UDC 625.717.02 (045)

Taras Bliznyuk

THEORETICAL ASPECTS OF LIGHTWEIGHT HELIPAD PAVEMENT CALCULATION

National Aviation University
Kosmonavta Komarova avenue 1, 03680, Kyiv, Ukraine
E-mail: Bliznyuk10@mail.ru

Abstract. *The article focuses on the calculation of mobile heliport and airport pavement. Benefits and disadvantages of using steel plates as a pavement material and history of its development are presented. Basic calculation relations, which could be used in the development of standard calculation procedure of mobile pavements, are also given.*

Keywords: helipad; heliport; lightweight pavement; membrane shell; metal plate; mobile pavement.

1. Introduction

Today a helicopter is the most advanced representative of vertical takeoff aircraft's family.

Unlike an airplane a helicopter can move backwards and sideways, hover at one place.

This exceptional flight characteristics identified a wide range of its using.

At present, the scope of helicopter's widely used – it can be used even as an air crane during construction works.

Currently there is no normative document in Ukraine devoted to the design of heliports pavements.

This problem is related to the development of the modern national normative documents instead of the former Soviet design standards.

While the new regulations are being approved Ukraine should use the ICAO standards.

However, there are no recommendations for the design and calculation of the mobile pavement in the aforementioned normative document, and basis relations for determining the stress state of slabs are absent too.

2. Analysis of publications

Nowadays there is two most common pavement types for aircraft in the world [2]:

– rigid (concrete, reinforced concrete and asphalt cement-based pavements);

– flexible (asphalt concrete, pavements which is consist ofdurable stone materials treated with organic binders, crushed stone and gravel materials, soils and local materials treated with inorganic and organic binders, prefabricated metal, plastic or rubber elements).

However, taking into account peculiarities of takeoff and landing helicopters operations, we shouldadditionally distinguish pavements of rooftop helipads, ground helipads and pavements which arose above ground level and pavements for temporary helipads (mobile or dismountable pavements).

Of the proposed at different times prefabricated pavement designs (wooden boards, decking on joists, rubber-fabric or fabric rolls, canvas treated with bitumen, metal grid, grille with bars), some of them firmly entrenched in airfield construction practice.

Dismountable pavements with stamped metal plates were first proposed in the United States of America during the Second World War and have proliferated in peacetime.

For temporary helipads used pavements in the form of metal nets or sheet metal working only in tension.

Such pavements used earlier mostly in remote places.

Lightweight dismountablepavement previously was used for short-term aircraft operation during the war [4].

Construction of such pavements was supposed on airstrips intended for short-term aircraft deployment.

These pavements were applied in cases when construction of traditional pavements wasnot possible because of lack of time, building materials or adequate weather and suitable environmental conditions.

The use of metal pavements for temporary helipads has several advantages:

– sufficient bearing capacity for the expluatation of different types of helicopters;

– light weight (compared to the weight of material required for traditional rigid or flexible pavements);

– speed of construction (2-3 days) and its disassembly (1-2 days);

– ensuringsubbase fast drying.

However, high percentage of damaged plates and potential damage of aircraft wheels caused the need of searching other materials.

Particular interest arouse rubber-cord plates which are used, for example, for decking through railway crossing.

However, lack of calculation method makes impossible using of this perspective material.

Among theoretical studies the most significant results were obtained during studying the interaction of system: airplane – pavement – subbase.

Pavement behavior was studied as a whole structure and as individual plates in longitudinal and transverse directions.

Optimal shape of slab and its thickness, behavior of locking connection between the plates was investigated.

Service life of metal pavements for different aircrafts with different take-off weight and landing speed, design methods for metal pavements were determined [4, 5].

The most complete theoretical generalization and approximation of the behavior of real structure was done by V.K. Tsyhanovskij [6].

3. Lightweight mobile pavement strength calculation algorithm

The algorithm was developed based on the modified installation method and equations of motion of a discrete model integrating.

This algorithm, known as viscous relaxation, can be extended to solving the problem of numerical simulation of thin shells on linear elastic foundation deformation.

In practice these equations can be used to calculate runway lightweight mobile pavements for transport aircrafts in the field or in difficult terrain.

For these pavements can be used flexible shell made of composite materials which work together with soil foundation and are characterized by the presence of large deflections and strains.

Strength calculation of such pavements is related to the study of thin membrane shellson elastic foundation nonlinear deformation process.

Linear-elastic foundation on which the membrane shell based is approximated by a set of springs (Winkler foundation), connected at 90^0 to the elementary area of the membrane surface point in question.

Relations between elastic membrane shell and elastic foundation is unilateral it means that reaction appearsonly with a positive deflection.

It is assumed that the magnitude of response is proportional to deflection (Winkler hypothesis) at a given point on the surface of the membrane shell.

The proportionality factor "c" is the modulus of elasticity function "Winkler foundation" E(c) and the depth of layer function, depth in which there is a pressure distribution on the surface forces that act on the membrane shell.

Winkler hypothesis replaces the real elastic body (foundation) by a number of unrelated between themselves springs – elastic highly compressible rods.

Assuming that reaction is proportional to vertical deformation, we find that continuously distributed on the area of the membrane reaction determined by following relation

$$q = -cv, \qquad (1)$$

where c – coefficient of proportionality;

v – deflection by the normal to the shell, mm.

A simplified mathematical model of elastic foundation (1) reproduces the properties of the soil quite well, although it can't be considered as an elastic body because cohesion between its particles much smaller than the solid elastic body.

The assumption of proportionality between deflection and reactions are performed strictly for cylindrical shell submerged in liquid.

In this case the reaction is the Archimedes lift force.

Comparing this physical membranes model on elastic foundation with a physical membranes model, for which the mathematical model based on the method of viscous relaxation, we note that they are the same [6].

Therefore, the mathematical model of differential shell scheme on elastic foundation based on the recurrent relations with elaboration of diagonal stiffness matrix and the vector of external influences caused by the influence of linear elastic foundation.

To determine the proportionality coefficient of foundation it's necessary to determine the length of elastic, highly compressible rod in Winkler foundation approximation.

Expected value of the depth (thickness) of the layer for each specific task is determined by the adopted assumptions.

For example with radius of semicircle equal to half span of the membrane shell as a criterion for determining elastic deformation area that interacts with the membrane, can be used the value of the pressure in the soil from the impact of the stamp.

Width of stamp is equal to the span of membrane.

Thus, as a spring, which affects at a given point and a discrete area of the membrane shell, we use prismatic rodas high as thickness of the deformed layer h(x) which is taken into account, and the cross-sectional area F (s).

Then proportionality coefficient of foundation reactions can be defined as

$$c = -\frac{E_{(0)}F(s)}{h(x^{\alpha})},$$

where *E* – elastic modulus, MPa;

F (s) – cross-sectional area, mm^2;

h – membrane thickness, mm;

or, in the special case for the dissemination area of deformation (pressure) in foundation soil as a semicircle

$$c = -\frac{2\sqrt{2}}{b} E_{(0)}F(s),$$

where *b* – half deflection of the membrane shell, mm.

Taking into account joining the foundation springs by normal to the deformed surface of the membrane, foundation reaction in normal decomposition in the basis defined by the components in a global basis as:

$$Q^{i'}_{(0)} n = -\frac{2\sqrt{2}}{b}(E_{(0)}F(s))_{(N)} n^{i'}_{(N)} \upsilon,$$

where $n^{i'}_{(N)}$ – components of the unit normal vector to the membrane surface at the node *N*.

After an implicit integration we obtain the following recurrent formulas for the shell on elastic foundation:

$$\left[K^{i'j'(n)}_{(NL)} + \underline{c^{(n)}_{(N)} n^{(i')}_{(N)} n^{(j')}_{(M)} \delta^{i'j'} \delta_{(NL)}}\right] \Delta\left\{u^{j'(n+l)}_{i+l}\right\} =$$
$$= \left\{Q_{(N)}(u^{i'(n+l)}_{i})\right\} - \left\{R_{(N)}(u^{i'(n+l)}_{i})\right\} - \underline{Q^{i'}_{(N)(0)}};$$
$$\left\{u^{i'(n+l)}_{i+l}\right\} = \left\{u^{i'(n+l)}_{i}\right\} + \Delta\left\{u^{i'(n+l)}_{i+l}\right\},$$

where $n^{i'}_{(N)}$ – components of the unit normal vector at the nodes of the shell;

$c^{(n)}_{(N)}$ –coerced coefficient of proportionality of foundation reaction;

$Q^{i'}_{(N)(0)}$ – components of foundation reactions.

Underlined components determine the impact of foundation in the interaction with membrane.

In solving problems of nonlinear shell deformation on elastic foundation with contact or concentrated influences it should be considered uniaxial stress state of shell membrane.

For shell on elastic foundation, it is necessary to analyze unilateral relations of the local discrete shell model in the tangential plane and in the direction of motion by the normal vector, which leads to significant non-linearity in the behavior of membrane deformation.

4. Stress-strain state of the membrane

Let's present an infinitesimal element of the membrane, uniformly – distributed load with intensity p = p (x, y) acts on its surface.

Let us show stresses at points k and k_1 of cross-sections which are parallel to the planes YZ and XZ respectively.

Points k and k_1 are located on the distance z from the middle plane of the membrane.

For each tangential stress first index corresponds to the normal vector to the section on which the stress acts, and the second index indicates the direction of tension.

In accordance with the rule of the parity of shear stresses

$$\tau_{xy} = \tau_{yx}.$$

We examine effect of load acting perpendicular to the median plane.

Therefore, the resultant of all forces, which are determined by stresses σ_x, σ_y i τ_{xy} are equal to zero and corresponding forces that calculated based on this stresses represented only as moments.

Stress σ_x is transformed into M_x moment and stress σ_y- into M_y moment (Fig. 1).

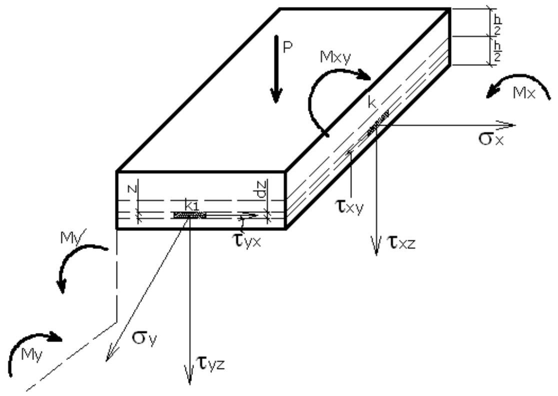

Fig. 1. Infinitesimal element of the membrane

All forces (and moments) is calculated as the resulting stress per unit of length.

Stresses σ_x, $\sigma_y$will give moments

$$M_x = \int_{-\frac{h}{2}}^{+\frac{h}{2}} \sigma_x z dz; \; M_y = \int_{-\frac{h}{2}}^{+\frac{h}{2}} \sigma_y z dz; \qquad (2)$$

where Mx, My –moments, kNm.

Moment M_x acting in XZ plane, and the moment M_y – in YZ plane.

Stresses τ_{xy} and τ_{yx} represented as torque moments

$$M_{xy} = M_{yx} = \int_{-\frac{h}{2}}^{+\frac{h}{2}} \tau_{xy} z dz; \qquad (3)$$

where τ_{yx}– shear stress, MPa.

Size dx on dy membrane element presented on the Fig. 2 and positive directions of internal forces $Q_x, Q_y, M_x, M_y, M_{yx}, M_{xy}$ are shown.

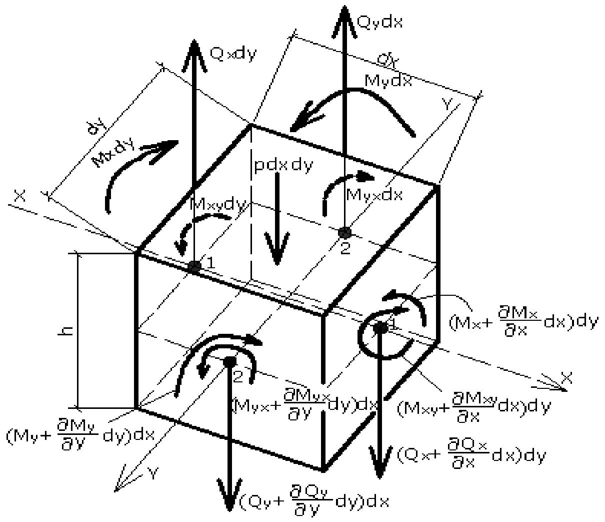

Fig. 2. Element of membrane with all components of internal forces

Projecting all forces applied to the membrane element on vertical axe Z taking into account the equilibrium conditions we obtain following relation

$$pdxdy + \frac{\partial Q_x}{\partial x} dxdy + \frac{\partial Q_y}{\partial y} dydx = 0.$$

By summing equilibrium conditions in the form of the sum of moments relative to axes 1 and 2 which are parallel to the axes X and Y, neglecting the small second-order summands and keeping in mind that $M_{yx} = M_{xy}$, we obtain following equation

$$\frac{\partial^2 M_x}{\partial x^2} + 2\frac{\partial^2 M_{xy}}{\partial x \partial y} + \frac{\partial^2 M_y}{\partial y^2} = -p.$$

This equation is not enough to determine three bending moments M_x, M_y i M_{xy} and to solve this problem we need to consider the deformation of the membrane by presenting bending moments through the second derivative of deflection [1].

5. Differential equations of curved membrane surface

For thin plates we introduce following assumptions:

1. We assumed that all points of the plate, which lie opposite to each other in vertical direction, receive the same deflection, which does not depend on coordinate z, ie, $w = w(x, y)$.

Mutual compression of membrane layers is neglected.

2. The normal vectors to the median plane of the membrane (c-c) remain perpendicular to the curved surface after deformation (Fig. 3).

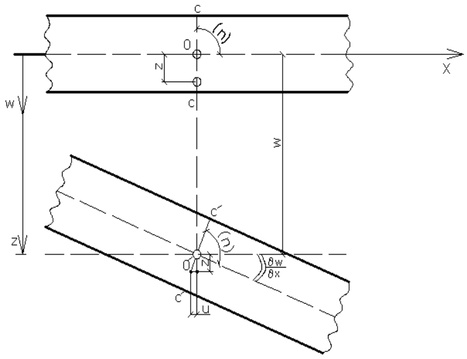

Fig. 3. A fragment of the membrane before and after deformation

Normal stress σ_z is much smaller than σ_x, σ_y, so it is not included in the calculations.

Therefore, the relative strain ε_x, ε_y can be defined by the following:

$$\left.\begin{aligned} \varepsilon_x &= \frac{\partial u}{\partial x} = \frac{1}{E}(\sigma_x - \nu\sigma_y); \\ \varepsilon_\nu &= \frac{\partial \nu}{\partial y} = \frac{1}{E}(\sigma_y - \nu\sigma_x), \end{aligned}\right\}$$

where ν – Poisson's ratio.

Furthermore:

$$\gamma_{xy} = \frac{\tau_{xy}}{G} = \frac{\tau_{xy} \cdot 2(1+\nu)}{E}.$$

Solving the above equation with respect to stresses, we obtain

$$\left.\begin{aligned} \sigma_x &= \frac{E}{1-\nu^2}\left(\frac{\partial u}{\partial x} + \nu\frac{\partial v}{\partial y}\right); \\ \sigma_y &= \frac{E}{1-\nu^2}\left(\frac{\partial v}{\partial y} + \nu\frac{\partial u}{\partial x}\right); \\ \tau_{xy} &= \frac{E}{2(1+\nu)}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right). \end{aligned}\right\} \qquad (4)$$

Let's express displacements from Fig. 3 (using 1st and 2nd assumptions)

$$u = -z\frac{\partial w}{\partial x}; \quad v = -z\frac{\partial w}{\partial y}.$$

Taking into account these relations and introducing them into the equation (4), we obtain the following final relation between stresses and plates deflection:

$$\left.\begin{aligned} \sigma_x &= -\frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right); \\ \sigma_y &= -\frac{Ez}{1-\nu^2}\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right); \\ \tau_{xy} &= -2Gz\frac{\partial^2 w}{\partial x \partial y} = -\frac{Ez}{1+\nu}\cdot\frac{\partial^2 w}{\partial x \partial y}. \end{aligned}\right\} \quad (5)$$

Equation (5) we introduce in relation (2) and (3). After integration over the cross section height we get following equations for M_x, M_y and M_{xy}

$$\left.\begin{aligned} M_x &= -D\left(\frac{\partial^2 w}{\partial x^2} + \nu\frac{\partial^2 w}{\partial y^2}\right); \\ M_y &= -D\left(\frac{\partial^2 w}{\partial y^2} + \nu\frac{\partial^2 w}{\partial x^2}\right); \\ M_{xy} &= -(1-\nu)D\frac{\partial^2 w}{\partial x \partial y}, \end{aligned}\right\}$$

where D – membrane stifness:

The equation for determining the transverse forces D_x, D has the following form [3].

$$\left.\begin{aligned} Q_x &= -D\frac{\partial}{\partial x}\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right) = -D\frac{\partial}{\partial x}(\Delta w); \\ Q_y &= -D\frac{\partial}{\partial y}\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right) = -D\frac{\partial}{\partial y}(\Delta w). \end{aligned}\right\}$$

Therefore, all efforts expressed through derivatives of plate deflection w.

Using the equilibrium conditions and the equation for the moments after transformations we obtain the differential equation curved middle surface of the membrane:

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \Delta\Delta w = \frac{p}{D}.$$

It is a heterogeneous biharmonic equation.

It can be briefly written as

$$\Delta\Delta w = \frac{p}{D},$$

on the left side there is biharmonic operator on w.

Applying it, we are faced with difficulties in finding a suitable solution that should satisfy fixation conditions the plate edges – so-called boundary conditions.

6. Conclusions

1. The history of lightweight mobile airport pavments was reviewed.

This pavement type can be used when construction of traditional pavements is impossible because of lack of time, building materials or adequate weather and suitable environmental conditions.

Undeniable advantage of mobile lightweight pavement is fast pace of its construction (2-3 days).

Particular attention is given to dismountable lightweight pavement of metal plates.

However, present time requires reduction of pavement elements weight.

Therefore metal plate slightly lost its popularity. Instead of this pavement type come pavements with other more lightweight, but strong enough materials (plastic, rubber).

Obtained relations can be used to determine the internal forces in pavement elements from such materials.

2. Strength calculation algorithm of lightweight mobile pavement was developed.

Design model of lightweight mobile pavement is presented as shell membrane.

3. Differential equation derivation ofmembrane shell curved middle surface was shown.

Without this relation any analysis of the stress-strain state of mobile lightweight pavement is impossible.

Further Outlined material can be used as a basis for the development of calculation methods for lightweight pavement design in further investigation

References

[1] *Avdonin, E. S.* Applied analysis methods of shells and thin-walled structures.Oniks, 2012. 404 p. (in Russian).

[2] *Buzunov, V.K.* Airport – combat aircraft position. Moscow, Voenizdat. 1969. 135 p. (in Russian).

[3] *Golovanov, A. I.; Kornishyn, N. S.* Introduction to the finite element method of static thin shells. KphTU. 1989. 271 p. (in Russian).

[4]*Pershakov, V.M.; Lutcenko, O.K.; Pluzhnikov, B.O.* Military airfields. Metal airports pavement. Kyiv. 2004. 58 p. (in Ukrainian).

[5] *Polyakov, A.V.* Airport pavements. Leningrad, VIKI. 1968. 456 p. (in Russian).

[6] *Tsyhanovskij, V.K.; Kozlovets, S.M. ; Koryak A.S.*Thin plates on elastic foundation calculation by finite element method. Kyiv, Publishing House “Stal“. 2008. 236 p. (in Russian).

Recevied 23 June 2014.

Т. В. Близнюк. Теоретичні особливості розрахунку мобільних вертодромних покриттів
Національний авіаційний університет, просп. Космонавта Комарова, 1,Київ , Україна, 03680
E-mail: Bliznyuk10@mail.ru
Розглянуто питання визначення напружено-деформованого стану тимчасових покриттів під повітряні судна, розрахунку мобільних аеродромних та вертодромних покриттів. Зазначено, що в Україні не існує нормативної документації щодо проектування, розрахунку вертодромних покриттів різних типів, влаштування тимчасових покриттів із тонких металевих або гумокордових плит. Як модель плити покриття для отримання основних розрахункових залежностей вибрано тонкостінну оболонку на пружній основі. Роботу основи змодельовано за допомогою набору пружин, що не пов'язані одна з одною. Наведено розрахункові залежності, які можуть бути використані під час розроблення нормативної методики розрахунку мобільних покриттів.
Ключові слова: вертодром; вертолітний майданчик; збірне покриття; мембранна оболонка; металева плита; полегшене покриття.

Т.В. Близнюк. Теоретические особенности расчета мобильных вертодромных покрытий
Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Украина, 03680
E-mail: Bliznyuk10@mail.ru
Рассмотрены вопросы определения напряженно-деформированного состояния временных покрытий под воздушные суда, расчета мобильных аэродромных и вертодромных покрытий. Отмечено, что на Украине не существует нормативной документации по проектированию, расчету вертодромных покрытий разных типов, устройству временных покрытий из тонких металлических или резинокордовых плит. В качестве модели плиты покрытия для получения основных расчетных зависимостей выбрана тонкостенная оболочка на упругом основании. Работа основания смоделирована с помощью набора пружин, не связанных друг с другом. Приведены расчетные зависимости, которые могут быть использованы при разработке нормативной методики расчета мобильных покрытий.
Ключевые слова: вертодром; вертолётная площадка; мембранная оболочка; металлическая плита; облегчённое покрытие; сборное покрытие.

Bliznyuk Taras (1988). Postgraduate student.
Department of Reconstruction of Airports and Highways of Airports, National Aviation University, Kyiv, Ukraine.
Education: Automobile and Road Technical University, Donetsk National Technical University, Donetsk, Ukraine (2011).
Research area: improving the design methods of airfields pavements and heliports pavements.
Publications: 3.
E-mail: Bliznyuk10@mail.ru