Research on Fractal Fatigue Failure Mechanism and Application of Cement Concrete Pavement

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Keywords: Cement Concrete Pavement; Fractal Theory; Fatigue Failure; Application

Abstract: Bending fatigue fracture is the basic basis for damage analysis of cement concrete pavement. However, the fatigue equation established on the basis of the indoor trabecular fatigue experiment has a large dispersion and cannot be equal to the actual pavement structure,and there are certain differences between them. Therefore, it can not be used to explain the influencing factors of pavement fatigue characteristics. Combining with fractal theory, the fractal fatigue equation of concrete is proposed, and factors influencing fatigue characteristics of concrete pavement are explored. Based on this, the method of concrete pavement is designed, and the remaining life of the old cement concrete pavement is calculated by formula.

Cement concrete pavement is also called rigid pavement, and it consists of cement concrete panels and other bases. According to the different components, it is divided into reinforced concrete pavement, ordinary concrete pavement and steel fiber concrete pavement. At present, ordinary concrete pavement is widely used in China, which is characterized by no reinforcement at joints. The fatigue failure mechanism analysis of ordinary concrete pavement is helpful to grasp its application and ensure the safety of road use.

1. Common Damage of Cement Concrete Pavement

1.1. Seam Destruction

(1) Crush

Crushing generally occurs at the transverse joints of cement concrete. Because the sliding force-transmitting rods located in the transverse joints are significantly deviated under the action of external forces, and lose their normal sliding function, and the concrete face slab on both sides of the transverse joint will have static friction and crush into pieces. In addition, during the construction process, due to construction technical problems, hard objects enter the transverse joints, which directly affects the thermal expansion effect of the concrete panel. And the concrete can be subjected to a higher compression force when it expands. The squeezing force exceeds the strength of the concrete shear stress, causing the concrete panel to break due to extrusion.

(2) Arching

When the concrete panel is heated, the volume of the concrete panel will become larger due to expansion. When the volume change is hindered, the joints of the concrete panel will be arched. Because the gap will be completely opened when the concrete panel shrinks. The joint filler does not perform its normal function at this stage, and the gap is filled with hard objects. Eventually, the relaxation function of the gap cannot be effectively performed when the concrete panel is heated and the volume becomes larger, leading to the phenomenon of arching.

(3) Misplacement

Misplacement refers to the displacement of the concrete panels on both sides of the joint, because the caulking panels and gaps on both sides of the transverse joints fail to effectively correspond, or the center line of the concrete panel on both sides of the transverse joint is not kept at

the same position, and the volume changes of the panel will squeeze each other after heating, resulting in the occurrence of up and down dislocation. The water on the cement concrete pavement penetrates into the joints, which will cause the cement concrete on both sides of the joints to soften, and its normal function will be restricted, causing misalignment. In addition, the traffic load on the cement concrete pavement is not evenly distributed, which will also cause different degrees of sagging of the web above the horizontal joints and cause misalignment.

(4) Mud pumping

Mud pumping mainly refers to that when the joint of concrete face plate passes through the automobile, the slurry is sprayed out from the gap due to the external load. The main reason for mud pumping is that the base course of cement concrete is deformed due to long-term involvement, and is separated from the concrete panel, resulting in the internal cavity of cement concrete. In this case, the accumulated water on the ground will enter the cavity inside the concrete through the joint and be stored. It will form a slurry with the fine material in the cement concrete and the infiltrated soil, which is subject to external loads. The action mud will be ejected from the joints due to squeezing. The mud will cause the edge of the panel to lose support, which will cause horizontal seams around the seams.

(5) Pavement subsidence

Pavement subsidence refers to the continuous subsidence of pavement. This kind of damage often occurs in bridge head section and high fill section. When the road surface subsidence, it will lead to uneven road surface, and is extremely easy to cause pavement cracking under the frequent action of wheel load and seriously affect road driving.

(6) Pits and holes

The pit is caused by the aggregate falling off from the pavement, which leads to the long groove. Holes are local cavities caused by pavement damage. Generally, the damage of pits and holes occurs on heavy haul road sections. In order to increase the bearing capacity of heavy haul road sections, the content of sand and gravel in them is often increased. The bumping of vehicles in the process of driving will cause pits and holes, which will aggravate such damage problems. In serious cases, vehicles will get stuck in the holes and cause serious traffic accidents.

(7) Pitted surface, exposure and polishing

Pockmarked surface is the phenomenon that the binder on the road surface is polished and the pavement is rough. Exposure is the phenomenon of aggregate exposure due to the loss of a large number of protective layers. Polishing means that the road surface is repeatedly rubbed by wheels, or its own wear resistance is not enough to be polished. In this case, the friction force of the road surface will be greatly less than the limit value, which is extremely easy to cause traffic accidents.

1.2. Failure of Concrete Slab Itself

The main failure modes of concrete slab are fracture and crack. The main reason for the failure of concrete slab is that the external pressure exceeds the strength limit that the concrete slab can bear. The common types are as follows: (1) the concrete slab is too thin or the wheel load pressure is too large; (2) the channelization effect of traffic load, that is, the action times of driving load have exceeded the allowable range; (3) the plane size of the concrete panel is too large and the temperature warping stress exceeds the standard, which makes it easy to damage itself under the action of external load; (4) the shrinkage pressure given to the concrete panel during the maintenance of the concrete panel is too large; (5) the base part of cement concrete pavement has serious plastic deformation, and the concrete panel is unable to bear the void; (6) the materials and construction technology used in the construction process of cement concrete pavement are not up to the standard, so that the strength of cement concrete pavement can not reach the specified standard.

2. Fractal Fatigue Failure Mechanism

2.1. Analysis of Fractal Fatigue Crack Growth

The growth of microcracks and the process of their interconnection is the growth process of

fatigue crack. In this stage, considering the local distribution of microcracks, the evolution of damage is chaotic. From the statistical point of view, the fatigue fracture surface shows fractal. When describing this phenomenon, empirical formula put forward by Paris and Erdogan in 1936 are used as follows:

$$da/dN = C\ (\Delta K)^n$$

Afterwards, with the continuous research of people, the fatigue crack growth formula is optimized, and finally the current fractal fatigue equation is formed.

$$C = \frac{K_{IC}(1-R)-\Delta K}{D_s-1}(C_1 E)^{(D_s-2)/(D_s-1)} a^{2-D_s}$$

2.2. Fractal Fatigue Characteristics of Cement Concrete Pavement

Based on the concrete fractal fatigue equation obtained from the above analysis, the fractal fatigue characteristics of concrete are studied. For cement concrete pavement, load stress and temperature stress can be regarded as high stress, and temperature stress can be regarded as low stress. With reference to fracture mechanics, the stress intensity factor is:

$$K_1 = Y(a)\ \sigma\sqrt{\pi * a}$$

Therefore, the critical stress intensity factor should be:

$$K_{IC} = Y(a)\ f_r\sqrt{\pi * a_c}$$

The difference between critical stress intensity factor and stress intensity factor is the load stress, substituted into the fractal fatigue equation, and the integral can be obtained.

$$N - N_0 = \frac{2a_c^{\frac{n}{2}} D_s - 2}{S^n 3 - D_s}\left[a_a^{D_s-\frac{n}{2}-1} - a_c^{D_s-\frac{n}{2}-1}\right]$$

2.3. Influencing Factors of Concrete Fatigue Characteristics

The influence of the maximum aggregate particle size on the fatigue characteristics of concrete is mainly reflected in the coefficients of the concrete fractal fatigue equation, which is related to the roughness of the fracture surface and the particle size of the concrete aggregates. With the increase of these two parameters, the surface fractal dimension increases correspondingly. In addition, the aggregate particle size will also affect the length of the initial cracks formed in the cement concrete and the growth rate of the initial cracks and the fatigue damage. There is a positive correlation between the length of the initial crack and the particle size of the aggregate, that is, the former increases as the latter increases, and decreases as the latter decreases. It can be seen from the fatigue performance of concrete will obviously decrease with the increase of aggregate particle size, which will affect its service life.

The influence of stress ratio and cyclic characteristics on the fatigue characteristics of concrete is reflected in the load stress fatigue coefficient. The load stress fatigue coefficient will also affect the coefficient of the concrete fatigue equation. With the increase of stress ratio, the fractal dimension increases, and the stress ratio also has a great influence on the load stress fatigue coefficient.

3. Engineering Application of Fractal Fatigue Failure Mechanism of Cement Concrete Pavement

3.1. The Choice of Grass Roots

The use of other base course in cement concrete pavement is mainly to fill the concrete panel, provide guarantee for the uniform sewing of load, and effectively prevent the slab fracture and joint

dislocation. Therefore, there are two main requirements for the selection of base course.

First of all, it is necessary to have good anti scour ability and effectively prevent cement concrete damage such as joint pumping and staggered platform.

In addition, it is necessary to have good corrosion resistance. Corrosion will reduce the strength of the base course, lead to loose base course and lower bearing capacity, and increase the occurrence of staggered platform. Selecting the base with better corrosion resistance can maintain sufficient strength and prolong the service life.

3.2. For Repair Technology

By analyzing the mechanism of fractal fatigue failure of cement concrete pavement, bandage repair technology, a new pavement crack repair technology, can be tried. The difficulty of bandage repair is to repair the crack again and increase its load transfer capacity. Cracks on the pavement will cause misalignment and expansion, and its load transfer capacity will decrease. In addition, the cracks generated in the pavement are not regular and have certain fractal characteristics. If the cracks are not repaired in time, they will expand, and there is the risk of edge collapse and corner fall, which eventually makes the pavement panel develop into a broken slab.

Generally, the load transfer capacity of cracks can be restored by setting dowel bars. An extremely important prerequisite for choosing to add tensile force transmission rods to hardened concrete is that professionals should evaluate whether the concrete can be grooved and the width and depth of the groove. When adding a tensile force transfer bar, it is generally selected to set it under the concrete slab. And the parameters of slotting should be determined according to the basic situation of cement concrete, and the width of slotting should be more than three times of the diameter of reinforcement, so as to avoid the problem of stress concentration in the process of using the tension bar.

Concrete slotting belongs to dead joint, and the deformation of slotting is relatively small, which is generally in the order of magnitude of micro strain. It is worth noting that problems such as strip effect and joint treatment of new and old concrete will occur in the process of concrete slotting. The former refers to the phenomenon of expansion along the strip direction when the concrete shrinks after slotting, resulting in strip fracture, while the latter refers to the situation that the participation of new and old concrete is inconsistent, such as bond performance, which makes the joint easy to debonding and cracking. For the above two bad phenomena, the calculation should be carried out in strict accordance with the fractal fatigue equation of concrete, and the appropriate materials and repair methods should be selected to achieve the purpose of repairing.

4. Conclusion

With people's in-depth research on the fatigue failure mechanism of cement concrete pavement, as well as the common failure phenomenon and cause analysis of concrete roads, the fractal fatigue failure equation has been continuously sorted out. Through the influence of size effect on the growth of concrete cracks, and the application of linear elastic fracture mechanics to the analysis of fatigue fracture, the reasons for its formation are analyzed to help people better design cement concrete pavements, extend their service life. At the same time, the solution of its mechanism can be used to repair the pavement.

References

[1] Tang Bo. *Research on Anti-fatigue Optimization Design of Cement Concrete Pavement* [J]. Fujian Transportation Science and Technology, 2019(04): 37-40.

[2] Wang Xiaoping. *Research on the Reliability Design Method of Highway Cement Concrete Pavement* [J]. Sichuan Cement, 2019(02): 4.

[3] Hu Qinghua. *Analysis of the Failure Mechanism of Cement Concrete Pavement* [J]. Quality Exploration, 2016, 13(06): 38-39.

[4] Zhou Zhigang. *Research on Vibration Damping, Energy Absorption and Fatigue Characteristics of Rubber Cement Concrete in the State of Vacant Grassroots* [D]. Guangxi University, 2016.

[5] Yan Xiaohui. *Research on Application Technology of Oblique Continuous Reinforcement Prestressed Cement Concrete Pavement* [D]. Shenyang Jianzhu University, 2016.

[6] Chen Yulin. *Research on the Dynamic Effect of Heavy Load on Cement Concrete Pavement* [D]. Fuzhou University, 2015.

[7] Dai Chuyuan. *Research on Dynamic Energy Dissipation Mechanism of Asphalt Buffer Isolation Layer on Cement Concrete Pavement* [D]. Guangxi University, 2015.

[8] Dan Ruiqiang, Tian Xiaoge, Li Shaopeng, Peng Kai, Li Moren. *Analysis of the Influence of Overload on Pavement Structure* [J]. Northern Transportation, 2015(04): 55-58.

[9] Li Chunmei, Song Xianghong, Wang Guishi. *Research on the Cracking Mechanism and Failure Process of Cement Concrete Pavement* [J]. China Building Materials Science and Technology, 2015, 24(02): 168-169+189.

[10] Xie Xiaodi. *Research on the Isolation Performance of Wax Curing Agent Based on Water-stable Base Layer* [D]. Changsha University of Science and Technology, 2015.

[11] Chen Liangliang. *Research on the Prediction Model of Continuous Reinforcement Cement Concrete Pavement Thrust Failure* [D]. Harbin Institute of Technology, 2014.