Modeling of live load influence in analysis of bridge structures endurance

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Abstract. This article presents the results of the research phase of existing methods for calculating the endurance of bridge structures. The presented stage of the analysis of the endurance of bridge structures is devoted to the creation of an algorithm for modeling the impact of moving loads on the controlled elements created. The process of obtaining the necessary initial data is described, including finite element modeling of the span and its subsequent structural part to obtain matrices and analyze surface effects. Available initial data and load characteristics were the basis for the development of a particular program for the analysis of the effects of loads on the bridge. It is shown that this algorithm can be used to compare the effects of design loads both among themselves and with the effects of possible actual loads.

1. Introduction
Calculation of the endurance of elements under conditions of the multi-cyclic circulating load is one of the keys to bridging structures [1]. Design of structures, taking into account the fatigue of the elements for the required service life, provides more excellent reliability and operational safety relative to the design, taking into account only short-term loads [2]. At the same time, it should be noted that at present, the general approach to assessing the endurance and cyclic fatigue of elements is not fully formed. The algorithms cited in various regulatory documents are based on significantly different hypotheses. The most common in these algorithms is the use, as one of the parameters of the functions, of a value characterizing the stress-strain state of the point under study, and the value is taken not at a specific point in time, but taking into account the duration and cyclic load [3]. To analyze the ways and methods for determining this parameter, the author, as part of a study of existing methods for calculating the endurance of elements of bridge structures, develops an algorithm for modeling the effects of moving loads on a controlled element.

2. Problem statement
In the analysis of existing methods for calculating the endurance of elements carried out at the previous stage of the study, a significant difference was noted in the methods used in the Russian Federation and the methods standard in several other countries [4]. According to the current standards of SP 35.13330.2011 [5], the indicator of the magnitude of the stress is the maximum absolute value, and the general structure can be expressed by the formula (1):

$$\frac{\sigma_{\text{max}}}{c} \leq K \cdot R_y \tag{1}$$
In the formula (1), \( K \) is some composite coefficient, which includes coefficients for reliability, working conditions, and others; \( C \) is a coefficient characterizing the properties of the material and structure during cyclic operation; \( \sigma_{\text{max}} \) is the maximum absolute voltage in the element; \( R_y \) is the elastic limit of the material.

At the same time, as in the national norms of Ukraine [6] and the Eurocode [7], stress swings are used to assess fatigue effects, the general structure corresponds to (2).

\[
\Delta \sigma \leq K \cdot \Delta \sigma_c
\]

In the formula (2), \( K \) is a particular composite coefficient, which includes coefficients for reliability, working conditions, and others; \( \Delta \sigma \) is the calculated range of stresses in the structural element; \( \Delta \sigma_c \) is the relative threshold of possible stresses for the part category.

Modeling of the processes of the loads' impact on the bridge structures' elements in dynamics over time is associated with the need to compare the previous approaches, as well as to assess their correlation with possible actual loads. The task of this study is to develop a universal algorithm that allows evaluating the effect on the loads' elements that change over time.

### 3. Methods

The simulation algorithm was developed in the following particular initial conditions:

- Span structure – typical, steel-reinforced concrete, split, with an estimated span of 42.0 m, performed according to the standard project 3.503.9-119.93;
- Controlled parameter – normal (axial) stresses;
- Parameter control points – the lower flange of the wall of the main beam No. 2 in the middle of the span.

The above parameters were chosen for reasons of convenience of monitoring the performance and debugging of the developed algorithm.

A finite span model was created for obtaining information on the magnitude of the loading of the element under consideration. Modeling and further analysis were performed in SOFiSTiK (Fig. 1).

**Figure 1.** FEA model of bridge substructure

The calculation and analysis of the surfaces of influence on the standard stress value at the control point are based on the created two-dimensional grid of loads with unit loads on the surface of the spanning plate. The grid pitch along the X-axis (along the bridge) was 0.852 m, along the Y-axis (across the bridge) – 0.730 m. Based on the calculation results, a matrix of stress values was generated at the control point of size 21x51. A graphical interpretation of the matrix in the form of an influence surface is presented in Fig. 2.
Obtaining data on the dynamics of changes in stresses in a controlled element depending on time is based on a developed program that runs a given load over the influence surface with a record at the time point of the summing effect from all load components. The main parameters for modeling a load run on a surface are:

- Type (distributed or mobile), scheme and values of the considered loads;
- Functions of movement of given loads of the format \( x = (t) \);
- Load arrangement in the transverse direction;
- Time discretization parameter (frequency of reading) and metric parameters of the influence surface matrix (grid step).

Point movable loads (car type) were programmed for movement along the entire length of the influence surface, taking into account the stages of the incomplete location of the load on the surface (entering the surface and leaving the surface). The function of the load movement was taken into account to study the influence of the combined effects of various loads when moving at different speeds.

Distributed loads (line type) specified in the simulation program were taken into account unambiguously or with a restriction on the sign of the arising forces (only tensile or only compressive). To calculate the effect of the distributed load, we used the integration of the surface function over a given line of load action.

The result of the algorithm is a sequence of values of the total control values (for this case, the voltage in the lower zone of the main beam) corresponding to a sequence of time points with a particular frequency.

### 4. Testing and results

The developed algorithm was used to compare the impact on the control element of the following calculated loads (Fig. 3). The movement of these loads was modeled uniformly, with a unit speed of 1 m/s:

- A14 according to SP 35.13330.2011 (Russia);
- A15 (endurance calculation scheme) according to DBN B.2.3-26: 2010 (Ukraine);
- Model 3 according to EN 1993-2 (Eurocode).

Besides, the following combinations of possible actual loads were considered taking into account possible differences in speed (Fig. 4):

- A truck with a total mass of 30 tons with a unit speed of 1 m/s;
- Passenger car with a conditional total weight of 4 tons and increased to 2 m/s speed;
- A combination of one convoy of trucks moving in the flow in one direction (4 cars, with a
distance of 20 m between each), in a neighboring convoy – cars (10 cars, with a distance of 15 m between each).

**Figure 3.** Relation between axial stress (MPa) in Beam-2 lower flange in 1/2 span and loading time for several national design loads (Russian, Ukrainian and Eurocodes)

As can be seen from Figure 3, the graphs obtained to compare the effects of different types of calculated loads and evaluate both the magnitude of the stresses and the absolute values. The application of the obtained algorithm to compare the possible actually and calculated loads (Fig. 4) helps to analyze the correlation of effects by controlled parameters.

**Figure 4.** Relation between axial stress (MPa) in Beam-2 lower flange in 1/2 span and loading time for several proposed “real” loads and Russian design loads

5. **Conclusion**

Testing of the developed algorithm showed its operability, which allows it to be further used to model the dynamics of actions in more complex structures and under more complex conditions. In continuation of the present study, it is planned to use the described algorithm for modeling the operation of continuous structures in regimes with a frequent change of stress signs, statistical modeling of loads from actual traffic flows, as well as an active study of stresses in nodes along the upper belt of metal structures, at the junction with reinforced concrete slabs.
Acknowledgments
I express gratitude for the ideological inspiration and scientific advice to the professor of SPbGASU, Ph.D. Bystrov V.A. For help in the implementation of the algorithm, I express gratitude to Korolev E.A.

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