Analysis of Early Crack at Bottom of Cement Concrete Pavements Slab

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ABSTRACT: During hardening behavior of concrete, shrinkage is induced. While, new poured pavements slab is subject to constraint by subsurface structure which always arouses tensile and shear stress concentration at end-bottom of slab. Employed finite element method, this paper aimed at stress analysis of slab bottom during hardening, and derived the disciplinarian of nonloaded crack formation at bottom of slab.

Keywords: cement concrete pavement; bottom of slab; early crack; nonloaded crack

INTRODUCTION

Usually, the new pouring concrete to produce larger contraction deformation, and generally does not cause the load crack under the condition of no external constraints. For cement concrete road surface, if after construction cut seam, not in time inevitably leads to the top surface tensile stress is too large, the formation of irregular load crack and cause so early. For surface underside, top kerf could not release the tensile stress produced by bottom material shrinkage due to the restraint of grassroots, coupled with the road slab structure of large size, the bottom of the plate is likely to form a larger, shear stress concentration, leading to the bottom of the plate produced a series of cracks with the increase of concrete shrinkage, according to the basic principle of fracture mechanics, the existence of cracks will greatly reduction pavement service life. The stress state of visible, early research board for guiding pavement design, estimate the service life of pavement is of great significance.

1 The main factors that influence the pavement early cracks

As is known to all, concrete cracking is result from concrete shrinkage, creep, elastic modulus, tensile strength and the limited level of the comprehensive. Cement concrete pavement plate after pouring concrete material hardening, final set indicates the material internal bearing skeleton basic formation. At this stage, once local tensile strength is less than the tensile stress, inevitably makes the stress release in the form of crack, form the initial injury. Therefore, early cement concrete pavement plate stress and early performance of concrete material change and basic constraints are closely related.
1.1 The influence of early concrete performance

1.1.1 Shrinkage performance

Generally speaking, the shrinkage deformation of concrete includes plastic shrinkage, autogenously shrinkage and drying shrinkage, etc. The early concrete pavement slab bottom close to humidity closed before pouring the grass-roots full wet conditions, so you can think of early concrete pavement slab bottom mainly produces plastic shrinkage and the drying shrinkage; both contractions are the result of cement hydration. Plastic shrinkage occurs mostly before the final set while concrete in plastic stage, although at this stage of concrete volume change is very big, but the concrete hardening, without causing stress in the concrete, will not cause cracking; while the autgenously shrinkage occurred in the hardening process of concrete, hydration of cement particles continue to hydration leading to inside the concrete dry and contraction. Outside the constraints may make skeleton has formed the bearing damage, so crack formation.

Past studies have shown that the autogenous shrinkage of cement is small, usually only 50 με. This is due to the cement particles larger (smaller surface) and the label is low, so early cement hydration degree is low and early strain value is very small, there would be no problem of early crack. With the constant improvement of the cement mark today, however, the improvement of cement hydration, the effect of autogenous shrinkage is more and more obvious. Studies have shown that [1], the early autogenous shrinkage concrete can be as high as more than 200 με, it is bad to the early crack resistance of concrete.

1.1.2 The early elastic modulus

Elastic modulus reflects the relationship between the stress and strain of the material, is the most basic parameters that reflect the material deformation. After the condensation, the early concrete elastic modulus is growing very quickly, usually within 3 days can be more than 50% final value elastic modulus; therefore, the elastic modulus of concrete stress growth plays a larger role.

1.1.3 The early tensile strength

The early tensile strength of concrete is directly related to the growth rate of within the concrete structure crack resistance, crack is gradually formed if the early tensile strength is lower than the tensile stress.

For studying early tensile strength of concrete is less at home and abroad, especially for the tensile strength of age less than 1 day, due to the early strength of concrete discreteness and the limitation of test method, for this stage of the tensile strength of general adopt empirical formula of prediction.

1.1.4 The constraints of the role at the local level

The cement concrete road surface is paved on the grassroots directly. Basic structure of RCC lean concrete can be used or asphalt concrete and cement stabilized aggregate base type. In general, choose corresponding different stiffness as the traffic level of grassroots, stiffness of strong base is suitable for heavy traffic road. Stiffness method is used in large type at the grass-roots level inevitably have stronger constraint effects on surface shrinkage, prompted the tensile stress in the growth, which will go against the pavement slab bottom stress.
1.1.5 The early concrete creep

Restrained shrinkage of concrete in the process, the high stress is often associated with early creep deformation. Lange \cite{2} and other early are studied by experiment under the restriction of the axial shrinkage and creep of concrete. Research shows that: the early concrete under axial shrinkage constraint, cracking of creep coefficient of 0.9, 1.5 and 1.0 when water cement concrete is 0.32, 0.4 and 0.5, respectively. This suggests the creep largely reduce the shrinkage stress of about half under the condition of that concrete completely constraints. So early creep of concrete crack play a great role.

2 The stress analysis

2.1 Calculate the access parameters

Taking a typical highway pavement structure calculation parameters, and draw lessons from the structure of the cement concrete pavement design specifications \cite{3}, and USES the design parameters is shown in figure 1.

![Figure 1. A typical cement concrete pavement structure and parameters.](image)

For new pouring concrete pavement, the material parameters, including elastic modulus \( E_c(t) \) and tensile strength, changes over time. In addition, under the condition of without external constraint free shrinkage of concrete \( \varepsilon_{sh}(t) \) also increases with time. For the time variable parameter value is as follows:

Modulus of elasticity of forecasted by ACI209 (82) suggested that the elastic modulus of prediction formula (1)\cite{4}

\[
E_c(t) = E_{28} \sqrt{ \frac{t}{a+bt} } \quad (1)
\]

Type of the constants a and b values using I type cement suggestion values under wet curing.

The free shrinkage of concrete \( \varepsilon_{sh}(t) \) using [1] table 3-2 test data, as shown in table 1, the setting time of concrete used for 12 h. Visible, concrete condensation after a period of time (i.e., the age of 12 ~ 36 h), the shrinkage rate of up to 100 x 10-6 above, then the shrinkage rate tends to be stable gradually. Visible, the influence of shrinkage cracking in concrete is very important during this period.
Table 1. The relationship between concrete free shrinkage with age.

<table>
<thead>
<tr>
<th>age /h</th>
<th>shrinkage (10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>47.0</td>
</tr>
<tr>
<td>12</td>
<td>77.4</td>
</tr>
<tr>
<td>24</td>
<td>160.4</td>
</tr>
<tr>
<td>36</td>
<td>180.0</td>
</tr>
<tr>
<td>48</td>
<td>188.0</td>
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</tbody>
</table>

Given before the final set, the modulus of elasticity is small when concrete in plastic stage, but after the final set, the modulus of elasticity and autogenously shrinkage of concrete of the actual situation of a sharp growth can be ignored before the final set elastic modulus and shrinkage effects on increase of stress. Therefore, ignoring the \(0 \sim 12\) h shrinkage effects on increase of stress and other corresponding shrinkage rate of the stress contribute to the growth of the age section according to its shrinkage rate reduction \(12\) h age shrinkage rate calculation, and according to the thermal expansion coefficient into equivalent temperature on the surface; At the same time, for ACT's elastic modulus prediction formula (1) the following modifications:

\[
E_c(t) = \begin{cases} 
0 & 0 \leq t \leq t_0 \\
E_{28} \sqrt{\frac{(t-t_0)}{a+b(t-t_0)}} & t \geq t_0 
\end{cases}
\]

(2)

\(t_0\) For condensation time (d).

2.2 The establishment of the model

This paper adopts the general finite element software ANSYS to analyze the pavement panel stresses. Establishing proper model is the key to guarantee the final result objectivity. Model is shown in figure 1 using the typical pavement structure; the finite element model is shown in figure 2.

Figure 2. Pavement structure finite element analysis model.

Finite element model is simplified as plane strain problem to simulate the road the stress of the longitudinal section to simplify the model calculation. Foundation adopts the Winkler springs foundation to LINK1 two-dimensional bar element simulation, surface, base and cushion layer adopts PLANE182 plane unit simulation. Model takes plate long only 1/2, plate cross section in a symmetrical boundary; Surface completely disconnected in the joint, the surface cross section structure layer under the joint
adopts the symmetrical boundary; Ground rod coupling unit bottom completely solid. At the same time, the completely continuous between layers.

2.3 The results analysis

Figure 3 is the distribution of shear tensile stress of 5 m board long board at the end of each point in 48 h instars, with the increasing degree of surface concrete contraction, the surface seams at the bottom of the principal tensile stress and shear stress SXY SX concentration obviously at the bottom of the plate end, higher than that of plate tensile stress at the bottom of the plate in the tensile stress at the bottom of the eight times, the biggest more than 11 MPa; And shear stress are mainly concentrated on board a certain range, the largest of more than 7.5 MPa. Principal tensile stress occurs. Shear stress concentration and the stress concentration at the same location, namely, figure 2 point 1.

![Figure 3. Bottom tensile and shear stress concentration.](image)
Figure 4. Early plate bottom stress growth curve of stress concentration.

Figure 4 a, b, c respectively for plate length 6 m, 5 m, 4 m, the bottom stress concentration in the stress increase with age. The tensile stress and shear stress is growing very quickly within 48 h shown in the figure, to 5 m plate as an example, the principal stress reaches 14.6 MPa in 48 instars, and the road longitudinal stress is 11.4 MPa, shear stress - 7.6 MPa. Even the mature concrete could not reach the tensile and shear strength.

We can draw 48 h instars the main stress concentration change with plate long, as shown in figure 5 as shown below.

Figure 5. 48h principal stress concentration values change with plate long.

It can be seen that the main tensile stress as the plate reduced with the decrease of the long, however, even in the plate length of 3 m (less than 4 m's specification [3] value), the finite element analysis results of the stress concentration values are not less than 11 MPa.

The stress concentration at the bottom of the plate end is still quite big even considering the creep early can ease around half of shrinkage stress; therefore, the early concrete pavement slab bottom must produce a wide range of severe cracking.

2.4 The cracking of the bottom, and evolution

At the bottom of early cement concrete pavement slab forms a larger the shear and tensile stress concentration, makes the form of cracking is divided into two kinds,
namely the tensile cracks caused by tension stress and shear stress caused by shear fracture, as shown in figure 6.

Figure 6. Bottom fracture produce and evolute.

Shear stress in the direction of the rough and the road surface longitudinal is consistent due to stress concentration, at the same time, considering the material of concrete itself is uneven, the interface between aggregate and cement paste is the weakest link in the concrete, Tensile cracks mainly along the road of the vertical of the weak interface, and the shear fracture is roughly along the weak transition between layers [5] for extending. Two cracks form to promote each other, make early plate at the bottom of the cracks by end gradually expand to the board of direction, formed a wide range of damage and cracking.

Crack formation of greatly affect the performance of the pavement. Horizontal shear fracture surface and grass-roots form of local separation, namely the interlayer half combining state, this half combining state of the maximum flexural stress effect of [6] is very significant. And vertical tensile cracks (according to the basic principle of fracture mechanics) will make the road surface under the action of vehicle in the bottom of the plate flexural crack tip stress singularity, crack extension will so damage reduction pavement service life greatly under long-term load.

CONCLUSIONS

Due to constraints at the grass-roots level and the effect of early shrinkage of concrete, the tensile and shear stress grow rapidly at the bottom of the early cement concrete pavement slab at the plate end, will make the larger severe cracking of the pavement at the bottom of the plate produced, there are two main types of crack form, namely, the vertical tensile stress and shear stress level of cracks. Two cracks form to promote each other and make the bottom of the plate crack by end gradually expand to the board of direction, formed a wide range of damage and cracking.

REFERENCES
