External Post-Tensioning
Extends Load Carrying Life of
Wood Bowstring Trusses

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Common Trusses
Used in Building Construction

(Photographs Courtesy of David W. Cocke, SE, Structural Focus)
Comparison of Axial Stresses

Sec. 1.31 Stress analysis 117

Fig. 1.17 Aliens using proper and design stress.

TYPICAL TRUSS ANALYSIS

**Typical Truss Analysis**

- 100 ft. span
- 15 ft. entrance
- 15 ft. rear (20 ft. wing)
- 10 ft. 4 in. span
- 10 ft. 4 in. span
- 10 ft. 4 in. span

Department of Mechanics

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Most Common Commercial Bowstring Truss Manufacturers In California

- Arch-Rib Truss Co. Ltd. (Multi-Member Chord)
- Summerbell Roof Structures (Multi-Member & Mono-chord)
- Vo-Vec Roof Structures (Multi-Member Chord)
- Commercial Roof Structures (Multi-Member Chord)
- National Truss Company (Multi-Member Chord)
- Easybow Trusses by U. S. Structures (Mono-chord)
- Mack Truss by Mackintosh & Mackintosh, Inc (Mono-chord)

Typical Truss Profiles for Arch-Rib Trusses
- Multi-Member Chords
- Segmental Upper Chord
- Inside Shoes at Heels in earliest trusses
- Outside Shoes at Heels in Later Construction
  - Inside Shoes Tended to cause Splitting in Lower Chords at Heel Connection

Typical Truss Profiles for Summerbell Roof Trusses
- Multi-Member chords
  - Upper chords of nail laminated construction
Standard Summerbell
Upper Chord Sections
of Nail Laminated
Construction

- Used when rafters were specified to be supported by hangers
- Also specified when rafters installed above and lapped over upper chord

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(Circa 1930’s Summerbell Design Manual)

Standard Summerbell
Upper Chord Section
with Ledger Lamination

- Used when rafters specified to rest on ledger
- Small block used to tie rafters together above upper chord
- Primary cause of web-pullout and upper chord buckling

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(Circa 1930’s Summerbell Design Manual)

Nail Laminated Upper Chord

Common Nailing 16d and 30d for 2x laminations
30d and 50d for 3x laminations

Used in Summerbell Roof Trusses and Easybow Roof Trusses

(Parker Design and Construction Manual; 1956)
Standard Segmental Bowstring Roof Trusses
Designed by Mackintosh & Mackintosh, Inc.
Used by: Vo-Vec Roof Structures
Commercial Roof Structures
National Truss

- Multi-member chords
- Split shoes and heels
- Segmental upper chord construction
- STILL USED TODAY

Typical Multi-Member Segmental Band-Sawed Upper Chord Construction

Used in Arch-Rib, Vo-Vec, Commercial and National Roof Truss Construction

Easybow Truss
by
U.S. Structures

- Webs are Radial
- Mono-chord Construction
- Used Nail Laminated Upper Chords & Glu-laminated Timber
Example of Easy Bow Truss

Easy Bow Truss Web Connection

Mack Truss
Mono-Chord Truss Construction
designed by Mackintosh & Mackintosh, Inc.

Used in Trusses fabricated by Vo-Vec Roof Structures,
Commercial Roof Structures and National Roof Structures
Why Do Bowstring Trusses Fail?

Recent testing has shown that the allowable tensile stresses in timber used in the original design of these trusses was too high.

<table>
<thead>
<tr>
<th>1955 stresses</th>
<th>1997 stresses</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_t = 1450 psi</td>
<td>F_t = 675 psi</td>
</tr>
<tr>
<td>F_b = 1450 psi</td>
<td>F_b = 1000 psi</td>
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</tbody>
</table>
Why Do Bowstring Trusses Fail?

(cont)

• Cross grain shrinkage of timber attached with steel side plates with multiple rows of bolts often causes the initial splitting.
Why Do Bowstring Trusses Fail?

(cont)

• Cross grain shrinkage of timber attached with steel side plates with multiple rows of bolts often causes the initial splitting.
• Timber defects (Large knots)

Example of Timber Defect

Why Do Bowstring Trusses Fail?

(cont)

• Cross grain shrinkage of timber attached with steel side plates with multiple rows of bolts often causes the initial splitting.
• Timber defects (Large knots)
• Bolts in a row
Why Do Bowstring Trusses Fail?
(cont)

- Excess Loading
  - Gravity
  - Mechanical Equipment
  - Multiple layers of roofing

Example of Bolts In A Row

Roof Mounted Equipment
Why Do Bowstring Trusses Fail?
(cont)

• Excess Loading
  – Gravity
  – Mechanical Equipment
  – Multiple layers of roofing
• Stability problems associated with upper chord
Why Do Bowstring Trusses Fail?
(cont)
• Stability problems associated with upper chord
• Earthquake induced loads

The Most Common Failures in Bowstring Roof Trusses
• Splitting of Lower Chord along Bolt Lines at Steel Splice Plates and Heel Plates

Example of Splitting caused by Cross Grain Timber Shrinkage in Lower Chord
The Most Common Failures in Bowstring Roof Trusses (cont)

- Splitting of Lower Chord along Bolt Lines at Steel Splice Plates and Heel Plates
- Tension Failure in Lower Chord
The Most Common Failures in Bowstring Roof Trusses (cont)

- Splitting of Lower Chord along Bolt Lines at Steel Splice Plates and Heel Plates
- Tension Failure in Lower Chord
- Web Splitting and Web Pull-Out
The Most Common Failures in Bowstring Roof Trusses (cont)

- Splitting of Lower Chord along Bolt Lines at Steel Splice Plates and Heel Plates
- Tension Failure in Lower Chord
- Web Splitting and Web Pull-Out
- Upper Chord Splitting

Example of Upper Chord Splitting

Upper Chord Rib Replacement
Upper Chord Splitting

The Most Common Failures in Bowstring Roof Trusses (cont)

- Splitting of Lower Chord along Bolt Lines at Steel Splice Plates and Heel Plates
- Tension Failure in Lower Chord
- Web Splitting and Web Pull-Out
- Upper Chord Splitting
- Upper Chord Buckling

Upper Chord Buckling
Instances where upper chord instability can occur

Completed Repair

Upper Chord Stability Bracing Missing
Truss Repair Procedure

• Shore truss up to restore original truss geometry and to remove stress from truss members.
Truss Repair Procedure (cont)

• Shore truss up to restore original truss geometry and to remove stress from truss members.
• Manipulate truss with rods or jacks to restore geometry when broken. (Almost like an art.)
• Carefully measure and replace broken truss elements making sure that they are the same length as when fabricated.

• Tighten all original truss bolts (be careful not to over-tighten and crush wood).
Truss Repair Procedure (cont)

- Tighten all original truss bolts (be careful not to over-tighten and crush wood).
- Re-install new steel tension rods from heel-to-heel one on each side of truss. These rods usually engage the existing heel bolts.
- Tighten steel tension rods in small increments, equally on both sides of truss until truss lifts up off of the shores or until the specified tension is obtained.

Do’s & Don’ts of Truss Repairs (cont)

- Never recommend the simple replacement of a fractured lower chord element without installing steel tension rods from end-to-end.
Do’s & Don’ts of Truss Repairs
(cont)

• Never recommend the simple replacement of a fractured lower chord element without installing steel tension rods from end-to-end.

• Use kiln dried lumber for replacements or use laminated veneer lumber. I prefer LVL.

Do’s & Don’ts of Truss Repairs
(cont)

• Design and size lower chord tension rods for 100% of dead load plus 100% of live loads. A simple stiffness calculation comparing the strain in the Timber Lower Chords vs. the strain in the New Steel Tension Rods will reveal that most of live load will be resisted by the steel tension rods. Most of the time the tension rods are tightened for dead load only.

Do’s & Don’ts of Truss Repairs
(cont)

• Always restore the member capacities of the original trusses and their connections so that unbalanced loads have a complete load path. Sometimes it is difficult due to physical dimension constraints at original splice locations.
Do’s & Don’ts of Truss Repairs (cont)

• If high strength steel cables are used to reinforce the lower chords of the trusses, it is our standard that the steel cable and its anchoring connections should be sized for 100% of the dead load and 100% of the live load and that the cables be tensioned for **DEAD LOAD ONLY**. The truss members that were fractured should be repaired to restore 100% of their original capacity for they **will** resist 100% of the live load.

Do’s & Don’ts of Truss Repairs (cont)

• If steel tension rods are specified to reinforce a truss with an inside shoe configuration remember to design the new heel bolts for bending also. This means that these heel bolts will probably end up being ASTM A490 bolts or SAE Grade 8 high strength bolts.

Do’s & Don’ts of Truss Repairs (cont)

• If steel tension rods are specified to reinforce a truss with an inside shoe configuration remember to design the new heel bolts for bending also. This means that these heel bolts will probably end up being ASTM A490 bolts or SAE Grade 8 high strength bolts.

• Rod tensioning must be completed in the presence of a licensed deputy building inspector.
Do’s & Don’ts of Truss Repairs (cont)

- Recommend experienced truss reinforcement contractors only. We require 10 years experience.

- Structural observations always required.

Why Post-Tension a Bowstring Truss?

- Because post-tensioning removes almost all of the stress from the lower chords which are the most susceptible members to failure.

What is post-tensioning?

- Post-tensioning is the application of a compression force applied to the ends of the lower chords of Bowstring trusses thus counteracting or reducing the tension in the lower chords.
- The Post-tensioned elements are attached to the both ends of the trusses and at each node by engaging one existing truss rope and each new truss connection plate which are connected to steel rods, the steel rods are continuous and generally connected by ASC cast turnbuckles which are tightened to a prescribed tension.
- Once the Post-tensioning has been applied then the likelihood of having a lower chord tension failure is reduced significantly.
- Post-tensioning reduces the stresses in the lower chord members themselves.
- Post-tensioning reduces the stresses in the heel and splice connections.
- Post-tensioning will make an old truss perform like a new truss.
Example of Lower Chord Tension Rod Reinforcement Calculation
Example of Truss Repair Elevation
TYPICAL TRUSS REPAIRS AND/OR REINFORCEMENTS
Heel Connection and Seismic Splice for Mack Truss

Tension Rod at Lower Chord with Web Reinforcement

Upper Chord Reinforcement by Field Laminating
COMMON TENSION
ROD
CONNECTION
DETAILS
Do’s & Don’ts of Truss Repairs
(cont)

• Tensioning of steel rods shall be done with a calibrated torque wrench and in the presence of a licensed deputy building inspector.
Coupling Nut on Lower Chord Tension Rods with Witness Holes

NEW BOWSTRING TRUSS CONSTRUCTION
New Bowstring Truss Assembled On-Site

New Bowstring Truss being Set In-Place

INTERESTING LAMELLA CONSTRUCTION
Lamella Roof Under Construction (P.F. Changs; Long Beach, CA)

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Lamella Roof Under Construction (Legends; Belmont Shore, CA)

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Lamella Rib Is Similar to Bowstring Rib with Compound Mitered Ends

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Questions?

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