Finite Element Modeling of Airfield Aluminum Matting System

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Abstract

Airfield aluminum matting systems are prefabricated panels that are compact and easily transportable. They have been mainly used for expedient construction of temporary airfields, rapid airfield repair or to provide maneuvering support for military aircraft, and it has rarely been used in civil aviation, due to lack of design and construction specifications. Because of the limited use, matting systems had very few studies to explain its behavior under different circumstances, and previous evaluations have commonly been restricted by full-scale testing, with only a few numerical models found in the academic environment. However, knowing the practicality of the material, matting systems are being considered to be used under the long term and extreme weather conditions, such as in remote northern communities in Canada. For this purpose, a finite element model of aluminum panels laid on a soft soil has been built in the ABAQUS FEA Software adopting a solid element to represent the soil, shell elements for the panels, and hinge-type connections along the panels. The model was used to predict stress and displacement along the panel set under static loads. After validated with full scale results, different soil stiffness was tested in order to assess the panel's behavior under certain conditions.

Introduction

Aircraft landing mats, also known as airfield matting systems are prefabricated modular panels that can be used to create runways and temporary airfields in areas where there is no time or requirement to install a permanent airfield. For this reason, the panels are usually very compact and easily transportable. When used over a gravel runway for example, the landing mats can prevent foreign object damage, and enhance the subgrade support, while the use of the system over soft soils can help to stabilize the landing area.

The aircraft landing mats, however, have been mainly used for expedient construction of temporary airfields. For this reason, there are very few studies to explain its behavior under different circumstances, and previous evaluations have commonly been restricted by full-scale testing, with only a few numerical models found in the academic environment.

One of the early publications on this matter presents the fabrication of the panels with fiberglass-reinforced plastic composite characteristics (Springston & Claxton, 1986), however, matting systems can have a variety of designs, fabrication processes and materials. Modern matting systems can include the use of fiberglass, light aluminum alloys, polymers, and composites, with varying assemblies' characteristics, such as rolls, folded mats, and individual panels. The U.S. military largely uses the aluminum matting system for expedient airfield construction (Garcia & Howard, 2016).

Considering the practicality of the landing mats, such systems are being considered to be used under long term and extreme weather conditions, such as the conditions presented in the northern territories in Canada, however, further studies are needed before this material can be used for civilian purposes. The performance of the panels over different soils and load applications must be further investigated, and specifications have to be developed. For this reason, this research developed a numerical model to evaluate the behavior of an aluminum matting system under the load of a F-15E aircraft, over a soft soil. To this end, a three-dimensional model was built in ABAQUS, adopting solid element to represent the soil and shell elements for the panels to predict stresses and strains along the panel set. After validated with full scale results, different soil stiffness was tested to assess the panel's behavior under certain conditions.

Finite element model inputs

The main inputs to the numerical model were:

- Aluminum matting system properties
- Soil properties
- Load cart and traffic application
- Boundary Conditions
- Interaction between the matting system and the soil
- Connection between panels

Those items are going to be addressed with detail along the next sections.

Material properties

The Aluminum Truss matting system studied is the S45 panel set, fabricated by FAUN Trackway. They consist of two aluminum extrusions with isosceles triangle cross sections that are friction stir welded together. The panels are connected on the short end by a double-arrow-shaped locking key inserted into connector slots in the welded end connectors. The connections along the long dimension are hinge-type male/female system (Garcia, 2016). A photograph of the panel S45 being installed can be seen in Figure 1.

Figure 1: Installation of aluminum truss matting system S45 (Garcia, 2016).

The prefabricated panels are 264 cm long by 52 cm wide, and 3.4 cm high. The weight of the laid unpainted surface is approximately 28.8 kg/m^2. The material properties of the panels are defined in Table 1. This information was inputted in the software ABAQUS considering the material's behavior as linear elastic.

Table 1: Aluminum Matting System Material Properties. Source: Granted by FAUN Trackway.

Linear Elastic Properties	
Young`s Modulus (MPa)	70000
Poisson`s Ratio	0.3
Density (g/cm^3)	2.7
Yield Stress (MPa)	307

The soil properties were verified during the full-scale test and incorporated into the finite element model. The matting system test section was constructed on the top of a high-plasticity clay, classified as a CH according to the Unified Soil Classification System with a CBR of 6 ± 1% [1]. The Young's Modulus (E) of the soil was considered to be 41.4 MPa, while the Poisson's Ratiov was assumed to be 0.3. The definition of the material properties in ABAQUS can be seen in Figure 2.

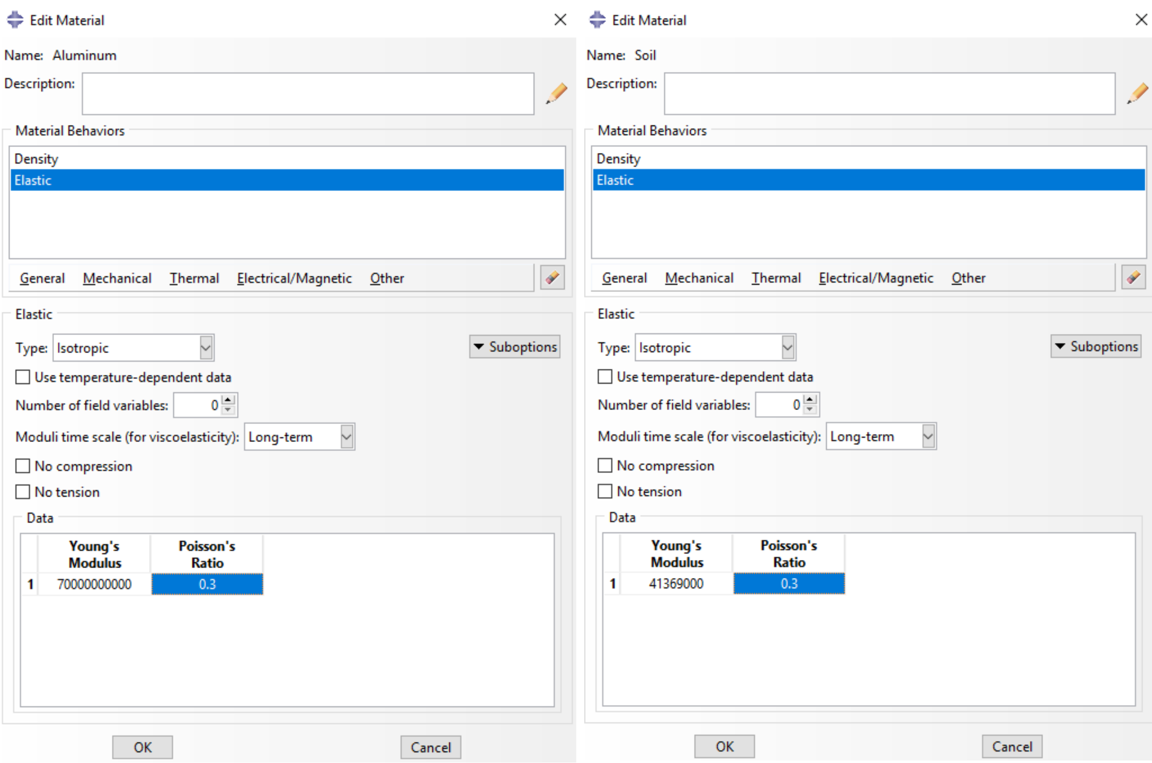

Figure 2: Definition of the material properties in ABAQUS.

Loading characteristics

A load cart designed to simulate a fully loaded F-15E aircraft was used for trafficking the experimental mat surfaced section. The load cart was equipped with a single tire inflated to an internal pressure of 2.24 MPa. An F-15E aircraft loaded to its maximum capacity weighs 359,948.05 N, with the main gear carrying 87 percent of that load (i.e., 313,154.8 N). Therefore, the load cart was designed such that the test wheel was supporting half of the main gear load (i.e., 156,577.4 N) (Garcia, 2016).

The contact width between the wheel and the aluminum panel was measured as 22.86 cm, in the full-scale facility. The PCA (1984) method, based on the finite element procedure, assumes that the contact area between the wheel and the surface can be represented by a rectangle (PCA, 1984). Similarly, in this research, the load was considered to be applied in a rectangular area of 22.86 cm by 30.56 cm.

Although the full-scale experiment tested the panels applying dynamic loads, with traffic moving forward and backward over the shorter length of the test mat, to simplify the analysis, the load was considered as static in the finite element model. Figure 3 shows the definition of the load pressure in ABAQUS.

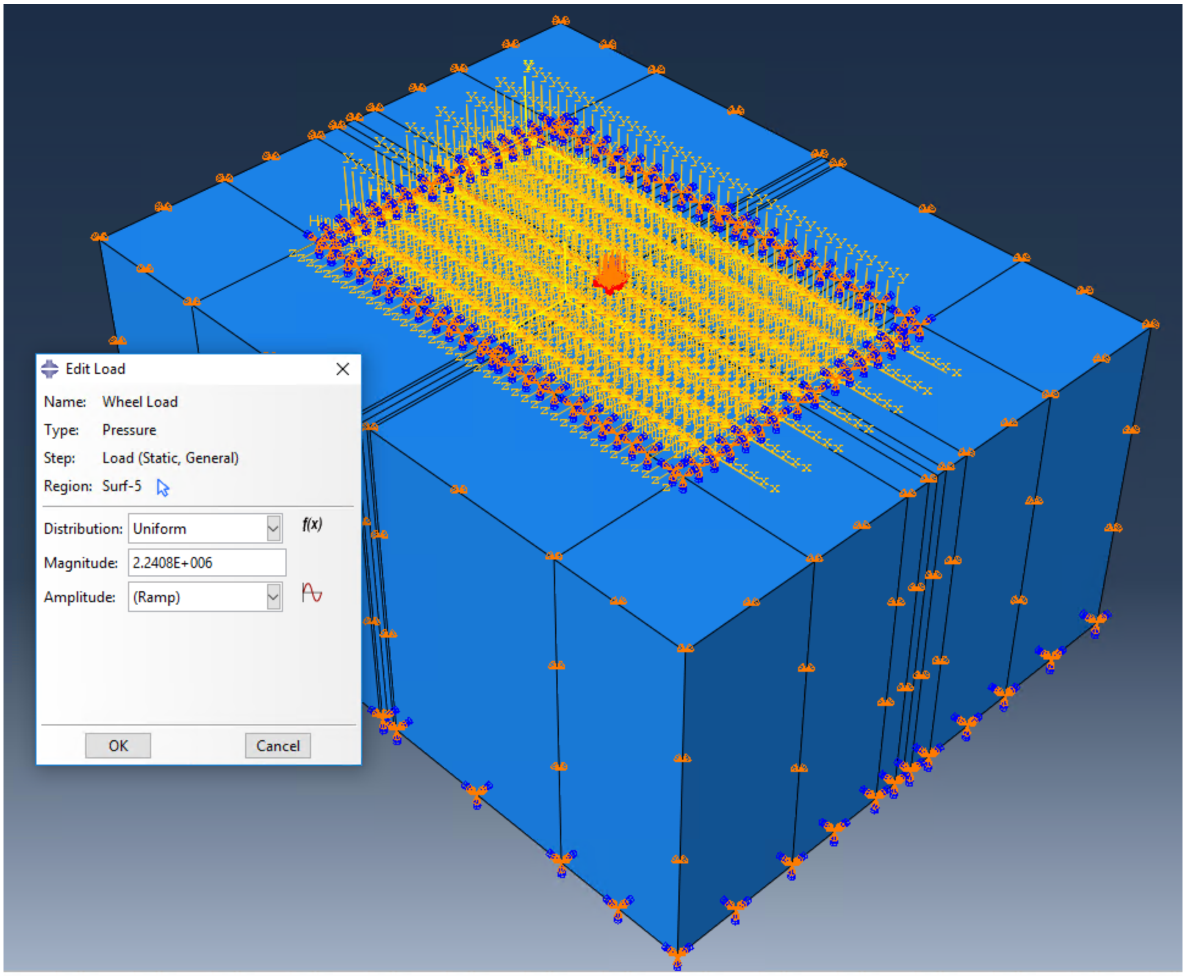

Figure 3: Definition of load pressure in ABAQUS.

Boundary Conditions

A boundary condition was defined at the lateral walls of the simulated soil element which prevents it from moving in the horizontal direction but letting it free to move in the vertical direction. The bottom of the foundation was constrained from moving in any direction. This condition was imposed to represent the confinement of the soil. The matting set is tied by an anchorage system in the borders, securing the periphery of the aluminum panels. To capture this, the edges of the simulated matting system were also constrained.

Matting system and soil interaction

It is common in the modeling of flexible pavements to consider the layers interfaces as being completely bonded, while in rigid pavements, it is usual to consider the development of a friction between the slab and the soil. In the case of the matting system, the resistance to horizontal movement will vary considerably with the type of material on which the panels rest, and the presence of texture in the panels down face.

FAUN Trackway states that the ideal replicate of the operational reality allows the panels surfaces to slide under low friction at the interfaces. This is as would occur when a panel is sandwiched between an aircraft tire and the relatively loose surface of the substrate. Since no specific studies were developed to assess the friction coefficient developed during the full-scale tests, a sensibility analysis was performed evaluating a range of coefficients varying from 0 to 1.5. This is defined in ABAQUS in the tangential behavior settings, under the contact property characterization, as can be seen Figure 4.

Regarding the normal behavior settings, the pressure overclosure was defined as a hard contact, meaning that one element cannot pass though the other. When defining the contact interaction, the sliding formulation was set to allow only small sliding, and the discretization method was from node to surface.

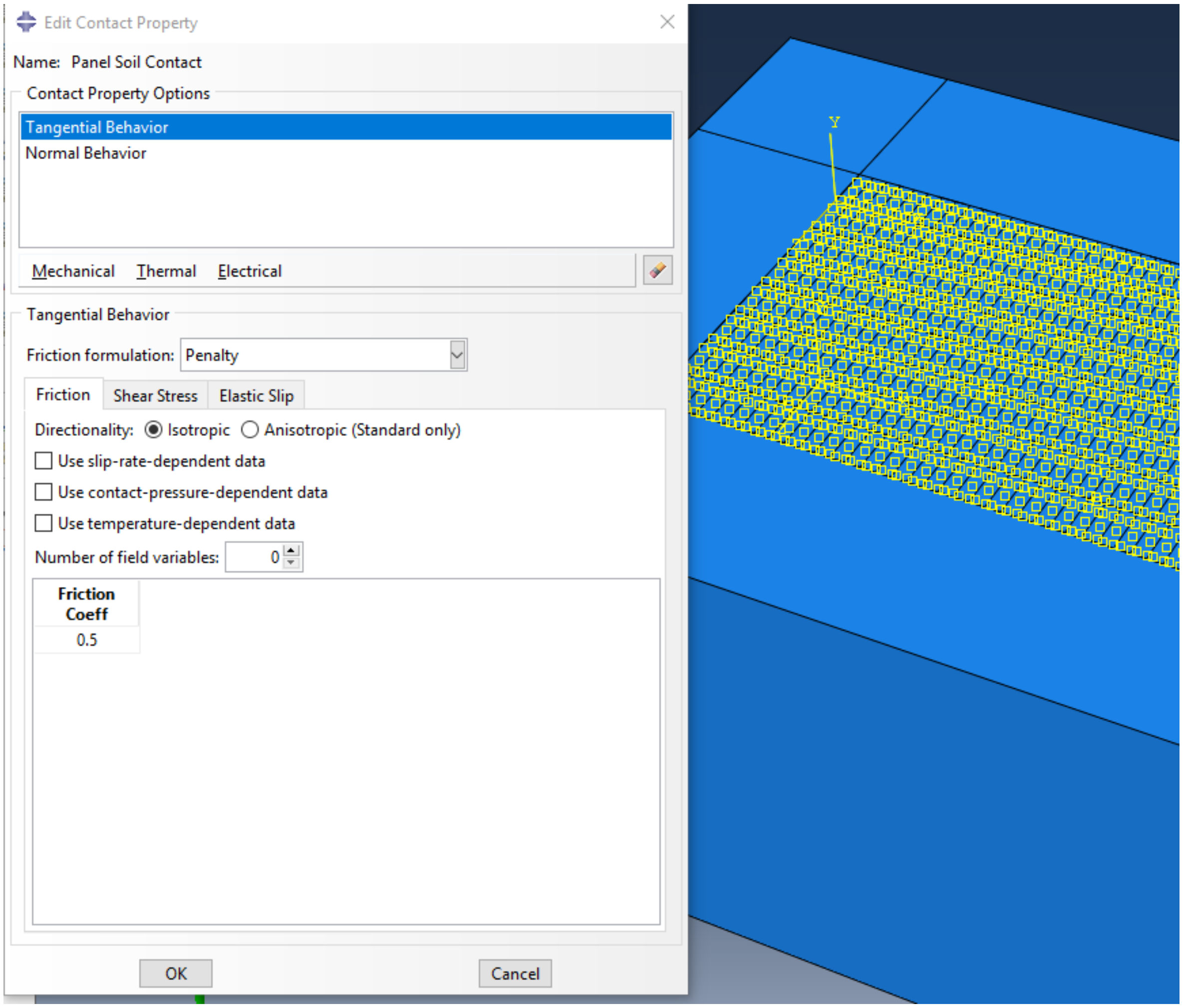

Figure 4: Contact property between panels and soil in ABAQUS.

Connection between panels

The panels were modeled as shell elements. Shell elements are used to model structures in which one dimension, the thickness, is significantly smaller than the other dimensions. This case applies well for the panels, knowing that their thickness is only 3.4 cm, compared to 264 cm long and 52 cm wide. In a shell case, the thickness is defined through the section property definition.

In a panel set, when the matting system is put together, the connection along the long dimension is a hinge-type male/female system. A locking key is inserted between panels in the short dimension, making sure they cannot separate, or rotate in this direction. A drawing of the panel set scheme can be seen in Figure 5.

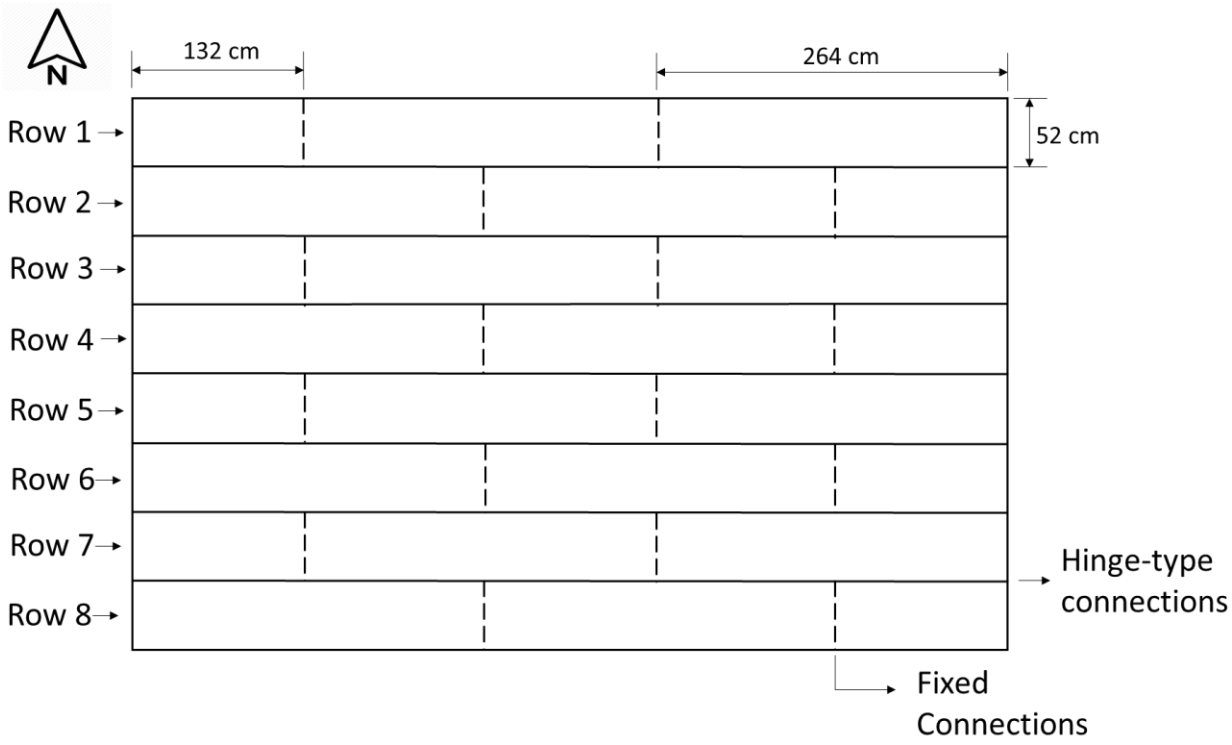

Figure 5: Panel scheme.

Since the short edges of the panels are rigidly connected, each row of panels was modeled as they were one very long panel, resulting in a total of 8 rows. The hinge system between panels, on the other hand, was simulated using an ABAQUS connector that can capture this behavior. A screen shot of the assembly scheme in Abaqus can be seen in Figure 6.

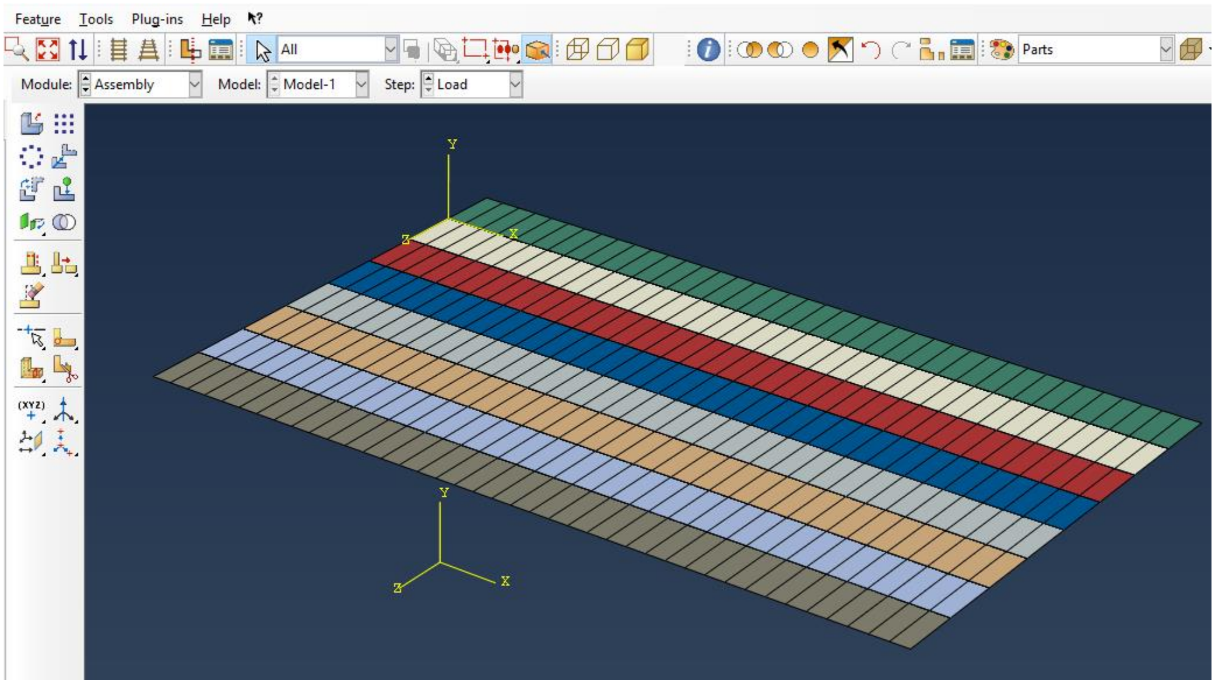

Figure 6: Panels assembly in ABAQUS.

To define the hinges, first it was necessary to create a wire feature, define a connector section and apply it at the wires previously created. The definition of the connector section can be seen in Figure 7.

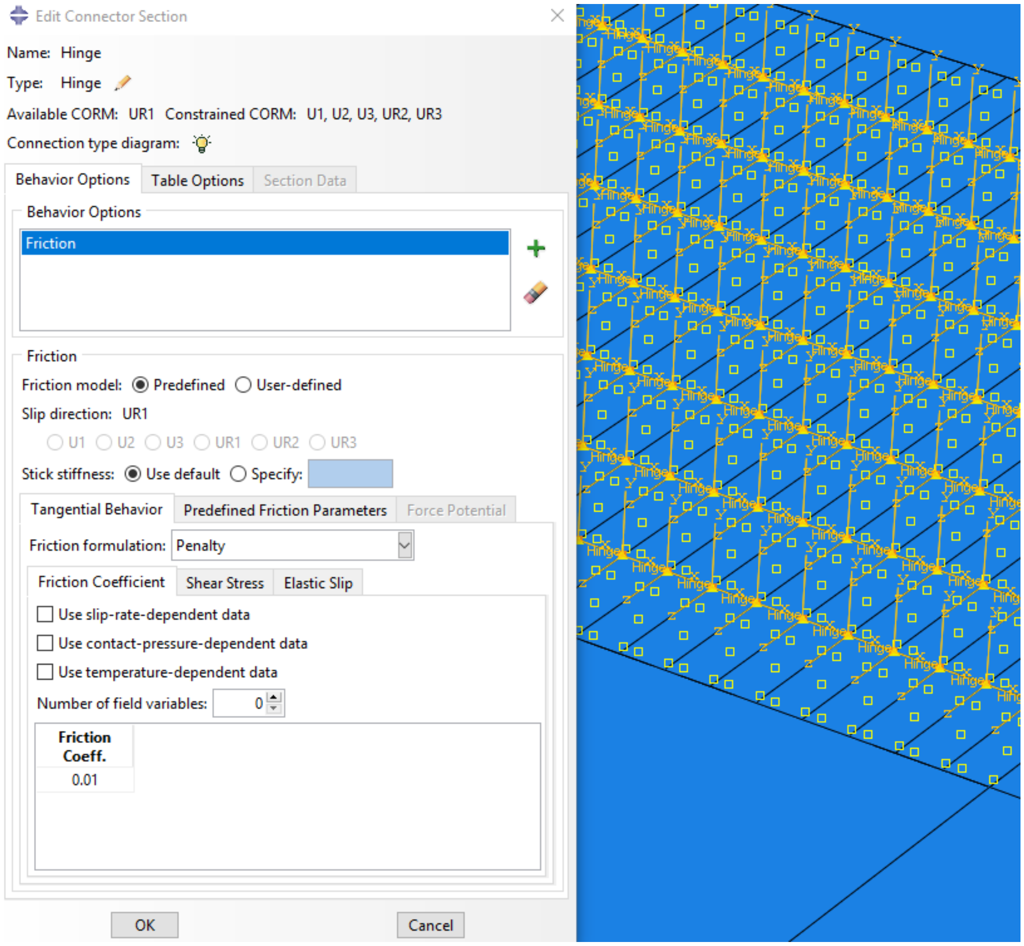

Figure 7: Definition of the hinge connectors in ABAQUS.

Meshing

The meshing was constructed using hexahedral elements in quadratic order. Since very small meshes can consume lots of computational time, a fine mesh was used in all the matting system area, and an even finer mesh in the load area, however a bigger mesh size was used in more distant areas, as can be seen in Figure 8.

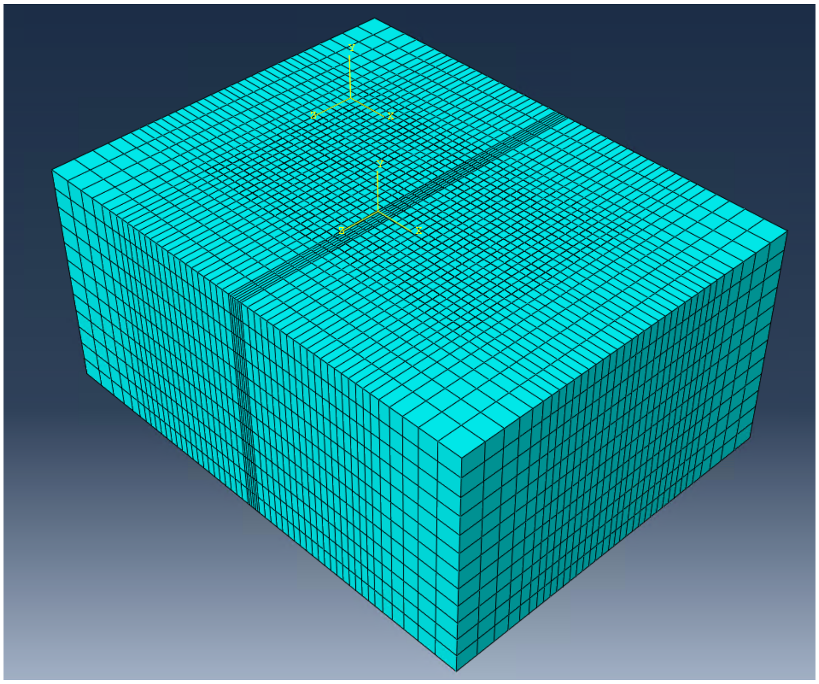

Figure 8: Model Mesh.

Results

Full scale measurements

A full-scale test was performed by FAUN Trackway to measure the deformations of the panels under the F-15E aircraft. The load was applied by a loading cart that moved forward and backward in the north direction (as indicated in Figure 5) over the length of the test mat and then shifting the path of the load cart laterally approximately one tire width on each forward path. This procedure was continued until one pattern of traffic was completed. The patterns of traffic were 16, 48, 112, 240, 496, 752 and 1,008 repetitions. Figure 9 shows the deformation of the panels under the repetitive dynamic loading of the full-scale test.

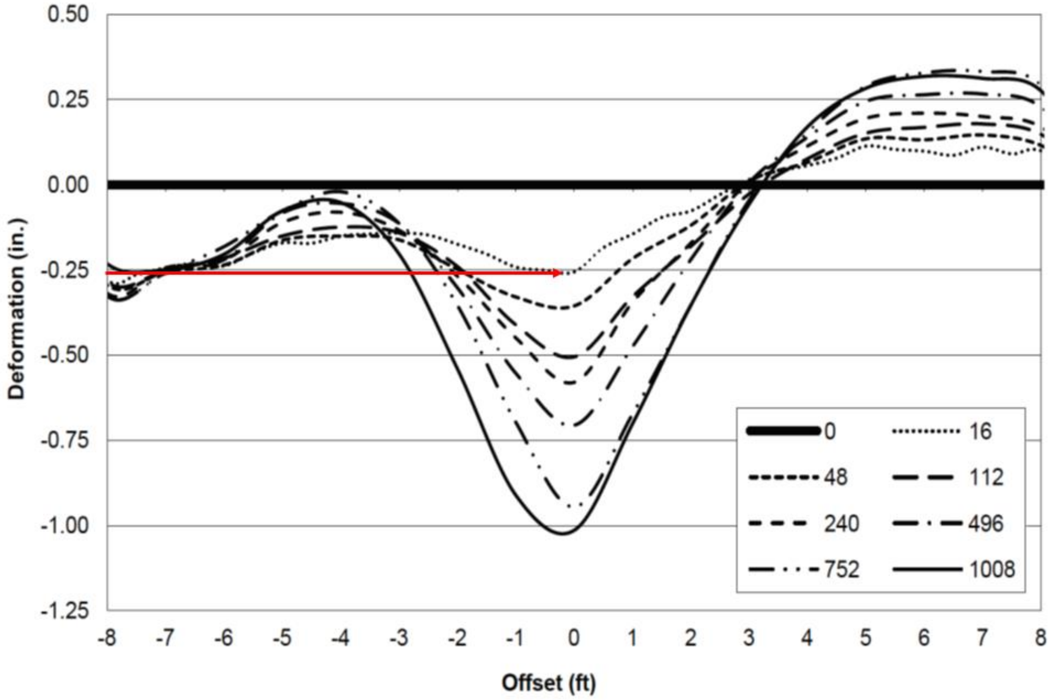

Figure 9: Full-scale panel average deformation along the loaded mat surface. Granted by FAUN Trackway.

In Figure 9, the deformations of the mat surface were measured under loaded conditions, therefore, this implies that the deformation presented is a sum of both elastic and permanent deflections. Since the loads were applied repetitively, there was a residual deformation accumulating, due to the elasto-plastic properties of the aluminum panels. Therefore, the more the load repetitions increase, the more the deformations will differ from the numerical analysis, due to the accumulation of the residual deflection. However, in the first 16 repetitions the permanent deformations were still small, therefore, the displayed result relates mostly to the elastic deflection of the matting system. The measured deflection of the aluminum matting system under the 16 repetitions scenario was close to 0.25 in (pointed by the red line in Figure 9), that is, 6.35 mm. Figure 10 presents the maximum deformations according to the number of load repetitions.

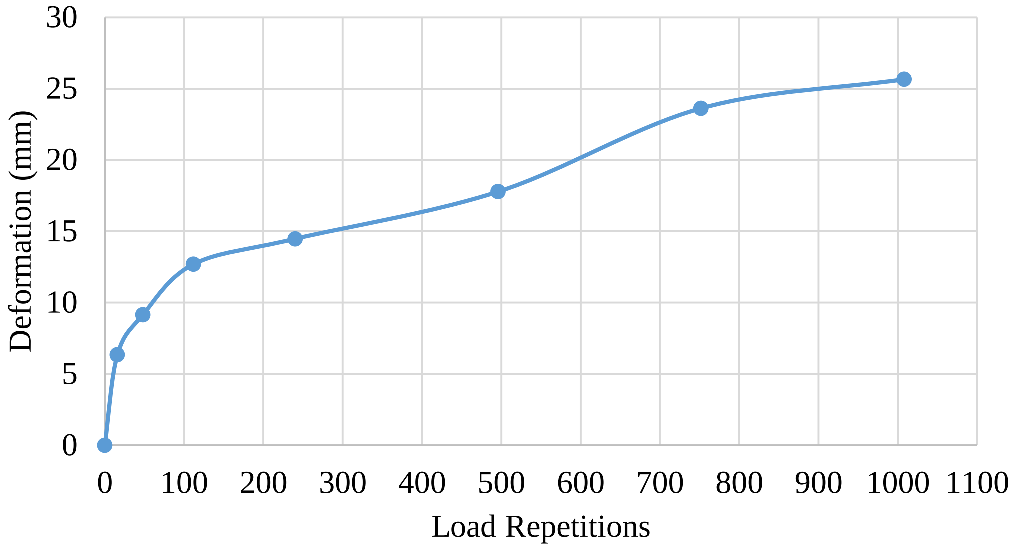

Figure 10: Full-scale maximum deflections under growing load repetitions. Modified from Figure 9.

It is possible to notice from Figure 10 that the increase in deformation is steep from 16 to 112 load repetitions, however, the rate lowers from 112 repetitions forward. Since the runway matting systems were originally meant for expedite runways, the concern with plastic deformation was small, considering that the system was meant to least only for a limited number of repetitions. However, for the future commercial use of the panels, much more studies need to be developed to investigate the growing plastic deformation, and how would this matting survive impact loading from other airplanes. Further research should also include simulations considering the subgrade stress dependency, as well as the elasto-plastic properties of the panels.

Sensitivity analysis of the friction coefficient

As previously explained, the ideal replicate of the operational reality allows the panels surfaces to slide under low friction at the interfaces, however, no specific studies were developed to assess the friction coefficient developed during the full-scale tests, and for this reason, a sensibility analysis was performed in ABAQUS evaluating the coefficients 0, 0.5, 1.0 and 1.5. The results of the maximum stresses and displacements developed under the four coefficients are presented in Table 2.

Table 2: Sensibility analysis of the friction coefficient.

Friction Coefficient	Max Stress (MPa)	Max Displacement (mm)
0.0	42.54	6.22
0.5	42.17	6.14
1.0	42.00	6.11
1.5	41.89	6.09

The maximum displacement presented under the zero friction coefficient is the closest to what was measured in the field, with a difference of only 2%, however, it is possible to note that the variation in friction does not introduce a drastic impact in the analysis. The deformed shape of the aluminum matting system is presented in Figure 12 and the stress patterns are presented in Figure 11, both figures being in a deflection scale factor of 123.5.

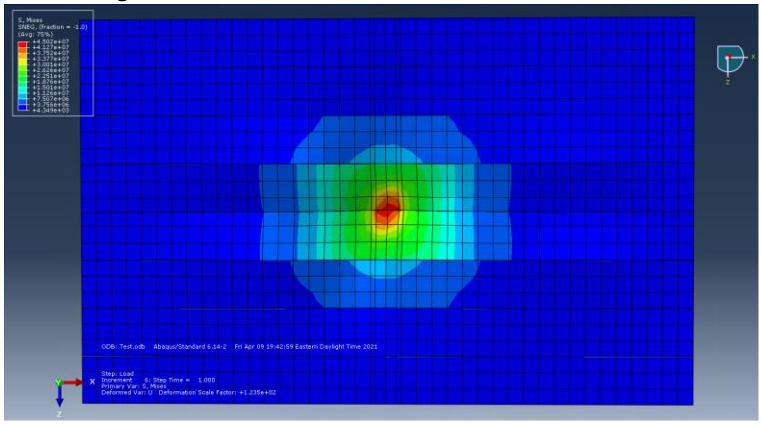

Figure 11: Visualization of stresses at the aluminum matting system, view from the top of the panels.

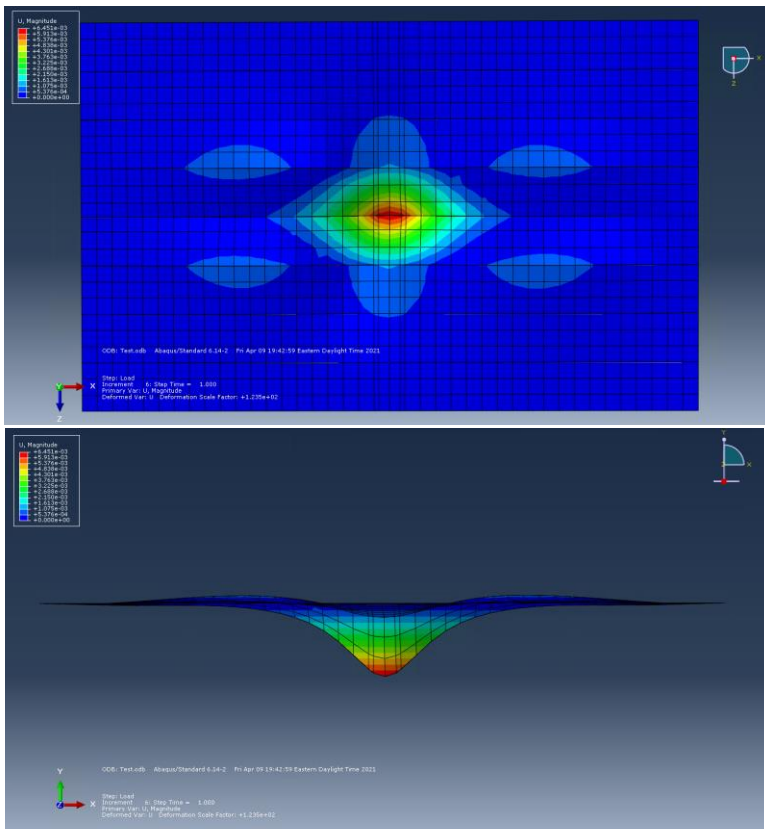

Figure 12: Deformed shape of the aluminum matting system, top figure presents a view from the top of panels, and bottom figure presents a lateral view of the panels.

It is possible to affirm that the numerical analysis has reasonable results when compared to the full-scale test, since the field measured deflection of the aluminum mat was close to 6.35 mm, while the simulations presented deformations ranging from 6.09 to 6.22 mm, from the highest to the lowest friction coefficients, respectively.

Variation of soil stiffness

According to FAUN Trackway, the S45 panels should be laid on soils with a minimum CBR of 6%. Considering the correlation between the CBR and the resilient modulus of subgrade soils proposed by (Van Til & Cecil , 1972), a CBR of 6% is roughly equivalent to a resilient modulus of 6000 psi, that is, around 41.4 MPa.

Therefore, to access the impact that soil stiffness could have on the elastic deflections of the aluminum matting system, 4 other soil scenarios were evaluated in which the friction coefficient was held constant at 0.5, while the soil stiffness varied from a minimum of 27.6 MPa to 55.2 MPa. The results showed an increase in 35% in displacement and 11% in stress over the weakest soil, and a decrease of 19% in displacement and 7% decrease in stress over the strongest soil evaluated, as can be seen in Figure 13.

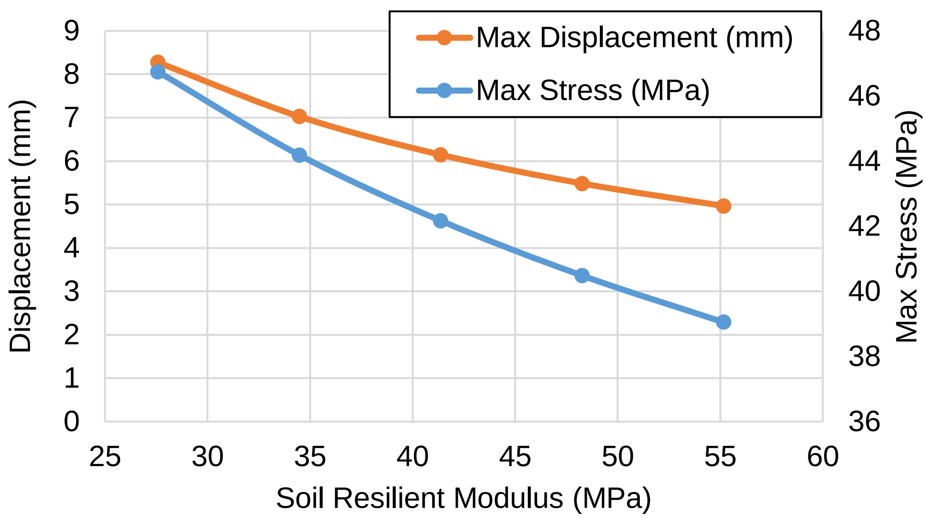

Figure 13: Variations in maximum displacement and stress under different soil stiffness.

In the scenarios in which the panels were laid in soils with the resilient modulus lower than 41.4 MPa, the recoverable displacements seem to be acceptable, with values ranging from 7 to 8.3 mm, however, more studies to access the plastic deformations under these scenarios are extremely necessary for long term use of the panels.

Conclusion

This paper evaluated the mechanistic responses of an airfield aluminum matting system, utilizing the finite element modeling approach. Very few studies were found in the literature regarding this type of material; therefore, the importance of this research lies not only on the results, but it illustrates opportunities on how this type of material can be effectively modeled in a finite element software. Regarding the modeling mechanism, it can be said that the use of shell elements for the panels enabled for a good representation of the hinges through creating a wire feature with the correct connector inputs, while modeling the soil as a large solid element enabled the representation of the subgrade as a homogeneous half-space. The results obtained from modeling the aluminum panels utilizing the combination of shell and solid elements seems reasonable when compared with full-scale measurements, however, more studies to access the plastic deformations of the soil and panels are extremely necessary for long term use of the matting system.

References

Garcia, L. (2016). *Full-scale instrumented evaluations of multiple airfield matting systems on soft soil to characterize permanent deformation.* Vicksburg United States: Geotechnical and Structures Laboratory, US Army Engineer Research and Development Center.

Garcia, L., & Howard, I. L. (2016). Full-scale instrumented testing of multiple airfield matting systems on soft soil to characterize permanent deformation. *Transportation Geotechnics*, 80-95.

PCA. (1984). *Thickness Design for Concrete Highway and Street Pavements.* Portland Cement Association.

Springston, P. S., & Claxton, R. L. (1986). *Prefabricated panels for rapid runway repair and expedient airfield surfacing.* U.S. Patent No. 4,629,358.

Van Til, & Cecil , J. (1972). Evaluation of AASHO interim guides for design of pavement structures. *Highway Research Board*.