ID 1033

STRUCTURAL DESIGN AND DEFORMATION ANALYSIS OF FRP LAMP POLES

Hong Lei Yi [1], Zhu Lin Zhou [2] and Xue Dong Wu [3]

[1] *Department of Textiles, Xinjiang Institute of Technology, Urumqi 830008, China*

[2] *Shanghai FRP Research Institute, Shanghai 200126, China*

[3] *Shanghai Elite Textile Co. Ltd., Shanghai 201100, China*

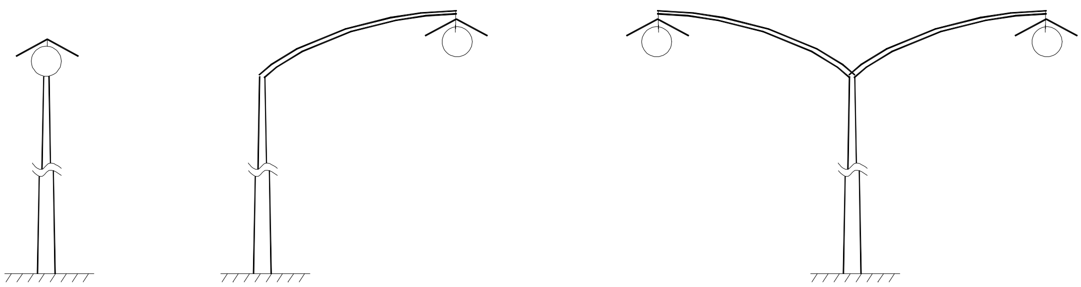
SUMMARY: FRP lamp poles have been used in municipal engineering due to their superior strength-to-weight ratio, high corrosion resistance, maintain-free, and fine-looking appearance etc. However, because the diameter, wall thickness and elastic modulus is variational along the length direction of the pole, it is difficult to analysis their mechanical properties. In the paper, the external load and internal stress on the lamp poles were calculated on the basis of American ANSI C136.20, and the theoretical formula of the lamp poles strength was obtained according to FRP design standard. Then, the wall thickness of lamp poles were given out in accordance with maximum permitted stress, and were compared to the ones which were calculated according to maximum permitted deflection. The results shown that the strength of FRP lamp poles have always more than needed, so their structure should be designed according on the maximum permitted deflection criterion.

KEYWORDS: FRP Lamp Poles, Allowable Stress, Allowable Deflection, Wall Thickness, Gradient Parameters

FRP (Fiber Reinforced Plastic) lamp poles have been used in municipal engineering due to their superior strength-to-weight ratio, high corrosion resistance and fine-looking appearance etc. However, because the diameter, wall thickness and elastic modulus is variational along the length direction of the pole, it is difficult to analysis the mechanical properties. In this paper the structural design of FRP lamp poles is discussed in detail.

EXTERNAL LOAD OF LAMP POLE

The lamp pole can be divided into I-pole and Y-pole. Moreover, the Y-pole can be divided into r-pole (single arm) and T-pole (double arms), as shown in Fig. 1.



(a) I-pole (b) r-pole (c) T-pole

Fig. 1 Schematic diagram of structure of various lamp poles

I-Type Lamp Pole

a) Wind-load on the lamp pole

$$F_1 = 0.0399685v^2 C_d C_h (D_1 + D_2)H \tag{1}$$

b) Wind-load on the Lamp and lanterns

$$F_2 = 0.079937v^2 C_d^{'} C_h^{'} E \tag{2}$$

Thus, maximum bending moment on the lamp pole bottom can be obtained by

$$M_b = F_1 \frac{(D_2 + 2D_1)H}{3(D_2 + D_1)} + F_2 H \tag{3}$$

In above equations (1)-(3), D_1 , D_2 is the diameter at lamp pole top and bottom, respectively. H is the total height of the lamp pole (m). V is wind speed(*Km/h*); C_d is the configuration coefficient of lamp pole. According on the American ANSI C136.20[1], C_d is equal to 1.1 when lamp pole is type of cylinder. C_h is the height coefficient of lamp pole. C_h is equal to 1.0 while $4.27m \le H \le 8.84m$ and is equal to 1.10 while $8.84m \le H \le 14.94m$. For the lamp and lanterns, $C_h^{'}$ is same as above, $C_d^{'}$ is equal to 1.2 (lean to safety). However, it can also be assume as 0.5 if lamp and lanterns posses of round surface. E is projection area of lamp and lanterns, and E is equal to $0.12m^2$.

Y-Type Lamp Pole

- r-type lamp pole

a) Wind-load on the lamp pole

$$F_1 = 0.0399685v^2 C_d C_h (D_1 + D_2)H_2 \tag{4}$$

b) Wind-load on the lamp and lanterns

F_2 is same as equation (2)

c) Wind-load on the arms of lamp pole

$$F_3 = 0.079937v^2 C_d^{''} C_h^{''} R \tag{5}$$

d) Bending moment by support and lamp

$$M_a = L_b W_b + W_a L_b / 2 \tag{6}$$

In above equations (4)-(6), H_2 is the height of straight part of lamp pole. $C_d^{''}$ and $C_h^{''}$ refer to the above-mentioned $C_d^{'}$ and $C_h^{'}$. R is the projection area of support, and is equal to $0.11m^2$. L_b is the length of the pole arm. W_b is the weight of the lamp and lanterns, and is equal to 49*N*. W_a the weight of the pole arms, and is equal to 69*N*. Assume that support

is long and thin, and its thickness variety is very little, thus the distance from the center of body of support to the center line of lamp pole is think as $L_b/2$.
The maximum bending moment on the lamp pole bottom can be given by

$$M_b = \left\{ \left[F_1 \frac{(D_2 + 2D_1)H_2}{3(D_2 + D_1)} + F_2 H + F_3 (H_2 + \frac{H_1}{2}) \right]^2 + M_a^2 \right\}^{0.5} \quad (7)$$

where, H_1 is the projection height of bending part of lamp pole, and total height of lamp pole is H, and $H = H_1 + H_2$.

- T-type lamp pole

a) Wind-load on the lamp pole

F_1 is same as equation (4)

b) Wind-load on the lamp and lanterns

$$F_2 = 0.159874 v^2 C_d^{'} C_h^{'} E \quad (8)$$

c) Wind-load on the arms of lamp pole

$$F_3 = 0.159874 v^2 C_d^{''} C_h^{''} R \quad (9)$$

d) $M_a = 0$

e) Maximum bending moment on the lamp pole bottom

$$M_b = F_1 \frac{(D_2 + 2D_1)H_2}{3(D_2 + D_1)} + F_2 H + F_3 (H_2 + \frac{H_1}{2}) \quad (10)$$

DESIGN OF WALL THICKNESS OF LAMP POLE BASED ON MAXIMUM STRESS CRITERION

If maximum stress criterion is adopted to calculate the thickness of pipe wall, we have,

$$\sigma = \frac{M_b}{W} = \frac{4M_b}{\pi (D_2 - T_0)^2 T_0} \le [\sigma] \quad (11)$$

where, T_0 is the nominal wall thickness of pole, and $[\sigma]$ is the allowable stress.

According to the testing results, the bending strength of lamp pole material is equal to 320*MPa*. If the discrete coefficient *Cv* is assume as 10%, the statistical value of materials strength, which is over reliability of 99.9%, can be given:

$$\sigma_p = \sigma_B (1 - 3Cv) = 320(1 - 3 \times 0.1) = 240MPa \quad (11a)$$

If the safety index is assume as 3, the allowable stress is：

$$[\sigma] = \sigma_p / 3 = 74.67 \approx 75MPa \tag{11b}$$

Since equation (11) is a transcendental equation about variable T_0, it is impossible to extract analytic expression to T_0. In the paper, a numerical approach using law of one dividing two[2] is used to seek for approximative value of T_0, as shown in Fig. 2.

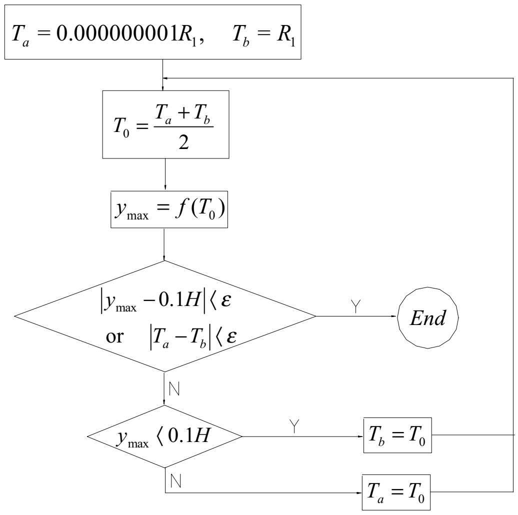


Fig. 2 Law of one dividing into two algorithm

DESIGN OF WALL THICKNESS OF LAMP POLE BASED ON MAXIMUM DEFLECTION CRITERION

The elastic modulus, radius, and wall thickness at the top of the lamp pole is noted as E_0、R_1 and T_0 respectively, and gradient parameters from the top to the bottom of the lamp pole is: $1/S_1$、$1/S_2$ and $1/S_3$ respectively. Regarding lamp pole as a cantilever beam, and the deflection equation can be given:

$$\frac{d^2 y}{dx^2} = \frac{M_x}{E_x I_x} = \frac{Fx}{\pi(E_0 + x/S_1)(R_1 + x/S_2)^3 (T_0 + x/S_3)} \tag{12}$$

Thus, the deflection curve equation of lamp pole can be obtained:

$$\begin{aligned} y = \frac{F}{\pi}[& \frac{-E_0 S_1^2 S_2^3 S_3}{(E_0 S_1 - S_3 T_0)(E_0 S_1 - R_1 S_2)^3}(E_0 S_1 + x)(\ln(E_0 S_1 + x) - 1) \\ & + \frac{R_1 S_1 S_2^4 S_3}{2(E_0 S_1 - R_1 S_2)(R_1 S_2 - S_3 T_0)(R_1 S_2 + x)} \\ & - \frac{E_0 S_1^2 S_2^3 S_3^2 T_0 - R_1^2 S_1 S_2^5 S_3}{(E_0 S_1 - R_1 S_2)^2 (R_1 S_2 - S_3 T_0)^2} \ln(R_1 S_2 + x) \\ & + \frac{R_1^3 S_1 S_2^6 S_3 + E_0^2 S_1^3 S_2^3 S_3^2 T_0 - 3E_0 R_1 S_1^2 S_2^4 S_3^2 T_0 + E_0 S_1^2 S_2^3 S_3^3 T_0^2}{(E_0 S_1 - R_1 S_2)^3 (R_1 S_2 - S_3 T_0)^3}(R_1 S_2 + x)(\ln(R_1 S_2 + x) - 1) \\ & - \frac{S_1 S_2^3 S_3^2 T_0}{(E_0 S_1 - S_3 T_0)(R_1 S_2 - S_3 T_0)^3}(T_0 S_3 + x)(\ln(T_0 S_3 + x) - 1) + Cx + D] \end{aligned} \tag{13}$$

where,

$$
\begin{aligned}
C = & \frac{E_0 S_1^{2} S_2^{3} S_3}{(E_0 S_1 - S_3 T_0)(E_0 S_1 - R_1 S_2)^3} \ln(E_0 S_1 + H) \\
& + \frac{R_1 S_1 S_2^{4} S_3}{2(E_0 S_1 - R_1 S_2)(R_1 S_2 - S_3 T_0)(R_1 S_2 + H)^2} \\
& + \frac{E_0 S_1^{2} S_2^{3} S_3^{2} T_0 - R_1^{2} S_1 S_2^{5} S_3}{(E_0 S_1 - R_1 S_2)^2 (R_1 S_2 - S_3 T_0)^2 (R_1 S_2 + H)} \\
& - \frac{R_1^{3} S_1 S_2^{6} S_3 + E_0^{2} S_1^{3} S_2^{3} S_3^{2} T_0 - 3E_0 R_1 S_1^{2} S_2^{4} S_3^{2} T_0 + E_0 S_1^{2} S_2^{3} S_3^{3} T_0^{2}}{(E_0 S_1 - R_1 S_2)^3 (R_1 S_2 - S_3 T_0)^3} \ln(R_1 S_2 + H) \\
& + \frac{S_1 S_2^{3} S_3^{2} T_0}{(E_0 S_1 - S_3 T_0)(R_1 S_2 - S_3 T_0)^3} \ln(T_0 S_3 + H)
\end{aligned} \tag{13a}
$$

$$
\begin{aligned}
D = & \frac{E_0 S_1^{2} S_2^{3} S_3}{(E_0 S_1 - S_3 T_0)(E_0 S_1 - R_1 S_2)^3} (E_0 S_1 + H)(\ln(E_0 S_1 + H) - 1) \\
& - \frac{R_1 S_1 S_2^{4} S_3}{2(E_0 S_1 - R_1 S_2)(R_1 S_2 - S_3 T_0)(R_1 S_2 + H)} \\
& + \frac{E_0 S_1^{2} S_2^{3} S_3^{2} T_0 - R_1^{2} S_1 S_2^{5} S_3}{(E_0 S_1 - R_1 S_2)^2 (R_1 S_2 - S_3 T_0)^2} \ln(R_1 S_2 + H) \\
& - \frac{R_1^{3} S_1 S_2^{6} S_3 + E_0^{2} S_1^{3} S_2^{3} S_3^{2} T_0 - 3E_0 R_1 S_1^{2} S_2^{4} S_3^{2} T_0 + E_0 S_1^{2} S_2^{3} S_3^{3} T_0^{2}}{(E_0 S_1 - R_1 S_2)^3 (R_1 S_2 - S_3 T_0)^3} (R_1 S_2 + H)(\ln(R_1 S_2 + H) - 1) \\
& + \frac{S_1 S_2^{3} S_3^{2} T_0}{(E_0 S_1 - S_3 T_0)(R_1 S_2 - S_3 T_0)^3} (T_0 S_3 + H)(\ln(T_0 S_3 + H) - 1) - C \cdot H
\end{aligned} \tag{13b}
$$

when $x=0$, the maximum deflection of lamp pole, y_{max} is

$$
\begin{aligned}
y_{\max} = & \frac{F}{\pi} \Big[\frac{E_0^{2} S_1^{3} S_2^{3} S_3}{(E_0 S_1 - S_3 T_0)(E_0 S_1 - R_1 S_2)^3} (1 - \ln(E_0 S_1)) \\
& + \frac{S_1 S_2^{3} S_3}{2(E_0 S_1 - R_1 S_2)(R_1 S_2 - S_3 T_0)} - \frac{E_0 S_1^{2} S_2^{3} S_3^{2} T_0 - R_1^{2} S_1 S_2^{5} S_3}{(E_0 S_1 - R_1 S_2)^2 (R_1 S_2 - S_3 T_0)^2} \ln(R_1 S_2) \\
& + \frac{R_1^{3} S_1 S_2^{6} S_3 + E_0^{2} S_1^{3} S_2^{3} S_3^{2} T_0 - 3E_0 R_1 S_1^{2} S_2^{4} S_3^{2} T_0 + E_0 S_1^{2} S_2^{3} S_3^{3} T_0^{2}}{(E_0 S_1 - R_1 S_2)^3 (R_1 S_2 - S_3 T_0)^3} (R_1 S_2)(\ln(R_1 S_2) - 1) \\
& - \frac{S_1 S_2^{3} S_3^{3} T_0^{2}}{(E_0 S_1 - S_3 T_0)(R_1 S_2 - S_3 T_0)^3} (\ln(T_0 S_3) - 1) + D \Big]
\end{aligned} \tag{14}
$$

where, F is the equivalent load. If relative structures of lamp pole are designed according to maximum allowable deflection criteria, we have:

$$
y_{\max} \le 0.1H \tag{15}
$$

Thus T_0 can be obtained from equation (14) and (15) by means of the numerical approach, which is same as equation (11).

RESULTS AND DISCUSSION

As a example, the design thickness of lamp pole for the ALB1000-type (straight pole, $H = 10m$, $D_1 = 0.1m$) was calculated on the basis of maximum allowable stress criteria, maximum allowable deflection, respectively, and shown in Fig. 3.

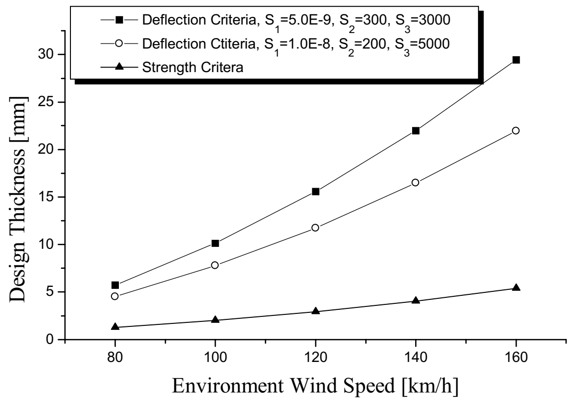


Fig. 3 Plot of design thickness vs. wind speed

From Fig.3, it can be noted that the wall thickness, which is designed on the basis of maximum allowable stress criteria, is more less than that designed by maximum allowable deflection criteria. From the point of safety, the structure of lamp pole should be designed according to the maximum allowable stress criteria. In addition, it can also be seen that the wall thickness of the pole, which designed on the basis of maximum allowable deflection criteria, is different from that calculated from different gradient parameters. So, it can be concluded that optimization of the gradient parameters of the lamp pole is possible.

REFERENCES

1. ANSI C136.20, AASHTO LTS－2 1995, U.S.A
2. Jiang, E. X. and Zhao, F. G., "Numerical approximation", Fudan University Publishing House, Shanghai, China, 1996, pp. 229-230.