DESIGNING AND CONSTRUCTION OF ROADS, SUBWAYS, AIRFIELDS, BRIDGES AND TRANSPORT TUNNELS

UDC 625.717

Voronezh State University of Architecture and Civil Engineering

Rector, Prof. I. S. Surovtsev

The First Deputy Rector for Science, Innovations,

and High-skilled Personnel Training Prof. Yu. M. Borisov

Military Aircraft Engineering University (Voronezh)

Ph. D in Engineering, Assoc. Prof. of Dept. of Survey

and Design of Airfields D. E. Barabash

Russia, Voronezh, tel.: 8-919-235-64-54;

e-mail: barabash60170@rambler.ru

I. S. Surovtsev, Yu. M. Borisov, D. E. Barabash

AN ASSESSMENT OF THE OPERATIONAL LIFE OF CONCRETE AIRFIELD PAVEMENTS ON THE BASIS OF RELIABILITY THEORY

The mathematical model of development and accumulation of defects of airfield pavements obtained with the use of the principal dependences of reliability theory is proposed. This model is implemented in the method of assessment of an operational life of concrete airfield pavements.

Keywords: airfield pavement, operational life, concrete pavement, reliability theory.

Introduction

The basis for concrete airfield pavement operation is a planned preventive maintenance system. This system provides regularity and safety of aircraft equipment and involves execution of works on restoration of operational characteristics of airfield pavements for the purpose of preventing damages. Integrated airfield planned preventive maintenance system involves predominantly deadline inspections to assess the technical conditions of airfields.

In actual practice, various Russian and foreign techniques for expeditious assessment of technical state of airfield pavements are applied depending on pavement type:

- assessment of the technical state of surfaces of rigid pavements by pavement conservation index *MI* (technique of 26 Central Scientific Research Institute of Ministry of Defense);
- assessment of the technical state of surfaces of nonrigid pavements by pavement quality index P_o (technique of Scientific Research Institute "Aeroproekt";
- assessment of the technical state of surfaces of airfield pavements by integrated index $K^к$ (technique of 26 Central Scientific Research Institute of Ministry of Defense);
- abroad the standard method of definition of pavement conditions index (*PCI*), developed by the United States Army Corps of Engineers, is used for quantitative and qualitative assessment of the airfield pavement surface state.

Despite the common principles, each method has some peculiarities:

- different approaches to the algorithm of visual examination;
- different lists of pavement damages;
- different indices of the pavement condition.

The common drawback is that all the methods provide the assessment of pavement condition during examination and do not allow researchers to predict its change and, therefore, to plan in advance routine maintenance works and to reserve needed financial means.

This drawback can be remedied by using the mathematical model of development and accumulation of defects of airfield pavements developed on the basis of central tenets of reliability theory.

It is known that the reliability of an airfield pavement is a number characterizing the property of the system to work without failure, that is, to provide safe takeoff, landing, and taxiing of aircrafts. It is evident that perfectly safe pavement is impossible, as well as any other engineering system.

In connection with this, during operation of a pavement made of N_O slabs, there are usually N_H undamaged slabs and N_{ot} failed slabs by the instant of time *t*. Let us assume that the failed slabs are not renewed, then, a reliability expression can be written as follows:

$$P(t) = \frac{N_H}{N_O} = 1 - \frac{N_{Ot}}{N_O}. \tag{1}$$

Present regulations establish the following system reliability indices depending on system function and operational conditions:

1) reliability;
2) availability;
3) maintainability;
4) persistence, and any combinations of them.

To assess the operational suitability of airfield pavements, it is feasible to enter a supplementary indicator — operational life — describing the property to function until the assessed condition is reached.

This condition corresponds to the bearing capacity requirements, but does not provide flight safety. Consequently, operational life defines time interval of airfield pavement work in the presence of certain damages total amount of which is determined from the condition of light safety insurance.

By differentiating reliability expression with respect to *t* and dividing both members on the number of undamaged slabs, we obtain damage intensity:

$$\lambda = \frac{1}{N_H}\frac{dN_{Ot}}{dt} = -\frac{N_O}{N_H}\frac{dP(t)}{dt} = -\frac{1}{P}\frac{dP(t)}{dt}. \tag{2}$$

In formula (2) value $\frac{dN_{Ot}}{dt}$ is a damage frequency, that is, a damage distribution. By dividing it into the total number of slabs, we obtain $\frac{1}{dN_0}\frac{dN_{0t}}{dt}$, that is, a damage probability density function.

It is evidently that assessment of airfield pavement reliability involves inclusion of time factor *t* and dilapidating effects determined by the flight intensity, amount of applied antiicing agent, the number of defrosting and thawing cycles, etc.

Let us apply logarithmic scale and enter new variable – $x=lg\ (gt)$, where *g is the* intensity of action in a unit of time. In this case damage probability density function has the form:

$$f(x) = \frac{1}{N_O}\frac{dN_{Ot}}{dx}. \tag{3}$$

By integrating expression (3), we obtain the formula for calculating the damage probability in the range from x_1 *to* x_2:

$$Q_П\ \ x_1 \le x \le x_2\ \ = \int_{x_1}^{x_2} f(x)dx = \frac{1}{N_0}\int_{x_1}^{x_2}\frac{dN_{Ot}}{dx}dx. \tag{4}$$

It is possible to increase the reliability of airfield pavement to the required value during operation by the replacement of the damaged slabs. Assuming that new slabs differ from the old ones only in service life, we use uniform damage probability density function with different limits of integration (Fig. 1).

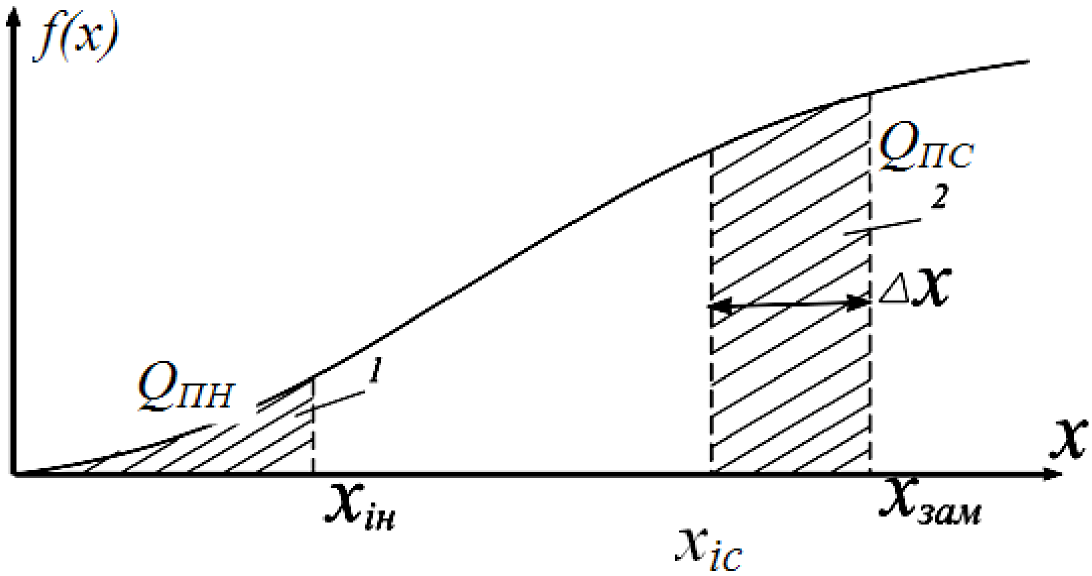

Fig. 1. Damage probability density function of airfield pavements:
1 – contribution of damaged new slabs; 2 – contribution of damaged old slabs

The use of these limits gives the following equations for determining the number of damages:

– for old slabs

$$Q_{ПС} = \int_{-\infty}^{x_{ic}} f(x)dx - \int_{-\infty}^{x_{зам}} f(x)dx = \int_{x_{зам}}^{x_{ic}} f(x)dx; \qquad (5)$$

– for new slabs

$$Q_{ПН} = \int_{-\infty}^{x_{ін}} f(x)dx. \qquad (6)$$

If total number of slabs is N_o, and the number of replaced slabs is $N_{зам}$, then the value of airfield pavement damageability in an interval Δx is as follows:

$$Q_{ПО} = Q_{ПС} + \frac{N_{зам}}{N_0} Q_{ПН} = \frac{1}{N_0} \int_{x_{зам}}^{x_{ic}} \frac{\partial N_{0t}}{\partial x} dx + \frac{N_{зам}}{N_0^2} \int_{-\infty}^{x_{ic}} \frac{\partial N_{0t}}{\partial x} dx, \qquad (7)$$

After replacement of all damaged slabs, we obtain the pavement without visible signs of damage. Then processes of aging of new and old slabs will occur simultaneously, therefore, values $Q_{ПН}$ and $Q_{ПС}$ will increase. After following (partial) slab replacement we will have three summands: $Q_{ПН}$; $Q_{ПС1}$ and $Q_{ПС2}$, where $Q_{ПС2}$ corresponds to the number of the damaged slabs allowed for the further operation, and so on.

To obtain objective assessment of operational life of airfield pavement as a system, it is feasible to use an index of airfield pavement operational condition θ_t which is a function of damages of a pavement:

$$\theta_t = f(n_a; n_b; n_c ...), \tag{8}$$

where n_a, n_b, n_c… are defects of an airfield pavement.

Let us group the defects of airfield pavements by their origin and their effect on flight safety.

A function of defect occurrence has the form:

$$n_a = f(KL_i; GS_i; TH_i), \tag{9}$$

where KL_i is the environmental effects; GS_i is the mechanical loads; TH_i is the operational and technological effects.

Let us consider the problem of defect accumulation in time. Assume that defect distribution is described by two parameters: M_x is the mathematical expectation and S_x *is the* root mean square deviation.

It is known that defects in slabs emerge when parameter caused by an action exceeds specified limits. Let us consider this statement by an example of defect formation under the action of mechanical factors. In this case, defects occur if stress in a slab exceeds specified limits.

This fact define confidence time interval of defect formation or, in the case of mechanical destruction, allowable number of loads, which is shown in Fig. 2.

On X-axis, confidence interval of the airfield slab material strength and confidence interval of a stress occurring in a slab are shown. Slab strength decreases in time because of concrete aging.

Considering the triangle: rated value of M_n – actual value of $M_ф$ – mathematical expectation of x, we obtain an expression for determining the mathematical expectation M_x:

$$M_x = \frac{1 - \frac{M_ф}{M_n}}{tg\alpha}, \tag{10}$$

where $M_ф$ *and* M_n are the mean values of actual and rated values of concrete indices. Assume $M_n=1$, then value $M_ф$ should be expressed in a decimal fraction.

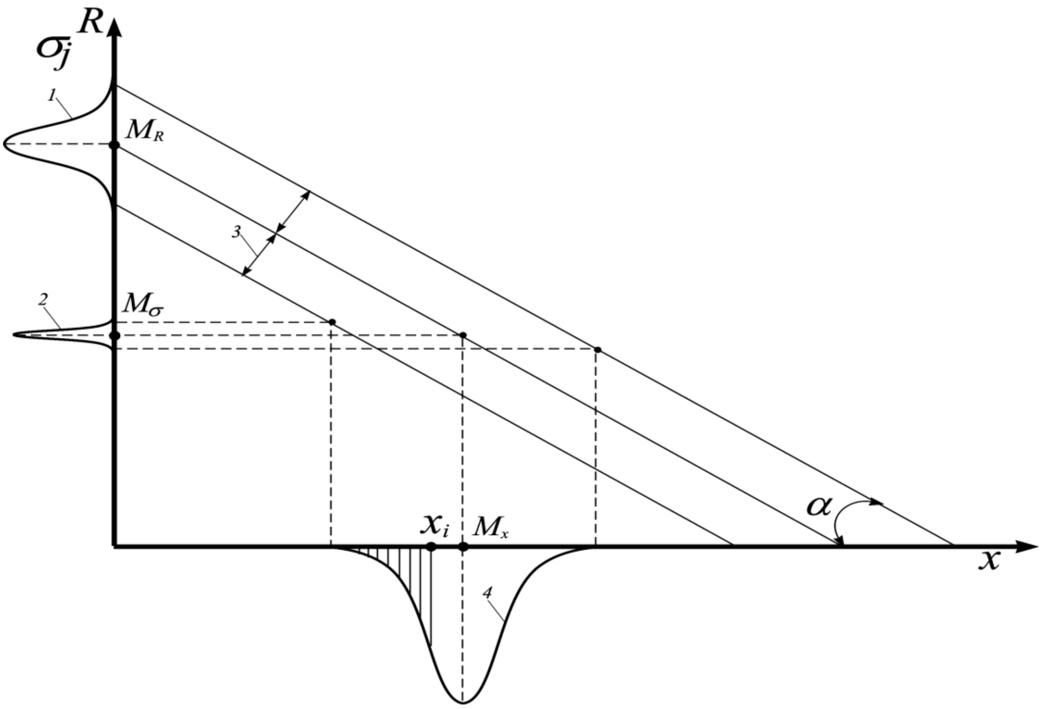

Fig. 2. Distribution of reliability parameters of an airfield pavement:
1 – distribution of concrete strength; 2 – distribution of active stresses;
3 — confidence boundary of concrete fatigue function; 4 – distribution of the number of loads

In a similar manner we determine roof-mean-square deviation by Fig. 2 using Write criterion:

$$S_x = \frac{1}{tg\alpha}(S_ф + S_n). \tag{11}$$

M_x and S_x obtained by formulae (10), (11) make it possible to determine a function of distribution of x. Integration of the function in the range from -∞ to x_i gives current value of airfield pavement damage probability depending on the factors which cause the damages:

$$Q_{П_i} = \frac{1}{S_x\sqrt{2\pi}} \int_{-\infty}^{x_i} e^{-\frac{z-Mx\ ^2}{2S_x^2}} dz. \tag{12}$$

The function of defect accumulation makes it possible to define pavement operational life. The number of slab subject to different factors causing the damage is determined as follows:

$$N_{\phi i} = Q_{\phi i} No, \tag{13}$$

where $Q_{\phi i}$ is the probability of the fact that a slab will be subject to different combinations of disturbing factors; *No* is the total number of slabs.

The number of damaged slab in a time *t* under the influence of, for example, environmental factors is

$$N_{oti} = N_{\phi i} Q_{\Pi i} = No Q_{\phi i} Q_{\Pi i}, \tag{14}$$

where $Q_{\Pi i}$ is the probability of the fact that defects in a slab will occur under the influence of environmental factors.

In a similar manner expressions for calculating the number of the damaged slabs under the effect of mechanical, operational and technological factors and different combinations of them can be obtained.

The total number of damaged slabs is

$$N_{0t} = No Q_{\phi 1} Q_{\Pi 2} + No Q_{\phi 2} Q_{\Pi 2} + No Q_{\phi 3} Q_{\Pi 3} + \ldots . \tag{15}$$

$Q_{\Pi i}$ is the number of damaged slabs in a raw of slabs of a runway or a taxiway. To finds the values of damageability for all the rows of a pavement, it is necessary to perform corresponding summation. New defects forming during further operation are the summand of the total sum.

Therefore, the function will have value equal to the volume of damages accumulated by the moment of inspection.

With respect to the flight safety defects are classified in:

- defects which may lead to the accident (unallowable defects); they are remedied immediately after detection;
- defects which do not bring the threat to the pavement integrity; they are remedied during basic repair by strengthening the pavement or replacing particular elements;
- defects which do not lead to the accident but decrease their operational properties.

To predict the change in pavement technical condition in time and to assess its operational life, we assume that pavement technical condition is a scope of damages.

The influence of each defect on the flight safety is evaluated by the weight coefficient. Then the index of technical condition is

$$\theta_t = \theta_0 - N_{ot1} k_1 - N_{ot2} k_2 - N_{ot3} k_3 - \ldots = \theta_0 - \sum_{1}^{n} N_{oti} k_i, \tag{16}$$

where θ_t is the index of a pavement technical condition; θ_0 is the maximum value of a technical condition index corresponding to a new pavement $\theta_0=1$; N_{oti} is the number of defects, expressed as a decimal fraction; k_i is the weight coefficient of defect influence of flight safety obtained with the use of an expert judgment method.

Let us predict the change of airfield pavement technical condition in time. For this purpose we make a series expansion of the function of technical condition in the powers:

$$\theta(t)=\theta_{t=t_0}+\left[\frac{d\theta(t)}{dt}\right]_{t=t_0}(t-t_0)+\frac{1}{2}\left[\frac{d^2\theta(t)}{dt^2}\right]_{t=t_0}(t-t_0)^2, \qquad (17)$$

where $\theta(t)$ is the function of pavement condition change in time; $\theta_{t=t_0}$ is the initial technical condition of the pavement by the moment of inspection.

The first member of the series is the ordinate of technical condition by the point of time t_0, the second member shows the dynamics in the change of condition. If technical state of a pavement do not vary with time, then

$$\frac{d\theta(t)}{dt}=0,\ \theta_t=\theta_{t=t_0}.$$

If the following inequality

$$\frac{d\theta_1(t)}{dt}<\frac{d\theta_2(t)}{dt}$$

takes place, we may consider that the state of the first pavement is better than the state of the second pavement.

Therefore, value of $\frac{d\theta(t)}{dt}$ can be chosen as a pavement technical state criterion along with value of $\theta(t)$.

A perfect state of a pavement is characterized by the following expressions:

$$\left[\frac{d\theta(t)}{dt}\right]_{t=t_0}(t-t_0)=0,\ \left[\frac{d^2\theta(t)}{dt^2}\right]_{t=t_0}(t-t_0)^2=0. \qquad (18)$$

A normal (regulable) state of a pavement is characterized by the following expressions:

$$\left[\frac{d\theta(t)}{dt}\right]_{t=t_0}(t-t_0)=const,\ \left[\frac{d^2\theta(t)}{dt^2}\right]_{t=t_0}(t-t_0)^2=0. \qquad (19)$$

If a pavement is destructed intensively (unregulable destruction), then:

$$\left[\frac{d\theta(t)}{dt}\right]_{t=t_0}(t-t_0)\neq const\,,\ \left[\frac{d^2\theta(t)}{dt^2}\right]_{t=t_0}(t-t_0)^2\neq 0\,. \tag{20}$$

By using a function of pavement state change in time, it is possible to plan maintenance repair of an airfield pavement. Forecast is based on the following condition:

$$\frac{d\theta(t)}{dt}\leq\eta\frac{dL(t)}{dt}, \tag{21}$$

where L is the means used for pavement maintenance repair; η is the coefficient of proportionality.

It is obviously that flying operation of an airfield is not affected if the sum of time intervals between flights $\sum t_0$ which are suitable for repair is more than time t_n required for operating repair of an airfield pavement:

$$t_n<\sum t_0\,,\ \text{if}\ t_n>\sum t_0\,,$$

repair is impossible. Therefore, the coefficient of proportionality is taken as criterion of repair possibility:

$$\eta=\frac{t_n}{\sum t_0} \tag{22}$$

Summary

The presented model can be implemented in practical guidelines on assessment of airfield pavement technical state after detailed elaboration and experimental testing.

The model makes it possible to reveal the sections subject to destruction, assess the operational life of the pavement, and formulate recommendations on its repair.

References

1. Technique of assessment of operational suitability of pavements of air forces airfields. Moscow, 2007.

2. Kulchitsky, V. A., Makagonov, V. A., Vasilyev, N. B., Chekov, A. N., Romankov, N. I. Airfield pavement. Present view. Moscow, 2002. 528 pp.

3. Vinogradov, A. P. Reliability and certification of cement stone pavements of airfields. Moscow, 1994 125 pp.