Theoretical and Numerical Analyses of Thermal-Load Behavior of Steel-Concrete and Steel-Fiber-Concrete Slabs.

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Abstract: The increase in the volume of using concrete and structural changes in operating conditions requires continuous improvement of concrete structures that is the effective combination of concrete, steel and other components. To have a wide application of these structures in the construction practices it is necessary to improve methods of their calculation, in particular at thermal power influences. This article deals with the features of the work and determination of the limits of fire resistance steel-concrete slabs at thermal power influences and hinged support. Various ways of supporting a slab have been considered, but only using force action. Along with the use of structures with external sheet reinforcement it is effective to add various additives into the concrete in the form of fibers. Using fiber can significantly improve the performance of the structure under force action. The article deals with steel, basalt and polypropylene fibers, which were selected on the basis of rational parameters of early experimental studies. During the literature analysis it was found out that there is no practical data on the strength of fiber-reinforced concrete at thermal power influences. This stimulates new experimental and theoretical studies of fiber-reinforced concrete in case of fire. The article also describes the program Tens. Pas, which helps to carry out the calculation of hinged steel-concrete-slabs on the thermal power influences.
Keywords: slabs; steel concrete; composite; fibrous; fibrous concrete; fire endurance; thermal power influences; border conditions.

1. Introduction

In recent years double-layer plates are more and more widely used in various structures, particularly in transport construction, as they appear to be much lighter in weight than one-layer ones, but have the same bending rigidity. Steel concrete structures are more effective compared to reinforce concrete ones due to multifunctional using of a steel sheet. The greatest effect of an external reinforcement is achieved in bending two directions floor slabs and pavement buildings. Flat steel sheet runs under biaxial stretching, thereby increasing the rigidity and load carrying capacity compared steel-concrete slabs with reinforce concrete ones at the same flow rate of the metal. One of the issues of the comprehensive analysis is the improvement of existing methods for calculating steel concrete construction, in particular strain modeling at thermal power influences. Adding various kinds of fibrous to the concrete improves the strength and deformation structure characteristics. The implementation of bending in two directions steel-fibrous concrete plates is hampered by inadequate development of methods of calculation and design, especially taking into account the high-thermal-effects, as the structure equally should meet not only the strength, rigidity and fracture toughness requirements, but also fire safety requirements.

2. Methods Calculation of bends in two directions slabs

In the work [1] it was developed a mathematical apparatus for calculating steel concrete rectangular slab at thermal power influences with hinged support, and also provided a fire protection of the structure. Methodology of assessing the fire endurance of the main tenets of the theory contains steel-concrete slabs, which takes into account the addition of power, temperature effects, and is a development study [2, 3, 4 and 5]. The equilibrium conditions of steel concrete slabs element, obtained in [3] is being used:

$$\frac{\partial^2}{\partial x^2}\left(M_T - M_x\right) + \frac{\partial^2}{\partial y^2}\left(M_T - M_y\right) - 2\frac{\partial^2 M_{xy}}{\partial x \partial y} = q(x,y) \tag{1}$$

Temperature bending moments in the concrete and steel sheet are defined as follows:

$$M_T = M_T^c + M_T^s \ ; \tag{2}$$

$$M_T^c = -\int_{x_{ti}}^{x_i} \frac{\alpha_c E_c (T - T_0)}{3(1-\nu_c)} x dx \ ; \ M_T^s = -\int_{h_c}^{h_c+\delta} \frac{\alpha_s E_s (T - T_0)}{3(1-\nu_s)} x dx \ ,$$

where T_0 is the initial temperature;

α_c, α_s is the thermal expansion coefficients of concrete and steel.

Moments M_x, M_y, M_{xy} are associated with stiffness coefficients and curvature dependences [3];

$$\begin{vmatrix} M_x \\ M_y \\ M_{xy} \end{vmatrix} = \begin{vmatrix} D_{11} & D_{12} & D_{13} \\ D_{21} & D_{22} & D_{23} \\ D_{31} & D_{32} & D_{33} \end{vmatrix} \begin{Bmatrix} K_x \\ K_y \\ 2K_{xy} \end{Bmatrix}, \tag{3}$$

where $D_{i,j}$ – bending rigidity;
K_x, K_y, K_{xy} – curves.

To solve the problem of stress-strained state of steel-concrete slabs it is necessary to know the distribution of temperature and humidity of the field in its section. It was assumed that the structure is uniformly warmed: a) from the steel sheet; b) from concrete; c) from the steel sheet and the concrete simultaneously [2, 6].

Modeling of deformation process steel concrete slabs under load carried out in steps of 10 kN/m^2. The action temperature was taken into account to the equation of the standard fire and simulated as a supplement to the load at each point of the finite-difference grid. The temperature fields were determined at an interval of time until the moisture evaporates – 0.67 min., after evaporation – 1.67 min. As a numerical method for solving the finite difference method was used MKP.

Fire endurance design was characterized by its ability to resist the effects of temperature and determines the time t, when the stove loses load bearing capacity. In turn, the bearing capacity was characterized by the following factors taking place in any point of the finite-difference grid: the strength of concrete, the strength steel sheet and the strength of contact [4].

To use the program one must first calculate the distribution of temperature fields by the program «Pole», where the given information is necessary to calculate the temperature field slab thickness (the thickness of concrete, concrete density, moisture content, porosity, etc.). If the calculation includes fire protection, it is necessary to specify the data on the protective layer (protective layer thickness, density, specific heat, thermal conductivity). The calculation program «Pole», the file is formed pole *1-2.rez*, necessary programs *Tens.Pas*.

The entrance of the original data is produced in the file *Tens.ini*, where the data on parameter steel concrete slab (steel sheet - the area, thickness, Poisson's ratio, elastic modulus, yield strength, concrete - slab thickness, elastic modulus, Poisson's ratio, the estimated compression endurance, Plate Size) is set.

In the process of calculating two documents with the results of the calculation are formed. The first document *Tens.out* contains the information for each point of the finite-difference grid. This document, in spite of the information content, in terms of size is very large, makes it difficult to work with it. Therefore, for the working convenience another document is formed, Tabs. out - which contains the information for one central slab point for each load slab at a predetermined pitch, and for each temperature, which is determined depending on time according to the scheme of standard fire.

For numerical calculations steel concrete slab 6000x6000 mm thick h_c = 300 mm of concrete strength f_{cti} = 20 MPa were used. Slab of steel flat sheet thickness of δ = 3 mm of steel with a yield strength of physical σ_y = 235 MPa.

The calculation results are shown in fig.1, 2. From fig.1 it shows that when the temperature is provided on top of the impact of the required fire resistance in accordance with DBN-1.1.7-2002 to load 90% of the failure. The fire exposure from the steel slab and on both sides of the bearing capacity is not ensured even with minimal exertion. In this case it is necessary to provide structural protection to the temperature. Therefore, we propose different ways to fire protection of the steel sheet (mineral wool plate, asbestos cement slab, cement-bonded and a layer of lightweight concrete). As seen from fig.2 the type of the protective layer significantly increases the fire endurance of steel concrete slab under the action of fire from a steel sheet.

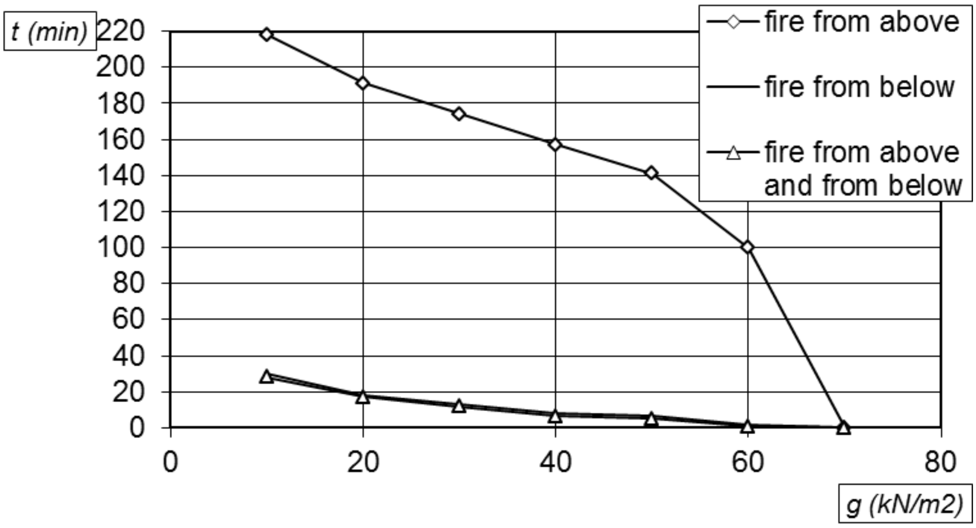

Fig.1 Dependence of the bearing capacity of steel concrete slab upon the circuit thermal effects

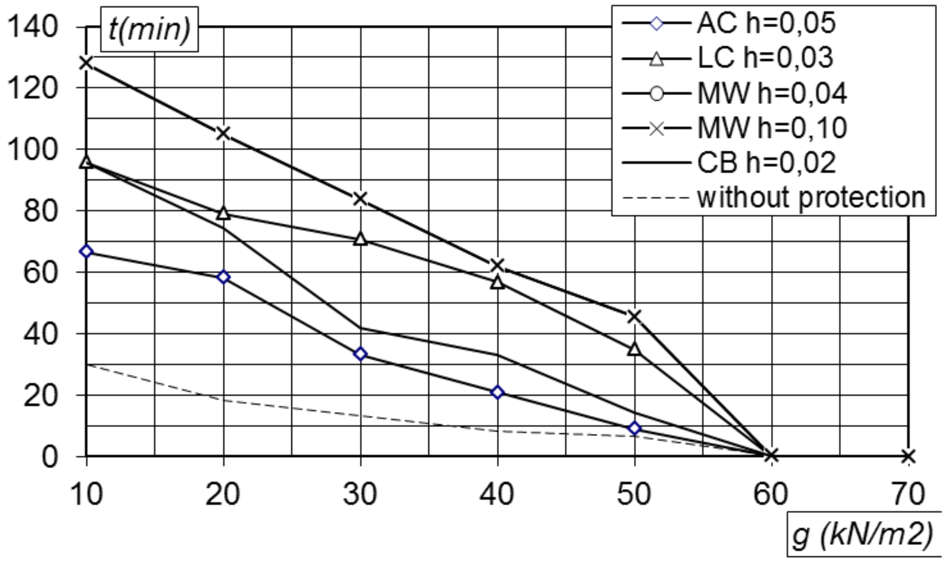

Fig.2 Dependence of the bearing capacity of steel concrete slab upon the type of thermal protection

The described method that is based on thermal force action provides only hinged support slab.

In [7] using the method of finite difference equations we obtained permit equations of the stress-strain state of the plate with a symmetric transverse in homogeneity at thermal power influences. It was noted that the three-layer plate, the middle part is less rigid than the outer, pressure $\vec{\tau}$ equalized to a greater extent than in the case of a homogeneous plate to which we would have a purely parabolic shape. In this regard, the most tangential stress at z = 0 is smaller than the homogeneous plate. In [8] the methodology of calculating rectangular steel-concrete slabs on the force action at various ways of support has been outlined (fig.3).

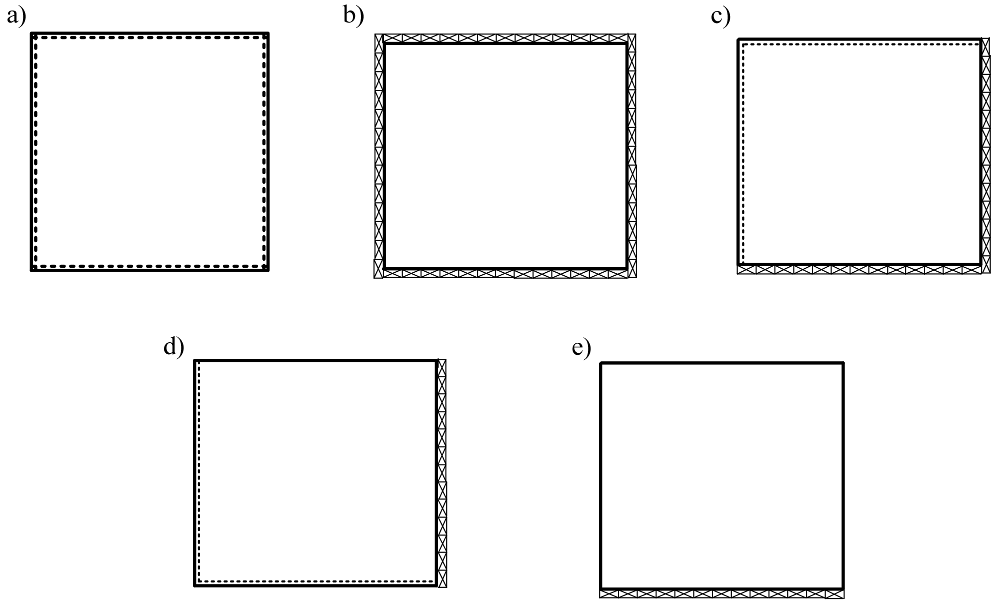

Fig.3 Schemes of supporting slabs: a) with hinge-supported edges; b) with fixed edges; c) 2 fixed edges, 2 hinge –supported edges; c) one fixed edge; d) plate console, that is one edge is fixed, and the rest are free.

During the calculation by the method of finite differences to describe the stress-strain state structure one has to deal with the aquifer functions deflection values that should be linked with additional (boundary) conditions with the values of this function within a loop. The boundary conditions are taken into account when writing the equations allowing the finite difference method; the central differences were taken for the entire structure. For different conditions of fixity in fig.4 boundary conditions for the joint and sealing the free edge are given. However, in this paper the temperature effect on the structure is not considered.

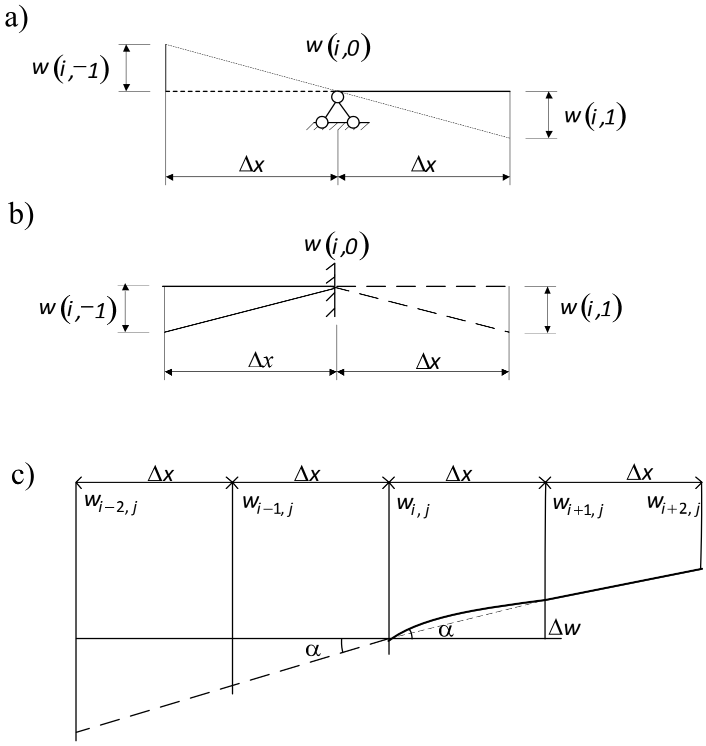

Fig.4 Boundary conditions: a) hinge support; b) seal; c) free edge

(Where, w – dips in the nodes of finite-difference grid, Δx - step of the grid)

3. Evaluation of rational parameters of fibrous reinforcement

The described calculation methods of hinge-supported slab on the combined effect of load and temperature, and a force influence on the slabs with different support conditions do not take into account influence peculiarities of the fibrous supplementation on strength concrete properties.

One of the promising areas of concrete improvement is the introduction in the concrete of different types of fibrous (basalt, steel, polypropylene, etc.). The result is a new composite material with new improved properties. For widespread fibrous concretes structures it is necessary to take into account the structure fire endurance for the design, among other characteristics. This requires mathematical apparatus for calculation of fibrous concretes slabs on the thermo power effects.

The optimal parameters of various kinds of fibrous have been proposed on the basis of the literature analysis [9].

The effect of different fibrous parameters on the strength characteristics of the fibrous-endurance concrete for different deformation types was analyzed in the article [9]. Experimental studies of various authors and the conclusions of rational parameters of fibrous reinforcement **we**re analyzed for each of the fibrous types.

Basalt fibrous is a basalt fibrous pieces integrated in the form of friable monofilaments length of 3 ... 30 mm, in some cases up to 50 mm, a diameter of 13 ... 20 mkm (fig.5). Fibrous length 12 mm with the percentage of 0.2% is for basalt fibrous. With these parameters, according to [10], the flexural strength is 30.7 MPa, compression – 88.6 MPa (tab.1).

Fig.5 Basalt fibrous

Table 1 The strength of fibrous concrete

№ experience	The number of fibrous, % by weight of cement	The length of fibrous, mm	The strength after 28 days, MPa	
			under bending	under compression
1 test	–	–	11,7	60,0
2	0,10	6	15,4	62,5
3	0,10	12	17,5	64,9
4	0,10	18	18,3	63,6
5	0,15	6	23,1	75,3
6	0,15	12	24,6	77,8
7	0,15	18	25,3	77,2
8	0,20	6	28,5	85,4
9	0,20	12	30,7	88,6
10	0,20	18	31,4	81,7
11	0,25	6	32,5	80,3
12	0,25	12	34,1	76,8
13	0,25	18	33,3	73,9

Polypropylene fibrous thread is made by the continuous process from pure polypropylene pellets by extrusion and stretching with heating (fig.6). For polypropylene fibrous the best strength characteristics showed the samples of the parameters fibrous length of 12mm, a diameter of 17 ... 21 mkm and a flow rate of 1 kg/m^3. According to the experimental data compressive strength has been obtained – 49.67 MPa, tensile – 6.36 MPa

[11]. According to the author, the introduction of fibrous produced by "DIIF", which corresponds to TU U 25-2-32781078-004 gives better strength physical and mechanical properties compared to fibrous from other manufacturers [12].

Fig.6 Polypropylene fibrous

The steel fibrous is the most durable and popular material [13]. The length of the fibrous depends on the technology of its manufacture. The diameter of the fibrous also affects the properties of steel fibrous concrete. The sectional shape of the steel fibrous may be different, so given diameter is often used. By reducing the diameter the efficiency of fibrous reinforcement increases, however, the technology of preparing a mixture and manufacturing unit is complicated. Important characteristics of the fibrous, affecting the physical-mechanical and deformation characteristics, are the ratio of length to diameter, shape, and surface condition. So the higher saturation mixture of fibrous threads, is as the greater the contact zones the better the strength and deformation characteristics of the material. Based on the analysis made in [9], it was concluded about using effectiveness of fibrous "Chelyabinka." It is manufactured according to TU 1276-001-70832021-2005 from rolled steel (a tape, a sheet), and it is a steel strip having the anchors at the ends in the form of circle segments, radius associated with the straight portions of the strip. The ends of the strips are unfolded from each other by an arbitrary angle (fig.7).

Fig.7 Fibrous «Chelyabinka»

“Chelyabinka "has higher physical and mechanical properties compared to other types of fibrous, as evidenced by the results of tests of open join-stock company “CNIIS” (tab.2). This recommended dosage of fibrous depends on the design purpose and for residential buildings - 25 ... 50 kg/m^3. According to the company Volvek Plus, Chelyabinka fibrous has higher strength characteristics in comparison with other fibrous [14]

Table 2 The test results of fibrous concrete specimens

Test type	Chelyabinka	HAREX	DRAMIX	MagFibrous-stroy
	R, MPa	R, MPa	R, MPa	R, MPa
compression	49,4	50,0	47,2	49,2
stretch	3,34	2,82	2,72	2,64
bend	7,89	6,57	7,41	5,57

After analyzing the various types of steel fibrous, it can be concluded that the most efficient is the use of fibrous "Chelyabinka" because this fibrous is manufactured at the factory according to TU, which excludes its various defects. Sheet, wire, turning and milling fibrous are obtained either by cutting the ropes or sheet, or from waste products, however, these fibrous may contain a starting material defects or defects resulting from its manufacture.

4. Conclusions

One of the issues of a comprehensive analysis is to improve existing methods of calculating concrete structure, modeling of their behavior work at thermal power impact. The conducted analysis of the literature showed that there is practically no active strength of the fibrous-steel concrete at thermal power influences. The nature of the deformation and the exhaustion of the bearing capacity of bending in two directions steel-fibrous concrete slabs that are exposed not only to the use of force, but also thermal impact, including fire conditions has been insufficiently studied.

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