The optimization design of Piled raft foundation for substation building in US code

Yang Qingtao^{*1}, Chen Ying¹, Li Wei¹, Wei Xiao¹, Gan Xing²

¹State Nuclear Electric Power Planning Design & Research Institute, Beijing 100095, china;

²Construction Branch of State Grid Xinjiang Electric Power Co., Ltd, Urumqi 830002, china

Abstract: In order to get a more safety and economic foundation, finite element method was performed for a piled mat cap and piled strip cap by the software of STAAD. Through the finite element analysis, plate distribution region of bending moment and shear stress were researched; meanwhile, considering the compatibility of deformation of element plate, how to chose the design value of plate stress was researched. The result showed that: single plate value is not representative , average of value of 9 plates (3x3 array) is close to the fact. Strip cap is better than mat cap both from the moment value and shear value of plate element in this project; strip cap was recommended due to its remarkable economic benefit.

1 Introduction

Substation building is an essential facility in the substation, which ensures the reliability of urban power supply. Figure 1 is a building of 230kV substation in the Philippines. The substation building is a fifth-layer concrete frame structure, which is 26.8 meters high. 230kV gantry on the top of substation building , which is 21 meters high. Pile foundation was used in substation building. Pile arrangement and pile cap types were the major work for the engineer designer^[1].

Figure 1. substation building in the Philippines

2 Design input condition

2.1 Wind load

- 1) Wind load maximum wind speed (3seconds gust speed at 10m height above soil) is 75m/s.
- 2) Exposure category D.
- 3) Structure Category II.
- 4) Gust effect factor $G=0.85$.

2.2 Seismic loads

Seismic zone factor $Z=0.4$, Soil type S_D , Seismic source type B.

R (response modification factor) for substation building the structure system should choose Special moment-resisting frame, the value of R is 8.5; refer to steel supports (non-buildings structures not similar to buildings), proposed R will be 3 for gantries^[2].

2.3 Load combinations

This project was suggested to design with US code, both Ultimate Limit State and Serviceability Limit State should be considered in piled raft foundation design^[3]. The ULS and SLS load general combinations according to contractual specifications are based on ASCE7-10.

^{*}u2760@snpdri.com

Figure 7. Color nephogram of bending moment Mx and My for strip cap

Table2. Maximum value of bending moment

Moment	Mat	Strip
	(kN-m/m)	
Mx-top	1010	1270
Mx-bot	-438	-540
My-top	1345	1194
My-bot	-671	-224

We used the Wood-Armer equations for reinforcement calculations^[7], as follows: Mx, My, and Mxy are calculated, by STAAD. They are used to compute the values of design moments, Mxd and Myd.

For top reinforcement, we computes:

$$Mx1 = Mx + \text{abs}(Mxy)$$

$$My1 = My + \text{abs}(Mxy)$$

$$Mx2 = Mx + \text{abs}(Mxy2 / My)$$

$$My2 = My + \text{abs}(Mxy2 / Mx)$$

If both Mx1 and My1 are positive, Mxd = Mx1 and Myd = My1.

If both Mx1 and My1 are negative, Mxd = 0 and Myd = 0.

If Mx1 is negative and My1 positive, Mxd = 0 and Myd = My2.

If My1 is negative and Mx1 positive, Mxd = Mx2 and Myd = 0.

For bottom reinforcement:

$$Mx1 = Mx - \text{abs}(Mxy)$$

$$My1 = My - \text{abs}(Mxy)$$

$$Mx2 = Mx - \text{abs}(Mxy2 / My)$$

$$My2 = My - \text{abs}(Mxy2 / Mx)$$

If both Mx1 and My1 are positive, Mxd = 0 and Myd = 0.

If both Mx1 and My1 are negative, Mxd = Mx1 and Myd = My1.

If Mx1 is negative and My1 positive, Mxd = Mx2 and Myd = 0.

If My1 is negative and Mx1 positive, Mxd = 0 and Myd = My2.

Table3. Maximum value of bending moment for design

Moment	Mat	Strip
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	(kN-m/m)	
Mxd-top	1094	1279
Mxd-bot	-499	-599
Myd-top	1382	1424
Myd-bot	-710	-285

The color nephogram of bending moment showed that only a few moment value of plates reached the maximum value. Consider the compatibility of deformation of element plate, the average of value of nearest 9 plates (3x3 array) was performed as the design value conservatively, which made the calculate results close to the fact.

Table4. Max plate bending moment (kN-m/m)

From the table above, mat cap plate top value of moment are 823 and 680 , strip cap plate top value of moment are 885 and 675 . The moment on the top plate of Strip cap increase 7.5% than the moment of mat cap. Mat cap plate bottom value of moment are -569 and -282, strip cap plate top value of moment are -356 and -58 . The moment on the bottom plate of Strip cap reduce 37.4% than the moment of mat cap. Strip cap is better than mat cap from the moment value of plate element.

4.2 Shear stress

The result of shear stress for piled raft cap is shown in the following figure.

Figure 8. Color nephogram of shear stress Sqx and Sxy for mat cap

Figure 9. Color nephogram of shear stress Sqx and Sxy for strip cap

The color nephogram of shear stress showed that only a few stress value of plates reached the maximum value. Consider the compatibility of deformation of element plate, the average of value of nearest 9 plates (3x3 array) was performed as the design value conservatively, which made the calculate results close to the fact.

From the table below, mat cap plate top value of shear stress are 0.74 and 0.57, strip cap plate top value of shear stress are 0.6 and 0.45. The shear stress on the top plate of Strip cap reduce 18.9% than the shear stress of mat cap. Mat cap plate bottom value of shear stress are -0.73 and -0.64, strip cap plate top value of shear stress are -0.65 and -0.64. The shear stress on the bottom plate of Strip cap reduce 11.0% than the shear stress of mat cap. Strip cap is better than mat cap from the shear stress value of plate element.

Table5. Max plate shear stress (N/mm²)

5 Result

1) single plate value is not representative, average of value of 9 plates (3x3 array) is close to the fact.

2) The moment on the top plate of Strip cap increase 7.5% than the moment of mat cap. The moment on the bottom plate of Strip cap reduce 37.4% than the moment of mat cap. Strip cap is better than mat cap from the

moment value of plate element.

3) The shear stress on the top plate of Strip cap reduce 18.9% than the shear stress of mat cap. The shear stress on the bottom plate of Strip cap reduce 11.0% than the shear stress of mat cap. Strip cap is better than mat cap from the shear stress value of plate element.

4) Strip cap reduce 20.8% reinforcement concrete than mat cap. We recommend strip cap in the project due to its remarkable economic benefit.

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