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# DESIGN EQUATIONS FOR DOWEL EMBEDMENT STRENGTH AND WITHDRAWAL RESISTANCE FOR THREADED FASTENERS IN CLT


| | | |
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| | Mohammad | MOHAMMAD |


# PRESENTATION PLAN

- 1. INTRODUCTION
  - 1.1 MOTIVATION
  - 1.2 BACKGROUND
  - 1.3 OBJECTIVE
- 2. MATERIALS
- 3. METHODOLOGY
- 4. ANALYSIS
- 5. WITHDRAWAL
- 6. EMBEDMENT
- 7. CONCLUSION

# 1. INTRODUCTION

## 1.1 MOTIVATION

- CLT PRODUCTS PRESENT A GOOD DEVELOPMENT IN EUROPE
- IN CANADA CLT IS LAGGING BEHIND
  - IN PARTICULAR, ABSENCE OF DESIGN EQUATIONS FOR FASTENERS IN THE CANADIAN WOOD DESIGN STANDARD (CSA O86)
- TIMBER CONSTRUCTION IS GROWING IN POPULARITY
- MIDRISE AND HIGHRISE BUILDINGS
- HIGHRISE BUILDINGS = HIGH FORCES IN THE STRUCTURE

# 1. INTRODUCTION

## 1.2 BACKGROUND - WITHDRAWAL

### SAWN TIMBER & GLULAM

TWO DIFFERENT WITHDRAWAL EQUATIONS IN CSA O86-09

- Wood Screws

$$P_{rw} = \phi y_w L_{pt} n_F$$

where $y_w = 68\ d_F^{0.82}\ G_0^{1.77}$

- Lag Screws

$$P_{rw} = \phi y_w L_{pt} n_F$$

**Table 10.6.5.1**
**Basic withdrawal resistance for lag screws, $y_w$, N/mm**

| | Shank diameter, in | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Species group | 1/4 | 5/16 | 3/8 | 7/16 | 1/2 | 5/8 | 3/4 | 7/8 | 1 |
| Douglas Fir-Larch | 74 | 97 | 120 | 140 | 170 | 200 | 240 | 280 | 310 |
| Hem-Fir | 37 | 55 | 70 | 86 | 100 | 130 | 150 | 180 | 200 |
| Spruce-Pine-Fir | 31 | 42 | 61 | 75 | 91 | 120 | 140 | 170 | 190 |
| Northern Species | 27 | 42 | 58 | 70 | 84 | 110 | 130 | 150 | 180 |

### CLT

RESEARCH BY UIBEL AND BLASS (2007)

- EN 1382 (1999) Equation for Self-Drilling Screws in CLT

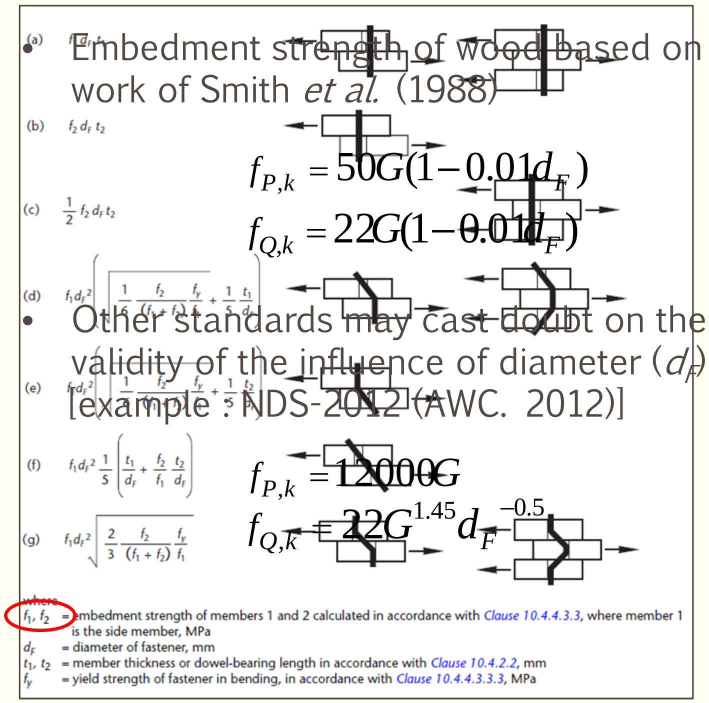
$$R_{ax,s,k} = \frac{0.35 \cdot d_F^{0.8} \cdot L_t^{0.9} \cdot \rho_k^{0.75}}{1.5 \cdot \cos^2\theta + \sin^2\theta}$$

# 1. INTRODUCTION

## 1.2 BACKGROUND - EMBEDMENT

### SAWN TIMBER & GLULAM

- European yield model




- Embedment strength of wood based on the work of Smith *et al.* (1988)

$$f_{P,k} = 50G(1-0.01d_F)$$

$$f_{Q,k} = 22G(1-0.01d_F)$$

- Other standards may cast doubt on the validity of the influence of diameter ($d_F$) [example : NDS-2012 (AWC. 2012)]

$$f_{P,k} = 12000G$$

$$f_{Q,k} = 22G^{1.45}d_F^{-0.5}$$

### CLT

RESEARCH BY UIBEL & BLASS (2006)

- EN (2006) CLT dowel embedment equation

$$f_{\theta,k} = \frac{0.31\rho_k^{1.16}(1-0.015d_F)}{1.1\sin^2\theta + \cos^2\theta}$$

# 1. INTRODUCTION

## 1.3 OBJECTIVE

- VALIDATE OR DEVELOP DESIGN EQUATIONS FOR WITHDRAWAL RESISTANCE AND EMBEDMENT STRENGTH OF FASTENERS IN CANADIAN MADE CLT

# 2. MATERIALS

## 2.1 FASTENERS UNDER STUDY

- LAG SCREWS

- SELF-DRILLING SCREWS (self-tapping screws)

- BOLTS

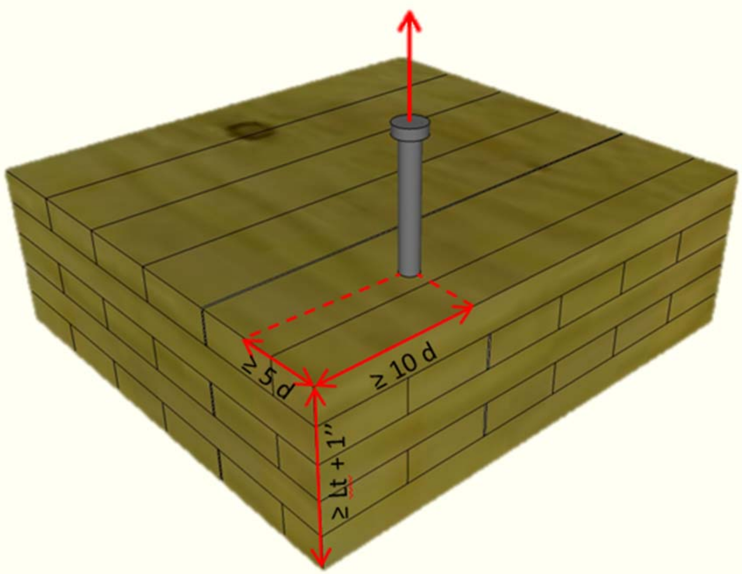
## 2.2 WOOD PRODUCT UNDER STUDY

- CLT: FROM TWO CANADIAN SUPPLIERS
- SPECIES: SPF (Spruce-Pine-Fir)

# 3. METHODOLOGY

## 3.1 WITHDRAWAL

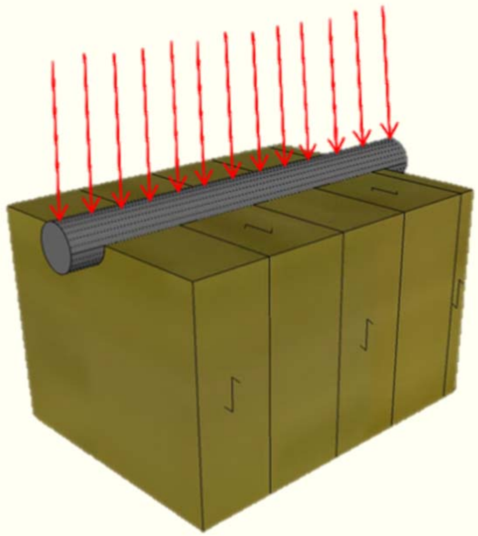
- STANDARD EN 1382
- INSERTION PERPENDICULAR
- LARGE DIAMETER FASTENERS ($d_F \geq$ 6mm)
- TWO LENGTH OF PENETRATION/DIAMETER
- END DISTANCE = $10d_F$
- EDGE DISTANCE = $5d_F$
- LEAD HOLE = $0.7d_F$
- STANDARD TEST CONDITIONS
  65% ± 5% HR AND 20 °C ± 3 °C
- N = 10 REP. PER SERIES
- TOTAL TESTS = 360 (lag screws)
  = 120 (self-drilling screws)



# 3. METHODOLOGY

## 3.2 EMBEDMENT

- ASTM D5764 HALF-HOLE TESTS METHOD
- EMBEDMENT OF THE THREADED AND NON-THREADED PORTIONS
- LARGE DIAMETER FASTENERS ($d_F \geq$ 6mm)
- TWO LENGTH OF EMBEDMENT
- LOAD APPLIED AT 0°, 45° AND 90° TO THE GRAIN
- STANDARD TEST CONDITIONS
  65% ± 5% HR AND 20 °C ± 3 °C
- N = 10 REP. PER SERIES
- TOTAL TESTS = 720 (lag screws)
  = 360 (self-drilling screws)



# 4. ANALYSIS OF EXPERIMENTAL DATA

- WITHDRAWAL

- EMBEDMENT

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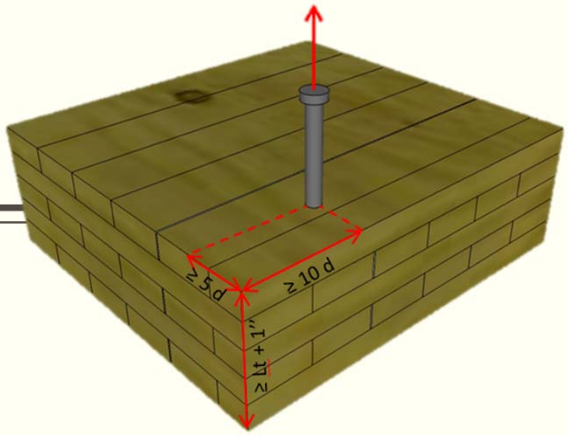
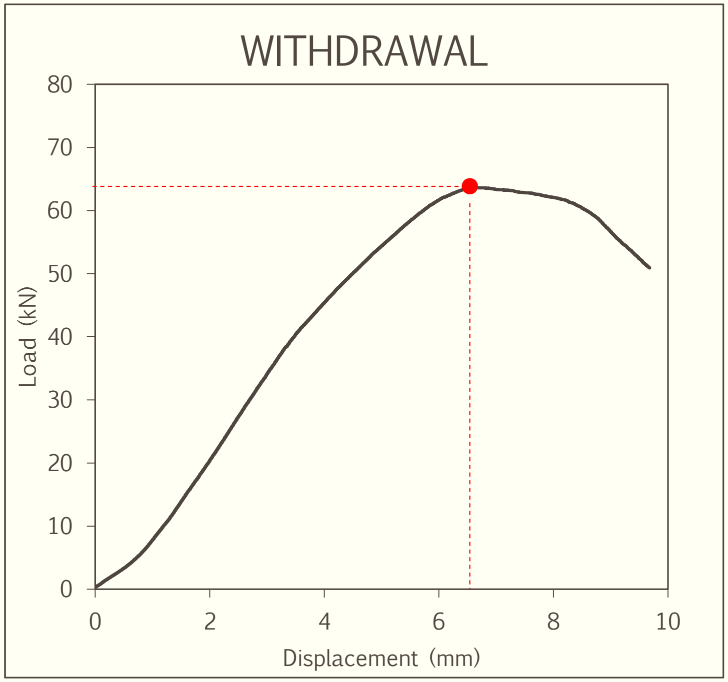



- WITHDRAWAL → Peak Load (kN)
  → Displacement at Peak Load (mm)

- EMBEDMENT



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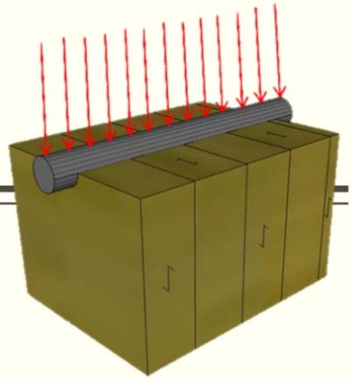
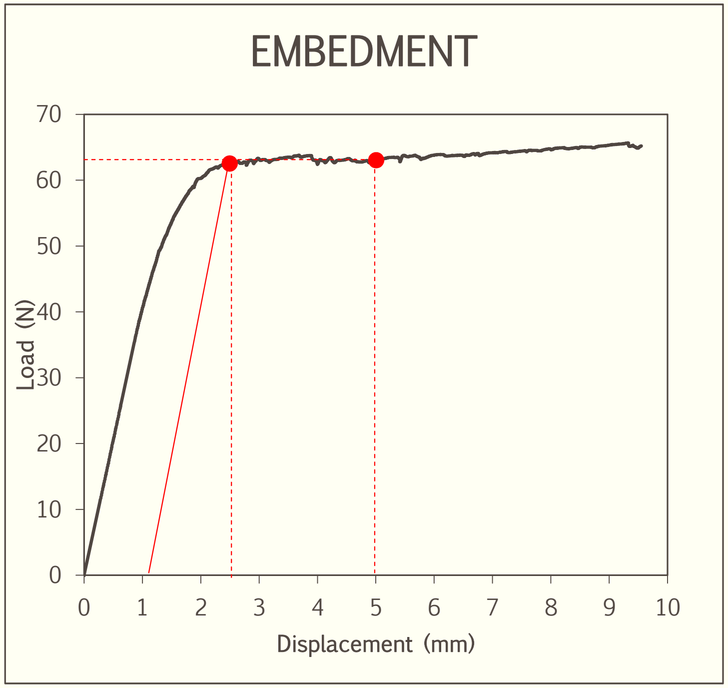


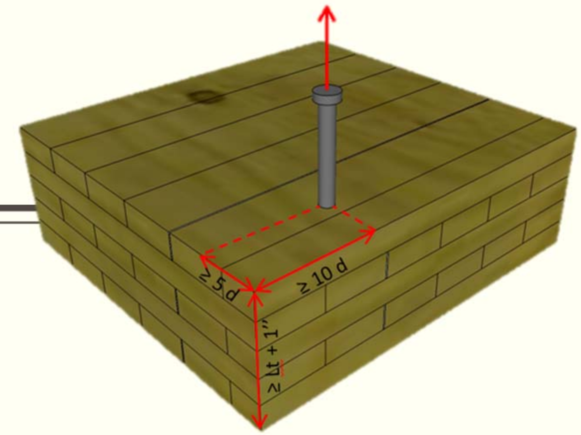
- WITHDRAWAL
  - ⟶ Peak Load (kN)
  - ⟶ Displacement at Peak Load (mm)

- EMBEDMENT
  - ⟶ Peak load (kN)
  - ⟶ Displacement at peak load (mm)
  - ⟶ 5% diameter offset load ($P_y$) (kN)
  - ⟶ Displacement at 5% diameter offset load (mm)

$$f_i = \frac{P_y}{l \cdot d}$$

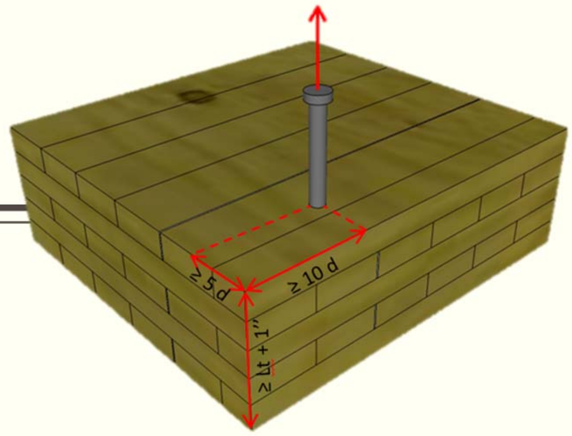


# 5. WITHDRAWAL




- CSA O86-09 (2009) EQ. WS
  - $P_{rw,\ avg} = 112\ d_F^{0.82}\ G_0^{1.77}\ L_t$
  - $P_{rw} = 59\ d_F^{0.82}\ G^{1.77}\ L_t$
- NDS (AWC 2012) EQ. LS
  - $P_{rw,\ avg} = 116\ d_F^{0.75}\ G_0^{1.5}\ L_t$
  - $P_{rw} = 62\ d_F^{0.75}\ G^{1.5}\ L_t$
- NDS (AWC 2012) EQ. WS
  - $P_{rw,\ avg} = 98\ d_F\ G_0^{2}\ L_t$
  - $P_{rw} = 52\ d_F\ G^{2}\ L_t$
- EN 1382 (1999) EQ. SDS IN CLT
  - $P_{rw,\ avg} = 62\ d_F^{\ 0.8}\ \rho_{12}^{\ 0.75}\ L_t^{0.9}$
  - $P_{rw} = 37\ d_F^{\ 0.8}\ G^{\ 0.75}\ L_t^{0.9}$

# 5. WITHDRAWAL RESULTS




- CSA O86-09 (2009) EQ. WS
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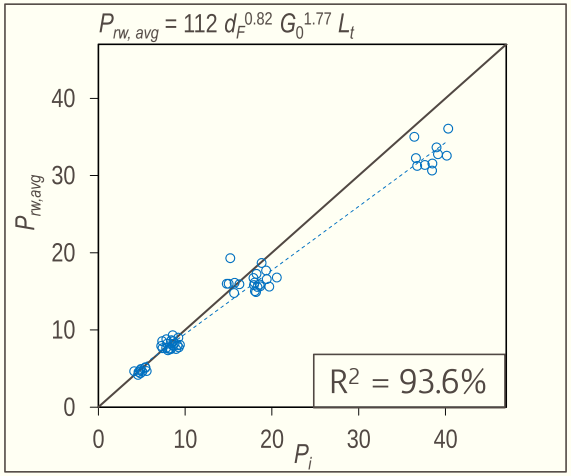
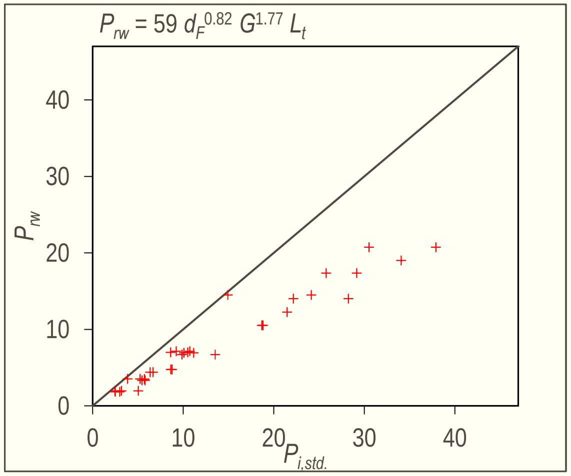
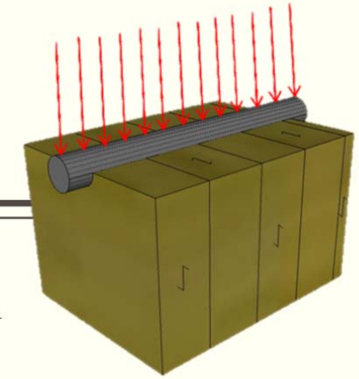


# 6. EMBEDMENT



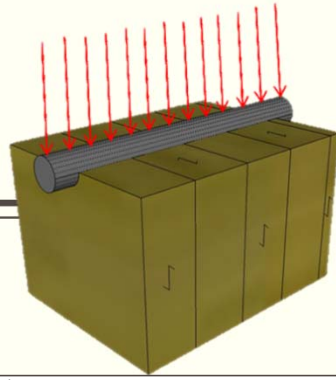
## 6.1 COMPLEMENTARY RESEARCH – EMBEDMENT IN GLULAM PRODUCTS

- EVALUATION OF THE INFLUENCE OF DIAMETER

1. SIMPLE RELATIONSHIP BETWEEN THE EMBEDMENT STRENGTH AND THE DIAMETER
   $y = Ax + b$

2. COMPARISON OF NEW MODEL VS. EXPERIMENTAL DATA

# 6. EMBEDMENT



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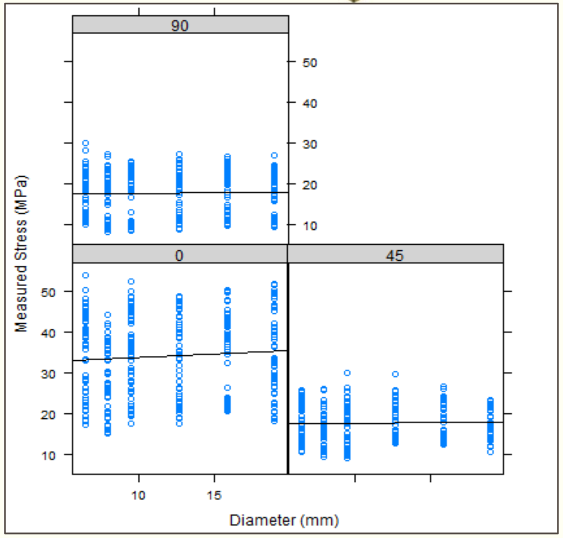


p-value (0°) = 0.169
p-value (45°) = 0.743
p-value (90°) = 0.771

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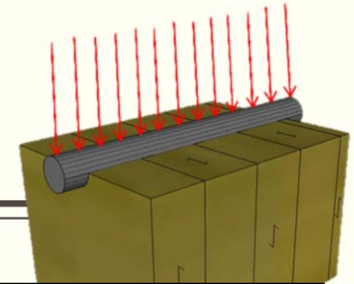

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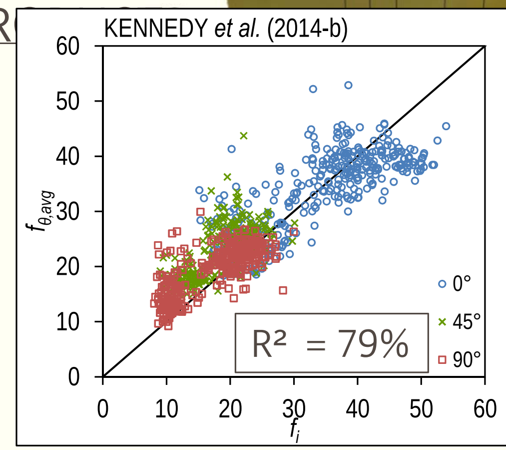
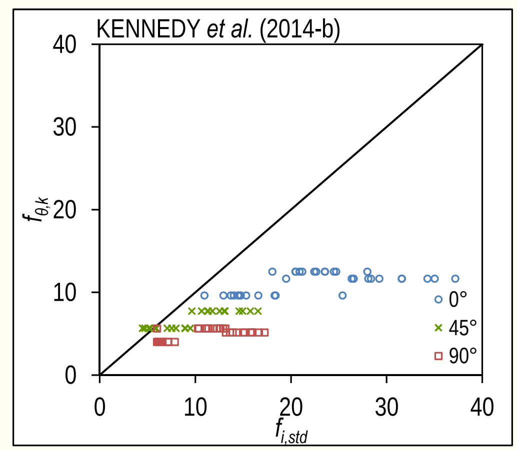
   y = Ax + b

2. COMPARISON OF NEW MODEL VS. EXPERIMENTAL DATA

$$f_{\theta,avg} = \frac{108\rho_{12}^{1.7}}{\left(1.54\rho_{12}^{-0.5}\right)\sin^2\theta + \cos^2\theta} \qquad f_{\theta,k} = \frac{42G^{1.7}}{\left(1.54G^{-0.5}\right)\sin^2\theta + \cos^2\theta}$$

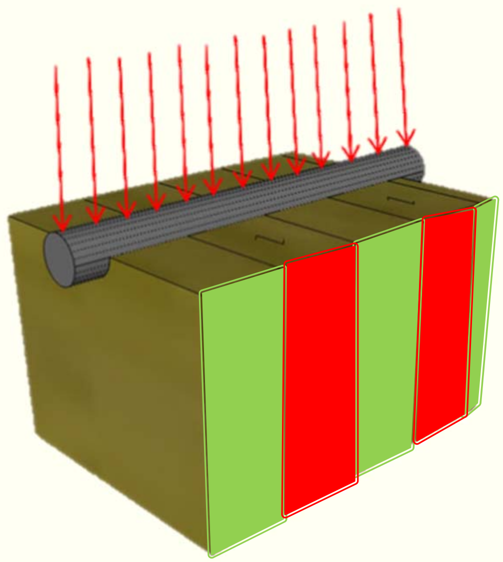


# 6. EMBEDMENT

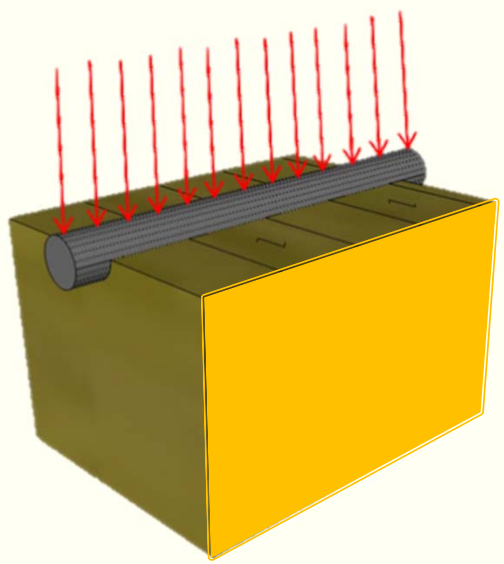
## 1st APPROACH – US CLT APPROACH

$$f_{\theta,CLT} = \left(l_{\parallel} f_P + l_{\perp} f_Q\right) l_p^{-1}$$



## 2ND APPROACH – EUROPEAN

$$f_{\theta,CLT} = f_{\theta}$$



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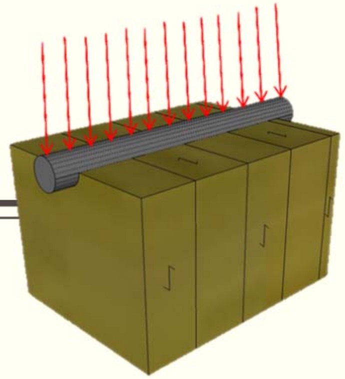

## 1st APPROACH – US CLT APPROACH

$$f_{\theta,CLT} = \left(l_{\parallel} f_P + l_{\perp} f_Q\right) l_p^{-1}$$

- CSA O86 EMBEDMENT EQUATIONS

$$f_{P,k} = 50G(1-0.01d_F)$$
$$f_{Q,k} = 22G(1-0.01d_F)$$

- NDS EMBEDMENT EQUATIONS

$$f_{P,k} = 12000G_0$$
$$f_{Q,k} = 6100G_0^{1.45} d_F^{-0.5}$$

- KENNEDY ET AL.(2014-b) EMBEDMENT EQUATIONS

$$f_{P,k} = 42G^{1.7}$$
$$f_{Q,k} = 27G^{2.2}$$

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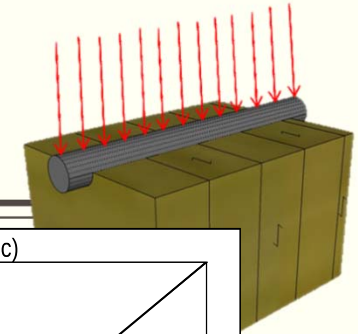

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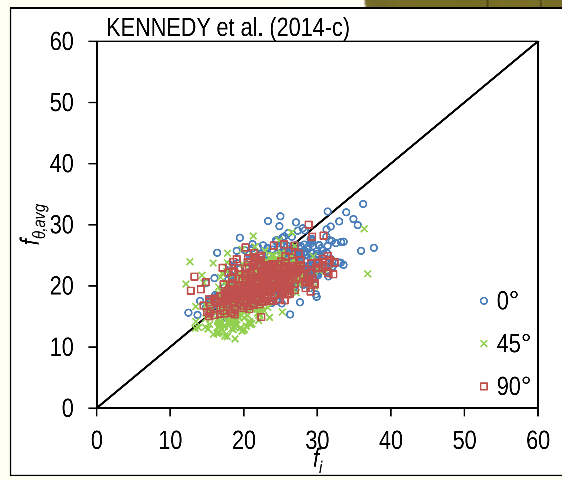


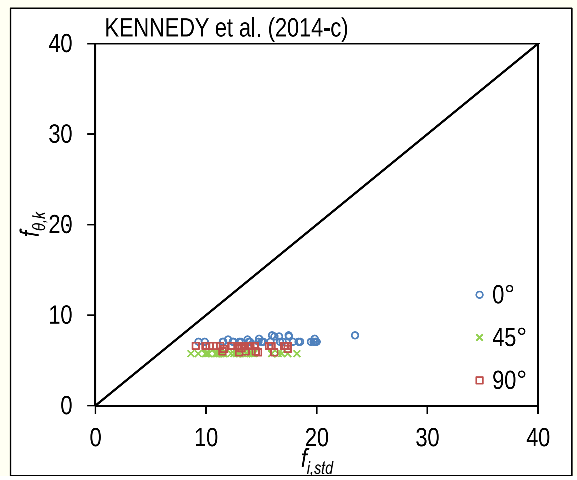

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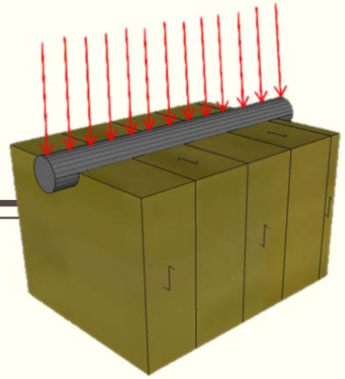

## 2ND APPROACH – EUROPEAN

$$f_{\theta,CLT} = f_{\theta}$$

- EUROPEAN (2006) CLT DOWEL EMBEDMENT EQUATION

$$f_{\theta,k} = \frac{55G^{1.16}(1-0.015d)}{1.1\sin^2\theta+\cos^2\theta}$$

- KENNEDY ET AL.(2014-C) CLT EMBEDMENT EQUATION

$$f_{\theta,k} = \frac{41(\rho_{12}-0.12)^{1.11}}{1.07(\rho_{12}-0.12)^{-0.07}\cdot\sin^2\theta+\cos^2\theta}$$

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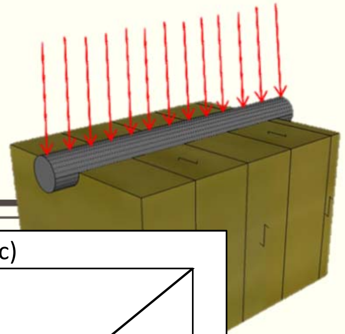

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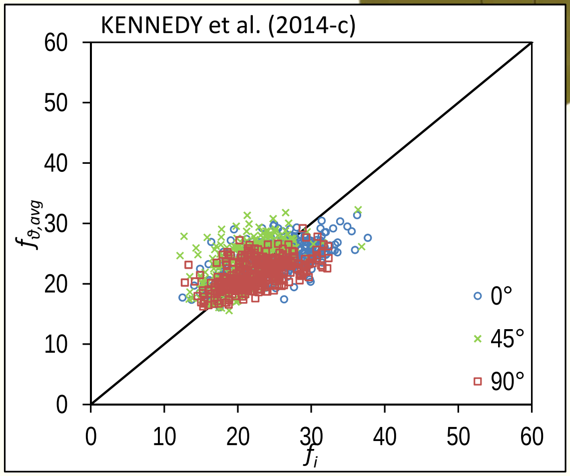


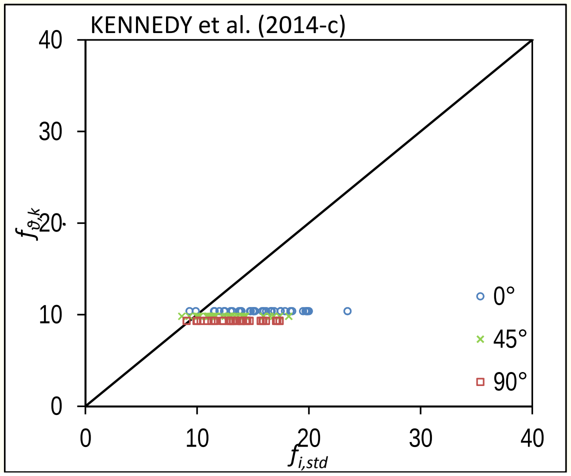

# 7. CONCLUSION

WITHDRAWAL

- CSA O86-09 (2009) EQ. WS

EMBEDMENT

- EVALUATION OF THE INFLUENCE OF DIAMETER
- $1^{ST}$ APPROACH : KENNEDY ET AL.(2014-b) EMBEDMENT EQUATIONS
- $2^{ND}$ APPROACH : KENNEDY ET AL.(2014-C) CLT EMBEDMENT EQUATION

# THANK YOU!