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METHOD OF CALCULATION OF TEMPERATURE FIELD AND DEFLECTED MODE OF BRIDGE STRUCTURES IN SOFTWARE ENVIRONMENT NX NASTRAN

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1. Actuality of the problem

Designs of bridges and overpasses during operation are sustained to complex climatic factors [1 – 4]. Study of heat exchange components is an integral part of preparation data for thermal stresses and deformations calculation. Sequence determination of thermal stresses and deformations of bridge structures is shown on Fig. 1.

Close conditions of the structural elements of modern bridges and overpasses, a variety of their shapes, materials and sizes result in extremely difficult and expensive full- or part-scale investigations. In this regard, there is need to develop and apply various computational approaches that allow relatively in a short time and with little cost to obtain data about engineering structures.

2. Analysis of the latest publications and researches

The most commonly used in engineering practice are models for calculating the strength of structures. Calculation of the deflected mode caused by temperature fields is less common spread [1].

It is necessary to note the creation of mathematical models of the real structure. On the one hand, the model should most closely reproduce the work of the actual design. And on the other hand, the model should not be too complicated. Deviations in the design model in either direction can lead to inconsistency of model to actual design or complication of the model to the extent that does not allow calculating even on the most powerful computers.

Thus, the model's choice in the calculation of engineering structures is one of the most crucial points. The first and a very important step in preparing the model to calculation is the destination of her dimension. In this paper three-dimensional (3D) models are used, although there are many calculations in project entity, including strength, strength of materials methods performed (one-dimensional formulation of the problem).

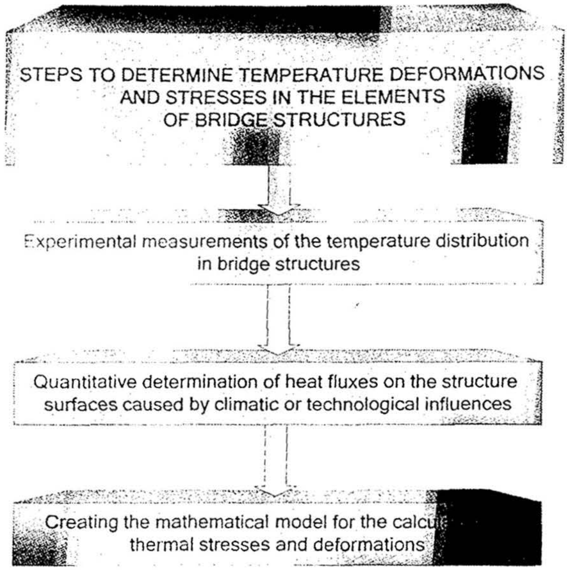

Fig. 1. Calculation stages of thermal stresses and deformations of bridge structures.

It is believed that the best model of real structures is three-dimensional model. This is particularly evidenced for asymmetric structures. Two-dimensional models can yield to three-dimensional in calculation accuracy, but give a significant gain in space.

In addition, the calculation of some designs do not need to use complicated 3D models, if sufficient are 2D models. This applies to the calculation of such structures as retaining walls, gutters, and culverts under embankments, long foundations and walls. Thus, we can reduce the dimension of the model in case of structures in plane stressed or plane deformed state.

In most cases, the choice of the dimension of the actual construction depends on the experience of the engineer who performs the calculations, and the power of computers, on which calculations will be performed. Recently, the preference still is three-dimensional modeling, such as that actually simulates the operation of bridges.

In the work [3] is observed that for the full data of deflected mode spans of bridges caused by temperature fields, one-dimensional solution of the problem (only in the vertical plane) is not enough to consider multiaxis stressed state.

3. The purpose of the work

The aim is to develop a method of calculating caused by heat fluxes, stresses and strains of bridge structures in software environment NX Nastran.

Based on experimental measurements of temperature distribution in bridge structures [5], by the method published in [6], the value of heat fluxes is calculated that suits bridges. The calculated heat fluxes are shown in Fig. 2.

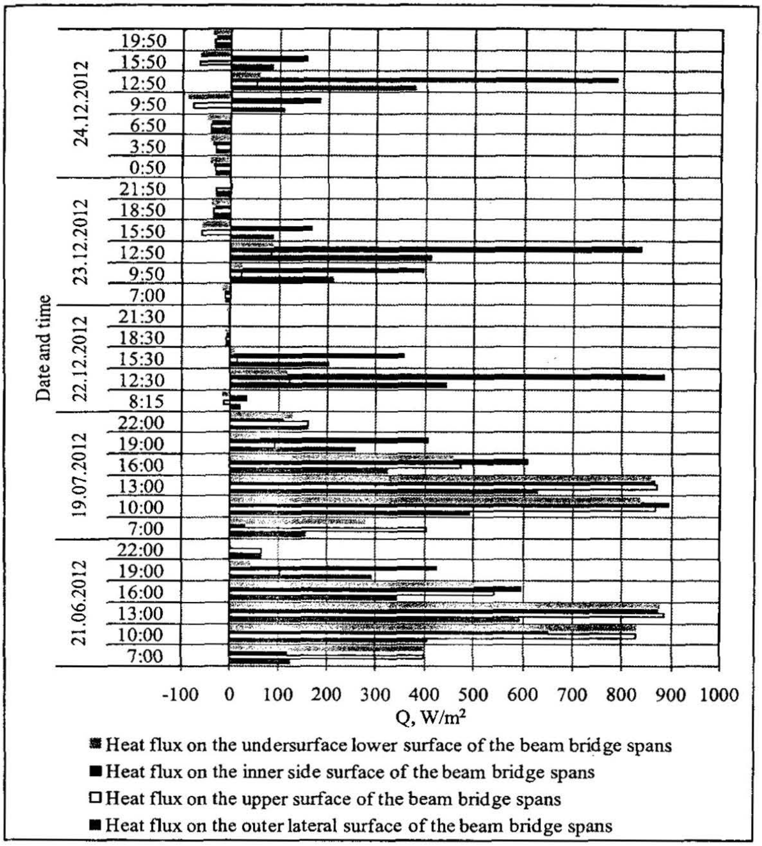

Fig. 2. The value of heat fluxes that suit concrete bridge construction.

Maximum value of heat flux, that is suitable for concrete railway bridge, is 895 W/m^2.

Based on the calculated heat fluxes let us determine the deflected mode of the concrete bridge. To this effect this method of calculation is developed. The methodology is based on solving three-dimensional problems of thermo elasticity in the software environment NX Nastran [7]. Since these bodies are usually of complex configuration, to obtain more accurate results, it is desirable to apply three-dimensional formulation of the problems.

4. Statement of the boundary value problem of heat conductivity

The span bridge will be simulated by the beam that takes the following area

$$(V)=\{(x,y,z): 0 \le x \le x_1, 0 \le y \le y_1, 0 \le z \le z_1\},$$

where x, y, z are a rectangular Cartesian coordinate system.

Let us assume that the temperature of the beam does not depend on time. Then the heat equation has the form

$$\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}+\frac{\partial^2 t}{\partial z^2}=0, \tag{1}$$

where t is the temperature.

Heat exchange between the beam and the environment is defined by the equation

$$\frac{\partial t}{\partial n}=t^{*}(x,y,z) \text{ на } S, \tag{2}$$

where n is an outer normal to the beam's surface; $t^{*}(x,y,z)$ is a given function; S is the surface of the beam.

5. Problem formulation of the theory of thermo elasticity

Determining the deflected mode of the beams the equation of the theory of thermo elasticity is used.

The equilibrium equations have the form

$$\begin{aligned}
&\frac{\partial \sigma_1}{\partial x}+\frac{\partial \sigma_{12}}{\partial y}+\frac{\partial \sigma_{13}}{\partial z}=0,\\
&\frac{\partial \sigma_2}{\partial y}+\frac{\partial \sigma_{23}}{\partial z}+\frac{\partial \sigma_{21}}{\partial x}=0,\\
&\frac{\partial \sigma_3}{\partial z}+\frac{\partial \sigma_{31}}{\partial x}+\frac{\partial \sigma_{32}}{\partial y}=0.
\end{aligned} \tag{3}$$

where $\sigma_{21}=\sigma_{12};\sigma_{31}=\sigma_{13};\sigma_{32}=\sigma_{23};\sigma_1, \sigma_2, \sigma_3, \sigma_{12}, \sigma_{13},...,\sigma_{32}$ are the components of the stress tensor.

Duhamel – Neumann relation is presented in the form of

$$\begin{aligned}
&e_1=\frac{1}{E}\left[\sigma_1-\nu(\sigma_2+\sigma_3)\right]+\alpha t,\\
&e_2=\frac{1}{E}\left[\sigma_2-\nu(\sigma_3+\sigma_1)\right]+\alpha t,\\
&e_3=\frac{1}{E}\left[\sigma_3-\nu(\sigma_1+\sigma_2)\right]+\alpha t,\\
&e_{12}=\frac{1}{G}\sigma_{12},\ e_{23}=\frac{1}{G}\sigma_{23},\ e_{31}=\frac{1}{G}\sigma_{31},
\end{aligned} \tag{4}$$

where $G=\dfrac{E}{2(1+\nu)}$ is a shear modulus; $e_1, e_2, e_3, e_{12}, e_{23}, e_{31}$ are deformation tensor components; E is modulus of elasticity; ν is Poisson's ratio; α is a linear thermal expansion coefficient.

Deformation components are associated with the Cauchy relations movements:

$$e_1 = \frac{\partial u}{\partial x}; \quad e_2 = \frac{\partial v}{\partial y}; \quad e_3 = \frac{\partial w}{\partial z}; \quad e_{12} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}; \quad e_{23} = \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}; \quad e_{31} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}. \qquad (5)$$

Let us assume that the surface $x = 0$ is rigidly fixed and other surfaces are free from stress.

6. Numerical study and analysis of results

Let us consider the example of calculation the temperature field and the deflected mode of the concrete bridge spans of the railway haul Pidzamche – Lviv, 1475 km pk6.

Numerical study are feasible for parameter values $x_1 = 18{,}7$ m, $y_1 = 4{,}16$ m, $z_1 = 1{,}55$ m, $k = 19$ W/(m °C), $E = 3{,}6 \cdot 10^4$ MPa, $\nu = 0{,}25$, $\alpha = 1{,}0 \cdot 10^{-5}$ 1/°C and the heat fluxes values suitable to the bridge construction 12.23.2012 at 12:50 h. (Fig. 2). Thus, the heat fluxes on each surface are assumed as $x = 0, x = x_1, y = 0, y = y_1, z = 0, z = z_1$ is constant, and streams on the end surfaces $x = 0, x = x_1$ are equal to heat fluxes on the outer lateral surface $y = 0$.

For finite elements the volume element of type SOLID with the form of eight node hexahedron is selected.

To solve the boundary value problem of heat conduction is desirable to set the value of the initial temperature in all nodes of the finite grid. To set the value of the initial temperature is not required; it must be such that the temperature deformation is absent. Next, it is necessary to specify the boundary conditions, in this case the value of the heat fluxes on the bridge spans surface. Their distribution is given in the nodes of the finite grid.

The next stage is the creation of the analysis task. It is necessary to open the dialog panel, where the type of the problem is selected (in this case it is stationary heat conduction).

Results of the solved problem (temperature distribution in a field) are shown on Fig. 3. On this figure the inner side of the beam has a temperature in the range of -1,8°C to -3,1°C, while the outer side has the temperature of -1,8°C to -2,06°C, is shown. The inner side of the beam has a lower temperature than the outer (exterior) side, as the sun warms it slowly, especially in the early spring.

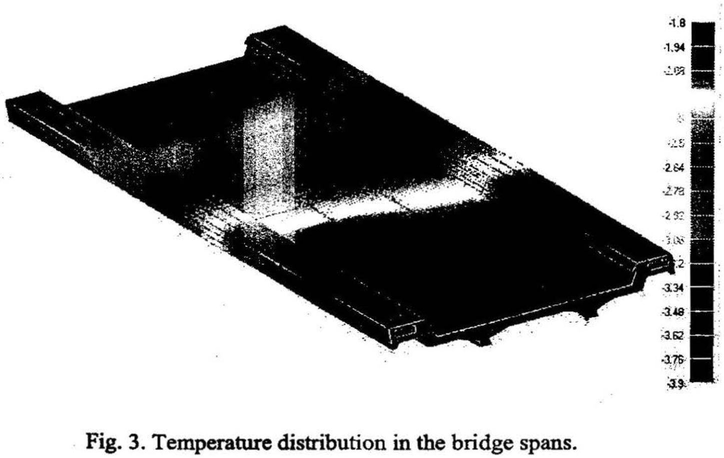

Fig. 3. Temperature distribution in the bridge spans.

Determining the deflected mode of the bridge beams one of the obtained temperature values vectors at the nodes must be taken as boundary condition of the problem. It is necessary to specify the boundary conditions of the first kind (fixing in space and communications), which exclude the possibility of the beam's movement as a rigid whole. But these attachments and relations should not contradict the design scheme of the boundary problem, create parasitic stresses and deformations.

The result of the calculation of normal stresses is shown on Fig. 4.

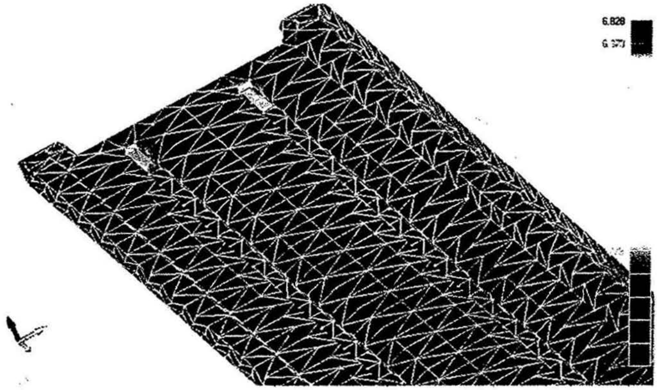

Fig. 4. Distribution of normal stresses.

The largest thermal stresses occur in the longitudinal direction 6,8 MPa, in the transverse direction stresses are of 0,9 MPa, and in the vertical direction 2,1 MPa. As it is seen from Fig. 4, the maximum strains occur in fixed bearings.

Results of calculation of the concrete bridge spans movements in the direction of the axis x, y, z are shown on Fig. 5-7.

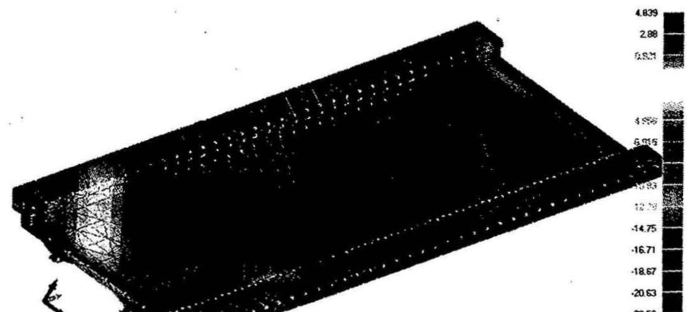

Fig. 5. Movement in the direction of the axis x.

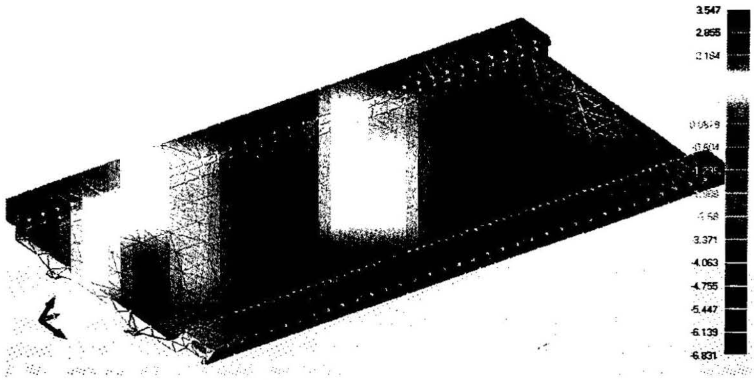

Fig. 6. Movement in the direction of the axis y.

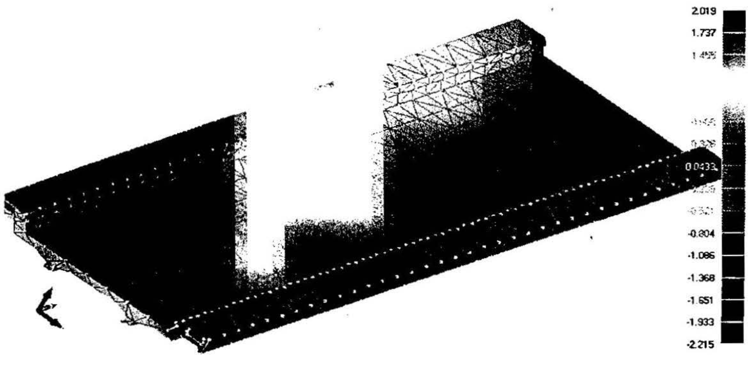

Fig. 7. Movement in the direction of the axis z.

The maximum movements in the direction of the axis x are -24,6 mm, in the direction of the axis y are -6,8 mm and axis z are -2,2 mm.

Deformations that occur in such stressed state in the longitudinal direction are 0,9 mm, in the transverse direction is 0,2 mm, and in vertically direction is 0,17 mm.

7. Conclusions

The calculation results showed that the boundary conditions must be added to the finite model spans in the form of heat fluxes, which are defined depending on the geographic location of the bridge, on the period of the year and on the day time.

Tensions caused by the action of heat fluxes have maximum values in the fixed bearings bridge structures. The largest deformations occur in the longitudinal direction spans bridge construction.

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МЕТОДИКА РОЗРАХУНКУ ТЕМПЕРАТУРНОГО ПОЛЯ ТА НАПРУЖЕНО-ДЕФОРМОВАНОГО СТАНУ МОСТОВИХ КОНСТРУКЦІЙ У ПРОГРАМНОМУ СЕРЕДОВИЩІ NX NASTRAN

Аннотация

При розрахунках мостових конструкцій з урахуванням температурних впливі необхідно розглянути випадок швидкого зниження температури навколишньог середовища при ясному небі в нічні години доби, до сходу сонця, та випадо однобічного нагрівання конструкції залежно від її орієнтації відносно сторін.

Розрахунки напружено-деформованого стану прогонових будов мостів необхідн виконувати за відповідних до температур значень міцнісних характеристик матеріалів. При однобічному нагріванні конструкції слід застосовувати розрахунки температурні полів і напружень для дня року, що приблизно відповідає умовам найбільш спекотн доби, а також для весняного періоду при суттєвій різниці між нічною та денно температурою повітря.

До скінченноелементної моделі прогонових будов рекомендовано додавати крайс умови у вигляді теплових потоків, які визначаються у залежності від географічно розташування моста, періоду року і часу доби.