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BEHAVIOR OF AIRPORT FLEXIBLE PAVEMENT OVER SWELLING SOIL REINFORCED BY NEW ASPHALT LAYERS

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Abstract:

Longitudinal fractures are a common occurrence in runway pavements built on expansive soil subgrades. Such soil behavior leads to a reduction in the carrying capacity and lifespan of runways, as variations in water content accelerate cracking and deformations in the various pavement construction layers. To examine the behavior of reinforced runway flexible pavement over expanding subgrade soil, this study uses experimental and numerical analyses. Non-destructive deflection test is used to assess static behavior, measuring deformations and stresses in various runway profiles both before and after reinforcing with new asphalt layers created using the ACN-PCN process. Using the software program PLAXIS 3D, a three-dimensional (3D) finite element model (FEM) was designed to anticipate pavement distortions resulting from sudden, high-pressure movements caused by the expansion of soil.

The materials were simulated using a soft-soil model (SSM) for the expanding subgrade and nonlinear behavior for the pavement layers. The experimental results and computer analyses were compared, and it was discovered that the measured and calculated deflection curves generally match very well.

Keywords: *Swelling Subgrade; Flexible Pavement; Runway; Strengthening; (3d) Model.*

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1. Introduction

The major fracture failure mode in flexible pavements overlaying expansive subgrades carried on by repetitive airplane loads and soil movement over time is longitudinal cracking. The carrying capacity of the structural pavement, the material's mechanical characteristics, the resistance of the asphalt layers, and other environmental factors all affect how quickly cracks appear. These motions, which are brought on by the expanding soils and facilitated by variations in water content, appear as upward and downward movements, respectively, as the water content changes. The severity of this occurrence highlights runway cracking, raises maintenance costs, and shortens the lifespan of the tarmac [1]. In recent decades, various studies have explored methods to reinforce and restore roads and runways. [2-9]. It proved the use of geosynthetics, geogrids, glass fiber and carbon, geocomposites, and waste plastics in asphalt layers can increase the resistance of pavement layers, limit cracking and rutting, and reduce the interlayer shear strength [10, 11]. Despite its potential advantages, the construction of asphalt layers is limited by various factors, including costly expenses and construction difficulties. To improve the mechanical properties of asphalt layers, it is recommended to use accepted procedures such as applying bituminous layers, modified concrete bitumen, and high-modulus bitumen.

In this studios work, we conduct an experimental and analytical analysis of the flexible pavement of Larbi Tebessi International Airport's runway 12/30, which was built from 1943 to 1956. To ensure its longevity, the pavement will undergo various rehabilitations and be strengthened with a slightly thicker layer of new asphalt. Our analysis is based on the Pavement Classification Number (ACN-PCN) technique, and we anticipate that the restored runway pavement and the additional asphalt layer will have a service life of 15 years.

A simulation was conducted to study the behavior of the system pavement structure and swelling subgrade under the landing gear of an ATR 72-600 aircraft. To carry out the analysis, a 3D finite element model was used with PLAXIS 3D software under static load. Both linear and nonlinear models were employed to account for the pavement's constituent materials. A full-scale case study of a runway was used to validate the numerical model.

2. Materials and Methods

2.1. Description and characteristics

In the east of Algeria, 2.5 km north of Tebessa, is the study area for a runway (12/30) at Larbi Tebessi Airport (Fig. 1). At 811 meters above mean sea level, it has a reference temperature of 34.6 degrees Celsius and receives 10 to 50 millimeters of precipitation annually. During World War II, the airfield was built in 1943, and it began to be used in 1956. The airport is primarily made up of two runways: the first one is 2400 meters long and 30 meters wide with orientation (12/30), while the second one is 3000 meters long and 45 meters wide with orientation (11/29). The critical aircraft at this airport is the B727-800, and both runways have shoulders of 7.5 meters each. Since its establishment, the airport has had a number of renovations; the most recent ones, which included a complete rehabilitation of parking and taxiways, were completed between 2007 and 2015. The geotechnical characteristics for runway 12/30 are made up of 0.20 m of asphalt concrete as the top surface, 0.25 m of granular materials (bank gravel) as the foundation layer, and 0.20 m of granular materials (natural angular gravel) as the subbase layer, per the soil studies. The entire structure was above a 3% California Bearing Ratio (CBR) clayey silt subgrade.

Fig. 1 Location of airport (Google Earth).

2.2. State of degradation

The runway and its adjacent areas have suffered damage, including high joint fractures, low fatigues, high longitudinal and transverse cracks, and medium fatigue cracking in the central bands. These cracks have been caused by significant changes in temperature and precipitation over time. Furthermore, the runway is subject to large tensile strains due to the subgrade's shrinkage and expansion, as well as its poor bearing capacity (CBR= 5), which are both influenced by fluctuations in water content. Additionally, the runway's extreme bands, which are around 3 meters wide, have suffered severe degradation (Fig. 2). In addition, the planes complete over 700 takeoffs and landings annually. Therefore, it is required to scarify the current asphalt concrete layer and replace it with a new bituminous layer in order to fortify the runway.

Fig. 2. Longitudinal cracking on the runway.

2.3. Runway strengthening

It was advised to add the new layer over the current surface course because the additional reinforcement provided by bitumen layers limits the spread of cracks and boosts the runway's carrying capacity [12]. The process for reinforcing was as follows: The process involves removing the current shoulders of the one-meter-deep asphalt concrete layer along the runway. These shoulders are replaced with rock boulders that are 0.4 meters, a 0.2 meter thick layer of sand to prevent contamination, and two layers of granular materials. The base layer will be 0.2 meters made of natural angular gravel, while the subbase layer will also be 0.2 meters thick and consist of natural angular gravel. The runway needs to be cleaned, cracks sealed, and an asphalt coat should be applied to the top surface to ensure proper adhesion.

3. Numerical analysis

We used a commercial program called Plaxis 3D 2013 to create a 3-D computational model of the runway pavement using finite elements. In Figure 3, you can see the model's shape. By analyzing it statically, we were able to measure the amount of tension, strain, and deflection caused by ATR 72-600 wheel loads. To solve this problem, I treated the runway portion as an axisymmetric issue and divided it into small pieces using a 3D finite mesh with 10-node tetrahedral elements. The Mohr-Coulomb model (MC) was used to simulate the base and subbase layers, while the Soft-Soil Model (SSM) was used to describe the behavior of the expansive subgrade. The asphalt concrete layer was simulated using the linear elastic model. To minimize the impact of boundary conditions on the findings, we used a model with dimensions of 6 x 6 x 3 meters. We confirmed the results of our finite element simulation by comparing them to the outcomes of experimental investigations on in situ laboratory tests (HDW). The physico-mechanical parameters used for the numerical simulation are listed in Table 1.

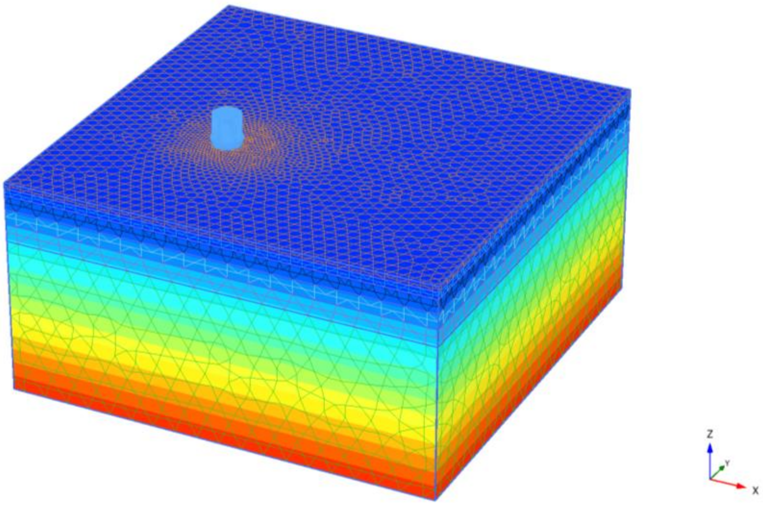

Fig. 3. 3D FEM symmetrical model of the pavement

Table 1. Input parameters of the used materials

Used Materials	*AWC**	*ABC**	*EAWC**	*Base course*	*Subbase*	*Subgrade*
Thickness, m	**0.08**	**0.10**	**0.20**	**0.20**	**0.25**	**3.0**
Young's modulus, MPa	**6188**	**6188**	**6188**	**408**	**408**	**141**
Poisson's ratio	**0.35**	**0.35**	**0.35**	**0.35**	**0.35**	**-**
Unit weight, kN/m^3	**25**	**21.2**	**22.0**	**22.0**	**22.0**	**18**
Cohesion, kPa	**-**	**30**	**20**	**20**	**20**	**100**
Friction angle (°)	**-**	**43**	**44**	**44**	**44**	**16**
Dilatation angle (°)	**-**	**13**	**14**	**14**	**14**	**0**
Modified compression index, □*	**-**	**-**	**-**	**-**		**0.086**
Modified swelling Index ,□*	**-**	**-**	**-**	**-**		**0.043**
Swelling pressure kPa	**-**	**-**	**-**	**-**		**250**
Volumic Strain, ε_v (%)	**-**	**-**	**-**	**-**		**0.7**

***AWC: asphalt wearing course; ABC: asphalt base course, EAWC: Existing asphalt wearing course.**

4. Results and discussion

In Figs. 4–5, the outcomes of the numerical simulation are shown. The overall displacements revealed that, prior to reinforcing, the pavement had vertical upward displacements of 3.621x10^{-3} m, which were caused by the subgrade's swell. The vertical downward displacements on the pavement are 0.291 x 10^{-3} m after the placement of the new asphalt layers. The results show that, the new asphalt layers restrict the most significant displacement at the asphalt layer zone and minimize vertical swelling deformations by 92%.

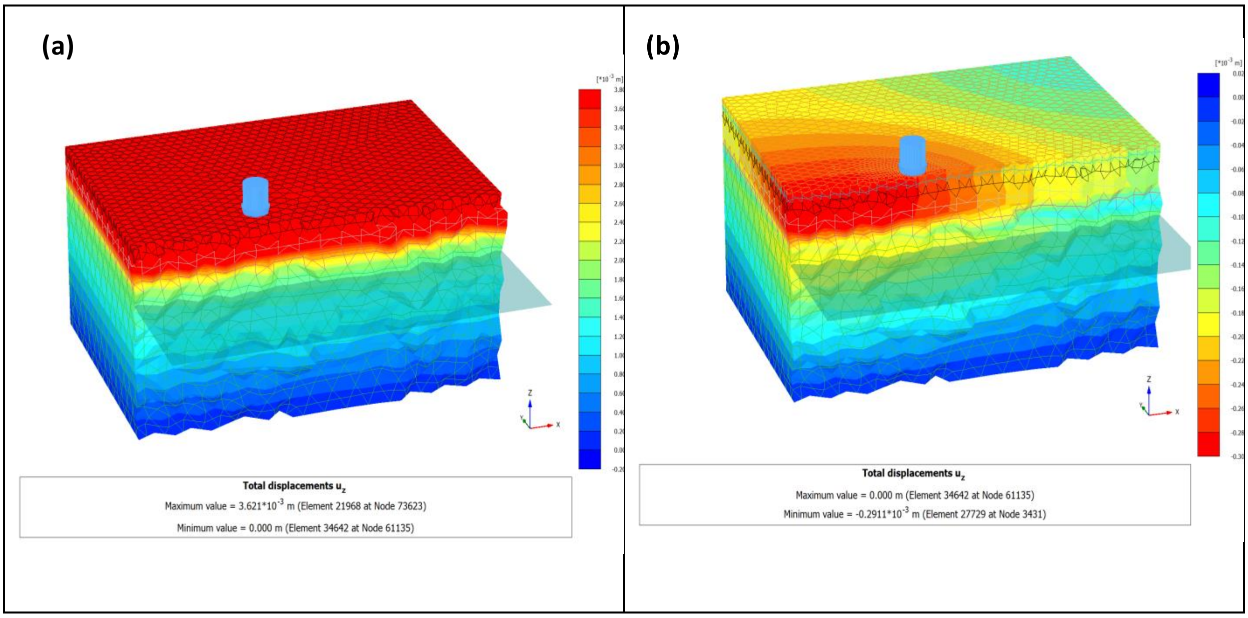

Fig. 4. Total displacements (Uz). (a) Before strengthening (b) After strengthening.

Before reinforcement, it was revealed that shear stresses had a significant impact on the connection between the pavement and subgrade, reaching a peak of 60 kN/m² and affecting the entire pavement structure. This particular distribution of shear stress is highly sensitive to the swelling pressure created by the subgrade soil. After the strengthening process, the main focus of the shear stresses shifted to the point where the landing gear makes contact with the pavement, with a reduction to 25 kN/m². It was also observed that the pavement's shear loads were decreasing, which led to a longer lifespan for the runway by limiting the spread of fractures caused by swelling subgrade and landing gear. After analyzing the data, it can be concluded that the inclusion of additional asphalt layers leads to a reduction of shear stresses by 42%. Additionally, it also decreases the maximum stresses at the contact of runway and tires.

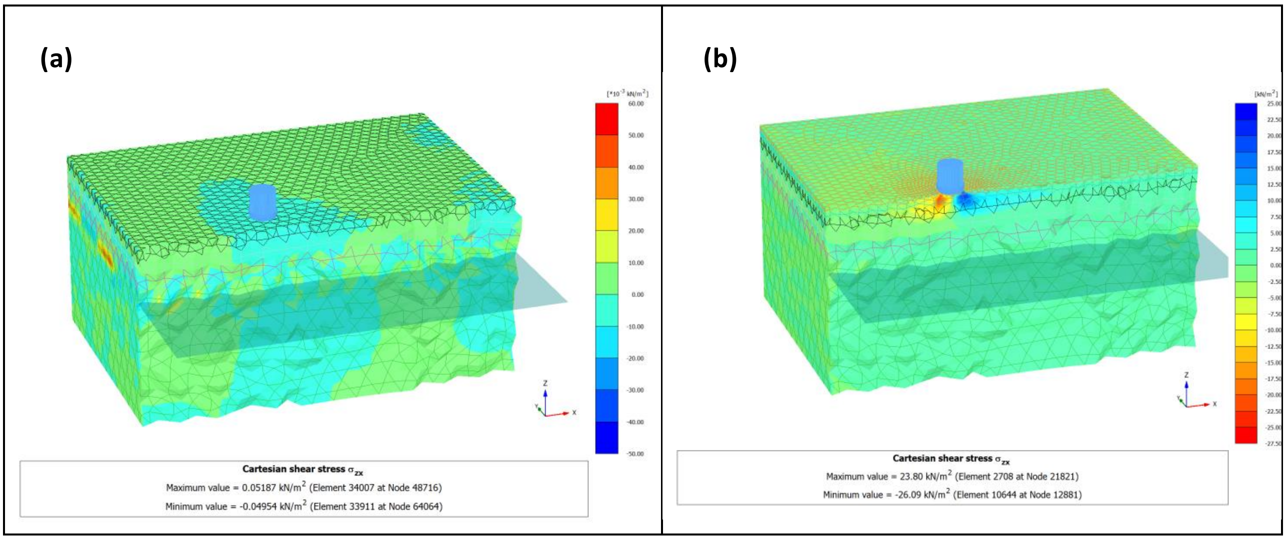

Fig. 5. Shear stresses (□$_{zx}$). (a) Before strengthening (b) after strengthening.

5. Conclusion

This work has looked at the numerical analysis of a flexible runway across a large subgrade. The behavior of the pavement has been investigated through the measurement of stresses and deflections after reinforcing it with additional asphalt layers. To approximate the behavior of the runway pavement, a 3D finite element model has been created. According to the analysis of this study project, we may draw the following conclusions:

- Through a numerical study, it was found that assuming non-linear behavior for all pavement layers except the asphalt layer and simulating the swelling behavior of the subgrade using the soft-sol model led to highly accurate results in the simulated deflection.
- The application of the new asphalt layers restrict the maximum displacement at the asphalt layers zone by 92% and minimize vertical swelling deformations by those amounts.
- The maximum stresses at the contact of the tire and asphalt wearing course region are limited by the reinforcing with asphalt layers, which decreases shear stresses by 42%.
- The use of a numerical model can greatly aid in the design of a runway built on expansive soil. It can also predict how the pavement structure will behave in similar situations with varying levels of complexity.

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