Comparative Study on Power Poles with Various Shapes of Their Cross Sections

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Abstract

This paper presents a comparative study on power poles with various shapes of their cross sections. Prestressed concrete poles with four different shapes of cross sections including square solid, square hollow, I-shaped, and circular hollow sections are studied. Cross section areas, weights, costs, cracking moment capacity, and ultimate moment capacity of all sections are calculated and compared. The study shows that the square hollow section is the most efficient section, whereas the circular hollow section is the most economical one.

KEY WORDS: Electric pole, Prestressed concrete, Flexural strength

1. INTRODUCTION

Overhead transmission lines are a vital part of power supply system. The stability of electrical transmission lines is of importance to the reliability of power transmission system.

Provincial Electricity Authority (PEA) is a government enterprise responsible for transmission and distribution of electricity throughout Thailand except for the metropolitan area.

Power poles are the supporting structures of overhead transmission lines. The shape of the cross section has a bearing on the strength, weight, and cost of power poles.

PEA has more than 20 million electric poles utilized across Thailand [1]. Most PEA poles have square solid section and square solid section with lower portion of I-shaped section as shown in Figure 1. The poles are relatively heavy resulting in high cost and difficult installation.

With the electricity transmission and distribution role to fulfill, PEA embarks on enhancing the reliability of its power transmission system. However, there is a considerable difference of opinion concerning the best shape of cross section of poles. Therefore, this study compares power poles with various shapes of cross sections to determine the most efficient section of poles.

Figure 1. PEA prestressed concrete poles.

2. PRESTRESSED CONCRETE POLES

Most electric poles are made of prestressed concrete because of its strength, durability, and economy.

The prestressed concrete pole offers two main advantages: (1) the concrete is of a quality sufficient to resist penetration of water, and (2) in a prestressed concrete pole, the concrete is usually in compression, and cracking is not possible except under abnormal conditions of handling or service. These characteristics give the prestressed concrete pole greater advantages over the normal reinforced concrete pole and are the reason for the development and use of prestressed concrete poles [2].

Prestressed concrete poles can be made using static casting method or spun casting method. The spinning method makes poles with hollow core and dense concrete resulting in less weight and more strength [3]. Moreover, spun prestressed concrete is extremely resistant to corrosion and impact [4].

2.1 Strength

A prestressed concrete pole should be designed for the cracking moment capacity to exceed the moments calculated from service loads, and the ultimate moment capacity to exceed the moments calculated from the appropriate factored loads applied to the structure [5].

2.2 Cracking moment

Cracking moment is the moment at which the tensile stress in the extreme fiber of concrete reaches its modulus of rupture. Stress distribution across pole section at cracking moment is shown in Figure 2.

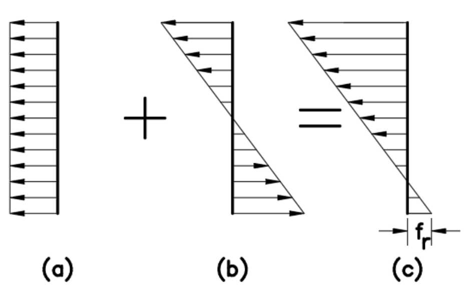

Figure 2. Stress distribution at cracking moment (a) Effective axial stress (b) Applied flexural stress (c) Resultant stress.

Cracking moment capacity can be calculated using the following equation [6]:

$$M_{cr} = S(f_r + \frac{P_{se}}{A_c}) \quad (1)$$

Where
S = Section modulus
f_r = Modulus of rupture of concrete
P_{se} = Strand force after losses
A_c = Area of concrete section

2.3 Ultimate moment

Ultimate moment is the moment at which a pole reaches its failure. Stress distribution across pole section at ultimate moment is shown in Figure 3.

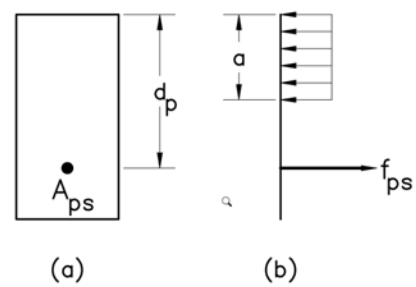

Figure 3. Stress distribution at ultimate moment (a) Pole section (b) Stress distribution.

Ultimate moment capacity can be determined using the following equation [7]:

$$M_n = A_{ps} f_{ps} (d_p - \frac{a}{2}) \quad (2)$$

Where
A_{ps} = Area of prestressing strands
f_{ps} = Strength of prestressing strands
d_p = Depth of prestressing strands
a = Depth of compressive stress block

3. STUDY DATA

3.1 Pole cross sections

Four shapes of pole sections including square solid, square hollow, I-shaped, and circular hollow sections are studied. The pole sections with steel strand arrangement are shown in Figure 4.

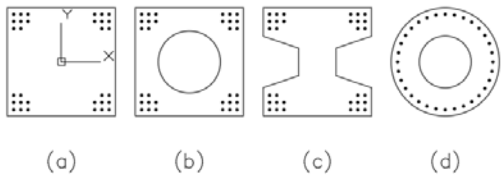

Figure 4. Pole cross sections with strand arrangement (a) Square solid (b) Square hollow (c) I-shaped (d) Circular hollow.

3.2 Pole parameters

Study parameters including material strength, prestressing steel strand, and pole dimension are shown in Table 1.

The same parameters are applied to all pole sections.

Table 1. Pole parameters.

Parameter	Value
Compressive strength of concrete	500 kg/cm^2
Tensile strength of prestressing strand	1720 MPa
Prestressing strand size	9.3 mm
Prestressing strand area	51.6 mm^2
Prestressing strand number	32 strands
Pole length	22 m
Pole size at top	25 cm
Pole size at ground level	42.27 cm
Pole size at bottom	44 cm

Cross section area, cracking moment, and ultimate moment are calculated for the sections at ground level.

Cracking moment capacity and ultimate moment capacity are determined using the equation (1) and (2), respectively.

4. RESULTS

4.1 Pole cross section areas

Figure 5 shows the comparison of cross section areas of poles with various shapes of cross sections. It can be seen that the square solid section has the largest area of about 1,800 cm^2, whereas the circular hollow section has the smallest area of about 1,100 cm^2 or about 61% of area of the square solid section.

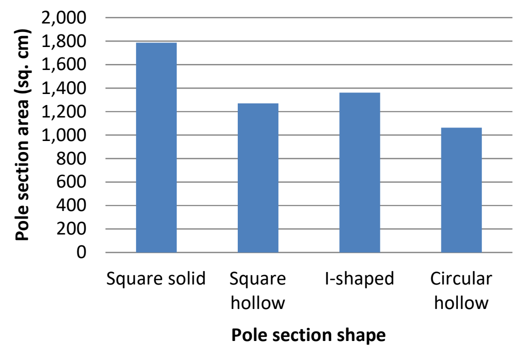

Figure 5. Comparison of cross section areas of poles with various section shapes.

4.2 Pole weights

Figure 6 shows the comparison of weights of poles with various shapes of cross sections. It can be observed that the pole weights vary with the pole section areas. The pole with square solid section gives the heaviest weight of about 6,800 kg, whereas the pole with circular hollow section yields the lightest weight of about 4,200 kg or about 62% of weight of the pole with square solid section.

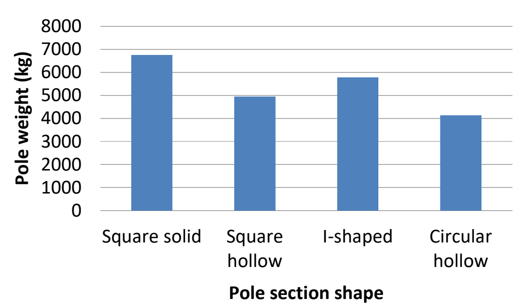

Figure 6. Comparison of weights of poles with various section shapes.

4.3 Pole costs

Figure 7 shows the comparison of costs of poles with various shapes of cross sections. The cost of a pole depends on production and transportation expenses. The transportation expense is based on distance of 150 km. It can be seen that the costs vary with the pole weights. The higher weight results in the higher cost of production and transportation of poles. The pole with square solid section gives the highest cost of about 25,200 Baht, whereas the pole with circular hollow section yields the lowest cost of about 21,700 Baht or about 86% of the highest one.

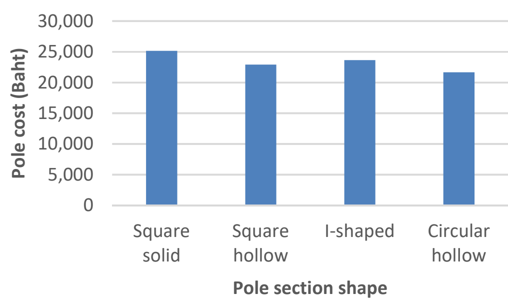

Figure 7. Comparison of costs of poles with various section shapes.

4.4 Cracking moment capacity

Figure 8 shows the comparison of cracking moments of poles with various shapes of cross sections. It can be observed that I-shaped section gives the highest cracking moment of about 19,600 kg-m for X-axis and the lowest one of about 12,600 kg-m for Y-axis or about 64% of the highest one. The square hollow section yields the cracking moment as high as that of the I-shaped section.

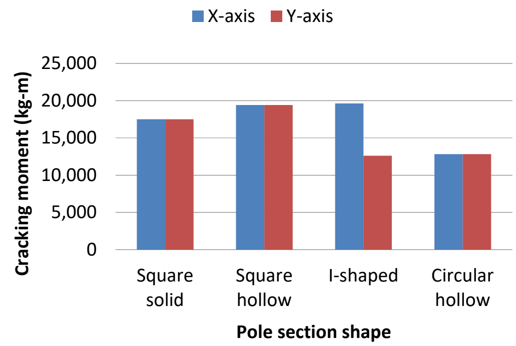

Figure 8. Comparison of cracking moments of poles with various section shapes.

4.5 Ultimate moment capacity

Figure 9 shows the comparison of ultimate moments of poles with various shapes of cross sections. It can be seen that the square solid and square hollow sections give the highest ultimate moment of about 45,000 kg-m for both axes, whereas the I-shaped section yields the highest ultimate moment only for X-axis. The circular hollow section gives the lowest ultimate moment of about 35,000 kg-m or 78% of the highest ones.

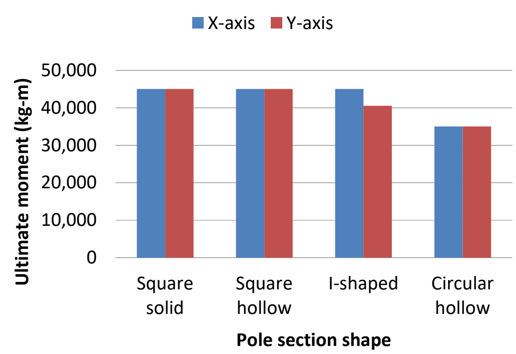

Figure 9. Comparison of ultimate moments of poles with various section shapes.

Figure 10 shows the comparison of ultimate moment per section area of poles with various shapes. It can be observed that the square hollow section gives the highest ultimate moment per section area of 34, whereas the square solid section yields the lowest ultimate moment per section area of 25.

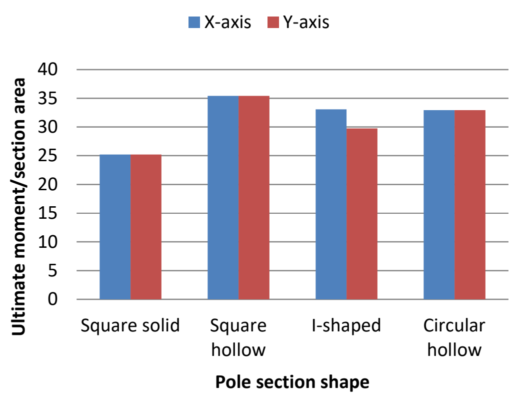

Figure 10. Comparison of ultimate moment per section area of poles with various section shapes.

5. CONCLUSIONS

Prestressed concrete poles with four different shapes of cross sections including square solid, square hollow, I-shaped, and circular hollow sections are studied. Cross section areas, weights, costs, cracking moment capacity, and ultimate moment capacity of all sections are calculated and compared. As a result of study, the following conclusions can be drawn.

1. The square hollow section is the most efficient section since it gives the highest ultimate moment per section area.
2. The circular hollow section is the most economical and the lightest section.
3. The I-shaped section is efficient in the strong axis (X-axis) but less efficient in the weak axis (Y-axis).
4. The square solid section is the least efficient section since it yields the lowest ultimate moment per section area.

6. RECOMMENDATIONS

For application and practice, the following recommendations are proposed.

1. The poles with circular hollow section are recommended for structures subjected to low to medium load such as tangent structures since they have an efficient section and the lowest weight and cost. Furthermore, the poles with circular section can reduce wind load better than those with square section.
2. The poles with square hollow section are recommended especially for structures subjected to high tension of conductors such as dead-end and large angle structures.

References

[1] Provincial Electricity Authority, "Executive Information System," [Online] Available at: gis.pea.co.th/peawebsite/eis.

[2] T. E. Rodgers Jr., "Prestressed Concrete Poles: State-of-the-Art," PCI Journal, vol. 29, September-October 1984, pp. 52-103.

[3] F. H. Fouad, et al, "Spun Prestressed Concrete Poles – Past, Present, and Future," Concrete International, November 1992, vol. 14, pp. 25-29.

[4] F. Dittmar, and H. Bahous, "Spun Pre-stressed Concrete Poles: Alternative to Wooden and Steel Poles for Low, Medium, and High Voltage," 21st International Conference on Electricity Distribution, 2011.

[5] W. J. Oliphant, et al, "Prestressed Concrete Transmission Poles: Recommended Practice for Design and Installation," ASCE Manual and Reports on Engineering Practice No. 123, ASCE, Virginia, 2012.

[6] N. K. Raju, "Prestressed Concrete," 6th Edition, McGraw-Hill Education (India), 2018.

[7] C. W. Dolan, and H. R. Hamilton, "Prestressed Concrete: Building, Design, and Construction," Springer International Publishing, 2019.