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NON-STATIONARY SPATIAL HEAT TRANSFER IN A HETEROGENEOUS CLAYDITE-CONCRETE WALL

A.N. Khutornoy, A.Ya. Kuzin, N.A. Tsvetkov, T.A. Miroshnichenko, A.V. Kolesnikova

Tomsk State University of Architecture and Building
E-mail: kaftgs@tsuab.ru

Thermal condition of a heterogeneous three-layer claydite-concrete wall fragment with face heat insulation on flexible stay is investigated with the help of mathematical simulation. The character of temperature field distribution in claydite-concrete construction is stated. The influence zone of flexible stay on wall temperature field is estimated. The developed numerical method permits to diagnose rapidly the heat insulation of exterior heterogeneous claydite-concrete walls with different thermal-physical and geometric material properties in real service conditions.

The questions of energy-saving are considered to be priority direction of science, technology and engineering development of the Russian federation. It is obvious the the solution of such problems should have a complex character. In the work [1] the energy efficiency of energy saving actions in some buildings of public functions in Moscow was estimated. The total energy savings appeared to be highly significant (56...63 %), the part of heat insulation of non-translucent protections amounted 16...20 %. In the work [1] the importance of energy saving actions connected with warmth-keeping of non-translucent protections as those providing total decrease of building energy consumption less than twice is underlined. In this connection development of methods increasing heat efficiency of exterior walls of existing buildings and creation of new constructions with high heat-protection properties is the barest necessity.

To increase the level of heat insulation of exterior wall of buildings is possible due to making interstices in the construction thickness filled with efficient heat insulator [2]. However, as it is shown in [3], for some climatic zones this solution can be insufficient. To meet the requirements of СНиП II-3-79* «Stroitelnaya Teplotechnika» it is necessary to create additional warmth-keeping of frame filling, that can be performed by means of face heat insulation systems of flexible stay.

Physico-mathematical problem definition. Let us consider non-stationary energy transfer through three-layer heterogeneous construction consisting of claydite-concrete – 1 with vertical interstice filled with warmth-keeping material – 4, heat-insulator of face warmth-keeping system – 2 and sheathing – 3 (fig. 1). Claydite-concrete and sheathing are connected by flexible linkage (connector) – 5. The form of claydite-concrete, interior warmth-keeping material, connector, heat-insulator of face warmth-keeping system and sheathing is a right parallelepiped, the longitudinal sections of which represent scalene rectangles. The thermal-physical characteristics of the system materials (λ_i, ρ_i, c_i, $i=\overline{1,5}$), its geometrical sizes, temperatures of exterior ($t_{g,e}$) and interior ($t_{g,ins}$) environment, coefficients of heat emission on the exterior (α_w) and interior (α_0) surfaces of protection [4] are known.

One needs to calculate the fields of temperature and densities of heat flows in sections of heterogeneous claydite-concrete wall with face heat insulation.

Heat transfer in heterogeneous claydite-concrete fragment of wall is described in Descartes coordinate system by three-dimensional nonlinear non-stationary equations of heat conductivity.

$$(\rho c)_i \frac{\partial t_i}{\partial \tau} = \frac{\partial}{\partial x}(\lambda_{x,i}\frac{\partial t_i}{\partial x}) + \frac{\partial}{\partial y}(\lambda_{y,i}\frac{\partial t_i}{\partial y}) + \frac{\partial}{\partial z}(\lambda_{z,i}\frac{\partial t_i}{\partial z}),$$
$$i=\overline{1,5}. \quad (1)$$

Set of equations (1) is closed by initial and boundary conditions:

$$t_i\big|_{\tau=0} = t_{in}(x,y,z), \quad i=\overline{1,5},$$
$$x,y,z \in \{0 \le x \le X_\kappa, 0 \le y \le Y_\kappa, 0 \le z \le Z_\kappa\}; \quad (2)$$

$$-\lambda_{x,1}\frac{\partial t_1}{\partial x}\Big|_{x=0} = \alpha_0(t_{g,ins} - t_0),$$
$$y,z \in \{0 \le y \le Y_\kappa, 0 \le z \le Z_\kappa\}; \quad (3)$$

$$\lambda_{x,3}\frac{\partial t_3}{\partial x}\Big|_{x=X_\kappa} = \alpha_w(t_{g,e} - t_w),$$
$$y,z \in \{0 \le y \le Y_\kappa, 0 \le z \le Z_\kappa\}, \quad (4)$$

where t_{in} – temperature at the initial moment of time, °C; t_0, t_w – temperatures at the inner and outer surfaces of the wall, °C; τ – time, c; *x, y, z* – coordinates, m; *c* – coefficient of specific heat, J/(kg·K); λ – heat conductivity coefficient, W/(m?K); ρ – density, kg/m³; X_κ, Y_κ, Z_κ – coordinates of the upper boundaries of calculated area along *x*, *y* and *z*, m.

At the outer boundaries of calculation area *D* $\{0 \le x \le X_\kappa, 0 \le y \le Y_\kappa, 0 \le z \le Z_\kappa\}$ at $x=X_0$ and $x=X_\kappa$ the boundary conditions of the third genus (3), (4) are used; at $y=0$, $y=Y_\kappa$ and $z=0$, $z=Z_\kappa$ the symmetry conditions are given. At the outer planes of calculated area at the interfaces between the fragment of different materials the boundary conditions of the forth genus are used.

Method of solution and results of numerical calculations. For numerical realisation of mathematical model the method of splitting is used [5]. The equations of heat conductivity in one-layer and multilayer areas obtained in splitting along the corresponding directions *x*, *y*, *z* are calculated by efficient iteration-interpolation method [6] with iterations by the coefficient with specified accuracy.

Numerical solution of the problem by the algorithm mentioned above is made by means of the program de-

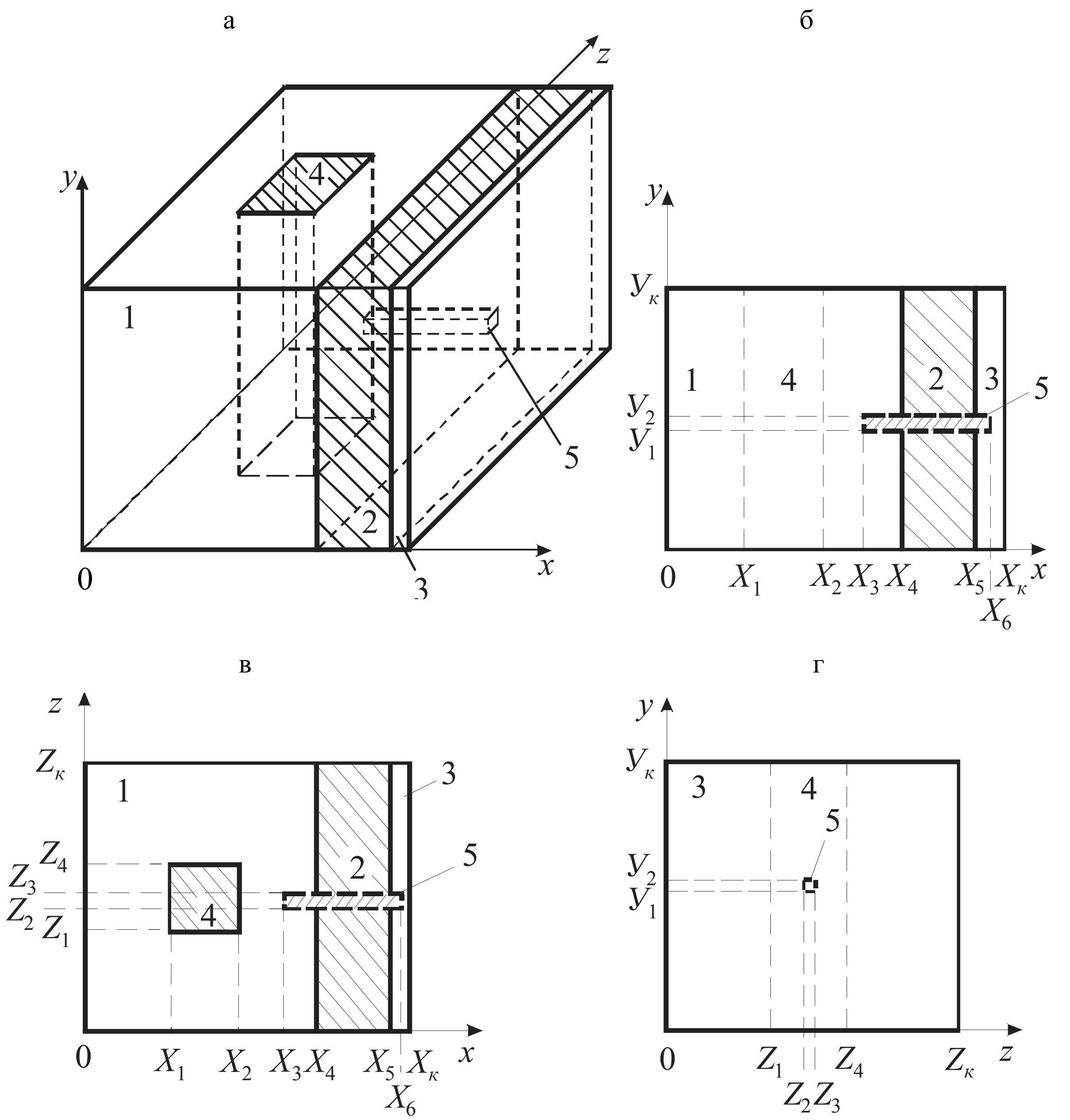

Fig. 1. *Scheme of heterogeneous fragment of claydite-concrete wall: 1) claydite-concrete; 2) heat-insulator of face warmth-keeping system; 3) sheathing; 4) interior warmth-keeping material; 5) connector. a) general view of the fragment; б-г) side view of the fragment (b, c) and view from above (d)*

veloped on module principle in FORTRAN language. Testing separate program modules is carried out by the known analytical solutions [7]. Estimated steps on the surface in the directions x, y, z in general case are taken as variables due to large difference in characteristics of materials of wall layers and connector. Problem solution is checked by thickening meshes in space and time. The number of mesh points along x, y, z is taken as 89, 127 and 157, the iteration in time – 50 min. Time of calculation of basic variant to finite moment of time $\tau_к$=170 h amounts about 30 min by PS Pentium-4. To make the analysis of calculation results easy thermal-physical characteristics of fragment materials are suggested to be isotropic. As an initial profile the stationary analytical solution of three-layer homogeneous exterior protection without warmth-keeping material in claydite-concrete and connector is used. Initial and calculated temperatures are taken in °C.

To estimate heat protection efficiency of heterogeneous fragment and to check accuracy of calculation non-stationary heat flows through open interior Q_0 (from the direction of room) and exterior Q_w (from the direction of outer air) surfaces of the fragment by the formulae

$$Q_0 = \int_0^{Y_к}\int_0^{Z_к} q(0,y,z)\,dy\,dz, \quad Q_w = \int_0^{Y_к}\int_0^{Z_к} q(X_к,y,z)\,dy\,dz,$$

where q – density of heat flow, W/m^2.

In the basic variant of calculation the following initial data are used: λ_1=0,9 W/(m·K), ρ_1=1800 kg/m^3, c_1=840 J/(kg·K), λ_2=0,05 W/(m·K), ρ_2=80 kg/m^3, c_2=1470 J/(kg·K), λ_3=0,55 W/(m·K), ρ_3=1350 kg/m^3, c_3=1062 J/(kg·K), λ_4=0,05 W/(m·K), ρ_4=80 kg/m^3, c_4=1470 J/(kg·K), λ_5=60 W/(m·K), ρ_5=7850 kg/m^3, c_5=482 J/(kg·K), X_1=0,2 m, X_2=0,3 m, X_3=0,35 m, X_4=0,4 m, X_5=0,5 m, X_6=0,505 m, $X_к$=0,510 m, Y_1=0,123 m, Y_2=0,127 m, $Y_к$=0,250 m, Z_1=0,075 m, Z_2=0,123 m, Z_3=0,127 m, Z_4=0,175 m, $Z_к$=0,250 m, $t_{g,ins}$=20 °C, $t_{g,e}$=–40 °C, α_0=8,7 W/(m^2·K), α_w=23 W/(m^2·K). The side of cross square section of connector was taken as 4 mm.

The presence of low- and high heat-conductive inclusions at the construction thickness results in distortion of wall temperature field (fig. 2, 3).

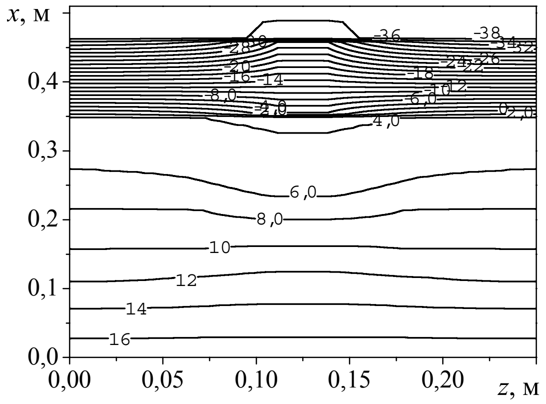

Fig. 2. *Isotherms in cross-section of the fragment $y=Y_к/2$=0,125 m, crossing the axis of connector at τ=170 h. t, °C*

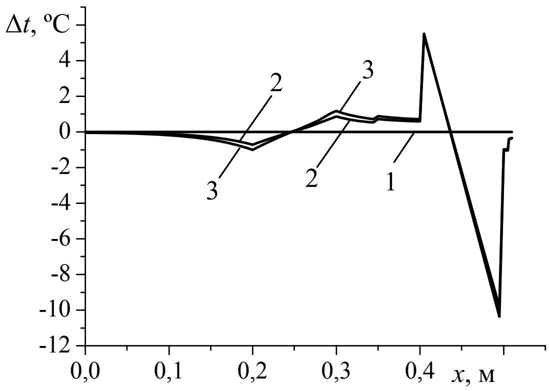

Fig. 3. *Temperature difference $\Delta t=t(x,Y_к/2,Z_к)-t(x,Y_к/2,Z_к/2)$ in thickness of the fragment with heating put in at different moments of time τ: 1) 0; 2) 2,5; 3) 170 h*

As it is seen from fig. 3 in stationary conditions of heat transfer in the plane of contact of heat insulator with claydite-concrete at coordinate x=0,2 m temperature difference is negative and equal approximately to –1 °C, but at coordinate x=0,3 m it is positive and amounts approximately 1,2 °C. It indicates that in the thickness of claydite-concrete construction there is a section (at coordinate x=0,25 м in this case), before which heat is deviated from the axis to its periphery, but after which, on the contrary, is led from periphery to its axis.

In the zone of fastening connector in the construction layer of the wall (0,35≤x≤0,4 m) the heat coming from inner to outer surface of the wall collides with heat insulator. This enhances heating of the given region and presence of positive and practically constant temperature difference equal to approximately 0,7 °C.

In the sections with coordinates x=0,4 and 0,5 m temperature difference comes approximately to 5,4 and –9,8 °C, the character of curve distribution 2 and 3 in the given area indicates the presence of adiabatic section in the centre of exterior heat layer with coordinate x≈0,45 м before which heat is led to connector, but after which, on the contrary, is taken away from it (fig. 3).

The results obtained correlate well with the conclusions of the work [8], where it is shown on the bases of researching the process of heat transfer through three-layer brick wall with connector that in the plane of contact of warmth-keeping material with brick setting the zone of connector influence made of fixture wire of 4 mm diameter, temperature field comes to about 0,06 m.

Fig. 4 demonstrates the value of connector influence zone on temperature field of heterogeneous claydite-concrete wall.

As it follows from fig. 4, temperature difference across the connector is absent due to its high heat conductivity. Outside the connector, nearly 5...6 sm distance from its surface a sharp growth of temperature difference is observed (curve 1), but then there is its smooth approach to asymptote.

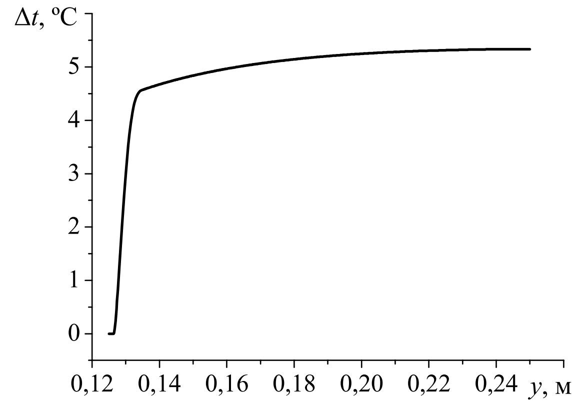

Fig. 4. *Distribution of temperature difference $\Delta t(y)=t(X_4,y,Z_к/2)-t(X_4,Y_к/2,Z_к/2)$ at the moment of time τ=170 h*

In terms of the stated regularities of temperature field formation thermal losses through the fragment of wall involved are determined (fig. 5).

According to СНиП II-3-79* «Stroitelnaya Teplotechnika» thermal-engineering calculation of exterior walls of buildings with flexible stay is carried out using coefficients of heat-engineering homogeneity representing the relation of heat losses through the wall without heat-conductive inclusions and heat losses through the wall with heat-conductive inclusions. However, the data on values of these coefficients for flexible stays of 4 mm diameter and of claydite-concrete density equal to 1800 kg/m^3 are absent in the norms.

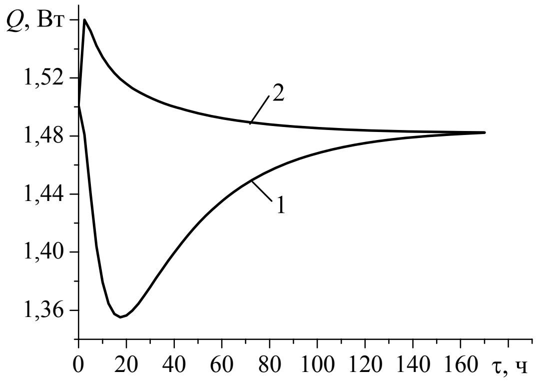

Fig. 5. *Heat flows through: 1) interior and 2) exterior surface of the wall fragment with heating put in it*

For the fragment of wall with connector considered in the work thermal losses in stationary conditions of heat transfer amount 1,48 W (fig. 5), without connector – 1,44 W. The value of heat-engineering homogeneity coefficient is rather high [9], equal to 0,97.

Thus, the performed numerical investigation of thermal conditions of heterogeneous claydite-concrete wall with connector makes possible to reveal the regularities of difference temperature distribution and estimate the influence zone of heat-conductive inclusion. The developed numerical method allows prediction of heat conditions of exterior heterogeneous walls with different thermal physic and geometric characteristics of the materials in cold climatic conditions.

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DEFINITION OF THERMAL RESISTANCE OF PIPE WALLS OF SMALL THICKNESS BY THERMAL FLOWS DENSITY CHANGE

A.A. Makeev

Tomsk Polytechnic University
E mail: ghost@tpu.ru

The provisions basing structural dependence of thermal resistance of materials of pipe walls made of boiler steels in dimensional thickness where effects of bounder jumps of temperatures creating distortions in measurements of heat conductivity factor are shown are presented. The established dependences are explained from positions structural crack formation in undersurface areas.

At research of processes of heat exchange in multilayered cylindrical constructions to which it is possible to attribute multielement systems of heatdump of loop channels of research nuclear reactors, collector packages of electric generating channels of thermoemission nuclear power installations, multielement welded or soldered constructions consisting of thin-wall pipes, thin coatings applied by thermal and galvanic way and other thermally thin layered bodies, thermal resistance of the thin-wall envelopes making heat-transmitting system got the important value. In a modern science of heat exchange « thermal resistance « is defined when the case in point is transport of heat through a complex of constructional materials. Classically transport of heat through constructional materials is usually linked with concept of heat conductivity, factor of heat conductivity λ, thermal diffusivity factor a when the case in point is non-stationary processes, that is applicable and proved for massive, homogeneous, continuous physical bodies. The phenomena of dispersion of energy on a surfa-