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OPTIMAL VERTODROME COVERINGS CALCULATION AND DESIGNING

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Abstract. The article considers the calculation of rigid helipad coverings, single-layer covering modeling in PC LIRA CAD, FEAFAA; calculation of cement-concrete covering, temporary coverings of metal plates, the differential equation of the membrane curved surface. A great contribution to this work was made by the master of construction T.V. Blyznyuk.

Keywords: calculation of rigid helipads, modeling single-layer covering, cement-concrete covering, temporary covering of metal plates, membrane curved surface differential equation.

Calculation of rigid helipad coverings

For heliports located at ground level, it is recommended to use cement-concrete coverings (prefabricated or monolithic). Given the relatively small loads from the helicopter undercarriage, only single-layer coverings are used. However, due to the large range of loads from the helicopter main landing gear (it varies in the range of 0.5 t to 20-30 t), the use of this type of covering is not always appropriate, as it doesn’t fully utilize the covering strength. In addition, heliports, unlike airfields, handle a relatively small area (a circle with a radius of 200 – 300 km), due to the cost of helicopter flight hour. Sometimes it is necessary to build a temporary heliport or relocate the existing one, and in this case the use of cement concrete covering is uneconomic [1,2]. In such cases, it is proposed to make prefabricated helipads, but for this purpose it is necessary to determine helicopter categories for which such structures are suitable. Therefore, mathematical models and software packages must be used to choose an optimal heliport design.

Modeling a single-layer covering in the PC LIRA CAD

In PC LIRA CAD, the covering was modeled in the form of a matrix of 9 plates. Elastic connection with pins is provided between the plates (or, in the case of PAG plates staples of adjacent plates are welded). The use of one plate is not allowed as in this case the interaction between the covering plates will not be taken into account [3 – 5].

Modeling the connection between the plates by means of pins was performed with the help of finite elements № 55 in the PC LIRA CAD. This type of finite element works linearly in tension and compression to «infinity» with a given stiffness R. It is used to account for the yieldability between the covering model nodes, the element allows you to design both the linear and angular yielding of connection relative to the X, Y and Z axes in the global coordinate system (Fig. 1).

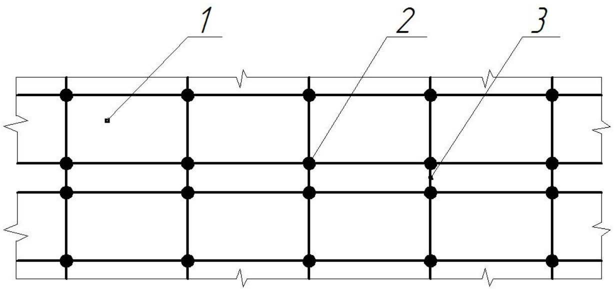

Fig. 1. Pin connections between the cover plates in the LIRA PC: 1 – finite element plate; 2 – node; 3 – finite element № 55 (simulates elastic connection between pavement slabs)

In this work, the software package PC LIRA CAD, developed at the department at NAU, was used. For comparison, the FEAFAA software package was used as the most common for use abroad[6].

The stiffness of the covering plates pin connection is determined by formula (1):

$$k = \frac{D}{s}, \tag{1}$$

where s is the pins pitch;

D is the coefficient, the value of which is determined by the pin adhesion to the concrete (determining the vertical stiffness) and the stiffness caused by the plate bending. It is determined by the formula:

$$D = \frac{1}{\frac{1}{DCI} + \frac{1}{12C}}, \tag{2}$$

where DCI is the pin interaction with the pavement slab concrete. It is determined based on the assumption [7] that the pin is a beam on an elastic basis by the formula:

$$DCI = \frac{4\beta^3}{2+\beta w} E_d I_d, \tag{3}$$

where *Ed* is the Young's modulus, MPa;
I_d – inertia moment of the pin section, m^4;
w is the seam width, m;
β is the coefficient determined by the formula:

$$\beta = \sqrt[4]{\frac{Kd}{4E_d I_d}}, \tag{4}$$

where *K* is the coefficient characterizing the pin adhesion to the covering concrete, MN/m^3; *d* is the pin diameter, m

The coefficient K value depends on the method of pin arrangement, for the method of immersion, *K* is equal to 4.07 x 10^5 MN/m^3 [8,9].

The variable *C* in equation (2) is determined by the formula:

$$C = \frac{E_d I_d}{w^3 (1+\phi)}, \tag{5}$$

where ϕ is the coefficient determined by the formula:

$$\phi = \frac{12 E_d I_d}{G_d A_z w^2}, \tag{6}$$

where A_z is the pin effective area, assumed to be 10% smaller than the actual area of the rod:

$$A_z = 0{,}9 A_d = 0{,}9 \frac{\pi d^2}{4}, \tag{7}$$

E_d – shear modulus of the rod, MPa determined by the formula:

$$G_d = \frac{E_d}{2(1+\mu_d)}, \tag{8}$$

where μ_d is the pin Poisson's ratio, MPa.

Substituting the values for the parameter ϕ, formula (6), and for the reinforcing pin effective transverse area (7) in expression (5), we obtain the following dependence:

$$C = \frac{0{,}9 G_d E_d I_d A_d}{0{,}9 G_d A_d w^3 + 12 E_d I_d w}. \tag{9}$$

The expression for determining the amount of pin adhesion to the pavement slab concrete (2), taking into account expression (9) will take the form:

$$D = \frac{1}{\frac{w}{0{,}9 G_d A_d} + \frac{w^3}{12 E_d I_d} + \frac{2+\beta w}{4\beta^3 E_d I_d}}. \tag{10}$$

Taking into account expression (10), the formula for calculating the pin connection stiffness will take the form:

$$k = \frac{1}{s\left(\frac{w}{0,9G_d A_d} + \frac{w^3}{12E_d I_d} + \frac{2+\beta w}{4\beta^3 E_d I_d}\right)}. \quad (11)$$

Given that along the length of the plates connection several pins are installed with certain spacing, the stiffness of one pin will be determined by the formula:

$$R = \frac{1}{s(n-1)\left(\frac{w}{0,9G_d A_d} + \frac{w^3}{12E_d I_d} + \frac{2+\beta w}{4\beta^3 E_d I_d}\right)}, \quad (12)$$

Where *n* is the number of nodes along the length of the connection.

For the nodes located at the edge of the plate, the stiffness is reduced by half [10].

This approach allows you to design the load transfer between the plates. In PC LIRA CAD the obtained value is used as the stiffness of finel elements №55 in the vertical direction, which are used to simulate the connection between the plates.

Modeling single-layer covering in FEAFAA. The FEAFAA (Finite Element Analysis Federal Aviation Administration) software was developed by the US Department of Airport Technology R&D Branch as a stand-alone tool for calculating hard airfield pavements (and reinforced coverings) using the finite element method. This program is used to accurately determine the values of stresses, deformation and deflection of the pavement slabs under the action of a particular aircraft main landing gear [11].

The main FEAFAA features:

−the covering is modeled by 9 plates, the connection between the plates is provided by insertion of metal pins;

−up to 6 layers can be used in the calculation;

−infinite model of the ground bed;

−modeling the covering central and edge loading;

−modeling and calculation of reinforcement layer;

−the plates sizes are set by the user;

−flexible aircraft library.

When calculating the program uses such preprocessors as: NIKE3D (used for final element analysis) and INGRID (generates the final element grid). INGRID receives output data directly from FEAFAA [12, 13].

The three-dimensional model of the airfield pavement consists of 9 plates arranged in the form of a 3x3 matrix and connected by linear elastic seams. Discrete vertical elements (springs) connect adjacent plates at key points and provide the transmission of stress through the seam, the nominal value of strength is 100000 pounds/inch per each inch of seam length.

Hard pavement modeling in the FEAFAA program is based on the following provisions [14 – 17]:

−the main finite element type in FEAFAA is an eight-node hexagonal connecting element. The model uses only one type of element for all structural layers. Compared to a standard hexagonal element, the eight-node element has some difference at bending strain;

−due to different bending work, each structural layer consists of one element by thickness. Using this approach it is possible to accurately model the covering with a minimum number of elements;

−voltages in the elements are calculated at eight integration points. For elements that are predominantly bendable, the average stress value will be close to 0. In this case, it is recommended to use an average stress value at four integration points in the extended zone and at four points in the compressed zone;

−in the general case, two contact surfaces can be defined for each covering plate. The first is the plane between the plate lower surface and the upper surface of the base layer, the second is the plane between the covering upper surface and the lower surface of the reinforcement layer. If there is no reinforcement layer, only one contact surface is defined. At modeling it is considered that covering layers work without mutual sliding;

−the lower layer of the ground bed final elements consists of eight nodal «infinite» elements. Like standard elements, infinite elements are eight-nodal hexagons. However, infinite elements have a special mapping function that mathematically simulates eight-node geometry in “semiinfinite” space. Thus, FEAFAA models a rigid covering structure on an infinite elastic basis;

−infinite elements require an additional parameter that determines the direction of infinity in one of the six main directions in the local coordinate system;

−pin plate joints are modeled by individual finite elements. An element in the form of a unidirectional spring is used for modeling [18]. In the general case, the force transmitted by the spring in the i-th direction is determined by the formula:

$$F_i = k\Delta_i\,, \quad (13)$$

where F_i is the force transmitted by the spring in the i-th direction; *k* is the spring stiffness; Δi- spring deformation in the i-th direction.

It is believed that the shear force is linearly proportional to the relative vertical displacement between the plates. The seam is characterized by such a parameter as the equivalent at stiffness shear kjoint , expressed in the units of force relative to the vertical displacement per length unit of the seam.

When modeling pin joints, the following data are input: the pins diameter, the pins pitch, the thickness of the seam between the plates, as well as the method of arranging the joints. There are two ways to arrange the joints: in fresh concrete (using vibrating plungers) and in drilled holes [19, 20].

The node model is used in order to more accurately take into account the shear effect at bending. The fundamental differences in the operation of a conventional connecting element and a nodal element are shown in Fig. 2.

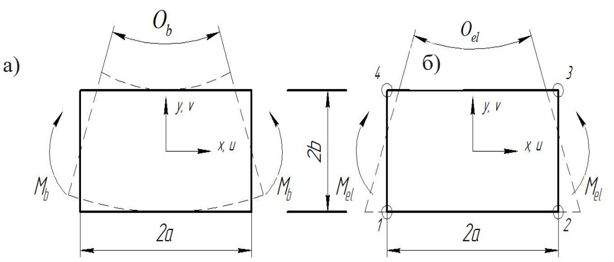

Fig. 2. Deformation of the element during bending: a)conventional element; b)proposed eight-node element

Figure 2a shows the element operation (vertical and horizontal displacement) at pure bending. It's obvious that there are no shear deformations or they are close to zero. However, when a four-node element plan view is introduced into calculation (Fig. 2b), it is seen that there are only horizontal movements of nodes. Vertical deformations equal zero or have very low values. So the element shows the shift, and not bend. It is the so-called false shift that determines the element rigidity. The effect of false shift can be levelled by introducing the equation of the quadratic deformation model. This equation is added to the standard function:

$$u(,) = \sum_{i=1}^{4} N_i(,)u_i + \sum_{i=5}^{6} N_i(,)a_i, \quad (14)$$

where $N_{1...4}$ are functions related to the standard bilinear function describing the position of the nodes;

$N_{5.6}$ – functions related to additional types of functions describing the nodes position determined by the formulas:

$$N_5(,) = 1 - ^2, \quad (15)$$

$$N_5(,) = 1 - ^2, \quad (16)$$

a_i – represents the number of degrees of freedom in the nodes,since it can not be associated with any node, it is considered to be the "internal" number of the element degrees of freedom;
u_i – node displacement.

Application of these incompatible models of behaviour gives a good result in bending, even if the modeling provides for only one element by thickness of the layer. Thus, for the eight-node connecting element, the total node displacement can be calculated as the sum of its displacements in two incompatible behavior patterns (Fig. 2 a, b):

$$u = \sum N_i u_i + (1 - ^2)a_1 + (1 - ^2)a_2 + (1 - ^2)a_7, \quad (17)$$

$$v = \sum N_i v_i + (1 - ^2)a_3 + (1 - ^2)a_4 + (1 - ^2)a_8, \quad (18)$$

$$w = \sum N_i u_i + (1 - ^2)a_5 + (1 - ^2)a_6 + (1 - ^2)a_9. \quad (19)$$

where *u, v* are the plate displacement in the horizontal area in the directions *x* and *y*, respectively; *w* is the vertical movement in the direction of the z axis.

Work in the program begins with the selection of the estimated aircraft. FEAFAA contains an aircraft library, containing most of the existing serial passenger, transport and military aircraft. The program also provides the possibility of editing the proposed landing gear configurations and saving the result in the standard library. The position of the aircraft wheels, the percentage weight distribution between the main and auxiliary supports, the number of supports and the pressure in the wheel tires of the undercarriage are input [21].

When calculating, there are two possible ways to transmit the load from the wheel to the covering – by the area of the square and by the area of the rectangle. The square imprint of a wheel is usually used with a circular load (LEAF program). The area of the rectangular wheel imprint is determined according to the recommendations of the Portland Cement Association (PCA). The dimensions of the imprint are: 0.8712Lx0.6L, where L is the length of the equivalent elliptical imprint of the wheel, determined by the formula: $L = (A/0.5227)^{0.5}$. The validity of using the wheel imprint rectangular area was proved by PCA in the development of design schedules for rigid airfield pavements.

CONCLUSION

1. Comparing the FEAFAA and PC LIRA CAD calculation complexes, the flexibility of the latter should be noted. The FAA focuses on the calculation of traditional aerodrome covering designs. The software package is characterized with the ease of entering information and an integrated database of the most common passenger and military aircraft. However, the user is not able to set coverages of any arbitrary sizes for calculating, and the aircraft data base does not include the characteristics of helicopters. Moreover, the possibility of taking into account the sliding landing gear is not provided either.

2. In PC LIRA CAD it is possible to calculate the covering of any size by changing the size of final elements. In addition, this software package allows to set the load both from the wheel landing gear and the skids. That is why LIRA CAD PC was used for further calculations.

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АНОТАЦІЯ

Aijun Yao, Бєлятинський А., Yulin He, Jian Sun. Розрахунок та проектування оптимального вертодромного покриття.

У статті розглянуто розрахунок жорстких гелікоптерних покриттів, моделювання одношарового покриття в ПК ЛІРА САПР, FEAFAA, розрахунок цементобетонного покриття, тимчасового покриття з металевих пластин, диференціальне рівняння криволінійної поверхні мембрани. Дана робота виконана майстром будівництва Близнюк Т.В.

Ключові слова: розрахунок жорстких шоломів, моделювання одношарового покриття, цементобетонне покриття, тимчасове покриття металевих пластин, диференціальне рівняння криволінійної поверхні мембрани.

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