Mechanics of Inhomogeneous Deformation of Concrete Pavement under Temperature Effect

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Abstract: For the concrete pavement, it has a significant characteristics of Principle of Expand on Heating and Contract on Cooling, which probably causes a bending stress for the slabs. The temperature of upper slab waves a lot rather than the lower part for the effect of fluctuation of environmental temperature. And inhomogeneous deformation of the slab will be caused by the temperature difference, which relates to several typical defects of the concrete pavement. A theoretical analysis as well as a numerical analysis have been made in this paper. According to result of the numerical simulation, the maximum voiding length $c_{\text{max}}$ is 2.176mm. And the result of theoretical analysis is 2.343mm. The error of both results is 7.12%, which proved the reliability of both methods.

1. Introduction

It is of the characteristics of Principle of Expand on Heating and Contract on Cooling for the concrete pavement slab material. The temperature of upper pavement waves a lot rather than the lower part for the effect of fluctuation of environmental temperature$^{[1~5]}$. The temperature fluctuation includes both a normal daily shift and a rapid change under special weather. Actually, the temperature effect on the slab will be delayed by the change of temperature, which brings about a temperature gradient from top to the bottom of the pavement slab. Inhomogeneous deformation of the slab will be caused by the temperature difference, which relates to several typical defects of the concrete pavement (Figure 1.).

![Figure 1. Typical defects caused by inhomogeneous deformation](image-url)
2. Theoretical analysis of temperature effect for pavement slab

2.1. Typical conditions of slab deformation

There are both types of deformation caused by temperature\(^4\)\(^-\)\(^6\). When the upper temperature is higher than the bottom, it will cause a void at the middle of the slab for a salient of the slab. The stress of the middle of the voiding slab is much less than other parts and the void will not develop as a frost boiling one because the water can’t get into the void. When the bottom temperature is higher than the upper, it will cause voids at the corners of the slab. Voids at the corners is bad for the slab because it will cause a significant stress at the corners of the slab, which probably causes severe damage of the slab. What’s more, the water get into the voiding area which causes a frost boiling void.

2.2. Analysis of mechanical response of the voiding slab

Among the slabs, there is a significant constraint caused by dowels, rods and skeletons, although one single slab was cut into regular parts by joints\(^7\). A theoretical analysis of deflection of the slab and response caused by stress was showed as follows. The pattern of the analysis model is showed as figure 2.

![Figure 2. The pattern of the analysis model](image)

Several hypothesises have been made in the theoretical analysis. The temperature difference between upper and bottom is \(\Delta T\). The weight and the skeletons from other slabs are not considered in the calculation. The bending slab can be reckoned as a sphere of which the radius is \(R\). The length of the curve of upper slab is \(L\) and the bottom curve is \(L+\alpha \Delta T\), in which \(\alpha\) is thermal expansion coefficient. The base can not bear a tension but only a pressure as well as the slab. In that, the base can not cause a tension for the slab. According to the analysis above, geometric relation can be derived as follows. In the formula, \(\theta\) is the central angel of the curve.

\[
L = R \cdot \theta \quad \text{(1)}
\]

\[
L + \alpha L \Delta T = (R + h) \cdot \theta \quad \text{(2)}
\]

According to both formulas above, a relation can be derived as follows. In the reasoning, the \(R+h\) is hypothetically reckoned as \(R\). In the formula, \(d\) is the distance from edge to centre of the slab.

\[
R = \frac{h}{\alpha \Delta T} \quad \text{(3)}
\]

\[
c = \frac{d^2}{2R} \quad \text{(4)}
\]

And with formula (3) and(4), the deflection caused by a temperature difference can be calculated as follows.

\[
c = \frac{\alpha \Delta T d^2}{2h} \quad \text{(5)}
\]
3. A numerical simulation of temperature effect for pavement slab
In order to verify theoretical result, a numerical simulation has been made with ABAQUS. The significant parameters were set as follows. Geometry size is 5.0m×5.0m×0.4m. Thermal expansion coefficient $\alpha$ is 10^{-5}. The temperature difference between upper and bottom $\Delta T$ is 30℃. Modulus of the material is 35GPa. Poisson ratio is 0.15. According to result of the numerical simulation, the maximum voiding length $c_{\text{max}}$ is 2.176mm. And the result of theoretical analysis is 2.343mm. The error of both results is 7.12%, which proved the reliability of both methods.

![Figure 3. The pattern of the numerical analysis model](image)

4. Conclusion
In dealing with the problem of damages caused by temperature effect, theoretical analysis as well as numerical analysis have been made in this paper. And the conclusion can be listed as follows. There are both types of deformation caused by temperature. When the water gets into the voiding area, it will causes a frost boiling void and worse damage for the slabs. According to result of the numerical simulation, the maximum voiding length $c_{\text{max}}$ is 2.176mm. And the result of theoretical analysis is 2.343mm. The error of both results is 7.12%, which proved the reliability of both methods.

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