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EFFECT OF SURFACE CRACKING ON RESPONSES OF FLEXIBLE PAVEMENTS STRUCTURE

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Pavement cracking is a major factor of failure in surface of pavements structure, In spit of this, seldom intention has been considered how is the pavement structure has been affected when surface cracking are presented and/or progressed. On the other hand, higher costs are presented for maintenance and repair. Generaly, pavement surface conditions in terms of pavement surface cracks, rutting, roughness and pit-holes are the main factors used to establish criteria for pavement maintenance and repair. Structural adequacy factor of the pavement is usualy neglected. The accurate decision making processes for maintenance and repair works must be done not only due to functional conditions, but also due to structural conditions.

Finite element analysis is used in this research paper using the ANSYS-10 program. SOLID45, and SOLID185 elements represent unbounded layers, and asphalt cement layers respectively to evaluate the stresses in a flexible pavement system under different conditions. These conditions were: (1) The vertical load of a single wheel was modeled as uniform pressure placed directly at the edge of the transverse crack. (2) The effects of seasonal differentiation of the pavement material properties during winter and summer. and (3) Various crack depthes which represent 25% , 50%, 75% and 100% of the asphalt layer thicknesses are also, considered in the analysis. The horizontal normal stresses along the top and bottom of the AC layer, and vertical stresses at selected points in the base has been investigated.

Comparisons of stresses finally were made for all studied cases. It is found that the presence of crack in the AC layer significantly increases both the vertical stresses and the horizontal stresses in the AC layer which indicate a greater potential for tensile stresses outside the tire treads than in the middle of the treads. With the wheel load located at the edge of transverse crack there is considerable change in the values of horizontal and vertical normal stresses in the asphalt pavement layers. Seasonal variation has significant effect on the normal stresses values, where the maximum horizontal tension stresses (σ_{yy}) is higher in winter than that in summer with about 66%.

Finally, it is recommended that at crack depth ratio (CDR) 50% pavement must be rehabilitated to prevent initiation of new cracks or rutting of asphalt pavement surface. In other side the winter season is considered the critical for initiation of cracking, as summer season is considered critical for rutting occurrence.

KEYWORDS: *Pavement Surface Cracking, Three dimensional finite element, Horizontal stresses, Vertical stresses*

1 - INTRODUCTION

Cracks are the major indicative of failure in the pavement structure. In other context higher costs are presented for maintenance and repair works. Generaly, pavement surface conditions in terms of pavement surface cracks, rutting, roughness, and pit-holes are the main factors used to establish criteria for pavement maintenance and repair while structural adequacy factor of the pavement is usualy neglected. Longitudinal cracks or, as it is sometimes called top-down cracking have been observed to form perpendicular to the edge of the transverse cracks in the wheel paths, and then propagate away from the transverse cracks until they eventually meet and form one continuous cracks the entire length of the pavement. However, the causes of pavement cracking are very complicated where cracks occur in flexible (asphalt) pavements for several reasons. The most probable causes of top-down cracking (TDC) include poor compaction binder stiffening and/or low binder content, in addition to thermal stresses in the asphalt [1, 2].

In (1992), Matsuno and Nishizawa [3] reported that TDC are a major distress that occurs near the wheel paths in pavements. They conducted mechanistic analyses using finite element method on two typical pavement cross sections and concluded that traffic loads cause high tensile strains in hot pavements and that the pavement cross section had little effect on the surface tensile strains. In (2000), Uhlmeyer et al [4] observed that TDC occur in and around the wheelpaths in pavements 3 to 8 years old with AC thickness of more than 16-cm (6.3-inch). Hence, they concluded that pavement thickness has an effect on the initiation of TDC, which contradicts the findings of Matsuno and Nishizawa and Meyers et al. In (2002), Tunwin Svasdisant et al [5] conducted field investigation to determine the causes of TDC. They conclude that the surface radial tensile stress induced by wheel load and enhanced by differential stiffness due to construction, temperature and aging can cause TDC. Also the locations of the maximum surface tensile stress predicted by the mechanistic analysis correspond very well to the locations of the TDC observed in the field. Wang et al (2003) [6], presents a new approach to investigate the causes of top-down cracking using micromechanics. They found that the TDC may not necessarily initiated only at the pavement surface. It may also be initiated at some distance down from the surface. They conclude that both tensile-type and shear-type cracking could initiate top-down cracking.

Theoretical analysis of continuous flexible pavement systems have been presented by several researchers provide valuable tools by using Finite Element Method (FEM) for stress, strain, or displacement calculations. Generic computer code such as ABAQUS [7], or specialized computational modules such as CIRCLY [8], and BISAR (9), provide valuable tools for stress, strain, or displacement calculations. Limited references describe the effect of cracks on the behavior of flexible pavements; notable results on deflection profiles and stress concentrations due to surface load and preexisting cracks in flexible pavements [10]. Matsuno and Nishizawa [3] performed axisymmetric elastic finite element analysis with uniform normal contact stress. From the analysis, the authors concluded that the strains under the tire are mainly compressive in the vertical direction, and high lateral tensile strains at the tire edge were sufficient to cause cracking.

Myers *et al*. [11] performed studies on the potential mechanisms of surface cracking. The stresses in the pavement were determined using the program BISAR. Asphalt concrete thickness and modulus were varied in their study; base thickness remained constant, but modulus varied, and the subgrade had constant modulus. The interface between each layer was modeled both in full slip and full contact. Tire/pavement contact stress distributions were obtained from experimental data on radial-ply truck tire provided by Pottinger [12]. Each tire tread was modeled with at least 2 circles across. The direction of uniform shear tractions was taken as pointing outward due to Poisson's effect of each tread. The authors concluded that the location where the maximum surface tensile stresses occur is the center of the outer treads, rather than the edge of the tread. The magnitude of the predicted tension appears to increase with the width of the tire tread, with the highest tension found under the center of the widest tread.

Uddin and Pan [13] used the finite-element code ABAQUS. They introduced a crack, either a longitudinal, transverse, or alligator crack, into the model using the special-purpose gap elements available in ABAQUS. The maximum dynamic deflections were calculated for each of the differently cracked pavements and compared to the calculated deflection of an uncracked pavement. When a longitudinal crack was present, the pavement experienced a deflection increase of approximately 17% compared to the calculated deflection of an uncracked pavement. The pavement displayed only an increase in deflection of 10% when a transverse crack was present. When a pavement had severe alligator cracking, the calculated deflection was about 36% higher than the calculated deflection for an uncracked pavement.

Bensalem *et al.* [14] performed field observations to study surface cracking in flexible pavements. A study of numerous cores revealed that surface cracks were present in pavements at least 160 mm thick. They concluded that bottom-up cracking was rarely the main failure mechanism. Instead, surface cracking was the main failure mechanism.

The objective of this research was to investigate the effect of transverse cracks with different depths on stresses at selected cross sections and locations in flexible pavement systems. Empirical data from literature will be assessed critically to extract the main features of the stresses at the layers of uncracked and cracked pavement. A numerical elastic model will be developed that allows for determining the stresses at the surface of the pavement as well as within the pavement. ANSYS-10, a finite element computer program, will be used as a calculation tool. The effects of seasonal differentiation of the pavement material properties during winter and summer are considered. Also, different crack depths which represent 25% , 50%, 75% and 100% of the asphalt layer thickness are represented. Valuable conclustions about the effect of different material properties and crack depths on the structural behavior of the asphalt pavement are extracted out. The critical crack depth is also investigated.

2- COMPUTER PROGRAM

Three-dimensional finite element model (3-D FEM) was used to represent the asphalt pavement layer structures with fully bonded layers was used. Analysis using the ANSYS computer program Version-10 was selected [15]. To represent asphalt surface layer model, SOLID185 is used for the 3-D. It is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, stress stiffening, creep, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials. To represent base and subgrade layer model, SOLID45 is used for the 3-D finite element model. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

3 – FINITE ELEMENT MODELING METHODOLOGY

3.1 Model Geometry

The developed finite element codes represent a variety of three-layer systems that are encountered regularly in typical flexible pavement structure. The bonds between all layers are assumed perfect, and each was modeled as an isotropic elastic material. The dimensions of the modeled prism are 300 cm x 300 cm x 202 cm as pavement layers thickness were considered as 12 cm AC, 30 cm base layer, and 160 cm for subgrade. These dimensions were selected to reduce any edge effect errors, while keeping the elements' sizes within acceptable limits (modeling constraints). Due to the symmetry in loading and geometry, The prism simulated a symmetrical half of the physical prism (road) cut by a plane perpendicular to the crack (see **Fig. 1**). Vertical axel is considered Z axel, while Y axel is considered in the crack direction and X axel represented perpendicular to crack length. The generated mesh was designed to give an optimal accuracy (fine mesh around the crack and at load position, and coarse mesh far from the crack). The model consisting of 27232 elements was constructed, and its accuracy was verified as sufficient. To improve the rate of convergence, 8-node linear brick reduced integration elements were used with variable thickness depending on the layers. All layers were simulated with the same shape to preserve the continuity of nodes between consecutive layers. **Figure 2** shows an elevation of the finite element model. The plane of model is shown in **Fig. 3**.

3.2 Boundary Conditions

The boundary conditions for the sides of the model were roller supports, so there was no horizontal displacement. The bottom base of the subgrade is prevented from axial movements in the three directions , they are completely fixed.

3.3 Layered System

The top layer is asphalt surface course (AC) had thickness 120 mm (4.72 in.). was modeled by using four layers element, each 30 mm height. The base course was 300 mm (11.8 in.) thick was modeled by using three layers element, each 100 mm height The subgrade was 1600 mm (62.93 in.) thick. The subgrade was subdivided into sixteen layers element each 100 mm height The model consisted of 27232 three-dimensional brick elements.

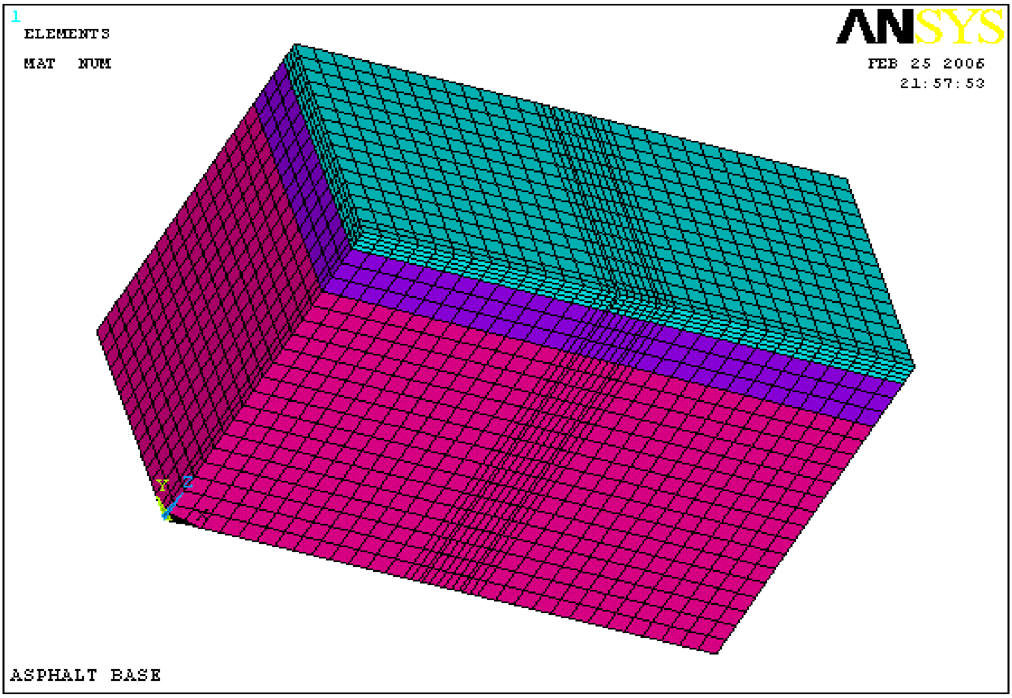

Fig. 1: General layout of the developed 3-D finite element model.

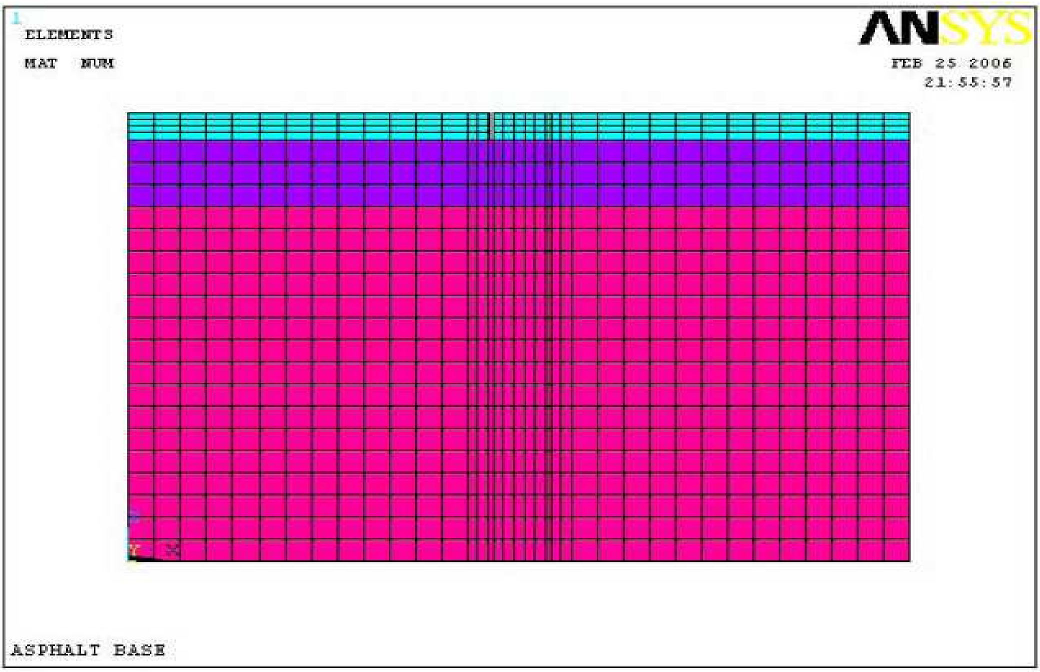

Fig. 2: Elevation of the finite element model.

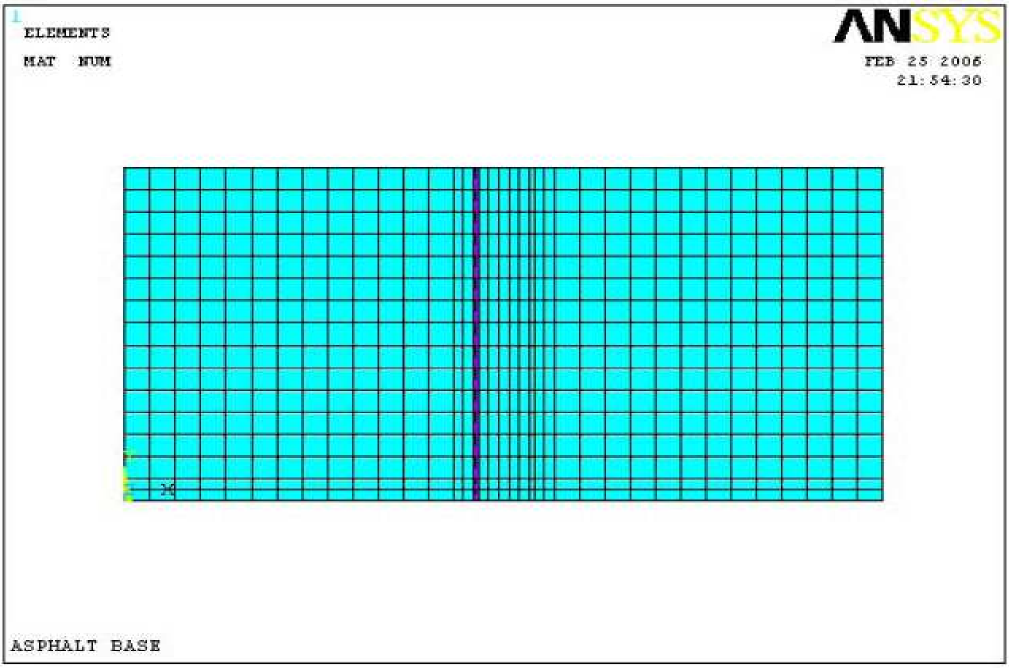

Fig. 3: Plane of the finite element model.

3.4 Load Position

A vertical uniform contact pressure of 0.7 MPa (101.5 psi) were considered to represent the stresses of the tire contact with a pavement layer over uniform normal contact pressure as a unit loading acting over square contact area 200 x 200 mm (7.87 x 7.87 in.). The position of the load is at the center of the prism model While the location of the crack was taken directly at the edge of the contact area figure as shown in **Fig. 4**. This location was chosen because it is expected to be the most detrimental to the pavement.

3.5 Crack Simulation

The models were created in ANSYS code. The motivation for creating five different models. One to investigate of the stresses of uncracked pavement, and the others to investigate the stresses in the AC layer and base layer of the open crack with different depths where four different crack depths were considered . To investigate the crack depth value, its considered as a ratio of asphalt layer thickness , crack depth ratio termed (CDR).
where :

$$\text{CDR}\ \% = \frac{\text{crack depth value}}{\text{asphalt concrete layer thickness}} \text{x}100 \qquad (1)$$

The considered crack depths are: 3 cm, 6 cm, 9 cm and 12 cm. The ratio of these depths to the asphalt concrete layer thickness which was 12 cm, (CDR values) are 25 %, 50 %, 75 %, and 100 %, respectively.

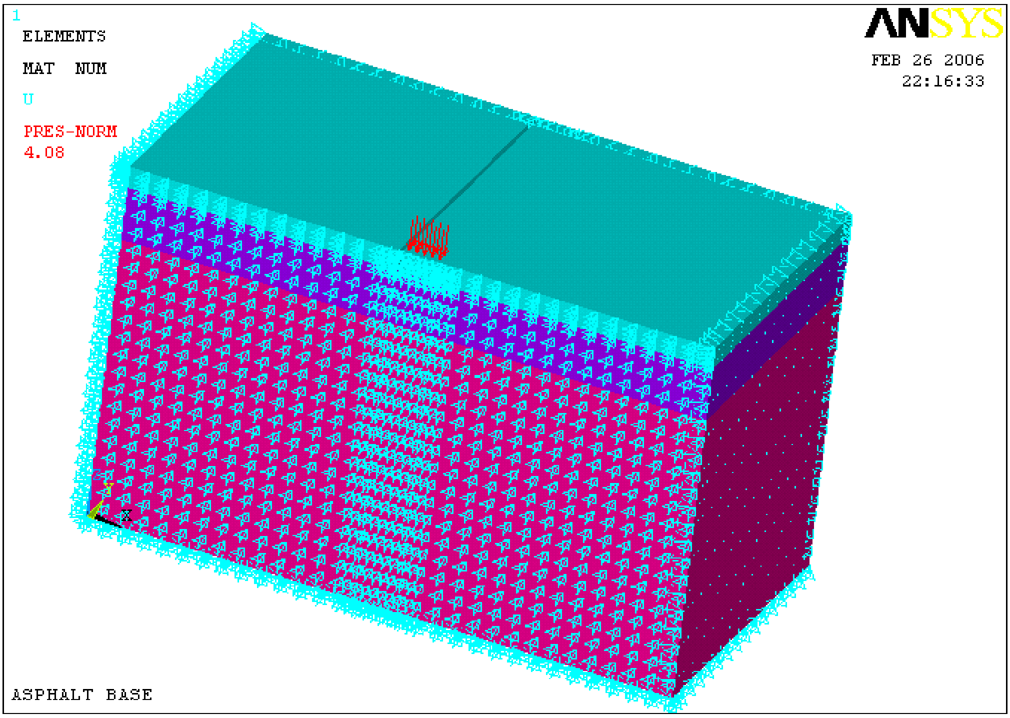

Fig. 4: General layout of crack and load position on the model.

4- MATERIAL PROPERTIES

Two seasons of winter and summer (different properties of material) are considered in the analyais. The first layer which represent the asphalt concrete layer with a modulus of elasticity of 21,346 MPa (3,096,000 psi) in winter and 1,766 MPa (256,100 psi) in summer and, Poisson's ratio is equal to 0.15 and, 0.38 in winter and summer respectively [16]. Density is equal 2.2 g/cm^3. Young's modulus for the material of the base layer is equal to 345 MPa (50,000 psi) in the winter and 131 MPa (19,000 psi) during summer. The density is 2.0 g/cm^3 , cohesion factor 0 Pa, angle of internal friction Φ is 40^o. For the subgrade clay loam is considered, Young's modulus is equal to 345 MPa (50,000 psi) in winter and 43 MPa (6,200 psi) during summer. The density is 1.8 g/cm^3 , cohesion factor 40 Pa, angle of internal friction Φ is 13^o . The Poisson's ratio for the base and subgrade materials is 40 considered the same in winter and summer [16].

In the pavement structure model using in ANSYS program, the values for various material properties were adjusted according to the specified layer thickness of the model, where the first four elemental layers of the model would all have properties of AC. The second three element layers would have base material properties, and the remaining elemental layers would all have subgrade material properties.

5 - STRESSES DISTRIBUTION

Normal horizontal stresses are considered in the analysis. The horizontal stresses σ_{yy} (acting in the Y axel direction) and horizontal stresses σ_{xx} (acting in the X axel direction) along the top and bottom of the AC layer, respectively were extracted from ANSYS. These were used to create graphs to illustrate how the variation in the material properties and different crack depths on the stresses values along the entire cross section through the center of loading of the pavement.

(1) stress σ_{xx} along the top of the AC layer,
(2) stress σ_{xx} along the bottom of the AC layer,
(3) stress σ_{yy} along the top of the AC layer, and
(4) stress σ_{yy} along the bottom of the AC layer.

5.1 Horizontal Stresses Perpendicular To Crack Direction σ_{xx}

5.1.1 Stress σ_{xx} along the top of the AC layer

Horizontal stresses σ_{xx} along the top of the AC layer have been shown in **Figs. 5** and **6** in both winter and summer, respectively. It is noted that negative stresses (compression) values has been found at the path wheel load while positive stresses (tension) values are found at outside the wheel path. The maximum value of compression stresses has been found in case of uncracked pavement. Tension stresses value has been found on the other side, Its value is the minimum in case of uncracked pavement, while at the CDR 75 % the values of stresses are higher with about 144 % than that of uncracked one in winter. Due to the hardining of the asphalt material properties in winter than that in summer, the tension stresses are found higher in winter than in summer with about 48 %. This would cause initiation of new crack in winter parallel to the existing one.

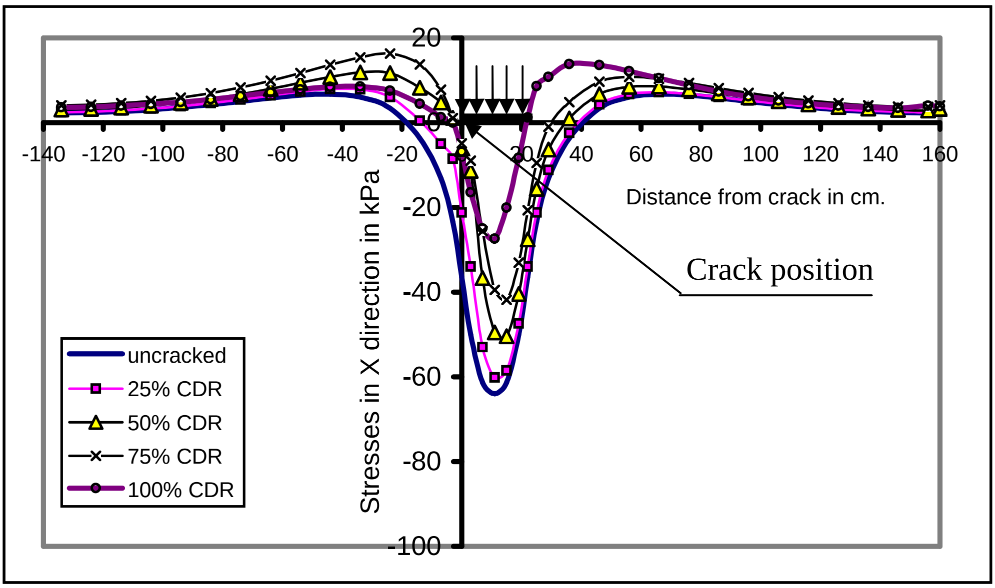

Fig. 5: Horizontal stress σ_{xx} on the top of asphalt surface (in winter).

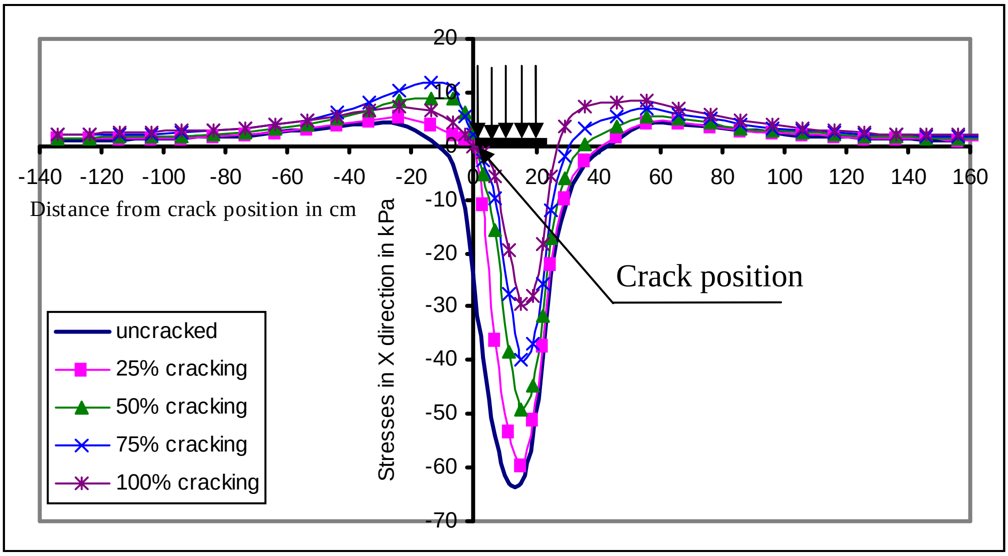

Fig. 6: Horizontal stress σ_{xx} on the top of asphalt surface (in summer).

5.1.2 Stress σ_{xx} along the bottom of the AC layer

Horizontal stresses (σ_{xx}) along the bottom of the AC layer have shown in **Figs. 7** and **8** in winter and summer respectively. It is noted that positive stresses (tension) values has been found under wheel path and negative stresses (compression) values are found at the two sides of wheel path. The maximum value of tension stresses are found in case of uncracked pavement. As shown in **Figs. 7**, **8** the tension stresses σ_{xx} was found higher in winter than that in summer with about 48 %.

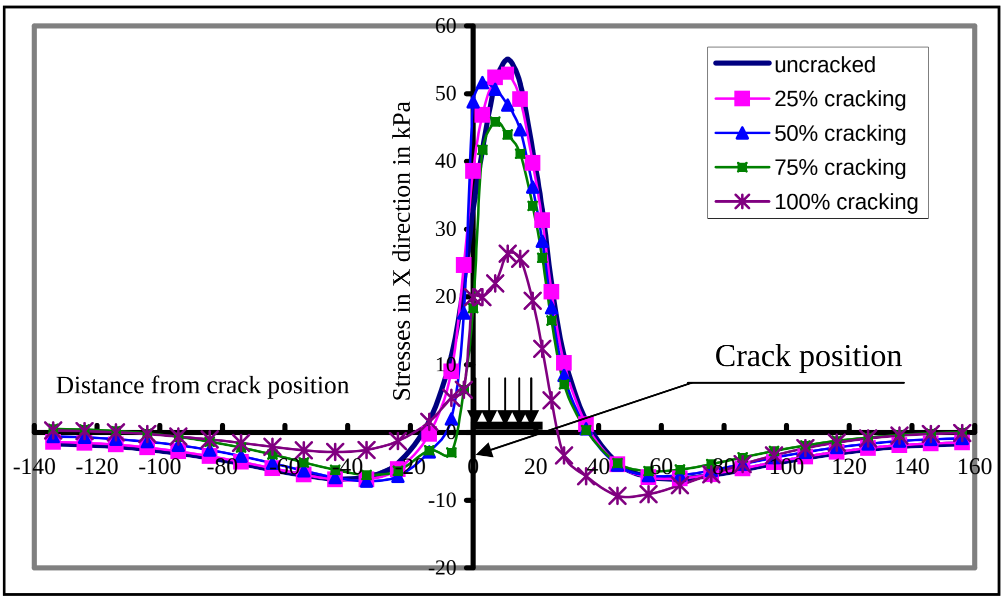

Fig. 7: Horizontal stress σ_{xx} on the bottom of asphalt surface (in winter).

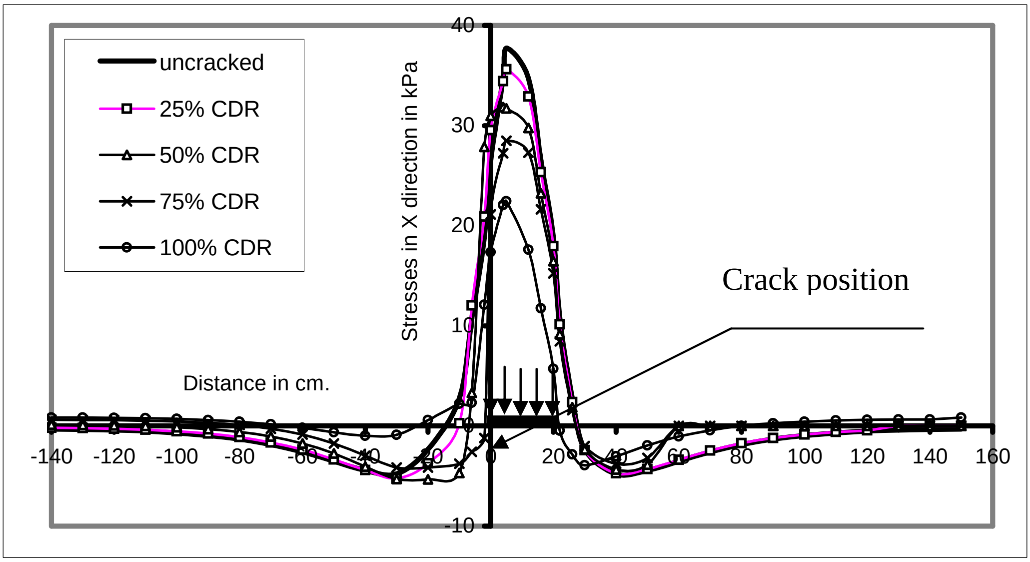

Fig. 8: Horizontal stress σ_{xx} on the bottom of asphalt surface (in summer).

5.2 Horizontal Stresses Parallel To The Crack Direction σ_{yy}

5.2.1 Horizontal stress σ_{yy} along the top of the AC layer

Figures 9 and **10** depict the stress distributions σ_{yy} through the center of wheel load along the top of AC for material properties in winter and summer respectively. The conditions for an uncracked pavement (represented by the solid line) and cracked pavement (represented by the dotted lines). Compression stresses are generally found at the top of AC, while tension stresses are presented at the bottom of AC.

In winter it is found that for crack depth ratios (CDR) 25%, 50% and 75% there is no significant difference between the values of stresses if compared with the case of uncracked AC as shown in **Fig. 10**. But, Significant difference in stresses values are found at CDR 100%, where its value increase with about 40% than that of uncracked AC as clear in **Fig. 9**. The maximum values has found at the edge of the crack . This would cause initiation of cracks perpendicular to the existing one. While in summer the presence of crack has no significant effect on the values of horizontal stresses $\boldsymbol{\sigma_{yy}}$ as shown in **Fig. 10**. Considering the effect of seasons, its found that the maximum compression stresses is higher in winter than that in summer with about 42% for case of 100% CDR, while no significant difference for other cases.

5.2.2 Horizontal stress σ_{yy} along the bottom of the AC layer

Figures 11 and **12** show the stress distributions σ_{yy} through the center of wheel load along the bottom of AC for material properties in winter and summer respectively.. All figures shows that in summer the presence of crack has no significant effect on the values of horizontal stresses $\boldsymbol{\sigma_{yy}}$ which parallel crack direction.

Considering the material properties in both winter and summer for 100% CDR, its found that the maximum tension stresses is higher in winter than that in summer with about 77%. If the case of uncracked pavement is considered , the tension stresses value in winter is higher with about 46% than that in summer.

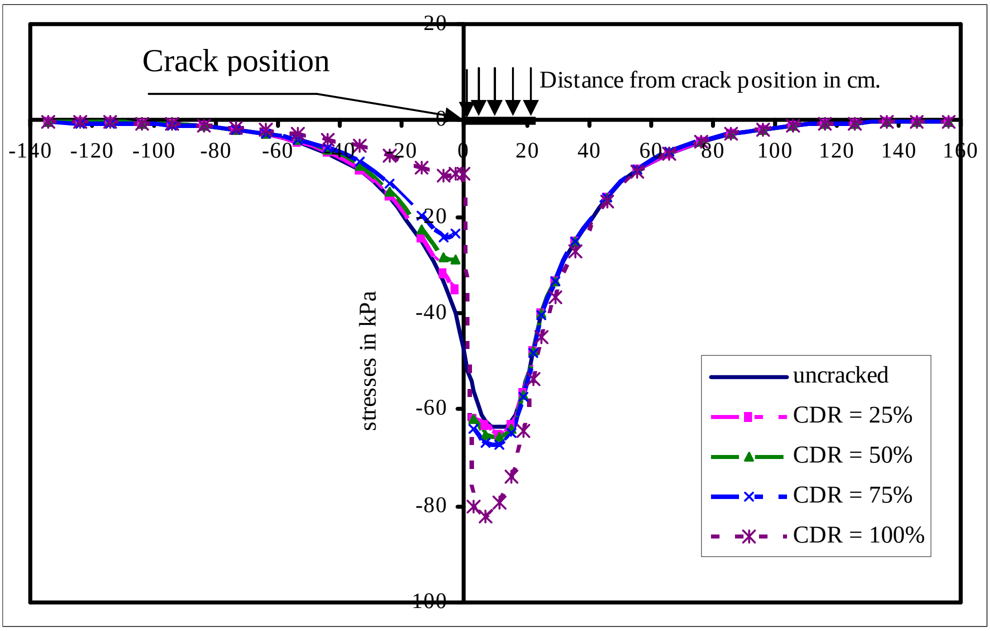

Fig. 9: Stresses σ_{yy} at the top of AC surface for (in winter).

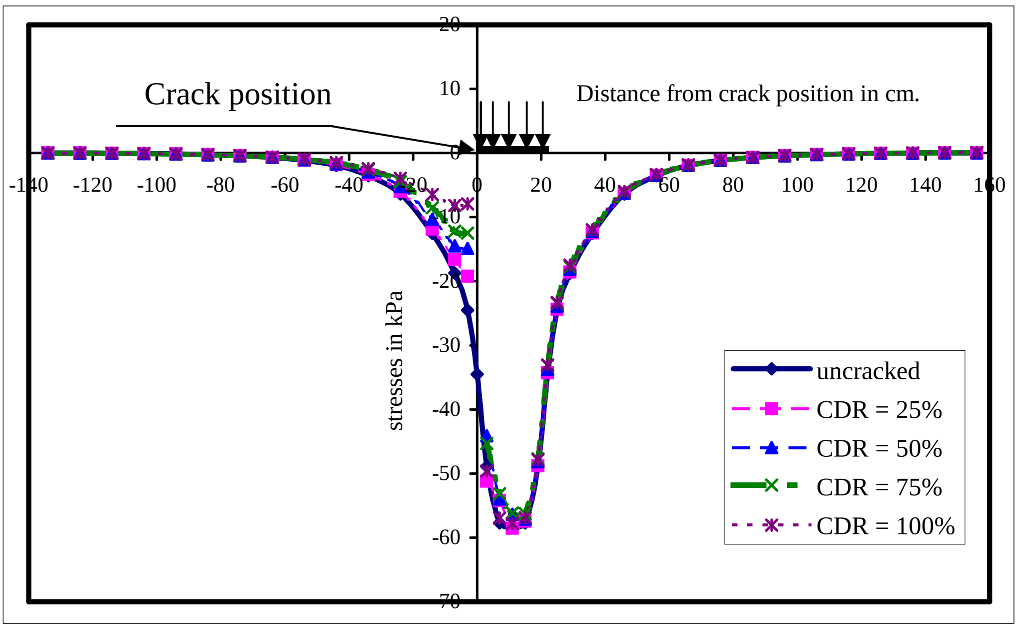

Fig. 10: Stresses σ_{yy} at the top of AC surface for (in summer).

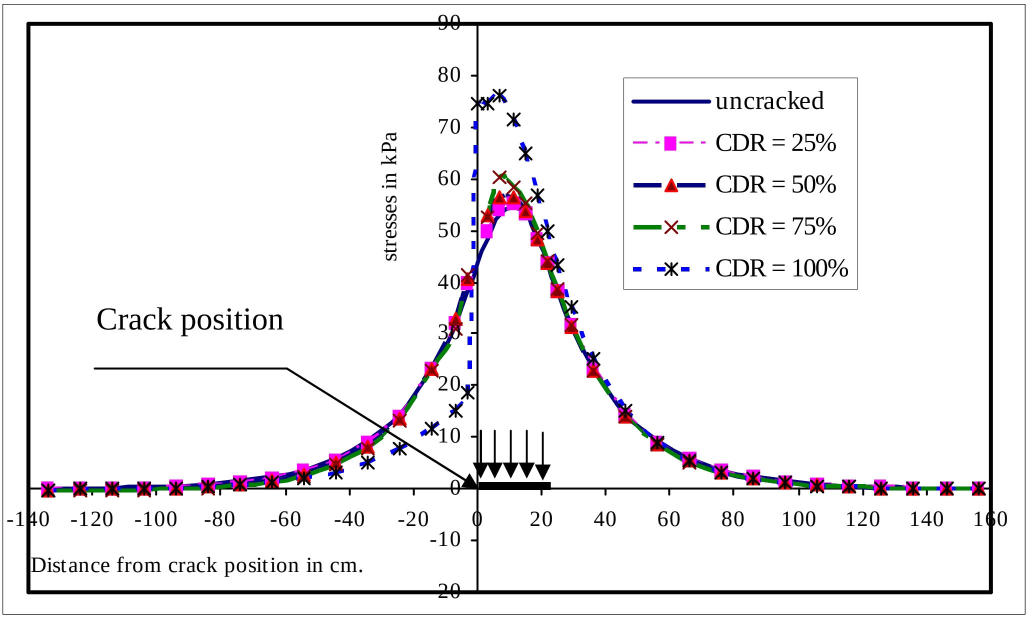

Fig. 11: Stresses σ_{yy} at bottom of AC surface (in winter).

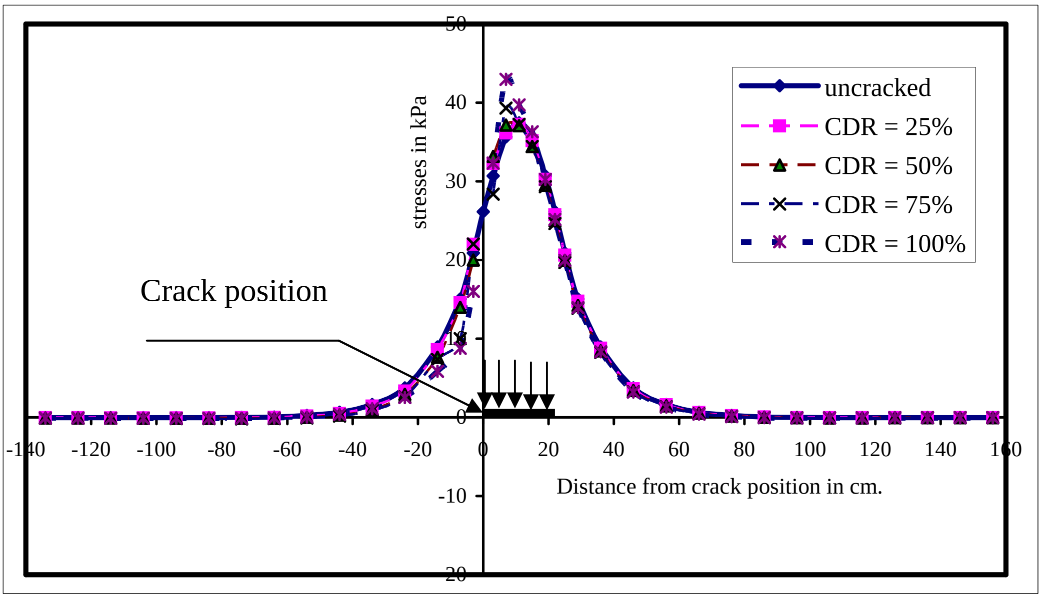

Fig. 12: Stresses σ_{yy} at bottom of AC surface (in summer).

6. CRITICAL STRESS LOCATIONS AND LOADING

To study the effect of surface cracking on the stresses at specific points, the magnitude of σ_{xx}, σ_{yy}, and σ_{zz}. at selected location were investigated.

In the current approaches, of primary interest are horizontal stresses, and vertical stresses, beneath the center of the wheel load of a continuous flexible pavement system. In particular, the horizontal tensile stresses σ_{xx}, and σ_{yy}, at the top and bottom of the AC layer (**Figs. 14 , 15**), respectively, the vertical normal stress σ_{zz} at the interface (**Fig. 13**), in the base next to the interface, are considered as the possible cause of rutting edge of the crack and under the center of load. In the analysis presented in this paper, the location of the crack was taken directly at the edge of the loaded area. This location was chosen because it is expected to be the most detrimental to the pavement. In fact, the pavement should experience the highest stresses and largest displacements when the load is positioned at the edge of the crack. In addition to presenting stress values, the effect of cracks on the value of stresses were quantified by the crack/no crack (stress) ratio CNR, defined as [16]:

$$CNR = \frac{\text{stress in a cracked pavement}}{\text{stress in an uncracked pavement}} \tag{2}$$

where CNR = 1 when there is no change in stresses.

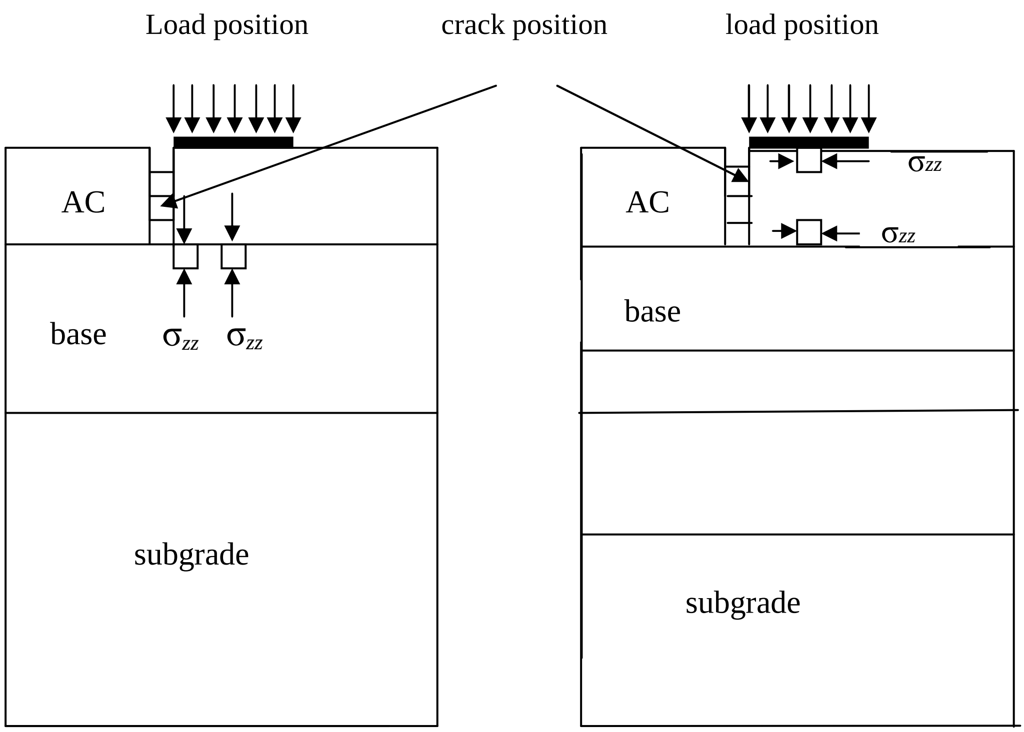

Fig. 13: Critical position of elements considered for σ_{zz}

Fig. 14: Critical position of elements considered for σ_{xx}

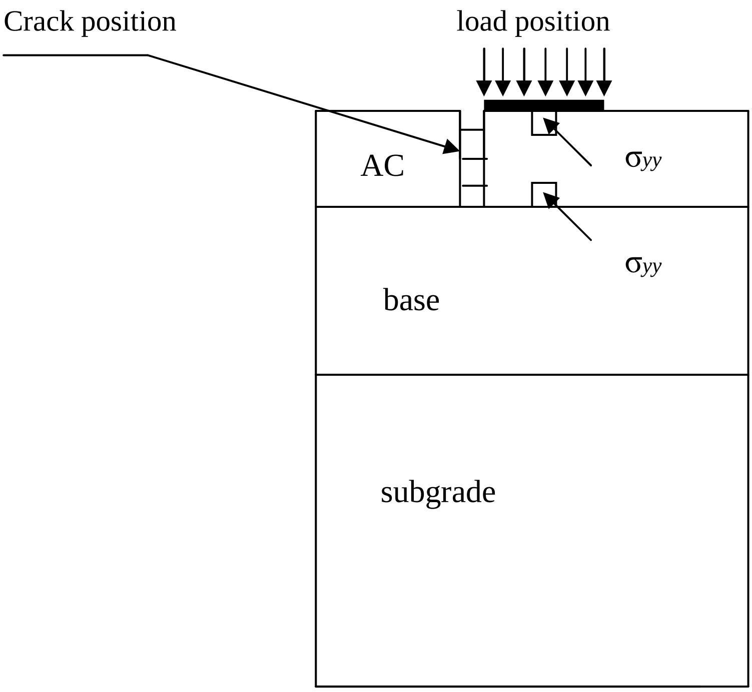

Fig. 15: Critical position of elements considered for σ_{yy} .

6.1 Horizontal Sresses At The Center Of Wheel Load σ_{xx}

Table 1 presents the horizontal stresses σ_{xx} at selected two locations found in **Fig. 14**. The value of stresses at the element located at the top and bottom of the asphalt layer under the center of wheel load are found in the absence of crack and with different crack depths. From table it is found that the magnitude of stress σ_{xx} along both the top (compressive) and bottom (tensile) of the AC layer decrease with the increasing of a crack depth in both winter and summer. No significant difference in the stresses value at winter and summer in case of compressive stresses, while tension stresses are mostly higher in winter than that in summer with about 48 %.

Table 1: Stresses σ_{xx} in (kPa) at the center of wheel load.

Crack depth ratio (CDR)	In top of AC				In the bottom of AC			
	In winter		In summer		In winter		In summer	
	Values In kPa	CNR	Values in kPa	CNR	Values in kPa	CNR	Values in kPa	CNR
0	-64.0	1.0	-59.2	1.0	55.1	1.0	37.7	1.0
25%	-60.1	0.94	-55.3	0.93	53	0.96	35.6	0.94
50%	-49.5	0.77	-45.3	0.77	48.3	0.88	31.7	0.84
75%	-39.5	0.62	-36.5	0.62	44	0.80	28.5	0.76
100%	-25.0	0.39	-27.9	0.47	26.4	0.48	22	0.58

6.2 Horizontal Sresses At The Center Of Wheel Load σ_{yy}

Conversely, with the perpendicular stresses, **Table 2** represents the parallel stresses σ_{yy} along the top and bottom of the AC layer, which are increased with the increasing of the crack depth. Scientifically increase in cold season when the Young's modulus of AC attains the highest value. At full crack depth the CNR ranging from 1.24 in the top of AC (compression) to 1.3 at the bottom of AC (tension) in winter, while in the summer the change in CNR values are not significant. Comparing the tension stresses in both winter and summer, its values increases with about 48% to 57% in winter than that in summer for case of uncracked pavement to CDR 75%. The most critical value was found at CDR 100%, where the stresses is about 80% higher in winter than the corresponding values in summer.

Table 2: Stresses σ_{yy} in (kPa) at the center of wheel load.

Crack depth ratio (CDR)	In top of surface				In the bottom of surface			
	In winter		In summer		In winter		In summer	
	Values in kPa	CNR	Values in kPa	CNR	Values in kPa	CNR	Values in kPa	CNR
0	-63.7	1.0	-58.1	1.0	54.7	1.0	37.1	1.0
25%	-65.2	1.02	-58.5	1.0	55.2	1.01	37.2	1.0
50%	-65.8	1.03	-58.5	1.0	56.5	1.03	37.2	1.0
75%	-67.2	1.05	-58.7	1.01	58.5	1.07	37.2	1.0
100%	-79.1	1.24	-59.8	1.02	71.3	1.30	39.7	1.07

6.3 Vertical Sresses At The Top Of The Base Under The Center Of Wheel Load And At Crack Edge σ_{zz}

Vertical compressive stress σ_{zz} at the two selected locations are shown in **Table 3**. Up to CDR 50% no significant variation in stresses values in summer as well as in winter. At CDR 75% the value of stresses increased by about 49% than that of uncracked pavement. Also, stresses are higher in summer than that in winter with about twice time. **Table 3** shows that the critical stresses is at the edge of crack where, the CNR reaches up to 3.71 in winter to 2.9 in summer in case of full crack depth. However, only moderate increase in σ_{zz} is observed below the center of loading, CNR about 1.62 at winter to 1.32 at summer. This is increase in vertical compressive stresses worn to rutting exist.

Table 3: Stresses σ_{zz} (kPa) at the top of the base throught the center of wheel load and at edge of the crack.

Crack depth ratio (CDR)	In base of AC at the cinter of load				In base of AC at the crack edge			
	In winter		In summer		In winter		In summer	
	Values in kPa	CNR	Values in kPa	CNR	Values In kPa	CNR	Values in kPa	CNR
0	-3.48	1.0	-6.76	1.0	-3.18	1.0	-5.83	1.0
25%	-3.56	1.02	-6.86	1.01	-3.39	1.06	-6.3	1.08
50%	-3.76	1.08	-7.15	1.05	-3.82	1.20	-7.16	1.23
75%	-3.97	1.14	-7.55	1.12	-4.41	1.38	-8.68	1.49
100%	-5.64	1.62	-8.95	1.32	-11.8	3.71	-16.9	2.90

7- CONCLUSIONS

In the current paper, three dimensional finite element analysis is performed using the ANSYS-10 program to investigate the effect of surface cracking on the responses of flexible pavements structure. The normal stresses induced by a single wheel load located adjacent to crack with various depths in flexible pavements as 25% 50% 75% and 100% of asphalt layer thickness. The analysis also, consider the variation in the material properties in winter than in summer.

The following conclusions are drawn out.

1. With the wheel load located at the edge of the crack, there is a considerable change in the values of horizontal and vertical normal stresses in the asphalt concrete and in the base layers
2. Structural behavior of asphalt layer is scientifically affected seasonally for both horizontal and vertical stresses.
3. At the top of the AC layer, horizontal compressive stresses σ_{xx} beneath the wheel load is decreased as the crack depth increase, while tension stresses are found outside the location of wheel load. That tension stresses increases as the crack depth increases. Significant values are found at CDR equal 75%, where the values of stresses is higher with about 144% than that of uncracked one in winter. This is would cause initiation of top down cracking parallel the existing one.
4. Tension stresses σ_{xx} at the bottom of the uncracked AC layer is higher in winter than that in summer with about 48%.
5. Considering the effect of seasons variations, its found that the maximum compression stresses is higher in winter than that in summer with about 42% for case of 100% CDR, while no significant difference for other cases..
6. Considering the material properties in both winter and summer for 100% CDR, its found that the maximum tension stresses is higher in winter than that in summer with about 77%. But in the absence of cracks, it was found that the maximum tension stresses $\boldsymbol{\sigma_{yy}}$ is higher in winter than that in summer with about 46%.
7. Vertical stresses σ_{zz} at the surface of base layer are significantly affected by (different material properties), where the values of σ_{zz} in summer is about twice more than that in winter. A greater increase in magnitude is found at the edge of crack than that at the center of loading.

8. Vertical stresses σ_{zz} at the surface of base layer are significantly increased in summer at CDR 75% where its value increased with about 49% than that of uncracked one
9. Finally, it can be recommended that at CDR 50% pavement must be rehabilitated to avoid the higher stresses which may cause initiation of new cracks at asphalt pavement surface. In other side the winter season is considered the critical for initiation of cracking, as summer season is considered critical for rutting occurrence.

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تأثير الشروخ السطحية للأسفلت على السلوك الإنشائى للرصف المرن

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تعد الشروخ السطحية من أهم مؤشرات الإنهيار الإنشائى للأسفلت، والذى يتحدد بناءاً عليه أعمال الصيانة أو التقوية لطبقات الأسفلت. هذا ومن النادر حساب مدى القصور الذى تسببه هذه الشروخ فى قوة تحمل طبقات الرصف للأحمال المارة عليها. ومن ناحية أخرى للحد من التكاليف العالية لعمليات صيانة الطرق فإن الأمر يستوجب قراراً مناسباً عند وضع أوليات الصيانة وخصوصا عندما تكون الإمكانيات المادية محدودة كما هو الحال فى الدول النامية. لذا إتجه هذا البحث لدراسة السلوك الإنشائى لطبقات الرصف في الظروف المناخية المختلفة وعند ظهور الشروخ السطحية بأعماق مختلفة. وقد تم التحليل بإستخدام نظرية العناصر المحددة ثلاثية الأبعاد بإستخدام برنامجANSYS-10 . وقد تم إعتبار نموذج من منشور رباعى بأبعاد 300×300×202 سم^3 حيث تم تقسيمه إلى 27232 عنصر ثلاثى الأبعاد . وتمت دراسة السلوك الإنشائى لطبقات الأسفلت المختلفة وهى الطبقة السطحية بسمك 12 سم، وطبقة الأساس بسمك 30 سم، بالإضافة إلى طبقة التربة بسمك 160 سم. وتم أخذ مسطح حمل العجلة على مساحة 20×20 سم وضغط عجلة مقداره 0.7 ميجاباسكال توثر فى منتصف المنشور. وتم التحليل أولا بإعتبار عدم وجود شروخ بالسطح حيث تم دراسة السلوك الإنشائى للطبقات مع تغير خواص مواد الرصف خلال فصلي الصيف والشتاء. وبسبب زيادة جساءة الطبقة الأسفلتية فى فصل الشتاء عنه فى فصل الصيف فقد تبين أن الأسفلت أكثر عرضة للبدء فى التشريخ فى

فصل الشتاء بسبب زيادة إجهادات الشد الأفقية فى الشتاء عنه فى فصل الصيف بنسبة تصل إلى 48% فى إجهادات الشد العمودية على أتجاه الشرخ وحوالى 77% فى إجهادات الشد الموازية للشرخ. كما تمت فى نفس منهاج البحث دراسة حالة وجود شروخ رأسية بأعماق مختلفة أخذت كنسبة من سمك الطبقة السطحية، وهى 25% : 50% ، 75% بالإضافة إلى العمق الكلى للطبقة الأسفلتية والممثلة فى 100% من سمك الطبقة السطحية. وقد تمت الدراسة بإعتبار حمل العجلة فى الوضع الحرج على حافة الشرخ، وقد تم من خلال هذا البحث إستنباط أن ألتأثير الإنشائي لعمق الشرخ حتى 50 % من سمك الطبقة السطحية على الإجهادات الإفقية أو الرأسية غير مهم بينما يصبح هذا التأثير هام وقوي على الإجهادات الأفقية أعلى وأسفل الطبقة السطحية عندما يصل عمق الشرخ إلى 75 % من سمك الطبقة السطحية، حيث بلغت نسبة الزيادة فى إجهادات الشد العمودية على إتجاه الشرخ 144% زيادة عن الإجهادات فى السطح بدون شروخ. بينما بلغت نسبة الزيادة فى الإجهادات الموازية لإتجاه الشرخ حوالى 40 % عن الحالة بدون شروخ، هذه الزيادة قد تسبب فى بداية لشروخ سطحية جديدة عمودية أو موازية للشرخ القائم. أيضا بالنسبة للإجهادات الرأسية بلغت نسبة الزيادة حوالى 49 % فى حالة نسبة عمق الشرخ 75%، وقد بلغت الإجهادات الرأسية فى فصل الصيف حوالى الضعف عنه فى فصل الشتاء.