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PRELIMINARY STUDY OF DYNAMIC SIMULATION FOR AIRCRAFT TIRE AND ASPHALT PAVEMENT USING ABAQUS

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Abstract: Airport flexible pavements are challenged by increasing aircraft weight and various ground maneuverings. The currently applied mix design methods for airport runways and taxiways does not contain horizontal impact from aircraft tires under different aircraft operations such as slow turning, full-brake and landing. In this study, a three-dimensional FEM model was established by using ABAQUS to investigate horizontal impact of aircraft tire to asphalt pavement. The model takes into consideration that viscosity and elasticity of asphalt concrete, dynamic interaction between aircraft tire and pavement runway, the result can be used in further research for shear-related mechanical analysis of tire-pavement.

1 INTRODUCTION

Airport pavements are essential components for airport infrastructure. Lower initial cost and easy to maintain make asphalt pavement the first choice when it comes to pave runways and taxiways, Aprons are normally built with concrete considering it withstands large static aircraft loads. In north America, 80-85 percent of the airport are paved with asphalt (European Asphalt Pavement Association, 2003). The airside pavement design should be distinguished from which of highway pavement regarding the different loading conditions. The magnitude of wheel load (up to 30t) and tire pressure of aircraft (1.5MPa) is significantly higher than that of traffic vehicles on highways (6.5t and 0.8MPa), while the loading frequency of aircraft (only hundreds repetitions a day) is much lower than that of highway traffic, which is up to 50,000 repetitions a day (Garg & Mounier, 2013).

Apart from loading magnitude and frequency, the way that aircraft load applies to the pavement is unlike the road traffic, which are mainly considered as vertical load. The horizontal impact of aircraft tire has been missing during the airside pavement design phase, this effect is especially significant when an airplane conducts various ground maneuverings such as taking-off, landing, slow turning, and full-brake etc. With the unique engineering properties of asphalt mixture, namely time-temperature dependent visco-elasto plastic material, and tremendous horizontal impact from gear tire during aircraft ground maneuverings, airport flexible pavements are frequently suffered from shear-related distress (Figure 1), maintenance of such pavement distress cause unpredictable economic loss from closure of runway.

Figure 1. Shear Distress at Airport Runway (Rizvi, Tighe, Uzarowski, & Session, 2015)

The measurement of such horizontal impact between pavement and aircraft tire in site is extremely challenging regarding the disruption of associated field work to the airport runways and taxiways. Therefore, using FEM modeling for such purpose of research shows its benefits and advantages.

The objective of this study is to establish a 3-dimensional FEM model for the dynamic simulation of pavement and aircraft tire. The model should consider the complexity of asphalt mixtures and aircraft tire, and the model should be able to simulate the dynamic interaction between aircraft tire and asphalt pavement.

2 LITERATURE REVIEW

The challenge for asphalt pavement modeling is the engineering properties of the material, asphalt concrete is well-known for its combined properties—elasticity, viscosity and plasticity. Leon et. al (Leon, Charles, & Simpson, 2016) used uniaxial compression test procedure tested different types of mix at different height and temperatures, the results include yield stress and elastic modulus can be used in FE (finite element) programs such as ABAQUS that uses elastic and plastic data to model asphalt concrete material. Taha et. al (Taha et al., 2013) found that the stiffness of the asphalt pavement is notably affected by temperature, the higher the temperature applied to the flexible pavement layer, the more the elastic modulus value decrease. In contrast, the lower the temperature imposed on the flexible pavement layer, the more the elastic modulus value increase. Poisson's ratio, together with Young's modulus, is a main input parameter in asphalt pavement simulation in FE programs, Camarena (Camarena, 2016) used indirect tension configuration and uniaxial configuration to investigate the potential variations of Poisson's ratio value among several asphalt mixture treated with different asphalt modifiers. Elseifi (Elseifi, Al-qadi, Asce, & Yoo, 2006) et. al incorporated laboratory-determined parameters into a three-dimensional finite element model to accurately simulate pavement responses to vehicular loading in different temperatures and speeds, the study indicates that the elastic FE model could not simulate permanent deformation or delayed recovery. In contrast, the FE viscoelastic model were in better agreement with field measurements.

The dynamic interaction modeling between asphalt pavement and aircraft tire is a convenient method of finding the critical stress and stain status during various airplane ground maneuverings. Kim (Kim & Tutumluer, 2011) et. al used the measured responses of airfield flexible pavement test sections trafficked under 4-wheel and 6-wheel aircraft gear configurations to validate the three-dimensional nonlinear finite element model, he found that the predicted pavement responses closed matched with the displacements and stresses measured in field and FE model could be applied to the airfield pavement design. Leonardi (Leonardi, 2016) conducted a numerical study of aircraft wheel impacting on asphalt pavement using multi-layer pavement structure and elasto-viscoplastic behaviour of asphalt mixture was considered, the results demonstrate the capability of the model in predicating the permanent deformation distribution in asphalt layers. Yin et. al (Yin et al., 2011) used three-dimensional finite element modeling techniques to determine asphalt pavement response to loading with different configurations, speed and temperatures, linear viscoelastic and linear elastic behaviors were assumed for asphalt concrete and granular materials. Wang (Wang, Al-qadi, & Stanciulescu, 2012) simulated tyre-pavement interaction using 3D FE model, the analysis results show that vehicle manoeuvring behavior significantly affects the tyre-pavement contact stress distributions.

3 FINITE ELEMENT MODELING

3.1 Pavement Model

A three-dimensional finite element model (2.3m*1.5m*0.4m) was built using FE software Abaqus, the material chose 3D deformable solid. In this model, temperature dependent elastic modulus was considered for engineering properties of asphalt concrete. Density was determined as 2400kg/m^3. According to study (Taha et al., 2013), an empirical equation to determine the elastic modulus of the asphalt layer can be shown as following:

$$E_1(t) = 15000 - 7900 * \log(t) \tag{1}$$

Where,

$E_1(t)$ = The elastic modulus of the asphalt mixture layer at temperature t (t>1°C)

And the Poisson’s ratio of asphalt concrete under different temperatures was determined by NCHRP 1-37A (ARA,Inc., 2004) .

Table 1 Values of Poisson’s Ratio for Level 3 According to NCHRP 1-37A (Camarena, 2016)

Temperature	Poisson's Ratio
< 0 °F (-17.8 °C)	0.15
0 - 40 °F (-17.8 – 4.4 °C)	0.20
40 - 70 °F (4.4 – 21.1 °C)	0.25
70 - 100 °F (21.1 – 37.8 °C)	0.35
100 - 130 °F (37.8 – 54.4 °C)	0.45
> 130 °F (> 54.4 °C)	0.48

Therefore, the elastic modulus and Poisson’s ratio under different temperatures are shown as following Table 2.

Table 2 Temperature-dependent Elastic Modulus and Poisson’s Ratio

Temperature (°C)	Elastic Modulus (Mpa)	Poisson's ratio
1	15000.00	0.20
15	5708.88	0.25
30	3330.74	0.35
45	1939.62	0.45
60	952.61	0.48
75	187.02	0.48

3.2 Tire Model

In order to establish a dynamic interactive pavement-tire model with a moving tire, the aircraft gear tire was simplified as a 3D discrete rigid, which is different from realistic situation. The size of the tire (500mm Diameter*450mm width) also didn't consider real aircraft tire size and morphological characteristics such as shape and texture. These will be optimized in further study. The tire model was partitioned symmetrically into 8 parts for the convenience of assembling pavement and tire, the partitioned tire model is shown in Figure 2.

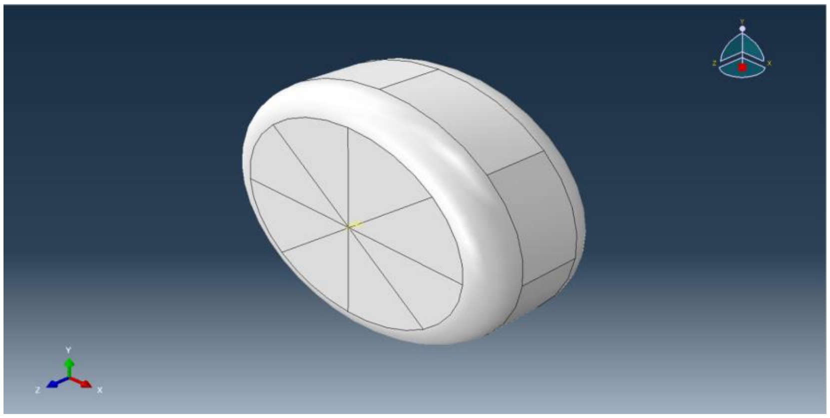

Figure 2. Partitioned Tire Model

3.3 Analyzing Step

A dynamic, explicit step was applied in this study, time period is 4, the whole model used 5.55e-07 as target time incrementation. The linear bulk viscosity parameter is 0.06 and quadratic bulk viscosity parameter is 1.2.

3.4 Pavement Tire Interaction

In this study, explicit analysis type was chosen for dynamic modeling between pavement and aircraft tire. Surface 1 was defined as pavement surface and surface 2 was tire external surface as shown in figure 3. Mechanical constraint formulation was set as Kinematic contact method, sliding formulation chose finite sliding. Friction formulation was specified as penalty, friction coefficient is 0.55 (Hisao, 1970).

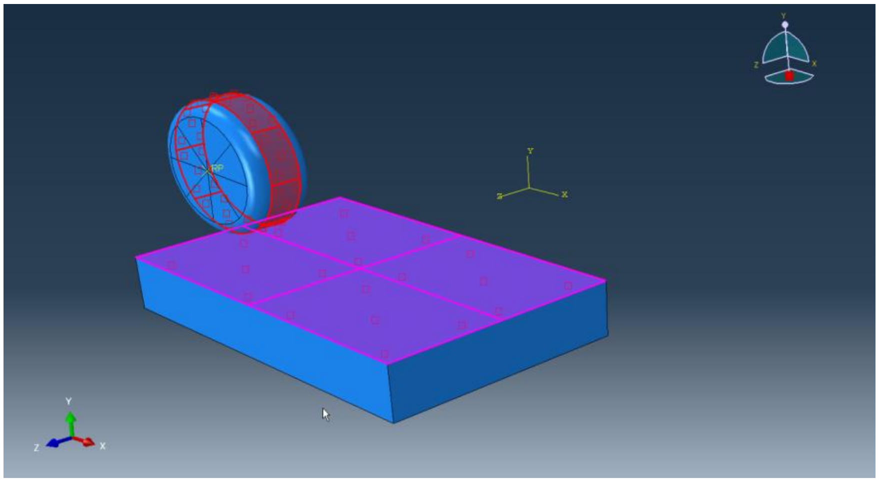

Figure 3. Surface to Surface Contact

3.5 Load and Boundary Conditions

Four different boundary conditions were applied on the model to make the tire move along with the pavement surface.

For the reference point, which was defined as the center of the tire, the displacement/rotation boundary condition applied was U1=U2=U3=UR1=UR2=0, this BC (boundary condition) will only allow the tire to have rotation freedom with axis Z. Also, a velocity/Angular velocity BC was applied at the reference point. VR3=-5, this will guarantee that the tire has a rotatable direction and speed.

For the sides of the pavement model, a symmetry/Antisymmetry/Encastre BC was applied as ZSYMM (U3=UR1=UR2=0). This will restrict the pavement model have rotations around axis X and Y, also the model will not have deformation along the direction of axis Z.

For the bottom of the pavement model, a displacement/Rotation BC was applied as U2=0, this will restrict the bottom of the pavement model have vertical displacement along the direction of axis Y.

3.6 Mesh

For the tire model, mesh element type is discrete rigid element R3D3: A 3-nodes 3-D rigid triangular facet. For the pavement model, mesh element type was chosen as reduced integration C3D8R: An 8-nodes linear brick, reduced integration, hourglass control. Meshed tire and pavement model are shown in Figure 4.

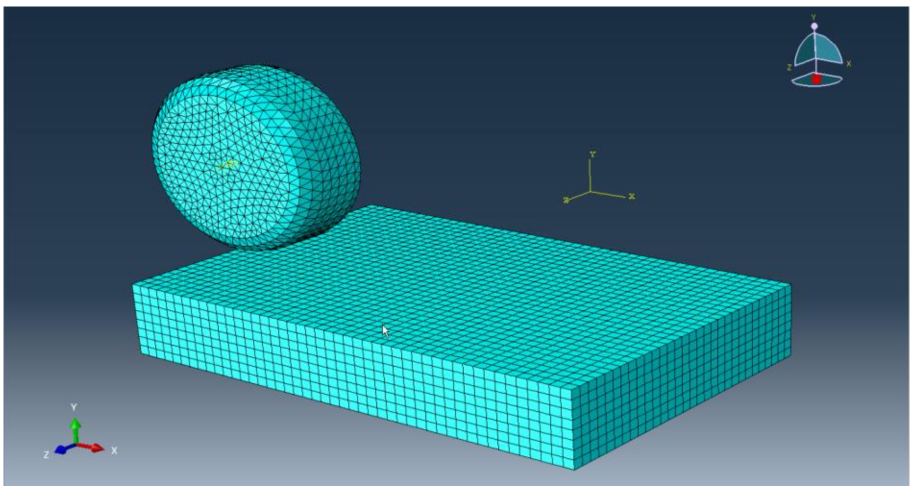

Figure 4. Meshed Tire-Pavement FE model

3.7 Calculation Trial and Visualization

Several calculation trials have been conducted based on previous steps, a dynamic explicit tire-pavement model was accomplished. The visualization of moving tire on pavement surface is shown in Figure 5.

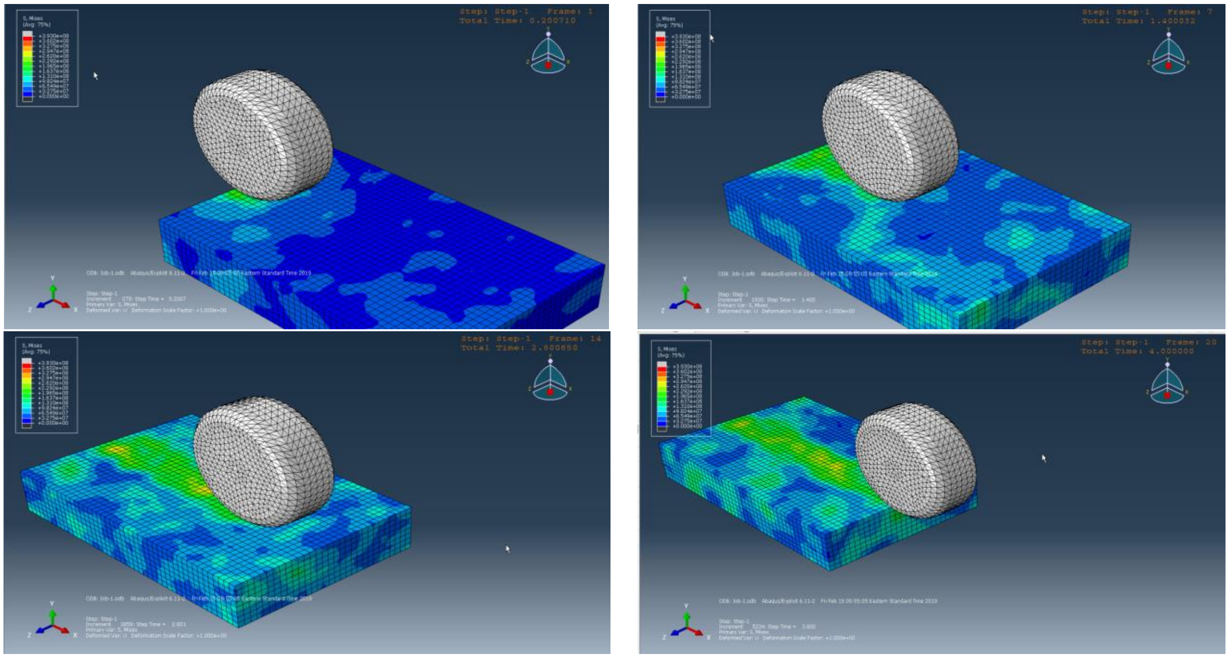

Figure 5. Visualization of Tire-pavement Dynamic Model

4 SUMMARY AND NEXT STEPS

This study presents a three-dimensional dynamic finite element model of Tire-Pavement, the asphalt concrete model took temperature dependent elastic modulus and Poisson's ratio into consideration, tire-pavement finite sliding friction coefficient was also included in surface to surface contact. The model can be used in further shear stress analysis between pavement and aircraft tire under various ground manoeuvrings.

Nevertheless, there are some limitations and needs to be addressed in further studies.

1. Temperature dependent elasticity is insufficient to reflect the mechanical properties of asphalt concrete under complex stress conditions, linear viscoelasticity or plasticity should be incorporated in the model.

2. The tire model was oversimplified into rigid discreet materials, which should be reconsidered as two different parts, the rubber should be treated as hyper-elastic material, and the rim should be considered as linear elastic material. The texture and shape of the tire should also be considered in further modeling.

3. The loading methods including tire pressure under various airplane operations needs to be applied in the model during the dynamic analysis.

4. ACKNOWLEDGEMENTS

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