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Assessing the Effect of Wide-Body Aircraft Landing Gear Configuration on the Stresses Acting on the Composite Pavements using Numerical Analysis

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Abstract: The researches have been done about composite pavements to date, indicating the suitable performance of these types of pavements in comparison with flexible and rigid pavements. In this study, the HMA/PCC structure of composite pavement is modeled with ABAQUS Finite Element Software in a 3D virtual environment and the effect of two wide-body aircraft configurations with similar assumptions has been analyzed in the model and the responses of the composite pavement have been evaluated. The results of this study showed that the horizontal stresses under the concrete slab based on the thickness of pavement layers is in about 22-26% of the stress under the asphalt layer, also the ratio of the maximum horizontal stress of the concrete slab to asphalt layer for the B777-300R airplane is about 2.9 while this ratio of the A380-800 plane is about 1.18 which is implied better configuration of A380-800 landing gear with respect to B777-300R and also the module of elasticity of 4137 MPa could be selected as a suitable amount from the perspective of better decreasing of stresses and deflections.

Key words: Composite pavement, stress, ABAQUS, better, deflections, Iran

INTRODUCTION

Now a days, construction of composite pavements and using its many benefits is proven in the Europe and United States and shows the direction of agencies and highway organization's management toward economic and stable pavement structures. Some critical properties of composite pavements are as follows (Rao, 2013).

Design with long life for the lower solid structure layer of Portland Cement Concrete (PCC) (designed for minimum damage due to fatigue in a period of 40 years). Ability in reconstructing thin surface of pavement by Hot Mixed Asphalt (HMA) with high quality supporting different traffic and weather type (by removing and replacing asphalt materials).

Avoidance of different outstanding damages which happens in usual pavements but are rare or does not exist in composite pavements. Reducing the costs of life cycle, due to less costs of construction and reduction of improvement and maintenance costs during the time.

Excellent properties of the surface including thinness and high quality of the asphalt or concrete layer of the pavement which are reduction of the wheel sounds (especially for permeable mix), high friction, very well smooth surface, minimum groove creation and good durability of more than 10-15 years.

HMA layer reduces the temperature and humidity gradients (from the size and the nonlinearity point of view) in the PCC eagle. This is effective in reducing the curvature of slab, relevant loads and thermal stresses of the eagle.

One of the other benefits of the composite pavement is the deflection of the neutral axis in the pavement layer and the increase of its section the flexural modulus. In fact, when the asphalt layer is completely engaged with the concrete layer, a homogeneous layer with more depth is created which its result is an increase in the flexural modulus and increase of pavement resistance (Donald, 2003). Composite pavements mainly have the advantages of HMA and PCC while they minimize.

Their disadvantages and according to the investigation of the fatigue failure mechanisms, it does not seem to be worry about these pavements in comparison with usual pavements (Rao, 2013). At the moment, the use of composite pavements is focused on the roads with heavy traffic like highways and the main artery roads but the present techniques of construction, technical direction and specification for construction of composite pavements are not studied well and needs more studies and documentations.

Definition of the problem: In recent years (especially in the current decade) abundant researches have been done

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about pavement of runways. Among pavement analysis methods, finite element method has good accuracy in reception different geometry and boundary conditions and always the 3D finite element modeling is regarded as the best analysis method of the main behavior of the pavement structure. ABAQUS Software is a high-level program (Finite Element Method FEM) and has provided a set of scalable tools for the users so that, they simulate and build the model as a completely realistic manner.

In this study, HMA/PCC composite pavement structure with the structural specification of a runway is modeled by ABAQUS Finite Element Software in 3D virtual environment and the effect of A380-800 and B777-300R wide-body airplane's landing gear with similar assumptions is studied in the model and the reaction of composite pavement from the view point of stresses and critical deflection has been studied.

Research background: In the field of runway pavement software analysis and design and the effect of different airplanes, abundant researches have been done and developed. In 1999 the US aviation agency by using field tests and with real scales with the help of real simulation facilities has simulated different type of airplanes from the perspective of landing gear configuration and weights (Garg *et al*., 2004). Also, for the purpose of investigation of design methods in solid and flexible pavements has established laboratory equipment in real scale for the new generation of wide-body airplanes like B777 and B747 (Adil *et al*., 2011).

Tutumluer and Kim (2004) in the studies of the permanent deformation investigation of runway pavement accomplished many tests on the B777-300, A380 and B747 civil airplanes and some type of military airplanes which based on the results A380 and B777-300 had a large effect on the created grooves on runway pavement.

Brill *et al*. performed studies about three software LEDFAA, FEDFAA and FAARFIELD; this study showed for airplanes with 4 and 6 wheels like B777 and A380 the results acquired from FAARFIELD Software are more in agreement with real test results.

Chia-Pei and Wang on the field research results in Chang Sheck international airport of Taiwan and generalization of the results in the 3D virtual environment of the finite element, it was found that the characteristics of the main landing gears has the fundamental effect on the damages inserted in the pavements and are effective in the useful life of the pavement and thickness of the concrete eagles of the pavements. Also with the simulation of the movement of the B777-800 and B747 airplanes it was shown that the horizontal stresses acting on the pavement based on static loads are more than the case of dynamic loads applying.

In 2006, some studies were done with some software of the US aviation agency like LEDFAA and FEDFAA and by the exploitation of the past records of analysis and design of airports in the world and the necessity of development and progress of it some results were presented for the future generations of wide-body airplanes.

US aviation agency has also developed different software for the design of airport pavements. This agency has introduced the LEDGA Software in 1999 and LEDFAA Software in 2004 which have the capability of pavement design and flexible pavement and plating.

Arriving new generation of wide-body airplanes like the A380 and B777 with various configurations, this agency has issued its latest software, FAARFIELD in 2009 which has the capability of designing solid and flexible airport pavements and determining the damages of each airplane. This software works based on the elastic layer theory and finite element method and based on the fatigue and grooving models and its latest version is emerged in 2010 (FAA, 2009).

In 2011 Godiwalla and Pokhrel in a paper which they presented in the Texas airport pavement seminar, emphasized on the necessity of utilizing powerful software in the field of design and analysis of runway pavement and with an abridgement comparison of structure basis of work and the given results of a number software, introduced some proposed software based on the result of their study (Garg *et al*., 2004).

In 2012, in a part of the Second Strategic Highway Research Program (SHSRP2) which was accomplished under the support of US national council academy of transport, different composite pavement was evaluated using in-field tests and by real comparison in order to determining the behavior, property of the materials and performance using design and modeling algorithms and practical recommendations were presented for future design, construction and development (Rao, 2013).

In 2014, the last edition of the CAMFAA 3.0 Software is produced by the US aviation academy which is able to compute the Aircraft Classification Number (CAN) and Pavement Classification (PCN) (FAA, 2014).

Zayari and Moniri in a case study about the Zanjan-Ghazvin highway have compared the current composite and flexible pavement in Iran technically and economically and have shown that the final costs of composite pavement is 0.65 times of the flexible pavement.

MATERIALS AND METHODS

The main purpose of this study is to determine the amount of stress inserted on the HMA/PCC composite pavement under the load of the two airplanes AIRBUS A380-800 and BOING 777-380R by using the ABAQUS/CAE 6.11.

In this study, HMA/PCC composite pavement is modeled using cubic elements in the form of 3D while the reduced integration is active. The element used in the modeling is C3D8R solid. Stress concentration around the loading surface necessitates using more elements and nodes around the loading surface. It leads to increase the time computation by the computer, so, the size of the selected elements should be somehow considered that the balance remains between the time and accuracy of the results.

The study attempts to decrease the time of the computation by dividing the model to different areas and using elements of different sizes in each of them in addition to maintain the accuracy of the results. Also, one of the assumptions of the problem is the linear elastic property of the pavement materials and the static configuration of the airplanes landing gears is studied.

Pavement structure model: The materials and sizes of the pavement layers of partitioning are based on Table 1. Selection of the names and the thickness of the layers are based on the federal aviation organization circular which is published under the title of airport pavement design and evaluation (FAA, 2014).

Also, in modeling, only the concrete and asphalt layers was separated due to the existence of the seam of the edges in the concrete slab but the base, sub-base and the natural bed become model due to the integration continuously. Figure 1 illustrates the modeling.

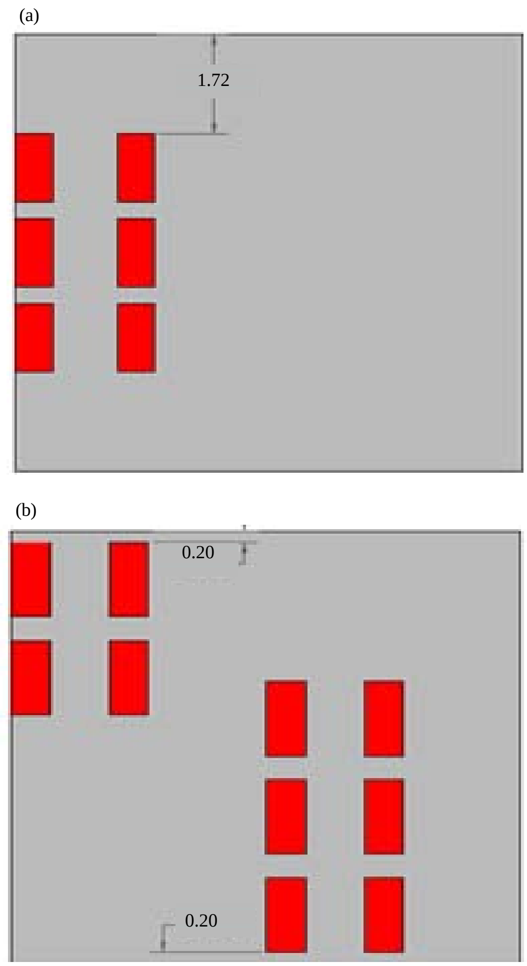

Fig. 1: Modeling of the landing gear (wheel load near the slab and the length of the wheel tire along the edge of the pavement; a) B777-300R airplane; b) A380-800 airplane

Structural assumption in the pavement model: In this analysis two behavioral models are considered for the definition of the material behavior of the under loading. In the elasticity mode, the material behavior is selected linear and in the plasticity mode the Mohr-Coloma behavior is selected (Sirin *et al*., 2007).

For defining the linear elastic behavior two properties of Young modulus and Poisson's ratio is needed and defining the Mohr-Coloma behavior is required three properties of the internal friction angle, dilatation angle and adhesion of the materials.

The properties used for the pavement layer in the model are given in Table 2. For choosing the specification of the materials in the elastic case the help of the HMA pavement design has used which is published by the airport asphalt pavement technology program under the supervision of Auburn University in US.

Interfacial layer friction: As the pavement layers are modeled in different genus and thicknesses and the interfacial condition has major effects in the reaction of pavement under loading and insufficient inter-laminar friction in horizontal loading results in wavy deformation in slopes, turning parts and points of which the airplane starts moving (Novak *et al*., 2003), so in this study to introduce the contact interaction behavior, the friction coefficient values of contact behavior of interfacial and normal behavior of interaction is considered as given in Table 3.

Table 1: Genus and layers of the composite pavement model

Layer arrangements	Layer names	Genus of the layers	Size (m×m)	Thickness (m)	Density (kg/m^3)
1	P-403 HMA	Hot mixed asphalt	7.5×70	0.11	2300
2	P-501 PCC	JPC	7.5×7.5	0.36	2350
3	P-304 CTB	Modified base with cement	12×12	0.15	2000
4	P-209 Cr Ag	Sub-base arising from crushed aggregate	14×14	0.15	1900
5	P-152	Natural bed	20×20	1.50	1600

Table 2: Structural specification of the composite pavement layers

		Mohr-Columba			Elastic	
Rows	Model pavement layers	Adhesion C (Pa)	Dilatation angle (ψ)	Internal friction angle (φ)	Poisson's ratio (υ)	Young Modulus (E) (MPa)
1	Hot mixed asphalt	6e15	2	30	0.35	1379
2	JPC	-	-	-	0.15	27588
3	Modified base with cement	2000	2	40	0.20	3448
4	Sub-base from gravels	2000	2	40	0.35	244
5	Natural bed	4000	2	30	0.40	103.5

Table 3: Contact interaction behavior

Contact surface of interfacial layer	Friction coefficient of contact behavior	Normal behavior
Hot asphalt mix-Portland cement concrete	0.5594	Hard
Portland cement concrete-modified base with cement	0.5594	Hard
Sub-base from crushed Aggregate-natural bed	0.4329	Hard

Boundary condition: In the created models, it is assumed that the soil model is located on the stone bed and at this condition the bottom of the bed layer is closed completely to avoid from any of its vertical or horizontal deflection. Also, the surrounding nodes of the model are bounded from horizontal movements; however, their vertical movements are possible.

As the horizontal translational movement in the direction of dowels of the concrete slab and in the path of the landing gear is possible, a special boundary condition is considered and for this reason the surrounding nodes of the concrete slab in the direction of the airplane wheel for some of the modeling states are not bounded and horizontal deflection for these models are possible.

Modeling landing gear system of airplane and loading system: Different states exist for loading of the landing gears, for instance loading in the center of the pavement and or loading at the edge of the pavement in which the width of the tire is adjusted at the edge, nevertheless in this study to consider the most critical cases it is assumed that one time the wheel load in applied near the slab and the length of the wheels tire is placed along the edge of the pavement. And in the other phase, the load on the wheel is supposed to enter to the corner of the concrete slab. Using the symmetry condition in the configuration of the landing gears in both of the planes, only the main wheels on one side of the symmetry axis is used and in order to apply the effect of the size of the wheels on the pavement, the contact surface of the wheels on the pavement is considered as the equivalent rectangle with the shapes which are given at Fig. 1 and 2 (Huang, 2003; Ozawa *et al*., 2009).

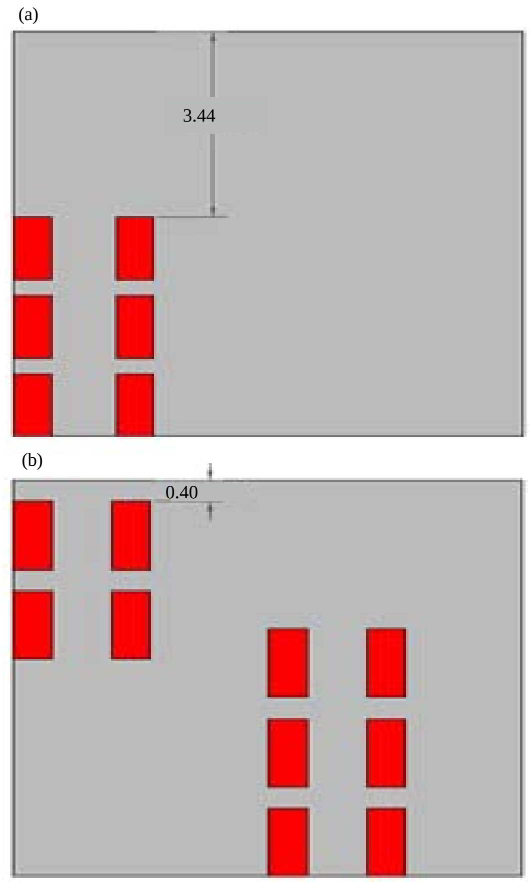

Fig. 2: Modeling of the landing gear (wheel load near the corner of the concrete slab: a) B777-300R airplaneand b) A380-800 airplane

Figure 3 the specification of weight and contribution of each main wheel of the airplane is shown which is used in modeling.

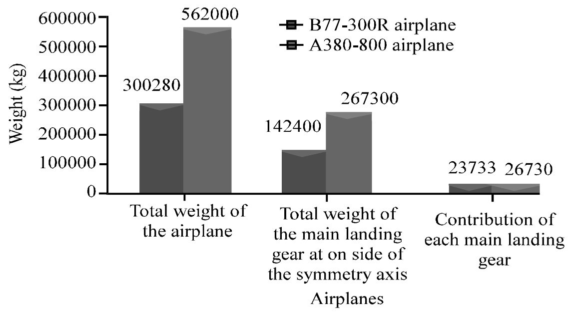

Fig. 3: Weight and contribution specifications of each wheel in the model airplane

RESULTS AND DISCUSSION

The result of analyzing models: In this stage, in order to study the effect of the airplane weight on the composite pavement model, the values of maximum von Mises stress, vertical stress, horizontal stress in the lateral direction and horizontal stress in the longitudinal direction and also maximum deflections under the pavement layers in three types of loading in conditions that the tire length in the direction of the edge and in the slab corner with the assumption of possibility of horizontal movement along the of the slab in the direction of the airplane wheel movement due to the existence of dowels is obtained from the software and are shown briefly in Fig. 4-8.

In order to study the effect of modulus of elasticity on the pavement fluctuations in the model of B777-300R airplane landing gear configuration in the case which the load of the airplane wheel is applied to the slab corner and the length of wheel tires is along the pavement edge, the magnitude of the elasticity of the asphalt was increased from 1379 MPa to 6 times of the primary size of analysis and reached to 8274 MPa and the result of the fluctuation maximum under the wheels and under the asphalt layer was plotted as shown in Fig. 8.

Considering the slope of the graph and the magnitude of the fluctuation under the asphalt layer it is observed that this slope is too much for the initial state which shows the excessive effect of the Young modulus on reduction of the fluctuations. However, in the second part of the graph the amount of its slop decreases and it is appeared that more increase in the Young modulus has not the obvious effect of decreasing fluctuations.

Thus, it is concluded that excessive increasing of the modulus of elasticity, not only does not have the obvious effect of fluctuations but it leads to increase the cost of construction of the pavement and if in the pavement

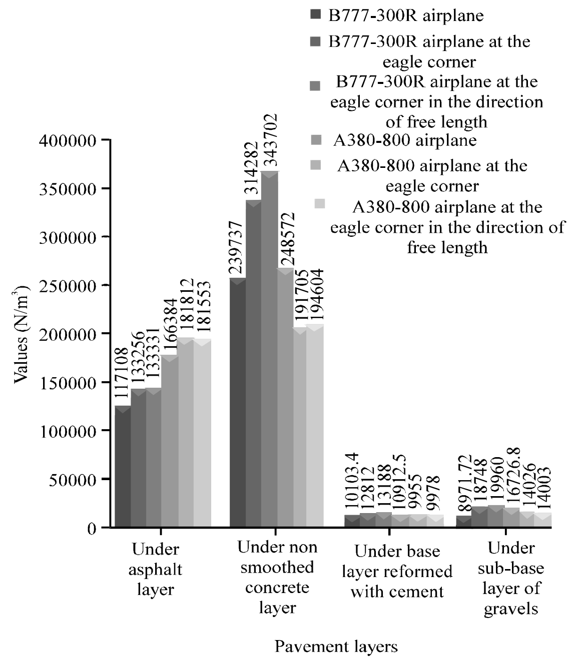

Fig. 4: Maximum values of von Mises stress under the composite pavement layers

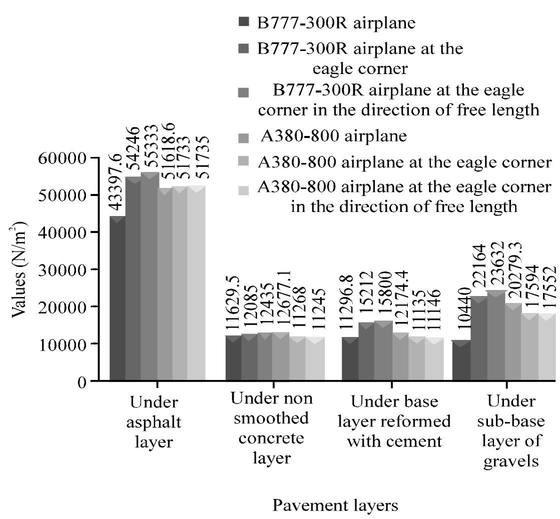

Fig. 5: Maximum values of the vertical stress under composite pavement layers

design, less fluctuations be needed using other methods are suitable including the use of interfacial layer absorbent of stress and strain absorbent.

As shown in Fig. 6, the magnitude of the vertical stress under asphalt layer is meanly 4 times of the vertical stress under the concrete layer and due to in this study the asphalt modulus of elasticity is considered at least 1379 MPa. And with notice in the effect of

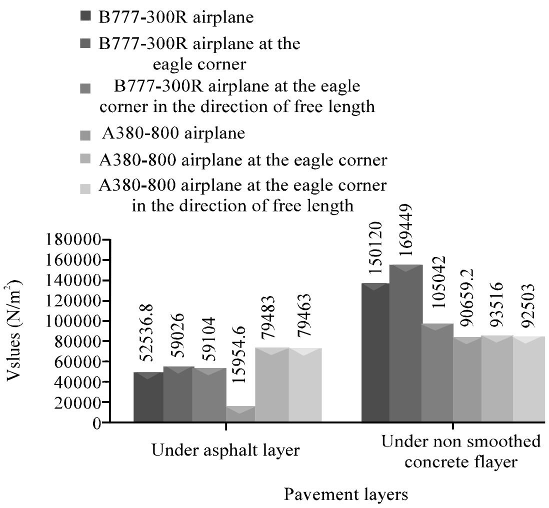

Fig. 6: Values of the horizontal stress maximum in the longitudinal direction under composite pavement layers

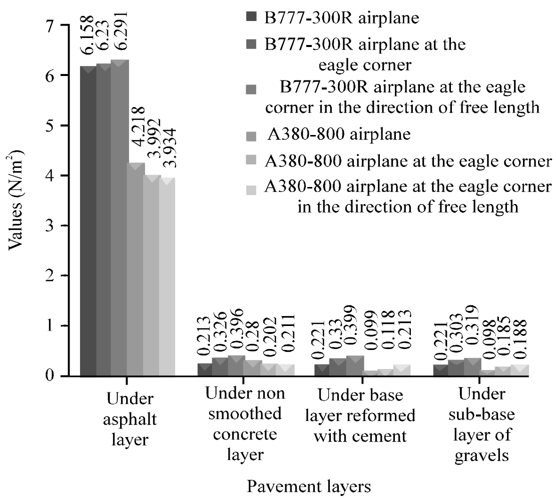

Fig. 7: Values of the fluctuations maximum under composite pavement layers

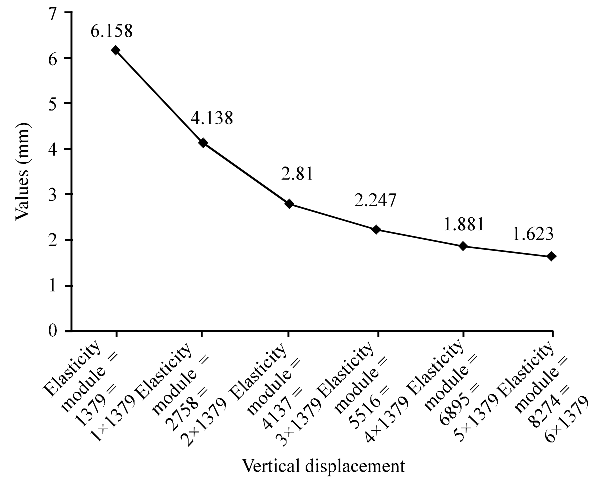

Fig. 8: Fluctuation maximum values under asphalt layer with different modulus of elasticity

asphalt modulus of elasticity on the fluctuation which based on the modeling is shown in Fig. 8, the modulus of elasticity of the asphalt can be selected about 4137 MPa as a suitable base for decreasing the stresses and fluctuations. Also, it is observed that the value of vertical stresses under the concrete layer and under the stabilized layers are close together and meanly have a deviation of 10%. While, this value of stress under the sub-base with crushed aggregate is even more than the maximum of the values under the basis-layer (meanly more than 50%) and concrete sub-layer. The result of this issue can be found in the value of the modulus of elasticity and the thickness of the mentioned layers. To specify, modulus of elasticity of the concrete layer is 27588 is modified basis with cement of 3448 and the sub-base is crushed aggregate with 244 MPa and their thicknesses are considered 36, 15 and 15, respectively. Thus, if the modulus of elasticity of the concrete with the value 27588 MPa is considered as a suitable basis, it is possible by increasing the elasticity of the modified-base to 2 times and to about 6896 MPa and increasing the thickness of 20 cm and increasing the modulus of the sub-basis to 70% and changing its genus to modified sub-base with lime and with the rate of 414 MPa and simultaneously increasing the thickness to 30 cm to have a better distribution in the magnitude of stresses (Fig. 6) and a decrease in fluctuation of under sub-base layers with crushed aggregate and stabilized base-layer with cement (Fig. 8) which have values near together and with this condition it is possible to decrease the thickness of the concrete layer and in this case the thickness of the concrete layer can be reduced and it leads to decrease the costs. So, it is possible to optimize the distribution of the loads applied by changing the thickness and elasticity and the fluctuations in the runway composite pavements for the wide-body airplanes. This type of pavement is exactly similar with the mentioned thicknesses and modulus of elasticity of the layers under the concrete layer of the runway pavement of Denver international airport in Colorado State and shows its reliability for wide-body airplanes.

Also by observing Fig. 6 and 7 and maximum horizontal stresses in the lateral and longitudinal directions under the concrete eagle layer and asphalt layer, it is noted that the ratio of the maximum horizontal stress of the concrete slab layer to asphalt layer for B777-300R is about 2.9. While this ratio for A380-800 airplane is 1.18 which shows suitable distribution of load under the A380-800 airplane loading gear configuration and by comparison of the fluctuation in Fig. 8. it is seen that in spite of more stresses in the pavement under the effect of the A380-800 airplane with respect to B777-300R, the fluctuations due to B777-800R airplane loading is much more and more critical which illustrates this important point that even with more total weight and more contribution of weight in any wheel of the A380-800 airplane, the increase of the tandem of the wheels at the right place under the airplane causes more interaction of the wheel's impacts on each other which results in rhythmical operation of the wheels and finally results in loading distribution on the pavement and less fluctuation.

CONCLUSION

Based on the analysis of the models and their results, the conclusion of this study is as follows: It is observed based on the study of von Misses stresses that maximum stresses are supported by the pavement slab which illustrates its structural role in composite pavements. Also, it is seen that for B777-300R airplane, the loading condition at the corner with freeing the longitudinal horizontal movement, the maximum of the stress is created and it is considered as the critical state and in A380-800 airplane when the loading is modeled at the corner of the slab, the maximum of the stress happens at the asphalt layer, however, for the other layers of the composite pavement, the critical state happens when the wheel load is applied near the slab and the length of the wheels tire stays along the pavement edge.

Studding the graph of the normal stresses, it is seen that maximum vertical stress happens under the asphalt layer, so that, the stress under the slab is 22-26% of the stress under the asphalt and the most critical state in B777-300R airplane happens when loading is at the corner and the longitudinal horizontal movement is free.

Based on the study of horizontal stresses and comparison of it with vertical stresses it is noted that lateral and longitudinal horizontal stresses are surprisingly more than vertical stresses.

The lateral and longitudinal horizontal stresses under the asphalt layer in B777-300R is lesser than its values in A380-800 airplane, however, stresses under the slab of the pavement in B777-800R are more critical and greater in ratio to A380-800 airplane.

The ratio of the maximum horizontal stress of the concrete slab layer of the asphalt layer for the B777-300R is about 2.9 while this ratio for the A380-800 is 1.18 which shows a more appropriate load distribution under the landing gear configuration of A380-800 airplane and shows better configuration of the A380-800 in ratio to B777-300R.

Increasing the minimum elasticity module of asphalt in the composite pavement model under the configuration of the B777-300R airplane landing gear, the amount of fluctuation decreases and this increase in the modulus at the beginning is much more effective with high slope, however, its effectiveness decreases from the modulus of 4137 MPa.

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