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THE MATHEMATICAL MODEL FOR CALCULATION OF BRIDGE TEMPERATURE CONDITIONS

Background. Long-term practice of bridge operation confirms the fact that in winter bridges need special maintenance, namely, complex of measures on prevention of negative influence of anti-icing materials on the bridge structures. To ensure traffic safety in winter, state standards strictly regulate time required for eliminating the repercussions of adverse weather conditions. To meet the state standard requirements is possible only if optimal strategies of winter slipperiness elimination and prevention are selected.

Results and conclusions. The mathematical model for calculation of the temperature conditions of the bridge is presented. Logical and mathematical relations describing the formation of various types of winter slipperiness on the bridges are revealed. The order of computational experiment performance is suggested. The problems for further study are stated.

Keywords: winter road maintenance, dew point, black ice, temperature conditions, boundary conditions, heat exchange conditions.

Introduction

An automobile road being complex engineering structure is characterized by the variety of the winter slipperiness formation factors. Practice of winter road maintenance shows road bridges and overbridges are the most dangerous with respect to ice formation and, therefore, with respect to the probability of traffic incidents.

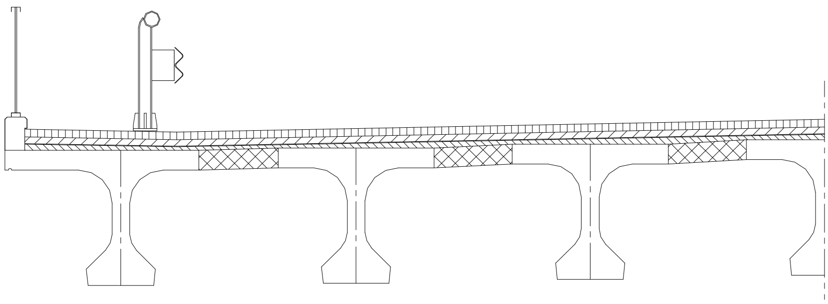
In addition, long-term practice of bridge operation confirms the fact that in winter bridges need special maintenance, namely, complex of measures on prevention of negative influence of anti-icing materials on the bridge structures. To ensure traffic safety in winter, state standards strictly regulate time required for eliminating the repercussions of adverse weather conditions. To meet the state standard requirements is possible only if optimal strategies of winter slipperiness elimination and prevention are selected.

To implement prevention technologies, specialized forecasts of road pavement condition are required. To obtain forecast dependencies, a large body of statistical information is needed. In present, this information is not available. The solution of the problems of specialized forecasts of road pavement conditions is possible with the use of the methods of mathematical modelling of their temperature conditions in winter.

The determination of road pavement temperature conditions was described by T. V. Samodurova [1, 2], however, temperature conditions of bridges are investigated for the first time. Unlike road pavement and ground base, which are multilayer bodies, road bridge floors are considered as multilayer plates in the medium with constantly changing temperature. Therefore, temperature conditions of the bridge differ from the temperature conditions of the road pavement.

To determine the design scheme, we considered the most commonly encountered bridge structures (Fig. 1).

a)



b)

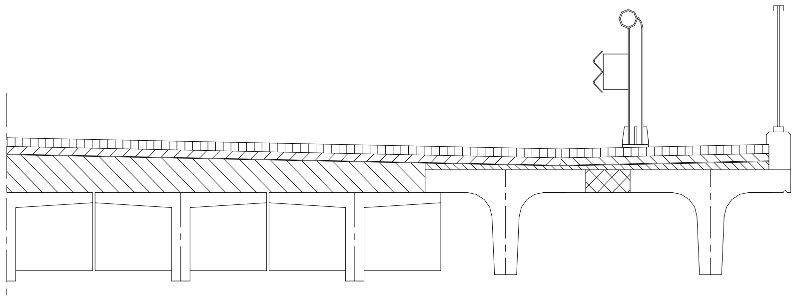
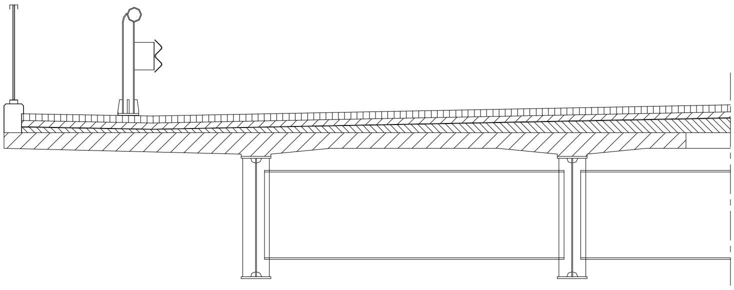


Fig. 1. Types of bridge cross-section:
a, b — beam spans, c — composite span, d — slab span,
e — box-type span, f — metal span

c)



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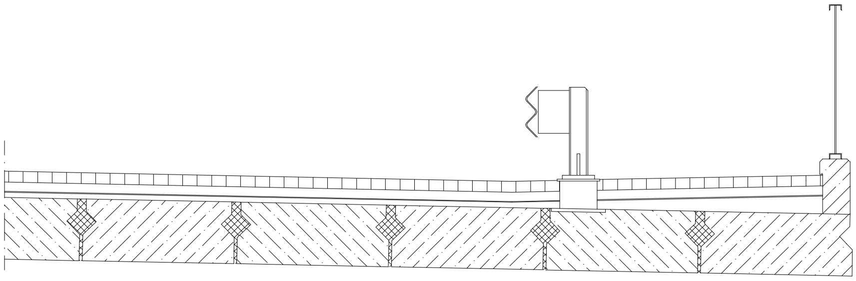

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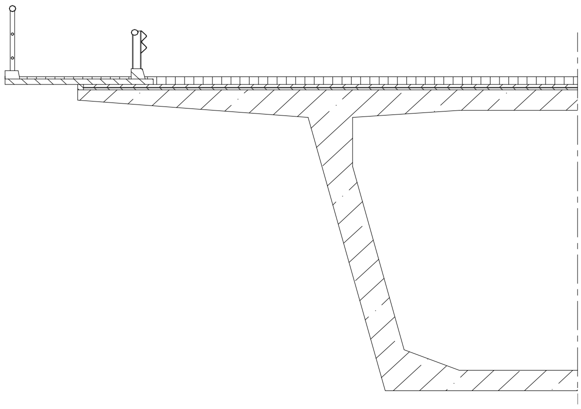

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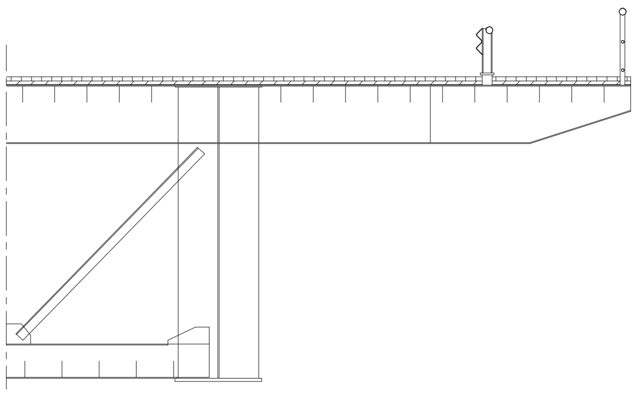

Fig. 1 (end). Types of bridge cross-section:
a, b — beam spans, c — composite span, d — slab span, e — box-type span, f — metal span

Analysis of the physical statement of the problem makes it possible to choose the design scheme shown in Fig. 2. Each layer of the bridge floor has width H_i and thermophysical characteristics λ_i, c_i and ρ_i.

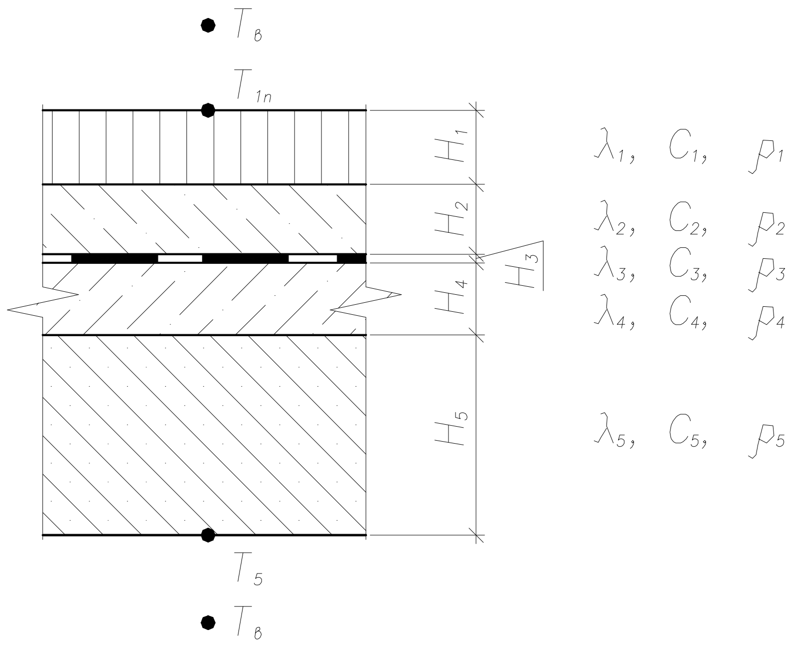

Fig. 2. Design scheme of a road bridge floor for calculating the temperature conditions

In the absence of the ground base, the purpose of the problem temperature condition study is in finding the bridge surface temperature depending on the time-varying air temperature $T_в(\tau)$ and heat exchange condition on bridge uppermost and lowermost surfaces.

A nonstationary temperature condition of a road bridge can be described by one-dimensional heat conduction equation [3]:

$$c\rho\frac{\partial T(x,t)}{\partial\tau}=\lambda\frac{\partial^2 T(x,t)}{\partial x^2}, \qquad (1)$$

where $T(x,t)$ is the temperature in bridge floor at a depth of x at t, °C; λ_i is the heat conduction of *I* layer, W/m· Celsius degree; c_i is the specific heat capacity of *I* layer, kilojoule /kg·degree; ρ_i is the density of the material of ***I layer***, kg/m^3.

Initial conditions take the form

$$T(x,0)=T_в. \qquad (2)$$

Boundary conditions for uppermost and lowermost bridge surface are as follows [4]

$$\begin{cases}\lambda_1\dfrac{\partial T}{\partial x}+\alpha_в\left[T_{1п}(\tau)-T_{в.усл}(\tau)\right]=0\\ \lambda_5\dfrac{\partial T}{\partial x}+\alpha_н\left[T_{5п}(\tau)-T_в(\tau)\right]=0\end{cases}, \qquad (3)$$

$$T_{в.усл}(\tau) = T_в(\tau) + \frac{\rho_п \cdot q_п}{\alpha}, \quad (4)$$

where ρ_n is the coefficient of radiation absorption by the bridge pavement; q_n is the radiation intensity, W/m^2; α is the heat exchange coefficient; $T_в(\tau)$ is the ambient temperature, ^oC.

In accordance with the accepted classification of winter slipperiness types [2], mathematical models describing their formation on the bridges can be represented as logical and mathematical relations.

The results of a logical calculus are meanings "true" or "false". Their substantial senses for the problem under consideration are as follows: "at available parameter combination, formation of the slipperiness of the given type is possible" or "at available parameter combination, formation of the slipperiness of the given type is impossible".

With accepted notations: $T_в$ is the air temperature, $T_{пм}$ is the bridge pavement temperature, T_d is the dew point, $t_{пд}$ is the time of rainfall aftereffect, *OS* is the rainfall type, *SP* is the road pavement condition, *q* is the rainfall amount. Logical relations have true meanings:

1) for ice-slick, if the following condition is fulfilled:

$$(T_в < 0) \& (T_{пм} < 0) \& (SP = wet) \& (t_{пд} \leq 12) \& (OS = no); \quad (5)$$

2) for black ice:

$$(T_в < 0) \& ((T_{пм} < 0) \& (T_{пм} < T_d)) \& (SP = dry) \& (OS = no); \quad (6)$$

3) for hard crust on the road due to the liquid rainfall:

$$(T_в > 0) \& (T_{пм} < 0); \quad (7)$$

4) for hard crust due to the sleet:

$$(-5 < T_в < 0) \& (T_{пм} < 0) \& (q = 0); \quad (8)$$

5) for glare ice:

$$(T_в < 0) \& (T_{пм} < 0) \& (OS = liquid\ (overcooled)). \quad (9)$$

To conduct calculation experiment, databases with meteorological parameters were made. They contain weather station observational data: data on rainfalls (type, start time, final time), temperature, relative air humidity, dew point, atmospheric pressure, wind speed and direction, cloudiness, aqueous tension (all the parameters are measured 8 times per day), rainfall amount (measured 4 times per day). In addition, database on road bridge floor structure were made. It contains code of bridge floor structure, cross-section scheme, list of materials of structure layers, their widths and thermal and physical characteristics.

Modeling was carried out in the following order: bridge structure data input, calculation of initial temperature distribution, input of meteorological parameters per observation day on weather station, information interpolation to the mesh points over the time, boundary condition calculation, bridge pavement temperature calculation, control of the presence of conditions for slipperiness formation with the use of logical relations (5)—(9).

If one condition was fulfilled, the moment of possible slipperiness formation, its type, meteorological parameters in the given moment of time and 3, 6, 9 and 24 hours prior to the moment of slipperiness formation were fixed.

Conclusion

In the course of calculation experiments databases describing bridge temperature calculation and cases of possible slipperiness formation on the bridge pavement.

Analysis of databases with meteorological parameters and databases with the results of modeling will be used for solving the following problems: 1) investigation of peculiarities of temperature conditions of the bridges with different floors; 2) investigation of conditions of winter slipperiness formation on the bridges; 3)investigation peculiarities winter slipperiness formation on the bridges in comparison with automobile roads; 4) justification of artificial structure winter maintenance costs with consideration for the winter slipperiness formation frequency and duration.

The solution of the problems makes it possible to develop: 1) models for short-term forecast of winter slipperiness formation on the pavements of the artificial structures [2]; 2) method of optimal work strategy selection; 3) maintain high consumer properties of artificial facilities in hard weather conditions, and save material resources on its maintenance.

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