Wood Poles

- Environmentalists are opposing logging & non-replacement.
- Long, straight poles are becoming difficult to obtain.
- Non-recyclable. Poles become hazardous waste due to chemical treatments.
- Poles twist, decay, split, bow.
- Can be damaged by insects, animals and fire.
Concrete Poles

- Spun-cast, prestressed concrete poles are very heavy, increasing the transportation and erection costs.
- Very high disposal costs.
- Weak in transverse shear, with low ductility.
Wood $\rightarrow$ Concrete Replacement Poles

Still common.

Dupont street, Toronto
Steel Poles

- Visually acceptable and “environmentally correct”.
- A recyclable and recycled material.
- Very low cost to fabricate and erect.
- Uniformity with dimensions and material properties → reliable.
Steel Poles

Extremely ductile in cases of overload or impact.
Steel Lattice Towers

- Very negative visual impact, appearing clumsy and anachronistic.
- Large base dimensions, large “footprint”, and loss of “right of way” area.
Most North American research has concentrated on polygonal, tapered, steel poles (Electrical Power Research Institute, etc.). Focus has been mainly on the pole structural behavior, especially the local buckling failure mode at bottom of pole, while acting as a cantilever.

Professor H. J. Dagher (University of Maine) has investigated poles (wood vs. steel) from a structural reliability analysis, concluding:

- There is a discrepancy in safety factors required for wood vs. steel, with steel penalized.

(1997 NESC, Grade C construction).

(Nominal pole strengths taken from ANSI 05.1 for wood poles, ASCE Manual 72 for steel poles).

- Probability of failure of wood poles is between 6 and 33 times that of equivalent Grade C steel poles.
Laboratory Verification of Pole Connections

Design loads for a FPL Transmission Line Pole
Testing Arrangement to Simulate FPL Pole Connection Loading

- Pulley apparatus (to position actuator)
- Jack (load control)
- Jack end (bolted to capping plate)
- Capping plate (welded to CHS)
- Polymer insulator arm
- Tubular pole bolted to strong floor
- Concrete-filled HSS
- 'Mechano set' column (secured to 'A' frame)
- 'A' frame (secured to strong floor)

American Iron and Steel Institute
University of Toronto
Testing Arrangement to Simulate FPL Pole Connection Loading

- **Pulley apparatus** (to position actuator)
- **Jack** (load control)
- **Jack** (deflection control)
- **Polymer insulator arm**
- **Jack end** (bolted to capping plate)
- **Capping plate** (welded to CHS)
- **Tubular pole** bolted to strong floor
- **Concrete-filled HSS** (secured to strong floor)
- **Mechano set column** (secured to A frame)
- **A frame** (secured to strong floor)

- **Strong wall**

American Iron and Steel Institute
University of Toronto
**FPL Connection Tests**

- Same connection hardware used as for wood poles.

- Through-bolts (7/8" or 22 mm diameter) used with a variety of backing washers.

- Pole 16" (407 mm) diameter x 1/4" wall (6.4 mm) at the connection.

- 78 ksi (535 MPa) pole steel.

- Polymer insulator arm proved to be the most critical element.
**Performance of Through-Bolts**

Even without backing washers, integrity of pole remained intact at several times the connection design loads.

Eventual local plastification strength of the tube wall can be estimated by simple yield-line theory.

\[
P_Y = \frac{t^2 F_y}{4} (4\pi)
\]

*Conical Yield Line pattern under point loading by bolt nut (or washer)*
A rectangular HSS cross-arm was welded to a 400 mm x 400 mm x 10 mm plate (15 3/4” x 15 3/4” x 3/8” PL.)

Plate in turn was bolted to another plate, bent into the shape of a channel and welded to the pole.

Connection Yield Load (again best predicted by yield line theory) in tests was produced by a flexural mechanism in the 400 mm x 400 mm x 10 mm plate, but at several times the design load.
Nailing of Mating Pole Sections

A novel joining technique, as an alternative to bolting or welding, developed at the University of Toronto.

A powder-activated tool (or “gun”) drives a high-strength ballistic point pin (or “nail”) through two layers of steel.

Simple, minimal training
Inexpensive, fast
Independently powered

Hilti DX750 direct fastening system used, with Hilti ENPH2-21L15 nails, through a combined steel thickness of 1/2” (12.7 mm).
HILTI ENPH2-21L15 Nails

Used for All Tests at University of Toronto in 1990s

- **Very high strength**
  
  \[ F_u = 319 \text{ ksi (2200MPa)}. \]

- **Very hard**

  Rockwell C hardness = 58

- **Potentially able to corrode in exposed pole applications**
“New generation” high strength stainless nails being used in subsequent tests in 21st century.
Very reliable and predictable behavior.

Behavior is similar to bolted, lap splice connections.

Three possible failure modes identified in 47 statically-loaded connection tests:

(i) Shearing of the nails
(ii) Bearing failure of the base (pole) metal
(iii) Net section fracture of the base (pole) metal

Connection resistance to be determined by the limiting (governing) failure mode.

(See ASCE “Journal of Structural Engineering”, August 1996)
Nail Shearing Failure Mode
Bearing Failure of the Base (Pole) Metal in a Nailed Connection
Net Section Fracture of the Base (Pole) Metal in a Nailed Connection
Fatigue Strength of Nailed Pole Connections

- Very reliable and predictable behavior.
- Nails do not “work loose”.
- Nails puncture the steel but the material around the nail is in local compression. This residual stress tends to close the cracks.
- Same three possible failure modes identified, in 19 fatigue tests, as for statically-loaded connections.
Simple S-N Fatigue Design Curves Available for Nailed Connections, Based on Classification Approach

![Diagram showing S-N fatigue design curves for different types of connections.](image)

- **Bolted shear splice**
  - CAN/CSA-S16.1-94
  - CSA Category B

- **Welded lap splice**
  - ANSI/AWS D1.1-2000
  - Curve F

- **Riveted Shear Splice**
  - AASHTO (1994)
  - Category D

---

American Iron and Steel Institute
University of Toronto
Conclusions

- Tubular steel is a logical alternative for the pole market.
- Connection hardware previously used on wood poles can often be directly used on steel poles.
- Connections tend to be non-critical, and various connection methods can be easily validated.
- Innovative developments with connections (such as nailing) expand the range of application of single steel monopoles.