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Durability Aspects in the Design of Steel Highway Bridges

Aspects de durabilité en vue du projet de ponts-routes métalliques

Aspekte der Dauerhaftigkeit beim Entwerfen der Stahlstrassenbrücken

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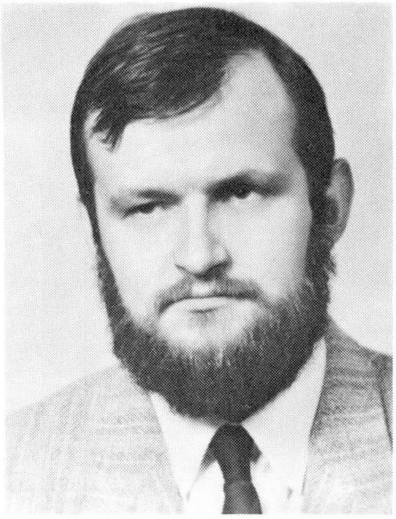

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SUMMARY

The paper contains a description of a method proposed by the author involving analytical and graphic method of operational durability estimation and design which takes into account the fatigue of the structural elements of bridges. By using this method, not only the operational life but also the permissible standard stress can be determined for the analyzed structural elements at the design stage, whereby the fatigue hazard is eliminated. This has been illustrated by calculation examples.

RÉSUMÉ

L'auteur propose une méthode analytique et graphique servant à déterminer la durée d'exploitation ainsi qu'à établir un projet en tenant compte de la fatigue des éléments structuraux des ponts. La méthode considérée permet de déterminer la durée de vie ainsi que la contrainte admissible pour les éléments structuraux analysés lors du projet. Le sujet est illustré par des exemples de calcul.

ZUSAMMENFASSUNG

Der Autor schlägt eine analytische und graphische Methode zur Bestimmung der Dauerhaftigkeit sowie des die Ermüdung der Brückenkonstruktionselemente berücksichtigenden Entwerfens vor. Die dargestellte Methode erlaubt die Bestimmung der Lebensdauer sowie die Festlegung der zulässigen Normspannung für die Konstruktionselemente. Das Vorgehen wird an einem Beispiel erläutert.

1. INTRODUCTION

Elements of steel bridges work in very unfavorable atmospheric conditions and they are subjected to variable loads of different duration and intensity. This applies particularly to highway bridges. As a result, a relatively great number of steel highway bridges have to be renovated and reconstructed. Also the neglect of fatigue effects at the design stage has resulted recently in numerous fatigue failures of various components of steel highway bridges.

In this context, the problem of complex evaluation of the operational durability margins of the existing bridges appears. And in the case of bridges that are to be designed, the problem how their structural elements should be designed to avoid the fatigue hazard and thereby to prolong their operational life becomes very important.

2. OPERATIONAL DURABILITY OF STEEL BRIDGES

Stress spectra from real loads serve as the basis for the evaluation of the operational durability of bridge elements. Continuous field measurements conducted on bridge objects are one of the ways in which the spectra can be obtained. However, due to the considerable problems associated with their realization, their labor-consumption and the necessity of using complicated equipment, the number of such measurements [1], [3] carried out on highway bridges in the world is rather small. For this reason we decided to carry out our own investigations that covered five steel highway bridges [4] situated on international heavy traffic routes. The investigated bridges differed in their static scheme, their structure, the number and the span of the main girders and the situation and the type of the deck. On all the bridges, measurements of unit strains and simultaneous recording of traffic volume and its composition were conducted. On the basis of the obtained results, the effect of real loads on the operational strength of different elements of the highway bridges was determined.

Due to the high labor-consumption and the high costs of operational field investigations it would have been very hard to carry cut a sufficiently great number of them in order to obtain representative results for all the different bridge elements. Therefore it seemed advisable to apply simulation methods [2], [5] and to use the experience gained from the investigations carried out on the real objects. For this purpose a computer program called TE-MD (operational durability of highway bridges) was developed. Because of the complexity of the considered problem, additional subprograms LW and MOMN that together with TE-MD form one system were developed. A deterministic model of the operational loads of bridge objects situated on the main roads in Poland determined on the basis of the author's measurements of the traffic volume and its composition on bridges (inside and outside cities) and the technical specifications of the different types of trucks that move on Polish roads formed a base for the calculations that were carried out with the help of the above program. Moreover, a random model of traffic on a bridge [4] which takes into account, among other things, the effect of simultaneous passing of vehicles over the bridge on the obtained static values and numbers of cycles was used in the calculations.

The TE-MD program can be used for the determination of stress spectra and operational durability parameters of different types of bridges of any static schemes, spans, cross-sections, any number of traffic lanes and at any number of considered vehicles, any traffic volumes and speeds. The basic strength and operational durability parameters obtained by computer simulation and the graphic relationships between them are shown in fig. 1.

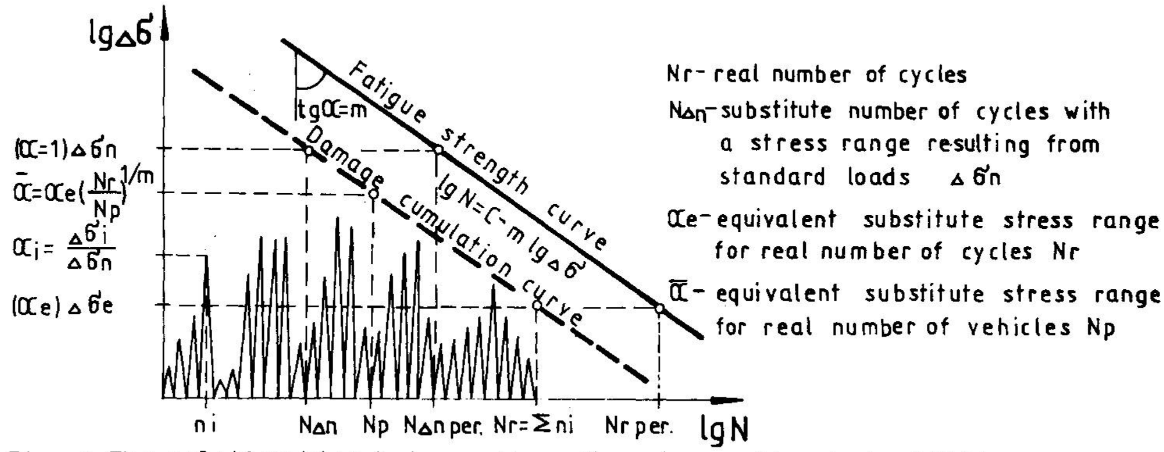

Fig. 1 The relationships between strength and operational durability parameters

Using expression

$$T = \frac{10^a}{(\sigma_n)^m \cdot 365 \cdot N_n^d} \tag{1}$$

after the substitution of values N_n^d (N_n for 24 hours) determined by simulation as well as fatigue strength curve parameters a and m, operational durability T (in years) of a considered bridge element can be determined for standard stress σ_n and for the type of the notch that occurs in it.

Fig.2 shows exemplary diagrams of operational durability T (in years) determined for the longitudinal ribs of the deck at cross-bars flexibility γ = 0,05 depending on: a) traffic volume per 24 hours N_p^d , b) type of notch, c) design standard stress σ_n.

After transformation of formula (1) the relationship for permissible stress from moving standard loads at which the fatigue hazard will be avoided assumes the form

$$\sigma_{n,per.} = \left[\frac{10^a}{T \cdot 365 \cdot N_n^d}\right]^{1/m} \tag{2}$$

3. AN EXAMPLE OF BRIDGE DESIGNING INVOLVING OPERATIONAL DURABILITY

In order to illustrate the described method of designing bridge elements that takes into account operational durability, an example of the determination of permissible stresses due to standard loads is presented.

3.1. Data

A longitudinal rib the orthotropic plate of a two-lane higway bridge where the longitudinal cross-bar spacing is t=3,50 m and cross-bar flexibility γ =0,05 is designed.

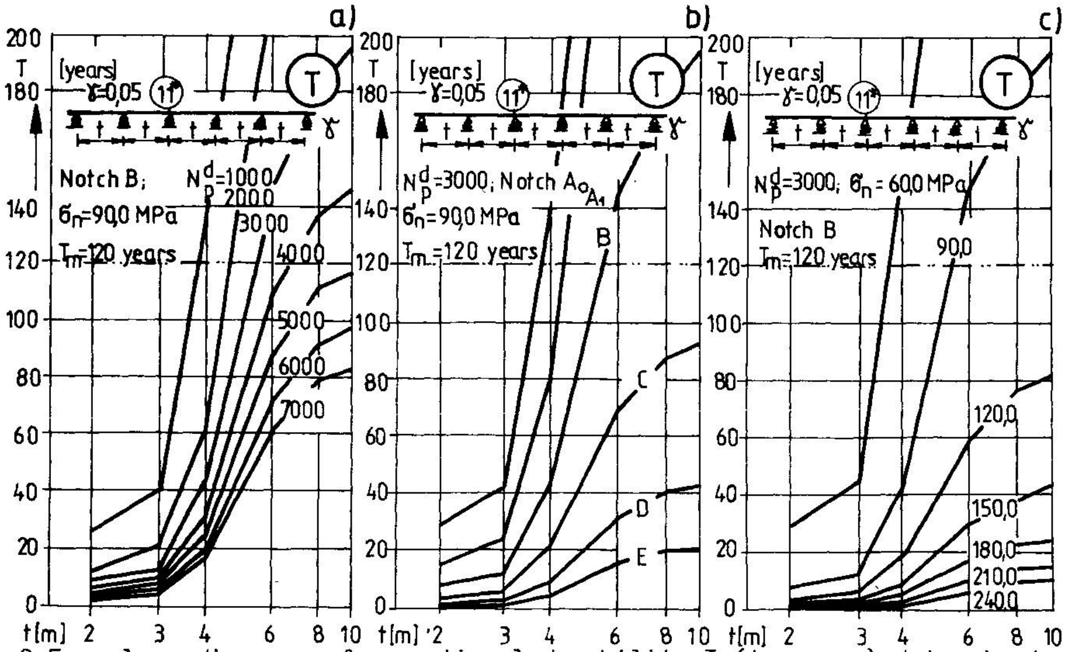

Fig. 2 Exemplary diagrams of operational durability T (in years) determined for the longitudinal ribs of the deck at cross-bars flexibility γ=0.05 depending on: a) traffic volume per 24 hours N_p^d, b) type of notch, c) design standard stress σ_n

Determine the permissible values of stress resulting from standard moving loads $\sigma_{n,per.}$ which can be adopted for the lower fibers of the span section of the rib without fatigue hazard in the case of notch B (without transverse welds) and C (with transverse welds) under assumed durability T=120 years and 24 hours volume of trucks traffic N_p^d=3500.

3.2 Determination of Permissible Standard Stress

Using the diagrams of equivalent substitute cycle numbers N_n^d [4] for the considered longitudinal rib at N_p^d = 3500 and t = 3,50 m, value N_n^d = 78,4 is determined.Then, from formula (2) the permissible standard stress for notch B is calculated

$$\sigma_{n,per.} = \left(\frac{10^a}{T \cdot 365 \cdot N_n^d}\right)^{1/m} = \left(\frac{10^{12.48}}{120 \cdot 365 \cdot 78.4}\right)^{1/3.0} = 95.81\,\mathrm{MPa} \quad (3)$$

and for notch C

$$\sigma_{n,per.} = \left(\frac{10^{12.16}}{120 \cdot 365 \cdot 78.4}\right)^{1/3.0} = 74.94\ \mathrm{MPa} \quad (4)$$

Similar values of permissible standard stress can be determined graphically using a special nomogram [4] and appropriate curves N_n^d. For the above data, the values read from fig.3 are $\sigma_{n,per.}$ = 98,0 MPa for notch B and 77,0 MPa for notch C.

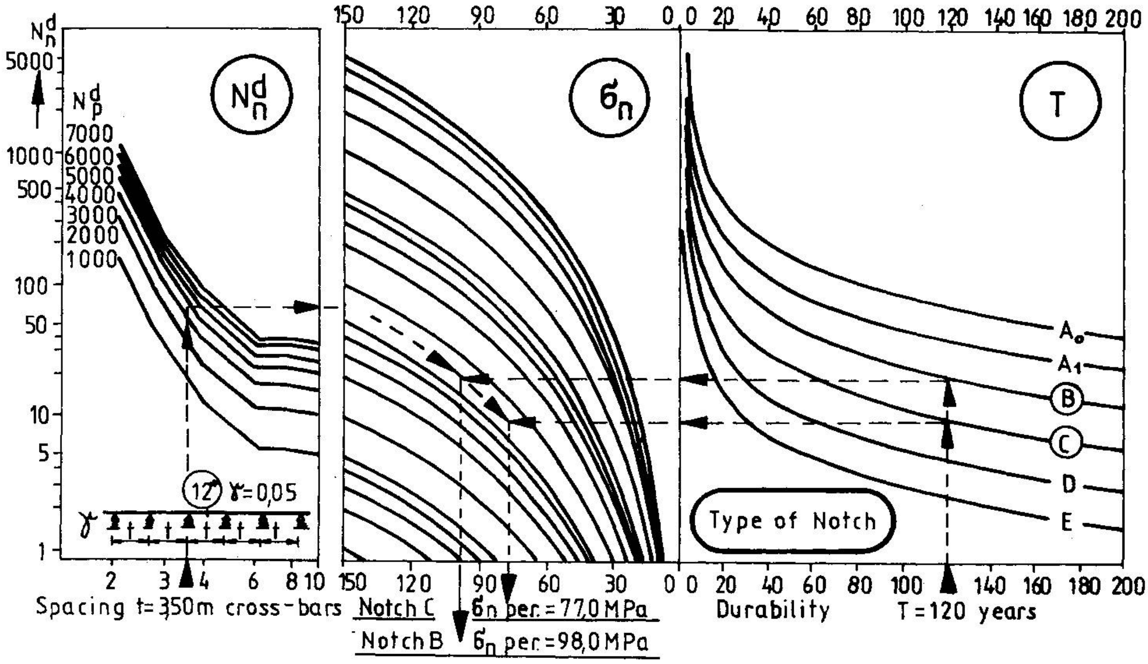

Fig. 3

4. FINAL REMARKS

In spite of the necessarily concise treatment of the problem, it is evident that the application of computer simulation verified by field studies resulted in the development of a relatively simple design method of steel highway bridges that takes into account operational durability.

On the basis of the experience gained from the practical use of this method, the following recommendations aimed at the prolongation of the operational life of to-be-designed steel bridge spans can be formulated:

- unfavorable structural notches should be avoided, particularly in deck elements and in span sections of the main beams characterized by a continuous static scheme,
- for the above elements at unfavorable notch coefficients, the design standard stress should be reduced appropriately (increase the cross-section) which will prolong their assumed operational life considerably (fig. 2c),
- for fatigue reasons, one should avoid main girders with a three-span static scheme having all the spans of equal length and aim at a situation where the length of the middle span in this scheme will be greater than that of the terminal spans,
- grades of high strength steel should, due to their susceptibility to fatigue, be used only in elements with small notch coefficients.

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