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Experimental and numerical analysis of the behavior of an airport pavement reinforced by geogrids

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HIGHLIGHTS

- Airport pavements deteriorate due to aircraft loads and environmental conditions.
- A case study for the application of geogrids in an airport runway is presented.
- An evaluation of the static behavior by (HWD) is performed.
- Geogrids reduce the stresses and strains and the propagation of the descending cracks.

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ABSTRACT

Airport flexible pavements are subjected during their use to continuous stresses from mainly dynamic repeated aircraft loads, environmental climatic conditions and hence the risk of fatigue and deterioration. Geosynthetics, such as geogrids, improve the performance of pavements and increase its bearing capacity and its life expectancy as the reduce cracking and damage of different layers. Few experimental and numerical studies are available in the literature to predict the behavior of pavement over time. In this paper, a case study for the application of geogrids in an airport runway is presented. An evaluation of the static behavior by measurement of deformations and stresses in different sections of runways are presented as well as non-destructive testing by heavy weight deflectometer (HWD), before and after geogrids reinforcement. A finite element numerical study on the behavior of these geogrids reinforced runway is also presented and compared to the experimental results.

1. Introduction

Roads and airport runways are subjected to cyclical and sometimes excessive loads during their use. In addition, stresses due to harsh environmental conditions cause losses of pavements structural characteristics. Although, owners inspect regularly runways and taxiways and perform routine maintenance and/or emergency repairs, there is still a need for adequate solutions to ensure the safety of these infrastructures and restore their original mechanical properties. The solution usually depends on the type of degradation, the propagation of cracks and the fatigue of materials.

Several strengthening techniques have been applied in flexible pavements in roads and runways repairs during the last twenty years. In addition to the traditional technique based on the application of bituminous concrete layer, the application of modified bitumen and high modulus bitumen can significantly improve the mechanical properties of pavement. However, for the strengthening and upgrading of flexible degraded and cracked pavements that have lost part of their mechanical characteristics, the application of geosynthetics seem to become an alternative efficient repair solution [1,2].

The most widespread geosynthetic materials for this type of application are geogrids. The performance of geogrids depends on the constituent material of the grid, the shape of the mesh, the dimensions, the rigidity and the position in the section. Geogrids increase fatigue resistance, reduce degradation over time, reduce crack propagation and increase structural performance. Recent research work highlighted the influence of these parameters through laboratory and situ investigations by non-destructive testing, especially in roads. Indeed, the position

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of the geogrid in the flexible pavement structure is one of the most widely discussed subject over the past three decades due to the important effects it produces during its use in roads [3].

The influence of geogrid on energy absorption and on reducing crack propagation has been investigated [4,5]. Austin and Gilchrist [6] tried to optimize the strengthening of bituminous concrete pavement using flexible biaxial geogrid. The behavior of the surface layer reinforced with geogrid was evaluated experimentally [7]. The effect of the bond between the asphalt and the geogrid on pavement behavior and the optimization of the thickness of the sub layers were also studied [8,9].

However, there is little research on strengthening of airport runways by geogrids. The main property investigated is the choice of the most optimal position of geogrid reinforcement. A laboratory and in-situ study of the performance of geogrids made of glass fibers to delay the first cracks was performed [10]. Case studies of aerodromes (runway, ramps, and taxiways) were also investigated.

In this paper, the behavior of airport runways reinforced by geogrids is analyzed by, comparing deformations and stresses in different critical sections of runways before and after strengthening by geogrids. Numerical analysis is performed using an algorithm based on the resolution of the differential equation of the fourth order by finite element method. Linear model is considered for the constituting materials of the pavement. The model is validated considering a full-scale case study of a runway in the south of Algeria [11].

2. Runway pavement case study

2.1. Description and characteristics

The case study concerns a secondary runway of Tiksa airport in the city of Djanet in the south of Algeria. It is located at 966 m above the sea level and the dominant temperature is 38–40 °C. The runway was built in 1984. It has been repaired many times since its construction. The repair and strengthening includes the total rehabilitation of taxiway and parking and the strengthening of the secondary and main runways between 2005 and 2007 [12].

The geometrical characteristics of the runway are length: 2400 m, width: 45 m, orientation 03/20 roadway, shoulders width = 2 × 7.5 m, critical aircraft: B727. The geotechnical characteristics, according to the soil investigation are: a 50 mm asphalt layer, a 60 mm thick layer as the surfacing course layer, a

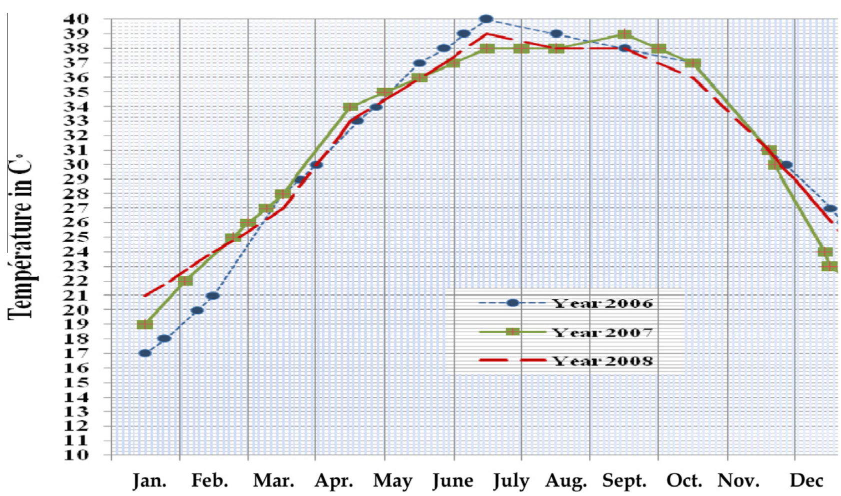


Fig. 1. Monthly maximum temperatures between 2006 and 2008.

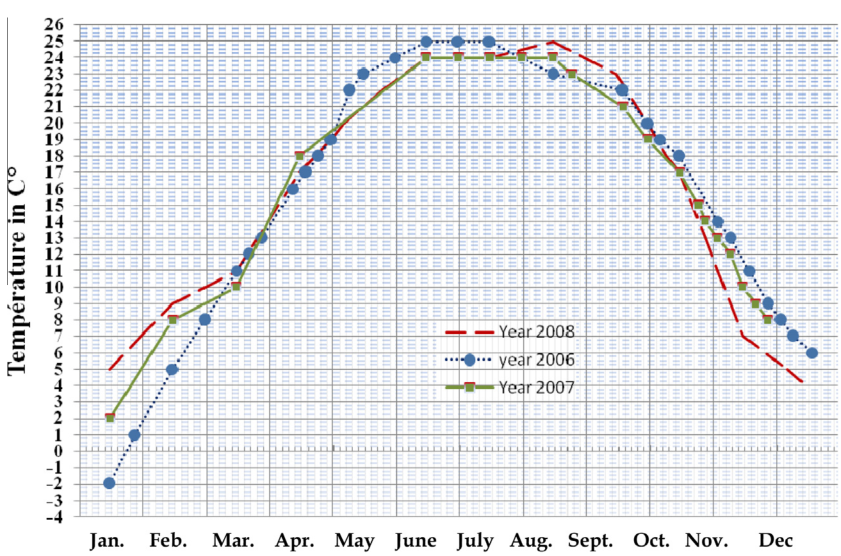


Fig. 2. Monthly minimum temperatures between 2006 and 2008.

Fig. 3. Longitudinal cracking.

200 mm thick granular (granite crushed rock) layer as the base course, a 250 mm thick granular (granite crushed rubble) layer as the subbase course (Foundation layer) and a subgrade of sandy gravel soil at the bottom. The California Bearing Ratio (CBR) value was 10.

2.2. State of degradation and diagnosis

Damages are visible on all of the runway and its annexes. They consist of longitudinal cracks ranging from 5 m to 23 m in length located on the central bands of the secondary runway, composed of six bands [13]. These cracks are probably due to gradients of temperatures around 30–40° in warm periods (Figs. 1 and 2). Furthermore, transverse cracks occur at the beginning of the runway, in the strand' band (number 5), have been noted (Figs. 3 and 4).

In addition to the large number of aircraft movements, of the order of 450 rotations annually by the B737-800, B737-600, Airbus 321 and Hercules C130 [13], the effect of temperature has an influence on the behavior of bituminous runways. Indeed, the shrinkage/expansion phenomenon induces the opening of cracks and hence involves large tensile stresses. In order to remedy this situation, several solutions were considered. This includes traditional strengthening of the runway by scarification of the existing bearing asphalt concrete layer and substituting it with a bituminous layer 60 mm thick. An alternative solution consists of posing a layer of geogrid, as a separator fabric, in the section of roadway either at the level of the surfacing course layer, between the surfacing course layer and the base layer or below the base layer.

2.3. Reinforcement of the runway

Because of the advantages of the reinforcement by geogrid in limiting the cracks propagation, the latter was recommended to be put between the surfacing course layer and the base layer [14]. A modeling study was conducted to find out the optimal position of the geogrid layer. The strengthening procedure was as follows:

Fig. 4. Transversal cracking.

Fig. 5. Placing of a layer of geogrid on the runway.

Fig. 6. Application of a bituminous layer on the geogrid.

- Scarification of 60 mm of the existing bearing asphalt concrete layer.
- Sealing of the cracks.
- Application of an adhering asphalt coat to the level of the scarified surface.
- Pose of the geogrid layer on the central part of the runway (2400×30) meters (Fig. 5).
- Passing of wide tires trucks on the geogrid layer to extract the entrapped air beneath (Fig. 6).
- Careful application bituminous concrete layers to the recommended thickness.
- Finishing.

The characteristics of the materials used are shown in Table 1.

3. Numerical analysis

A numerical three-dimensional modeling by finite elements was elaborated using the commercial software ABAQUS which is based on the entry of the geometric and mechanical characteristics of the runway and the gogrid [15]. Two types of elements have been chosen for the modeling of the section of the runway. The asphalt (bituminous concrete, gravel asphalt) and the soil support have been expressed using triangular elements according to the Mohr–Coulomb criteria. The element chosen for the geogrid is an elastic linear one-dimensional block element (Fig. 7). The finite element model was validated by comparison to the results of the experimental study on a set of laboratory tests.

Table 1
Mechanical characteristics of the materials used.

Materials used	Thickness (mm)	Modulus *E* (MPa)	Density (kN/m^3)	Module *G* (MPa)	Cohesion (kPa)	Poisson coefficient	Rubbing angle
Surfacing course	102	5400	24	1176	/	0.35	–
Base layer	300	260	24.7	–	20	0.38	43
Foundation soil (subbase)	300	120	18	–	20	0.48	44
Soil support	1000	50	16	–	8	0.40	36
Geogrid	1	629.3	11	–	–	0.3	–

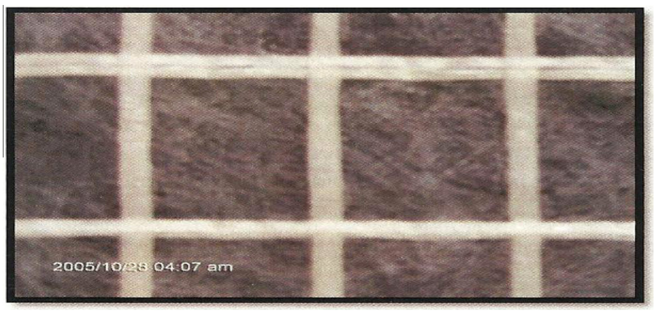


Fig. 7. Type of geogrid used for strengthening.

3.1. Calculation hypotheses

The layers are considered to be a one solid block, which is subdivided into sub areas, discredited into elements of finite dimensions [16]. Assembled, these elements are interconnected by nodes to their common edges. The numerical analysis provides an approximate solution of the modeled structure taking into account the types of boundary conditions and the effect of the type of loading. For the calculation of the stiffness matrix of the basic elements and the overall matrix of the structure, three primary factors have been introduced: the geometry of the element, the mechanical characteristics and the physical behavior of each element (Table 1). This analysis provides the stresses and the strains the critical nodes according to the location of the geogrid.

3.2. Static analysis

For static analysis, it was considered that each layer has a linear behavior. The elastic pavement structure is characterized by its elastic modulus *E* and Poisson's ratio *v*. The choice of this behavior was the subject of several works including those of Uddin and Pan [17].

The plane wheel contact with pavement is usually considered as rectangular or circular for laboratory simulation and finite element modeling [3,16]. In this study, the reference plane tire pavement contact area is considered as circular for simplicity and ease of modeling (Figs. 8 and 9).

The position generally recommended in the literature depends on the value of the bearing capacity of the soil. It can be at the bottom of the layer gravel bituminous layer if the foundation soil has a low CBR value (between 1.5 and 7) [18], in the middle of the gravel bituminous layer if the CBR value is of medium value [19], or between the gravel bituminous layer and the bituminous concrete layer if the soil has a high CBR value (see Fig. 10).

The elements introduced in modeling for the sub layers and the geogrid, are given in Table 2.

It's the C3DBR element at eight knots, with a linear elastic behavior, for the surfacing course layer, the base layer, the subase layer and the soil support.

The geogrid layer was modeled by 4-nodes quadrilateral – membrane (M3D4R) element [20]. The total number of the nods and elements for the modeling is respectively of 8173 nods and 5825 elements.

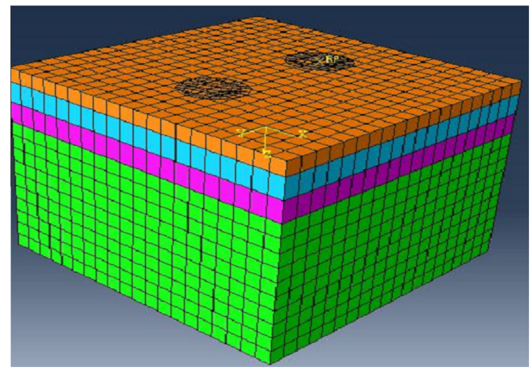


Fig. 8. The model used and discretization of the layers.

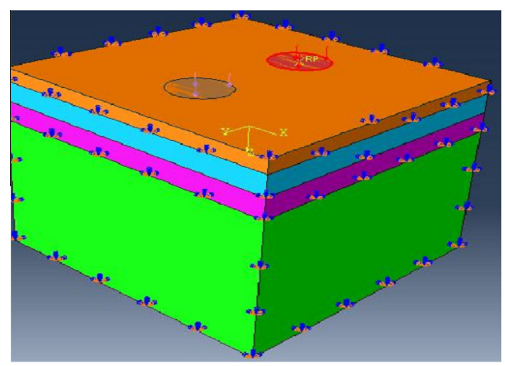


Fig. 9. The geometrical characteristics of the model.

The characteristics considered for the critical aircraft pneumatic loads are as follows [11,13]: Young modulus $E = 400$ kPa, Poisson coefficient = 0.33, speed ($v = 300$ km/h), vertical loads (Fz = 25 tons), nominal inflation pressure ($P = 15.5$ bars), angles of skid ($\beta = 16°$) for the simulation in classic rolling, constant rubbing coefficient ($\mu c = 0.48$) and distance between wheels axes ($L = 0.86$ m).

3.3. Results and discussion of numerical analysis

The results of the modeling are presented in Figs. 11–14. The obtained values indicate that the geogrid reduces vertical deformation by placing it at the depth of the roadway. Indeed, when placing the geogrid at 60 mm depth, the deformation is in the order of 40 µm, while the latter decreases to 26 µm, a reduction of 35%, when it is placed at 360 mm depth. As such, the optimal placement of geogrid is located at the base of the base layer. The same conclusion was reached by Al-Azzawi who studied the flexibility of flexible road pavements using Ansys-finite element modeling [21].

The values of deformations in the different layers, before and after strengthening by the geogrid in the optimal position, are illustrated in Figs. 13 and 14. The highest values of strains are presented for both cases before and after the application of the geogrid. In tension, the resulting maximum deflection is 311.6 µm which is reduced to 302.1 µm after reinforcement and hence a gain

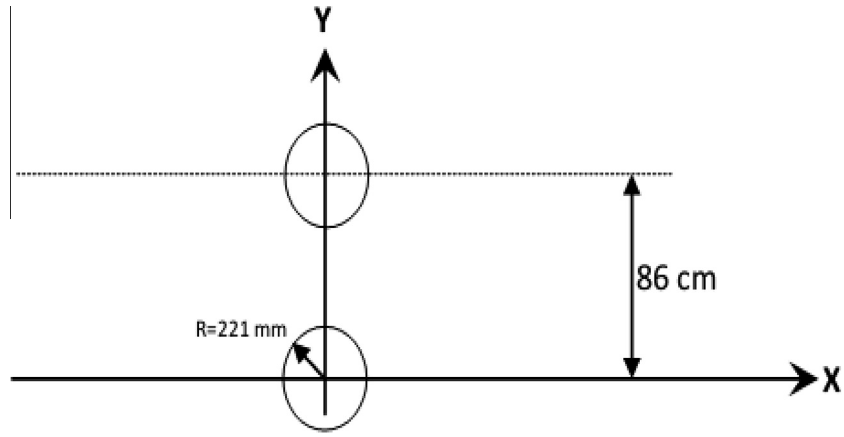


Fig. 10. Circular footprints of the critical aircraft.

Table 2
Types of elements for modeling.

Materials	Type of element	Reference	Number of nods	Number of elements
Surfacing course	8 nods, linear	C3D8R	882	400
Base layer	8 nods, linear	C3D8R	882	400
Foundation soil (subbase)	8 nods, linear	C3D8R	882	400
Soil support	8 nods, linear 3D	C3D8R	4851	4000
Geogrid	4 nods, quadrilateral membrane	M3D4R	676	625

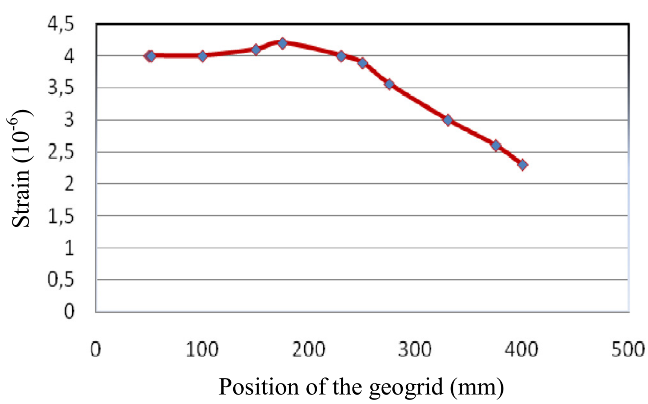


Fig. 11. The effect of the position of the geogrid on the deformation of the pavement.

of 3.10%. In compression, the gain is of 2.40% for the reinforced pavement where the deformation is reduced from 246.2 μm to 240.3 μm.

The cracks that are likely to develop on the surface of the pavement downward (tensile cracks) are reduced (or stopped). Therefore, the role of the geogrid is to delay the propagation of cracks and reduce the negative deformations at the base.

The maximum tensile stresses are localized at the level of the surface layer, which is respectively 95.38 kPa and 89.93 kPa, before and after strengthening. This shows a reduction in tensile stresses of 5.71% and hence the geogrid reinforcement reduces tensile stresses.

4. Experimental tests

4.1. In situ tests

To follow the evolution of the behavior of the pavement before and after strengthening, cores were drilled at the cracks location before and after strengthening (Fig. 15). The total number of cores is six, three before strengthening and three after strengthening.

The examination of all drilled cores showed that the layer of bitiminuous concrete is cracked and that the layer underneath (the base course) remained intact. The cracks observed on the entire thickness of the surfacing course layer stopped at the level of the geogrid without spreading to other adjacent layers, i.e. the base layer and the foundation soil. The geogrid layer played its role as a separator and stopped the descending crack propagation.

4.2. Non-destructive measurement of deflections

The heavy weight deflectometer (HWD) test was used for the determination of the bearing capacity of the airport runway. It consists of a droping weight which through a rigid plate and a damping system, gives at the surface of the pavement a pulse-type loading, intended to simulate the passage of an aircraft wheel. The generated deflections are measured during loading, using geophones placed under and in the vicinity of the plate [22].

The analysis of these deflections permits the determination of the structural properties of different layers through an identification digital procedure called "reverse calculation". It consists of choosing a mechanical model for describing the behavior of the pavement under loading on the one hand, and to identify the parameters of the model for better validation between numerical and experimental data, on the other hand.

The usual methods of the analysis of the data are based, for flexible pavements, on the use of elasto-static multi-layer models. The only structural parameters to identify are the rigidities of the various constituent layers. Longitudinally, the runway has been subdivided to equidistant lengths of 22.5 m. Deflections tests were conducted, on every length of 22.5 m, along the secondary runway, following a plan of distribution, where the six profiles are at 3. 5 m, 6 m and 15 m on both sides of the axis of the runway.

The bearing capacity of the pavement was evaluated before and after strengthening of the runway by comparison of the values of the deflections and stresses. The influence of the inclusion of the geogrid on the behavior of the runway is examined. Figs. 16–19 present the least favorable values. These figures show a relative uniformity of the deflections on the whole runway. The critical deflections values are of the order of 690 μm before strengthening and 585 μm after strengthening (the unfavorable case being at 6 m left of the centerline of the road), which is a reduction of 31.5%. The geogrid layer reduced deformations of the surfacing course layer.

The peak stress (at 3.5 m to the left of the axis) before reinforcement is of 2900 kPa and it is of 2550 kPa after strengthening, showing a reduction of 12%. For the peak at 6 m left of the centerline, it is 2850 kPa (before reinforcement) and 2280 kPa (after strengthening), showing a reduction of 20%. The reduction in the values of the tensile stresses could lead to a more economical surface layer of the runway section.

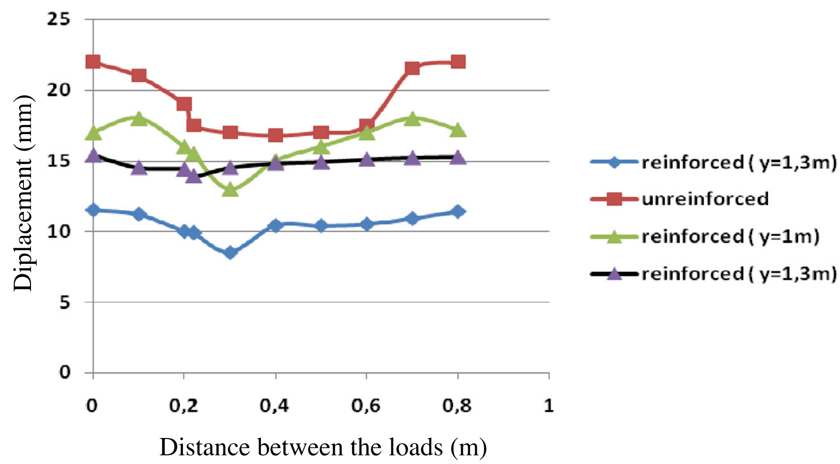
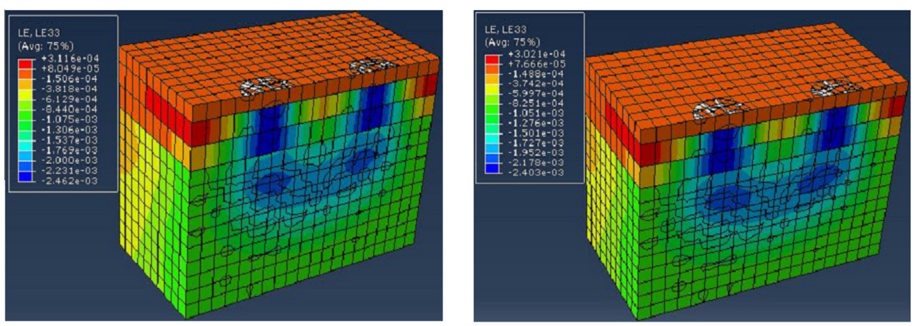
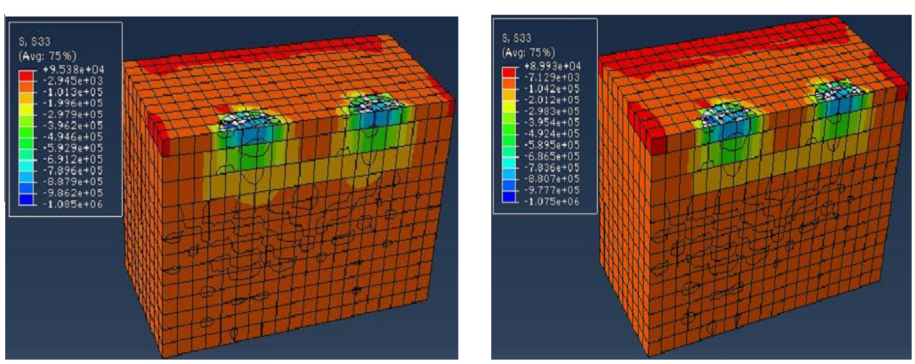


Fig. 12. Influence line of the pavement displacement.



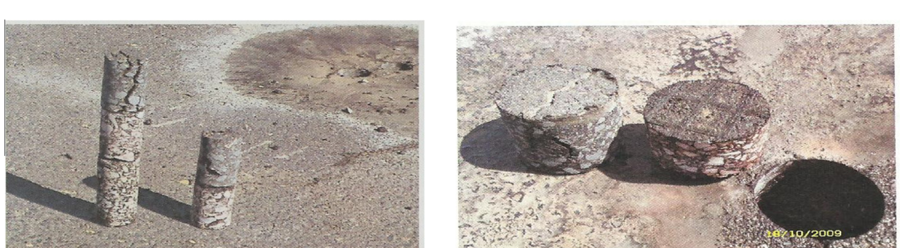
(a) (b)

Fig. 13. State of vertical deformations (z–z). (a) Before strengthening (b) after strengthening.



(a) (a)

Fig. 14. State of vertical stresses (z–z). (a) Before strengthening (b) after strengthening.



(a) (b)

Fig. 15. A core (a) before strengthening (b) after strengthening.

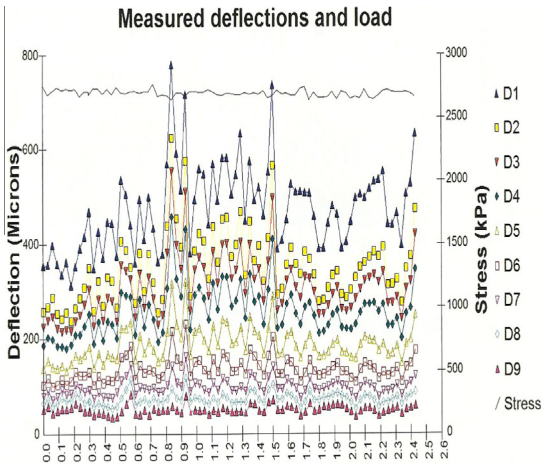


Fig. 16. Measured stress–strain before strengthening (3.5 m/left profile).

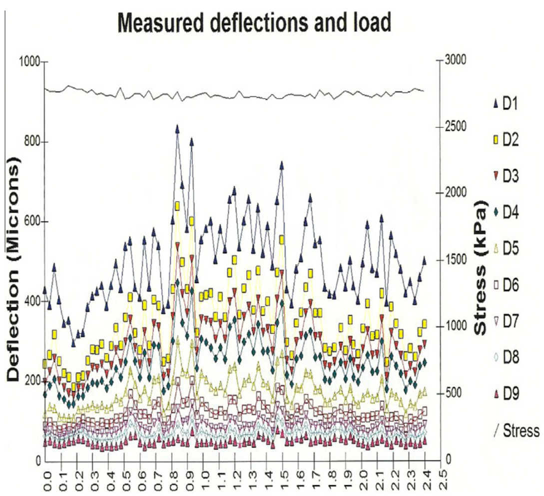


Fig. 17. Measured stress–strain after strengthening (3.5 m/left profiles).

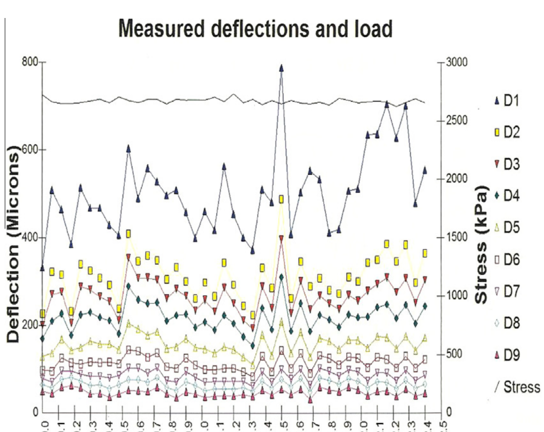


Fig. 18. Measured stress–strain before strengthening (profile 6 m/left).

4.3. Comparison between the model and the in-situ measurements

In order to validate the results obtained by numerical modeling, the results were compared those obtained by non-destructive testing (HDW).

A pseudo-elastic simulation of the falling mass of the HWD for planes type B737/600, B737/800 or A330, gives an equivalence of dynamic load (repeated twice in succession) equal to 700 kg for a fall from a height of 400 mm [23]. Table 3 shows

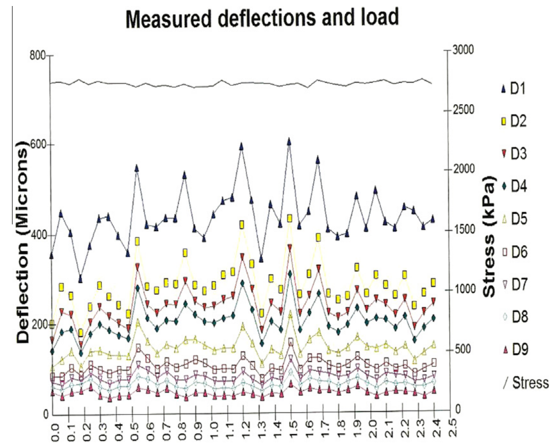


Fig. 19. Measured stress–strain after strengthening (profile 6 m/left).

Table 3
Comparison of deformation before and after strengthening.

		Tests	Finite element	Gap (%)
Before strengthening	Stress (kPa)	2875	2460	14.4
	Strain (μm)	690	623.2	9.7
After strengthening	Stress (kPa)	2415	2403	0.49
	Strain (μm)	585	604	−3.2

the differences observed between the measured and calculated average values of stresses and deformations.

These differences vary between 0.5% and 14% in absolute values, and hence the model needs improvement. The relatively large differences may be due to the choice of the calculation models and/or the mechanical characteristics of the layers as well as the simulation of the weight of the falling mass, with regard to the reference plane.

5. Conclusion

An experimental study was made by measuring deflections by HWD on flexible asphalt runway, before and after strengthening by geogrid, to monitor its short-term behavior by measurement of deflections and tensile stresses. In order to calibrate the experimental results, finite element 3D modeling of the runway pavement was conducted. The conclusions to be drawn from this investigation are as follows:

- It is possible to evaluate the static behavior of an airport runway by the application of non-destructive testing of HWD. The stresses and strains before and after strengthening are identified by this in situ test.
- The geogrid can be placed at different locations of the pavement section. The adopted optimal position contributes to the improvement of the stresses and strains and therefore reduced the propagation of the descending crack. Nevertheless, the geogrid alone cannot stop the occurrence of cracks in the bearing surface layer. Other solutions and remedies, such as the use of high modulus bitumen with additives for the bearing layer could be considered.
- The finite element modeling gave comparable values to those of the experimental tests with dispersions not exceeding 14%. The difference may be due to the error in the model and in the real characteristics of the materials and loads.
- In order to get more reliable results, it is recommended to use cyclic loads in the model to compare them with the results of the HWD tests.

Acknowledgments

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