THE PHENOMENON OF SEMICIRCULAR SHAPE CRACKS ON ASPHALT PAVEMENTS

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ABSTRACT

There are many different causes of cracks on the surface of asphalt pavements. The primary cause of cracking in asphalt layer is increasing tension stresses and related strains to the point when the tensile strength of the material is exceeded.
Semi-circular shaped cracks occur at the edges of the excavations and pavements where there is poor local sub-layers, thin layer of asphalt and excessive traffic loads. Semi-circular shaped cracks are very common. However, they are often confused with the netlike cracks. The typical form occurs when the crack progresses to a certain point of contact to the outside edge of the pavement, whereas in the opposite direction (inside) of the track it provides adequate resistance against the occurrence of crack. Cracks spread in the direction of poor sub-base and are formed gradually one next to the other or independently. This paper presents semi-circular shaped cracks with a single, double or several free edge. Semi-circular shaped cracks propagated from top to bottom at the cross section.
The analysis of numerical model shows that the line deflection and maximum tensile stresses on the toper surface are in a semi-circular, which indicates the formation of semi-circular shaped cracks. To determine the location of cracks it is necessary to look at the maximum tension stresses σij on the top surface of the model. The location of crack is somewhere in the area of maximum tension stresses and occur when the tensile strength of the material is exceeded.

Keywords: Crack propagation, Edge crack, Finite element method, Tension stress

1. INTRODUCTION

There are many different causes of cracks on the surface of asphalt pavements. The primary cause of the cracks in the asphalt layers is when tensile stresses and related strains exceed the material's tensile strength. Pavement cracking can be caused by several factors, such as:

- structural changes of the bituminous binder in bituminous mixtures because of the aging,
- large temperature changes during use,
- excessive traffic loads and/or
- deficiencies in the construction [4].

You can find in literature that the pavement cracks are classified according to their shape (form), place of creation, width and depth. Cracks in asphalt pavements can take many forms. The most common types of cracking are [3]:

- fatigue cracking,
- longitudinal cracking,
- transverse cracking,
- block cracking,
- slippage cracking,
- reflective cracking and
- edge cracking.

This paper discusses semi-circular shaped cracks, why & how they occur and in particular why they have such characteristic shape. The paper also discusses how such cracks spread over the pavement surface and how they propagate through the pavement layer / cross section. Schematics of the cracks with a single (one), double and several free edges are presented. Finally, this paper is presents the numerical model that illustrates this problem through a finite elements method (FEM).

The pavement surface can exhibit cracks in semi-circular shape (Fig .1). In the American literature we find the concept of edge cracks which form semi-circular shaped cracks. Edge cracks typically start as crescent shapes at the edge of the pavement. They will expand from the edge until they begin to resemble alligator cracking. This type of cracking is the result of lack of support of the shoulder due to weak material or excess moisture. They may occur in a curbed section when subsurface water causes a weakness in the pavement [2]. Literature mentions edge cracks up to 0.5 m away from the edge of the pavement, as shown in Fig. 2 left. Longitudinal edge cracks on the pavements occur if there is low bearing capacity on lower layers through the entire edge. These cracks are not considered semi-circular shaped cracks. Circular shape cracks occur at the edge of drains or manholes (Fig. 2 right), and in our view are caused by the same mechanism.

Figure 1: Semi-circular shaped cracks at the edges of the pavements (left) and excavations (right)

Figure 2: Longitudinal edge cracks at the edge of the pavements (left) and circular shaped cracks at the shafts (right)

2. SEMI-CIRCULAR SHAPED CRACKS (SCSC)

2.1 Characteristics of the SCSC

Semi circular shaped cracks have certain characteristics that distinguishes them from other types of cracks. We distinguish them by:

- shape and propagation of semi-circular shaped cracks,
- propagation through the pavement layer / cross section and
- cause of formation.

2.1.1 Shape and propagation of semi-circular shaped cracks

When a vehicle loads a weak location on the pavement a crack occurs that propagates into the interior (Fig. 3). A typical semi-circular crack on the pavement surface occurs when the crack progresses and stops at a particular point (crack a.) or progression route, making the characteristic circular shape, to the outer edge of the pavement (crack b.), because in the opposite direction of the pavement is more resistant to cracking. It does not run parallel to the pavement edge because at some point the support gets stronger, and so the crack turns back outward [1].

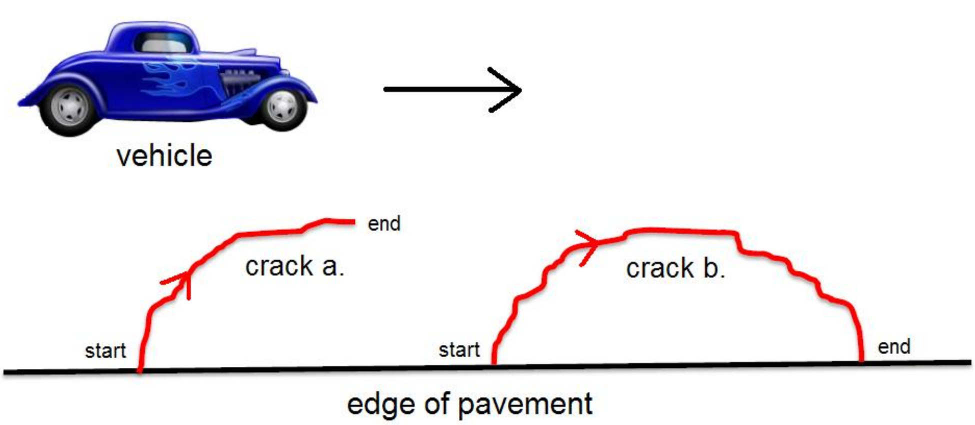

Figure 3: Schematic presentation of semi-circular shaped cracks propagated in the direction of low bearing capacity of lower layer with single free edge crack a. that extends into the interior and crack b. witch complete in the edge of the pavement

Fig. 4 shows how SCSC propagate on surface of the pavement. First is formed “1.” crack and then next “2.” crack occurs at the first and touches it at a different point or they can appear completely independently. So, SCSC propagate

next to each other in the direction of low bearing capacity of lower layers (sub-base or base). Fig. 4 also presents semi-circular shaped cracks with a single, double or several free edges. Semi-circular shaped cracks with a single (one) free edge are “1.” crack and the beginning and the end of the crack is at the same height.
Crack with two free edges (e.g. i. crack) has the beginning and the end of the cracks at different heights and one of free edge is already formed crack, in this case “2.” crack. Crack with several free edges is crack “n.” crack.

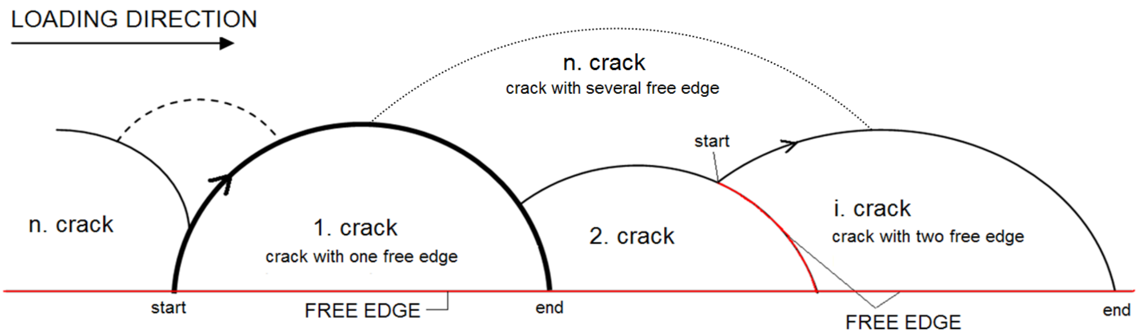

Figure 4: Schematic presentation of semi-circular shaped cracks propagated in the direction of low bearing capacity of sub-base or base layer with single (1. crack) and two free edge (i. crack)

2.1.2 Propagation through the pavement layer / cross section

On a Slovenian local road, an asphalt core was drilled on semi-circular shaped crack (Fig. 5 left). Fig. 5 right shows cross sections of this drilled core and we see that the crack propagated from top to bottom. So, at the top surface there must have been a tensile stress. This is not typical of fatigue cracks that grow from the bottom upwards. Shuler (2005) reports that edge crack propagation is from top to bottom. This means that upward movement from below and/or bending is causing excessive tensile strain at the surface of the pavement [5].

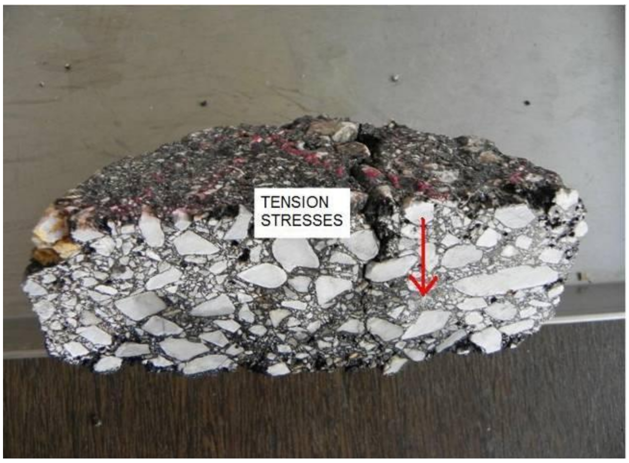

Figure 5: The location of asphalt core taken on semi-circular shaped cracks (left) and presentation of semi-circular shaped cracks propagated top to bottom through the cross section (right)

2.1.3 Cause of formation

Semi-circular shaped cracks occur at the edge of the pavement - edge cracks (near unpaved shoulder) or at the edge of the excavations on asphalt pavements. Fig. 6a shows schematically the formation of these cracks in the area near the maximum tensile stress of asphalt layers. The formation of those cracks is mostly attributable to:

- lower bearing capacity of lower layers (increased flexibility); the material is very dirty (contains clay) and can keep water in it (higher moisture) or because of weaker drainage capability at the edge of the pavement or the local lower density - called "nest" (Fig. 6b),
- thin asphalt layer (the pavement is too thin for the traffic loads),
- narrow pavement (heavy vehicles drive closer to the edge of the pavement),
- heavy traffic load during spring thaw (very weak and unstable shoulder and base),
- structural (hardening of bitumen) and thermal changes (cryogenic tension) in the asphalt layer.

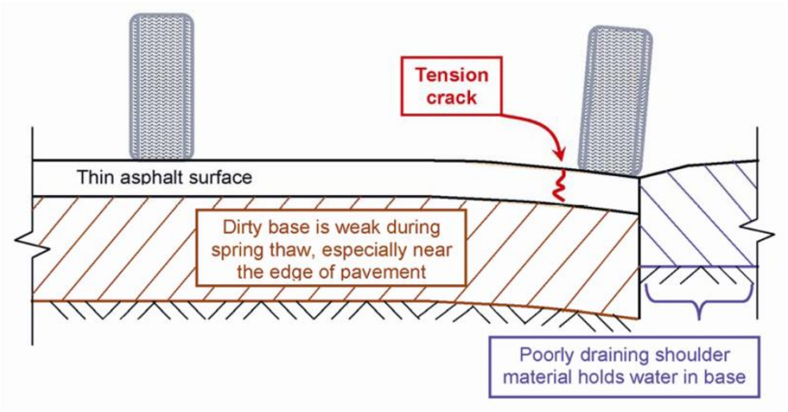

Figure 6a: Schematic view of cracking at the edge of pavement [1]

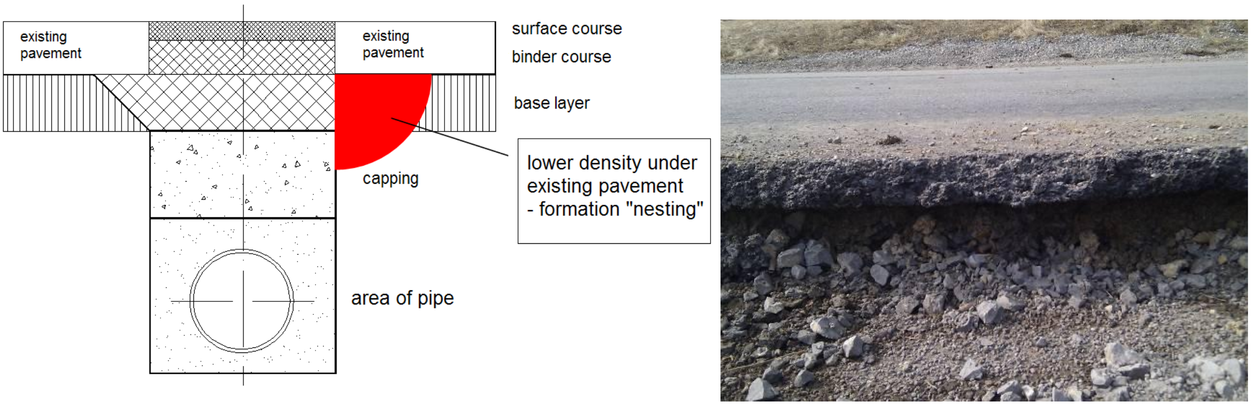

Figure 6b: Excavation on existing pavement – formation »nest«

2.2 Numerical model of semi-circular shaped cracks

Our numerical model represents formation of semi-circular cracks. It is prepared and processed in programming environment SAP2000 with finite element method (FEM), where we analyze the size and distributison of stress and strain. With this numerical model we want to answer why semi-circular shape occur in relation to these stresses and strains.

The assumptions for our model are:

- shell-thin layer (5 cm),
- material properties (elastic modulus E = 3500 MPa, Poisson ratio ν = 0.35),
- joint springs are flexible connections to ground (linear elastic) as sub-layer with modulus of soil reaction k1 = 50 MPa
- point force F = 50 kN as wheel load at the free edge and under is area of weak sub-layer with spring modulus of soil reaction k2 = 25, 40, 50 MPa.

With this assumption we create the worst possible conditions for occur semi-circular shaped crack. The numerical model is presented in Fig. 7.

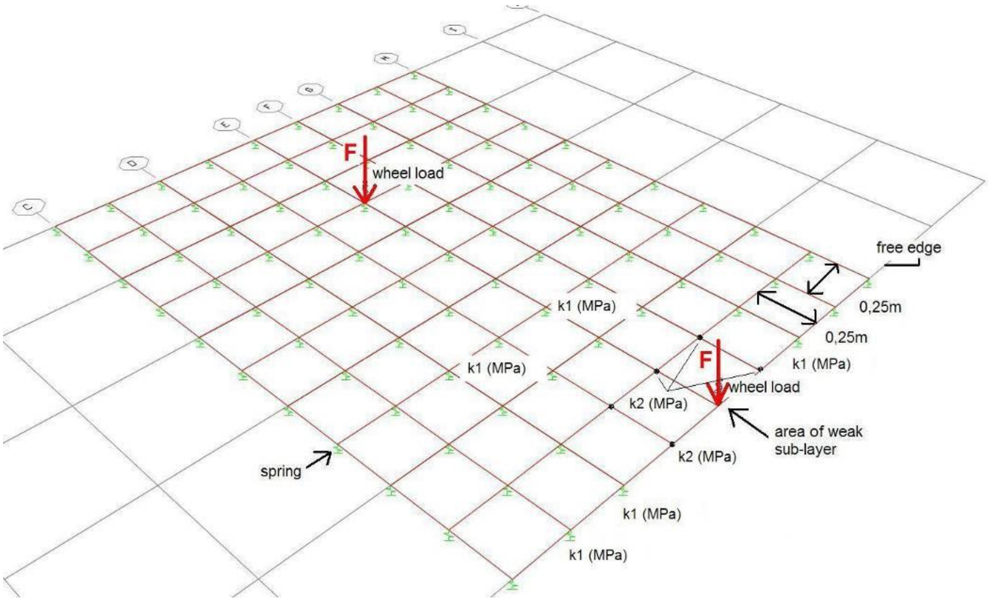

Figure 7: Showing numerical model

The variable in this model was a modulus of soil reaction k2 = 25, 40, 50 (MPa), because area of weak sub-layer it is not always the same.

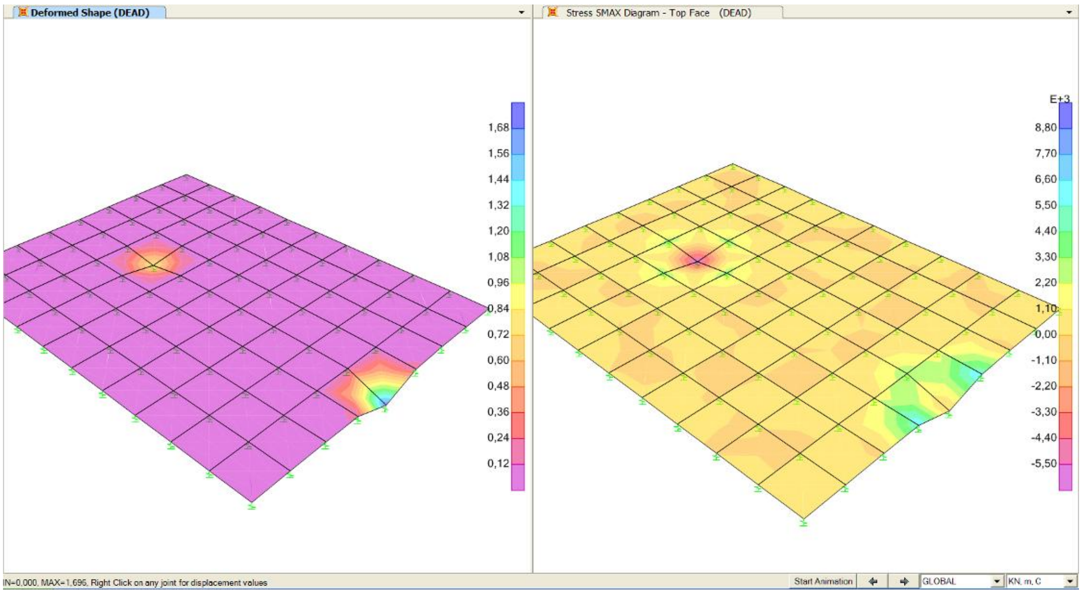

Figure 8: The results of deflection (left) and tension stress on the top surface (right); k1= 50 MPa and k2 = 25 MPa at force F = 50kN

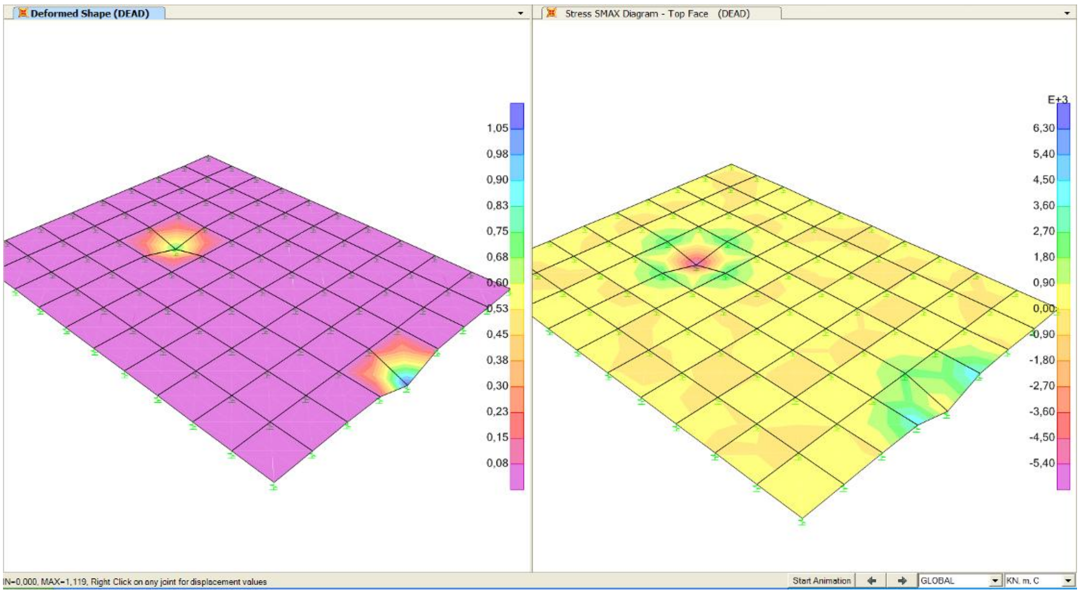

Figure 9: The results of deflection (left) and tension stress on the top surface (right); k1= 50 MPa and k2 = 40 MPa at force F = 50 kN

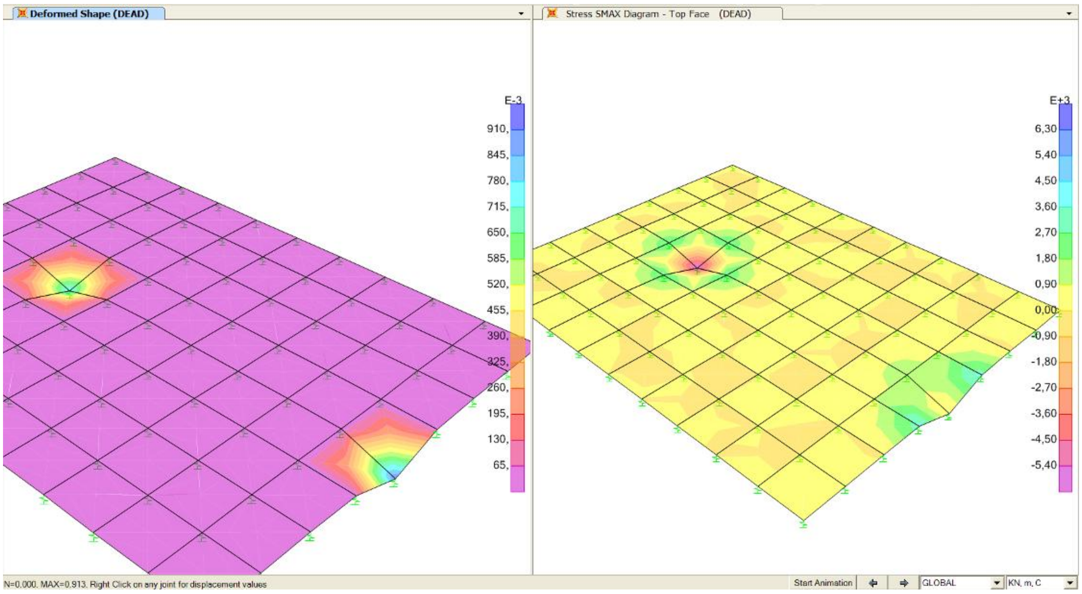

Figure 10: The results of deflection (left) and tension stress on the top surface (right); k1= 50 MPa and k2 = 50 MPa at force F = 50 kN

Fig. 8-10 show the line of deflection and maximum tensile stresses. Semi-circular lines are clearly visible at the free edge, which indicates a potential for the formation of semi-circular shaped cracks. It is a matter of where and when the crack occurs. To determine the location of cracks it is necessary to look at the maximum tension stresses σij on the top surface of the model. The location of crack is somewhere in the area of maximum tension stresses and occur when the tensile strength of the material is exceeded. Also, Fig. 8-10 clearly shows the area of maximum tension stresses (light to dark green) extending from the extreme edges towards the centre of the semi-circular form. On the bottom surface is compressive stresses, conclude that the crack propagated from the top to bottom. Fig. 8 and 9 shows that with increasing k2 decreases deflection and tensile stresses and vice versa. If we compare Fig. 8 (k2 = 25 MPa) and 10 (k2 = 50 MPa) we see that the deflection is lower at higher modulus k2 and maximum tension stresses is for almost half the size higher at lower k2.

3. CONCLUSION

This paper discusses semi-circular shaped cracks. Why and how semi-circular shaped cracks occur. Why they have such characteristic shape. It also shows how such cracks are spread on the pavement surface and the cross section.

Schematics are presented of cracks with a single (one), double and several free edges. Finally this paper presents the numerical model that illustrate this problem and is simulated in finite elements method (FEM).
Semi circular shaped cracks have certain characteristics that distinguish them from other cracks. This paper shows shape and propagation of semi-circular shaped cracks, propagation through the pavement layer / cross section and cause of formation. Semi-circular shaped cracks are very common, but often confused with the other types of like cracks. The typical form occurs when the crack progresses to a certain point of contact to the outside edge of the pavements, whereas in the opposite direction (inside) of the track it provides adequate resistance against the occurrence of cracks. The creation of those cracks is mostly attributable to: lower bearing capacity of sub-layers, thin asphalt layer, narrow pavement, heavy traffic load during spring thaw, structural and thermal changes in the asphalt layer. On surface of the pavement they propagate in the direction of low bearing capacity sub-layers layer, and are formed gradually one next to the other or independently. SCSC propagated from top to bottom at the cross section. This means that upward movement from below and/or bending is causing excessive tensile strain at the surface of the pavement.
The analysis of numerical model shows that the line deflection and maximum tensile stresses on the surface are in a semi-circular, which indicates the formation of semi-circular shaped cracks. To determine the location of cracks it is necessary to look at the maximum tension stresses σij on the top surface of the model. The location of crack is somewhere in the area of maximum tension stresses and occur when the tensile strength of the material is exceeded.

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