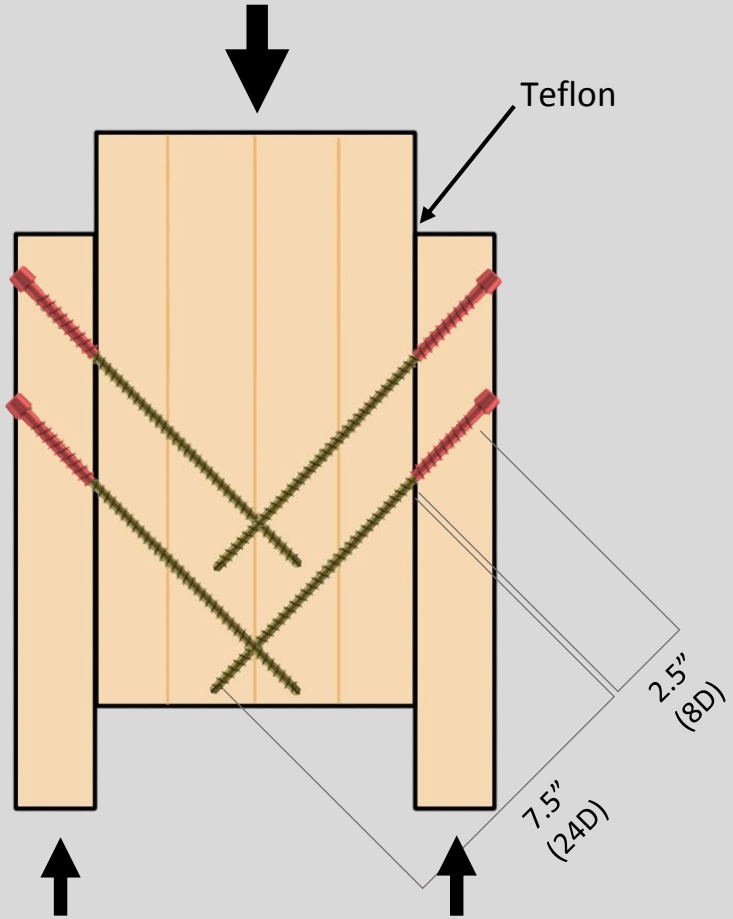


MyTiCon Timber Connectors

Simplified Truss Model



Simplified Truss Model



Withdrawal resistance, side members = 4,800lbs

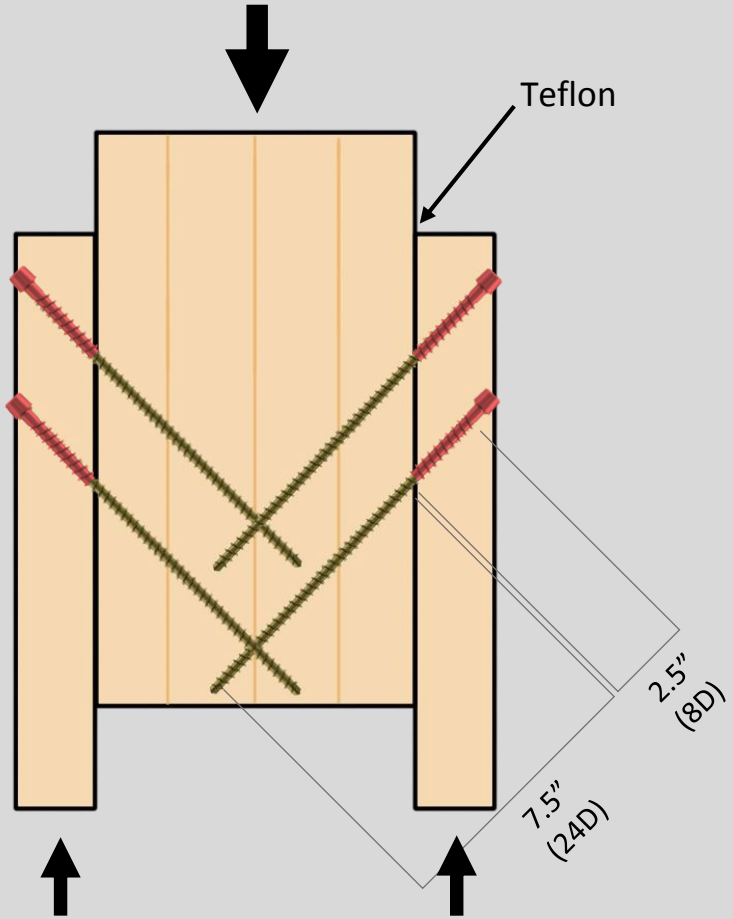
Withdrawal resistance, main member = 14,400lbs

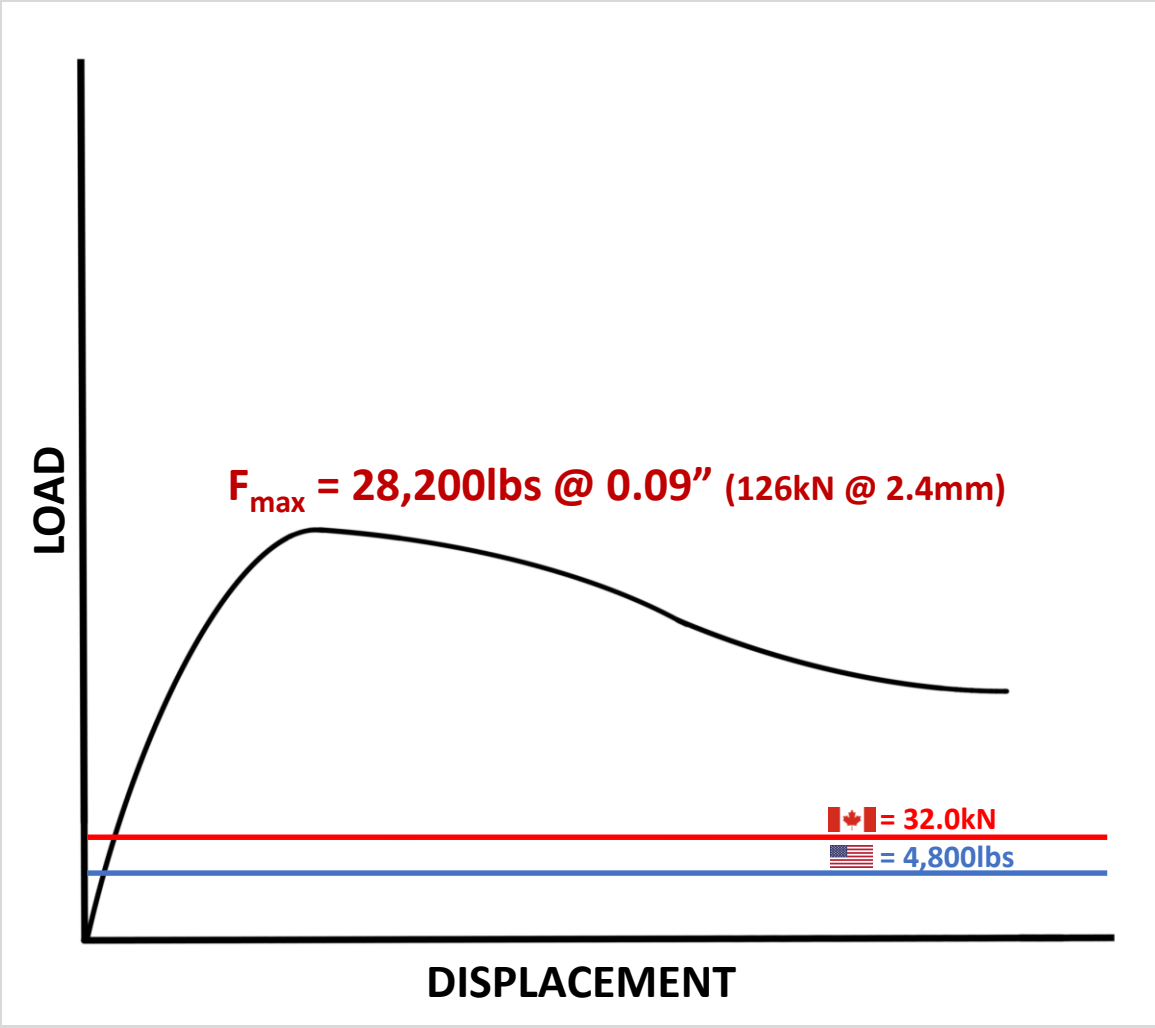
Tensile strength of the screws = 9,000lbs

Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Simplified Truss Model

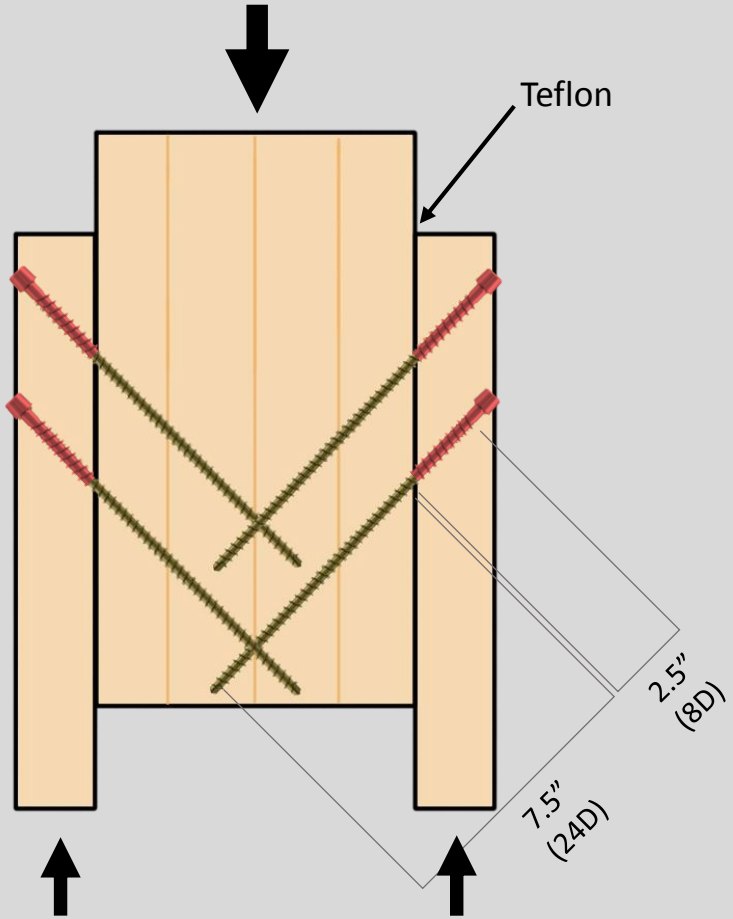


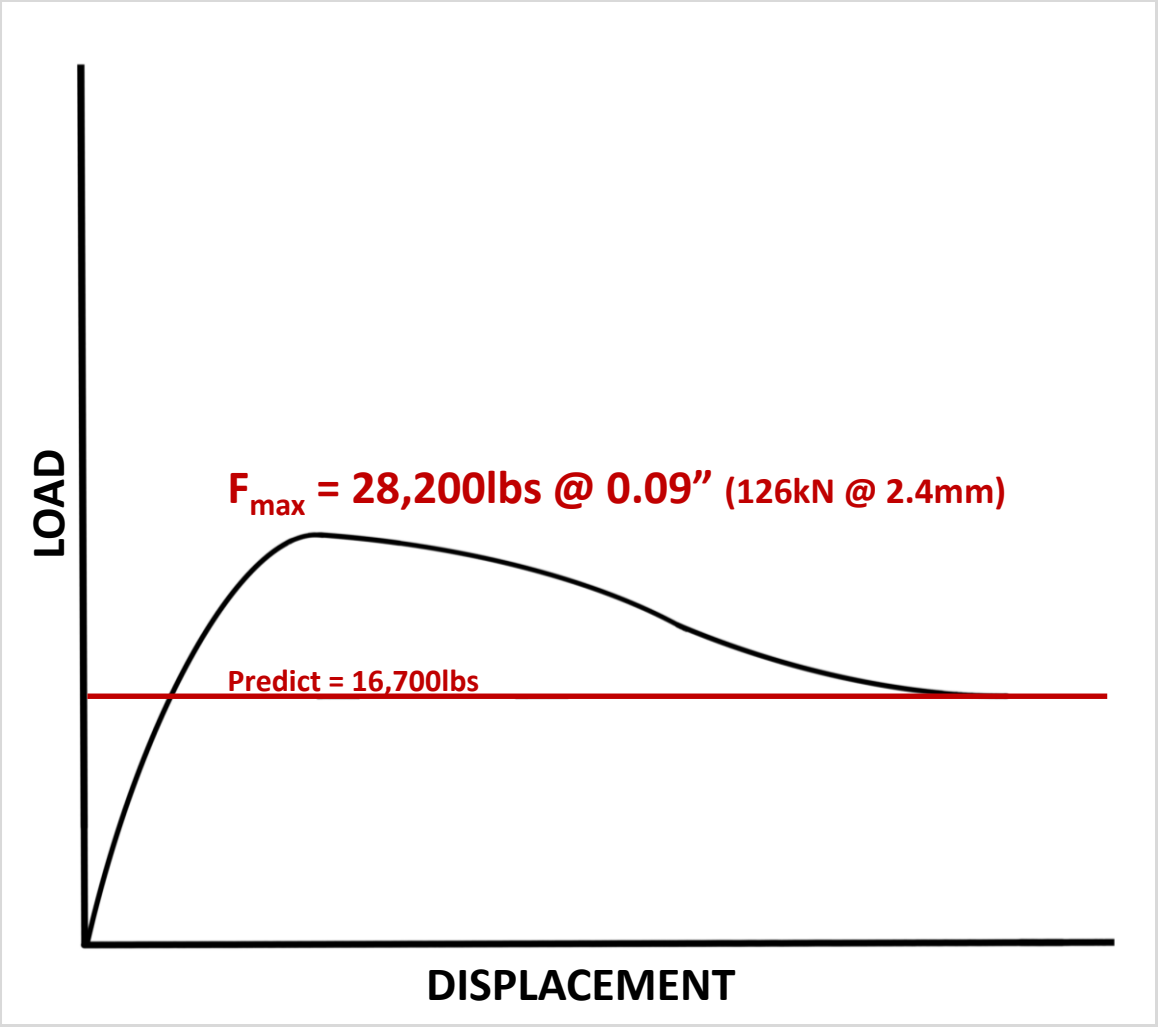


Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Simplified Truss Model

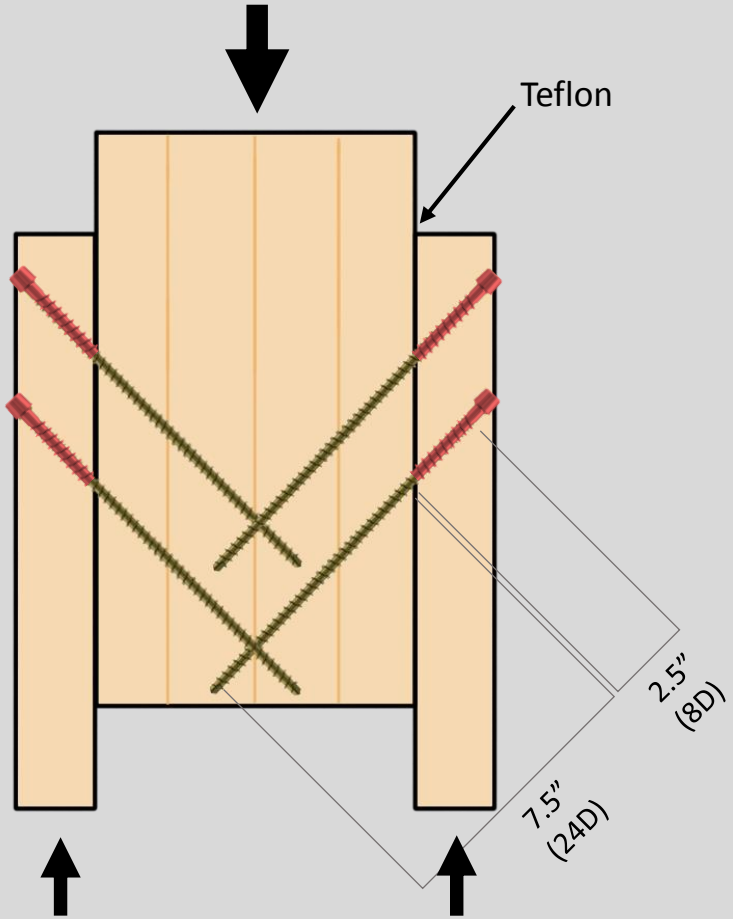


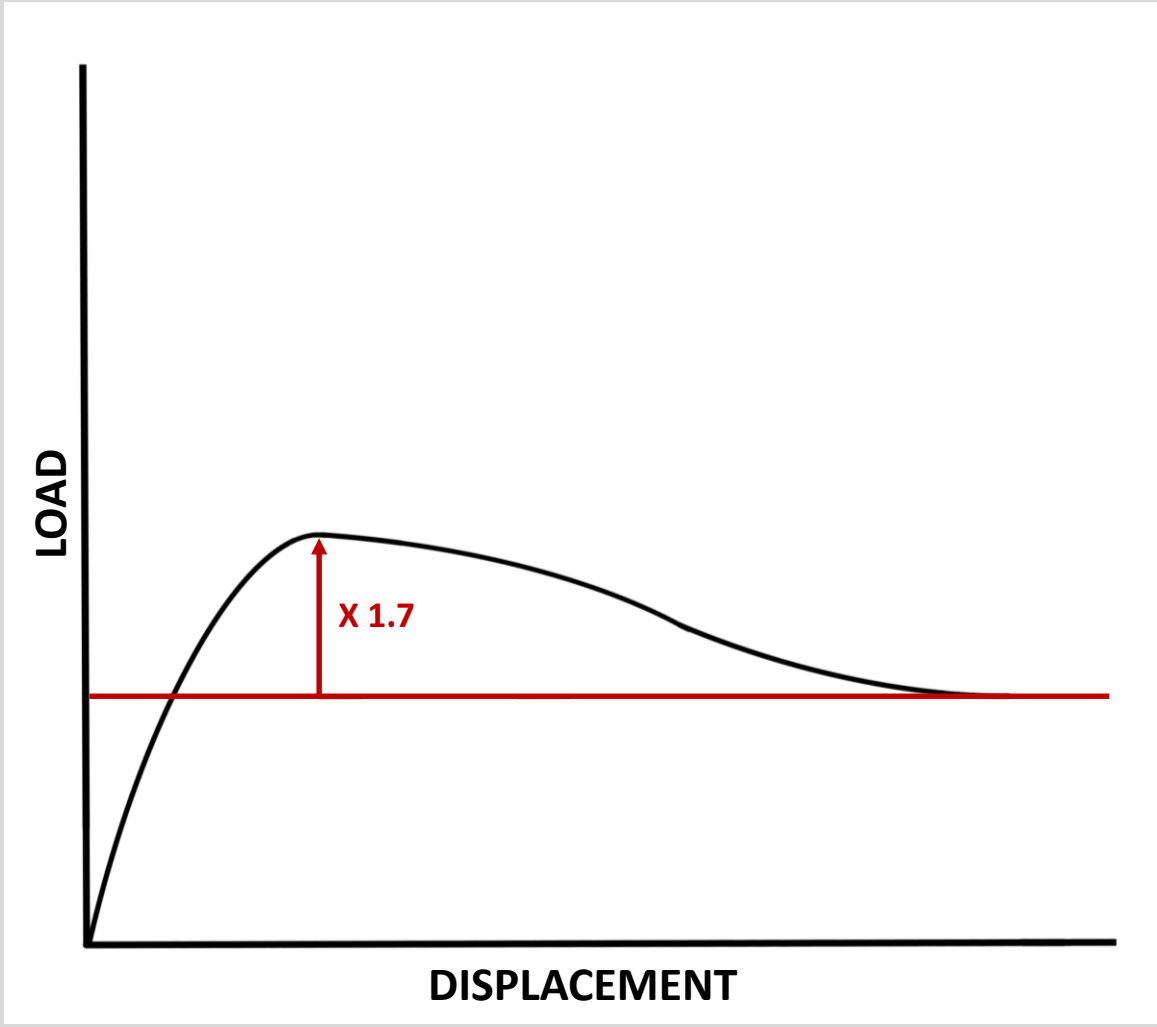


Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

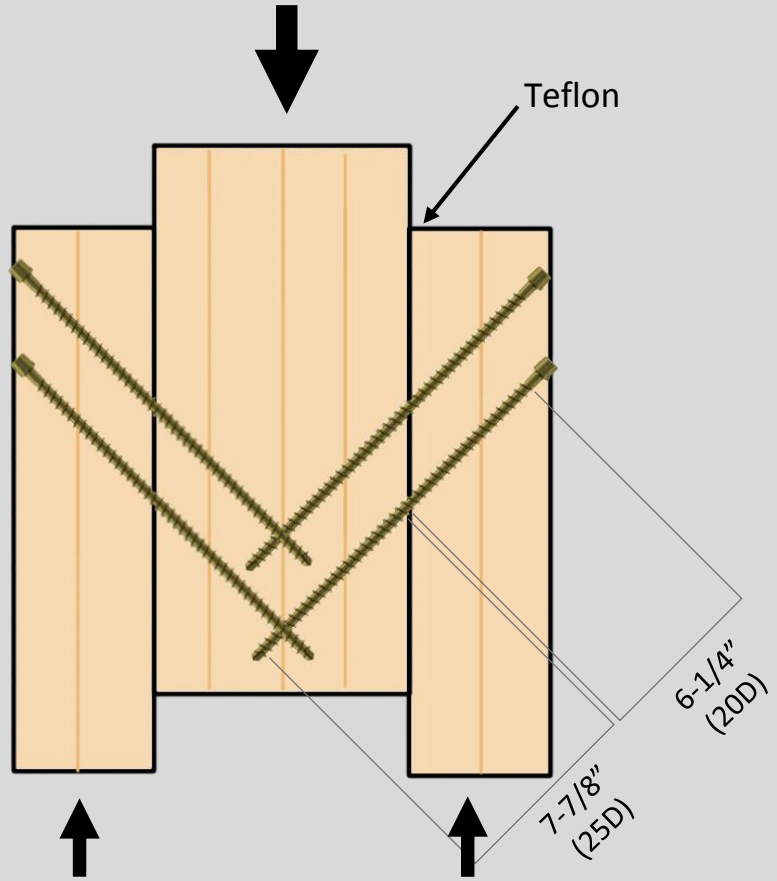
Simplified Truss Model





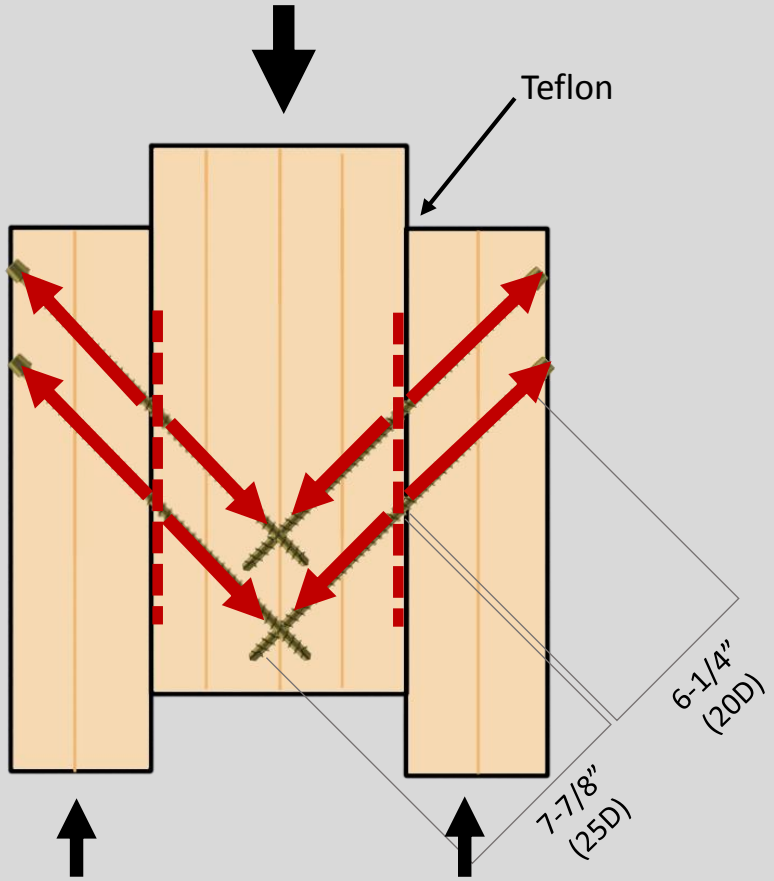
MyTiCon Timber Connectors

Simplified Truss Model



MyTiCon Timber Connectors

Simplified Truss Model



Withdrawal resistance, side members = 12,000lbs

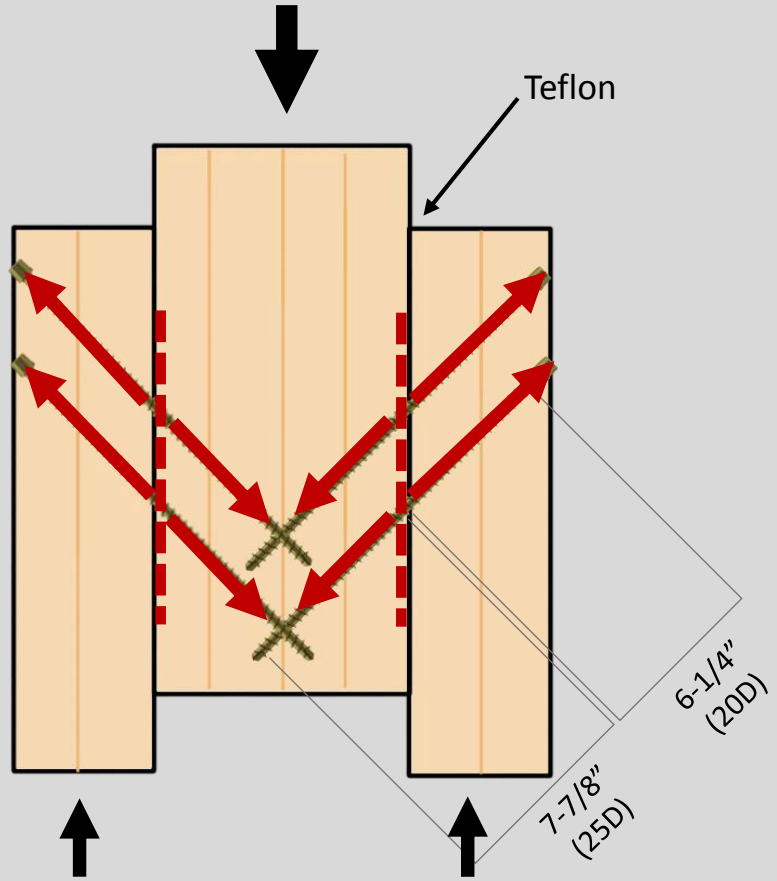
Withdrawal resistance, main member = 15,000lbs

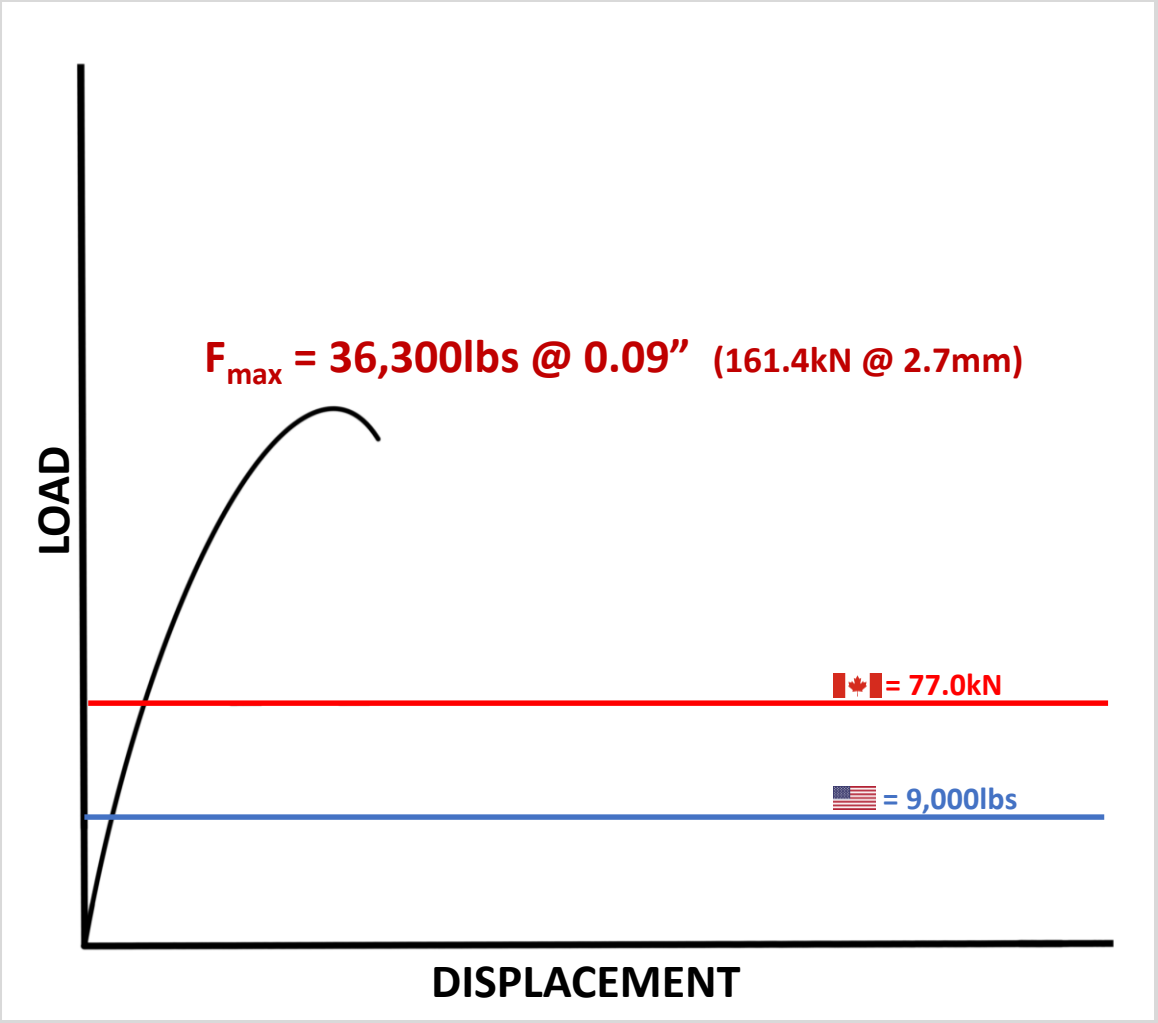
Tensile strength of the screws = 9,000lbs

Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Simplified Truss Model

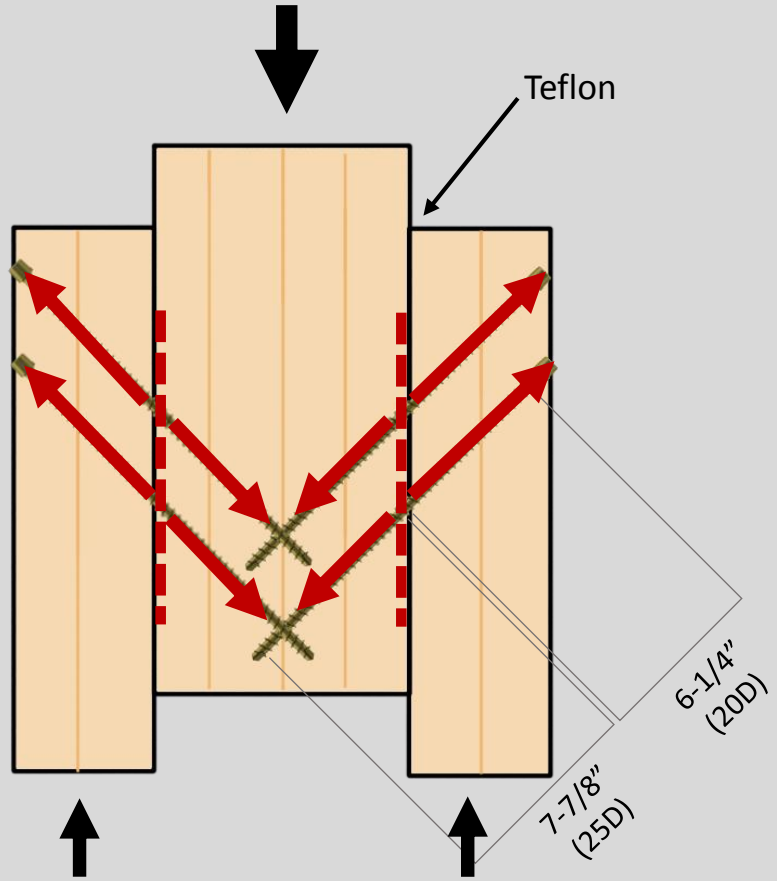


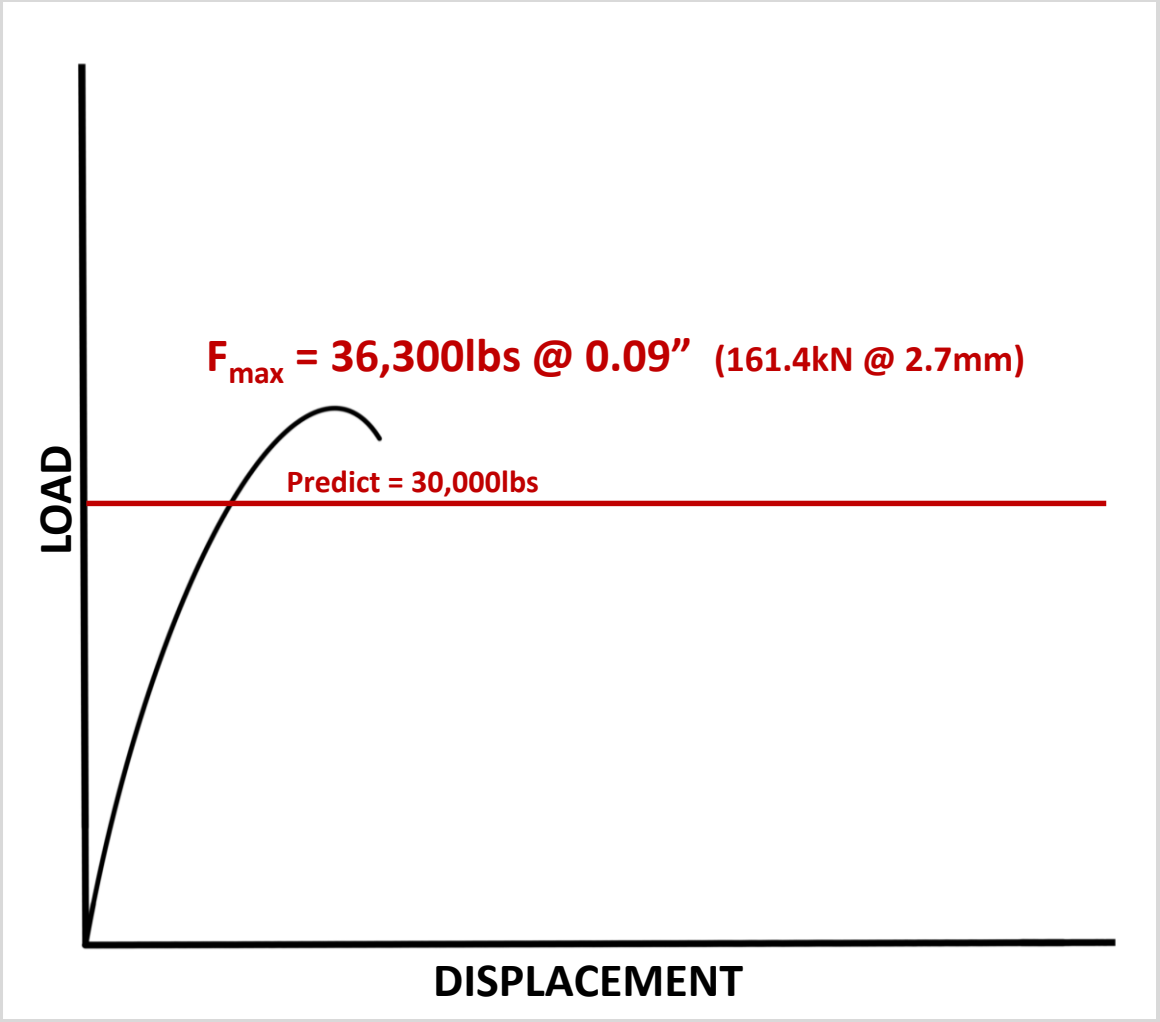


Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Simplified Truss Model

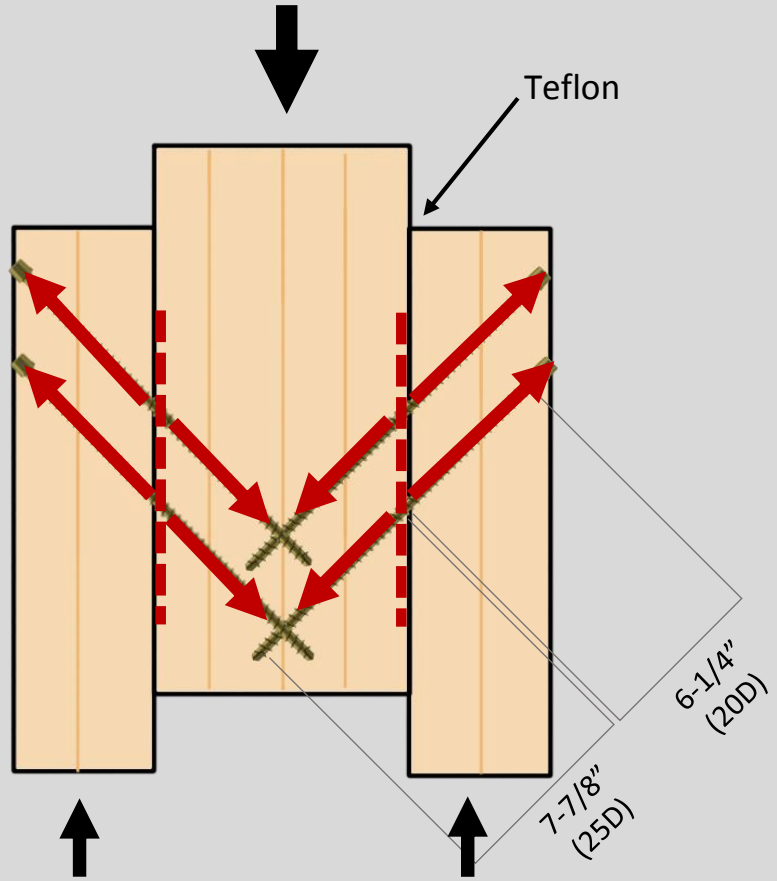


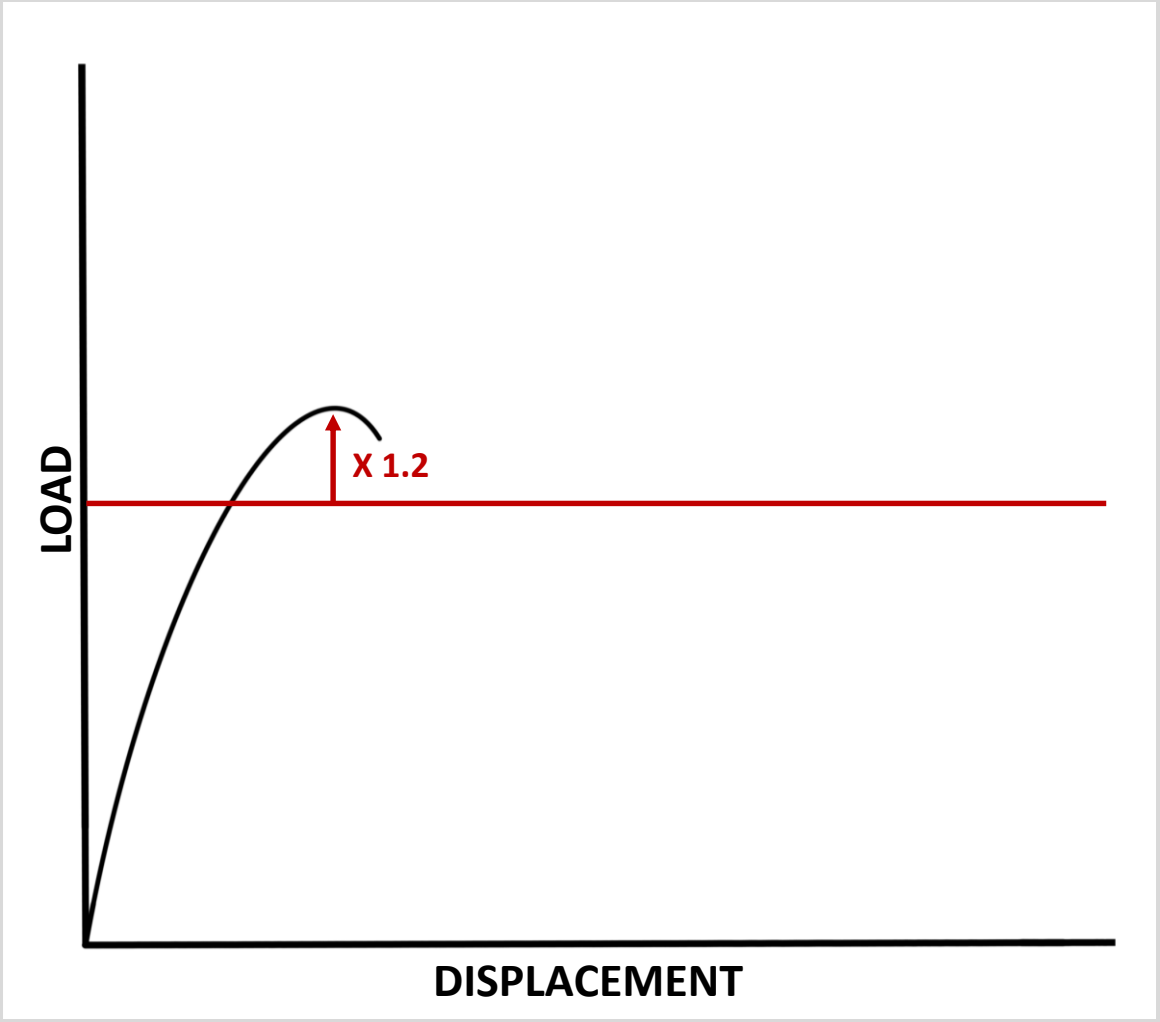


Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

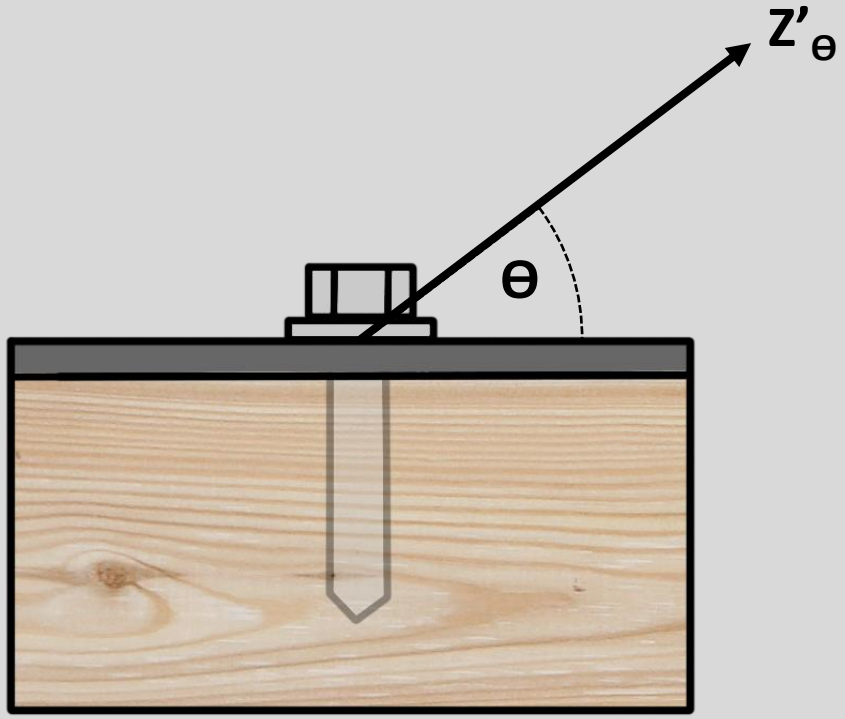
Simplified Truss Model





MyTiCon Timber Connectors

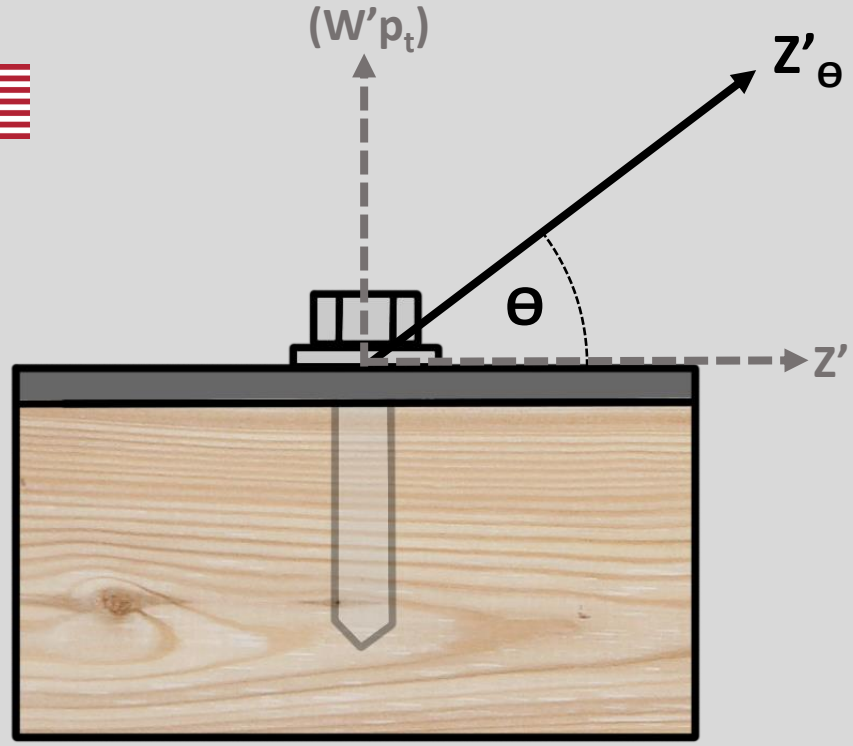
Combined Loading Equation



MyTiCon Timber Connectors

Combined Loading Equation

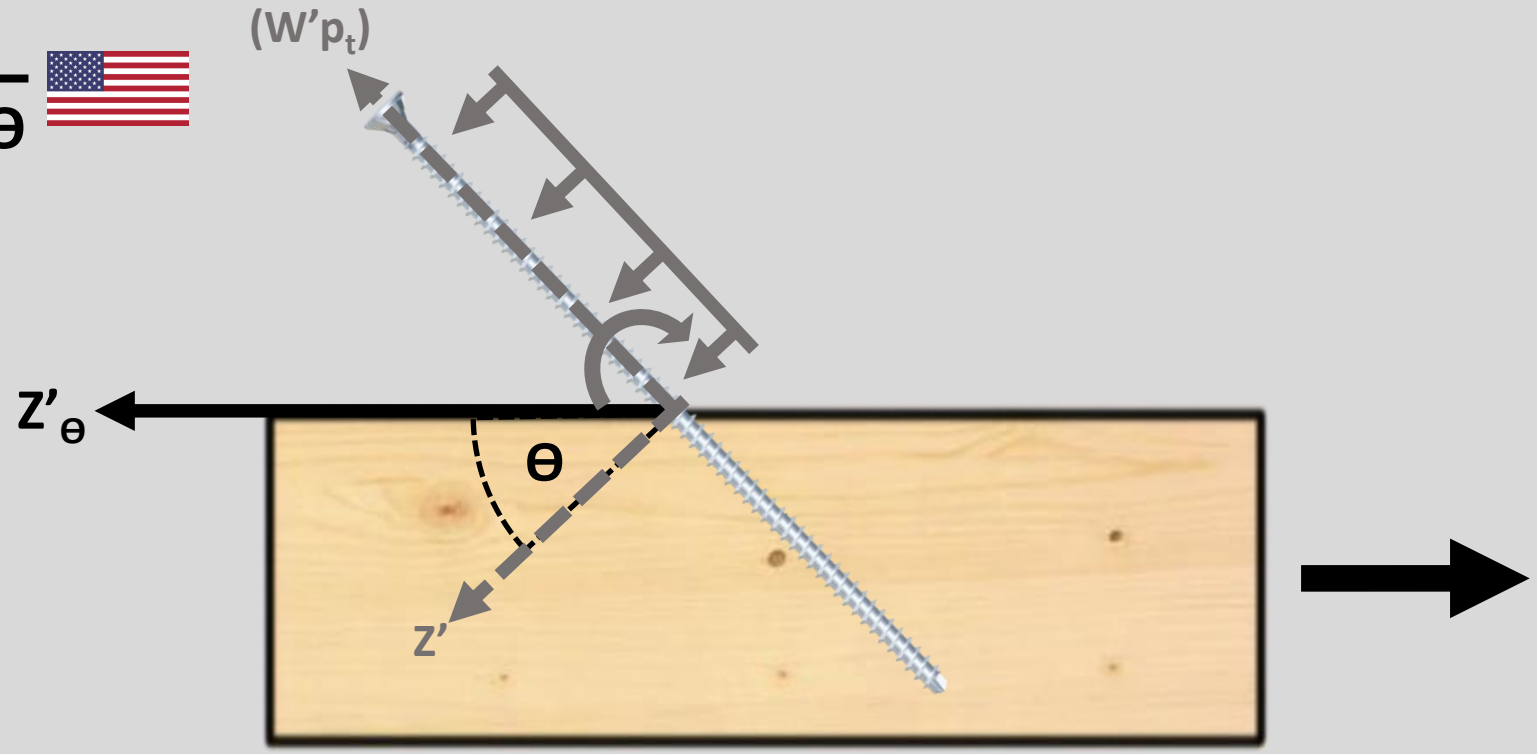
$$Z'_\Theta = \frac{(W'p_t)Z'}{(W'p_t)\cos^2\Theta + Z'\sin^2\Theta}$$



(McLain & Carroll, 1990)

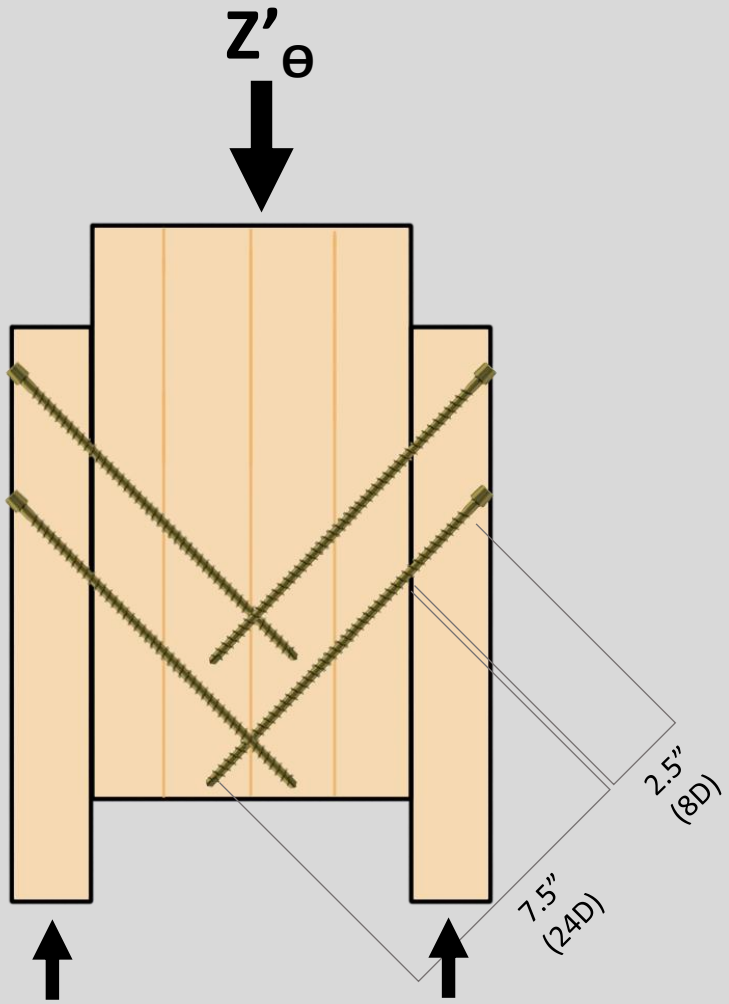
Combined Loading Equation

$$Z'_\theta = \frac{(W'p_t)Z'}{(W'p_t)\cos^2\Theta + Z'\sin^2\Theta}$$



MyTiCon Timber Connectors

Combined Loading Equation

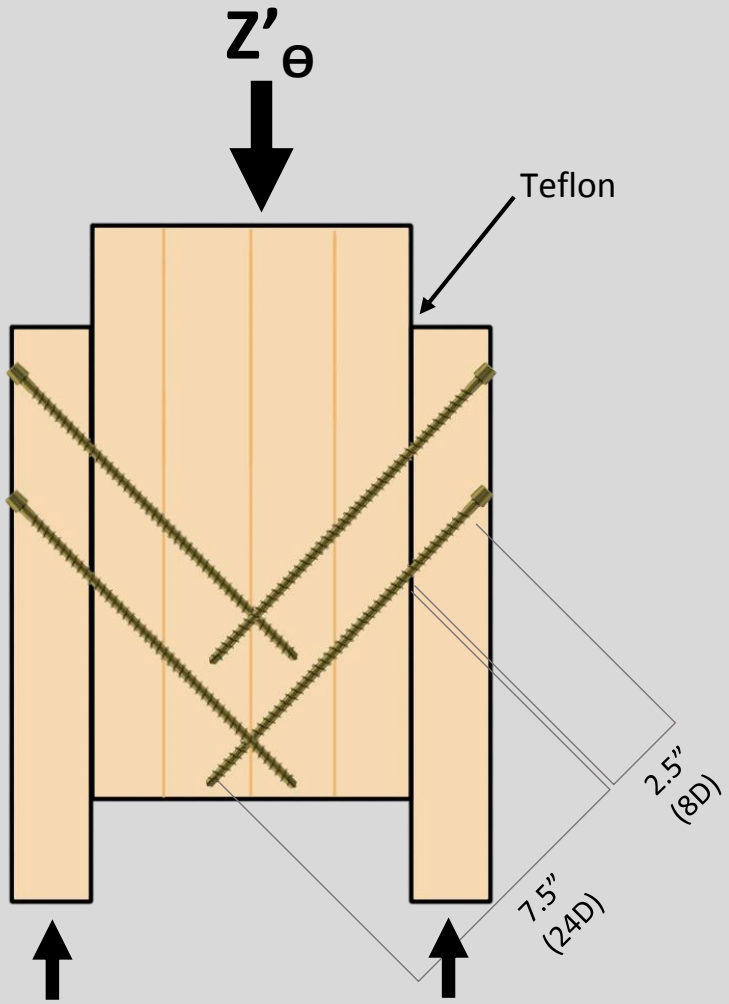


$(W'p_t)$ = 940 lb (per screw)

Z' = 400lb (per screw)

MyTiCon Timber Connectors

Combined Loading Equation



$(W'p_t)$ = 940 lb (per screw)

Z' = 400 lb (per screw)

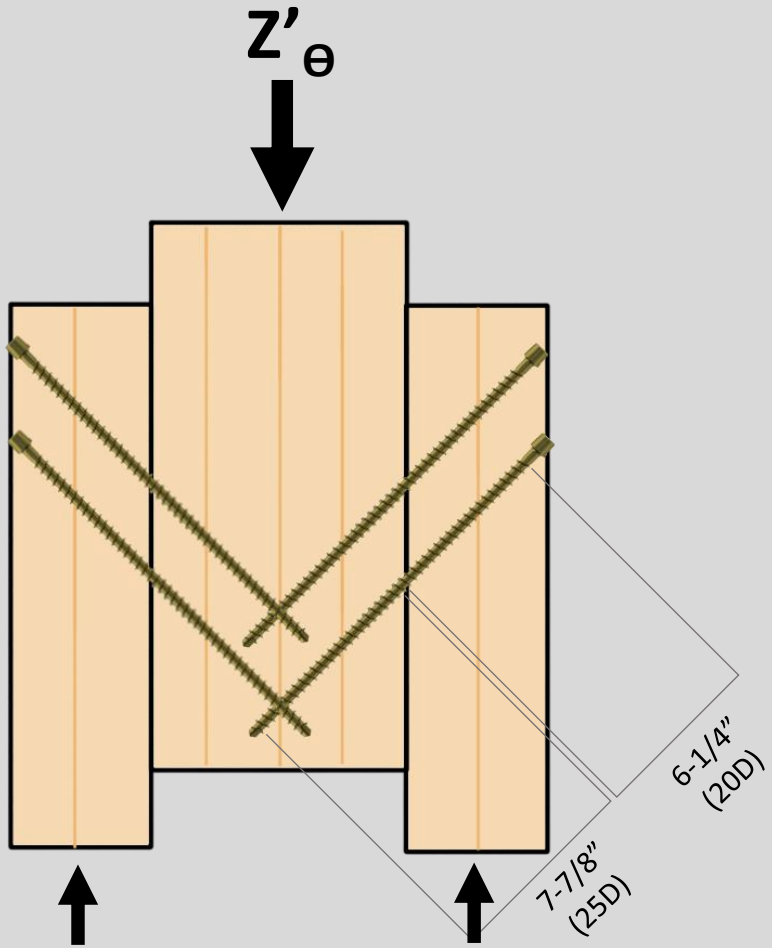
$(W'pt)/Z'$ = 2.4

Z'_θ = 4,600lbs

Truss Model Z' = 4,800lbs

MyTiCon Timber Connectors

Combined Loading Equation

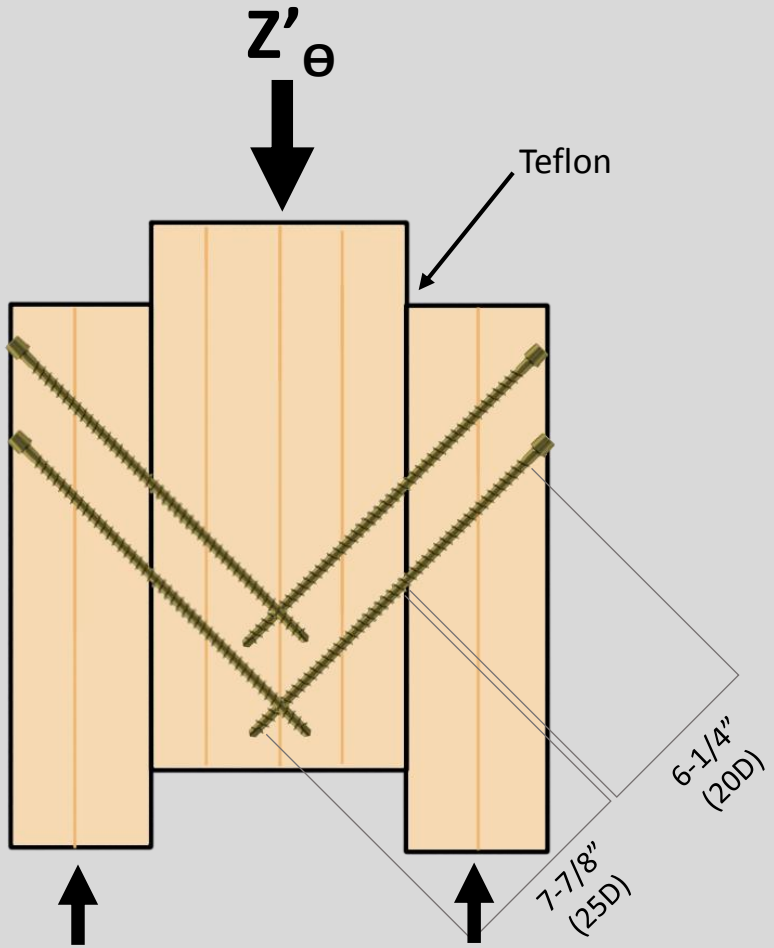


$(W'p_t)$ = 1,775 lb (T_a, per screw)

Z' = 400 lb (per screw)

MyTiCon Timber Connectors

Combined Loading Equation



$(W'p_t)$ = 1,775 lb (T_a, per screw)

Z' = 400 lb (per screw)

$(W'p_t)/Z'$ = 4.4

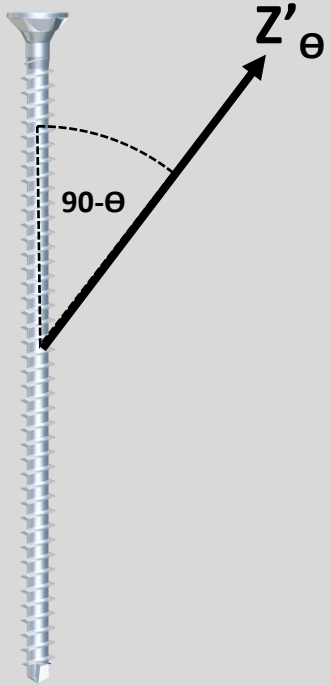
Z'_θ = 5,400 lb

Truss Model Z' = 9,000 lb

MyTiCon Timber Connectors

Combined Loading Equation

$$Z'_\theta = \frac{(W'p)Z'}{(W'p)\cos^2\theta + Z'\sin^2\theta}$$

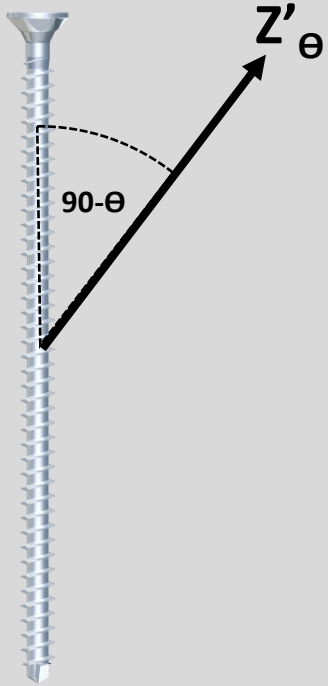


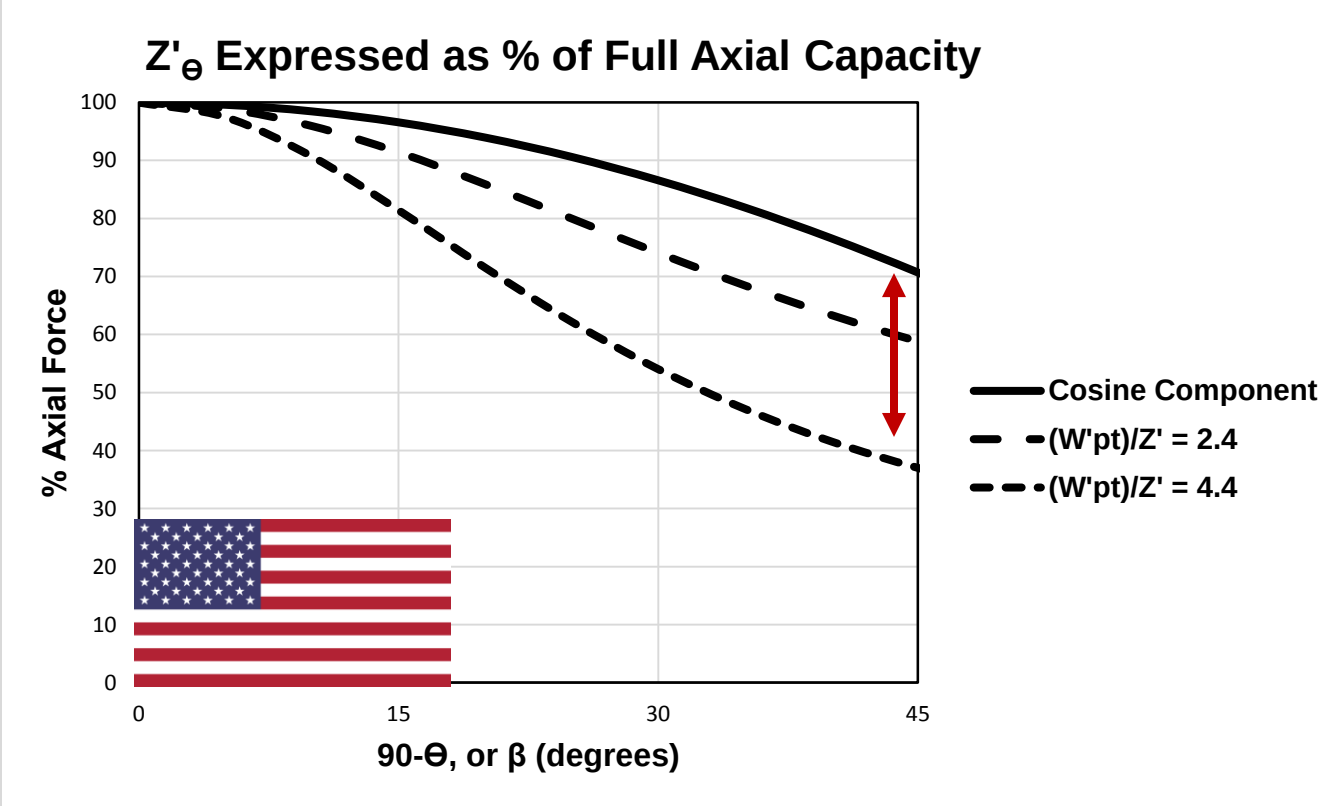
Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Combined Loading Equation

$$Z'_\theta = \frac{(W'p)Z'}{(W'p)\cos^2\Theta + Z'\sin^2\Theta}$$



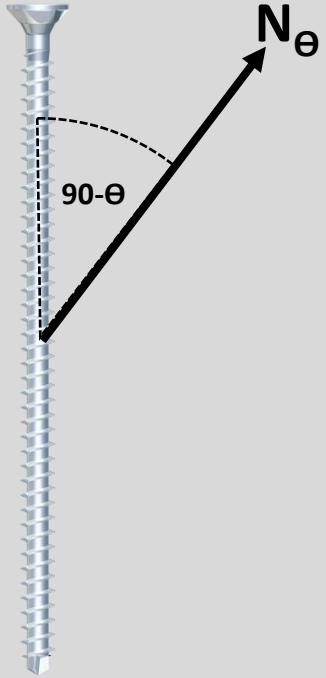


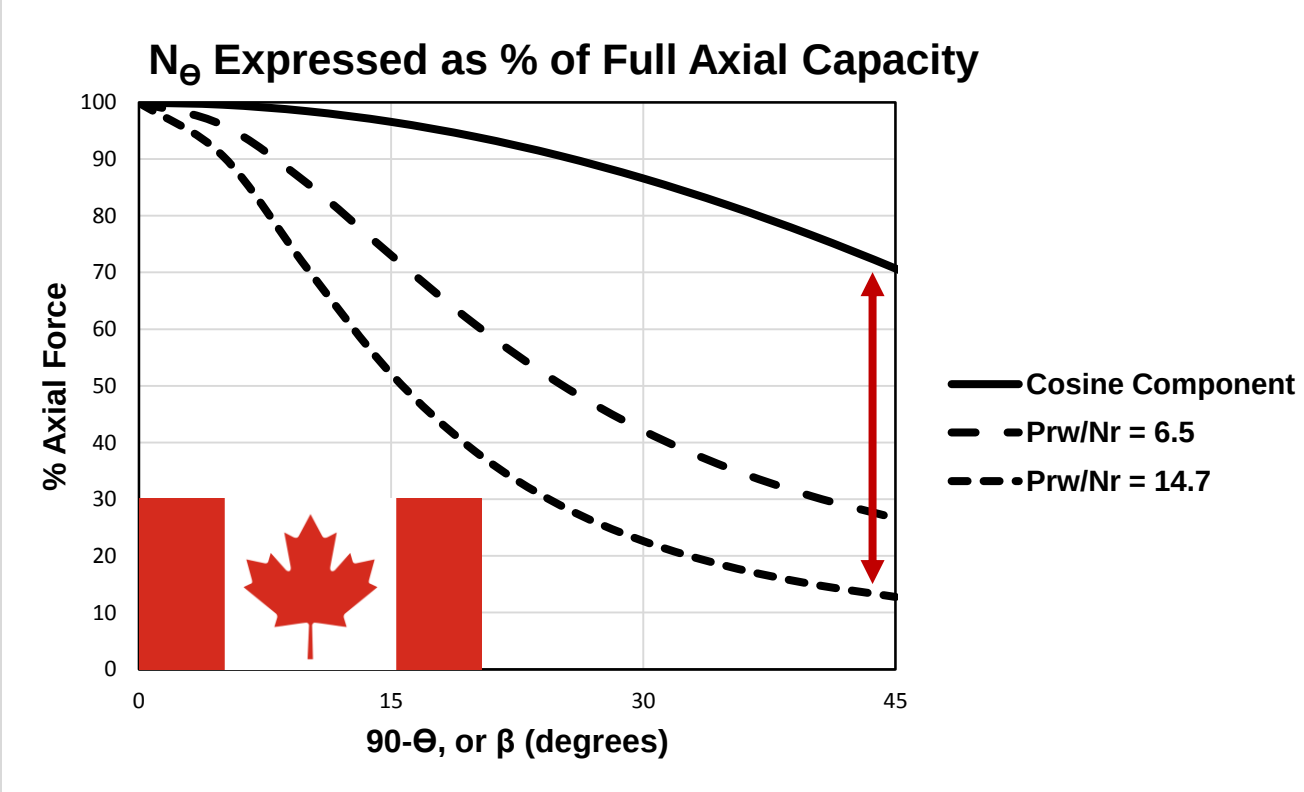
Advanced Theory and Behavior of Inclined Screws

MyTiCon Timber Connectors

Combined Loading Equation

$$N_\Theta = \frac{(P_{rw})N_r}{(P_{rw})\cos^2\Theta + N_r \sin^2\Theta}$$





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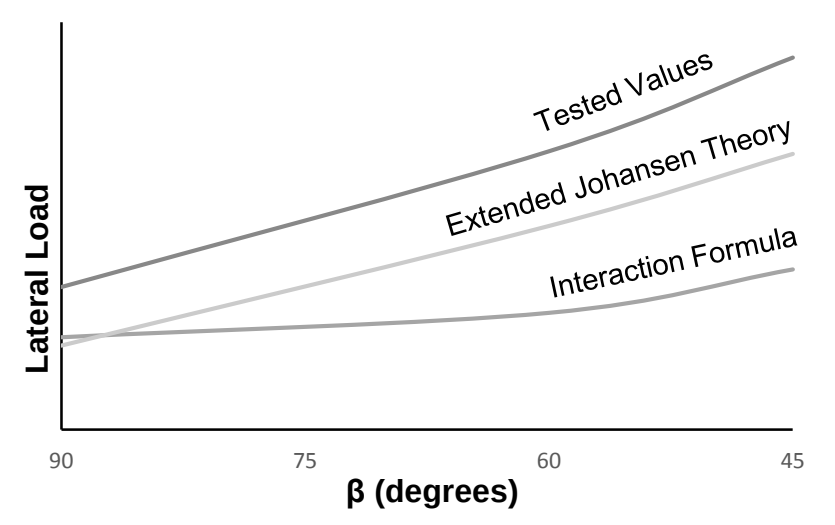
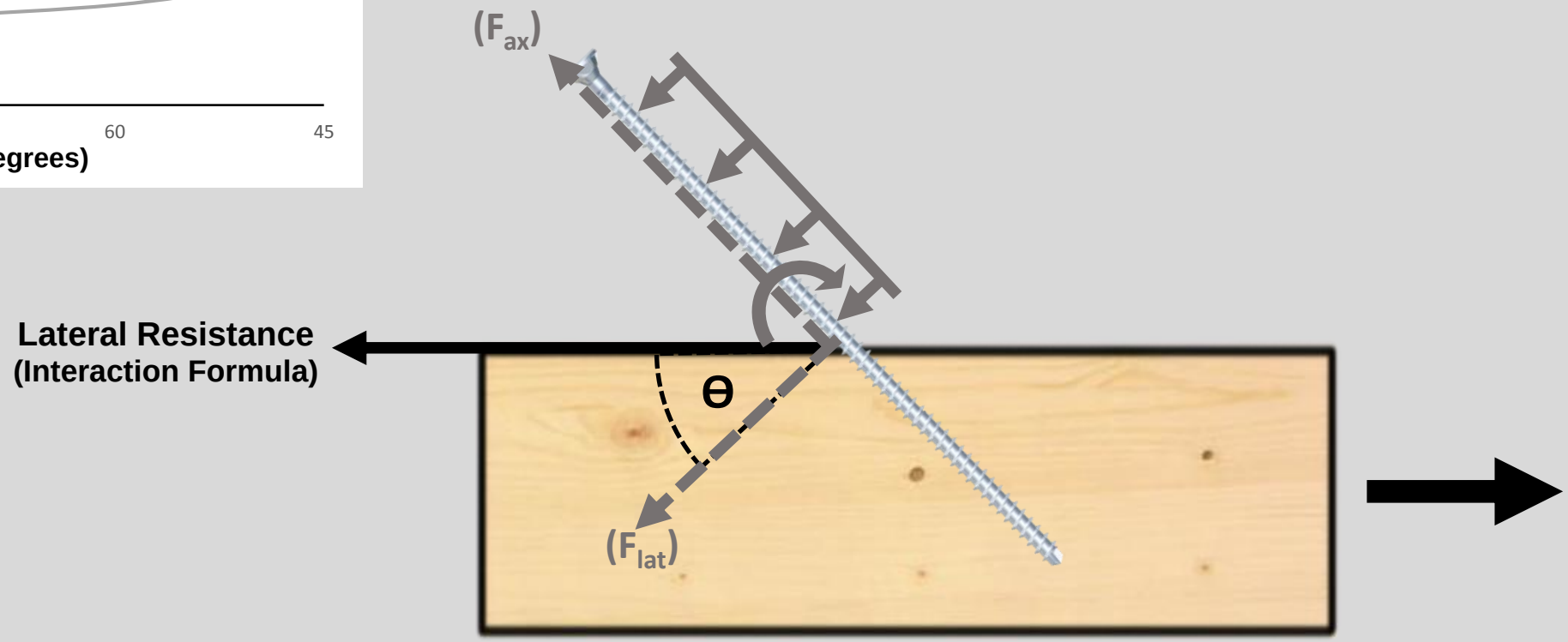


(Tomassi, Crosatti & Piazza, 2011)

$$\left(\frac{F_{axial,\,applied}}{F_{axial,\,design\,strength}}\right) + \left(\frac{F_{lateral,\,applied}}{F_{lateral,\,design\,strength}}\right) \leq 1.0$$



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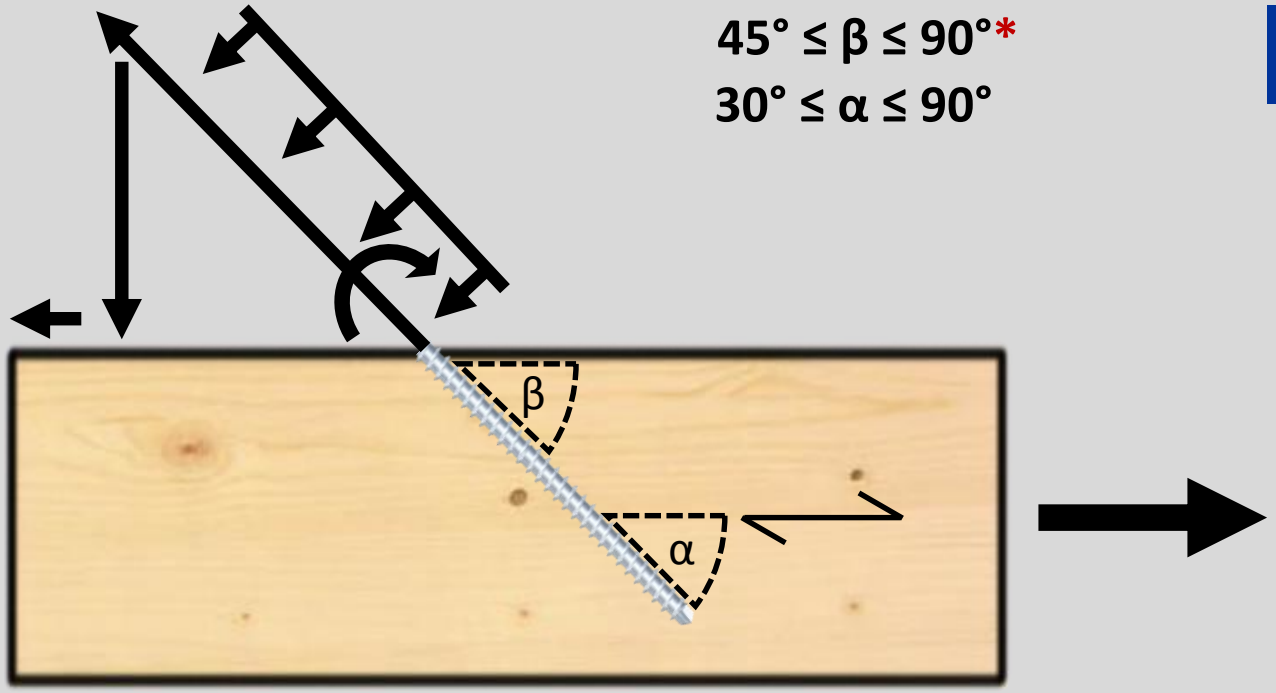
Extended Johansen Theory

Extended Johansen Yield Theory

45° ≤ β ≤ 90°*

30° ≤ α ≤ 90°



(Bejtka & Blass, 2002)

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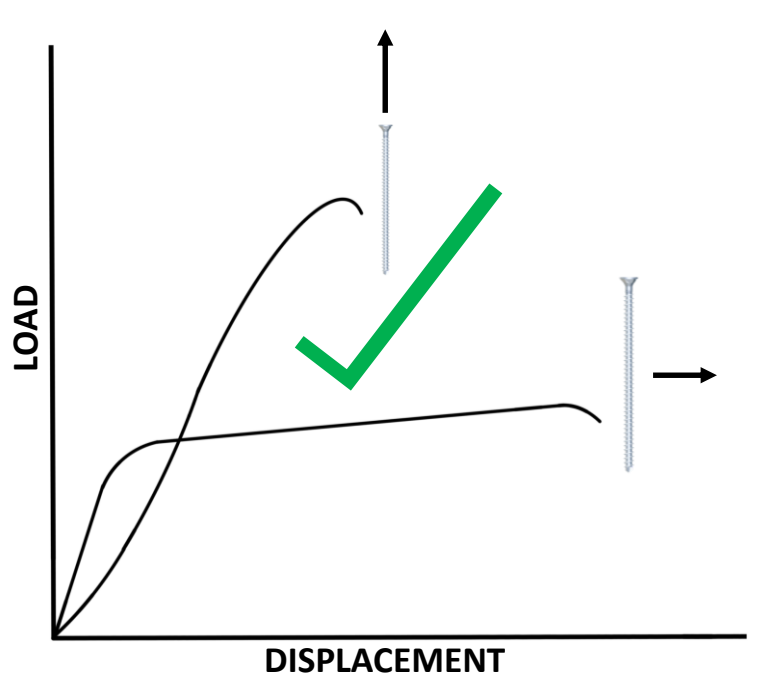
Extended Johansen Theory

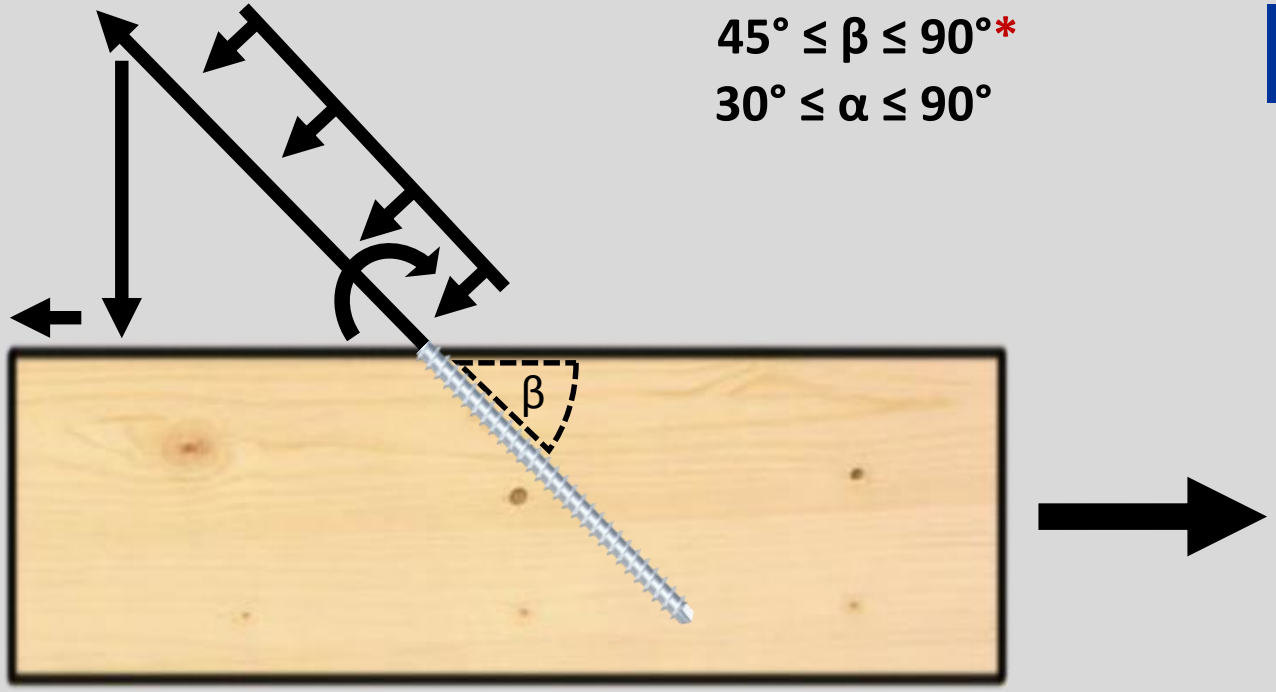


For illustrative purposes

Extended Johansen Yield Theory

45° ≤ β ≤ 90°*

30° ≤ α ≤ 90°



(Bejtka & Blass, 2001,2002), (Tomassi, Crosatti & Piazza, 2011)

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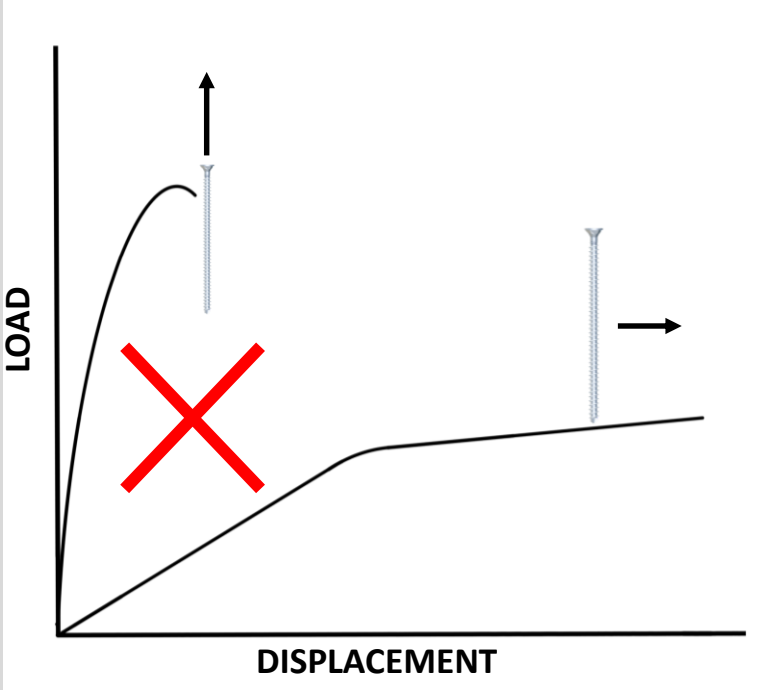
Extended Johansen Theory



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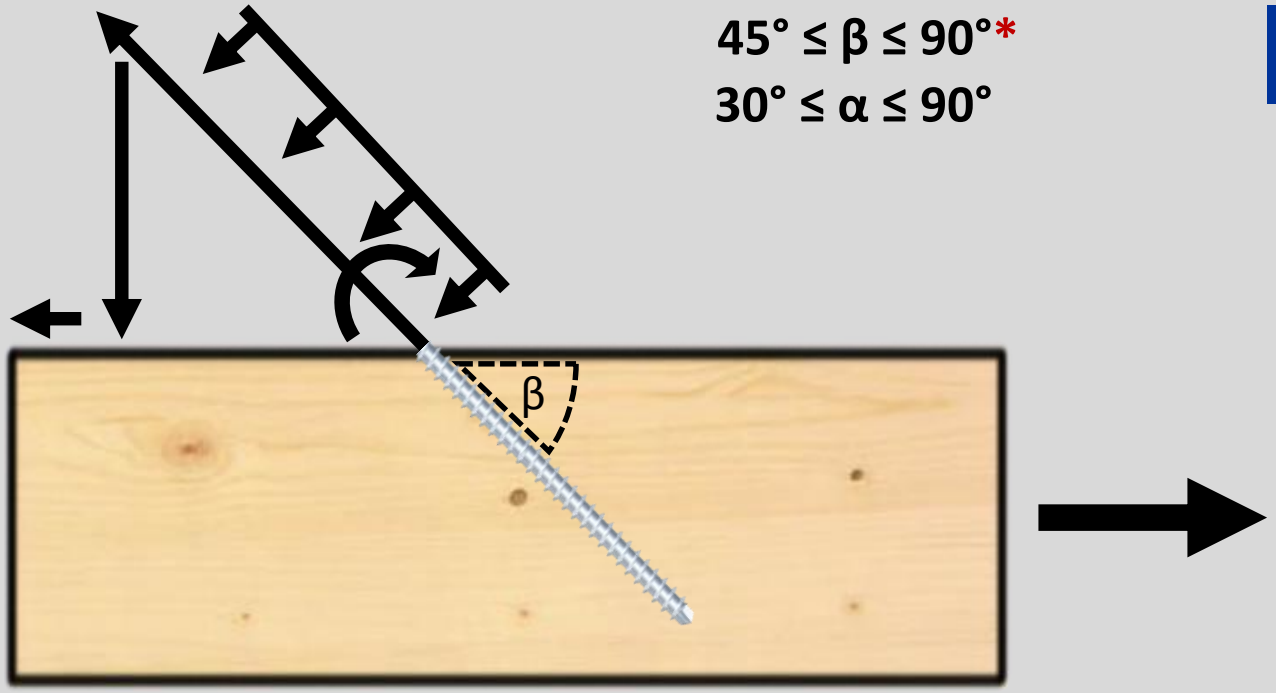

(Bejtka & Blass, 2001,2002), (Tomassi, Crosatti & Piazza, 2011)

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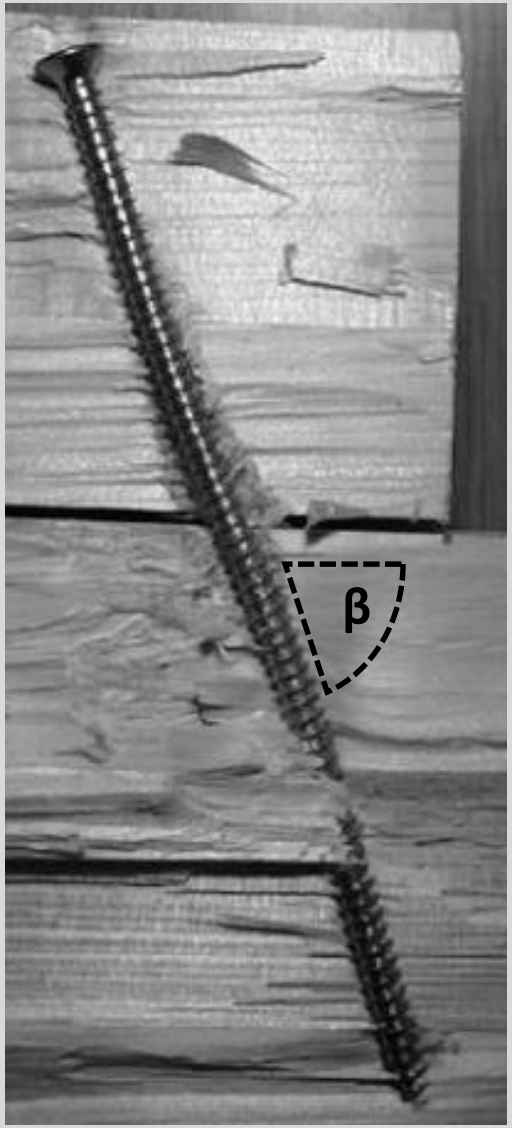
Extended Johansen Theory



(Image from Bejtka & Blass, 2002)

β = 75°

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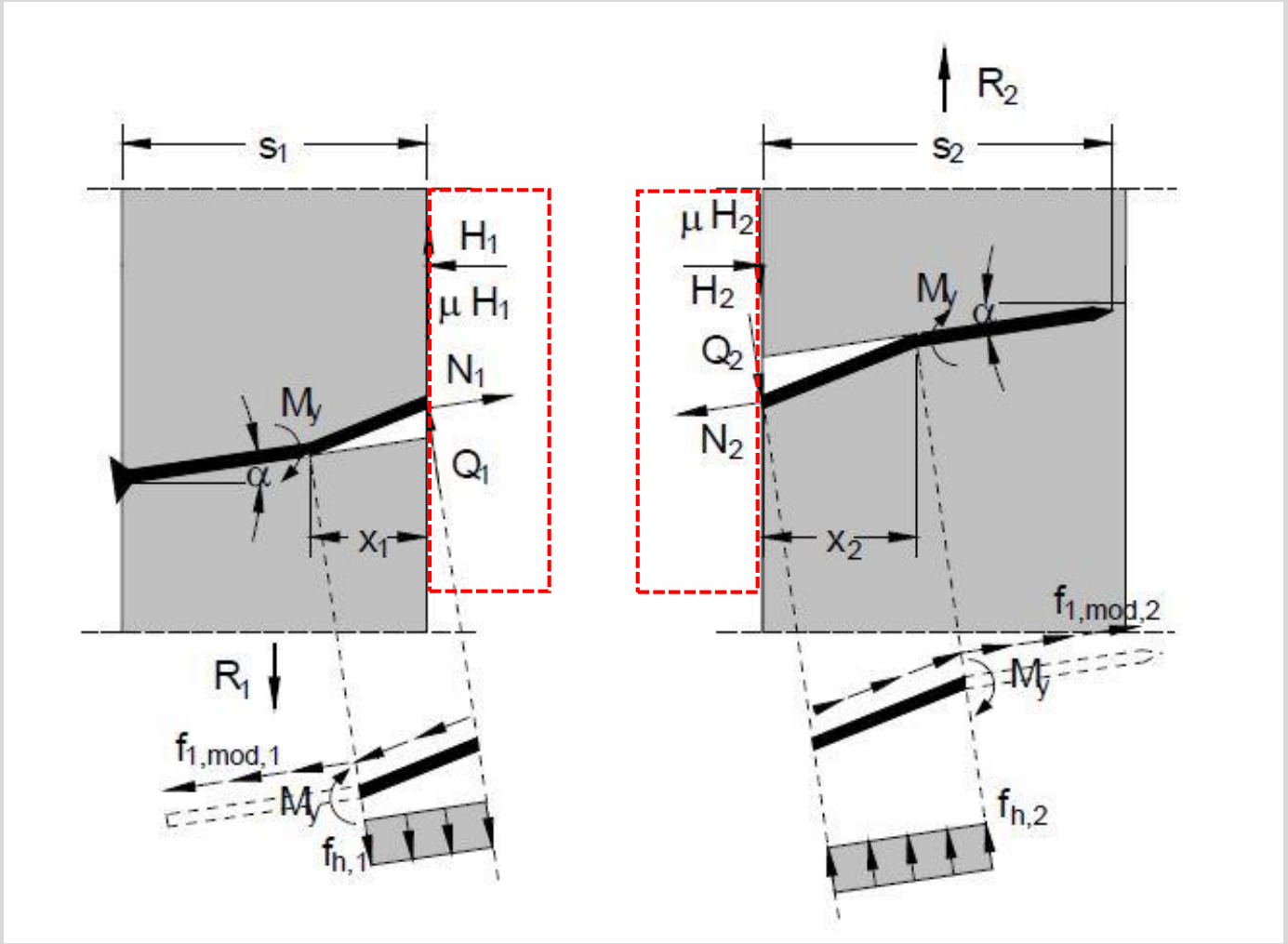

(Bejtka & Blass, 2002)

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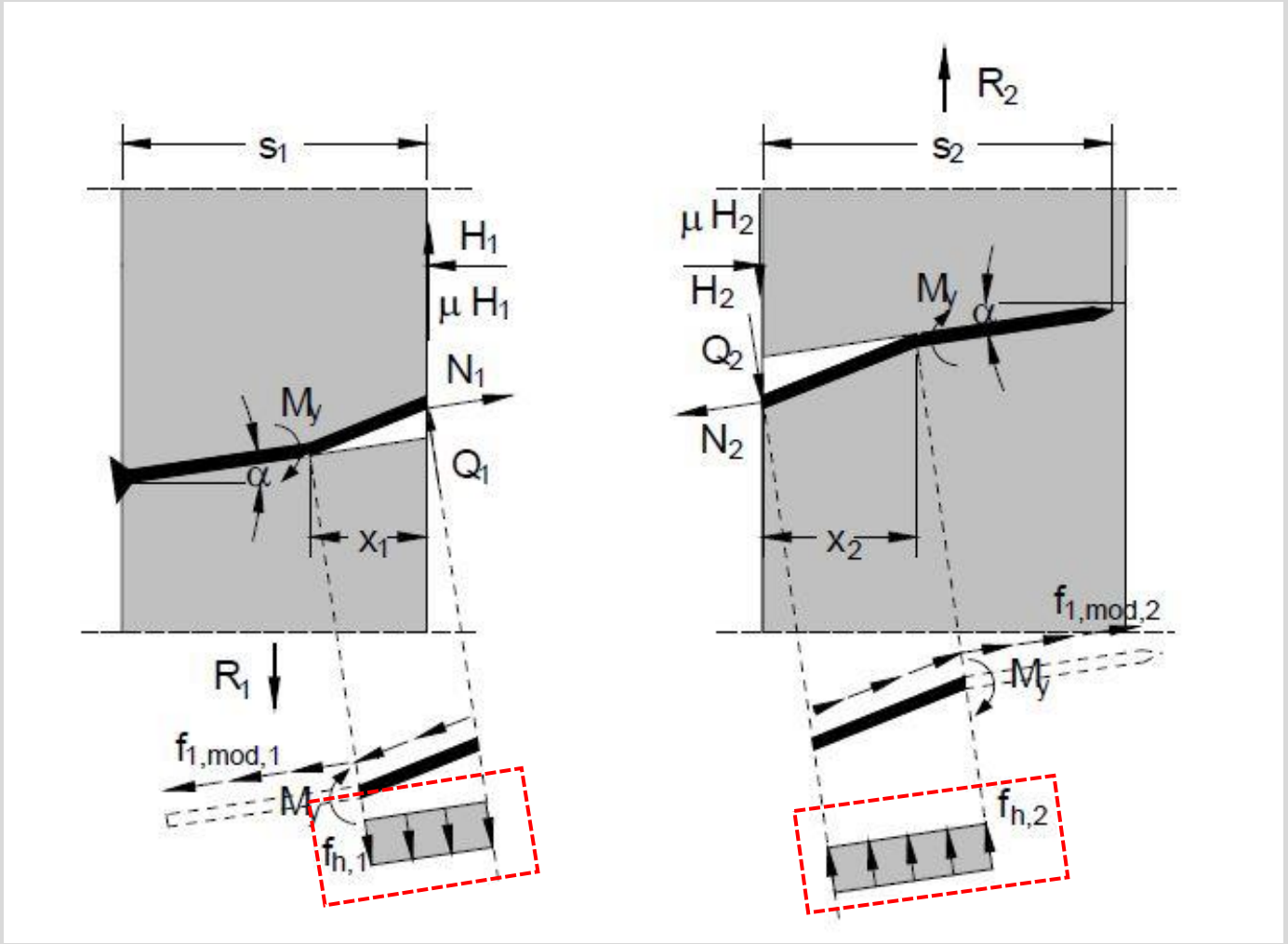
Extended Johansen Theory



(Bejtka & Blass, 2002)

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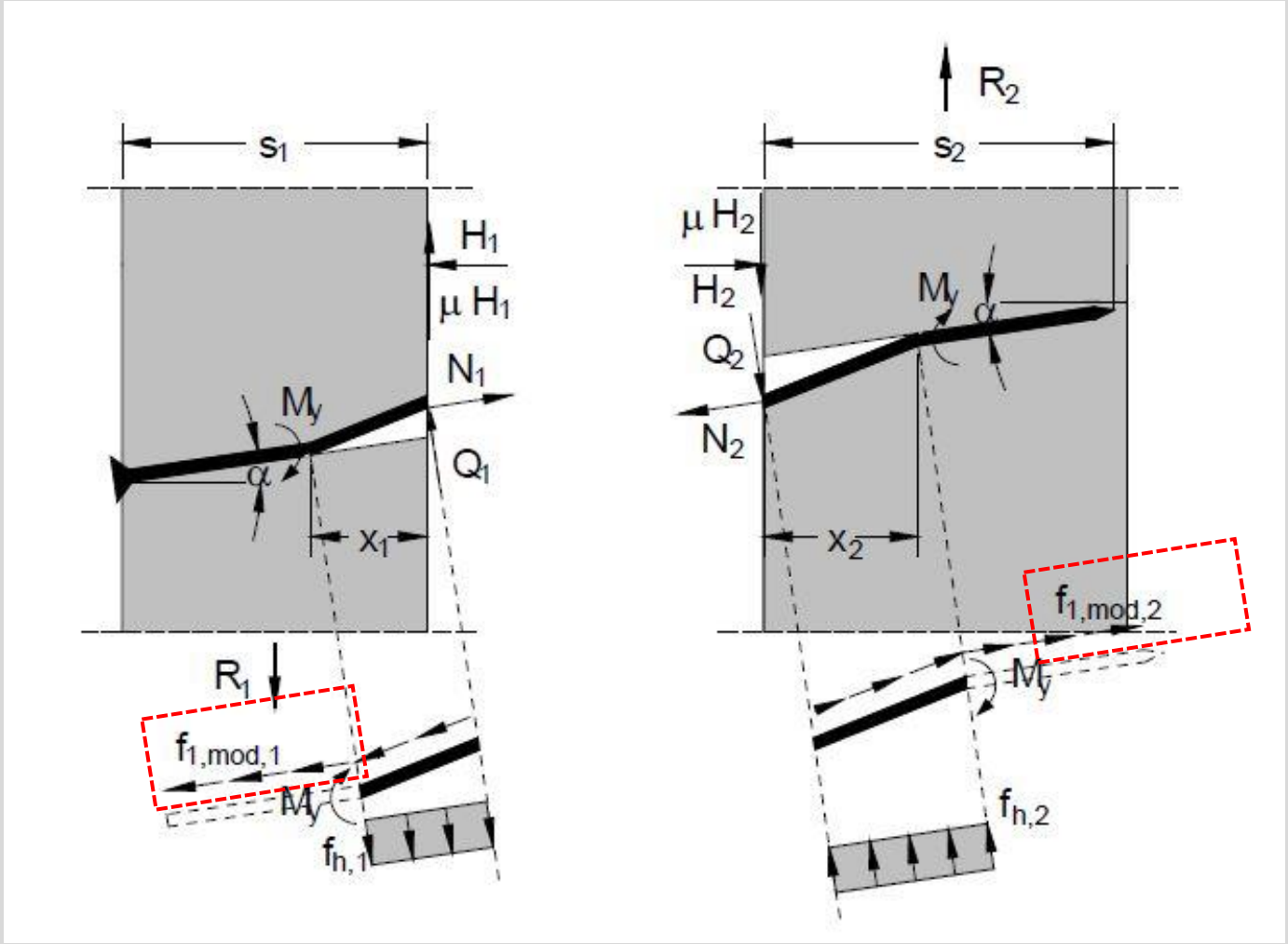
Extended Johansen Theory



(Bejtka & Blass, 2002)

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Extended Johansen Theory

$$R_a = R_{ax,k} \cdot \sin\alpha + f_{h,1,k} \cdot s_1 \cdot d \cdot \cos\alpha$$

$$R_b = R_{ax,k} \cdot \sin\alpha + f_{h,2,k} \cdot s_2 \cdot d \cdot \cos\alpha$$

$$R_c = R_{ax,k} \cdot (\mu \cdot \cos\alpha + sen\,\alpha) + \frac{f_{h,1,k} \cdot s_1 \cdot d}{1+\beta} \cdot (1 - \mu \cdot \tan\alpha) \cdot \left[\sqrt{\beta + 2 \cdot \beta^2 \cdot \left(1 + \frac{s_2}{s_1} + \left(\frac{s_2}{s_1}\right)^2\right) + \beta^3 \cdot \left(\frac{s_2}{s_1}\right)^2} - \beta \cdot \left(1 + \frac{s_2}{s_1}\right)\right]$$

$$R_d = R_{ax,k} \cdot (\mu \cdot \cos\alpha + sen\,\alpha) + \frac{f_{h,1,k} \cdot s_1 \cdot d}{2+\beta} \cdot (1 - \mu \cdot \tan\alpha) \cdot \left[\sqrt{2 \cdot \beta \cdot (1+\beta) + \left(\frac{4 \cdot \beta \cdot (2+\beta) \cdot M_{y,k}}{f_{h,1,k} \cdot d \cdot s_1^2}\right)} - \beta\right]$$

$$R_e = R_{ax,k} \cdot (\mu \cdot \cos\alpha + sen\,\alpha) + \frac{f_{h,1,k} \cdot s_2 \cdot d}{1+2 \cdot \beta} \cdot (1 - \mu \cdot \tan\alpha) \cdot \left[\sqrt{2 \cdot \beta^2 \cdot (1+\beta) + \left(\frac{4 \cdot \beta \cdot (1+2 \cdot \beta) \cdot M_{y,k}}{f_{h,1,k} \cdot d \cdot s_2^2}\right)} - \beta\right]$$

$$R_f = R_{ax,k} \cdot (\mu \cdot \cos\alpha + sen\,\alpha) + (1 - \mu \cdot \tan\alpha) \cdot \sqrt{\frac{2 \cdot \beta}{1+\beta}} \cdot \sqrt{2 \cdot M_{y,k} \cdot f_{h,1,k} \cdot d \cdot \cos^2\alpha}$$

(Bejtka & Blass, 2001,2002), (Tomassi, Crosatti & Piazza, 2011)

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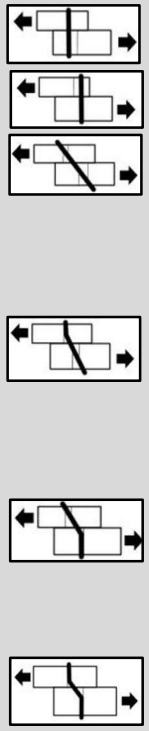
MyTiCon Timber Connectors

Extended Johansen Theory



I_s

I_m

II

III_s

III_m

IV

$$R_a = R_{ax,k} \cdot \sin\alpha + f_{h,1,k} \cdot s_1 \cdot d \cdot \cos\alpha$$

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(Bejtka & Blass, 2001,2002), (Tomassi, Crosatti & Piazza, 2011)

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Extended Johansen Theory

$$\text{Lateral Resistance} = R_{ax}\cdot(\cos\beta + \mu\cdot\sin\beta) + (1 - \mu\cdot\cot\beta)\cdot\sqrt{\left(\frac{2(f_{h2}/f_{h1})}{1+(f_{h2}/f_{h1})}\right)}\cdot\sqrt{(2\cdot M_y\cdot f_{h1}\cdot\sin^2\beta)}$$

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Extended Johansen Theory

$$\text{Lateral Resistance} = R_{ax}\cdot(\cos\beta + \mu\cdot\sin\beta) + (1 - \mu\cdot\cot\beta)\cdot\sqrt{\frac{2(f_{h2}/f_{h1})}{1+(f_{h2}/f_{h1})}}\cdot\sqrt{(2\cdot M_y\cdot f_{h1}\cdot\sin^2\beta)}$$

1

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Extended Johansen Theory

$$\text{Lateral Resistance} = R_{ax}\cdot(\cos\beta + \mu\cdot\sin\beta) + (1 - \mu\cdot\cot\beta)\cdot \sqrt{(2\cdot M_y\cdot f_{h1}\cdot\sin^2\beta)}$$

(see also Jockwer, Stieger & Frangi, 2014).

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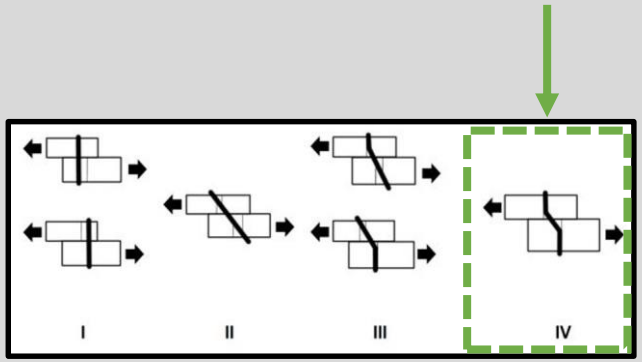
Extended Johansen Theory

$$\text{Lateral Resistance} = R_{ax}\cdot(\cos\beta + \mu\cdot\sin\beta) + (1 - \mu\cdot\cot\beta)\cdot\sqrt{(2\cdot M_y\cdot f_{h1}\cdot\sin^2\beta)}$$

$$\text{Lateral Resistance} = \begin{cases} \min[(W_\alpha' p_t), (T_a)]\cdot(\cos\beta + \mu\cdot\sin\beta) \\ \min[(P_{rw}), (\varphi T)]\cdot(\cos\beta + \mu\cdot\sin\beta) \end{cases}$$

Extended Johansen Theory

$$\text{Lateral Resistance} = R_{ax}\cdot(\cos\beta + \mu\cdot\sin\beta) + (1 - \mu\cdot\cot\beta)\cdot\sqrt{(2\cdot M_y\cdot f_{h1}\cdot\sin^2\beta)}$$



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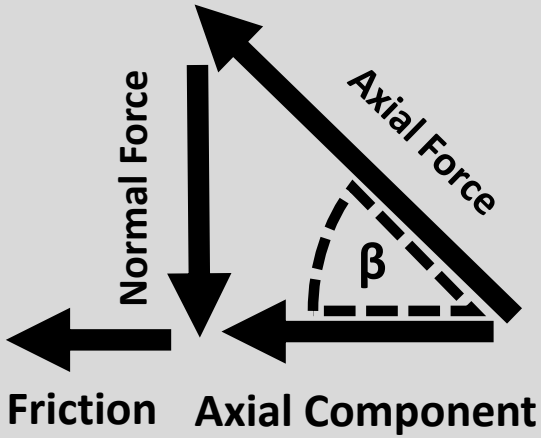
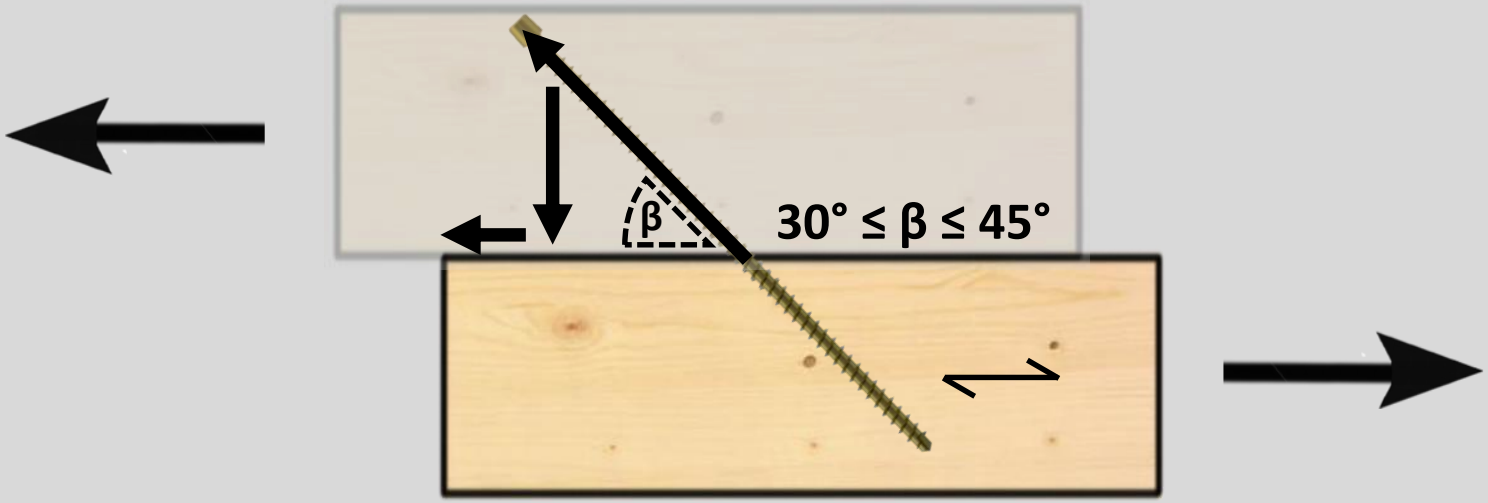
D (inches)	p_t	β	Lateral Resistance % Axial	Lateral Resistance % Johansen
5/16	8D	45	73	27
5/16	12D	45	80	20
5/16	16D	45	85	15
5/16	20D	45	87	13

Advanced Theory and Behavior of Inclined Screws

SUMMARY





-Truss Model easiest to adapt to North American Codes (use North American approved withdrawal and tensile resistances) and also most widely used in Europe

-Truss model increasingly accurate with angles approaching 30°

-Truss model increasingly accurate with long thread penetration lengths

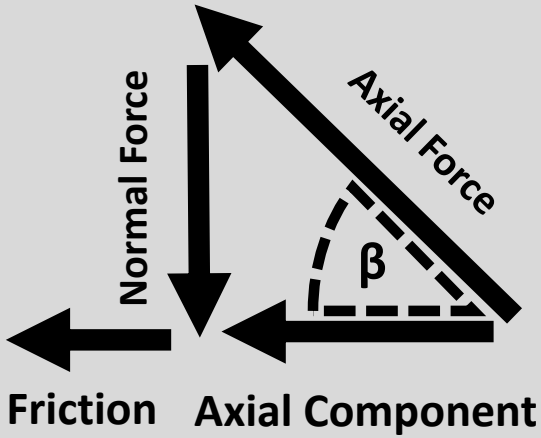
-Combined Loading Equation too conservative, especially for large ratios of axial/lateral capacities

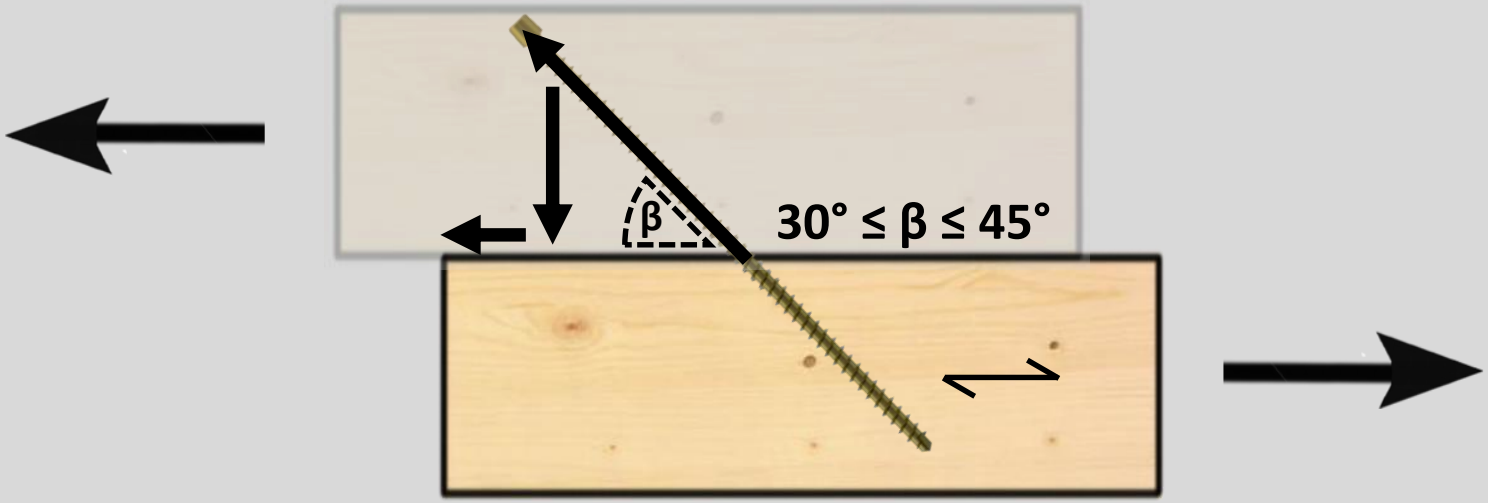
-Extended Johansen Theory can be simplified with boundary conditions concerning minimum penetration length-however, this model has not been assessed using North American design parameters-further research recommended, especially for angles below 45° and above 60°.

-ICC approval for truss model design process in the works

Advanced Theory and Behavior of Inclined Screws

SUMMARY





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