TEMPERATURE MODE OF AN ICE COVERING OF SPORTS CONSTRUCTIONS

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Abstract

The given article is about shaping of temperature conditions of an ice coating for skating sports, hockey and figure skating. The operation purpose is to work out a procedure of a heat calculation of a technological slab, definition of a construction of the slab ensuring excellence of ice with minimum capital and operational cost. Numerical methods solve a differential equation of a thermal conduction taking into account processes convective heat- and mass- transfer to an adjacent layer of air and radiation heat exchange with an environmental envelope.

KEYWORDS

Ice, ice area, ice rink, heat exchange.

INTRODUCTION

High level of the sport results displayed by sportsmen on various competitions of ice sports, is based on the solution of various problems, basic of which, undoubtedly, is level of preparation of sportsmen and engineering perfection of an ice complex.

The system solution of the problem of shaping of a slide resistance and purposeful structurization of a crystal lattice of a surface layer of ice, including the account of singularities of various sports, contains the greatest engineering possibilities and the minimal number of natural limitations for process of reaching of high sports outcomes. Essential influence on level of sports results among resorts of the engineering direction can render temperature conditions of an ice slab.

THERMOTECHNICAL CALCULATION OF THE ICE FIELD

It is possible to present an ice field as the capacious thermal object having some of the various operational periods. The initial stage is a tap of warmth from a multilayered substrate of an ice plate and its subsequent freeze. The second and the most intense period is heat elimination from consistently formed sheets of water in the course of gradual freezing an ice plate. In this period quantity of taken away warmth should provide cooling of a sheet of water to freezing temperature, phase transfer "water-ice", the subsequent cooling of generated ice layer to some temperature. In each of the considered above the periods it is necessary to compensate inevitable heat leakage from environment to a surface of a formed ice plate. At the end of the freezing of ice to the demanded thickness and carrying out of a stage of its operational development and polishing all system passes into indemnification mode only external heat leakage. Thermal load on system of cooling of an ice plate essentially decreases and includes following components: convective heat flow from air around; heat of phase transfer at condensation of water steams from the air environment on an ice surface; a radiating thermal stream forming by "visible" surface of ice of surrounding objects; a thermal stream forming by a ground heating system etc. [4]

The traditional thermotechnical calculation of an ice field is reduced by following basic moments [4]:

1. On the basis of the energy balance with the account of the time installed on process of freezing of ice, the total magnitude of an assigned heat flux for each of observed above phases is spotted.
2. Working out of a construction of a substructure and pipe system of an ice field.
3. Condition performances of fluxion cooling agent in pipes are as a first approximation spotted: charges, velocities, allocation cooling agent on various lots of pipe system with the account of a water resistance of separate contours and collecting channels.

4. The average value of the coefficient of a convective heat exchange from an interior surface of pipes to cooling agent is calculated on.

5. Then takes place the valuation of the correspondence selected constructive and operating conditions of pipe system to magnitude cooling effect machine. This account determines the underload meanings of the velocity of circulation cooling agent and the summary surface of pipes, and also interposition of the last etc.

Thus, traditionally applied procedure of thermotechnical calculation is reduced to the solution of an engineering problem of correspondence constructive and operating conditions of observed system. This procedure does not allow sizing up parameters of application of new embodiments of an ice slab, besides, she does not allow sizing up an aftereffect of the construction defects generated during building. On the basis of traditional approaches it is difficult to spend optimization of accepted solutions [4].

As a criterion function of optimization of system of heat elimination from an ice slab depending on demanded outcome following parameters can be selected: the minimum of material inputs on pipe system of a skating-ring (the total length of pipes, as a rule, makes tens kilometers); the maximum of energy efficiency of processes freezing processes and maintaining of an ice surface in demanded temperature conditions; the controllability of temperature conditions; the minimum cost of 1 m^2 of an ice field, including its bearing, thermohydroisolation and technological parts and etc.

One of components of algorithm of optimization is the presence of analytical associations linking major factors into uniform system. Unfortunately, available experience carry observational character, but not systematical. For deriving of the full information it is necessary to build and inspect assemblage of skating-ring or arenas, to carry out their full diagnostic study and to summarize outcomes. Taking into account that ice buildings are built by the various organizations and firms such generalizations is unreal, at least from the organizational point of view.

At designing of ice arenas it is expedient to solve a number of problems, including: calculation of the greatest possible axle base of pipes in a technological slab at which the cost saving caused by a decrease of the summary length of pipes, is compensated for by increase of an energy loss; definition of turndown of cooling agent movement velocity in which the necessary intensity of a convective heat exchange is attained at minimum possible power inputs on circulation etc. Thus in all cases it is necessary to ensure high quality of ice. Now there isn’t exist a design procedure considering all factors, influencing a temperature condition of an ice field.

PHYSICAL AND MECHNICAL PROPERTIES OF ICE

Water is the surprising natural joint possessing a number of the abnormal properties. One of them is a freezing-point reduction at pressure magnification. Pressure of a skate blade on an ice surface, mentioned over here, leads to a local rise of pressure and a freezing-point reduction, t_3. And if in the place of contact of the skates with an ice surface t_3 becomes below ice temperature the water film generates and play a role of lubrication. Thus the ice temperature, the area of skate blade and mass of the sportsman are the interrelated parameters spotting character of slide. For estimate of the slide process the constant of friction μ and a common sliding resistance force of the skates on ice F are injected quite defensible [2].

The ice surface, thus, should possess the minimum value μ and $F = \mu S+f$, where S - a contact area of skate blade with an ice surface, a f - the additional force caused by a point resistance at plunging of the skates under the gravity of the sportsman in ice. Ice should be equally slidable (the minimum value μ) and firm [2].

Some information about dependence the magnitude of the sliding resisting force F from ice temperature is presented in the literature. With a temperature reduction the constant of friction increases, but ice thus becomes harder and forces of a point resistance decrease. Opposite action of these two factors stipulates presence of a local extremum in association $F = f(t)$. The examinations spent by Faculty Human Movement Sciences of independent University in Amsterdam, have shown, that to a minimum of resisting force F there matches a temperature range of an ice surface from -6 to -8 °C, Fig. 1. [2]

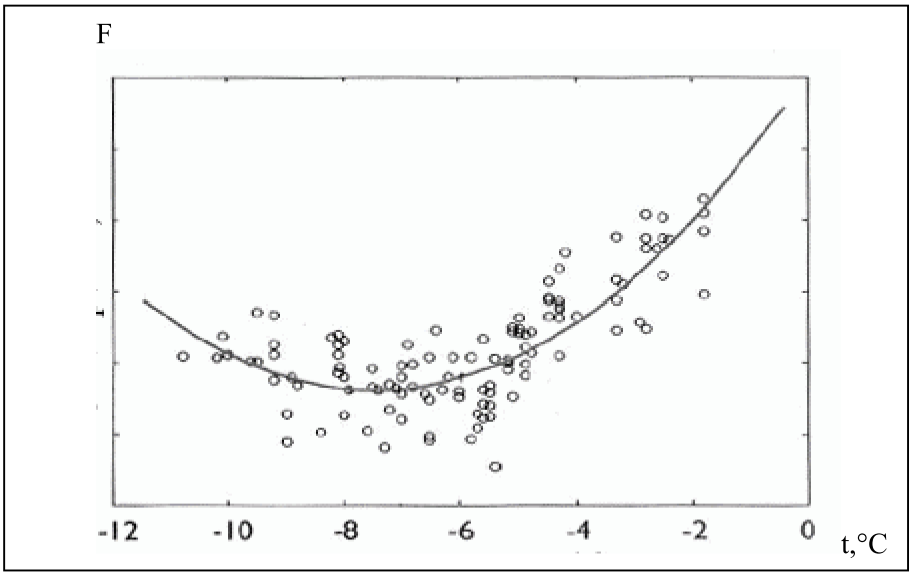

Fig. 1. The association of a common sliding resistance force from ice temperature [2]

The essential scatter of experimental data specifies that the ice temperature cannot be single parameter by search of its optimum magnitude. Above mentioned facts show, that thus at least optimum value of temperature depends on parameters of a blade and mass of the sportsman. For this reason at conducting of competitions to participation of men and women, and also at a modification of a sort of sports competitions it is necessary to change a temperature condition of ice. Engineering systems of an ice field should ensure a good controllability with a temperature condition [2].

To make ice harder, a lot of matters are undertaken on cleanout ice from extraneous: large, small, point wise, and also from own crystal imperfection - a jump of a proton along hydrogen connection from one molecule H_2O to another, therefore the pair of ionic imperfections hydroxide (OH^-) and hydroxonium (H_3O^+) and orientation imperfections Bjerrum (L - and D - imperfections) is organized. For this purpose it is necessary, at first, to apply the deep multilevel water treatment which is switching on all basic stages: from cleanout from mechanical admixtures, clarification, softening to a desalinization and removal of the dissolved gases. Secondly, to use production engineering of freezing ice body with low velocities of crystallization as at a low velocity lattice imperfections are more effectively torn away by ice and ice grows the purest. So more slowly the process of crystallization is and less the rates of temperatures are, the properties of gained ice are closer to a monocrystal. Thirdly, to spend high-heat treatment of the gained ice body - "annealing", i.e. to raise temperature of ice to a grade level and a certain time to stand it at this temperature with the subsequent reduction of temperature to working values. At "annealing" available imperfections come nearer to thermodynamic equilibrium value of parameters more intensive. Fourthly, "annealing" process to combine with a mechanical loading of ice, as thus there is its consolidation; interstices are forced out more intensive on a surface more intensive, foreign impurities and characteristic lattice defects. The loading can applied static (pressure of a weight of constant mass) or a dynamic method (for example, at rolling of ice by a roller through the soft laying) [5].

These facts show the difficult, nonstationary temperature conditions of the ice shaped by the cooling system, had in the structural substructure which layers have differing thermo physical coefficients. At system there are also interior radiant of heat in the form of a heating system of a ground and a heat flow to the cooling system of an ice slab.

Ice parameters are nonconstant enough during one flooding phase and have explicitly expressed maxima. Properties of ice are qualitatively presented in the form of a sliding curve, Fig. 2. The sliding curve has some the characteristic working areas. The working area I - a working area of a maximum of a rolling distance slid meter [1] (i.e. sliding properties of ice) - matches to a time of disappearance of lubricating liquid on a surface of ice and slide on quasiliquid layer. In this time the water flow friction of a liquid film practically disappears and intensity of the molecular interacting (adhesion operation) between the skates and ice is still too small [3].

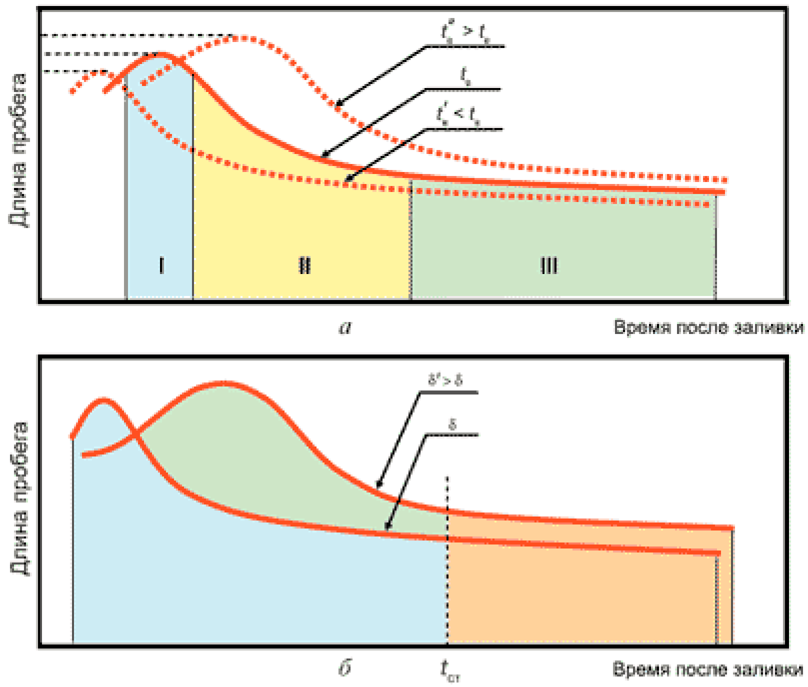

Fig. 2. Sliding curve [3]: a – the influence of temperature of flooded water $t_в$ by sight a line of sliding curve; I – working area of a maximum of sliding properties; II – working area of decrease in slipperiness; III – working area "plateau" is a stable slide; b – the influence of a thickness of a film of flooded water by sight a line of sliding curve; $t_{ст}$ – the time of regulation of sliding properties of ice for a thickness of film δ'

The working area II is a working area of decrease in a slipperiness of ice. It’s characteristic of it (working area II) gradual reduction of temperature of a surface of ice and increase of a constant of friction. Further there steps a working area III – a working area "plateau". In this working area the surface temperature approaches with temperature of the basic body and sliding properties of ice are stablly enough constant. They can be considered conventionally constant. Following a working area IV is a working area of a decline of requirements of slide: the condensate is precipitated on an ice surface, there are rough edges, mechanical failure, micro asperity and etc. Obvious that equal requirements for all sportsmen can be created only in a working area "plateau", provided maintenance of necessary parameters of aerial medium.

Thermal and physical characteristics and operating conditions, which influence on character and on arrangement of the characteristic working areas of line a sliding curve, are [3]:

- temperature of flooded water $t_в$;
- a thickness of a film of flooded water;
- velocity of crystallization of flooded water;
- parameters of aerial medium in immediate proximity from an ice surface.

Magnification of temperature of water used at pouring leads to later approach of a maxima of sliding properties and growth of its absolute value (Fig. 2 a). Magnification $t_в$ most essentially influences magnitude of values of run in a working area "plateau", and also the more slowly rate of process of crystallization, the better as a result velocity properties of ice after a film solidification. Magnification of a thickness of a film of flooded water also calls displacement of a working area of the best slide to the right on a time axis and increment of its absolute value (Fig. 2 b). The maxima of sliding properties can be knowingly displaced to a certain time, and level "plateau" can to become above or more low, than in the previous pouring. Thus, the modification of physical properties of process of pouring of ice can be the tool for manipulation and making of exclusive requirements of slide for certain group of sportsmen [3].

Further it is necessary to structure methods of making of an ice body, considering their physic mechanical properties. First of all, they are:

– to spot separation efficiency of water and composition flooding "solution";
– to select modes of flooding of each stratum, and also to discover its optimum thickness;
– to observe sequence of a modification of temperature, at flooding of each stratum;
– to spot composition of everyone flooding stratum;
– to consider temperature and an air humidity directly above the ice and at level of breath of running sportsmen.

The most important properties of sports ice is strength of deformation, a transparency, lack of dirty sediments of the multivendor inclusions etc. Factors, the defining enumerated indexes, can be conventionally parted on two groups: chemical and freezing conditions. Meanwhile, as operating conditions are considered not only a velocity of freezing ice, but also as dispersity of spray of water and a thickness of a flooding stratum. Rate of freezing in many respects also stipulates the presence of air bubbles in ice "body"; so, at the velocity of freezing 0,5 mm/min 1 sm^3 of ice contains approximately 6 air bubbles, and at the velocity of 5 mm/min their number attain 300. Air presence, in turn, makes ice not only matte and opaque, but also negatively affects the long-term strength of ice, promotes its elastic and a flowage, and also reduces ability to repeated solidification after fusion as a result of short-term impact of force with phase less than 1 second what skates slide is.

All foresaid makes the basis of technology of creation of an ice body for a specific sort of sports. The rigid ice is required for skaters, more elastic and soft ice is used for figure skaters, strong, resistant to against flaws ice - for hockey players. The same information is initial condition at the statement of the problem of examination of ice slab temperature conditions.

TEMPERATURE IMPERFECTIONS OF ICE FIELDS

According to the international standards the difference of temperatures between any points on an ice field no more than 0,5 °C is admitted [6]. So, for example, the presence of local ice temperature difference in (2-3 °C) on a bend can lead to a falling of the sportsman as a result of an appreciable modification of requirements of slide on this "temperature stain". As a rule, the minimal characteristic size possible "a temperature stain" is defined by a step of pipes with cooling agent grooming into concrete slab and makes about 10 cm. Nevertheless, even such inappreciable on the size local temperature difference can really provoke malfunction of sportsman while passing the distance. Thus, if the presence of similar temperature abnormality of an ice surface is fixed by engineering service of one of commands-participants this fact can serve as a motive for appeals of national teams and cancellation of outcomes of the international competitions [1].

The errors admitted at designing and installation of a cooling system of a concrete slab lead to the local temperature differences in some cases considerably exceeding the legitimate value -0,5 grades. Their square can range from unities of square decimeters to tens square meters and it is practically impossible to eliminate deficiencies of such character, not changing devices or a construction of a chilled slab as a whole, when the skating rink is built. [1]

The local temperature differences are cause by [1]:

– the magnitude of curvature of surface of a concrete slab which leads to a modification of the given correlation of a thickness of ice and concrete and, accordingly, total thermal resistance in the given local point of an ice field (Fig. 3, 4);
– the various magnitude of a water resistance of separate segments of a tube plate and, as consequence - intensity of a convective heat exchange in pipes (Fig. 5);
– the different thickness of a concrete layer over cooling system pipes that is a consequence or their not horizontal placement, or "emersion" on certain lots during pouring by concrete (Fig. 6);
– the equidistance violation between pipes in a concrete slab at their mechanical fixing and installation;
– the use of poor-quality concrete or concrete, different composition for separate lots of a field.

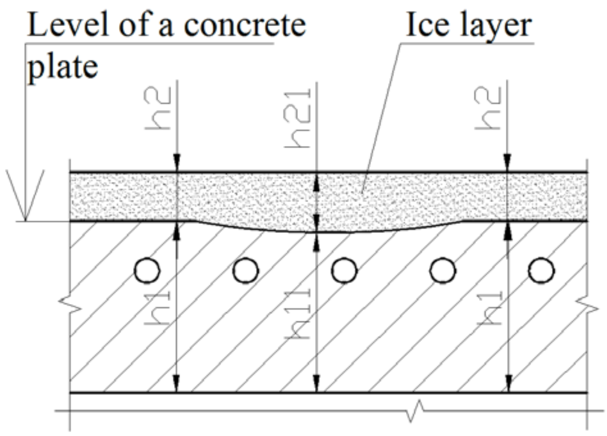

Fig. 3. Differences of a thickness of an ice layer [1]

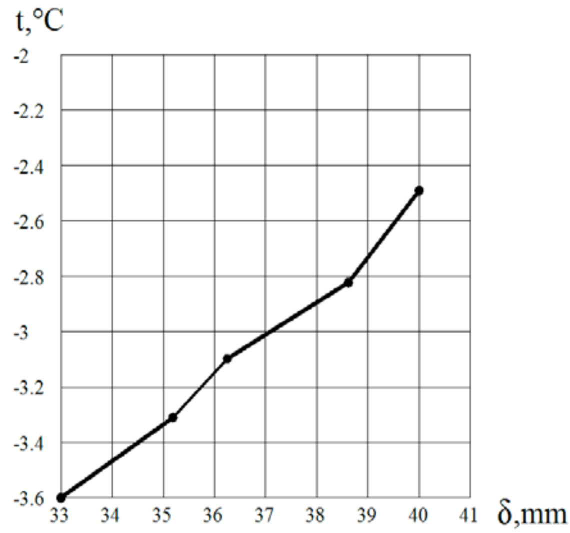

Fig. 4. Temperature of a surface of ice depending on a thickness of an ice coating (the experimental dependence) [1]

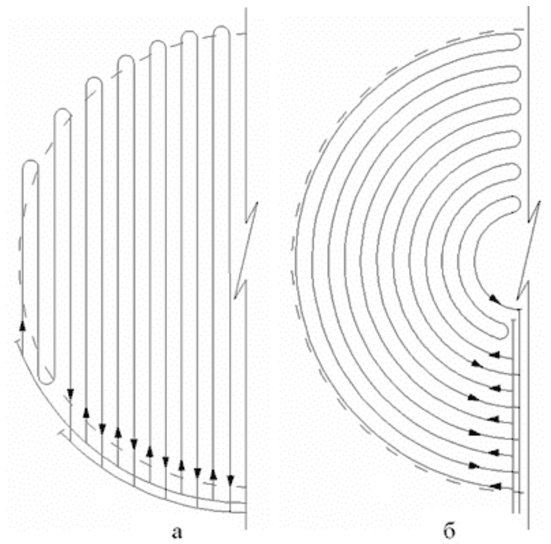

Fig. 5. Various alternatives of cable grooming of pipe system of the technological slab, illustrating an uneven distribution of cooling agent [1]

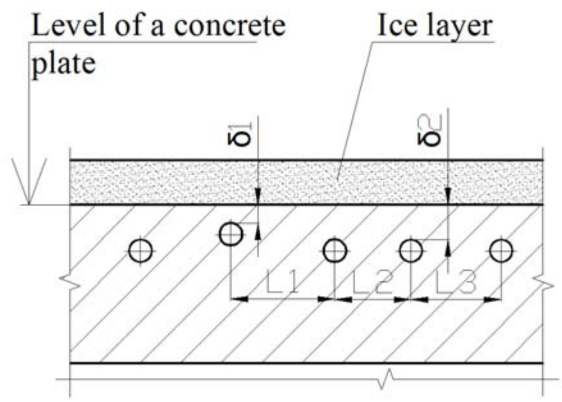

Fig. 6. Examples of a deflection of cable grooming of pipe system [1]

MATHEMATICAL PROBLEM DEFINITION OF SHAPING OF THE TEMPERATURE CONDITIONS OF THE ICE SLAB.

The temperature conditions of an ice field generally can be observed as a nonlinear, nonstationary problem of a thermal conduction with proportioned thermal and physical coefficients (λ, c, ρ) and with interior radiant (flows) of heat q_v. Owing to it at examination of observed processes the differential heat equation (eq. 1) is solved:

$$\rho c(x,y,z,T)\frac{\partial T}{\partial \tau}=\frac{\partial}{\partial x}\left[\lambda\left(x,y,z,T\right)\frac{\partial T}{\partial x}\right]+\frac{\partial}{\partial y}\left[\lambda\left(x,y,z,T\right)\frac{\partial T}{\partial y}\right]+ \\ +\frac{\partial}{\partial z}\left[\lambda\left(x,y,z,T\right)\frac{\partial T}{\partial z}\right]+q_v. \tag{1}$$

At the solution of the given equation boundary conditions are set proceeding from concrete conditions of carryover of heat in system of observed ice stadium.

On boundary line processes convective heat and mass transfer in an adjoining stratum of air and radiation heat exchange with an environmental envelope, and for open stadiums, including singularities of interacting with world space and an aerosphere, as well as sun raying are considered.

The boundary conditions are determined as follows:

$\lambda\left(\frac{\partial t}{\partial n}\right)_S = q_\kappa + q_M + q_p$ – for boundary line of conjugation of an ice slab with a surrounding;

$\lambda\left(\frac{\partial t}{\partial n}\right)_s = q_{geo}$ – for boundary line of the base of an ice slab;

$\lambda\left(\frac{\partial t}{\partial n}\right)_s = 0$ – for side boundary lines of an ice slab.

where λ – thermal-conductivity coefficient; q_κ – a convective heat flux to an ice surface; q_M – a heat flow caused by mass transfer processes; q_p – a heat flow caused by radiation heat exchange; q_{geo} – a geothermal heat flow; indexes: s - a surface.

Works on perfection of an ice coating are actively guided by all leading skating centers. It is natural, that in the conditions of most severe concurrence of national skating schools, growth of prestige of victories and struggle for right to accept the largest international competitions, nobody hurries to share with their advanced achievements and gained technologies (turned out production engineering). The information presented in the literature has not system character and do not allow to discover optimum designs. Examination of processes of shaping of temperature conditions of ice fields is an actual and important problem for deriving of high sports outcomes.

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