Mechanical Property Study on the rigid deck pavement based on Midas/civil finite element software

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Abstract. In recent years, with the rapid development of China's economy, the traffic volume is also increasing, and more and more rigid deck pavement has been damaged in advance. This not only affects the beauty of the bridge, causes economic losses, but also seriously endangers traffic safety. By using Midas/civil finite element software to simulate the stress state of the rigid deck pavement, with the help of the data obtained from the analysis, it can be concluded that the rigid deck pavement is easy to be crushed in the middle of the span, and easy to be pulled and cracked on both sides.

1. Introduction
In recent years, with the rapid development of China's economy, the traffic volume is also increasing, and more and more rigid deck pavement has been damaged in advance. The main forms of damage are: crack, pit, local damage, fragmentation, falling off, exposed reinforcement, etc. The early damage of rigid deck pavement has become a major disease affecting the highway bridges in China, which has attracted the attention of domestic research institutions. The Midas/civil is one of the most widely used engineering finite element simulation analysis software[1]. Using Midas/civil to analyze the stress and strain of the rigid deck pavement structure can not only meet the accuracy of the research requirements, but also effectively reduce the research cost.

2. Research model of mechanics
The Midas/civil software takes the finite element theory as the basic principle, When studying the rigid deck pavement, its mechanical model is mainly as follows:

2.1. Model discretization
The model structure is discretized into a finite number of mutually continuous elements of a certain size.

2.2. Basic assumptions
The displacement of element is assumed to be a simple function of coordinate.
2.3. Mechanical equation
Based on the analysis of mechanical characteristics, the element equilibrium equation is established, and its general formula as follows:

\[
K^e = \int_B B^T DB dV = B^T DB V \quad [2]
\]  

(1)

2.4. The global equilibrium equation is further established by the element equilibrium equation, and its general formula as follows:

\[
\begin{align*}
K &= \sum K^e G^e G^e \\
P &= \sum P^e G^e \\
Ka &= P
\end{align*}
\]  

[2]  

(2)

In the formula: “K” is the total stiffness matrix; “G” is the node transformation matrix; “P” is the load matrix; “a” is the node displacement matrix.

2.5. Solving unknown node displacement and calculating element stress
According to the specific characteristics of the set of equilibrium equations, the appropriate calculation method is selected to solve the unknown displacement and stress.

3. Establish the model of Rigid deck pavement
Using Midas/civil software to establish the numerical simulation model of the whole bridge, and the model is set as a simply supported beam with a span of 40m. Then, on the basis of the whole bridge model, several groups of rigid deck pavement models with thickness of 5cm, 8cm, 10cm and 13cm and material grade of C20, C30 and C50 are established respectively. The process is as follows:

3.1. Detailed model parameters
Main beam size: 40m (span) × 10.5m (deck width);
  - Main beam specification: 230cm (height) × 180cm (top width) × 6(pieces);
  - Main beam prestressed reinforcement: prestressed steel strand;
  - Main beam material: C40 concrete;
  - Design load: Automobile class I;
  - Pavement slope: cross slope 1.5%;
  - Pavement reinforcement mesh: 8mm diameter, 100mm spacing reinforcement mesh.

3.2. Establish the Midas/civil model[3] of Rigid deck pavement
According to the above selected bridge size and material parameters, the Midas/civil software is used to establish the calculation model, and the model is shown in the figure 1:

![Figure 1. Various screenshots of the calculation model](image)
3.3. **Model calculation**

Submit each group of rigid deck pavement model to computer for simulation analysis, and summarize and sort out the stress and strain data which comes from the calculation results of each part of the model. Then they can be used to analyze the mechanical characteristics of rigid deck pavement.

4. **Sorting out calculation results**

4.1. **Method of data arrangement**

4.1.1. **The stress and strain nephogram simulated by each finite element model are analyzed to find out the weak position of the rigid deck pavement under the most unfavorable load.**

4.1.2. **Find out the maximum stress of each finite element model at the most unfavorable position.**

4.2. **Analyze and summarize data**

4.2.1. **Run the Midas/civil software to analyze the model, and get the most unfavorable position of each model under loads [3], as shown in the figure 2:**

![Stress nephogram under various loads](image)

**Figure 2. Stress nephogram**

4.2.2. **Summarize and sort out the calculation results of MIDAS / civil models in each group, and find out the maximum stress at the most unfavorable position from each group of models, as shown in the table 1 ~ table 4:**

| Concrete grade | Maximum normal stress (kpa) | Maximum shear stress (kpa) |
|----------------|-----------------------------|----------------------------|
| C20            | 7601                        | 3880                       |
| C30            | 7783                        | 4139                       |
| C50            | 7944                        | 4997                       |

Table 1. The maximum stress in the most unfavorable position of the rigid deck pavement with a thickness of 5cm

| Concrete grade | Maximum normal stress (kpa) | Maximum shear stress (kpa) |
|----------------|-----------------------------|----------------------------|
| C20            | 8746                        | 3649                       |
| C30            | 8676                        | 3703                       |
| C50            | 8806                        | 3738                       |

Table 2. The maximum stress in the most unfavorable position of the rigid deck pavement with a thickness of 8cm
Table 3. The maximum stress in the most unfavorable position of the rigid deck pavement with a thickness of 10cm

| Concrete grade | Maximum normal stress(kpa) | Maximum shear stress(kpa) |
|----------------|---------------------------|--------------------------|
| C20            | 7753                      | 3435                     |
| C30            | 7771                      | 3488                     |
| C50            | 7769                      | 3531                     |

Table 4. The maximum stress in the most unfavorable position of the rigid deck pavement with a thickness of 13cm

| Concrete grade | Maximum normal stress(kpa) | Maximum shear stress(kpa) |
|----------------|---------------------------|--------------------------|
| C20            | 5798                      | 2291                     |
| C30            | 5772                      | 2310                     |
| C50            | 5778                      | 2325                     |

5. Conclusion

5.1. By observing and summarizing the calculation results (table 1 ~ table 4) and looking for the rules, it can draw the following main conclusions:

5.1.1. Stress variation law of rigid deck pavement

When the thickness of the rigid deck pavement increases, it can be concluded from the calculation results of the models that the ratio of the maximum normal stress of the pavement to the bearing capacity of the material increases first and then decreases. When the thickness reaches 8cm, the "extreme stress/bearing capacity" is significantly higher than that of 10cm.

According to the stress nephogram, it can be concluded that the compressive performance of the surface concrete of the pavement in the middle of the bridge span is greatly affected, while the thickness of 8 cm is relatively unfavorable to the thickness of 5cm and 10cm.

After that, with the increase of thickness, the "extreme stress/bearing capacity" of pavement began to decrease at 13 cm.

In addition, when the thickness of the rigid deck pavement increases, the pavement at the junction of the curb and the carriageway of the bridge is more likely to crack, so the thickness of 8 cm is a relatively unfavorable thickness to the stress of the pavement compared with the whole model.

5.1.2. The most weak position of rigid deck pavement

Through the analysis of the calculation results and stress nephogram of the model, it can be concluded that the weak part of the rigid deck pavement is at the end of the main beam, in which the web is easily affected by the larger shear stress, and the top of the beam is easily affected by the larger normal stress; the maximum stress of the pavement increases with the increase of the thickness of the pavement or the strength of the material[4].

In addition, the pavement in the middle part of the bridge span is affected by larger normal stress, which is easy to crush, and the pavement at the junction of the curb belt and the carriageway on both sides of the bridge deck is easily affected by larger shear stress, which is easy to crack.

5.2. The significance of the research conclusion for improving the design method of rigid deck pavement

At present, in the design of bridges in China, the stress calculation of rigid deck pavement is generally not carried out, but only considered as a structural measure. General Specifications for Design of Highway Bridges and Culverts (JTG D60-2015) stipulates that the thickness of cement concrete rigid deck pavement (excluding leveling layer and cushion) shall not be less than 80mm, and the concrete
strength grade shall not be less than C40. The pavement shall be equipped with steel mesh. The diameter of rebar shall not be less than 8mm, and the spacing shall not be greater than 100mm[5].

Combined with the conclusion of 5.1., it can be considered in the future rigid deck pavement design that:

5.2.1. **When the thickness of rigid deck pavement increases, the ratio of its maximum stress to bearing capacity increases first and then decreases, taking 8cm as the vertex, and when the thickness of the pavement layer is 10cm, its stress distribution is relatively balanced. If the thickness of pavement is less than 10cm, its stress is larger, which is not conducive to the pavement anti damage. Higher than 10cm, although the stress is small, it increases the cost and self weight[6].**

5.2.2. **When C35 concrete is used as the material of the rigid bridge deck pavement, the ratio of the maximum stress to the material strength is small, which can make the pavement leave enough surplus bearing capacity, and will not cause excessive material waste.**

5.2.3. **Through the simulation analysis of Midas/civil software, it can be found that: the maximum compressive stress of the rigid deck pavement comes from the mid span area, where it is easy to crush; the maximum tensile stress it receives comes from the intersection of the carriageway and the curb belt on both sides of the deck, where it is easy to crack. Therefore, in the design, construction and maintenance, attention should be paid to these areas.**

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