Transmission Line Design-Advanced
TADP 640

Steel Poles-Design Considerations - Miscellaneous Topics

Module 2.11

Dr. Prasad Yenumula

GONZAGA UNIVERSITY

Transmission & Distribution Program

ASCE/SEI 48-05 (2006)

- Reference document
  - ASCE/SEI 48-05 (2006) Design of Steel Transmission Pole Structures, ASCE Standard, American Society of Civil Engineers, Reston, Virginia

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 the designed to transfer the loads to concrete with enough embedment length

Anchor Bolts Design Considerations

- Bolts subjected to tension
  - Tensile stress in the bolt = T_s/A_s
  - Where
    - Ts = bolt tensile force
    - A_s = stress area = $\pi/4\ (d - (0.9743/n))^2$
    - 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 = 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
  - $V/A_s \leq F_v = 0.65\ F_y$
  - Where
    - V = shear force on bolt
    - $A_s = \pi/4\ (d - (0.9743/n))^2$
    - 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 = shear stress permitted
    - F_t = tensile stress permitted
    - f_v = 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
    - α =
      - 1.0 if Fy = 60 ksi
      - 1.2 if Fy = 75 ksi
    - β =
      - 0.8 if bolt spacing up to and including 6 in. on center
      - 1.0 if bolt spacing less than 6 in. on center
    - $\gamma = A_{s\ (req'd)} / A_g$
      - A_g = gross area of anchor bolt
      - $A_{s\ (req'd)}$ = required tensile stress area of bolt

Anchor Bolts Design Considerations

- l_d = basic development length of anchor bolt for #18 bars
- $l_d = (3.52\ \Theta\ F_y) / (\sqrt{(f'_c)})$
  - where
    - F_y = specified minimum yield stress of anchor bolt
    - F'_c = specified compressive strength of concrete
    - Θ = 1.00 for F_y and f'_c in ksi
- For equations of #11 & #14 bars, refer ASCE/SEI 48-05

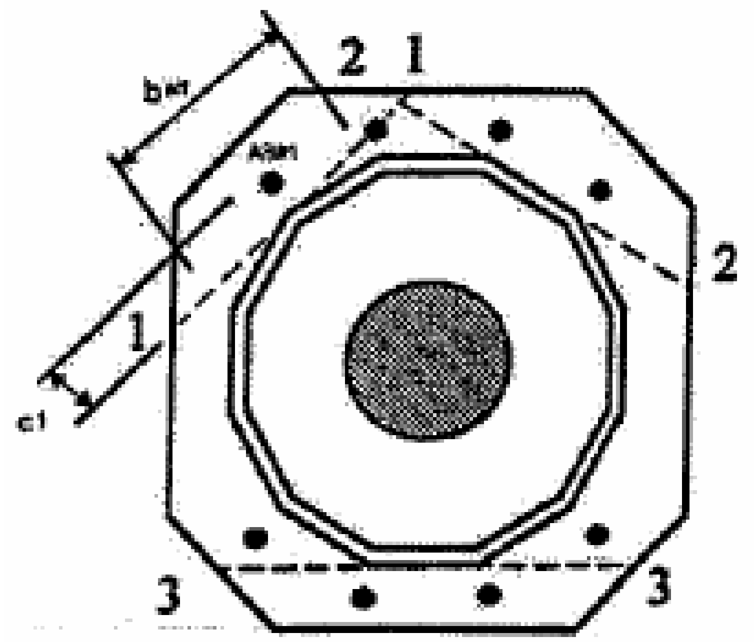
Base Plates Design Considerations

- 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

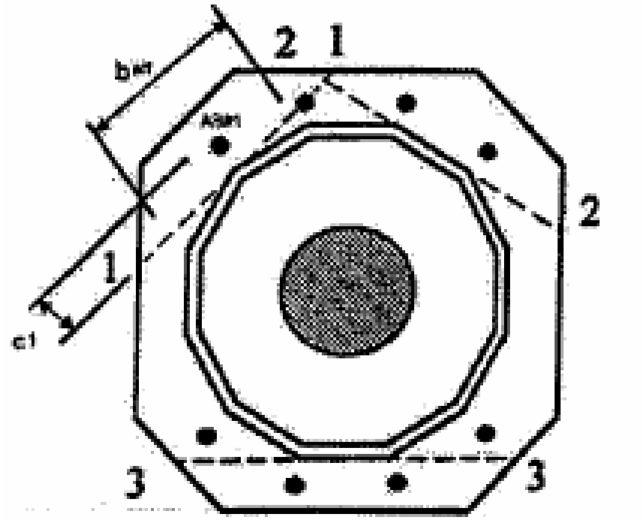


Source: ASCE/SEI 48-05

Base Plates Design Considerations

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

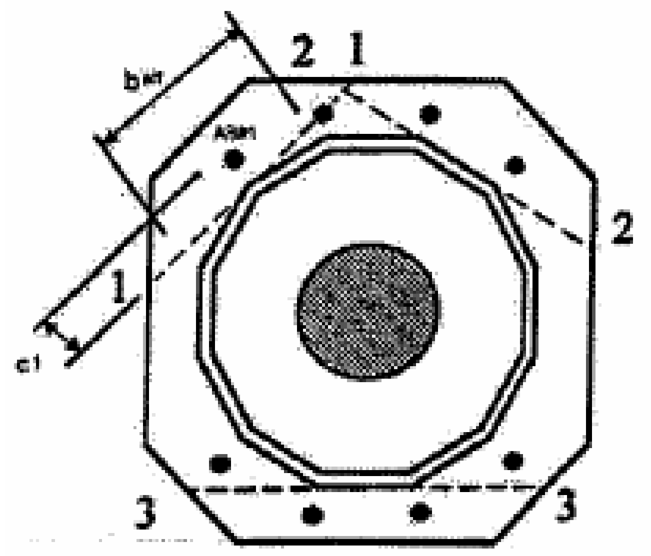


Source: ASCE/SEI 48-05

Base Plates Design Considerations

- The bending stress f_b for an assumed bend line < yield stress F_y

- $f_b = (6/\ t^2\ b_{eff})\ (BL_1c_1+BL_2c_2+\ldots\ldots+..)$
  - where
    - t= base plate thickness
    - BL= bolt load
    - c = shortest distance from anchor bolt to bend line
    - b_{eff} = effective width of bend line

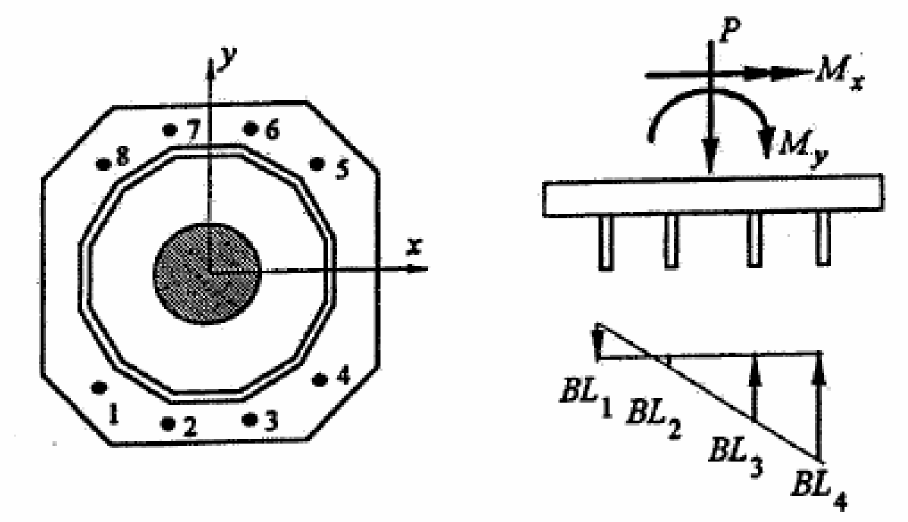


Source: ASCE/SEI 48-05

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 in to 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)

Class	Horizontal load (lbs)	Class	Horizontal load (lbs)
H6	11,400	H1	5,400
H5	10,000	1	4,500
H4	8,700	2	3,700
H3	7,500	3	3,000
H2	6,400	4	2,400

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 (Π x 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
  $= (360.4 \times 1000 \times 12) / 8000 = 540.6 \text{ in}^3$
- $\Pi d^3/32 = 540.6$
- Required ground line diameter = d = 17.66 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 = 29/Π = 9.231 in
- Diameter at 6 ft from butt = 57/Π = 18.144 in

- Diameter at ground line = 9.231 + (18.144-9.231) (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

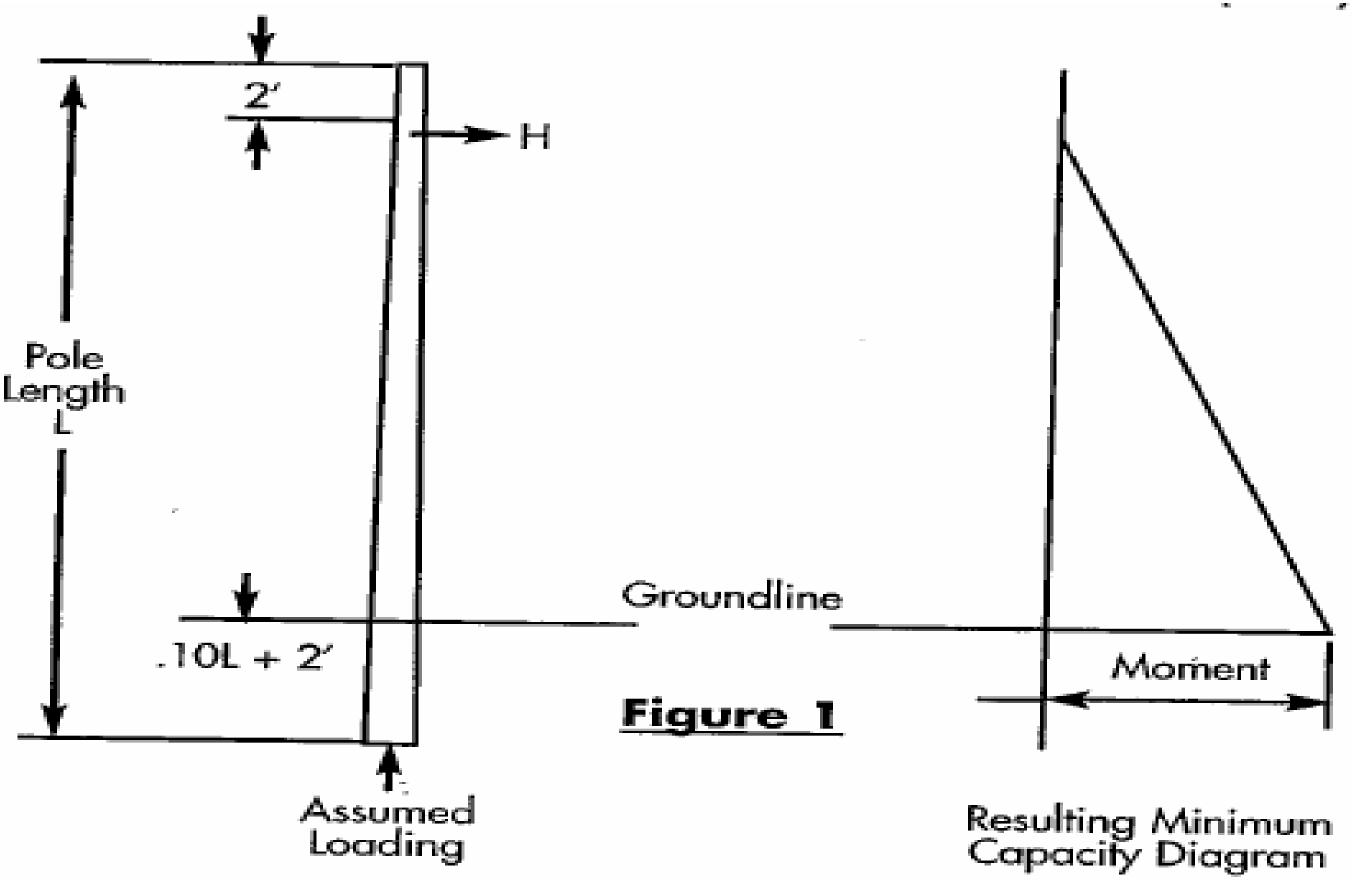
Wood Equivalent Steel Poles

- 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 x 2.5/4 = 157 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

Costs in today's dollars	Costs in the year they incurred (with 3% inflation)	Discounted costs	Present Value (dollars)
Initial Costs			
$2.4 million	$2.4 million	$2.4 million	$2.4 million

Wood vs Steel Poles Analysis

Item	Costs in today's dollars	Costs in the year they incurred (with 3% inflation)	Discounted costs (with 8% discount factor)	Present Value (dollars)
		Inspection costs		
At 20 years	100 poles*$50/pole= $5000	$5000 (1.03)^{20} =$ $9030	$\$9030/(1.08)^{20} =$ $1937	$1937
At 30 years	100 poles*$50/pole= $5000	$5000 (1.03)^{30} =$ $12,136	$\$12,136/(1.08)^{30}$ = $1206	$1206
At 40 years	100 poles*$50/pole= $5000	$5000 (1.03)^{40} =$ $16,310	$\$16,310/(1.08)^{40}$ = $751	$751

Wood vs Steel Poles Analysis

Item	Costs in today's dollars	Costs in the year they incurred (with 3% inflation)	Discounted costs (with 8% discount factor)	Present Value (dollars)
		Replacement costs		
At 20 years	1 pole x \$15000 = \$15000	$15000\ (1.03)^{20}$ = \$ 27091	$\$27091/(1.08)^{20} =$ \$5812	\$5812
At 30 years	1 pole x \$15000 = \$15000	$15000\ (1.03)^{30}$ = \$ 36409	$\$36409/(1.08)^{30}$ =\$3618	\$3618
At 40 years	1 pole x \$15000 = \$15000	$15000\ (1.03)^{40}$ = \$ 48,930	$\$48930/(1.08)^{40}$ =\$2252	\$2252

Wood vs Steel Poles Analysis

Costs in today's dollars	Costs in the year they incurred (with 3% inflation)	Discounted costs	Present Value (dollars)
Line rebuild cost at 50 years			
2.4 million	2.4 $(1.03)^{50}$ = $10.52 million	$10.52/$(1.08)^{50}$ = $224,299	$224,299

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