Design of Overhead Power Transmission Structures

Jon “Matt” Rouse
Department of Civil Engineering
Iowa State University
November 4, 2013

jmr19@iastate.edu
Current State of the Infrastructure

- 2013 ASCE Energy Infrastructure Grade: D+
  - $94 billion investment gap in electric T & D infrastructure by 2020

- 3300 new miles of new transmission lines/year needed in the next decade (N. American Electric Reliability Corp.)

- $880 billion national investment in transmission + distribution required to meet DOE renewable energy and carbon emission goals by 2030 (Brattle Group)

- “Terrorist attacks on multiple-line transmission corridors could cause cascading blackouts.” (Natl. Research Council of the Natl. Academies)
Current T&D Structure Types

- **Transmission-Scale Structures (ASCE MOP 74)**
  - Tubular Steel Monopoles (ASCE 48-11, 2012)
  - Lattice Towers (ASCE 10-97, 2000)
  - Prestressed Concrete Poles (ASCE MOP 123, 2012)
  - Wood or Steel H-Frames
  - Engineered Timber

- **Distribution-Scale Structures**
  - Wood poles (ASCE MOP 111, 2006)
  - Engineered Timber

- However...
Design Loads on Transmission Structures

- **Transverse design loads**
  - Well calibrated and specified
  - Typically govern size of a structure

- **Longitudinal loads on intact systems**
  - Differential ice/wind/temperature loads
  - Unequal wire tension

- **Secondary longitudinal loads and failure containment**
  - Result of an initial component failure
  - Caused by extreme natural events or manmade attack
  - Difficult to quantify
  - Can trigger a cascade event (progressive collapse)
Historical Perspective

- Early on (circa 1910) emphasis on longitudinal flexibility with no longitudinal strength requirements cascading collapses.
- 1921 NESC recommended dead-ends at least every 10 spans.
- 1941 NESC this recommendation was removed.
- 1977 NESC: “structures having a longitudinal strength capability be provided at reasonable intervals along the line.”
- This recommendation remains in the NESC today.
- ASCE MOP 74 moving toward reliability based design.
Preventing Longitudinal Cascades

• The problem: severely unbalanced wire tension

• Possible Causes
  ○ Extreme ice and/or wind events, landslides, ground movements, flooding, lightning, vehicle/aircraft accidents
  ○ Vandalism or sabotage

• Prevention
  ○ All tangent structures have significant longitudinal strength
  ○ Intermittent dead-ends or stop structures
  ○ Release mechanisms
  ○ A new alternative
A Different Approach to Cascade Prevention

- Substitute ductility for longitudinal strength
  - This approach is used for seismic design of buildings and bridges
  - Ductility is *not* flexibility
    - (Stringing difficulties arise with highly flexible structures)
  - Structures must continue to sustain significant longitudinal forces even while undergoing large longitudinal deflections
Which Behavior is Preferable?

![Diagram showing longitudinal load vs. top deflection for two cantilevers, along with equivalent maximum design load on an intact system.](image)
But what kind of pole can do this?

- Must be at least as strong as a typical structure in the transverse direction
- Must be designed for *both* ductility and strength in the longitudinal direction
- Must be cost competitive
- Ideally would be quickly reparable

Components of a prototype segmented pole
- **Hinge** near base to allow large longitudinal deflections
- **Structural fuses** to resist rotation and protect the rest of the structure
- **Elastic post-tensioning** to maintain resistance at large deflections
Reduced-Scale Push-Over Tests

- Longitudinal Axis & Load Direction
- Transverse Axis
- Pin
- Structural Fuse Plate
- Dead Weights
- Pin
- Load Direction
- Structural Fuse Plate
- Yielded Fuse Plate
- Buckled Fuse Plate
Push-Over Test Results

- Buckling of Structural Fuse on Compression Side
- Slippage of Bolted Fuse Connections
- Fracture of Structural Fuse on Tension Side

22% Drift while Sustaining 75% of Peak Resistance
Structural Fuse Plate

Slip Joint

Post-tensioning Tendons

Parallel (x) Axis

Transverse (y) Axis

Base Cross Sections

Prototype

Typical Monopole
Relative Advantages of the Prototype

- **Less steel per tangent structure**
  - 7.5% reduction for comparison example

- **Elimination of dead-end structures**
  - Assuming dead-ends every 5 miles and each dead-end costs 4x a tangent pole
    - 6.5% cost reduction for comparison example

- **Simplified erection**
  - Pole with slip joints assembled on ground and tilted up into place
  - Post-tensioning used to seat slip joints from ground level
  - No crane required
  - Less right of way for mobilization of large cranes?
  - Particularly advantageous for rough or environmentally sensitive terrain
Relative Advantages of the Prototype (cont.)

- **Lifecycle/maintenance costs**
  - No additional maintenance envisioned
  - Easily inspected from ground level
  - Post-tensioning reduces tensile stresses in base plate and base plate-shaft weld to alleviate fatigue

- **Wide range of applicability**
  - Large transmission-scale structures
  - Small distribution-scale poles

- **Enhanced Security**
  - Attack on a single structure or wires will not lead to a cascade
  - Cascades prevented at the point of origin not merely contained in magnitude
  - Reduces risk and enhances reliability
Moving Forward

- **Future Research**
  - Testing of full-scale transmission structures
  - Testing of multiple structures under worst-case scenario loading
  - Development of construction details
  - Formal design procedures and guidelines

- **Summary**
  - More Resilient, Reliable, and Sustainable
  - Lower Cost
  - Longer Service Life