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FEATURES OF CALCULATION OF PREFABRICATED STEEL FIBER CONCRETE AIRFIELD SLABS

O.D. Zhuravskyi [1]   N.E. Zhuravska [1]   A.M. Bambura [2]

1. Kiev National University of Construction and Architecture, Kiev, Ukraine
zhuravskyi.od@knuba.edu.ua, zhuravska.nie@knuba.edu.ua
2. State Enterprise, State Research Institute of Building Structures, Kiev, Ukraine, abambura@gmail.com

Abstract- The results of calculating bearing capacity of a standard airfield slab PAG-14 and a similar slab with steel fiber are presented. The authors propose a method for calculating the bearing capacity of bending combined reinforced elements with ordinary and pre-stressed reinforcement, as well as steel fibers. The calculation algorithm is based on the deformation method. Comparative analysis of the calculations showed the effectiveness of using steel fiber. In this case, it is possible to almost completely replace the reinforcement mesh with steel fiber. This factor indicates the development of energy-saving technologies in the production of precast concrete structures.

Keywords: Airfield Slabs, Bearing Capacity, Steel-Fiber-Concrete, Prestressed Reinforcement, Relative Deformations, Stresses, Curvature, Bending Moment.

1. INTRODUCTION

To improve the strength and deformation characteristics of concrete, steel fiber is added to its composition [5-8, 14, 16, 17, 19]. This concrete is called steel-fiber-concrete (SFC). Reinforced concrete has increased tensile strength compared to conventional concrete. Therefore, SFC reinforces the stretched area of the bending elements. There are no recommendations in the current regulations for the calculation of SFC bending elements with prestressed reinforcement [1-6, 13]. The aim of the work is to improve the design of typical aerodrome slabs using steel-fiber-concrete. For this purpose, a comparative analysis of the bearing capacity of typical aerodrome slabs and slabs with SFC was performed. To do this, an algorithm for calculating such structures based on the deformation method was developed.

2. FORMULATION OF THE PROBLEM

Prefabricated reinforced concrete prestressed slabs PAG-14, which comply with the current DSTU B B.2.6-136: 2010 [4], are used for the arrangement of aerodrome surfaces and helipads. The slabs have dimensions in plan of 6.0×2.0×0.14 m (Figure 1).

Typical slabs use class of the concrete C20/25. Slabs are reinforced with prestressed reinforcement 5Ø14A800 (in two levels) and two rebar mesh C2 with reinforcement 4Ø5Bp-I in the longitudinal direction of the slab and Ø5Bp-I with a step of 100 mm in the transverse direction of the slab (Figure 1) [4]. In the end parts there are rebar mesh C1 in two levels with reinforcement 4Ø8A400C, located in the transverse direction of the plate, and 2Ø5Bp-I+2Ø8A400C, located in the longitudinal direction of the plate.

For alternative airfield plates, the unstressed reinforcement was replaced with steel fiber grade STAFIB 50/1.0 ($f_f=1\times10^6$ kPa; $l_f=5.0$ cm; $d_f=0.1$ cm; $\mu_{fv}=0.01$). Estimated resistance of steel-fiber-concrete to compressive $f_{cf}=22.36$ MPa and tensile strength $f_{cft}=1.49\times10^3$ kPa. Modulus of elasticity of steel-fiber-concrete is $E_{cf}=24.94\times10^6$ kPa. Relative deformations of SFC on compression $\varepsilon_{cf1}=0.00176$; $\varepsilon_{cfu}=0.00293$. Relative tensile strains SFC $\varepsilon_{cft1}=0.00018$; $\varepsilon_{cftu}=0.00035$.

3. METHOD OF CALCULATING BENDING ELEMENTS WITH COMBINED REINFORCEMENT

For the calculation we take the bending SFC element of rectangular cross-section with pre-stressed reinforcement and conventional reinforcement, which are located in the compressed and stretched cross-sectional areas. Figure 3 shows the stress and strain state of the calculated cross section of the bending SFC element [19].

According to the current norms, the limit value of the bearing capacity of the bending SFC of the element occurs at the limit values of relative deformations in the stretched zone $\varepsilon_{cftu}=-2f_{cftu}/E_{cf}$.

A system of equilibrium equations is used to determine the bearing capacity of a combined reinforced bending element of rectangular cross-section (Figure 2) [5, 19].

$$\frac{bf_{cf}}{\aleph}\sum_{k=1}^{5}\frac{a_k}{k+1}\gamma^{k+1}-\frac{3}{4}bf_{cft}\left(h-x_1\right)+\sum_{i=1}^{n}\sigma_{si}A_{si}=0 \qquad (1)$$

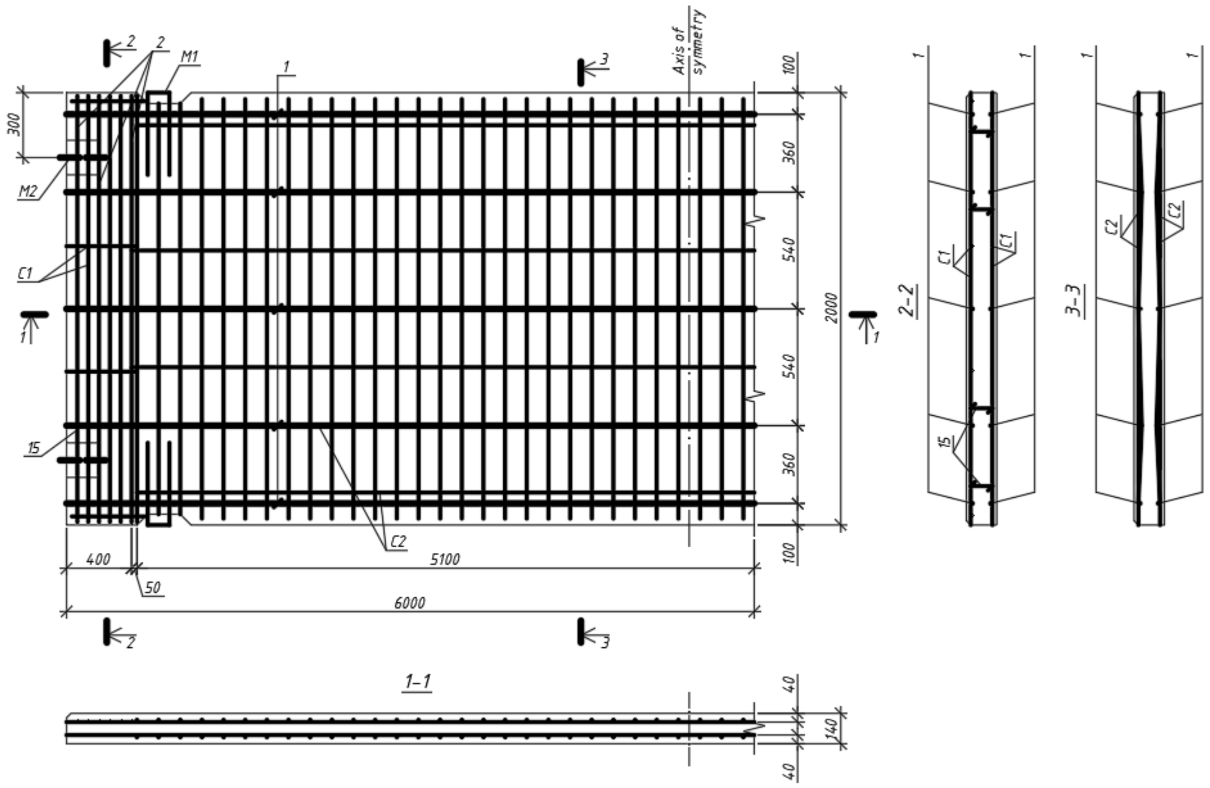

Figure 1. Reinforcement of the airfield slab PAG-14 [4]

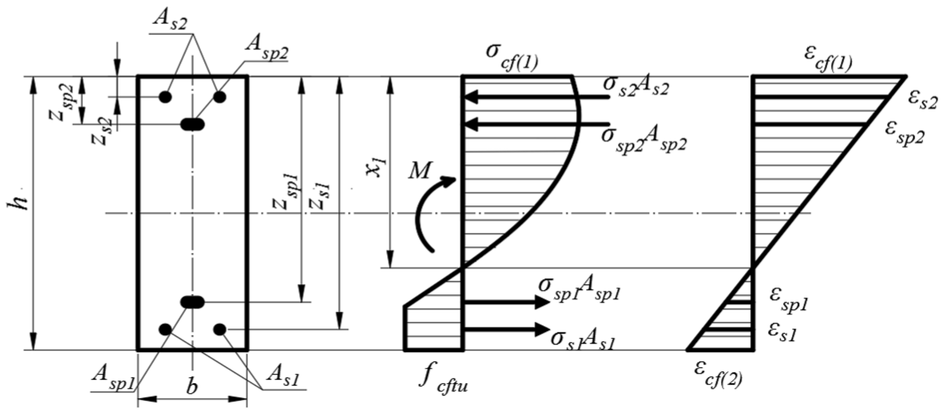

Figure 2. Stress and strain state of the calculated cross section of the bending SFC element

$$\frac{bf_{cf}}{\overline{\aleph}^2}\sum_{k=1}^{5}\frac{a_k}{k+1}\gamma^{k+2}-\frac{11}{24}bf_{cft}\left(h-x_1\right)^2+ \\ +\sum_{i=1}^{n}\sigma_{si}A_{si}\left(x_1-z_{si}\right)-M=0 \qquad (2)$$

In formulas (1), (2) the following parameters are used according to [5]. The $\aleph=\left(\frac{1}{r}\right)$ is curvature (1/m):

$$\aleph=\left(\frac{1}{r}\right)=\frac{\varepsilon_{c(1)}-\varepsilon_{c(2)}}{h} \qquad (3)$$

where, $\varepsilon_{c(1)}$ is relative deformations of SFC in the compressed area; and $\varepsilon_{c(2)}$ is relative deformations of SFC in the stretched area,

$$\gamma=\frac{\varepsilon_{c(1)}}{\varepsilon_{cf1}} \qquad (4)$$

where, ε_{cf1} is limit relative deformations of SFC in the compressed area; and x_1 is height of the compressed zone (m):

$$x_1=\frac{\varepsilon_{c(1)}}{\aleph} \qquad (5)$$

where, $\overline{\aleph}$ is relative curvature:

$$\overline{\aleph}=\frac{\aleph}{\varepsilon_{cf1}} \qquad (6)$$

where, σ_{si} is stresses in reinforcing rod; z_{si} is distance from the extreme compressed face of the section to the center of gravity of the reinforcing rod; and a_k is polynomial coefficients, which are determined by methods [8].

Equilibrium Equations (1) and (2) can be represented as [19]:

$$N_{cf} - N_{cft} + N_s = 0 \quad (7)$$

$$M_{cf} + M_{cft} + M_s = 0 \quad (8)$$

where, N_{cf}, M_{cf} are equivalent force and moment in the compressed zone of the SFC; N_{cft}, M_{cft} are equivalent force and moment in the stretched zone of the SFC; and N_s, M_s are equivalent force and moment in reinforcing rods.

The value of internal effort is determined by formulas [19]:

$$N_{cf} = \frac{bf_{cf}}{\aleph}\sum_{k=1}^{5}\frac{a_k}{k+1}\gamma^{k+1} \quad (9)$$

$$N_{cft} = \frac{3}{4}bf_{cft}\left(h - x_1\right) \quad (10)$$

$$N_s = \sigma_{s2}A_{s2} + \sigma_{sp2}A_{sp2} - \sigma_{s1}A_{s1} - \sigma_{sp1}A_{sp1} = 0 \quad (11)$$

$$M_{cf} = \frac{bf_{cf}}{\aleph^2}\sum_{k=1}^{5}\frac{a_k}{k+2}\gamma^{k+2} \quad (12)$$

$$M_{cft} = \frac{11}{24}bf_{cft}\left(h - x_1\right)^2 \quad (13)$$

$$\begin{aligned} M_s = {} & A_{s1}E_{s1}\aleph\left(x_1 - z_{s1}\right)^2 + A_{s2}E_{s2}\aleph\left(x_1 - z_{s2}\right)^2 + \\ & + A_{sp1}E_{sp1}\left(\aleph\left(x_1 - z_{sp1}\right) - \varepsilon_{p01}\right)\left(x_1 - z_{sp1}\right) + \\ & + A_{sp2}E_{sp2}\left(\aleph\left(x_1 - z_{sp2}\right) - \varepsilon_{p02}\right)\left(x_1 - z_{sp2}\right) \end{aligned} \quad (14)$$

where, ε_{p0i} is relative deformations in prestressed reinforcement. We use formulas to determine the stresses in the armature:

$$\sigma_{si} = E_{s1}\aleph\left(x_1 - z_{si}\right) \quad (15)$$

$$\sigma_{spi} = E_{spi}\left(\aleph\left(x_1 - z_{spi}\right) - \varepsilon_{p0i}\right) \quad (16)$$

Substituting expressions (5), (6), (15), (16) in Equations (9)-(11), we obtain [19]:

$$N_{cf} = \frac{bf_{cf}\varepsilon_{cf1}}{\aleph}\sum_{k=1}^{5}\frac{a_k}{k+1}\gamma^{k+1} \quad (17)$$

$$N_{cft} = \frac{3}{4}bf_{cft}\left(h - \frac{\varepsilon_{cf(1)}}{\aleph}\right) \quad (18)$$

$$\begin{aligned} N_s = {} & A_{s2}E_{s2}\aleph\left(x_1 - z_{s2}\right) - A_{s1}E_{s1}\aleph\left(x_1 - z_{s1}\right) + \\ & + A_{sp2}E_{sp2}\left(\aleph\left(x_1 - z_{sp2}\right) - \varepsilon_{p02}\right) - \\ & - A_{sp1}E_{sp1}\left(\aleph\left(x_1 - z_{sp1}\right) - \varepsilon_{p01}\right) \end{aligned} \quad (19)$$

substituting Equations (17)-(19) in (7), we obtain formulas for determining the curvature [19].

$$\aleph = \frac{-b_\Sigma + \sqrt{b_\Sigma^2 - 4a_\Sigma c_\Sigma}}{2a_\Sigma} \quad (20)$$

where,

$$\begin{aligned} a_\Sigma = {} & A_{s1}E_{s1}\aleph z_{s1} + A_{s2}E_{s2}z_{s2} + A_{sp1}E_{sp1}z_{sp1} + \\ & + A_{sp2}E_{sp2}z_{sp2} \end{aligned} \quad (21)$$

$$\begin{aligned} b_\Sigma = {} & \frac{3}{4}bhf_{cft} - \varepsilon_{cf(1)}(E_{s1}A_{s1} + E_{s2}A_{s2} + E_{sp1}A_{sp1} + \\ & + E_{sp2}A_{sp2}) \end{aligned} \quad (22)$$

$$c_\Sigma = -\frac{3}{4}bf_{cft}\varepsilon_{cf(1)} - bf_{cft}\varepsilon_{cf1}\sum_{k=1}^{5}\frac{a_k}{k+1}\gamma^{k+1} \quad (23)$$

Substitute the values $\aleph$ in formulas (12)-(14) and determine the magnitudes of the moments M_{cf}, M_{cft}, M_s. By formula (9) we determine the bending moment M. The calculation algorithm is step by step. At each step of the calculation of the value of $\varepsilon_{c(1)}$, which is successively increased by the value of $\Delta\varepsilon_{c(1)}$.

The calculation controls the voltage in the pre-stressed reinforcement in the stretched cross-sectional area. It is necessary to use the diagram "σ-ε" for pre-stressed reinforcing bars (Figure 3) [1]. Under the condition $\sigma_{sp} \geq f_{pd}$, the stress in the pre-stressed reinforcing bars must be determined by the formula [9].

$$\sigma_{sp} = f_{pd} + \left(\frac{f_{pk}}{\gamma_s} - f_{pd}\right)\frac{\varepsilon_{sp} - \varepsilon_{p0}}{\varepsilon_{ud} - \varepsilon_{p0}} \quad (24)$$

where, $f_{pd} = \dfrac{f_{p0.1k}}{\gamma_s}$; $f_{p0} = \dfrac{f_{pd}}{E_p}$; $\varepsilon_{ud} = 0.9\varepsilon_{uk}$ and

$$\varepsilon_{sp} = \aleph\left(x_1 - z_{sp}\right) - 0.0021$$

The calculation algorithm is implemented in the program Mathcad.

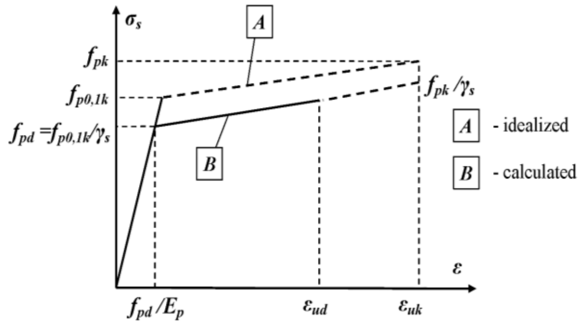

Figure 3. Diagrams σ-ε for pre-stressed reinforcing bars [1]

4. COMPARATIVE CALCULATION OF PRESTRESSED AIRFIELD SLAB

As an alternative to the standard slab PAG-14 was used slab PAG-14-SFC, in which used steel fiber STAFIB 50/1.0 instead of C2 reinforcing mesh. Comparative calculations showed that the bearing capacity of the slab PAG-14-SFC was M_u = 86.73 kNm (Figure 4). The bearing capacity of the standard plate PAG-14 was M_u = 71.49 kNm, which is less by 21.3%.

Steel fiber makes it possible to replace the reinforcing mesh with a total weight of 72.0 kg. There are also no costs for the manufacture of these grids. The performed researches have shown the possibility to reduce up to 10-15% of high-strength prestressed reinforcement.

The scientific developments of the authors of the article are related to their previous research, which is presented in [10, 12, 15].

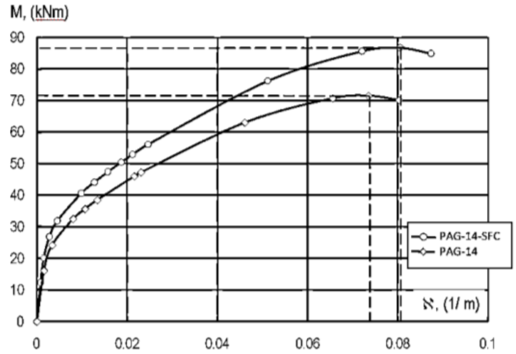

Figure 4. Graphs "bending moment-curvature" for metal fiber slab (PAG-14-SFC) and standard slab (PAG-14)

5. CONCLUSIONS

The authors propose a method and algorithm for calculating the combined reinforced steel-fiber-concrete bending elements of rectangular cross-section with pre-stressed reinforcement. This calculation method is based on the deformation method of calculation of steel-fiber-concrete elements. The work of steel-fiber-concrete in the stretched zone was taken into account.

Comparative calculations of the bearing capacity of the standard airfield slab PAG-14 and the alternative slab PAG-14-SFC showed that the bearing capacity of the slab PAG-14-SFC is higher than the slab PAG-14 by 21,3%. Steel fiber allows you to replace the structural reinforcing mesh and reduce the amount of pre-stressed reinforcement by 10...15%. Also slabs PAG-14-SFC have the best indicators on attrition.

These factors indicate the development of energy-saving technologies in the production of precast concrete structures [20-24].

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BIOGRAPHIES

Olexander D. Zhuravskyi was born in Glukhiv, Ukraine, in 1960. Head of the Department of Reinforced Concrete and Stone Structures of the Kiev National University of Construction and Architecture. He graduated from the Lviv Agricultural Institute in 1983. Candidate of Technical Sciences (Ph.D.) since 1988. Doctor of Technical Sciences since 2021. Professor since 2021. Author of over 100 scientific papers and textbooks. Sphere of scientific interests - uniaxially and biaxially prestressed reinforced concrete and fiber-reinforced concrete structures, creep of concrete and fiber-reinforced concrete under multi-axial compression.

Nataliia E. Zhuravska was born in Mogilev, Belarus, in 1969. Associate Professor at the Department of Labor and Environmental Protection at the Kiev National University of Construction and Architecture. She graduated the Kiev State Technical University of Construction and Architecture in 1994. Candidate of Technical Sciences (Ph.D.) since 2016. Associate Professor since 2018. Author of over 150 scientific papers and textbooks. Sphere of scientific interests - creation of environmental and technological monitoring solutions for dust and gas cleaning in industry, green building and environmental economics, in the context of the strategic plans of Ukraine, the foundations of sustainable development. Environmental protection technologies, the use of resource-saving environmental and economic technologies in the systems of thermal power facilities, modernization for various industries.

Andriy M. Bambura was born in Adamivka, Ukraine, in 1946. Head of the Department of Reliability of Structures of Buildings and Structures of the State Enterprise "State Research Institute of Building Structures" (Kiev). He graduated from the Kiev Civil Engineering Institute in 1971. Candidate of Technical Sciences (Ph.D.) since 1978. Doctor of Technical Sciences since 2006. Professor since 2015. Author of more than 200 scientific papers. Sphere of scientific interests - experimental and theoretical studies of real diagrams of different types of concrete. Experimental - theoretical researches of bearing capacity and stability of usual and prestressed reinforced concrete and steady reinforced concrete designs. Development of national building codes and standards. Calculations of unique buildings for load-bearing capacity and their resistance to progressive collapse.