Pre-stress in Wood Systems
David Bowick / December 13, 2012
What is Prestress?

Prestressing is a method of strengthening or stiffening a structural element by introducing internal stresses. Can be applied during the manufacturing process or during the installation process.

- Tempered Glass
- Prestressed Concrete
- Tensile Structures
Why Prestress?

- Prestressing can be used to couple a strong flexible element (steel tendon) with a weak stiff element (concrete) to create a strong stiff element (post-tensioned concrete)
Case Study

Simple Span Roof

L=18m

Structure at 2.0 m c/c

ω_d = 0.8 kPa

ω_l = 1.2 kPa

ω_w = 1.2 kPa (gross uplift)
Simple Beam

$W$ 10m

$V_e = 114.1$ kN

$M_e = 224.1$

$\Delta_e = 53.4$
Pinned Chord Truss

18 m

$V_f = \pm 28.5 \text{ kN}$

$M_f = 66.0 \text{ kN}\cdot\text{m}$

$\Delta_h = 54 \text{ mm}$

$C_f = 126.3$

$T_f = 267.9 \text{ kN}$

*Using Cable Load Factors $T_f/T_{BR} = 0.39$! *
But Dave...

What about wind uplift?
Pinned Chord Truss

- \( V_p = 265 \text{ kN} \)
- \( M_p = 66.0 \text{ kNm} \)
- \( \Delta u = 54 \text{ mm} \)
- \( T_p = 267.9 \text{ kN} \) (using cable load factors)
- \( T_{1/2} = 0.39 \)
Continuous Chord Truss

\[ V_0 = \pm 29.2 \]
\[ M_0 = \pm 6.5 \text{ kN}\cdot\text{m} \]
\[ H_0^t = \pm 60.5 \text{ kN}\cdot\text{m} \]

\[ \Delta_{\text{wind}} = \pm 100 \]
\[ \Delta_{\text{h}} = \pm 50 \text{ mm} \]

\[ C_0 = 172.6 \text{ kN} \]
\[ T_0 = 280.3 \text{ kN} \]
\[ C_0 = \pm 62.0 \text{ kN} \]

* To achieve \( \Delta_{\text{wind}} \leq 60 \text{ mm} \), size needs to increase to \( \pm 265 \times 570 \).
So...

We have a valid load path and it's strong, but to satisfy L/300 gross uplift deflection we need a section almost as big as the simple beam section. The cable utilization is negligible and the trussing is just bling.
Simple Beam – 265x646

Pinned Chord Truss – 265x380
But it's irrelevant because it doesn't work for uplift. We could ballast for uplift, but increased load results in increased size. Cable oversized to achieve stiffness.

Continuous Chord Truss – 265x570
Governed by uplift stiffness.

Prestressed Truss – 265x342
40% Savings in glulam relative to non-prestressed truss. Remains rigid under load reversal.
An Aside About Uplift...

- While we reasonably consider net uplift when designing for strength, we need to consider gross uplift when designing for stiffness.
An Aside Deflection Criteria...

- The “L-over” criteria for deflection is completely irrelevant for cantilevers.
A Possible Criteria...

**Criterion:** \( \frac{4 \Delta}{\text{SPAN}} + \frac{\text{SPAN}}{L \text{SPAN}} - \Delta \text{CANT.} \leq \frac{L}{180} \text{CANT.} \)
So, how do we design using prestress?
Most non-linear versions of analysis programs such as Etabs and SAP can accommodate prestress directly.
Designing with Prestress

Most simple analysis programs have the ability to accommodate stresses due to temperature changes. We can use this to apply prestress:

\[ \Delta L = L_0 \alpha \Delta T \]

where \( \alpha \) = coefficient of thermal expansion

\[ \Delta L = TL_0 / AE \]

Therefore

\[ L_0 \alpha \Delta T = TL_0 / AE, \text{ and} \]

\[ T = \alpha \Delta T / AE \]

This is valid for a member restrained against perfectly rigid supports.

Against elastic supports the force will be reduced by the movement of the supports and the temperature change will have to be adjusted by trial and error.
And how do they do it?
Applying Prestress

**DRIFTING**

Manufacture elements intentionally short by a specific amount. Force fit. This method is imprecise and probably appropriate for nominal prestress only.

**CONTROLLED STRETCH**

Elements can be pulled directly using a callibrated tension jack such as those used in prestressed concrete. This is probably most appropriate where prestress forces are large.

**SPRUNG STRUCTURE**

The structure can be deformed intentionally using simple tools such as bottle jacks and come-alongs. The prestressing tendon can be attached under zero stress, then the jack or come-along relieved, transferring the load to the tendon. The measured impact of the prestressed element can be predicted fairly accurately so the deformation of the structure itself becomes the gauge.
Bow Saw

- Direct tensioning using lever.
Long Bow

- Tensioning by Springing Structure
Hydraulic Jacking
To Brace or Not to Brace

- **Stable**: Centre of rotation, point of connection of chord below pt. of rotation, chord tension self-corrects.

- **Neutral**: Chord tension reinforces rotation.

- **Unstable**: Point of connection above pt. of rotation.
OK. The technical arguments are compelling. But how do we make it beautiful?
Cable Hardware

Swage Eye and Fork
Cable Hardware

Open Spelter Socket
Cable Hardware

Universal Pin Connectors
Cable Hardware

Architectural Swage Fitting
Milton Leisure Centre

Circa 1991
Completed 2004

Sir Sandford Fleming College
Rock community
Church

Circa 2006
Lakefield College School

Circa 2006
Local Church of the Saints

Completed 2012
St. Catharines Aquatic Centre

Completed 2012
Thank You!
Canadian Wood Council
G063
Pre-stress in Wood Systems
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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.
Pre-stress is a strategy used in concrete to create a strong-stiff system by combining a strong flexible element (tendon) with a weak stiff element (concrete). This presentation explores the positional of prestress in wood systems through case studies and hypothetical applications.
Learning Objectives

At the end of the this course, participants will be able to:

1. Have a basic understanding of the use of pre-stress as a general strategy and its various applications.
2. Have some slightly more detailed understanding of how to apply pre-stress in wood structures.
3. Be familiar with some of the hardware available and detailing techniques.
4. Be inspired to consider a broader range of application of timber in structures.
This concludes The American Institute of Architects Continuing Education Systems Course

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