TRANSMISSION LONG SPAN DESIGN

MIPSYCON 2014

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Stanley Consultants, Inc.
Objective & Basis

- Presentation of process and design considerations associated with design & engineering of long spans on transmission lines.

- Basis: 2700 ft crossing of Missouri River
  - Misc. specific examples of other considerations
Objective Considerations

- Routing & Location Selection
- Design Criteria Alternatives
- Wire Selection
- Structural Loads
- Operational
- Constructability
What Is Long Span?

- Spans between structures within a given design set that fall outside of the normal ruling span and require specific designs.

- Spans that fall outside of the ruling span criteria and are non-standard or abnormal design aberrations.
Routing & Location Selection
Key Considerations

- Corridor selection wide enough/variable enough to try & eliminate long spans
- Where inevitable, enough variability to allow selection alternatives
- Full understanding of regulatory challenges associated with each area
- Long Spans = Critical Routing Point
Corridor & Route Selection

- Environmental
- Land Use Limitations
- Land Owners
- Availability of Property
- Public Opinion/Opposition
Critical Routing Point

- Points in which selection will provide significant determination of remaining route selection
- Require early stakeholder agreement for selection
- Becomes significant basis for route selection
- Location drives design considerations
Corridor Alternatives
Route Selection
Design Criteria
Alternatives
Long Span Designs

- **Structure Loading**
  - Foundation & Structure

- **Regulatory Requirements**
  - Lighting, Marking, Clearances, etc.

- **Wire Selection**
  - Strength, Types, Load Cases

- **Environmental Impacts**
  - Clearances, Floodplain, Markings, Constructability
Long span design criteria typically fall outside of ‘normal’ design criteria. The same approach as ‘normal’ design, just higher loads and more considerations. Higher loads/longer spans exacerbate design issues, requiring additional QA/QC. Constructability reviews are more important.
‘Typical’ Long Span Concepts

- **Tension vs. Height**
  - ↑ Tension → ↑ Load & ↑ Galloping
  - ↓ Tension → ↑ Sag → ↑ Height

- **Tangent vs. Deadend**
  - Typically trade height for load & type
Flood Plain vs. Design

30' CLEARANCE ABOVE 100YR FLOOD
MISSOURI RIVER
100 YEAR FLOODPLAIN

SHEYENNE RIVER 100 YEAR FLOOD PLAIN 1315.2’ BASED ON KLJ’S RECOMMENDATION
Selection Considerations

- **Strength**
  - Higher loads = higher strength

- **Weather Cases**
  - Due to location additional considerations

- **Vibration**
  - Placement of vibration dampening (mid-span)

- **Constructability**
  - Larger equipment, heavier loads, site access
Conductor Testing

Load Meter (lbs) 12/12/2012

12/12/2012 13:47
Design for Vibration Problems

- Reduced Tension (longer spans)
  - Conductor Span Length and Tension
  - Conductor Tension Under 20% RBS
- Armor Rods (shorter spans)
- Cushioned Suspensions
  - More Dampening than Armor Rods
  - Small Compared to Dampers
- Dampers
  - Control Vibration
  - Manufacturer Determines Size and Placement
Design for Vibration Problems

- **Reduced Tension** (longer spans)
  - Conductor Span Length and Tension
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- **Cushioned Suspensions**
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- **Dampers**
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  - Manufacturer Determines Size and **Placement**
Galloping

- Low Frequency, High Amplitude Vibration
- Steady, Moderate Wind + Ice
- Irregular Ice Shape = Aerodynamic Lift
- Wind: 5 – 45 mph @ 10 – 90°
- Terrain: Flat or Rolling
Damage From Galloping

- **Contact Between Wires**
  - Arcing Damage to Conductor Surface
  - Broken Conductors
  - Failure in Ground Wires
  - Forced Outages

- **Structural Damage**
  - Dynamic Loads Cause Support Hardware Failure
  - Vibration Dampener Damage
  - Loosened Bolts
  - Jumper Displacement
Removal or Prevention of Ice on Conductors
  - Increase Load to Increase Temperature

Interfere with Galloping Mechanisms
  - Aerodynamic Drag Damper
  - Interphase Ties

Create Galloping Tolerant Lines
  - Ruggedness in Design
  - Increased Phase Clearance
# Wire Size Comparison

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>kcmil</th>
<th>OD</th>
<th>Al/Fe</th>
<th>Strength</th>
<th>Weight</th>
<th>Ampacity</th>
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<tbody>
<tr>
<td>959.6/Suwannee</td>
<td>ACSR/TW</td>
<td>959.6</td>
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<td>44/7</td>
<td>37,000</td>
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</table>
 Structural Load
Significantly higher load due to wire selection (strength)

Higher wire tensions further increase loading

Resulting ground line moments significantly higher

Total loading may result in alternative designs
Loading Considerations

- Guyed vs. Unguyed
- Deadend vs. Tangent
- Required additions
  - Markings, Lighting, Maintenance
- Geotechnical (soils)
- Environmental Concerns
  - Water flow, Flooding, Debris, Wildlife
Pole Loads - General

- Conductor Point Loads
- Pole Self-Weight
- Wind Acting on the Pole
- Hardware
- Maint/Construction
Structure Design

- Monopoles
Structure Design

- Multi-Pole Structures
Structure Design

• Lattice Structures
Conductor Resultant Load

- Conductor weight, ice, & wind combined
Pole Loads

- Transverse & Longitudinal Load due to Conductor Tension
  - Changes in Line Direction
  - Span Length Variation
  - Unbalanced Ice
  - Broken Wires
  - Dynamic Loads
Design Process – Single Pole

Single Pole w/o Guys

- Large overturning moment (M)
- Relatively small horizontal load (H)
- Vertical load (V) driven by structure height & wire

Typically use drilled piers, driven piles/caissons
Design Process – PLS Caisson
Lattice Tower w/o Guys

- Small leg base moment
- Relatively small horizontal shear load
- Large vertical load, downward or upward
- Typically use caissons, spread footings, or piling
Design Process – Lattice Tower

Drilled Shaft - Cylindrical Shear Design
Concrete Spread Footing - Cone Design

Design Process – Lattice Tower

\[ U \]

\[ W_s \]

\[ W_c \]

\[ H \]

\[ GWL \]

\[ \beta \]
## Empirical Values for $\phi$, $D_r$, and Unit Weight of Cohesionless Soils Based on Standard Penetration Resistance

<table>
<thead>
<tr>
<th>Description</th>
<th>Very Loose</th>
<th>Loose</th>
<th>Medium</th>
<th>Dense</th>
<th>Very Dense</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative density, $D_r$</td>
<td>0</td>
<td>0.15</td>
<td>0.35</td>
<td>0.65</td>
<td>0.85</td>
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<tr>
<td>Standard penetration number, $N$</td>
<td>4</td>
<td>10</td>
<td>30</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Approximate angle of internal friction, $\phi^{**}$</td>
<td>25°-30°</td>
<td>27°-32°</td>
<td>30°-35°</td>
<td>35°-40°</td>
<td>38°-43°</td>
</tr>
<tr>
<td>Approximate range of moist unit weight ($\gamma$)pcf</td>
<td>70–100+</td>
<td>90–115</td>
<td>110–130</td>
<td>110–140</td>
<td>130–150</td>
</tr>
</tbody>
</table>

*Use larger value of $\phi$ for cohesionless soils with 5% or less fine sand or silt, or both.
## Guide for Consistency of Cohesive Soils

<table>
<thead>
<tr>
<th>SPT Penetration (blows/ft)</th>
<th>Estimated Consistency</th>
<th>Range of Unconfined Compressive Strength lb/sq. ft.</th>
</tr>
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<tbody>
<tr>
<td>&lt; 2</td>
<td>Very Soft</td>
<td>&lt; 500</td>
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<td></td>
<td>(extruded between fingers when squeezed)</td>
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<tr>
<td>2 – 4</td>
<td>Soft</td>
<td>500 – 1000</td>
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<td>(molded by light finger pressure)</td>
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<tr>
<td>4 – 8</td>
<td>Medium</td>
<td>1000 – 2000</td>
</tr>
<tr>
<td></td>
<td>(molded by strong finger pressure)</td>
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</tr>
<tr>
<td>8 – 15</td>
<td>Stiff</td>
<td>2000 – 4000</td>
</tr>
<tr>
<td></td>
<td>(readily indented by thumb but penetrated with great effort)</td>
<td></td>
</tr>
<tr>
<td>15 – 30</td>
<td>Very Stiff</td>
<td>4000 – 8000</td>
</tr>
<tr>
<td></td>
<td>(readily indented by thumbnail)</td>
<td></td>
</tr>
<tr>
<td>&gt; 30</td>
<td>Hard</td>
<td>&gt; 8000</td>
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<tr>
<td></td>
<td>(indented with difficulty by thumbnail)</td>
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</table>
## Loading Comparison

### Normal

<table>
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<tr>
<th>LOAD</th>
<th>CASE 1</th>
<th>CASE 2</th>
<th>CASE 3</th>
<th>CASE 4</th>
<th>CASE 5</th>
<th>CASE 6</th>
<th>CASE 7</th>
<th>CASE 8</th>
<th>CASE 9</th>
<th>CASE 10</th>
<th>CASE 11</th>
<th>CASE 12</th>
<th>CASE 13</th>
<th>CASE 14</th>
<th>CASE 15</th>
<th>CASE 16</th>
<th>CASE 17</th>
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<tbody>
<tr>
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<td>1.2</td>
<td>1.7</td>
<td>1.6</td>
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<tr>
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<tr>
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</tbody>
</table>

All loads are in kips, are ultimate, and include all overload factors. *W* represents wind pressure (psf) to be applied to structures.

### Long Span

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<th>LOAD</th>
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<th>CASE 6</th>
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<th>CASE 11</th>
<th>CASE 12</th>
<th>CASE 13</th>
<th>CASE 14</th>
<th>CASE 15</th>
<th>CASE 16</th>
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<tbody>
<tr>
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<tr>
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</table>

All loads are in kips, are ultimate, and include all overload factors. *W* represents wind pressure (psf) to be applied to structures.
# Loading Comparison

<table>
<thead>
<tr>
<th></th>
<th>Camber</th>
<th></th>
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<th>NESC Heavy</th>
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<tbody>
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<td></td>
<td>Normal</td>
<td>Long Span</td>
<td>Normal</td>
<td>Long Span</td>
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</table>
## Loading Comparison

### Normal

<table>
<thead>
<tr>
<th>Pole</th>
<th>Tube Label</th>
<th>Tube Num.</th>
<th>Weight (lbs)</th>
<th>Load Case</th>
<th>Maximum Usage %</th>
<th>Resultant Moment (ft-k)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pole 1</td>
<td>1</td>
<td>6419</td>
<td>5-HEAVY ICE</td>
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</tr>
</tbody>
</table>

*** Overall summary for all load cases - Usage = Maximum Stress / Allowable Stress ***

### Long Span

<table>
<thead>
<tr>
<th>Pole</th>
<th>Tube Label</th>
<th>Tube Num.</th>
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<th>Resultant Moment (ft-k)</th>
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<tbody>
<tr>
<td>L</td>
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“Normal’
- Tangent → 7.5’ x 34’ → 125’ height
- Deadend → 12’ x 47’ → 125’ height

Long Span
- Deadend → 15’ x 67’ → 205’ height
  x3 (3-pole)
Operational Considerations

- **Terrain** → access for construction & maintenance
- **Additional Support** → lighting, supplemental power
- **Ground** → geotech, grounding, groundwater, flood plains
- **Flowing Water** → flood plains, debris damage, erosion
Flood Plain Factors

- Height of foundation vs. flood plain levels
- Loading from flowing water
- Loading & damage from debris
- Erosion from water flow
- Soil bearing assumptions
100 Year Flood Levels
100 Year Flood Levels
Site Conditions

- Site Access → can we get there
- Space Availability → can we build there
- Weather → when access not viable
- Maintenance → when go there
- Environmental → limitations to accessibility
Installation Factors

- Site access for materials & equipment
- Limitations to construction sequence for installation
- Locations to set-up construction equipment
- Environmental factors that would limit construction
- Scheduling & coordination concerns
Construction Methods

- Experience & expertise of contractors
- Detailed review of methods (alternatives) & expectations
- Site access requirement reviews
- Review of equipment to be used during installation
- Observation with design support during installation
TRANSMISSION LONG SPAN DESIGN

QUESTIONS?

Duane Phillips
Stanley Consultants, Inc.