Study on the influence of steel layout on steel reinforced concrete pier structure

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Abstract. In order to study the influence of the steel reinforced concrete pier structure by the steel layout, ANSYS software was used to construct a structural model of the steel reinforced concrete pier, by studying the effect of three different layout numbers on the pier crack development, pier stress and section steel stress under two different working conditions, it is concluded that the three-section steel cloth is the optimal layout. Based on this, we continued to study the influence of the layout angle and layout size on the structure of the pier, and finally concluded that the layout was optimal when the layout angle of the three-section steel was 12.5° and the layout size was two short and one long. The research results provide theoretical support for the design of steel reinforced concrete pier structures.

1. Introduction
The gate pier, as one of the key parts of the hydraulic structure, plays an important role in the safe operation of the gate. With the gradual increase of the scale of hydraulic structures, the general reinforced concrete structure can not meet the design requirements[1]. The steel reinforced concrete structure is more reasonable, ductile and economical [2], and has been favored by scholars in recent years. Yuan Chun [3] compared the different schemes and found that H-shaped steel was used in the design, and the protective layer thickness should be 400mm. Zeng Dejun[4] used numerical analysis to calculate and analyze the necessity of laying transverse I-shaped connecting steel between longitudinally stressed steel bars.

However, the shape of steel reinforced concrete pier is generally large and the external load it receives is also more complex, so the design experience of general engineering can not be fully referred to [5]. In this paper, the middle pier of the discharge part of a hydraulic structure is selected as the analysis object. By using the numerical simulation method, the number of steel sections in the pier structure and the angle between them are comprehensively studied. The final research results provide theoretical support for the application of section steel in the pier structure.

2. Influence of the number of section steel on pier structure

2.1. Finite element model of pier
In this paper, the ANSYS software is used to build a model, which defines that the direction of the downstream flow is the x-axis positive direction, the vertical upward direction corresponds to the Y-axis positive direction, and the left and right banks point to the right bank direction to the Z-axis positive direction. Taking three steel profiles as an example, the finite element model is shown in Figure 2(a); the calculation conditions are divided into normal two-side water blocking and left-side single-side water blocking.

2.2. Layout of shaped steel and finite element model

The steel distribution of steel reinforced concrete can neither be too much nor too small. According to the specification [6], the steel distribution of steel reinforced concrete is calculated. After calculation, the steel distribution of the pier neck is 650cm$^2$, and the steel distribution at the gate support is 104cm$^2$.

![Front view of steel reinforced concrete pier](image1)

![Top view of steel reinforced concrete pier](image2)

(a) Front view of steel reinforced concrete pier  
(b) Top view of steel reinforced concrete pier  

Figure 1. Layout drawing of steel reinforced concrete pier (cm)

![Pier finite element model](image3)

![Steel finite element model](image4)

(a) Pier finite element model  
(b) Steel finite element model  

Figure 2. Finite element model

In this paper, H-shaped steel is laid inside the pier. According to the requirements for H-shaped steel in the specification[7], determine the specifications of the H-shaped steel. H-beam specifications: height (H) × width (B) × web thickness (t1) × flange thickness (t2), specific dimensions are shown in Table 1.

| Steel/Project | Single steel | Three steel | Five steel |
|---------------|--------------|-------------|------------|
| Pier section steel cross-sectional area /cm$^2$ | 1×650 | 3×217 | 5×130 |
The steel bar length at the pier support is 2.5h~3.5h [8] (h: the height of the support). Due to the large force on the neck of the pier, the length of the steel in this article is 3.5h, which is calculated to be 26m. The thickness of the protective layer is 400mm. The three types of steel layout diagrams are similar. Take the layout number of three as an example. The layout diagram is shown in Figure 1. The shape steel finite element model diagram (taking three roots as an example) is shown in Figure 2(b).

2.2.1. The Influence of the Number of Shaped Steel Roots on the Development of Gate Pier Cracks

The distribution of cracks in the pier body is similar under the three different types of steel. Taking the three-type steel cloth as an example, the final crack range is shown in Figure 3.

As can be seen from Figure 3, when the number of steel profiles is set to three, under normal water blocking on both sides, the final crack occurs at the intersection of the pier body and the loading surface of the arc gate support, and on the left side when the water blocking is on one side. The final cracks covered the intersection of the gate pier and the left arc gate support and developed up and down along the intersection.

The distribution of cracks in the pier body when arranging single and five steel profiles is consistent with that when arranging three steel profiles, but there is a certain difference in the distribution range. The specific differences are shown in Table 2.

| Number of roots of section steel | Crack distribution /m |
|-------------------------------|-----------------------|
|                               | Normal water blocking on both sides | Left side water blocking |
|                               | X  | Y  | Z  | X  | Y  | Z  |
| Single lay                    | 1.42 | 5.33 | 0.29 | 1.76 | 7.02 | 0.51 |
| Three layouts                 | 1.41 | 4.69 | 0.29 | 1.48 | 6.29 | 0.45 |
| Five layouts                  | 1.50 | 4.99 | 0.39 | 1.54 | 6.38 | 0.49 |

Table 2. Crack distribution range of gate pier under different steel arrangement number
2.2.2. The Influence of the Number of Shaped Steel Layout on the Pier and Shaped Steel Stress

![Figure 4. Stress cloud diagram of the pier with three-type steel sluices on normal sides](image1)

(a) First principal stress nephogram  
(b) Third principal stress nephogram

Figure 4. Stress cloud diagram of the pier with three-type steel sluices on normal sides

![Figure 5. Stress cloud diagram of the three-type steel pier with pier on the left side](image2)

(a) First principal stress nephogram  
(b) Third principal stress nephogram

Figure 5. Stress cloud diagram of the three-type steel pier with pier on the left side

The stress distribution of the pier body is basically the same when the number of section steels is arranged differently under the two working conditions. Therefore, the stress distribution of the three-section steel is taken as an example. The stress cloud diagram is shown in Figures 4 and 5.

It can be seen from Figures 4 and 5 that the maximum value of the first principal stress in normal water-blocking conditions on both sides occurs on the side of the pier body about 0.33m above the upper corner of the arc gate support. In the case of unilateral water blocking on the left, the maximum value of the first principal stress occurs on the side of the pier about 0.67 m below the lower corner upstream of the left end of the arc gate support.

According to the calculation results, under the two working conditions, the maximum tensile stress of the section steels in the three types of steel layouts appears near the junction of the middle pier section steel and the middle transverse section steel.

The stress distribution law of pier and the location of maximum value of section steel stress when single-type steel and five-type steel are laid are the same as those of three-type steel, but there are certain differences in stress values, as shown in Table 3.
Table 3. Stress characteristic value of pier and section steel under different number of section steel

| Number of roots of section steel | Maximum value of the first principal stress of the pier S1/Mpa | Maximum tensile stress of section steel /Mpa |
|---------------------------------|----------------------------------------------------------|--------------------------------------------|
|                                 | Water blocking on both sides | Water blocking on the left | Water blocking on both sides | Water blocking on the left |
| Single lay                      | 1.13                        | 1.42                        | 34.74                        | 40.59                      |
| Three layouts                   | 1.07                        | 1.28                        | 26.00                        | 31.84                      |
| Five layouts                    | 1.14                        | 1.55                        | 29.28                        | 40.17                      |

It can be seen from Table 3 that in the two calculation conditions, the maximum tensile stress value of the pier and the section steel is at the minimum when the three-section steel is laid.

According to the calculation results of structural displacement, crack development of pier, and structural stress, the number of roots of the above-mentioned shape steel layout is the best.

3. The Influence of the Angle of the Shaped Steel on the Pier

The installation angle of the section steel is generally 10°~15°, so when the number of section steel is set to three, choose three placement angles of 10°, 12.5°, and 15° to study its effect on the reinforced concrete pier.

In the above calculation, the angle between the section steel is 12.5°, so only the calculation of the section angle between 10° and 15° is required. The layout diagram is similar to the figure 2(b), but the angle is changed to 10° and 15°.

3.1. The influence of the angle of the shape steel layout on the crack development of the pier

Under the two different working conditions, the crack development law of the 10° and 15° section steel is similar to that of the 12.5° layout, but there is a certain difference in the values. The specific differences are shown in Table 4.

It can be seen from Table 4 that in the two calculation conditions, the included angle of section steel is different, and the difference of crack range in X direction and Z direction is obvious. When the angle between sections is 12.5°, the crack range is the smallest.

Table 4. Crack distribution range of pier under different steel layout angles

| Sectional steel layout angle | Crack distribution /m | Normal water blocking on both sides | Left side water blocking | Normal water blocking on both sides | Left side water blocking |
|-----------------------------|-----------------------|-------------------------------------|--------------------------|-------------------------------------|--------------------------|
|                             | X        | Y        | Z        | X        | Y        | Z        |
| 10°                         | 1.89     | 4.75     | 0.69     | 1.97     | 6.23     | 0.71     |
| 12.5°                       | 1.41     | 4.69     | 0.29     | 1.48     | 6.29     | 0.45     |
| 15°                         | 1.70     | 4.60     | 0.69     | 1.87     | 6.27     | 0.69     |

3.2. The Influence of the Angle of Shape Steel Arrangement on the Stress of Pier and Shape Steel

The stress distribution law of pier and the maximum position of the section steel stress when the section steel is placed at 10° and 15° are the same as those at 12.5°, but there are some differences in the values. The specific differences are shown in Table 5.

Table 5. Stress characteristic values of pier and section steel under different steel arrangement angles

| Sectional steel layout angle | Maximum value of the first principal stress of the pier S1/Mpa | Maximum tensile stress of section steel /Mpa |
|-----------------------------|----------------------------------------------------------|--------------------------------------------|
|                             | Water blocking on both sides | Water blocking on the left | Water blocking on both sides | Water blocking on the left |
| 10°                         | 1.13                        | 1.42                        | 34.74                        | 40.59                      |
| 12.5°                       | 1.07                        | 1.28                        | 26.00                        | 31.84                      |
| 15°                         | 1.14                        | 1.55                        | 29.28                        | 40.17                      |
According to Table 5 above, in the two calculation conditions, when the angle of the section steel is 12.5°, the maximum value of the first principal stress of the pier and the maximum value of the tensile stress of the section steel both reach the minimum.

### 4. The influence of the shape steel layout size on the pier structure

From the above results, it can be seen that when three shaped steels are laid and the angle between them is 12.5°, it is the most reasonable layout form. The specification[8] recommends that the reinforcement in the local tension zone should be alternately arranged in lengths and lengths, so the three-section steel equal-length fan-shaped layout is changed to two different fan-shaped layouts of one long and two short and one short and two long, respectively. The total length of long steel is 26 m, and the length of short steel is 2.5 h, that is, the total length is 20 m. The layout diagram is similar to Figure 1(a), except that the length of the section steel at both ends or the middle is changed to 20 m.

It can be seen from the calculation that in the two working conditions, the difference in the size of the shape steel layout has little effect on the crack development of the pier and the stress distribution of the pier. However, from the economic aspect, it is more appropriate to select one length and two short sections of steel.

### 5. Conclusion

This article selects the pier in a practical project as the research object, uses ANSYS software to build its pier body model. The numerical analysis method is used to systematically study the influence of the number, angle, and size of the section steel laid on the pier crack development and stress. The following conclusions are obtained:

1. In the two calculation conditions, the number of steel sections is increased, and the maximum tensile stresses of the pier body and the steel section have a trend of decreasing first and then increasing, and the change amplitude is larger. And when the number of shaped steel is three, the crack distribution range of the pier body is the smallest, so it is optimal when the number of shaped steel is three.

2. In the two calculation conditions, the number of steel profiles is three. When the angle of the profile steel increases, the maximum tensile stress values of the profile steel and the pier body decrease first and then increase. When the section steel angle is set at 12.5°, the cracking range of the gate pier body is the smallest, so the optimum angle is 12.5°.

3. For a similar pier structure, it can be laid out in the form of a fan with three roots, a deployment angle of 12.5°, and a layout size of one long and two short. Under this layout scheme, the pier structure has the best mechanical performance and the most economy.

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### References

[1] Li S H, Gao D Y. (2012) Experimental study on the mechanical performance of cavity anchor block prestressed pier structure [J]. Journal of Yangtze River Academy of Sciences, 29 (12): 99-102.

[2] Harries K A. (2000) Behavior and Design of Reinforced Concrete, Steel, and Steel-Concrete Coupling Beams[J]. Earthquake Spectra, 16 (4): 775-799.

[3] Yuan C. (2014) Research on the influence of the section of section steel on the bearing capacity of steel reinforced concrete pier [D]. Guangxi: Guangxi University.
[4] Zeng D J. (2016) Research on the influence of transverse connection steel on the performance of steel reinforced concrete pier [D]. Guangxi: Guangxi University.

[5] Zhang J Q, Zheng Q G. (2016) Design of steel and concrete composite sections for highway deck of main ship channel bridge of Hutong Changjiang River Bridge[J]. Bridge Construction, 46 (4): 6-10.

[6] DL/T 5057-2009, Design Specification for Hydraulic Concrete Structures [S]. Beijing: China Electric Power Press, 2009.

[7] GB/T 11263-2010, Hot-rolled H-beam and split T-beam [S]. Beijing: China Standard Press, 2010.