METHOD OF DYNAMIC DESIGN OF RIGID AIRFIELD PAVEMENTS

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Abstract: *The article presents a method of dynamic calculation of rigid airfield pavement of the airports "Kep" and "Camranh" in Vietnam, taking into account surface roughness. The roughness of airfield pavement was calculated by studying the movement of airplanes on a concrete pavement, which is modeled as an infinite plate on an elastic foundation.*

Keywords: *Airfield pavement, estimation, spectrum density, dynamic coefficient, plate, elastic foundation.*

INTRODUCTION

During airplane movement on the airfield pavement, surface roughness of the pavement is one of the main reasons of the creation of dynamic loads, and must be taken into account in the strength calculation of airfield pavement.

The dynamic loads from the wheels of the airplane are taken into account by the introduction of dynamic factor k_d in the strength calculation of airfield pavements. The values of k_d, given in normative documents in Vietnam, were obtained in the 60-ies of XX century, on the basis of multiple tests carried out in the Soviet Union and Vietnam, and almost have not been adjusted. Currently, the fleet and construction equipment, used in the construction of airfields pavements, have significantly changed.

METHOD OF DYNAMIC CALCULATION OF RIGID AIRFIELD PAVEMENTS, TAKING INTO ACCOUNT SURFACE ROUGHNESS

The problem of calculation of rigid airfield pavements for strength is to verify structure design for the limit state [1]:

$${}_{\mathrm{d}} \leq \quad {}_{\mathrm{u}} \qquad (1)$$

Where: m_d - the calculated bending moment at the section under the slab, m_u - the ultimate bending moment at the section under the slab. The calculated values of the bending moments m_d per unit width of the cross section of single layer hard coatings determined by the following formula:

$${}_{\mathrm{d}} = \quad {}_{\mathrm{c,max}}.\mathrm{k}.\mathrm{k_N}.\mathrm{k}_{\mathrm{x}(y)} \qquad (2)$$

Where: $m_{c,max}$ - maximum bending moment under the central loading of the plate, which is calculated as the maximum total torque produced by the airplane wheel in the calculated cross sections of the plate:

$$_{c,max} = m_1 + \sum_{i=2}^{n_k} {}_{x(y)i} \quad (3)$$

k - transition coefficient of bending moment from the central load case to an edge load case, taken from [1]; k_N - coefficient taking into account the accumulation of residual deflections at the base; $k_{x(y)}$ - coefficient that accounts for the redistribution of the internal forces in orthotropic plates coatings, with different stiffness B_x and B_y in the longitudinal and transverse directions; for concrete, fibercrete and reinforced concrete pavement with non-stressed reinforcement $k_{x(y)} = 1$;

m_1 - the bending moment from the action of a wheel, whose print center coincides with the cross-section: $m_1 = \overline{m_1} F_d$;

$_{x(y)i}$ - the bending moment created by the action of the i-th wheel, which is located outside the calculated cross section plate: $_{x(y)i} = \overline{m}_{x(y)i}. F_d$;

$\overline{m_1}$ - unit bending moment from the action of a wheel, whose print center coincides with the cross section, defined by a table [1] depending on the given radius.

F_d - dynamic load from one wheel of the airplane main landing gear;

$$F_d = \frac{F_n}{n_k} k_d \gamma_f \quad (4)$$

F_n - load on the main support of design airplane;

n_k - number of wheels;

γ_f - coefficient of discharge, determined in accordance with a table [1];

k_d - dynamic coefficient.

In formula (4), the dynamic coefficient is determined according to table [1]. It depends on the internal pressure of the air in the tires of the wheels and of groups of sites of airfield coverings.

The article proposes to determine the dynamic coefficient as the ratio of the deflections of the coating under dynamic W_d and static W_0 loads from the wheel of the airplane:

$$k_d = \frac{W_d}{W_0} \quad (5)$$

To calculate the deflections of the airfield pavement, the model of a thin, infinite in plan, anisotropic and homogeneous plate resting on Winkler elastic foundation should be considered.

The equation of the dynamic equilibrium of such a plate (Fig.1) is a complex biharmonic equation in partial derivatives [2; 5].

$$\left(\nabla^4 + 1 + \frac{\rho}{\ell^2 K_S g}\left(\frac{\partial^2}{\partial\xi^2} V_x^2 + 2\frac{\partial^2}{\partial\xi\partial\eta} V_x V_y + \frac{\partial^2}{\partial\xi^2} V_y^2\right)\right) W(\xi,\eta) = \frac{q(\xi,\eta)}{K_S} \quad (6)$$

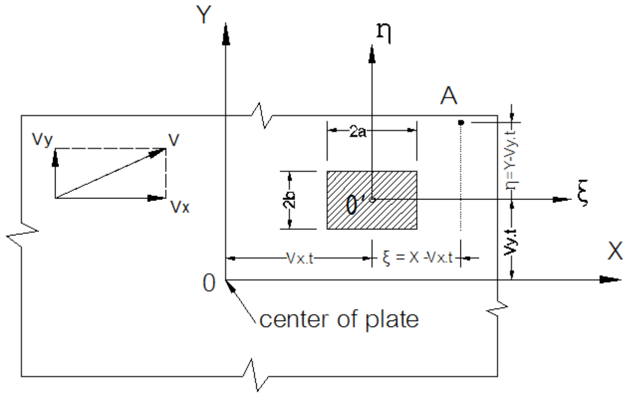

Fig 1. *Calculation scheme for solving the problem of motion of load at plate*

Where: $\nabla^4 = \left(\frac{\partial^2}{\partial \xi^2} + \frac{\partial^2}{\partial \eta^2}\right)^2$ – the differential operator; $W(\xi,\eta)$ - function of deflection of middle surface of plate under load $q(\xi,\eta)$; K_s - foundation reaction modulus; V - speed of airplane with projections on the axes V_x и V_y; g – acceleration due to gravity; $\ell = \sqrt[4]{\frac{B}{K_S}}$ – elastic characteristic of the plate; $B = \frac{Et^3}{12(1-\mu^2)}$ – cylindrical plate modulus; ρ, E, t, μ – accordingly, mass of plate per unit area, elastic modulus, thickness of plate, and Poisson's ratio; $\xi = \frac{(x\text{-}V_x)}{\ell}, \eta = \frac{(y - V_y)}{\ell}$ - reduced rectangular Cartesian coordinates in plane of plate;

Consider the problem of uniform motion of a load distributed over a rectangle, with sides 2a and 2b along the axis X. In this case we have:

$\xi = \frac{(x\text{-}V_x.t)}{\ell}$; $\eta = \frac{y}{\ell}$; $V = V_x$; $V_y = 0$. If we take the parameter of the inertia forces of the plate $\lambda = \frac{\rho V^2}{2\ell^2 K_S g}$, we get the equation (6) in the following form:

$$\left(\nabla^4 + 1 + 2\lambda^2 \frac{\partial^2}{\partial \xi^2}\right) W(\xi,\eta) = \frac{q(\xi,\eta)}{K_S} \quad (7)$$

The use of Fourier transforms allows you to find a solution to the differential equation (7) in the form of double improper integrals for various cases of application of the load.

$$W(\xi,\eta) = \frac{F_d}{\pi^2 abK_s} \int_0^\infty \int_0^\infty \frac{\sin\left(\frac{\alpha a}{\ell}\right)\sin\left(\frac{\beta b}{\ell}\right)\cos(\alpha\xi)\cos(\beta\eta)}{\alpha\beta[(\alpha^2+\beta^2)^2 + 1 - 2\lambda^2\alpha^2]} d\alpha d\beta \quad (8)$$

Consider a special case of this, which corresponds to the application of concentrated load at the origin $(\xi = \eta = 0;\ a \to 0, b \to 0)$. In this case, the resulting value of the deflection under a fixed and a movable load:

$$W_0 = \frac{F_0}{\pi^2 \ell^2 K_S} \int_0^\infty \int_0^\infty \frac{d\alpha\, d\beta}{\left(\alpha^2 + \beta\right)^2 + 1} \quad (9)$$

$$W_d = \frac{F_d}{\pi^2 \ell^2 K_S} \int_0^\infty \int_0^\infty \frac{d\alpha\, d\beta}{\left(\alpha^2 + \beta\right)^2 + 1 - 2\lambda^2 \alpha^2} \quad (10)$$

Where F_0 - static load from a single wheel of main landing gear of the airplane.

The exact value of the deflection in the formula (9) can be calculated analytically and is equal to $W_0 = \frac{F_0}{8 l^2 K_S}$. Thus, the value of dynamic coefficient is defined by the formula (5) can be written in the following form:

$$k_d = 8 \frac{F_d}{F_0\, \pi^2} \int_0^\infty \int_0^\infty \frac{d\alpha\, d\beta}{\left(\alpha^2 + \beta\right)^2 + 1 - 2\lambda^2 \alpha^2} \quad (11)$$

Value of the dynamic load F_d is calculated according to the three Sigma rule:

$$F_d = F_0 + 3C_2 \sqrt{D_{\delta ш}} \quad (12)$$

Where: C_2 - stiffness of the pneumatic airplane tires; $D_{\delta ш}$ - dispersion of compression of airplane tires, determined by the method of "Statistical dynamics" [4] by the following formula:

$$D_{\delta ш} = -\frac{CV}{2} \left[\frac{(M+m)^3 C_1^2}{M^2 R C_2^2} + \frac{m}{R} - \frac{(M+m)^2 R}{M^2 C_2} + \frac{2m(M+m) C_1}{M R C_2} \right] \quad (13)$$

Where: M - mass of the airplane attributable to main landing gear; m - mass of main landing gear; R - coefficient of damping of the strut main support; C_1 - stiffness of the strut; V - speed of movement of the airplane; C - level of the spectral density.

The spectral density of the airfield is represented by the following expressions:

$$S_q(\omega) = \frac{C}{\omega^2} V \quad (14)$$

Where: ω - spatial frequency.

In the end, we get a formula to determine the dynamic factor:

$$k_d = \frac{8(F_0 + 3C_2 \sqrt{D_{\delta ш}})}{\pi^2 F_0} \int_0^\infty \int_0^\infty \frac{d\alpha\, d\beta}{\left(\alpha^2 + \beta\right)^2 + 1 - 2\lambda^2 \alpha^2} \quad (15)$$

The application of the proposed method for the design of airfield pavements of airports "Kep" and "Camranh" in Vietnam allowed the following results:

The estimated airplane: IL-96

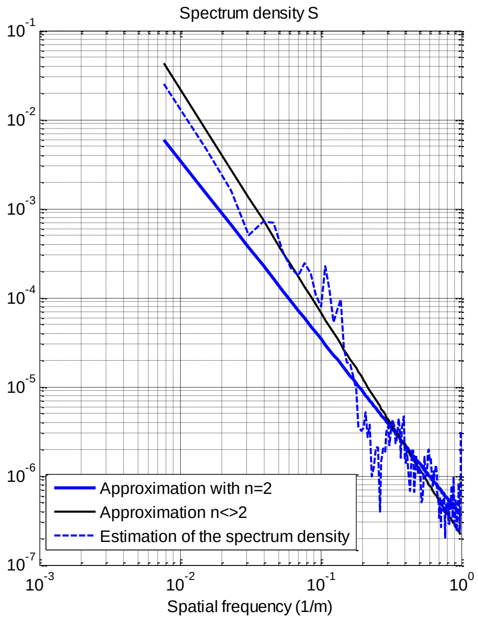

Fig 2. *Estimation of the spectral density of the airfield "Kep"*

Inputs to the calculation were the elevation of the longitudinal sections of the runways, obtained by geometric leveling with a step of 0.5 m, and the parameters of the design of the airplane. The calculations used the software package Matlab.

A graph of the dynamic coefficient function of the speed of the airplane is shown in figure 3:

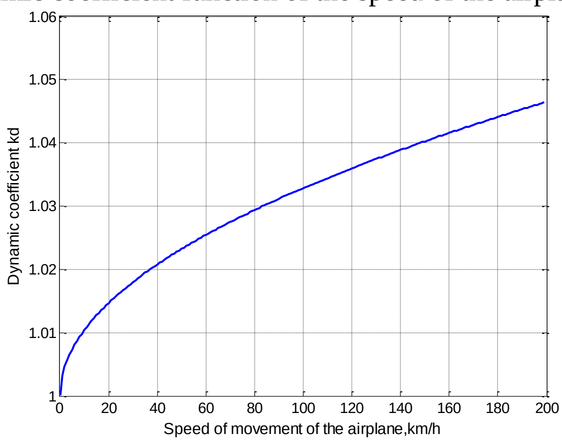

Fig 3. *Graph of K_d and V for the airport « Kep » and airplane IL-96*

Analysis of fig 3 shows that the value of the dynamic coefficient increases in proportion to the speed of the airplane. Some of the data calculated in the airports, "Kep" and "Camranh" is shown in table 1:

Table 1. *The results of the dynamic analysis by the proposed method*

Aiport	Kep		Camranh	
Speed of airplane (km/h)	Spectral density, C	k_d	Spectral density, C	k_d
0	0.3527e-6	1.000	1.1374e-6	1.000
10	0.3527e-6	1.010	1.1374e-6	1.019
30	0.3527e-6	1.018	1.1374e-6	1.033
50	0.3527e-6	1.023	1.1374e-6	1.042
100	**0.3527e-6**	**1.033**	**1.1374e-6**	**1.059**
200	0.3527e-6	1.047	1.1374e-6	1.083

Dynamic calculation should be done at the speed of taxiing of the airplane, that is up to 100 km/h. At higher speeds, a significant impact will be exerted a lifting force, reducing the load on the coating.

The results of calculations for various airfield pavements are given in table 2.

Table 2. *Characteristics of the layers of airfield pavements designed for airplane IL-96 for different values of k_d*

Characteristics of pavement	Unit	Dynamic coefficient			
		Airport «Kep»		Airport «Camranh»	
		k_d =1.25	k_d =1.033	k_d =1.25	k_d =1.059
Thickness of the concrete plate M350/45- t_b	m	0.39	0.34	0.39	0.36
Thickness of sand reinforced with cement (E_f = 4000 MPa), t_f	m	0.30	0.30	0.30	0.30
Thickness of the artificial base k_1 = 200 MN/m^3, t1	m	0.30	0.30	0.30	0.30
Natural foundation reaction modulus, k_f	MN/m^3	69.0		58.5	
Maximum bending moment in the central load case - $m_{c,max}$	KNm/m	59.314	47.008	59.978	51.327
Calculated bending moment - m_d	KNm/m	62.522	47.671	63.222	53.301
Ultimate bending moment - m_u	KNm/m	64.196	48.791	64.196	54.700
Percentage of under voltage ($\varepsilon = \frac{m_u - m_d}{m_u}.100\%$)	%	2.61	2.29	1.52	2.56

CONCLUSION

The result of conducted research and calculations shows that the value of dynamic coefficient is to cover airports do not exceed the value of 1.06, which is considerably below the value given in the normative documents (1.25). The technique of dynamic calculation, taking into account the surface roughness, presented in this work allows to reduce the thickness of the layers in airfield pavements.

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