Bending fatigue characteristics of fiber grid reinforced cement concrete pavement

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This study aims to improve the flexural fatigue performance of the extended or repaired cement highway pavement. The bending fatigue performance of the cement road surface was enhanced by the method of glass fiber grid reinforcement. The finite element analysis of the structure of the glass fiber grid reinforced cement road surface was carried out by ANSYS software. The influence of different reinforcement positions on the fatigue performance of the road surface was tested by the bending fatigue experiment of the small beam. After adding the glass fiber grid to cement pavement, the peak value of vertical compressive stress at the addition location significantly reduced. Although the horizontal stress increased, the horizontal stress on the upper and lower layers of the grid relatively reduced as the glass fiber grid shared the stress. The fatigue life significantly reduced as the alternating load stress level increased on cement pavement, and the bending stress and fatigue life basically showed a double logarithmic, linear relation. The bending fatigue performance of cement pavement can be effectively improved by using the method of glass fiber grid reinforcement, and the closer the location of grid reinforcement is to the bottom of the pavement, the more the fatigue life will be improved.

Keywords: glass fiber grid, cement, highway pavement, fatigue

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1. Introduction

With the rapid development of the economy and the increase of traffic volume, not only the existing roads are overcrowded, but also the road load of the original roads increases, causing road damage [1]. To meet the increasing traffic volume and repair the pavement damage, the original road needs to be expanded and repaired, during which, not only the expansion and repair of the pavement need to be considered, but also the strength and life of the extended and repaired pavement need to be considered. For the cement highway, its strength and service life mainly depends on the nature of the material, i.e., the various proportions of cement concrete. In addition, pavement strength and service life can be improved by adding additional structures [2]. For example, by imitating the cement beam and column in the building, reinforcement can be added in the cement road to improve its strength. Tang et al. [3] improved the strength of cement concrete pavement using fly ash and found through finite element analysis that the fatigue life of fly ash was effectively extended after fly ash was added into the cement pavement. Guo et al. [4] designed the fatigue loading experiment with stress levels of 0.3, 0.5, and 0.8, divided the fatigue strength into four grades, and found that the residual strength of the pavement reduced under the dynamic fatigue load. Jin et al. [5] obtained the change rule of fatigue performance of polyester fiber asphalt concrete under different asphalt content through the three-point bending test and found that the fatigue life of polyester fiber asphalt concrete increased first and then decreased with the increase of asphalt content and the optimal asphalt dosage was 4.8 %. In this study, the performance of the cement concrete pavement which was added with fiber grid was analyzed by the finite element analysis and actual fatigue test. Finally, it was found that the addition of the fiber grid could improve the cement pavement performance, especially the-anti fatigue performance. This study provides an effective reference for repairing the damaged cement pavement and improving the anti-fatigue performance of cement pavement. The future research direction is to further refine and explore the influence of grid laying position on cement pavement, so as to improve the performance of cement pavement more accurately.

2. Fiber grid reinforcement method

Glass fiber grid [6] has high tensile strength due to its high modulus, and the elongation of glass fiber is low; compared with other reinforced materials such as steel wire, glass fiber will not creep even after a long time of use. Glass fiber has the property of high-temperature resistance. Excluding the type with special treatment, the conventional melting point is about 1000 °C, and the increase of temperature caused by hydration heat released from cement concrete setting is far below 1000 °C; the glass fiber, which is made of silicate, has physical and chemical durability.

When the cement road is expanded or repaired, the glass fiber grid is added to the surface of the road base firstly to bond with the surface of the road base under the action of assembly glue, and the mixed concrete is added above the glass fiber grid after the glass fiber grid is paved, followed by compaction and smoothing. In the process of concrete compaction, aggregate in concrete will enter the grid, and cement colloid, aggregate, and glass fiber grid constitute a kind of interlocking system, which greatly limits the activity of aggregate and finally makes the solidified cement pavement more stable [7].

3. Experimental analysis

3.1. Finite element analysis of glass fiber grid reinforced cement pavement

In this study, the structure of glass fiber reinforced cement pavement was analyzed using ANSYS software [8]. The conditions are set: ① the materials of each layer of the structure are ideal elastic materials with uniform distribution; ② in the natural state, the internal stress is 0; ③ layers are in a continuous state rather than fractured; ④ the stress and displacement of infinite distance in the horizontal direction and vertical downward direction are all 0.

In this study, the finite element model of cement highway pavement structure is a two-dimensional model, as shown in Fig. 1. In general, it is divided into three layers, namely the pavement layer, base layer, and soil base layer. The pavement layer is divided into three layers, i.e., upper, middle, and lower layers, which is convenient for distinguishing the laying position of the glass fiber grid. The length of the pavement structure is 4 m in the horizontal X direction and 4 m in the vertical Y direction. According to the axle wheel load, the road load is simplified as the applied load block in Fig. 1, with a length of 20 cm, which is located on both sides of the road center, and the center distance of the load block is 32 cm. Axle wheel load adopts the standard 100 kN uniaxial load, and the tire ground pressure is 0.7 MPa. The pavement layer, base layer, and soil base layer adopt the four-node plane rectangular unit [9]. The glass fiber grid adopts the bar unit. The spring unit connects the grid and the upper and lower structural layers. The boundary conditions are set as no rotation at the left and right side of constraint, no rotation at the bottom edge of constraint, no constraint at the upper edge, and complete and continuous contact between layer and layer.

The relevant parameters of the pavement structure model are shown in Table 1.

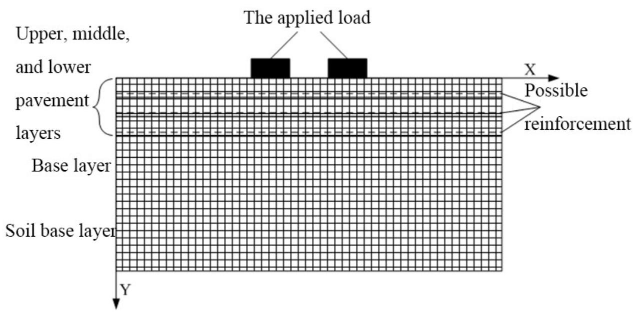

Fig. 1. The schematic diagram of the two-dimensional finite element model of the glass fiber reinforced cement highway.

Limited by the length of the paper, this paper only displays the difference of stress between the simulation model of pavement and actual pavement under the unreinforced condition, and the results are shown in Table 2. The comparison showed that the average error between the model and actual pavement was very small no matter under which depth and horizontal distance, and moreover standard deviations of those errors were also very small, indicating that the results obtained by the simulation model were very close to the actual situation and the analysis results of the simulation model were convincing.

3.2. Bending fatigue test of glass fiber grid reinforced cement concrete pavement

3.2.1. *Specimen preparation*

First of all, the cement concrete for the experiment was prepared, as shown in Table 3.

Table 1. Relevant parameters of the cement pavement structure model.

Structural layer	Material	Modulus of elasticity/MPa	Thickness/cm	Poisson's ratio
The upper layer of pavement	Cement concrete	1600	4	0.23
The middle layer of pavement			8	
The lower layer of pavement			10	
The base layer	Cement rubble	1400	50	0.25
Soil base	General soil	30	/	0.30
Glass fiber grid	/	50000	0.3	0.22

Table 2. The difference of stress between the simulation model of the unenforced pavement and actual pavement

Depth/m	Average error/MPa	Standard deviation /MPa	Horizontal distance/m	Average error/MPa	Standard deviation/MPa
0	0.0002	0.0001	0	0.0003	0.0001
0.04	0.0001	0.0002	0.4	0.0002	0.0001
0.08	0.0001	0.0001	0.8	0.0002	0.0002
0.12	0.0001	0.0001	1.2	0.0001	0.0001
0.16	0.0002	0.0001	1.6	0.0002	0.0001
0.20	0.0001	0.0002	2.0	0.0003	0.0001
0.24	0.0002	0.0001	2.4	0.0002	0.0001

Table 3. Proportion of experimental concrete

Material	Cement kg/m^3	Coarse aggregate kg/m^3	Fine aggregate kg/m^3	Water reducing agent kg/m^3
Dose	560	1080	650	5.5

The specification of the test specimen, which was made with the mold, is $Length \times width \times thickness = 300 \times 300 \times 100mm^3$. According to the addition position, the test specimens which were added with the glass fiber grid were divided into three categories: laying at the 1/4 thickness, 2/4 thickness, and 3/4 thickness. After the maintenance, the test specimen was cut perpendicularly to the surface of length × width into small beam-column specimens ($Length \times width \times thickness = 300 \times 300 \times 100mm^3$) [10].

3.2.2. Experimental method

In this study, the fatigue performance of the reinforced cement concrete pavement was tested by the small beam bending fatigue experiment [11]. The preparation of the test specimen is as described above, and then the bending fatigue test was carried out on the small beam-column specimen using a micro-computer hole electro-hydraulic servo press. The loading mode is as shown in Fig. 2.

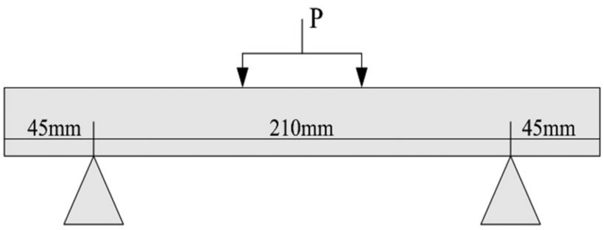

Fig. 2. The loading diagram of the beam-column specimen.

Four kinds of stress levels were set according to relevant experiment criteria of small beam bending fatigue in the experiment: 0.6, 0.65, 0.7, and 0.75. To simulate the situation when vehicles pass the cement concrete pavement, the applied load P was changed in sine alternating [12], and the change frequency was 15 Hz. The set stress level determined the maximum load in the change process.

There are four types of specimens in the experiment: ① the unreinforced concrete beam-column; ② the concrete beam-column with glass fiber grid at the 1/4 thickness; ③ the concrete beam-column with glass fiber grid at the 2/4 thickness; ④ the concrete beam-column with glass fiber grid at the 3/4 thickness. The dimension of the test specimens is shown in Fig. 3. The basic dimension of the unreinforced concrete beam-column specimen was consistent with the description in Fig. 3, 300 mm long, 100 mm wide, and 100 mm thick. The external dimension of the glass fiber grid reinforced concrete beam-column specimen was consistent with the unreinforced test specimen, but the difference lied in whether the glass fiber grid was added. ②, ③, and ④ in Fig. 3 are the cross sections of three reinforced test specimens, and the setting position of the glass fiber grid is as described above. The bending fatigue test was carried out for each specimen at four stress levels, three times for each stress level. Each test did not end until the specimen fractured, and the number of cyclic loading was recorded (one time of loading as one loading cycle). If the test specimen was not fractured after 100000 times of loading, the experiment stopped.

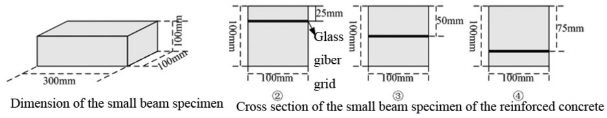

Fig. 3. The schematic diagram of the dimension of concrete small beam specimens.

3.3. Experimental results

In the finite element simulation results of cement concrete highway, the peak value of vertical compressive stress in different depth of highway under different reinforcement locations is shown in Fig. 4. It was seen from Fig. 4 that the peak value of vertical compressive stress decreased with the increase of the road depth, whether the road surface was reinforced or not. The addition of a glass fiber grid to the cement concrete pavement could effectively affect the vertical compressive stress of the pavement, and the vertical compressive stress at the position where was added with the glass fiber grid was significantly lower than that of the position without reinforcement.

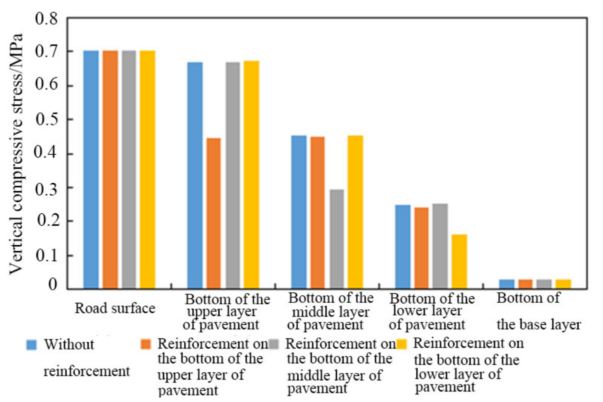

Fig. 4. Comparison of the peak value of vertical compressive stress of cement concrete highway under different reinforcement positions.

Through the finite element simulation, the peak value of horizontal stress at different depths of the highway under different reinforcement positions is shown in Fig. 5, where the positive and negative symbols represent directions of stress. It was seen from Fig. 5 that the peak value of horizontal stress decreased with the increase of highway depth and finally changed from horizontal compressive stress to horizontal tensile stress, whether the highway was reinforced or not. The upper pavement of the highway bore greater horizontal stress when the glass fiber grid was added to the bottom of the upper layer of the pavement, which was prone to fatigue damage; when it was added to the bottom of the middle and lower layers of the pavement, the horizontal stress at the position which was added with glass fiber grid was large at the same position but still lower than the overall, so that the great horizontal stress was bore by the grid and the horizontal stress that was bore by the pavement above and below the grid reduced, reducing the fatigue effect.

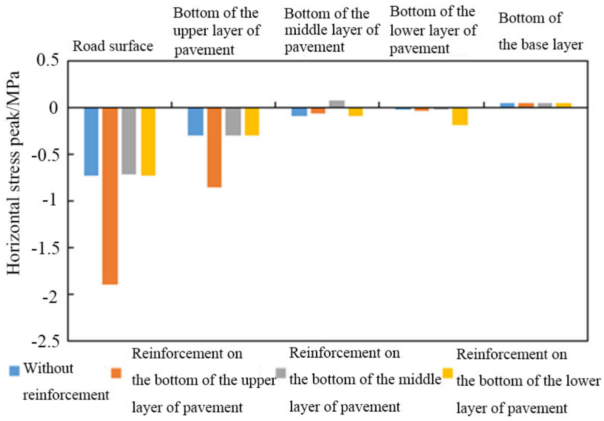

Fig. 5. Comparison of peak horizontal stress of cement concrete highway under different reinforcement positions.

It was seen from the logarithmic fatigue curves of four kinds of test specimens in Fig. 6 that the bending stress and fatigue life of the test specimen basically showed a logarithmic, linear relationship. The fatigue curve of test specimen ① which was not added with grid was $lg(N) = -3.4765lg(f) + 4.2973$ (N is fatigue life and f indicates bending stress), and the correlation coefficient $R^2 = 0.9187$; the fatigue curve of test specimen ② which was added with glass fiber grid at the 1/4 thickness was $lg(N) = -3.3768lg(f) + 4.3227$, and the correlation coefficient $R^2 = 0.9153$; the fatigue curve of test specimen ③ which was added with the glass fiber grid at the 2/4 thickness was $lg(N) = -3.0381lg(f) + 4.3309$, and the correlation coefficient was $R^2 = 0.9470$; the fatigue curve of test specimen ④ which was added with the glass fiber grid at the 3/4 thickness was $lg(N) = -2.6996lg(f) + 4.3783$, and the correlation coefficient was $R^2 = 0.9440$.

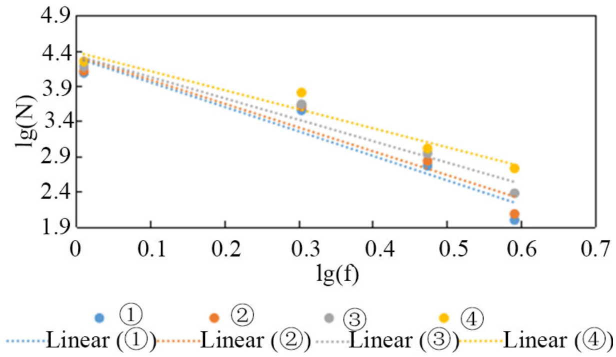

Fig. 6. Logarithmic fatigue curves of four kinds of test specimens.

4. Discussion

Tensile stress generated on the road outside the wheel and compressive stress generated in the center of the two wheels under the wheel load, and the grid shared the stress and dispersed the stress to the horizontal level. The reason for the increase of horizontal stress at the place where the grid was added was that the horizontal stress redistributed under the action of the grid, which had higher elastic modulus, especially distributed on the reinforcement layer. The horizontal stress of the upper layer of the pavement increased when the upper layer of pavement was reinforced, which was easy to damage the upper layer of pavement. When the reinforcement layer was at the middle and lower layers of the pavement, most of the horizontal stress concentrated at the middle and lower layer, leading to the decreased horizontal stress at the upper layer of the pavement and reducing the fatigue effect of the upper layer. The results of the small beam bending fatigue test also verified that reason. In the fatigue test, the increase of the stress level increased the bending stress and thus increased the horizontal stress, leading to a decrease in the fatigue life. After adding the grid, the horizontal stress mostly concentrated in the reinforced layer, which improved the fatigue life, and the closer the reinforcement layer was to the bottom layer, the larger the increase of the fatigue life was, which has been explained in the above text.

5. Conclusions

This paper introduced the concept of bending fatigue of cement concrete highway and the fiber grid reinforcement method used for improving the fatigue performance of cement highway pavement. Then, the finite element analysis of the structure of glass fiber grid reinforced cement pavement was carried out in ANSYS software, and the small beam bending fatigue test was carried out for the cement concrete pavement specimen with different reinforcement at different positions. The results are as follows: (1) in the finite element simulation, the peak value of the vertical compressive stress of the highway decreased with the increase of the depth, and the peak value of the vertical compressive stress of the position which was added with glass fiber grid decreased obviously; (2) in the finite element simulation, the peak value of the horizontal compressive stress of the highway decreased with the increase of the depth, and it gradually changed into the horizontal tensile stress; the horizontal stress of the position which was added with glass fiber grid had obvious improvement; (3) the results of the small beam bending fatigue experiment showed that the fatigue life of the specimen decreased rapidly with the increase of the stress level of the alternating load applied on the specimen; the relationship between the bending stress and fatigue life of the four specimens conformed to the logarithmic fatigue curve; the fatigue curve showed that the fatigue life of the cement pavement improved by adding the glass fiber grid, and the closer the addition position to the bottom, the larger the improvement.

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