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Modelling the wheel - soil interaction of airplane landing gear using in-situ loading tests - an approach

Modélisation de l'interaction roue - sol du train d'atterrissage d'avion à l'aide d'essais de chargement in situ - une approche

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ABSTRACT: The sinkage of aircraft wheels in the field can be assessed with the help of cohesive and frictional moduli, and the soil parameter. We can evaluate the soil performance considering the wheel rigid from the point of view of terramechanics model.
The cohesive and frictional moduli, and the soil parameter are determined from in-situ loading tests, using a series of diameters ratio of D-6*D-12*D. The wide range of loadig diameters allows us to take a high resolution for the thinny layers of the upper soils. The test results, conveniently plotted on a graphic as logaritmic function, give us the input data for the model we run. The airplane sinkage is modelated and a series of maps are generated over the airfield areas.
Our approach, furthermore is useful to predict the lenght needded to stop and various conditions of landing for the designing purpose.

RÉSUMÉ: On peut évaluer l'enfoncement des roues d'avion sur le terrain à l'aide de modules cohésifs et frictionnels, ainsi que du paramètre de sol. Nous pouvons évaluer la performance du sol en considérant la roue rigide du point de vue du modèle de terramécanique.
Les modules cohésifs et frictionnels ainsi que les paramètres du sol sont déterminés à partir d'essais de chargement in situ, en utilisant une série de diamètres de D-6 * D-12 * D. La large gamme de diamètres de chargement nous permet de prendre une résolution élevée pour les couches minces des sols supérieurs. Les résultats des tests, convenablement représentés sur un graphique en tant que fonction logarithmique, nous donnent les données d'entrée pour le modèle que nous exécutons. Le déversement de l'avion est modélisé et une série de cartes est générée sur les zones de l'aérodrome.
Notre approche, en outre, est utile pour prédire la longueur nécessaire à l'arrêt et les différentes conditions d'atterrissage aux fins de la conception.

Keywords: in-situ loading tests; modelling; sinkage; airfield

1 INTRODUCTION

The wheel - soil interaction, as sinkage and rolling resistance prediction, dates back to 50 – 60 s from the Bekker works. Nowdays, that became a distinct discipline of applied mechanics, named "terramechanics". For airplanes landing gears, the wheel - soil interaction started sistematically to study by Kraft (1968). In his initial paper, he presents conditions for the flotation criteria based on empirical results. He concludes that the sinkage has a significant variable in defining floatation.

The proposed calculation methods and formulae, on the elapsed time, have different accuracy due to the considered geotechnical, forces and wheel geometry data.

In the present paper, we propose a model of the wheel-soil interaction of airplane landing gear by assesing for the cohesive and frictional moduli, and the soil parameter the values based on the in-situ loading tests. The approach allows us to modelate large scale surfaces of airfield and to predict the weak areas from soil bearing capacity point of view.

2 THEORETICAL CONSIDERATIONS

Wheel acting to the ground generates a resistance force, R, due to the soil compaction and bulldozing of the soil (Wong 2010).

The high inflation pressure of the aiplane tires relative to the ground pressure results in little deflection and we can consider the tire as a rigid wheel (Bekker 1956).

For a rigid wheel, the mechanical behavior of soil (Stikei 2015), as shown in Figure 1 varies within the relationhip:

$$W = \int_0^A p_g \, dA \tag{1}$$

Where W (kN) is vertical load applied to the wheel, p_g (kN/m^2) is the pressure on the ground, and A (m^2) is contact area between wheel and ground.

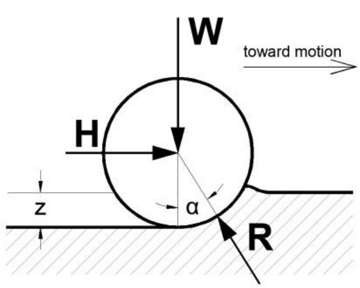

Figure 1. Forces acting upon a rigid wheel on deformable groung

The pressure sinkage relationship was proposed as:

$$p_g = \left(\frac{K_c}{b} + K_ø\right) z^n \tag{2}$$

Replacing p_g from equation (1) with the form given in equation (2) and integration along the area A, we obtain the sinkage equation:

$$z = \left(\frac{3W}{(3-n)(K_c + bK_ø)D^{0.5}}\right)^{\frac{2}{2n+1}} \tag{3}$$

Where b (m) and D (m) are the width and the diameter of the wheel, Kc, Kø and n are the sinkage parameters, and z (m) is the sinkage.

On the first step, the logarithmic form of the equation (2) is:

$$\log p_g = \log\left(\frac{K_c}{b} + K_ø\right) + \log z^n \tag{4}$$

$$\text{If } K = \left(\frac{K_c}{b} + K_ø\right), \tag{5}$$

then we have

$$\log p_g = \log(K) + n \log z \tag{6}$$

The graph of the equation (6) is a liniar function of $\log p_g$ versus $\log z$, with a slope of n and intercepts the vertical coordinate axis at $\log(K)$ (Hanamoto and Jebe 1963).

On the second step, similarly the graph of the equation (5) is a liniar function of K versus $\frac{1}{b}$, with a slope of K_c and intercepts the vertical coordinate axis at $K_ø$.

3 INPUT DATA OF THE MODEL – MATERIALS, ACTIONS, RESISTANCES

3.1 Ground profile and geotechnical characteristics

In the modelled airfield area, the groung profile has a lithology of three main soil categories (Figure 2). The natural soil in the area consists of silty clay (horizont A). On top of this cohesive lower soil, the soil is granular sandy gravel (horizont B), compacted and layed for drainage purpose. The upper soil (horizont C) is cohesive soil, silty clay, compacted and covered by grass.

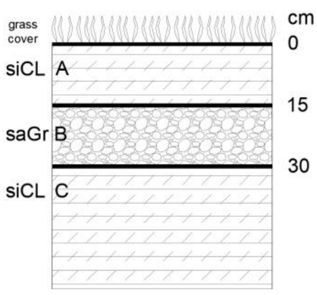

Figure 2. Ground profile for the modelled sinkage

The geotechnical characteristics are presented in Table 1. The values are average of measured laboratory data.

Table 1. Geotechnical characteristics and derived parameters of the soils

Soil type	Clayey	Granular
unit weight, γ (kN/m^3)	17.6	22.9
cohesion, c (kPa)	42.8	1.2
friction angle, Ø (degree)	16.2	32.1
Terzaghi's bearing capacity factors		
Nc	13.61	44.0
Nq	4.9	28.5
Nγ	1.8	26.8

3.2 The reference aircraft

In the running our model, we evaluated the wheel - soil interaction for the commercial passenger aircraft of AIRBUS A-320. To calculate the loadings, as forces and pressures on the ground, we considered the characteristics of the aircraft: the weight, the shape and the sizes of the wheels for the nose landing gear, also the main landing gear, and tires inflation pressure.

3.3 In-situ loading tests

In order to determine the sinkage parameters, we caried out a large set of in-situ loading tests. The tests were performed on the ground surface using CBR aparatus and Lucas plate of 300 mm and 600 mm (Youssel and Ali 1982).

We chose a range of loading diametes in the series of 6 (D-6*D-12*D), in order to intercept the resistences of the all three main horizonts of the soil profile. The CBR aparatus results are for the upper layer, horizont A.The large loading diameters allow us to have the loading behavior of the layered soil profile in depth (Fan 1985).

The CBR values also are determined, as shown in the Table 2. The Civil Aviation Regulations have specific requrements for the soil bearing capacity of the runway stip and runway end safety area (ICAO 2016). For example, in the upper 15 cm of soil profile the CBR is considered to range between 15-20%. This requrement is to ensure the safety of the aircraft and the passengers in the case of emergency landing.

4 RESULTS

Solving the equations (6) and (5), with the data we obtained from in-situ loading tests, gives us a series of graphics, as the one presented in Figure 3. With the form of equation (3) we obtain the sinkage values for the tested locations. The results are shown in Table 2. The CBR values presented are for comparison to sinkage.

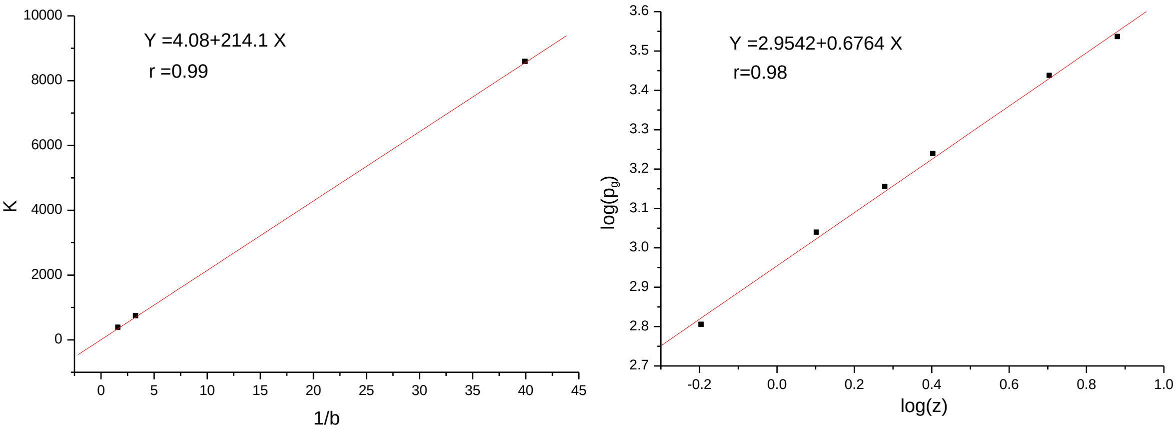

Figure 3. Graphical representations of the equations (6) and (5) for a tested location.

Table 2. Summary results: Bekker soil coefficients, sinkage, and CBR values for the specified locations

ID	n	Kø (kN/m^{n+2})	Kc (kN/m^{n+1})	z (cm)	CBR (%)
Ar-T1	0.9066	5.63	152.85	39	18
Ar-T2	0.8389	6.18	130.10	39	13
Ar-T3	0.6764	4.08	214.10	27	20
Ar-T5	0.7081	6.82	104.28	38	11
Ar-T7	0.8564	6.13	132.32	39	14
Br-T1	0.7458	4.15	211.82	34	28
Br-T2	0.6066	1.48	319.44	27	27
Br-T4	0.5884	3.71	229.17	29	20
Cb-T4	0.7434	4.75	187.30	26	19
Cb-T5	0.7894	7.46	78.97	43	10
Cb-T6	0.7531	7.27	86.40	39	9
Cb-T7	0.6404	5.79	145.96	26	14
Cb-T8	0.3748	6.58	113.48	20	10
Cb-T9	0.6864	4.80	185.54	24	17
Cb-T10	0.7033	4.88	182.14	25	17
Cb-T11	0.7053	1.03	337.90	19	29
Cb-T12	0.6655	2.56	275.35	20	24
Cb-T13	0.4043	4.33	204.77	16	13
Cb-T14	0.6779	7.46	78.30	38	9
Cb-T15	0.6052	5.47	159.39	23	11
Cb-T16	0.5918	6.23	112.56	28	8
Cb-T17	0.6918	6.24	128.10	29	10

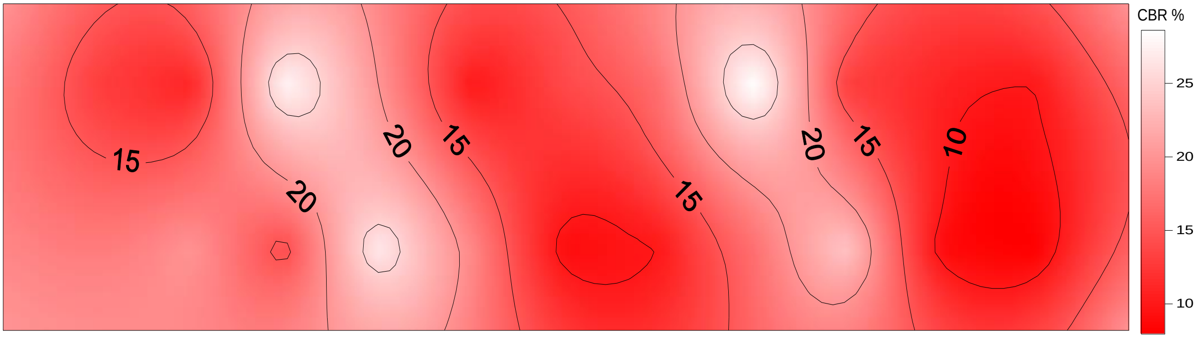

Figure 4. The CBR values on the ground surface of the airfield

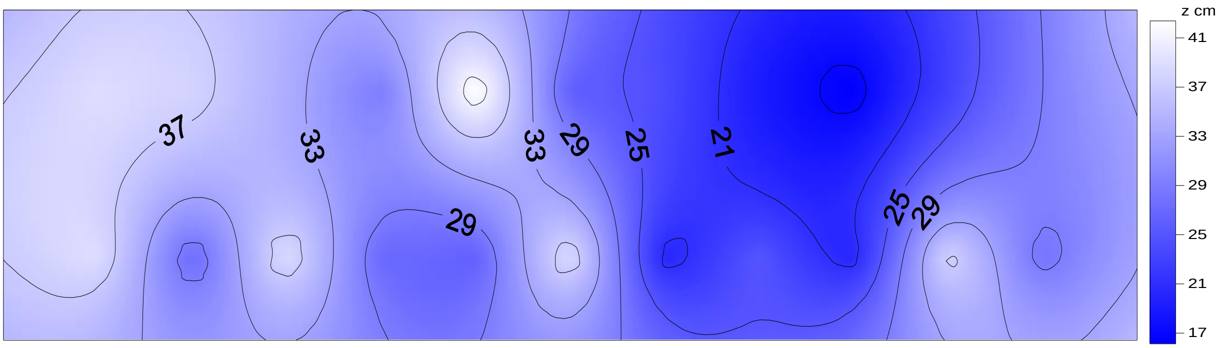

Figure 5. The modelled sinkage for the main landing gear of the aircraft

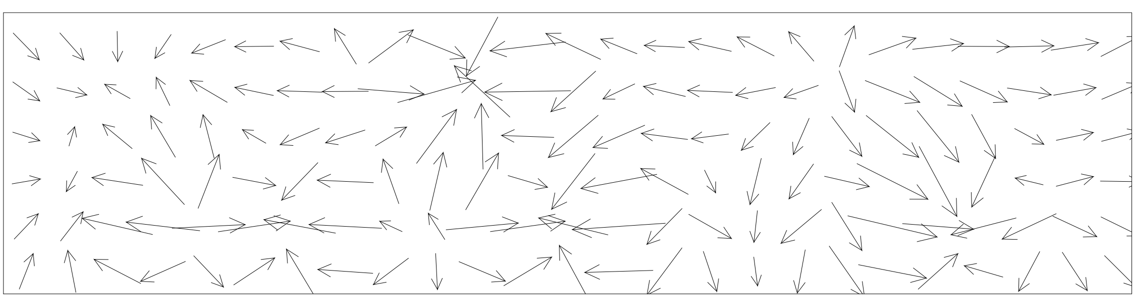

Figure 6. Vectorial map of the critical stopping zones on the ground airfield.

The Bekker soil coefficients and sinkage are presented for each in-situ measured locations.

The above presented figures show map views of modelled airfield area. The maps are generated using Gaussian regression method.

In the Figure 4 and Figure 5 are represented CBR map and modelled sinkage map, respectively. The Figure 6 show map of the critical stopping zones. The input data for this map considers both the nose and the main landing gear interactions. The vector convergences show the zones of the maximum and the vector length represents the relative magnitude to the minimum.

5 CONCLUSIONS

Based on the model we ran, the following main conclusions may be drawn:

(1) The results of our model show that the sinkage of the airplane landing gear apears to do not have a direct correlation with the CBR values determined by in-situ tests. This is probably because the in-situ tests are mainly the response of the upper layers, whereas in the model we developed, it is considered also the loading behavior for the deeper layers of the soil profile.

(2) Using this model we can estimate the areas of the airfield where the wheel-soil interaction can damage the landing gear, and consequently for those areas the bearing capacity can be improved by specific earthworks.

(3) The model presented here can give us the lenght neededd to stop airplane in the case of landing. This is a usefull information in order to design a proper airfield. Various parameters for landing airplane can be modeled in a similar approach on this model, such as time for stoping and decceleration.

In progress work for this project refers to the completion of the model considering more input data type and the validation of the model with documented landing events. This also includes the generation of nomograph series for the family A32x of AIRBUS and a more in-depth look into the impact of bulldozing effect on the landing gear.

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