Transmission Line Design-Advanced
TADP 640

Steel Poles-Design Considerations - Miscellaneous Topics
Module 2.11

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ASCE/SEI 48-05 (2006)

- Reference document
Discussion Topics

- Anchor bolts design considerations
- Base plate design considerations
- Wood equivalent steel poles
- Wood vs. Steel pole Analysis
Anchor Bolts Design Considerations

- Anchor bolts
  - Structural capability
    - They shall be structurally capable of carrying loads such as tensile, compressive and shear loads
  - Capability to transfer load to concrete
    - They should be designed to transfer the loads to concrete with enough embedment length
Anchor Bolts Design Considerations

- Bolts subjected to tension
  - Tensile stress in the bolt = \( \frac{T_s}{A_s} \)
  - Where
    - \( T_s = \) bolt tensile force
    - \( A_s = \) stress area = \( \frac{\pi}{4} (d - (0.9743/n))^2 \)
    - \( d = \) nominal diameter of the bolt
    - \( n = \) number of threads per unit of length
Anchor Bolts Design Considerations

- Tensile stresses in bolts shall not exceed tensile stress permitted ($F_t$)
  - Bolts with no specified proof-load stress or yield stress
    - $F_t = 0.60 F_u$
    - $F_u = \text{specified minimum tensile stress of bolt}$

- In case of bolts with specified proof load stress or yield stress
  - other equations recommended by ASCE/SEI 48-05
Anchor Bolts Design Considerations

- Bolts subjected to shear force
  - \( \frac{V}{A_s} \leq F_v = 0.65 F_y \)
  - Where
    - \( V \) = shear force on bolt
    - \( A_s = \frac{\pi}{4} (d - (0.9743/n))^2 \)
    - \( F_v \) = shear stress permitted
    - \( F_y \) = specified minimum yield stress of bolt material
    - \( d \) = nominal diameter of the bolt
    - \( n \) = number of threads per unit of length
Anchor Bolts Design Considerations

- Bolts with combined shear and tension
- Permitted axial tensile stress in conjunction with shear stress = $F_{t(v)}$
  - $F_{t(v)} = F_t [(1-(f_v/F_v)^2)]^{0.5}$
  - Where
    - $F_v = \text{shear stress permitted}$
    - $F_t = \text{tensile stress permitted}$
    - $f_v = \text{shear stress on effective area } (V/A_s)$
  - Combined tensile and shear stresses taken at the same cross section of bolt
Anchor Bolts Design Considerations

- Development length of bolt

- The bars must be embedded in concrete sufficiently so that tensile forces can develop
  - If there is inadequate development length
    - either the bars will pull out or
    - split the surrounding concrete
Anchor Bolts Design Considerations

- Development length of threaded reinforcing bar = \( L_d = l_d \alpha \beta \gamma \)
  - Where
    - \( l_d \) = basic development length of anchor bolt
    - \( \alpha = \)
      - 1.0 if \( F_y = 60 \text{ ksi} \)
      - 1.2 if \( F_y = 75 \text{ ksi} \)
    - \( \beta = \)
      - 0.8 if bolt spacing up to and including 6 in. on center
      - 1.0 if bolt spacing less than 6 in. on center
    - \( \gamma = \frac{A_{s \text{ (req'd)}}}{A_g} \)
      - \( A_g \) = gross area of anchor bolt
      - \( A_{s \text{ (req'd)}} \) = required tensile stress area of bolt
Anchor Bolts Design Considerations

- \( l_d = \) basic development length of anchor bolt for #18 bars

- \( l_d = \frac{(3.52 \Theta F_y)}{\sqrt{f'_c}} \)
  - where
    - \( F_y = \) specified minimum yield stress of anchor bolt
    - \( F'_c = \) specified compressive strength of concrete
    - \( \Theta = 1.00 \) for \( F_y \) and \( f'_c \) in ksi

- For equations of #11 & #14 bars, refer ASCE/SEI 48-05
Base Plates Design Considerations

- No standards for analysis of base plates of tubular pole structures

- Steel pole Fabricators developed
  - Guidelines based on empirical results
  - A lot testing performed to derive these guidelines and these information is highly proprietary

- Guide lines depends on own specific detailing and manufacturing practices, they differ among fabricators

- If we use a commercial software for analysis of a base plated steel pole, the software result may not represent fabricators’ base plate analysis
Base Plates Design Considerations

Bend lines
- Possible bend lines are sections 1-1, 2-2, 3-3
- Bend line orientation depends on
  - magnitude and direction of the resultant overturning moments for different load cases

Source: ASCE/SEI 48-05
Effective width of bend lines ($b_{eff}$)

- Width of base plate that is effective in resisting a specific resultant moment is called effective width of bend lines.

- It is not full length of a line that extends from one edge to the other.

Source: ASCE/SEI 48-05
The bending stress $f_b$ for an assumed bend line < yield stress $F_y$

$$f_b = \left(\frac{6}{t^2 b_{\text{eff}}}\right) (BL_1 c_1 + BL_2 c_2 + \ldots + \ldots)$$

- where
  - $t =$ base plate thickness
  - $BL =$ bolt load
  - $c =$ shortest distance from anchor bolt to bend line
  - $b_{\text{eff}} =$ effective width of bend line

Source: ASCE/SEI 48-05
Base Plates Design Considerations

Calculation of load in anchor bolt (BL)

- Assumption: base plate is infinitely rigid body
  - $P =$ total vertical load at the base of the pole
  - $M_x =$ base bending moment about $x-x$ axis
  - $M_y =$ base bending moment about $y-y$ axis

Source: ASCE/SEI 48-05
Wood Equivalent Steel Poles

- Wood poles classified into different classes

- Steel poles which are approximately equivalent to standard wood pole classes ‘in terms load carrying capacity’ are known as ‘wood equivalent steel poles’

- Examples of wood equivalent steel poles
  - T&B : LD poles
  - Valmont: SW poles

- Some advantages of wood equivalent steel poles over wood poles:
  - Normally lighter than wood or concrete
  - Less maintenance as compared to wood poles
  - Longer life than wood poles
Classification of Wood Poles Based on Size (ANSI Specifications)

- ANSI (American National Standards Institute) classified poles into different classes
  - based on minimum circumference of the pole 6 feet from the butt

- The horizontal loads (see the next slide) at 2ft from top of pole are basis for the determination of minimum circumference of the pole

- See the file Wood Poles - Geometry in this course material for geometry of wood poles as per ANSI.
## Classification of Wood Poles Based on Size (ANSI Specifications)

<table>
<thead>
<tr>
<th>Class</th>
<th>Horizontal load (lbs)</th>
<th>Class</th>
<th>Horizontal load (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H6</td>
<td>11,400</td>
<td>H1</td>
<td>5,400</td>
</tr>
<tr>
<td>H5</td>
<td>10,000</td>
<td>1</td>
<td>4,500</td>
</tr>
<tr>
<td>H4</td>
<td>8,700</td>
<td>2</td>
<td>3,700</td>
</tr>
<tr>
<td>H3</td>
<td>7,500</td>
<td>3</td>
<td>3,000</td>
</tr>
<tr>
<td>H2</td>
<td>6,400</td>
<td>4</td>
<td>2,400</td>
</tr>
</tbody>
</table>

Note: Horizontal load applied 2 ft from the top of the pole
Classification of Wood Poles Based on Size (ANSI Specifications)

- The different classes of the poles are
  - Class 10, 9, 8, 7, 6, 5, 4, 3, 2, 1, H1, H2, H3, H4, H5, and H6

  - The class 10 pole is smallest in size (diameter or circumference) and hence capacity is low

  - whereas class H6 is relatively largest in size and hence have highest capacity

- Normal sizes of wood poles for transmission application are class 2 or higher
Wood Equivalent Steel Poles

- ANSI assumes a horizontal force (H) applied at two feet from the top of the pole.

- In this classification, pole is assumed to be buried at 10%+2 feet.

- Therefore one can calculate the ground line moment due to the horizontal force (applied at 2 ft from top).

- Based on the ground line moment, required section modulus of wood pole section and hence diameter of the pole at ground line can be determined.

- Thus the minimum circumference ($\Pi \times$ diameter) requirement for a given class was established by the ANSI.
Wood Equivalent Steel Poles

- Class of the wood pole = H1
- Species of the pole = Douglas Fir (rupture bending stress = 8000 psi)
- Length of the pole = 80 feet
- Depth of embedment = 10 ft
- Length of the pole above ground = 80-10 = 70 feet
- Horizontal force (H) applied at 2 feet from top = 5.3 kips
- Ground line moment = 5.3 x (70-2) = 360.4 kips-ft
  = 360.4 x1000x12 lb-in
Wood Equivalent Steel Poles

- Based on ground line moment, one can determine required ground line diameter of pole

- Required section modulus of the pole at ground line =
  ground line moment / rupture bending stress
  \[ = \frac{(360.4 \times 1000 \times 12)}{8000} = 540.6 \text{ in}^3 \]

- \( \pi \frac{d^3}{32} = 540.6 \)

- Required ground line diameter = \( d = 17.66 \text{ in} \)
Wood Equivalent Steel Poles

- Note: Refer ANSI tables for 80 ft, Douglas Fir, class H1
- Minimum circumference of pole at top = 29 in
- Minimum circumference at 6 ft from butt = 57 in
- Diameter at pole top = $\frac{29}{\pi} = 9.231$ in
- Diameter at 6 ft from butt = $\frac{57}{\pi} = 18.144$ in
- Diameter at ground line = $9.231 + (18.144-9.231) \frac{(80-10)}{(80-6)} = 17.66$ in
- ANSI dimensions matching with the derived diameter through load calculation in earlier slide
- Following similar methodology, wood equivalent steel poles developed.
Wood Equivalent Steel Poles

- In case of steel poles also, H applied at 2 feet from top of the pole

- For a given class of steel pole, H is same for wood poles and wood equivalent steel poles

- However ground line moment for steel poles is calculated by multiplying with a ratio of 2.5/4.0 (Valmont SW series)
  - This ratio accounts for the differences in overload factors required by the NESC code for Grade B construction for wood and steel
Wood Equivalent Steel Poles

- For NESC District load case-Rule250B (Grade B construction)-Transverse load
  - NESC(1977)
    - Overload factor for wood poles = 4.0
    - Overload factor for steel poles = 2.5
    - In this case, strength factor for wood and steel is 1.0

  OR
  - NESC (current)
    - This is approximately same as applying an overload factor of 2.5 for wood and steel poles and
      - strength factor of 0.65 for wood pole
      - strength factor of 1.0 for steel pole
Wood Equivalent Steel Poles

- Class 2 wood pole
  - 80 feet wood pole
  - Ground line moment = 250.2 kips-ft

- Class 2 wood equivalent steel pole
  - 80 feet wood pole
  - Ground line moment = 250.2 \times \frac{2.5}{4} = 157 \text{ kips-ft}
  - Determine section of steel pole that provide the capacity at 157 kips-ft at ground line
  - Assume that the ground line moment variation from point of horizontal load (H at 2 ft from top) to ground line is linear
  - Both poles rated at the same class
Wood Equivalent Steel Poles

Source: Valmont SW series
Wood Equivalent Steel Poles

- Example:
  - Pole length = 80 ft
  - The maximum ground line moment (including overload factors) = 316 kip-ft
  - Select a wood equivalent steel pole with a catalogue no of (Valmont SW series) S 80-319 (class H-3) pole
  - Ground line moment capacity of this pole = 319 kip-ft > 316 kip-ft
  - Note: Valmont SW series are provided in readings
Wood vs Steel poles

- Life-cycle costs of poles
  - Initial costs
  - Maintenance costs and
  - Replacement/Rebuild costs
  - Reliability costs

- PV analysis of life-cycle costs
  - Inflation rate
  - Discount rate
  - Present value
Wood vs Steel Poles Analysis

- **Inflation**
  - rise in general level of prices of goods and services over time

- **Inflation rate**
  - rate at which the general level of prices for goods and services are rising

- **Calculation of inflated cost**
  - If cost of a product today = $C$ dollars and
  - inflation rate is 3%, then
  - Cost of the product at ‘n’ years from today = $C(1+3/100)^n$
Wood vs Steel Poles Analysis

- **Present value**
  - Current worth of a future sum of money or stream of cash flows
  - Future cash flows discounted at a certain discount rate

- **Discount rate**
  - Rate of return that could be earned on an investment with similar risk
  - Higher the discount rate, the lower the present value of the future cash flows
Wood vs Steel Poles Analysis

- PV = $C1/ (1+r)^n
  - If C1 dollars are spend at ‘n’ years from today (C1 are dollars in spend years, i.e. inflated), and
  - the discount rate is ‘r’
  - then the present value of cost is calculated using the equation shown above
Wood vs Steel Poles Analysis

Case Study

- For a given line design, let us say we need class 1 pole. We have a choice of wood or wood equivalent steel pole
- All the costs in today’s dollars

(a) Initial costs:
- Line cost with wood poles = 2.4 million
- Line cost with steel poles = 2.5 million
- Wood pole cheaper than steel pole by $1000 (including material and construction)
- 100 structures in the line
- Total savings with wood = $ 100,000
Wood vs Steel Poles Analysis

- (b) Wood poles maintenance costs
  - Wood pole ground line inspection cost = $50 per pole
  - Inspections are done for every 10 years after 20 years of the line installation

- (c) Replacement costs
  - During inspection, 1% of the wood poles replaced due to the ground line strength deterioration
  - i.e. 1 pole out of 100 poles need to be replaced after inspection

- (d) Line rebuild costs
  - Wood pole line has to be rebuilt after 50 years because of end of life of wood poles
  - Line rebuilt cost = 2.4 million costs
## Wood vs Steel Poles Analysis

<table>
<thead>
<tr>
<th>Costs in today’s dollars</th>
<th>Costs in the year they incurred (with 3% inflation)</th>
<th>Discounted costs</th>
<th>Present Value (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Costs</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$2.4 million</td>
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## Wood vs Steel Poles Analysis

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<tr>
<th>Item</th>
<th>Costs in today’s dollars</th>
<th>Costs in the year they incurred (with 3% inflation)</th>
<th>Discounted costs (with 8% discount factor)</th>
<th>Present Value (dollars)</th>
</tr>
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<tbody>
<tr>
<td><strong>Inspection costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At 20 years</td>
<td>100 poles*$50/pol e= $5000</td>
<td>5000 (1.03)^20 = $9030</td>
<td>$9030/(1.08)^20 = $1937</td>
<td>$1937</td>
</tr>
<tr>
<td>At 30 years</td>
<td>100 poles*$50/pol e= $5000</td>
<td>5000 (1.03)^30 = $12,136</td>
<td>$12,136/(1.08)^30 = $1206</td>
<td>$1206</td>
</tr>
<tr>
<td>At 40 years</td>
<td>100 poles*$50/pol e= $5000</td>
<td>5000 (1.03)^40 = $16,310</td>
<td>$16,310/(1.08)^40 = $751</td>
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<td><strong>Replacement costs</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>At 20 years</td>
<td>1 pole x $15000 = $15000</td>
<td>15000 (1.03)^{20} = $27091</td>
<td>$27091/(1.08)^{20} = $5812</td>
<td>$5812</td>
</tr>
<tr>
<td>At 30 years</td>
<td>1 pole x $15000 = $15000</td>
<td>15000 (1.03)^{30} = $36409</td>
<td>$36409/(1.08)^{30} = $3618</td>
<td>$3618</td>
</tr>
<tr>
<td>At 40 years</td>
<td>1 pole x $15000 = $15000</td>
<td>15000 (1.03)^{40} = $48,930</td>
<td>$48930/(1.08)^{40} = $2252</td>
<td>$2252</td>
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### Wood vs Steel Poles Analysis

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<td>Line rebuild cost at 50 years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4 million</td>
<td>2.4 ((1.03)^{50}) = $10.52 million</td>
<td>($10.52/(1.08)^{50}) = $224,299</td>
<td>$224,299</td>
</tr>
</tbody>
</table>
Wood vs Steel Poles Analysis

- **Summary**
  - Present Value (PV) of life-cycle costs for wood pole line option = 2.4 million + $239,875 = $2,639,875
  - Against steel pole line PV cost of $2,500,000
  - Based on life-cycle costs and PV analysis, in this case steel pole option is cheaper
  - Please note this is just an example to analyze wood vs. steel option, do not make any **GENERAL** conclusions out of this example