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# IMPROVEMENT OF CONCRETE AIRFIELD PAVEMENT DESIGN

*The State norms of Ukraine have only two values of transitive factor which do not account modern aircraft main landing gear configurations and number of wheels. New values of transitive factor for calculation of edge bending moment are determined for concrete airfield pavement. Transitive factor values are obtained by using finite element modeling programs LIRA and FEAFAA.*

In Ukraine concrete airfield pavement of the international airports is two-layer pavement with joint matching that's why improvement of its design is important especially for pavement analysis under impact of modern aircraft (A320, A350-900, A380-800, B737-900ER, B747-8, B777, B787-9) main landing gears.

In the State norms of Ukraine concrete slab structural analysis is performed using infinite slab model with loads placed on its center. The free-edge stress equals interior stress multiplied by transitive factor $k$=1,5. If slab has joints the edge stress is equal interior stress multiplied by transitive factor $k$=1,2 (СНиП 2.05.08-85). According to the analytical research of G. Glyshkov transitive factor value depends on main landing gear configuration and number of wheels [1].

Federal Aviation Administration (FAA) of the United States of America uses the simplified 25% reduction factor that has allowed the complex behavior of joints to transfer load (AC 150/5320-6E). Free-edge loading structural analysis is performed using single-slab model without joints and with wheel loads placed along the edge of the slab. Joint load transfer is not a constant but rather is a stochastic variable changing continually as a function of temperature, and degrading over time due to repeated loading. The degree of load transfer is commonly called load transfer efficiency (LTE) and can be defined based on stresses or deflections [2]. There are three widely-used definitions for load transfer at a pavement joint: $LTE_\delta$ or LTE(δ) – deflection-based Load Transfer Efficiency; $LTE_\sigma$ or LTE(S) – stress-based Load Transfer Efficiency; percent of "Free-Edge Stress" Load Transferred (LT). LT is determined by using the formula:

$$LT = \frac{\varepsilon_F - \varepsilon_L}{\varepsilon_F}, \tag{1}$$

where: $\varepsilon_F$ – bending strain for free-edge loading conditions; $\varepsilon_L$ – bending strain in the loaded slab edge at the joint [2].

New values of transitive factor are calculated by using finite element modeling of the two-layer concrete pavement with joint matching that can be provided in program LIRA and FEAFAA. Aircraft main landing gear interior load is modeled by using one concrete slab. Edge loading for joint transitive factor $k_{joint}$ determination is modeled by using multiple-slab jointed concrete pavement. Edge loading for free-edge transitive factor $k_{fe}$ determination is modeled by using 1 slab.

In program LIRA two-dimensional shell finite elements are used to represent the upper and lower concrete slab of two-layer pavement and stabilized base. The upper and lower concrete slabs are unbounded layers with separator layer. The separator layer is modeled by FE 262 of the program LIRA finite element library. Subgrade model is Winkler foundation. Joints between adjacent slabs are represented by FE 55. Wheel load was modeled as square load that has the same magnitude as the nominal tire contact area [3].

FEAFAA was developed by the FAA Airport Technology R&D Branch as a stand-alone tool for three-dimensional finite element analysis of multiple-slab concrete airfield pavements. It is useful for computing accurate responses of rigid pavement structures to individual aircraft landing gear. FEAFAA's basic element type is an eight-node hexahedral solid element. The model uses only one element type for all structural layers. The enhanced FEAFAA software uses linear elastic joints, where joint stiffness is modeled as a constant linear stiffness value [2].

Interior and edge loading of dual wheel, two dual wheels and three dual wheels in tandem main landing gears (table 1-3) are analyzed for the following case: 450 mm upper concrete slab (7,5- by 7,5-m. slab dimensions, $E$=35300 MPa), 300 mm lower lean concrete slab ($E$=17000 MPa), stabilized base ($E$=7800 MPa), and Winkler foundation ($K$ =60 MN/m$^3$), subgrade modulus 34 MPa.

*Table 1*

Dual wheel main landing gears

| Aircraft | Magnitude of the main gear static load, kN | Main gear tire pressure, MPa | Magnitude of the wheel load with dynamic ratio, kN |
|---|---|---|---|
| A320-200 | 364,00 kN | 1,44 MPa | 227,50 |
| B737-900ER | 403,67 kN | 1,52 MPa | 262,39 |

*Table 2*

Two dual wheels in tandem main gears

| Aircraft | Magnitude of the main gear static load, kN | Main gear tire pressure, MPa | Magnitude of the wheel load with dynamic ratio, kN |
|---|---|---|---|
| A350-900 | 1259,60 | 1,66 | 409,37 |
| A380-800 | 1069,20 | 1,50 | 334,13 |
| B747-8 | 1062,99 | 1,52 | 345,47 |
| B787-9 | 1177,4 | 1,54 | 382,66 |

*Table 3*

Three dual wheels in tandem main gears

| Aircraft | Magnitude of the main gear static load, kN | Main gear tire pressure, MPa | Magnitude of the wheel load with dynamic ratio, kN |
|---|---|---|---|
| A380-800 | 1603,80 | 1,50 | 334,13 |
| B777-300ER | 1629,34 | 1,52 | 353,02 |

The bending moment is determined on the upper concrete slab of airfield pavement. The finite element modeling (FEM) results for joint transitive factor obtained in LIRA and FEAFAA are summarized in table 4, 5.

FEAFAA calculates tensile stress that can be converted to bending moment $M$ by using FAA formula (AC 150/5320-6E):

$$M = 1,7\frac{\sigma \cdot I_g}{c}, \tag{2}$$

where: 1,7 – live load factor; $\sigma$ – stress, MPa; $I_g$ – the gross moment of inertia calculated for a 1-meter strip of the concrete slab, m$^4$; c – the distance from the neutral axis to the extreme fibre, assumed to be one-half of the slab thickness, m.

The transitive factor values are determined as bending moment ratio

$$k_{fe} = \frac{M_{edge}}{M_{int}}, \tag{3}$$

$$k_{joint} = \frac{M_{ejoint}}{M_{int}}, \tag{4}$$

where: $M_{edge}$ – edge bending moment, kN•m/m; $M_{int}$ - interior bending moment, kN•m/m; $M_{ejoint}$ - edge bending moment in slab of jointed pavement, kN•m/m.

*Table 4*

Results of finite element modeling (LIRA) for joint transitive factor

| Aircraft | $M_{ejoint}$, kN•m/m | $M_{int}$, kN•m/m | $k_{joint}$ |
|---|---|---|---|
| A320-200 | 69,451 | 58,362 | 1,19 |
| A350-900 | 101,021 | 76,903 | 1,31 |
| A380-800 (two dual wheels in tandem main gear) | 94,264 | 77,135 | 1,22 |
| A380-800 (three dual wheels in tandem body gear with perpendicular location to the slab edge) | 101,800 | 87,960 | 1,16 |
| B737-900ER | 82,165 | 68,361 | 1,20 |
| B747-8 | 103,540 | 87,078 | 1,19 |
| B777-300ER (gear perpendicular location to the slab edge) | 115,386 | 103,187 | 1,12 |
| B777-300ER (gear tangent location to the slab edge) | 105,665 | 103,187 | 1,02 |
| B787-9 (gear tangent location to the slab edge) | 105,411 | 81,984 | 1,29 |

*Table 5*

Results of finite element modeling (FEAFAA) for joint transitive factor

| Aircraft | $M_{ejoint}$, kN•m/m | $M_{int}$, kN•m/m | $k_{joint}$ |
|---|---|---|---|
| A320-200 | 69,464 | 57,992 | 1,20 |
| A350-900 | 98,302 | 74,527 | 1,32 |
| A380-800 (two dual wheels in tandem main gear) | 93,990 | 77,455 | 1,21 |
| A380-800 (three dual wheels in tandem body gear with perpendicular location to the slab edge) | 102,543 | 87,423 | 1,17 |
| A380-800 (three dual wheels in tandem body gear with tangent location to the slab edge) | 85,999 | 87,423 | 0,98 |
| B737-900ER | 82,867 | 69,056 | 1,20 |
| B747-8 | 103,207 | 86,118 | 1,20 |
| B777-300ER (gear perpendicular location to the slab edge) | 117,843 | 103,167 | 1,14 |
| B777-300ER (gear tangent location to the slab edge) | 101,269 | 103,16 | 0,98 |
| B787-9 (gear tangent location to the slab edge) | 100,913 | 78,325 | 1,29 |
| B787-9 (gear perpendicular location to the slab edge) | 100,557 | 78,325 | 1,28 |

Bending moment has maximum value for three dual wheels in tandem main gear when it has perpendicular location to the slab edge. Bending moment has maximum value for two dual wheels in tandem main gear when it has tangent location to the slab edge. This conclusion coincides with results of FAA NAPTF (National Airport Pavement Test Facility) CC2 [4].

The FEM results (LIRA, FEAFAA) for free-edge transitive factor are summarized in table 6, 7.

*Table 6*

Results of finite element modeling (LIRA) for free-edge transitive factor

| Aircraft | $M_{edge}$, kN•m/m | $M_{int}$, kN•m/m | $k_{fe}$ |
|---|---|---|---|
| A320-200 | 88,167 | 58,362 | 1,51 |
| A350-900 | 123,967 | 76,903 | 1,61 |
| A380-800 (two dual wheels in tandem main gear) | 119,823 | 77,135 | 1,55 |
| A380-800 (three dual wheels in tandem body gear) | 132,542 | 87,960 | 1,51 |
| B737-900ER | 108,843 | 68,361 | 1,59 |
| B747-8 | 129,035 | 87,078 | 1,48 |
| B777-300ER (gear perpendicular location to the slab edge) | 144,895 | 103,187 | 1,40 |
| B787-9 (gear tangent location to the slab edge) | 137,206 | 81,984 | 1,67 |

*Table 7*

Results of finite element modeling (FEAFAA) for free-edge transitive factor

| Aircraft | $M_{edge}$, kN•m/m | $M_{int}$, kN•m/m | $k_{fe}$ |
|---|---|---|---|
| A320-200 | 86,408 | 57,992 | 1,49 |
| A350-900 | 119,030 | 74,527 | 1,60 |
| A380-800 (two dual wheels in tandem main gear) | 116,934 | 77,455 | 1,51 |
| A380-800 (three dual wheels in tandem body gear ) | 131,966 | 87,423 | 1,51 |
| B737-900ER | 104,279 | 69,056 | 1,51 |
| B747-8 | 127,931 | 86,118 | 1,49 |
| B777-300ER (gear perpendicular location to the slab edge) | 140,906 | 103,167 | 1,37 |
| B777-300ER (gear tangent location to the slab edge) | 130,818 | 103,167 | 1,27 |
| B787-9 (gear tangent location to the slab edge) | 135,328 | 78,325 | 1,73 |
| B787-9 (gear perpendicular location to the slab edge) | 128,841 | 78,325 | 1,64 |

According to FEM analysis joint and free-edge transitive factor have values more or less than standard values. Their recommended values are represented in table 8. So long as aircraft B737-900ER has the same gear geometry as lower models (-400, -500, -600, -700, -800, -900, BBJ, BBJ2) transitive factor is shown for aircraft B737. Aircraft B747-8 has freight version with the same taxi weight and landing gears that's why table 8 includes factor values for freighter. Aircraft B777-300ER also has lower models (B777F, -200LR) with the same main landing gears.

*Table 8*

Recommended transitive factor values for modern aircrafts

| Aircraft | $k_{joint}$ | $k_{fe}$ |
|---|---|---|
| A320-200 | 1,20 | 1,50 |
| A350-900 | 1,30 | 1,60 |
| A380-800 (two dual wheels in tandem main gear) | 1,20 | 1,50 |
| A380-800 (three dual wheels in tandem body gear) | 1,20 | 1,50 |
| B737 | 1,20 | 1,55 |
| B747-8 (B747-8F) | 1,20 | 1,50 |
| B777-300ER, B777-200LR, B777F | 1,13 | 1,40 |
| B787-9 | 1,30 | 1,70 |

LT values are determined by using proposed formula $LT=(k_{fe}-k_{joint})/k_{fe}$.

Determined LT values are shown in table 9.

*Table 9*

Simplified LT values considering landing gears of modern aircrafts

| Aircraft | LT |
|---|---|
| A320-200, A350-900 | 0,20 |
| A380-800 (two and three dual wheels in tandem main gear) | 0,20 |
| B737 | 0,23 |
| B747-8 (B747-8F) | 0,20 |
| B777-300ER, B777-200LR, B777F | 0,20 |
| B787-9 | 0,24 |

## Conclusions

New values of transitive factor are determined by using FEM programs LIRA and FEAFAA for two-layer concrete airfield pavement with joint matching. Transitive factor values depend on aircraft main landing gears configuration and number of wheels.

Joint transitive factor value is equal standard value (СНиП 2.05.08-85) for A320-200, A380-800, B737 (-400, -500, -600, -700, -800, -900, -900ER, BBJ, BBJ2), B747-8 main landing gears. For A320-200, A380-800, B747-8 landing gears free-edge transitive factor value is the same as standard value too. Joint transitive factor of B777 gears is less than standard value. For aircraft A350-900 and B787-9 landing gears joint and free-edge transitive factor are more than standard values.

Percent of "Free-Edge Stress" Load Transferred (LT) value of B737 landing gear is equal 0,23 that coincides with C. R. Byrum, S. D. Kohn, C. A. Gemayel and S. Tayabji research results (0,22-0,25 – curled down analysis).

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