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Reliability Prediction for Steel Concrete Composite Bridges

Diagnostic de la fiabilité des ponts mixtes acier-béton

Sicherheitsprognose von Brücken in Verbundbauweise

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SUMMARY

The paper considers the spectrum of unstationary loading by applying live testing and operating loads to steel concrete composite continuous girders of highway bridges. The article interprets theoretically some experimental laws obtained. The analysis of the actual stress-strain state was done and the key details which are responsible for the bridge structures fatigue failure and reliability were established.

RÉSUMÉ

On a examiné les spectres du chargement non stationnaire des travées continues de ponts-routes de type mixte acier-béton, par mise en place des charges de service et des surcharges d'essai. On donne une interprétation de quelques lois expérimentales en découlant. On a présenté l'analyse de l'état réel des contraintes et des déformations; on a en outre établi les données-clés responsables de la fiabilité et de la rupture à la fatigue des structures de pont.

ZUSAMMENFASSUNG

Das Spektrum der beweglichen Lasten auf Durchlaufträger in Verbundbauweise bei Autobahnbrücken wird behandelt. Einige Versuchsresultate werden theoretisch begründet. Die vorhandenen Spannungen und Dehnungen, welche für die Ermüdungssicherheit massgebend sind, werden ermittelt.

A considerable number (morethan 110 units) of operated steel concrete composite bridges with continuous girders and the free beams within span-length range from 33 to 147 metres were tested in field and their stressed-strained state was investigated by using of theoretical-design methods realized by means of electronic computers. It resultedinthe most dangerous members and the "key details" which are responsible for structure's fatigue failure and reliability were established.

Those structure's characteristics depends on the properties of materials, the types of joints, the design standards and the quality of work. Above mentioned bridge structures were designed in according to the USSR normative documents and standard projects which have been applying for 1950-1990 years. Some of them were adapted to the particular local conditions.

The serviseability resources for the bridges can be estimated most completely by assessing of unstationary load effect with dynamic components selected out and studying of operating loading conditions. But this estimation also depends on spatial working of wide bridges either on features of bridge deck constructions.

It has been established in our previous studies [1... 4] that particular attention should be given to the most dangerous parts of construction such as the steel beam lower flange within zones of assembly joints, the upper flange extanded within zones with negative values of bending moments for continuous girders and also the zones with variable signs of efforts (fig.1,e,2-2). The reinforced concrete slab in these zones of composite bridge arouses an especial interest for it's working and for a stressed-state of reinforcement. The efforts in slab members can be increased considerably because of rough carriage way, impact factors of expansion joints and others.

Inspite of the fact that theoretical and experimental data confirming a considerable safety margin for standard reinforced concrete slabs from static loads was obtained recently, it is the slab which often determins the serviceability resources for absolute majority of composite bridges [1,2]. This fact is explained by not only concrete slab working together steel beam, but also by its working under local loading. Besides that the slab is subjected various environmental effects during its lifetime protecting the steel girders from this effect or taking it easer.

The results obtained by testing of two continuous composite girders of big bridge across the river Shelon built in 1963 are shown in diagram of stress probability density. (fig.1...3). She places of installations electric resistance gauges are maked with letter "D" in diagram.

The girders with riveted and welded joints made with R_{yn}=350 MPa steel adjointed the slab made of concrete B 30 exept zones above the piers by means of stiff connectors. The thickness of slab varies from 0,14 to 0,21 metres.

7 heavy trucks "CAMAZ"-5511" weighing from 190 to 192 kN were used as a testing load. They moved in columns in according to the test programm with velocities V=5,56 + 16 m/s. with intervals between them from 30 to 100 metres.

The rough sirface of carriage way was simulated in order to obtain the frequency of stress distribution. Unevenness was created

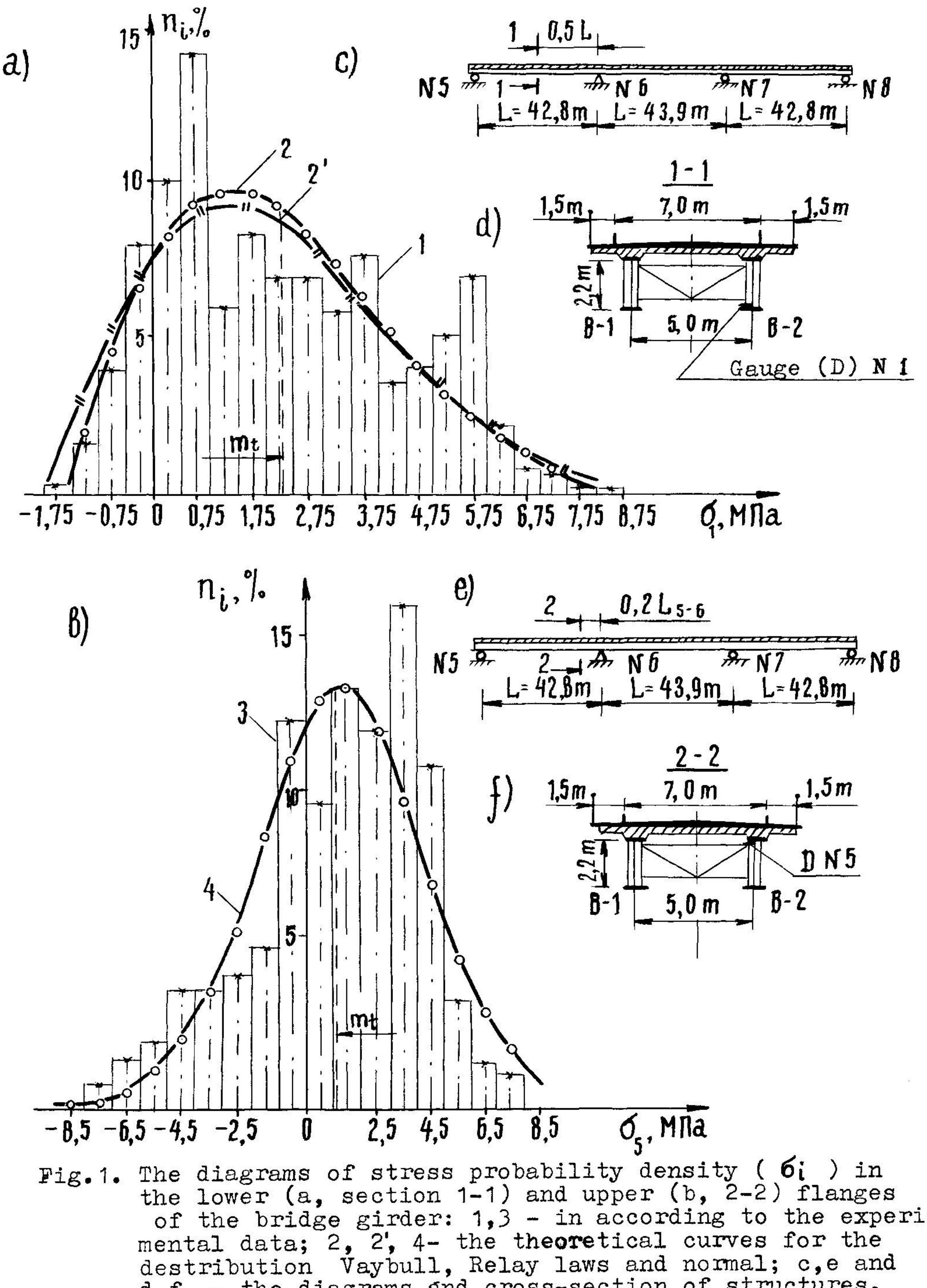

Fig. 1. The diagrams of stress probability density (σ_i) in the lower (a, section 1-1) and upper (b, 2-2) flanges of the bridge girder: 1,3 - in according to the experimental data; 2, 2', 4- the theoretical curves for the destribution Vaybull, Relay laws and normal; c,e and d,f - the diagrams and cross-section of structures.

by means of placing wooden planks 150x50 mm. Besides the currents of transit transport passing across the bridge in operating order were used also as a dynamic load.

The live load accounted for 88% for the design load and caused the maximum deflection equal 34 mm (1/1260). The constructive corrections for stresses from static load for considered sections didn't exceed the value equal one.

The oscillograms were treated by means of electronic analyser F-014. The obtained data were stored on computer to establish their probability characteristics. The dynamic characteristics of composite girders according to various velocities V(5,56-16 m/s) were established. The dynamic coefficient $(1+\mu)$ varies from 1,26 to 1,80; the free oscillation frequency ω_0 from 2,87 to 3,33 Hz; the repetition time of free oscillation from 0,348 to 0,298 s; the logarithmic decrement of attenuation δ from 0,50 to 0,65.

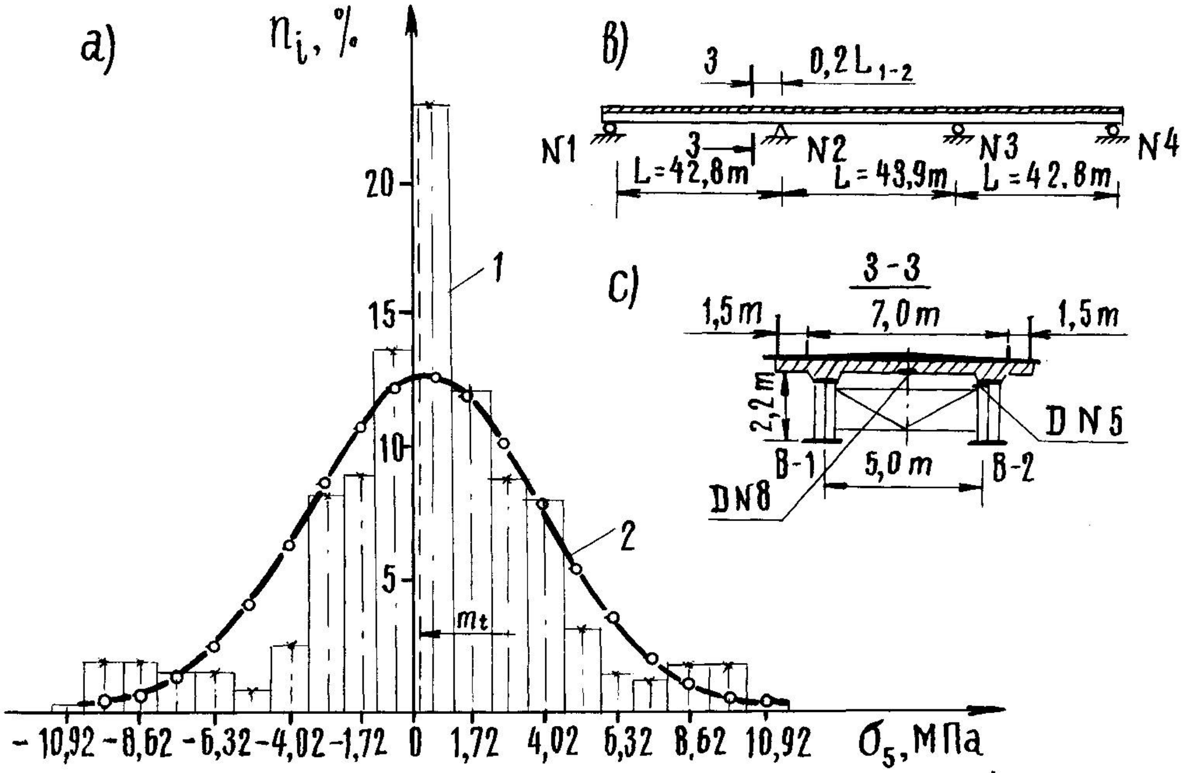

Fig.2. The diagram of stress probability density (σ_i) in the upper flange of the bridge girder B - 2 in the span L_{1-2} (section 3-3): 1 - in according to the experimental data; 2 - the theoretical destribution normal law.

As it was the velocity 5,56 m/s, that caused the maximum stresses, the represented diagrams describes, the truck passage both along the upstream part (fig.1) and along two parts (fig.2) of carriage way with velocity 5,56 m/s mainly. The maximum measured tensile stresses in the lower flange of the girder B-2 in the span L_{5-6} from the testing load (fig.1,a) don't exceed 9 MPa. The mathematical expectation of approximative curve m_t=2,35 MPa; the standard deviation σ_t=2,13 MPa; while the maximum stress from the design static load in this section totals 215,5 MPa. In fact the stresses in that section change from 224 to 214 MPa with the asymmetry cycle coefficient ρ =0,90...0,95.

The upper flange within section 3-3 shown in fig.2B works practically in symmetrical cycle both from the column of testing load (fig.1,b) and from the current of transit traffic loads (fig.2,a). The measured stresses can be approximated by the law of normal distribution, but the stress amplitude from transit traffic was greater and equal ±10,925 MPa. It resulted in the strong asymmetry cycle coefficient equal =-0,40 taking into account the load in the most dangerous case.

It can be derived from the represented studies, that various loading considerably influences the upper flange work in the zone with negative values of bending moments for continuous composite girders especially when the connection between the reinforced concrete slab and the steel girder doesn't work.

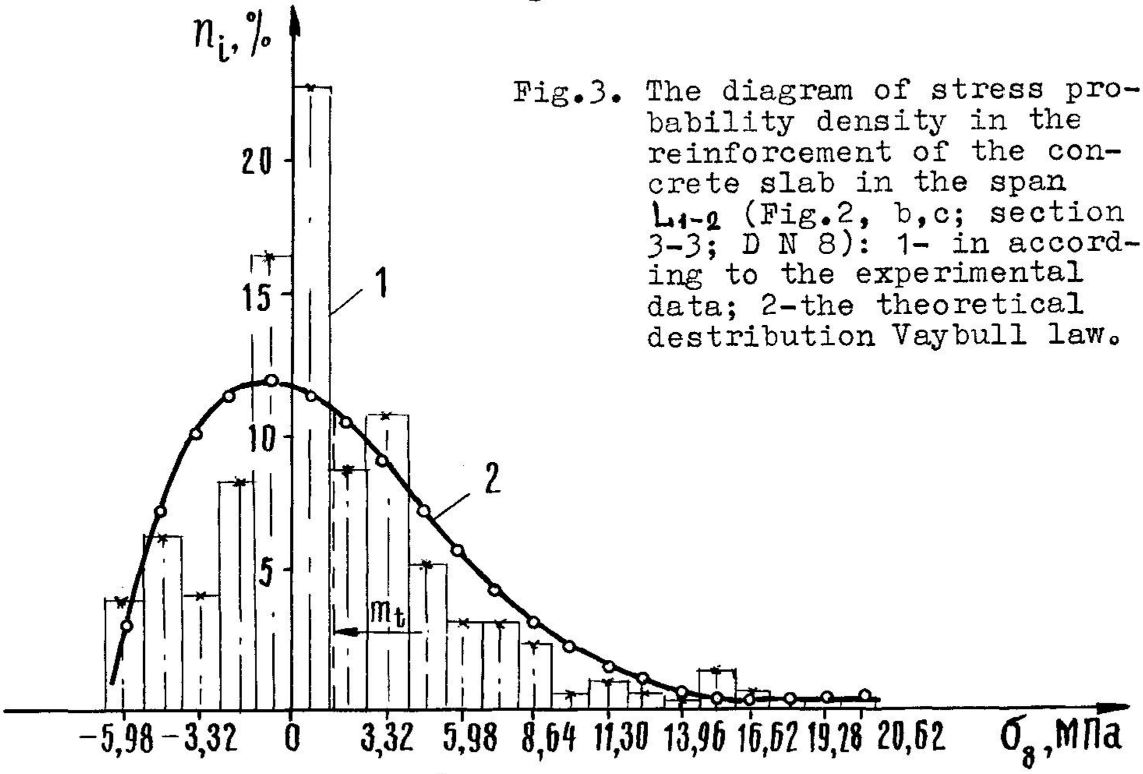

Fig.3. The diagram of stress probability density in the reinforcement of the concrete slab in the span L_{1-2} (Fig.2, b,c; section 3-3; D N 8): 1- in according to the experimental data; 2-the theoretical destribution Vaybull law.

The obtained stress destribution in the extanded slab reinforcement for section 3-3 is shown in fig.3. There was used the same load as for the girder upper flange. The asymmetry experimental diagram is approximated by Vaybull destribution low with the mathematical expextation m_t=1,49 MPa and the standard deviation σ_t=4,61 MPa. It shows high-stressed slab work under dynamic local loading. The tensile stresses in the reinforcement from the permanent load were equal 11,9 MPa while they were changed from 32,5 to 5,9 MPa from live load. The coefficient ρ =0,18 is close to the pulsating cycle wich is unfavourable for the reinforced concrete structure fatique. It is the value of coefficient which causes the most rapid loss of the slab safety margin inspite of the fact that the stresses in the reinforcement don't amount to the fatigue limit.

It can be pointed out that the considered analysis results of composite girders reliability correspond to an average statistical structure and don't take into account both the real values of the stress concentration coefficient β for joints and the possibility of their increasing because of some defects. This correction was provided by carefull monitoring and surveillance of every individual considered structure.

The serviceability resources estimation for the composite girder can be established by using the formula T/T_e expressed in cycle units [3]. However the approximation law should be corrected as this formula was derived by means of the law of normal stress destribution.

$$\frac{T}{T_e}=\frac{N_o e^{b\sigma_o}}{\sqrt{2\pi}\, b\sigma_t e^{0,5(b\sigma_t)^2}\left[\Phi(\sigma_{max}/\sigma_t-b\sigma_t)+\Phi(b\sigma_t)\right]+1} \qquad (1)$$

where $\Phi(\sigma)=1/\sqrt{2\pi}\int_0^{\sigma} e^{-u^2/2}du$ - the Laplas function calculated by the tables;

σ_t - the standard deviation of the stress destribution probability curve;

N_o, b, σ_o - the experimental parameters depending on the joint type and the durability of steel, for example for the assembly joint of the girder flange $N_o=0,886\times10^6$ cycles; b=0,296; $\sigma_o=187,0$MPa;

σ_{max} - the maximum stress, MPa;

T_e - the effective repetition time for the process with the appointed frequency ω is equal $T_e=2\pi/\omega$.

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