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Study on Fracture Analysis of Flexible Airport Pavement

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***Abstract*— Ground facilities are an integral part of an airport, which is the most important of them is airport pavements. One of the difficulties and the inevitable failure of the pavement is cracking. Cracking in flexible pavements is a distress seen in the most flight zones. Therefore, it is important to take action to reduced the speed of spread. In this study, pavement data from the runway of the Reggio Calabria (Italy) airport were used to achieve mentioned goal and to adapt the result. Study the FEM based analysis in FEA based software and determined the stress and displacement of the flexible airport pavement under the aircraft of airbus A321. Also the thickness of surface course layer of pavement was changed and the behaviour of flexible airport pavement was checked. Also initiate crack of 10 cm in upper layer of the pavement and determined stress intensity factor (SIF). Also check the behavior of SIF with increasing the thickness of top layer of pavement. After Analyzing the thickness of the asphalt concrete was changed and it was seen that by increasing the asphalt's thicknesses, the stress levels and displacement were reduced and also we can concluded that 0.2 m is best for surface layer thickness. And also shows that Stress Intensity Factor decreasing as increase the thickness of the uppermost layer of the pavement.**

Keywords— Airport Flexible pavement, FEA based software, Maximum stress, Maximum displacement, Crack Initiation, Stress Intensity Factor (SIF).

I. INTRODUCTION

Flexible pavements with asphalt concrete (AC) surface courses are used all around the world. The various layers of the flexible pavement structure have different strength and deformation characteristics which make the layered system difficult to analyze in pavement engineering. Asphalt concrete in the surface layer is a viscous material with its behavior depending on time and temperature. Most of the currently used flexible pavement structural analysis models assume linear elastic behavior. As the demand for applied wheel loads and number of load applications increases, it becomes very important to properly characterize the behavior of unbound granular material and subgrade soil layers as the foundations of the layered pavement structure[5].

In recent years several studies have analysed the behaviour of flexible pavements developing 3D finite element models. This paper represents the flexible airport pavement response due to the aircraft loading with the help of stress and displacement using FEA based software.

Past flexible pavement models used multi-layer elastic analysis, which assumes static loading, whereas in reality pavements are subjected to both static and moving loads. However, asphalt mixtures are viscoelastic material and clays exhibit plasticity (Zaghloul and White [6]). The model used in the study conducted by Zaghloul and White [6] incorporated an elasto-plastic model for the base, sub-base and subgrade and a viscoelastic model for the asphalt layer. Zaghloul and White[6] researched the ability of three dimensional dynamic finite element programs to predict the response of moving loads on pavement structures.

Michele Buonsanti and Giovanni Leonardi[3] employed 3D modeling to determine the contact stresses in a flexible pavement under landing aircraft loads is presented and also predict the dynamic behaviour of flexible airport pavement structure subjected to an impact load.

G. Leonardi[4] represents a numerical study of an aircraft wheel impacting on a flexible pavement. The proposed three dimensional model simulates the behaviour of flexible runway pavement during the landing phase. This model was implemented in a finite element code in order to investigate the impact of repeated cycles of loads on pavement permanent deformation.

Dr. Greg White[1] gives brief idea about airport pavement, comparison airport pavement and highway pavement, pavement responses to load in terms of stress strain and displacement[7].

Mohammad Javad[2], Akhavan Bahabadi, Mohammad Mehdi Khabiri and Alireza Fotouhi Firouzabadi represents the aircraft wheel loading effect on stress at fatigue crack by FEM software and also check effect of stress and displacement of pavement.

Mostafa A. Elseifi[9], Jongeun Baek & Nirmal Dhakal studied 3D modelling with crack initiation and propagation in flexible pavements using the finite element method in which two main approaches studied. In the first approach, 2D- and 3D-focused FE meshes are used to simulate the crack initiation and propagation phases. Focused meshes allow for the evaluation of the J-integral through different contour lines and the SIF. Since the SIF is a measure of the stress and

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strain environment around the crack tip (a greater SIF indicates a faster rate of propagation), the rate of crack propagation per cycle can be estimated based on empirical relations such as Paris' Law. In the second approach, the propagation of damage is simulated using FE and CZM. This approach allows studying the mechanisms responsible for progressing cracking damage in the pavement structure during loading. In summary, both presented approaches have merits in modelling cracking in flexible pavements.

Zainab Ahmed Alkaissi[10]authors have studied to identify the mechanisms for the development and propagation of longitudinal cracks that initiate at the surface of composite pavement. In this study the finite element program ANSYS software was used and the model worked out using this program has the ability to analyze a composite pavement structure of different layer properties. Also, studied the modeling and analyzing of the composite pavement structure with the physical presence of crack induced in concrete underlying layer and check the initiation and propagation of crack of composite pavements.

II. MATERIAL AND METHODS

A. *Pavement Model*

Flexible pavements can often be idealized as closed systems consisting of several layers; so it was decided to model the surface, base, sub-base and sub-grade material using three dimensional finite elements. The pavement structure in the application is based on the structure as found for the runway of the Reggio Calabria (Italy) airport[4], and it consists of a 100 mm thick asphalt concrete layer as the surfacing course, a 150 mm thick of bitumen-treated mixture as the base course, a 210 mm thick granular layer as the subbase course and 3040 mm a compacted soil subgrade[4].

B. *Contact Area and Associated stress*

The most common way of applying wheel loads in a finite element analysis is to apply pressure loads to a circular or rectangular equivalent contact area with uniform tire pressure. Even such a simple model of this impact as an uniformly distributed load of over a circular or rectangular area is commonly used in research and computing programs.

The contact area can be calculated as :

$$Ac = P/p$$

where P is the wheel load and p is the tire pressure.

In the model the Airbus 321 tires were considered.

TABLE I. A321 CHARACTERISTICS

A321 characteristics	
Maximum ramp weight	83400 kg
Percentage of weight on main gear group	95.4%
Nose gear tire size	30×8.8 R15
Nose gear tire pressure	10.8 bar
Main gear tire size	1270×455 R22
Main gear tire pressure	13.6 bar

C. *Material Properties*

The pavement configuration and the material properties of pavement layers are given in Table II.

TABLE II. LAYER THICKNESS AND ELASTIC PROPERTIES[4]

Layer	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's ratio
Surface asphalt concrete	0.1	7000	0.30
Base	0.15	2000	0.35
Subbase	0.21	400	0.35
Subgrade	3.04	70	0.33

D. *Modelling of four different layers of the flexible pavement*

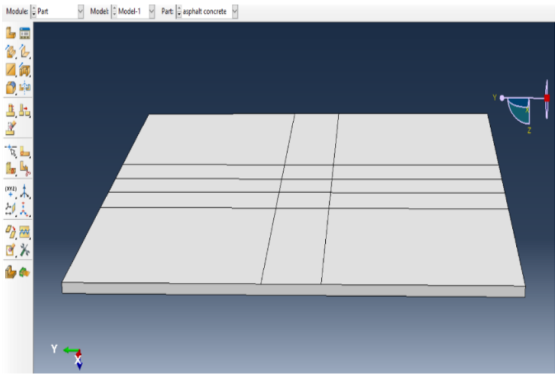

Figure 1 Asphalt concrete surface 0.1 m thickness

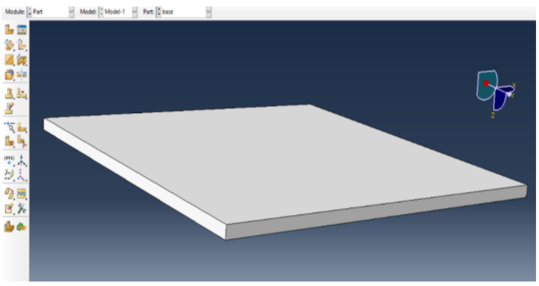

Figure 2 Base Course of 0.15 m thickness

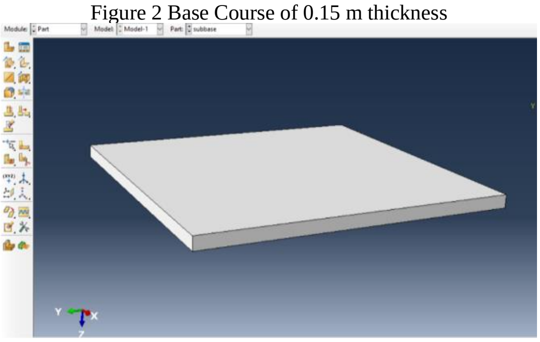

Figure 3 Subbase Course of 0.21 m

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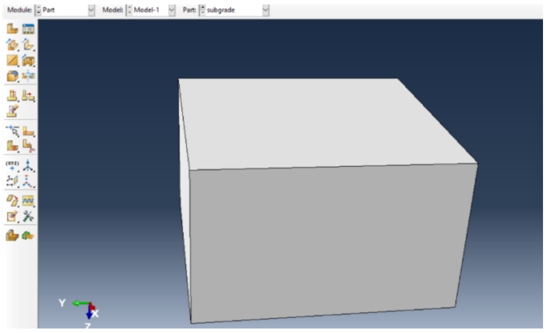

Figure 4 Subgrade of 3.04 m

E. Assembling and Meshing

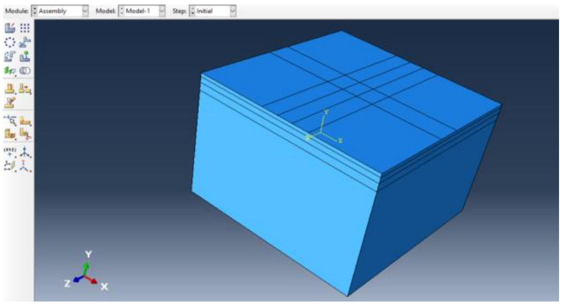

Figure 5 Assembling of 3D model

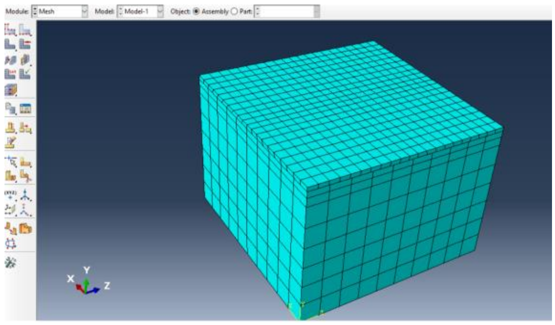

Figure 6 Meshing of 3D model

F. Boundary condition and loading

The model was constrained at the bottom, along the sides parallel to z-axis all nodes were constrained horizontally but were free to move in vertical direction. The boundary nodes along the pavement edges parallel to x-axis were free in both horizontal and vertical directions.

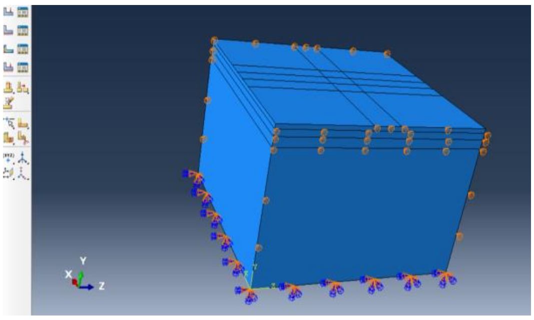

Figure 7 Boundary Condition

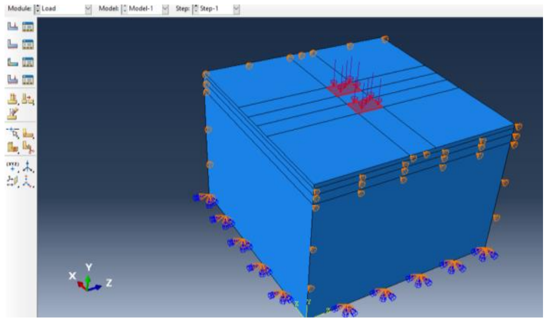

Figure 8 Loading Condition

G. Finite Element Model Geometry

The considered pavement section has the following dimensions: 5 m in x and y directions and 3.5 m in the z-direction. Figure presents a sketch of the pavement structure geometry with the model characteristics.The load of two main gear wheels during the landing phase was assumed to be symmetrically applied on the pavement surface. The model was constrained at the bottom; along the sides parallel to y-axis all nodes were constrained horizontally but were free to move in vertical direction. The boundary nodes along the pavement edges parallel to x-axis were free in both horizontal and vertical directions. Different FE analysis on model with different boundary condition at the edges parallel to x and y axis were performed to examine the boundary effect. No significant effect was found on surface deformations.

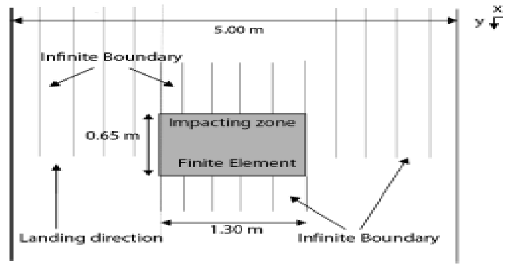

Figure 9 Sketch of the simulated pavement structure

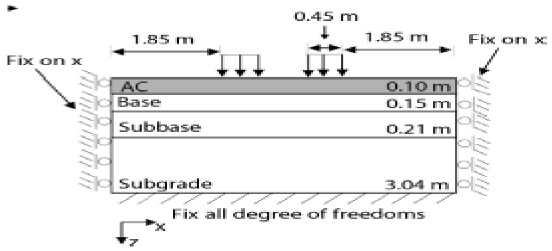

Figure 10 Sketch of the simulated pavement structure

All layers were considered perfectly bonded to one another so that the nodes at the interface of two layers had the same displacements in all three (x, y, z) directions. Assuming perfect bond at the layer interfaces implies that there will be no slippage at the interface. This assumption is more applicable to hot mix asphalt layers, since the possibility of slippage is greater at the subbase interface. The degree of mesh refinement is the most important factor in estimating an accurate stress field in the pavement. The finest mesh is required near the loads to capture the stress and strain gradients.

H. Initiate Crack in Model

The criticality of the stress field associated with the loading as well as the crack initiation stage can be investigated using a focused 3D mesh to calculate the SIF for different crack locations. This section discusses the major simulation steps that should be carried out during the modeling process to study the crack initiation phases.
A crack is first induced in the existing asphalt concrete layer which is the upper most layer of the flexible airport pavement as shown in figure.

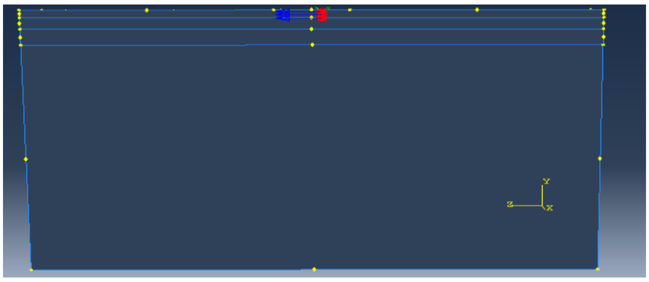

Figure 11 Crack initiate in top layer

Two crack locations should be investigated. Both are located close to the tires of aircraft. Each of the crack is 10cm length in y direction of the pavement. Meshing of the crack model is shown below figure.

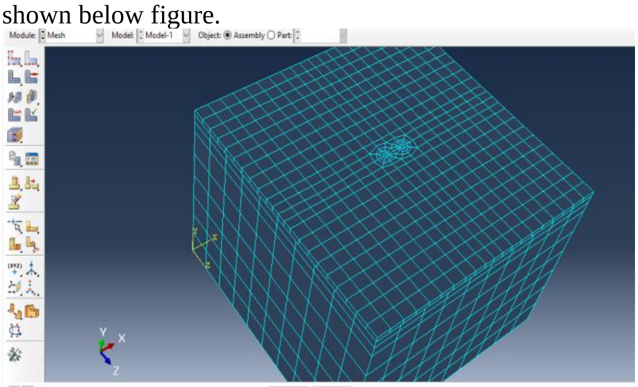

Figure 12 Meshing in crack model

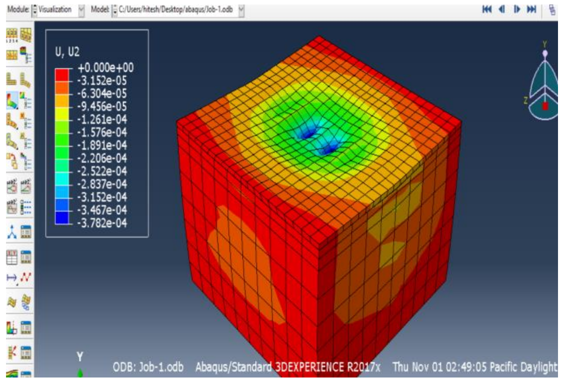

Figure 13 Visualization of displacement

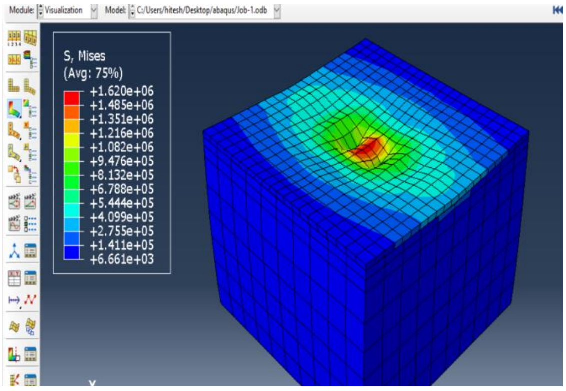

Figure 14 Visualization of stress

III. ANALYSIS AND RESULT

The objective of this study was to develop a 3D-FEM that would accurately predict the mechanistic response of flexible airport pavement. Specifically, the goal of this study was to use the FEM based software, determined flexible pavement response under aircraft loading and also initiate the crack in the uppermost layer of the flexible airport pavement and determined stress intensity factor (SIF) near the crack tip or maximum stress generated.
Each layer was modeled based on the tutorial of the FEM Based Software and in which the first layer consisting asphalt concrete and whole result is shown below the table.

TABLE III. RESULT OF STRESS AND DISPLACEMENT

Surface thickness (m)	**Stress (N/m^2)**	**Displacement (mm)**
0.1 m	1.62×10^6	0.03782
0.2 m	0.9482×10^6	0.03266
0.3 m	0.9108×10^6	0.02642
0.4 m	0.983×10^6	0.01701
0.5 m	0.872×10^6	0.01490

TABLE IV. RESULT OF STRESS INTENSITY FACTOR (SIF)

Surface thickness (m)	**Stress Intensity Factor (SIF) ($Pa\ m^{1/2}$) X 10^4**
0.1 m	8.4619
0.2 m	7.8478
0.3 m	7.3698
0.4 m	6.8463
0.5 m	6.4331

IV. DISCUSSION

In this model the top surface layer thicknesses of the pavement were changed. It was found that, by increasing the thickness of surface layer of pavement, displacement and the stress level were reduced shown in figure 15 and 16.It can also be seen that there is no major change in stress in the range of 0.2 m to 0.5 m of surface layer thickness so that if we want to chance to choose the surface thickness of the pavement then 0.2 m is suitable for surface layer of pavement. The displacement is also decreasing as increase the surface thickness of pavement shown in result in figure 15 and 16.

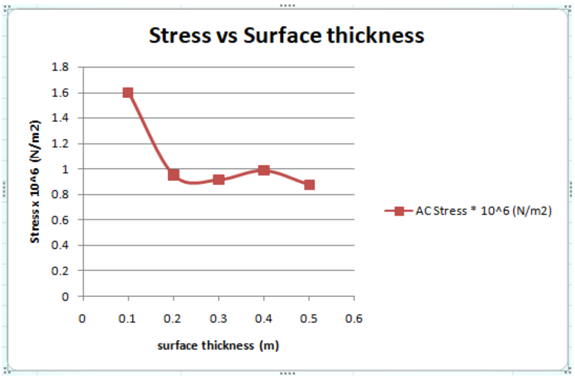

Figure 15 Stress vs Surface thickness

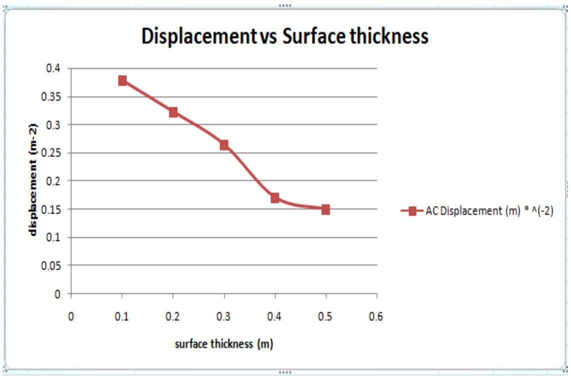

Figure 16 Displacement vs Surface thickness

Also checked the response of stress intensity factor (SIF) with increasing the thickness of the top layer of the flexible airport pavement shown in Table IV. In this model the uppermost layer of surface in which crack exist, it's thicknesses of the pavement were changed. It was found that, by increasing the thickness of surface layer of pavement, the stress intensity factor is gradually decreasing shown in figure 17.

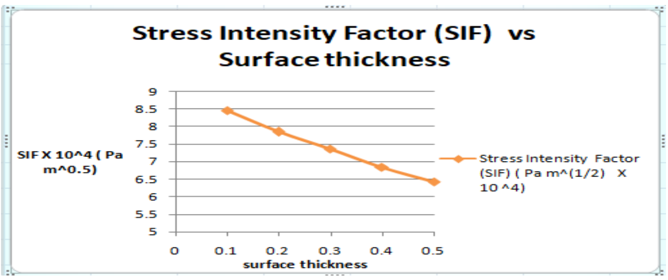

Figure 17 SIF vs Surface thickness

V. CONCLUSION

The main concluding remarks can be summarized as follows :

- In this study, a three dimensional finite element model was implemented by using FEA based software. This study simulated the effect of flexible Airport pavement against stress and deformation.
- The thickness of the asphalt concrete was changed and it was seen that by increasing the asphalt's thicknesses, the stress levels and displacement were reduced and also we can concluded that 0.2 m is best for surface layer thickness.
- Fracture mechanics analysis was successfully used to predict the flexible airport pavement performance in terms of assuming pre-cracked layer.
- Result shows that Stress Intensity Factor decreasing as increase the thickness of the uppermost layer of the pavement.
- Results show that there is a good correlation between SIF, surface thickness, crack, stress and displacement.

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FUTUREWORK

Future research advancements can be done in the direction of :

- The crack propagation in FEM based software.
- To suggest repair works for the cracks.
- Investigate the fatigue life of pavement.
- Finding out rutting depth in pavement.
- Also Analyzing with the use of Damage Mechanics in Airport Pavements.
- Future research advancements can be done in the direction of a better profiling of the pavement behaviour under stress, in function of different combinations of variables as temperature, tire type and pressure and the comparison with field pavement performance data will be conducted.

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TABLES

FIGURES