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A Study Supported By Numerical Modeling To Determine The Effect Of The Carbon Fibers Strengthening On The Strength Capacity Of Rigid Pavement

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ABSTRACT *"The Portland Cement Association (PCA) design method of rigid pavementhad been used as a reasonable base to set a design method for this kind of pavement in Egypt.The optimal thickness of rigid pavement depends on the Equivalent Single Axle Load (ESAL), Modulus of Rupture of concrete (MR) and Modulus of subgrade soil reaction (K). In this study we investigate how to increase the strength capacity of a rigid pavement section by increasing the (MR) of the plain concrete slabby strengthening it with the help of carbon fibers sheets.This investigation proceeds by establishing a 3D numerical model of a rigid pavement section with the help of the finite element software pack, ABAQUS. The pavement model is analyzed under a single wheel load of 65kNwith a tire pressure of 740kPa[(1)] applied at the concrete slabs' center, edge, and corner.Results of the models that are strengthen with carbon fibers sheets (Carbon Fibers Models "CFM") are compared with those control models (CM) that have no carbon fibers sheets strengthening. The comparison showed that the (CFM) presents a higher strength capacity than (CM) for the same section properties and dimensions.*

KEYWORDS:*Carbon fibers sheet, numerical model, Portland Cement Association (PCA), Rigid pavement, Strengthening,*

[(1)] $P_t = P_s / \pi . a^2$, *Where* P_t*= tire pressure,* P_s*= wheel load, a = radius of eq. contact area = 0.167 m*

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I. INTRODUCTION

There are many design methods for rigid pavements, and all of them were developed to determine the thicknesses of the rigid pavement layers (Concrete slab, Base, Subbase "optional"), by analyzing the stresses and displacements that generated on the layers from traffic loads and natural effects and frictional effects. All of these methods depend on: (a) Modulus of base and subgrade reaction (k), (b) Concrete slab properties, (c) Traffic loads, viz., ESAL. Although the (PCA) design method, is the recommended method in the Egyptian code ECP 104-2008 [1], but it does not give us the ability to determine and analyze the stresses at any load case except the interior one, and the ability to determine the displacement any load case at all. So, the WESTERGAARD equations are used to give us that ability to analyze the stresses and the displacements at any load case.

In this study, we have two types of rigid pavement sections. The first one is a control section with an ordinary composition of layers, in order to compare the results of analysis due to 2D analysis equations of the PCA and Westergaard, and due to 3D numerical model, to verify the 3D numerical model. The second one is a comparison section, which has the same composition of the control but its concrete layer is strengthen with carbon fiber sheet (CFS) through the layer by dividing the concrete layer into two layers and placing the (CFS) in between. By comparing the results of the control section, -theoretically and (FE) modeling- with the results of the comparison section that is obtained by analyzing in (FE) modeling, we can conclude that the strength capacity increased by strengthen it with (CFS).

By searching in some of the previous studies, we found that the representation of the rigid pavements under traffic loads in computer programs was so different [3:8]. The difference was due to many factors, such as the representation of load transfer at joints, the action of non-linear material, dynamic loads, and defining all of these factors to the programs. In this field and with ABAQUS software, Zdiri et al. [9] and Zaghloul et al. [10] developed models for the rigid pavement section with its foundation.

1. 2D ANALYSISOFRIGID PAVEMENT (CONTROL SECTION)

Westergaard at 1926 [2] proposed the first equations to solve the problem of a wheel load on a concrete layer that based on a subgrade soil, at interior, edge, and corner load cases. For the presented section of slab thickness h=0.2m, a wheel load P=65000 N with a tire pressure of 740 KPa, and $K_{subgrade}$= 90 MPa/m. Figure1shows the 2D model and summarize the section properties.

1.1. Corner load case

Westergaard [2] produced two equations (1,2) to calculate the tensile fatigue (σ) and the vertical displacement (Δ) as shown in equation (3) that occurred at the bottom fiber of the concrete slab:

$$\sigma = \frac{3P}{h^2}\left[1 - \left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right] \tag{1}$$

$$\Delta = \frac{P}{k \times l^2}\left[1.1 - 0.88\left(\frac{a\sqrt{2}}{l}\right)\right] \tag{2}$$

$$l = \left[\frac{E \times h^3}{12 \times k \times (1-\mu^2)}\right]^{\frac{1}{4}} \tag{3}$$

Where;l = radius of relative stiffness, E= modulus of elasticity of conc., a = radius of the eq. contact area, P= wheel load, h= conc. slab thickness, and k= modulus of subgrade reaction (MPa/m).

Note: All lengths by meter, loads by Newton, and stresses by MPa.

1.2. Interior load case

Westergaard [2] produced two equations (4,5) to calculate the tensile fatigue (σ) and the vertical displacement (Δ) that occurred at the bottom fiber of the concrete slab. PCA equation to calculate the tensile fatigue (σ) is shown in equation (6).

$$\sigma = \frac{3P(1+\mu)}{2\pi \times h^2} \times \left[\ln\frac{l}{b} + 0.6159\right] \tag{4}$$

$$\Delta = \frac{P}{8k \times l^2} \times \left[1 + \frac{1}{2\pi}[\ln\frac{a}{2l} - 0.673]\,(\frac{a}{l})^2\right] \tag{5}$$

$$** \; b = a \qquad if\ a \geq 1.724\,h$$

$$** \; b = \sqrt{1.6\,a^2 + h^2} - 0.675h \qquad if\ a < 1.724\,h$$

$$\sigma = \frac{0.316P}{h^2} \times \left[4\log\frac{l}{b} + 1.069\right] \tag{6}$$

Where;b = equivalent radius of resistingsection.

Note: All lengths by meter, loads by Newton, and stresses by MPa.

1.3. Corner load case

Westergaard [2] produced two equations (7, 8) to calculate the tensile fatigue (σ) and the vertical displacement (Δ) that occurred at the bottom fiber of the concrete slab.

$$\sigma = \frac{3P(1+\mu)}{\pi(3+\mu) \times h^2} \times \left[\ln(\frac{E \times h^3}{100k \times a^4}) - \frac{4\mu}{3} + \frac{1-\mu}{2} + \frac{1.18a \times (1+2\mu)}{l} + 1.84\right] \tag{7}$$

$$\Delta = \frac{P\sqrt{2+1.2\mu}}{\sqrt{E \times k \times h^3}} \times \left[1 - \frac{a(0.76+0.4\mu)}{l}\right] \tag{8}$$

Note: All lengths by meter, loads by Newton, and stresses by MPa.

II. 3D NUMERICALMODELANALYSISBY ABAQUS V6.14

3.1 The 3D modeling advantages

The pervious 2D formulas for the different load cases are very simple and depend on many assumptions. For example, these formulas consider the behavior of the concrete material used is a linear elastic, the subgrade soil is considered that does not stressed by shear stresses, the boundary conditions is assumed as fixed in the two dimension, the friction coefficients are not used to simulate the bonding between the surfaces of the layers, it just considered fully bonded. For the 3D numerical models, all pervious disadvantages are handled. The method of analysis by FE modeling gives the ability to simulate the non-linear behavior of concrete material; the actual boundary conditions that is - symmetric restraints - that represent the continuity of the subgrade from all directions. The computer software developed the analysis to simulate the interactions with layers, allows inputting the friction factors, and the degree of contact between layers.

3.2. The 3D modeling characteristics

Figure 2 shows the numerical pavement model that contains two sequent concrete slabs of 20 cm in thickness, separated by a 2cm expansion joint. The concrete slabs rested on a 30 cm of crushed stone base that laid over the subgrade soil. The base layer act as linear elastic material and the subgrade is also defined as homogenous linear elastic material. The friction coefficients between the surfaces of base and subgrade layers and between the surfaces of concrete and base layer are defined to the numerical software. All data of these 3D model characteristics are shown in Table 1. The concrete slab dimensions of 4m × 7m are assumed as it present the average value for the pervious researches and field studies [4, 6].

3.3. The behavior of the concrete material used

Figure3 shows an experimental non-linear behavior of the concrete material in compression that defined in the FE software according to Zdiri et al. [9]. In tension, the concrete material behavior considered linear until the cracking stress.

3.4. Boundary conditions

In order to simulate the real status as far as possible, the boundary conditions – as shown in Figure 4 - are chosen to be as follows:

3.4.1. The boundary condition of the subgrade

In the two-direction y and z, it is a roller fixation and in direction x it is symmetric restraint to simulate the continuity restriction of the subgrade.

3.4.2. The boundary conditions of the crushed stone base

In the direction z, it is a roller fixation. It is free in y direction and in direction x it is symmetric restraint to simulate the continuity restriction of the base in that direction.

3.4.3. The boundary conditions of the concrete layer

In the two-direction y and z, it is free and in direction x it is a spring fixation to simulate the dowel bars restriction between concrete slabs.

3.5. Wheel load transition

The three load cases models: interior, edge, and cornerare simulated in the FE modeling software ABAQUS v.6.14. The applied tire pressure is 0.740 MPa, with a wheel load of 65 kN; which mean the loaded area is equal to 0.088 m^2. The wheel load, the tire pressure and all properties is taken as 2D model analysis done before to compare the results of 2D theoretical analysis and 3D numerical computerized analysis.

3.6. Carbon fibers sheets action in the 3D model

This section has the same composition of the control one in addition to adding a carbon fibers sheet through the concrete layer, with a full bond condition with the concrete, in order to compare the strength capacity due to the strengthening by carbon fibers sheet. The carbon fibers sheetis simulated as crossed laminates to form carbon fibers mesh through the concrete layer. Figure 5 shows carbon fibers mesh and the stress distribution over it due to interior load case.

III. TESTRESULTSANDDISCUSSION

3.1. The results of 2D models for control sections

Table2 shows the stresses and displacements for the different load cases using Westergaard and PCA equations at control rigid pavement section.

3.2. The results of 3D numerical models

Table 3and Figures (6: 10) show the stresses and displacements for the different load cases using FE modeling at the control and comparison rigid pavement sections. The comparison of these results with the results of 2D models, mange the verificationof the 3D numerical models.

3.3. Comparison of the results

Table 4shows the increase in strength capacity due to the strengthening with carbon fibers sheets.

TABLE 1 - The parameters for the models

Property		Subgrade	Base	Concrete slab
Dimensions	**(m)**	4.0×20×1.2	4.0×20×0.3	4.0×7.0×0.2
Modulus of elasticity	**(MPa)**	50	150	30000
Poisson ratio		0.45	0.35	0.22
Friction ratio		1.1	1.5	-

TABLE2 -Control section results due to 2D theoretical analysis at different load cases over conc. slab

Property		Interior load cases	Edge load cases	Corner load cases
Modulus of elasticity	**(MPa)**	30000	30000	30000
k	**(MPa/m)**	90	90	90
a	**(m)**	0.167	0.167	0.167
l	**(m)**	0.695	0.695	0.695
σ (Westergaard)	**(MPa)**	1.996	3.453	2.323
σ (PCA)	**(MPa)**	1.882	-	-
Δ	**(mm)**	0.182	0.530	1.197

TABLE 3 -Control section results due to 3D numerical analysis at different load cases over conc. slab with the help of ABAQUS software

Interior load cases		Edge load cases		Corner load cases	
σ_{11}	Δ_{22}	σ_{11}	Δ_{22}	σ_{11}	Δ_{22}
MPa	mm	MPa	mm	MPa	mm
1.288	0.302	2.298	1.112	1.287	2.854

TABLE 4 - Comparison between 2D analysis and 3D numerical analysis for control section and the other two sections

Rigid pavement sections	Interior load cases		Edge load cases		Corner load cases	
	σ_{11}	Δ_{22}	σ_{11}	Δ_{22}	σ_{11}	Δ_{22}
	MPa	mm	MPa	mm	MPa	mm
Control (2D analysis)	1.996	0.182	3.453	0.530	2.323	1.197
Control (3D num. analysis)	1.288	0.302	2.298	1.112	1.287	2.854
Comparison (3D num. analysis)	0.994	0.281	1.839	0.59	1.028	2.585
The increase in strength capacity	22.8 %		20.0%		20.1%	
The increase in displacement restriction	7.0 %		47.0%		9.4%	

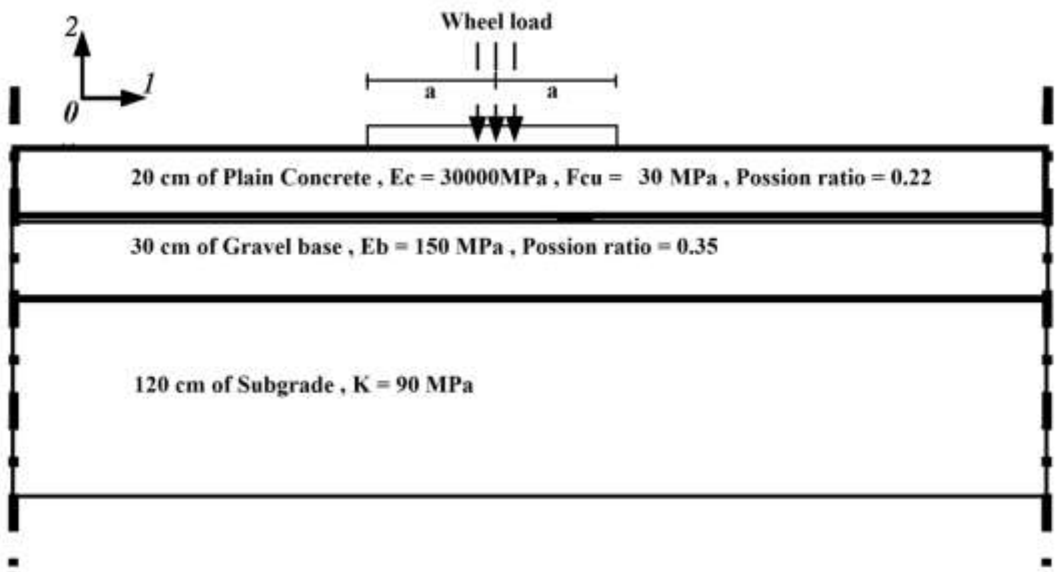

Fig.1 -2D model under wheel load

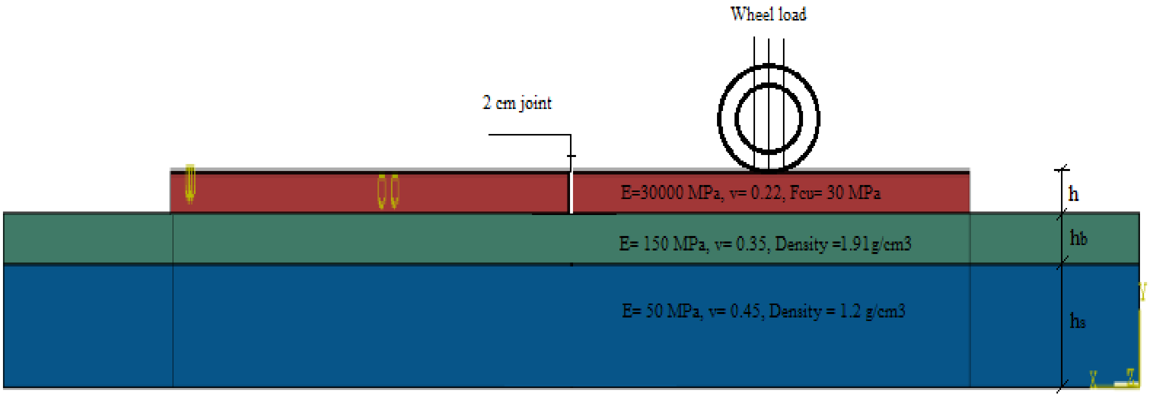

Fig. 2 -Numerical model under wheel load

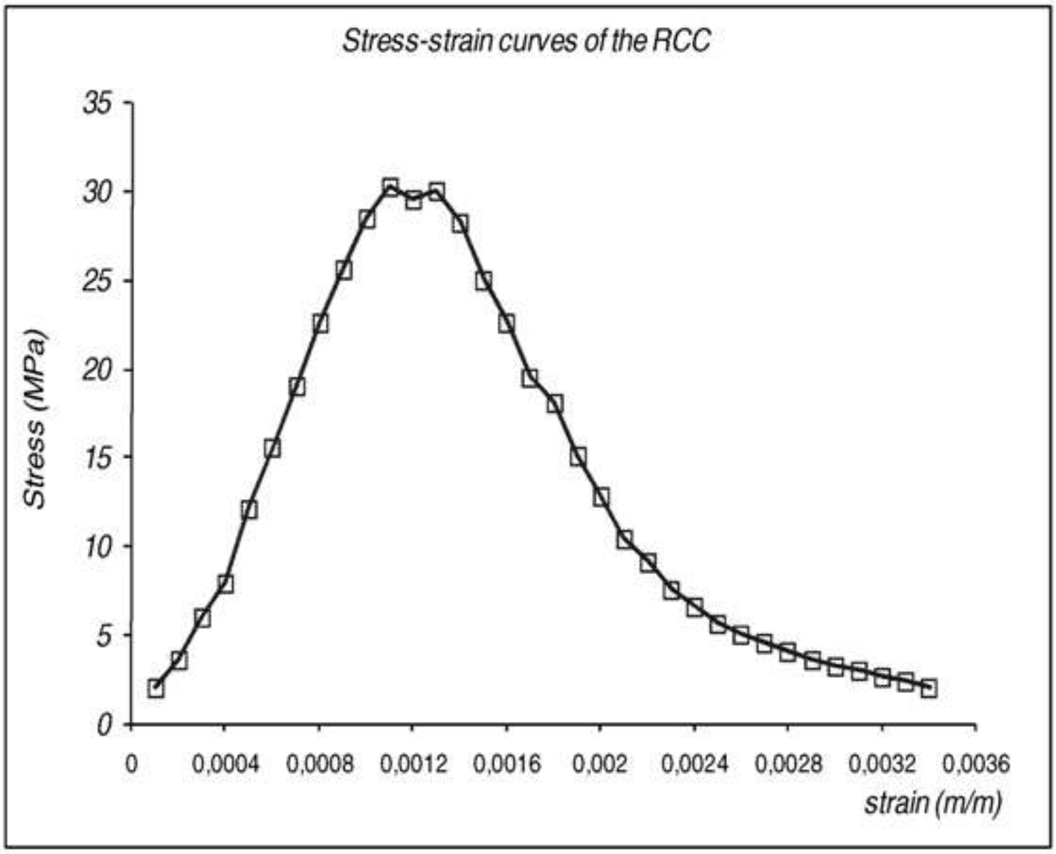

Fig. 3- Stress – Strain Curve of concrete material that defined in ABAQUS software, [10]

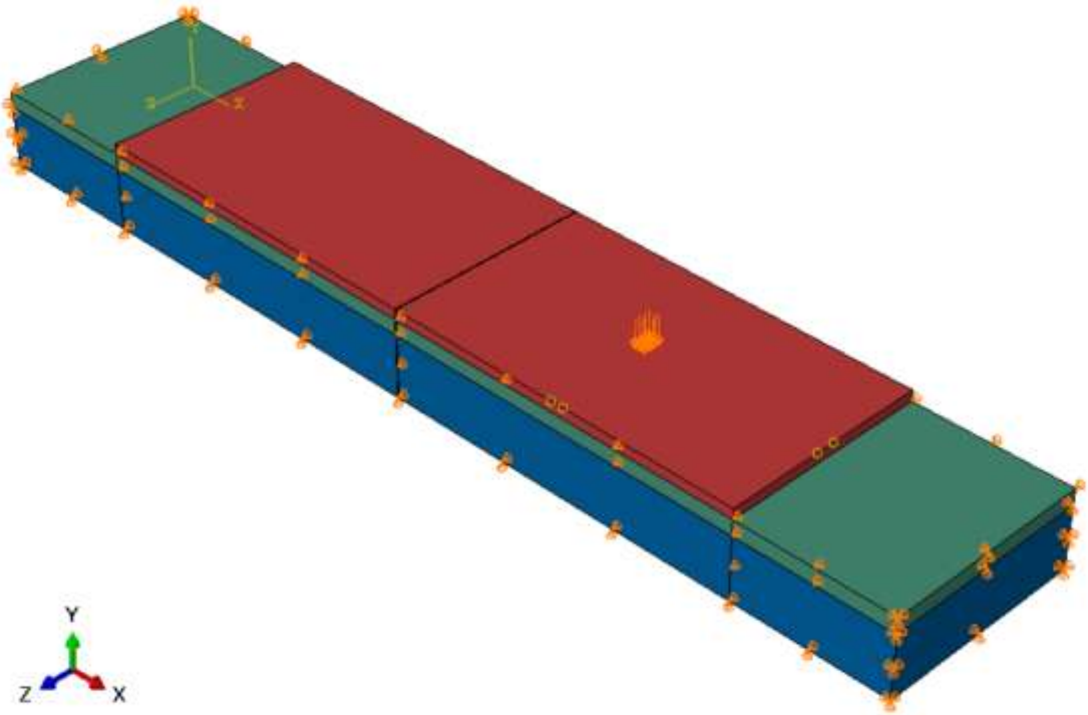

Fig. 4 -Interior load case and boundary conditions

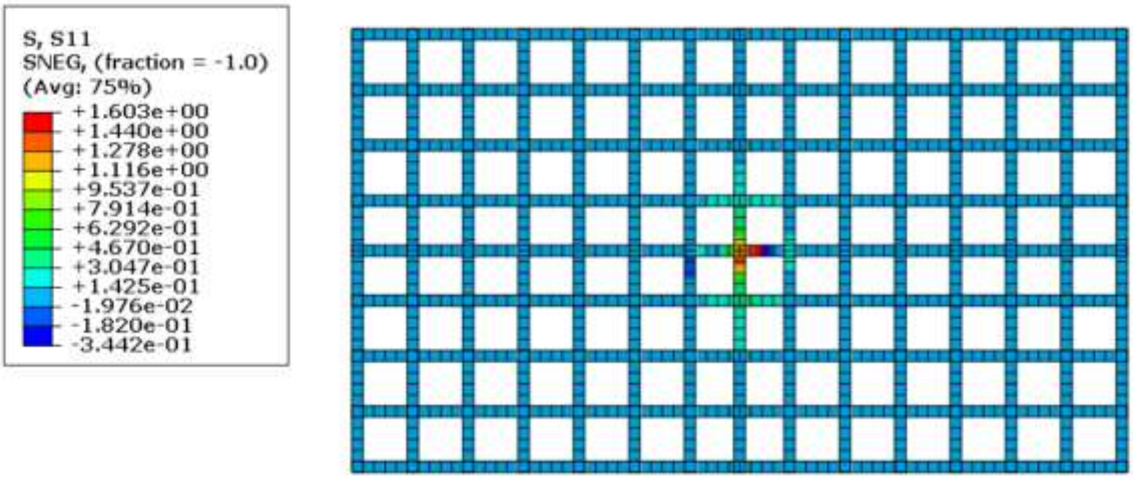

Fig. 5 -CFRP mesh through concrete layer

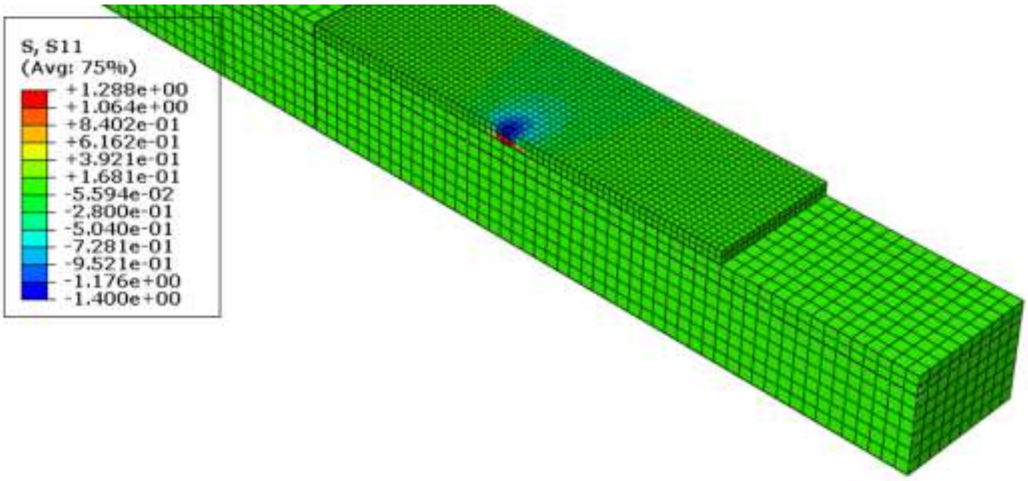

Fig. 6 -Interior load case stresses for control rigid pavement section

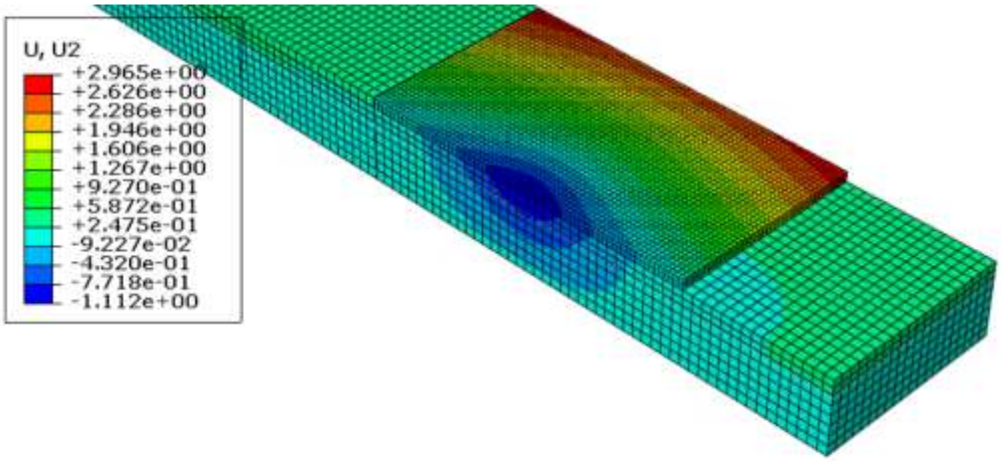

Fig. 7 -Edge load case displacement for control rigid pavement section

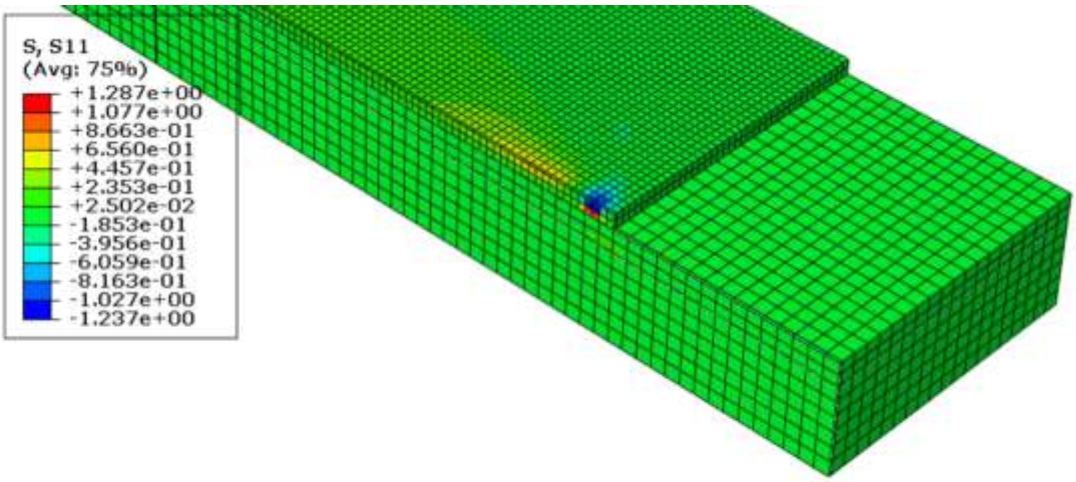

Fig. 8 -Corner load case stresses for control rigid pavement section

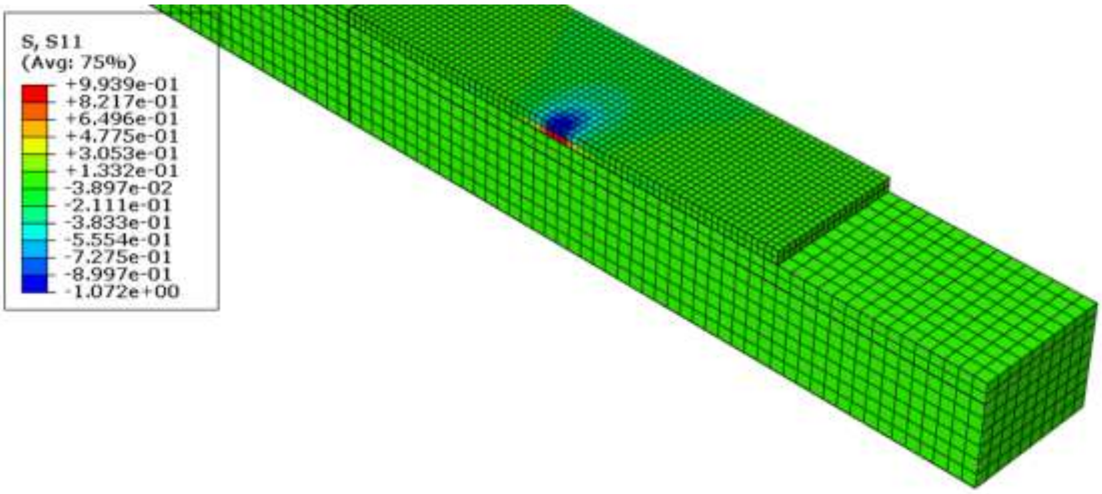

Fig. 9 -Interior load case stresses for CFRP strengthen rigid pavement section

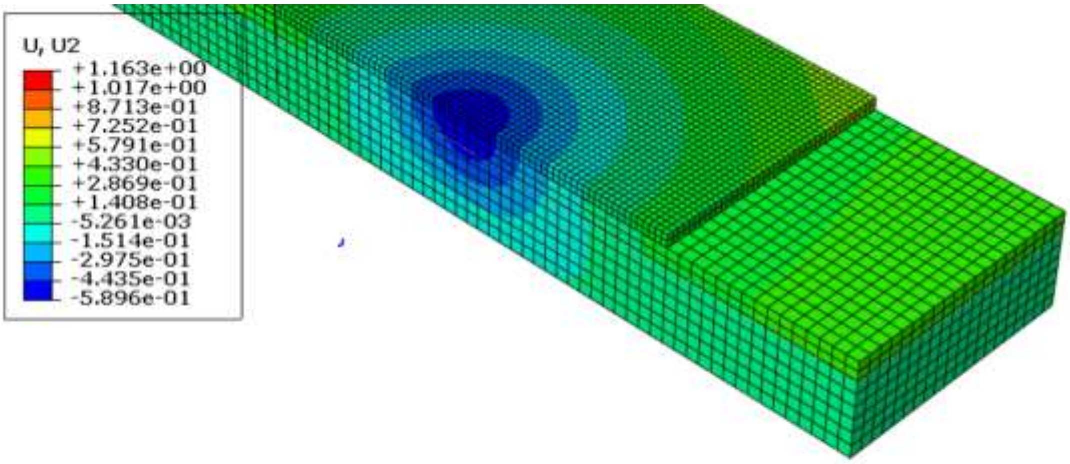

Fig. 10 -Edge load case displacement for CFRP strengthen rigid pavement section

IV. CONCLUSIONS

Based on the results of experimental work and review of literaturesthe following points can be concluded:

1. The difference in the results of control section due to 2D theoretical analysis and due to 3D numerical computerized analysis, show that the 2D formulas do not simulate the real situations accurately; it may be due to that the formulasbased on many assumptions and ignore many factors that already exist in the field.
2. All methods of analysis whether 2D formulas or 3D numerical show that the edge load case present the critical case of loading due to stresses because it gives the highest stresses among the others.
3. All methods of analysis whether 2D formulas or 3D numerical show that the corner load case present the critical case of loading due to displacements because it gives the highest displacement among the others.
4. Strengthening the concrete slab of a rigid pavement section by using CFRP mesh through the slab, will increase the strength capacity of the section about 20% at the different load cases.
5. Strengthening the concrete slab by using CFRP mesh through the slab, will increase the capacity to restrict the deformation by 47% at the edge load case.
6. At the interior load case, strengthening the concrete slab by using CFRP mesh will increase the capacity to restrict the deformation by 7%.
7. At the corner load case, strengthening the concrete slab by using CFRP mesh will increase the capacity to restrict the deformation by 9.4%.

REFERENCES

[1]. Egyptian code for rural and urban highways", ECP 104, Part 6, 2008.
[2]. Westergaard, H.M., "Stress in concrete pavement computed by theoretical analysis", Public roads, PP.25-35, 1926.
[3]. Tabatabaie, A.M. and Barenberg, E.J., (1980). Structural Analysis of Concrete Pavement Systems, Journal of Transportation Engineering, ASCE, National Research Council, Washington, DC, 106(5), pp. 493-506.

[4]. Chou, Y.T., (1981). Structural Analysis Computer Programs for Rigid Multi-component Pavement Structures with Discontinuities: WESLIQUID and WESLAYER, Technical Report GL-81-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, USA.

[5]. Tayabji, S.D. and Colley, B.E., (1986). Analysis of Jointed Concrete Pavements, Report No. FHWA/RD-861041, Federal Highway Administration, Mc Clean, VA, USA.

[6]. Choubane, B. and Tia, M., (1995). Analysis and Verification of Thermal-Gradient Effects on Concrete Pavement, Journal of Transportation Engineering, 121(1), pp. 75-81.

[7]. Khazanovich, L., Yu, H.T., Rao, S., Galasova, K., Shats, E., and Jones, R., (2000). ISLAB2000, Finite Element Analysis Program for Rigid and Composite Pavements, User's Guide, ERES Consultants, Champaign, Illinois, USA.

[8]. Huang, Y. H., (2004). Pavement Analysis and Design, 2nd Edition, Prentice Hall, pp. 147-166, University of Kentucky, USA.

[9]. Zdiri et al., "Numerical modeling of a roller compacted concrete pavement under vehicular loading", Chinese society of pavement engineering, Vol.2 No.5, 2009.

[10]. Zaghloul et al., "Dynamic analysis of FWD and pavement response using a three-dimensional dynamic finite element program", ASTM STP 1198,1994.

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