On the assessment of the stress condition of a T-shaped frame supporting structure during the experimental process

S V Durakov\textsuperscript{1*}, A I Bukovtsova\textsuperscript{1}, and N I Kozhukhova\textsuperscript{2}

\textsuperscript{1}Stary Oskol Technological Institute named after A. A. Ugarov branch of the National University of Science and Technology «MISIS», Stary Oskol, Russia
\textsuperscript{2}Belgorod State Technological University named after V G Shukhov, Belgorod, Russia

E-mail: 9507131581@mail.ru

Abstract. Due to the specifics of the distribution of forces in a two-span frame, it is necessary to increase the cross-sections of the central part of the girder, which negatively affects the consumption of steel for the production of the frame. To reduce the influence of the specifics of the distribution of internal forces on the weight indicators in the girder of a two-span frame, it is necessary to use innovative constructive ways of distributing forces in the girder of the frame, which affect the reduction of material consumption. Such structures include the two-span frame with T-shaped supports proposed in this article, the calculation method of which is based on the idea of combining functions. Since the design is a newly proposed one, it is necessary to identify its stress state. Experimental studies are one of the ways to identify the stress state. The experimental research methodology is presented in the article. This article proposes an assessment of the stress state of a new structural form of a frame with T-shaped support. The development of the section method and the finite difference method makes it possible to evaluate the stress state of the frame from the deformations measured in the experiment. The accuracy of this method is 2...6 %. The proposed technique will make it possible to assess the stress state of a new structural form of a frame with T-shaped support using measured deformations, which were determined as a result of experimental studies, as well as when assessing the stress state of operating frame structures.

1. Introduction

In current conditions of a market economy, the field of application of metal structures has changed. Earlier, a recommendation was applied to use metal structures mainly in industrial construction. Nowadays, there is a tendency to apply metal structures not only in industrial buildings but also for civil and agricultural purposes. In connection with the expansion of the areas of application of metal structures, it became necessary to search for their new structural configurations that would meet the requirements for the manufacture of the maximum volume of structures in the factory with a minimum labor intensity of their use at the facility. These requirements are met by lightweight metal structures, which are 2-3 times superior to the process of building buildings from traditional structures, for which the problem of reducing steel consumption is especially urgent. For example, in a two-span frame, due to the specifics of the distribution of forces, it is necessary to increase the cross-sections of the central part of the girder, which negatively affects the consumption of the frame metal. To reduce the influence of the distribution of internal forces on the weight indicators in the crossbar of a two-span frame, it is necessary to use new constructive methods of distribution of forces in the crossbar of the
frame, which affect the reduction of material consumption. Such new structures are the two-span frame with T-shaped supports investigated in the article. As the structure is new and poorly studied, it is necessary to identify its stress conditions, as a rule, experimentally. The experimental research methodology is described in this article [1-9].

In this article the assessment of the stress state of a new structural form of a frame with T-shaped support was studied. The development of the section method and the finite difference method makes it possible to evaluate the stress state of the frame from the measured deformations during the experiment. The accuracy of this method is in the range of 2...6 % [10-15].

2. Materials and methods

For the considered constructive solution of a two-span frame with a T-shaped supporting structure, a calculation method was proposed that takes into account the flexibility of the structure and the specifics of its operation. The method for calculating the stress-strain condition was developed on the basis that the innovative constructive form of two-span frame works differently.

Taking into account the variety of design techniques used to improve the operation of a two-span frame, one design model was adopted: a beam on elastic supports with Γ-shaped frames adjacent to it.

For the design systems of the T-shaped supporting structure, elastic compliance of all design solutions, as well the Maxwell-Mohr formula from the action of a single load was applied. To assess the stress condition of a two-span frame with a T-shaped supporting structure, the finite element method was used.

3. Results and discussions

The proposed estimation of stress condition was used for the considered design of a two-span frame with T-shaped supporting structure (Fig. 1).

![Figure 1. Scheme of a frame with a T-shaped supporting structure.](image)

The length of each crossbar element AB, BC, CD, DE was divided into three equal parts with a length of $\lambda n$. The equation of the bent girder axis under the calculated load was replaced by an interpolation function. The values of the functions at the division points coincide with the ordinate of the height position of the crossbar section, measured under experimental studies. Bending moments at the i-th point of the n-th crossbar element were determined from the following equation:

$$
\text{Min} = Ay(n) \vec{Y}(n),
$$

where
\[ A_{\text{in}} = \frac{E I}{\lambda_{\text{n}}} \begin{bmatrix} 1 & 2 & -1 \end{bmatrix}, \] 

\[ Y_{\text{n}} = \begin{bmatrix} y_{1}^{(n)} \\ y_{i-1}^{(n)} \\ y_{i+1}^{(n)} \end{bmatrix} \begin{bmatrix} \lambda_{1} \\ \lambda_{2} \end{bmatrix} \]

\[ y_{i}^{(n)} \] – high-altitude position of the bent axis of crossbar at the i-th point of the n-th element; 
\[ E I \] – bending stiffness of crossbar.

Span bending moments calculated with equation (1) were expressed in terms of the support moments \( M_{n}^{(n)} \), \( M_{k}^{(n)} \) of the n-th crossbar element, and moments from the effective design load \( q \) and were equated each other. Thus, a new vector equation has been obtained, which allows finding values of \( M_{n}^{(n)}, M_{k}^{(n)} \), and estimation of the fully stressed state for the n-th element of the girder. Consider the design diagram of the crossbar section AB (Fig. 2).

\[ M_{1}^{AB} = \frac{2}{3} M_{n}^{AB} + \frac{M_{k}^{AB}}{3} + 1.5 q \lambda_{1}^{2}, \]  

\[ M_{2}^{AB} = \frac{2}{3} M_{k}^{AB} + \frac{M_{n}^{AB}}{3} + 1.5 q \lambda_{1}^{2}. \]

For the first and second points, the bending moments for the crossbar element AB are the followings:

\[ M_{1}^{AB} = \frac{2}{3} M_{n}^{AB} + \frac{M_{k}^{AB}}{3} + 1.5 q \lambda_{1}^{2}, \]  

\[ M_{2}^{AB} = \frac{2}{3} M_{k}^{AB} + \frac{M_{n}^{AB}}{3} + 1.5 q \lambda_{1}^{2}. \]

In this case, the new vector equation for the section AB is as follows:

\[ A_{c} \tilde{M}^{(AB)} + W_{q} = B \tilde{Y}^{(AB)}, \]

where

\[ A_{c} = \frac{1}{3} \begin{bmatrix} 2 & 1 & 2 \end{bmatrix}. \]

\[ B = \frac{E I}{\lambda_{1}^{2}} \begin{bmatrix} 2 & -1 \\ -1 & 2 \\ -1 & 2 \end{bmatrix}. \]

\[ \tilde{Y}^{(AB)} = \begin{bmatrix} y_{1}^{(AB)} \\ y_{2}^{(AB)} \\ y_{3}^{(AB)} \end{bmatrix} \]

\[ W_{q} = 1.5 q \lambda_{1}^{2} \begin{bmatrix} 1 \end{bmatrix}. \]
Consider the calculated scheme of the crossbar element (Fig. 3)

\[ \overrightarrow{M(AB)} = ||M_n^{AB} M_k^{BC}||T \] (10)

\[ \text{Figure 3. Calculated scheme of the crossbar element BC.} \]

For the second and third points, the bending moments for the crossbar element BC are the followings:

\[ M_2^{BC} = \frac{2}{3} M_n^{BC} + \frac{1}{3} M_k^{BC} + 1.5 \lambda_2^2 \] (11)

\[ M_3^{BC} = \frac{1}{3} M_n^{BC} + \frac{2}{3} M_k^{BC} + 1.5 \lambda_2^2 \] (12)

In this case, the new vector equation for the BC section is following:

\[ A \overrightarrow{M(BC)} + W_q(\lambda 2) = B \overrightarrow{Y(BC)} \] (13)

\[ B = \frac{EIP}{\lambda^2} \left[ \begin{array}{cc} -1 & 2 \\ -1 & 2 \end{array} \right] \] (14)

\[ \overrightarrow{Y(BC)} = ||y_1^{BC}, y_2^{BC}, y_3^{BC}||T \] (15)

\[ \overrightarrow{MBC} = ||M_n^{BC} M_k^{BC}||T \] (16)

\[ W_q \lambda 2 = 1.5q \lambda_2^2 \left[ \begin{array}{c} 1 \\ 1 \end{array} \right] \] (17)

Ac, Wq are the same as in formulas (6) and (9).

After determining the parameters of \( M_n^{AB}, M_k^{AB}, M_n^{BC} \) and \( M_k^{BC} \), in the crossbar elements AB and BC, it is possible to determine the reaction at point B and find the bending moments in the console of the T-shaped supporting structure.

\[ M_n = R_k a^2 \] (18)

As an example, below the comparative data of the experimental and calculated values of deflections are presented (Table 1).

| Experiment | \( \Delta_{\text{theor}}, \text{mm} \) | \( \Delta_{\text{exp}}, \text{mm} \) | % |
|------------|------------------------|------------------------|---|
| 1          | 2.53                   | 2.27                   | 10.3 |
| 2          | 4.42                   | 4.18                   | 5.4  |
| 3          | 5.06                   | 5.18                   | 2.3  |

Table 1. Comparison of experimental and calculated values [4].
The calculated and experimental data were obtained on a model of a two-span frame with a T-shaped supporting structure. For the calculation, a model with a span of 1.8 meters was used. Analysis of the presented data demonstrated, the proposed method, when assessing the stress state of the frame from the measured calculated and experimental deformations, meets the requirements within an error of 2.3-10.3 %.

4 Summary
The proposed method makes it possible to assess the stress condition of a new structural form of a frame with a T-shaped supporting structure using measured deformations, in experimental studies, and in assessing the stress state of operating frame structures, as well.

5. References
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