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Sensitivity quantification of airfield rigid pavement stress responses using "Aerodrom 380" program

This study evaluated the sensitivity of "Aerodrom 380" airfield rigid pavement responses with respect to top-down and bottom-up cracking. The analysis was conducted by positioning a Airbus 380-800 (A380-800) aircraft at critical location as baseline while varying other "Aerodrom 380" inputs, including mechanical properties of paving and subbase materials.

"Aerodrom 380" (in Ukrainian) program has been developed for airfield rigid pavement design. It is written in Visual C++. "Aerodrom 380" has a certificate of recognition [1]. The program provides the required thickness of a concrete slab needed to support the Airbus 380 over a particular subgrade.

"Aerodrom 380" uses the maximum tensile stress at the bottom and top edge of the concrete slab as the design factor. The maximum tensile stress at the bottom edge of the concrete slab (free-edge stress) equals the interior stress multiplied by transition factor $k = 1.5$ [2]. If the concrete slab has joints, the edge stress is equals the interior stress multiplied by transition factor $k = 1.2$ [2]. The interior stress at the bottom of the slab is determined using an interior loading condition.

Computer program "Aerodrom 380" uses a fatigue failure concept that is expressed in terms of a damage ratio (D). It is expressed as the ratio of applied load repetitions to allowable load repetitions. The damage ratio is thus determined by using the FAA's CDF (cumulative damage factor) formula [3]. "Aerodrom 380" determines two damage ratios for every structural layer.

The damage ratios must equal 1. "Aerodrom 380" determines the maximum damage ratio for the desired conditions, and then performs the concrete slab thickness design. If the damage ratio is lower than 1, the computer program decreases the concrete slab thickness. If the damage ratio is more than 1, "Aerodrom 380" increases the concrete slab thickness. Computer program "Aerodrom 380" uses the concrete slab thickness in the range of 0.31–0.45 m. If the concrete slab thickness is greater than 0.45 m, the program calculates the pavement anticipated life [4].

Sensitivity analysis (SA) has become a useful tool in analyzing most engineering problems that involve a large number of interacting variables. One of the most common uses of sensitivity analysis is in pavement design and analysis [5].

In this research, SA can help to focus on those design inputs that have the most effect on airport rigid pavement thickness.

Chen et al. [6,7] identified the critical aircraft gear (single-gear and multiple-gear) loading position that induces the critical tensile stresses. Their study evaluated the effect of elastic modulus and thickness of each airfield rigid pavement layer and the joint stiffness on the critical tensile stresses and the critical top-to- bottom tensile stress ratio. They used three-layered pavement structure (concrete slab, granular subbase, and subgrade) under the loading condition (A380 aircraft load with an assumed equivalent thermal gradient). These studies [6,7] reported that the critical top-to-bottom tensile stress ratio (t/b ratio) was sensitive to the concrete slab thickness and the modulus of the subgrade variation, but it was not sensitive to the variation of subbase thickness, the modulus of concrete slab, and the modulus of subbase. Further investigations were performed by A. Rezaei-Tarahomi et al. [5] and included the use of different cases including a four-layered pavement structure, different loading conditions, and different load locations and case scenarios for a single aircraft type (B777-300ER). These studies [5] reported that all stress responses has the highest sensitivity to concrete slab thickness. For the top tensile stress, the thickness of pavement structural layers are the most effective inputs. It is noteworthy that subgrade modulus has a higher effect on bottom tensile stresses and shear stresses changes. Top tensile stresses are more sensitive to concrete slab thermal coefficient variations while bottom tensile stresses are more sensitive to the thermal gradient changes [5].

The objective of this paper is to quantify sensitivity of critical stress outputs to various inputs required in “Aerodrom 380” software for different load values and case scenarios for a single aircraft type (A380-800). Three loading levels were selected: A380-800 (WV007), A380-800 (WV004), A380-800 (WV008).

A three-layered pavement structure (concrete slab, lean concrete, cement treated base) with 7,5 m concrete slab was modeled to represent a typical and realistic airport pavement structure in Ukraine.

The analysis has been done for a three-layered pavement structure with 9 slabs by applying a A380-800 aircraft loading (Fig. 1).

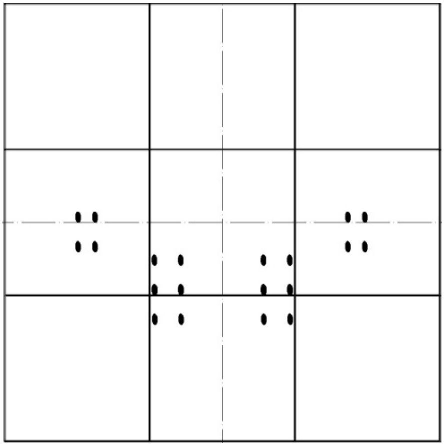

Fig. 1. Nine-slab geometry and load position for the A380-800 main landing gears

A One-at-a-time (OAT) SA was implemented using a baseline limit normalized sensitivity index (NSI) to provide quantitative sensitivity information. The sensitivity of the input parameters has been evaluated by considering their effects on the critical responses corresponding to the top-down and bottom-up cracking [5]. The OAT SA has been carried out on the “Aerodrom 380” program by varying one parameter at a time while holding the others fixed. This analysis helps to identify the most significant inputs in the airfield rigid pavement structural analysis.

Inputs that are needed for “Aerodrom 380” can be categorized as:

- pavement structure inputs;
- subgrade inputs;
- airplane inputs.

The goal is to evaluate the sensitivity of those input parameters which are more important for analyzing and designing airfield rigid pavements have been evaluated.

A detailed summary of ranges of the inputs to be varied as well as constant inputs are shown in Table 1.

Table 1.

Ranges of inputs for sensitivity analysis of “Aerodrom 380” software

inputs category	inputs		min	baseline	max	base case
pavement structure inputs	concrete slab	modulus, MPa	32400	35300	35300	35300
		thickness, m	0,36	0,4	0,45	0,45
		Poisson ratio	0,15	0,15	0,15	0,15
	lean concrete	modulus, MPa	13000	17000	26000	17000
		thickness, m	0,20	0,25	0,30	0,25
		Poisson ratio	0,15	0,15	0,15	0,15
	treated subbase	modulus, MPa	1950	4810	7800	7800
		thickness, m	0,15	0,20	0,25	0,15
		Poisson ratio	0,15	0,15	0,15	0,15
subgrade inputs	subgrade	subgrade ratio, MN/m^3	40	50	60	40
airplane inputs	airplane A380-800 parameters	ramp weight, t	492	562	577	492
		number of main gears	4	4	4	4
		maximum vertical wing gear ground load, t	93,6	106,92	108,85	106,92
		maximum vertical body gear ground load, t	140,41	160,38	163,27	160,38
		tire pressure, MPa	1,4	1,5	1,5	1,4

Each evaluated input was varied within its recommended range to study its effect on critical responses (maximum tensile stress at top/bottom of the concrete slab) while assigning base case values to all other input parameters.

To present the sensitivity of each parameter, a normalized sensitivity index (NSI) has been adopted as a quantitative metric

$$NSI = \frac{\Delta Y_j}{\Delta X_k} \frac{X_k}{Y_k}, \qquad (1)$$

where X_k – baseline value of input k, ΔX_k – change in input k about the base line, Y_j – change in output J corresponding to ΔXk, Y_K – baseline value of output J [5].

Analysis was carried out for mechanical loading only. Two stress types and one ratio were considered as critical stresses for wheel load of all main landing gears and used as outputs for the NSI calculation:

- maximum tensile stress at the top of the concrete slab (top tensile stress);
- maximum tensile stress at the bottom of the concrete slab (bottom tensile stress);
- critical top-to-bottom tensile stress ratio (t/b ratio).

Table 2 shows the sensitivity analysis results for different inputs. Concrete slab thickness has been identified as the most effective input for top and bottom tensile stresses. Top tensile stresses, unlike the bottom tensile stresses, exhibit significant sensitivity to the lean concrete and subbase thickness. Variations in modulus of concrete and subbase show less sensitivity index for bottom tensile stresses. However, alteration of subgrade ratio has considerable effect on all stress responses.

The top tensile stresses exhibit considerable sensitivity to most inputs, but the bottom tensile stresses have considerable sensitivity to just two inputs (concrete slab thickness and subgrade ratio). The stress responses are not sensitive to subbase modulus (lowest NSI) that coincide with conclusions of A. Rezaei-Tarahomi et al. [5].

Table 2.

Inputs ranking for stress responses

inputs	NSI top tensile stress	inputs	NSI bottom tensile stress
slab thickness	1,502	slab thickness	1,457
subgrade ratio	0,412	subgrade ratio	0,548
slab modulus	0,384	slab modulus	0,365
lean concrete thickness	0,342	lean concrete thickness	0,333
subbase thickness	0,239	subbase thickness	0,234
lean concrete modulus	0,104	lean concrete modulus	0,113
subbase modulus	0,009	subbase modulus	0,006

Table 2 also shows that all stress responses has the highest sensitivity to concrete slab thickness. For the top tensile stress, the thickness of pavement structural layers are the most effective inputs. It is noteworthy that subgrade modulus has a higher effect on bottom tensile stresses.

Airplane A380-800 weight variants (WV) maximum ramp weight and tire pressure have a higher effect on top tensile stress.

Inputs ranking for critical top-to-bottom tensile stress ratio (t/b ratio) is follows: subgrade ratio (0,134); concrete slab thickness (0,046); slab modulus (0,020); lean concrete modulus (0,015); lean concrete thickness (0,013); subbase thickness (0,008); subbase modulus (0,003). Thus the critical top-to-bottom tensile stress ratio (t/b ratio) is sensitive to the subgrade ratio and the concrete slab thickness, but it is not sensitive to the variation of subbase thickness, and the modulus of subbase that coincide with conclusions of Chen et al. [6,7].

Conclusions

All stress responses are most sensitive to concrete slab thickness, followed by subgrade ratio and slab modulus.

In the mechanical loading only concrete slab thickness and subgrade ratio are the most effective input parameters for stress responses.

For the top tensile stress, the thickness of concrete slab is the most effective input. Subgrade modulus has a higher effect on bottom tensile stresses.

Airbus 380 weight variants (WV) maximum ramp weight and tire pressure have a higher effect on top tensile stress.

In the mechanical loading subgrade ratio and modulus of concrete slab variation have effect on top and bottom tensile stresses.

The critical top-to-bottom tensile stress ratio is sensitive to the subgrade ratio and the concrete slab thickness.

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