Analysis of bearing capacity of the six-sided plate pavement structure considering connection

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Abstract: In order to study the bearing capacity of the six-sided plate pavement structure considering the connection relationship between six-sided plates, a finite element model of the six-sided plate pavement was established in ABAQUS software. Based on the ABAQUS finite element model, we focused on the influence of the thickness of the six-sided plate and the length of the connecting hooks on the carrying capacity of the six-sided plate pavement. By using the control variable method for simulation and analysis, the calculated results are reasonable, indicating that these two factors have a certain effect on the bearing capacity of the six-sided plate pavement structure.

1. Introduction
Fast assembling road equipment is one kind of the important equipment for mobile engineering support. It is not only conducive to the rapid movement of the army, but also important for rescue and disaster relief and field production operations[1]. The six-sided plate pavement is a kind of quick assembly pavement structure, which has unique advantages: adjacent six-sided plates are connected by connecting hooks, which are flexible in use, versatile in use, and relatively simple in manufacturing processes. Therefore, the analysis of the bearing capacity of the six-sided plate pavement structure is of great significance when considering the influence of the connection[2]. However, due to the complicated contact relationship between the six-sided plate and the six-sided plate and the ground, it is difficult to calculate the design of this structure. Chen Hao had greatly simplified the overall model of the pavement section, simplified the six-sided plate into a hexagonal flat plate, and simulated it with shell elements; the foundation was simulated by a rod element. The existence of connection part is not reflected in the model, which is different from the actual situation[3]. Because the stiffness of the connecting hook is smaller than the plate body, this may lead to greater calculation deformation. Chen Li et al used solid elements to simulate the six-sided plate and the foundation, defined the contact parts between the six-sided plate and the base part between the plate and the foundation as the contact relationship, and adopted explicit methods to solve[4]. This method is relatively slow to calculate. The above calculation methods all have some room for improvement. In this paper, shell elements were used to simulate a six-sided plate, solid elements were used to simulate the foundation, and the geometric dimensions of the connection joints between plates were reflected in the model to carry out the analysis of this structure.
2. Establishment of the calculation model

2.1 Introduction of the six sided plate structure
The six-sided plate pavement has unique advantages in various rapid pavement assembly structures. The shape of a single six-sided plate is regular, and each side is provided with a connecting hook for continuous connection with each other. The six-sided plate can be provided with anti-slip strips on the front side to enhance vehicle traffic, and the reverse side can be placed on the foundation, and reinforcing ribs can be provided to improve adhesion to the ground. Relying on the unique connection structure and interaction of six-sided plate, a dense pavement segment can be formed with various shapes, which can be assembled into various shapes of road surfaces such as bends, forks, and round roads, and has strong adaptability.

2.2 ABAQUS six-sided plate finite element model
Modeled and calculated the structures assembled from seven six-sided plates. The six-sided plate was simulated by a hexagonal plane, and a rectangular surface was extended on the three sides of the plate corresponding to the connecting hook to simulate the connecting hook. Shell elements were used to mesh the six-sided plate. The foundation was simulated by a cylinder, and solid elements were used to divide the grid. In order to speed up the calculation, the binding connection was adopted between the six-side plate and the upper surface of the foundation, without the contact relationship[5]. The outer side of the hook of the side-sided plate was bound with another to another six-sided plate edge in contact with it, only the translational degrees of freedom were bound, and the rotational degrees of freedom are not bound, so that the adjacent six-sided plates can rotate relatively, but the relative translational motion can not occur[6]. An evenly distributed load was applied to the upper surface of the six-sided plate in the middle, to simulate the behavior of a single wheel on the road. The total size of the uniform load is 50KN. The established models are shown in Figures 1 and 2. And put seven six-sided plate assembly structures on the foundation, and ensure that the foundation has a margin, as shown in Figure 3.

The focus of this paper is to analyze the bearing capacity of the six-sided plate pavement structure and consider the impact of the connection relationship between each other on the bearing capacity. Therefore, the model simplified the six-sided plate pavement in complex contact situations. The six-sided plate pavement is made of aluminum alloy, with an elastic modulus of 70 GPa, a Poisson's ratio of 0.3, and a density of 2.7 g/cm3; the elastic modulus of the foundation soil is taken as 0.002 GPa, with a Poisson's ratio of 0.3 and a density of 2.0 g/cm3.

Figure 1 Single block six-sided plate model
### 3. Optimization analysis of the six-sided plate pavement structure

#### 3.1 Analysis of influence of the thickness attribute of the six-sided plate pavement structure material

The properties of the six-sided plate used in the pavement structure have a great influence on the overall performance of the structure. Generally, the better the properties of the six-sided plate are, the stronger the bearing capacity of the pavement structure [7] is. Among the many properties of the six-sided plate, the thickness of the slab also plays a crucial role in the strength of the pavement structure. Therefore, this study used the thickness of the six-sided plate as a variable to analyze the effect of the thickness change on the pavement structure.

**Determination of analysis objects:** We intended to analyze the six-sided plates with thicknesses of 10mm, 11mm and 12mm respectively, and compare the analysis results of the pavement structure forces obtained at different thicknesses to explore the impact of different thicknesses of six-sided plates on the pavement structure effect.

#### 3.1.1 Calculation of three different thickness six-sided plate structural elements

This calculation used ABAUQS software for modeling calculations, and the results were shown in the table.

| Connector                        | 1      | 2      | 3      | 4      | 5      | 6      |
|----------------------------------|--------|--------|--------|--------|--------|--------|
| Shear force Fz (KN)              | 8.23295| 4.4145 | 8.23295| 4.4145 | 8.23295| 4.4145 |
| Bending moment Mx (KN.m)         | 0.07653| -0.0256| 0.07653| -0.0256| 0.07653| -0.0256|
| Bending moment Mz (KN.m)         | -0.1051| 0.03843| -0.1051| 0.03843| -0.1051| 0.03843|
| Max Z axis displacement (mm)     | -20.61 | -20.61 | -20.61 | -20.61 | -20.61 | -20.61 |
Table 2 (thickness of the six-sided plate = 11mm) statistics of the joint force

| Connector | 1       | 2       | 3       | 4       | 5       | 6       |
|-----------|---------|---------|---------|---------|---------|---------|
| Shear force Fz (KN) | 9.08535 | 3.2695  | 9.08535 | 3.2695  | 9.08535 | 3.2695  |
| Bending moment Mx (KN.m) | 0.11933 | -0.0559 | 0.11933 | -0.0559 | 0.11933 | -0.0559 |
| Bending moment Mz (KN.m) | -0.1392 | 0.06859 | -0.1392 | 0.06859 | -0.1392 | 0.06859 |
| Max Z axis displacement (mm) | -19.42  |         |         |         |         |         |

Table 3 (thickness of the six-sided plate = 12mm) statistics of the joint force

| Connector | 1       | 2       | 3       | 4       | 5       | 6       |
|-----------|---------|---------|---------|---------|---------|---------|
| Shear force Fz (KN) | 10.0509 | 5.07144 | 10.0509 | 5.07144 | 10.0509 | 5.07144 |
| Bending moment Mx (KN.m) | 0.15712 | -0.0952 | 0.15712 | -0.0952 | 0.15712 | -0.0952 |
| Bending moment Mz (KN.m) | -0.1501 | 0.07327 | -0.1501 | 0.07327 | -0.1501 | 0.07327 |
| Max Z axis displacement (mm) | -18.37  |         |         |         |         |         |

3.1.2 Comparison and analysis of the results

Comparing the calculation results obtained under the three different thicknesses of the six-sided plates, 10mm, 11mm and 12mm, the following comparison chart was obtained.
As the comparison diagrams show, the greater the thickness of the six-sided plate is, the greater the shear force at the joint position and the bending moments in the X and Z directions are, and the smaller the displacement value in the z direction is. With the increase of the thickness of the six-sided plate, the degree of deformation of the pavement structural unit after the load is gradually reduced. Because deformation means the loss of energy. The deformation is reduced, and the energy lost is also reduced accordingly, and the energy transmitted to the joint location is increased. As a result, the shear force and bending moment at the joint location are increased [8]. In other words, the deformation of the structural unit after loading is related to the joint force. The thickness of the six-sided plate is increased, the deformation of the pavement structure is reduced, and the force at the joint location increases; the thickness of the six-sided plate decreases, the deformation of the pavement structure increases, and the force at the joint location decreases. Therefore, when designing the six-sided plate pavement, the thickness of the six-sided plate can be appropriately reduced, which is conducive to
increasing the load on the pavement structure. After deformation, thereby reducing the force at the joint position.

In summary, within the scope of the structural unit's deformability, appropriately reducing the thickness of the six-sided plate and increasing the deformation of the pavement structure after loading can effectively reduce the stress level of the structure after loading.

![Figure 8 Comparison of stress distribution cloud diagrams (from left to right, the thickness of the six-sided plate is 10mm, 11mm, 12mm)](image)

3.2 Analysis of influence of connecting hook length on six-sided pavement structure

The six-sided plate pavement structure interaction also has a very large impact on the overall performance of the structure. On the premise of meeting the requirements of use, the unique structural form of the six-sided plate determines the criticality of the connection form [9]. Among many attributes, the length of the connecting hook also plays a significant role in the bearing capacity of the pavement structure [10]. Therefore, this study used the length of the connecting hook of the six-sided plate as a variable to analyze the response of the structure and explore the influence of the length of the connecting hook on the structure of the pavement.

Determination of the analysis object: This article intended to analyze the six-sided plates of the six-sided plate connecting hook lengths of 0.4 times, 0.6 times, and 0.8 times the side length respectively, and compare the analysis results of the pavement structure force obtained under different connecting hook lengths. This study explored the effect of six-sided plates with different connecting hook lengths on the pavement structure.

3.2.1 Calculation of three different size structural units

In order to make the experiment comparable, the same working conditions were used for the three different sizes of six-sided plate structural units in the calculation process, that was, seven aluminum alloy six-sided plate pavements were used for the calculation, and wheel loads of the same size acted on the center of the pavement. The foundation model was the same as before.

The calculation results were shown in Table 4, Table 5, and Table 6.

| Connector | 1       | 2       | 3       | 4       | 5       | 6       |
|-----------|---------|---------|---------|---------|---------|---------|
| Shear force Fz (KN) | 6.90826 | 5.03295 | 6.90826 | 5.03295 | 6.90826 | 5.03295 |
| Bending moment Mx (KN.m) | 0.05732 | -0.2062 | 0.05732 | -0.2062 | 0.05732 | -0.2062 |
| Bending moment Mz (KN.m) | -0.1032 | 0.27242 | -0.1032 | 0.27242 | -0.1032 | 0.27242 |
| Max Z axis displacement (mm) | -20.61   |         |         |         |         |         |

| Connector | 1       | 2       | 3       | 4       | 5       | 6       |
|-----------|---------|---------|---------|---------|---------|---------|
| Shear force Fz (KN) | 7.73627 | 5.47057 | 7.73627 | 5.47057 | 7.73627 | 5.47057 |
| Bending moment Mx (KN.m) | 0.30297 | -0.1743 | 0.30297 | -0.1743 | 0.30297 | -0.1743 |
| Bending moment Mz (KN.m) | -0.1805 | 0.39753 | -0.1805 | 0.39753 | -0.1805 | 0.39753 |
| Max Z axis displacement (mm) | -20.24   |         |         |         |         |         |
Table 6 (connection hook length = 0.8 times side length) statistics of the joint force

| Connector | 1    | 2    | 3    | 4    | 5    | 6    |
|-----------|------|------|------|------|------|------|
| Shear force Fz (KN) | 7.9905 | 6.55926 | 7.9905 | 6.55926 | 7.9905 | 6.55926 |
| Bending moment Mx (KN.m) | 0.40644 | -0.2759 | 0.40644 | -0.2759 | 0.40644 | -0.2759 |
| Bending moment Mz (KN.m) | -0.2626 | 0.18519 | -0.2626 | 0.18519 | -0.2626 | 0.18519 |
| Max Z axis displacement (mm) | -20.07 | -20.07 |

3.2.2 Comparison and analysis of the results

The joint forces of three different sized structural units were compared, and the results were as follows.
Figure 11 Comparison curve of z-direction bending moment of joint

It can be seen from the comparison of the above curves that as the length of the pavement structural unit connecting hook increases, the shear force at the joint decreases, and the bending moments in the X and Z directions continue to increase. Due to the low elastic modulus of the material, the structural unit has a weak resistance to deformation. Therefore, the larger the length of the connecting hook of the pavement structural unit is, the greater the structural deformation after loading is, and the shear force transmitted to the joint is reduced. In addition, as the length of the connecting hook of the pavement structural unit increases, the acting arm of the load point to the joint increases, which results in an increased bending moment at the joint. At the same time, it can be seen from the stress distribution cloud diagrams of structural units of different sizes that as the length of the pavement structural unit connecting hook increases, the force transmission effect between the pavement structural units gradually weakens, and the force at the joint gradually increases. In this case, the force of the six-sided pavement structure is unfavorable.

In summary, by analyzing the forces on three types of six-sided pavement structural units with different connecting hook lengths, the smaller the connecting hook length is, the more favorable the structure is.

Figure 12 Comparison of stress distribution cloud diagrams (from left to right: six-sided plate hook length = 0.4, 0.6, 0.8 times the side length)

4. Conclusions

By analyzing the thickness of the pavement structure and the length of the connecting hook, and combining the actual use conditions of the pavement, the following two optimization suggestions are proposed for the six-sided plate pavement structure:

1. Within the scope of the structural unit’s deformability, appropriately reducing the thickness of the six-sided plate and increasing the deformation of the pavement structure after loading can effectively reduce the stress level of the structure after loading;

2. On the premise that the structural unit meets the stress intensity, the length of the pavement
structure connection hook can be appropriately reduced during the design, thereby facilitating the improvement of work efficiency.

This paper analyzed the bearing capacity of the six-sided plate pavement structure affected by the connection from two angles, namely the thickness of the hexagonal plate and the length of the connecting hook. The subsequent research can consider other factors that affect the bearing capacity of the road surface to optimize the model.

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