SCIENTIFIC PAPERS
OF THE UNIVERSITY OF PARDUBICE
Series B
The Jan Perner Transport Faculty
1 (1995)

THE STATISTICAL ACCEPTANCE OF THE STEEL BRIDGE STRUCTURE MEMBERS

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1. Introduction

The proposed paper indicates the possibility of the application of statistical methods on the acceptance of steel bridge members. The research results of the reliability of the compression members at the Departement of Civil Structures and Bridges at UTC in Žilina are there reflected [3].

2. Resistance of the compression members

The resistance of material or of the structure members against the load actions is a random variable composed of entrance factors of the reliability reserve G given by the formula

$$G = R - S \tag{1}$$

The value of the resistance R determined by certain small probability of the occurrence of unfavourable state presents the ultimate limit strength of the structure or its member.

For a designer, this value presents the design resistance R_d. The best way for the determination of the member resistance R_d is testing. Generally, testing is very expensive and therefore not desirable. In the most cases, the calculation is used to determine R_d The creation of a real mathematical model is most important for the calculation. The determination of R_d for tension and single compression members is in [1], the practical utilisation of this check procedure is in [2] and [3]. For the compression members it is necessary to use such a procedure that takes into account the influence of the member buckling. The main factors of this influence are the slenderness ratio of the member, the cross-section shape and the geometrical and structural imperfections. The influence of these random variables for the reliability of the compression members is analysed in [2] and [3].

The resistance of the compression members could be expressed by the formula

$$R_c = \chi \cdot f_y \cdot \varphi_a \ , \tag{2}$$

where

f_y is the real value of the yield stress

$\varphi_a = \dfrac{A}{A_n}$ is the ratio of the real and nominal area of the member cross-section,

χ is the factor which includes the influences of the random variable parameters at the resistance from the view point of local an global stability failure.

For struts or columns χ represents the reduction factor for the relevant buckling mode, for plates, it is the buckling factor.

The knowledge of the real value of the buckling resistance determines the guality of the investigated sample of the products. This fact predicts the reliability investigation for the statistical acceptance procedure of the steel members.

It is only necessary to demonstrate that the probability of the occurrence of real resistance of the set of members $R_C \leq R_{dC}$ is smaller than beforehand fixed failure probability P_f. This fact is expressed by the inequality

$$P(R_c \leq R_{dc}) \leq P_f \ , \tag{3}$$

where

R_{dC} is the standard value of the compression member strength.

If the condition (3) is satisfied, the whole set of tested members can be taken as satisfactory from the point of view of their resistance against the loading actions.

In the opposite case, the critical value of at least one entrance parameter in relation (2) can be fixed to satisfy the relation (3). From the point of view of the statistical acceptance of steel members, only those products can be accepted which have the value of imperfection smaller then their critical value.

3. Statistical acceptance of the set of compression struts

If the strut calculation model as a uniaxial compression member with the initial bow in the sinusoidal shape is accepted, the relation (2) could be written in the following form

$$R_C = \left\{ \frac{f_y + \left(1 + \frac{e_0}{r}\right) \cdot \sigma_{Cr}}{2} - \sqrt{\frac{\left(f_y + \left(1 + \frac{e_0}{r}\right) \cdot \sigma_{Cr}\right)^2}{4} - f_y \cdot \sigma_{Cr}} \right\} \cdot \varphi_a , \tag{4}$$

where

e_0 is the amplitude of the sinusoidal initial bow of a strut,

r is the radius of gyration of effective strut cross-section,

$\sigma_{Cr} = \frac{\pi^2 E}{\lambda^2}$ is the elastic critical buckling stress,

λ is the slenderness ratio,

E is modulus of elasticity.

If the initial bow amplitude is expressed in the form according to [4]

$$e_0 = r \cdot \kappa \cdot \left(\frac{\lambda}{\lambda_y}\right)^2 , \tag{5}$$

the relation for κ could be derived in the form

$$\kappa = 8820\,(e_0 / L)(z_j / L)(235 / f_y) . \tag{6}$$

When the relation (6) is included to (4) with using the assumption that the radius of gyration could be expressed as a linear function of the depth of cross-section and taking into account the relations

$$\varphi_L = (L / L_a) , \quad \varphi_h = (h / h_n) , \quad \varphi_e = (e_0 / L) / (e_0 / L)_n = (\bar{e}_0 / \bar{e}_{0n}) ,$$
$$\bar{z}_{jn} = z_{jn} / L_n , \qquad (j = y, z) , \tag{7}$$

the resulting relation for the buckling stress is given by the formula

$$R_C = \left\{ \begin{array}{l} 0.5\left[f_y + \pi^2 E\left(\left(\dfrac{\varphi_h}{\varphi_L \lambda_n} \right)^2 + \varphi_e e_{0n} \overline{z}_{jn} \dfrac{\varphi_h}{\varphi_L} \right) \right] - \\ - 0{,}25 \sqrt{ \left[f_y + \pi^2 E\left(\left(\dfrac{\varphi_h}{\varphi_L \lambda_n} \right)^2 + \varphi_e e_{0n} \overline{z}_{jn} \dfrac{\varphi_h}{\varphi_L} \right) \right]^2 - \dfrac{\pi^2 E \left(\dfrac{\varphi_h}{\varphi_L} \right)^2}{\lambda_n^2} } \end{array} \right\} \cdot \varphi_a \cdot \qquad (8)$$

In the relations (6), (7), (8) the following denotation is used:

L (L_n) is the real (nominal) strut length,

h (h_n) is the real (nominal) cross-section depth,

z_j (z_{jn}) is the real (nominal) distance of the extreme fibres from centroid of effective strut cross-section,

$j = y, z.$

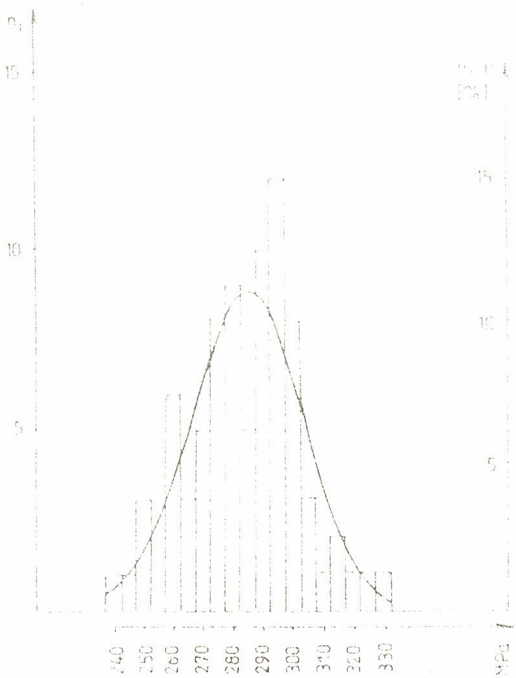

***Fig. 1**: The histogram and probability density function of the yield stress.*

Relation (8) expresses the resistance of the compression strut as a function of random variables in the form of the cross-section characteristics, slenderness ratio and the shape and amplitude of the initial bow. Using this relation, the real resistance of the set of the truss bridge structure diagonals has been analysed. The shape L for the diagonal cross-section has been used, steel 11373. The histograms of the random variables f_y, φ_h, φ_e are in Fig. 1÷3, the remaining random variables have the foloving characteristics:

φ_a - normal distribution with parameters

$\mu_a = 1{,}05$, $\sigma_a = 0{,}065$,

φ_L - normal distribution with parameters

$\mu_L = 1{,}0$, $\sigma_L = 0{,}00025$,

where μ_a , μ_L are the mean values of the random variables φ_a , φ_L ,

σ_a , σ_L are their standard deviations.

Constants in the relation (8) are

E = 210 000 MPa, $\overline{z_{vn}} = 0{,}0101$, $\lambda_n = 102{,}04$ according to [6], $\overline{e_{on}} = 0{,}001$ according to [7],

$R_{dc} = \chi_B \cdot R_d = 0{,}53 \cdot 210 = 111{,}3$ MPa according to [4].

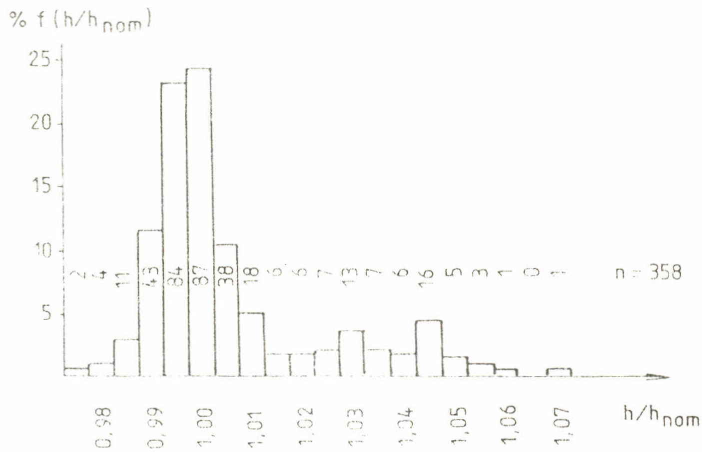

***Fig. 2**: The histogram of the random variable φ_h.*

The Monte-Carlo technique was used, generating 2000 values of random variable R_C according to (8). The resistance of the set of compression diagonals in the value of R_C = 134,5 MPa was found which corresponds to the failure probability $P_f = 10^{-3}$.

This value is greater then the standard value R_{dc} = 111,5 MPa and the whole set of products could be accepted.

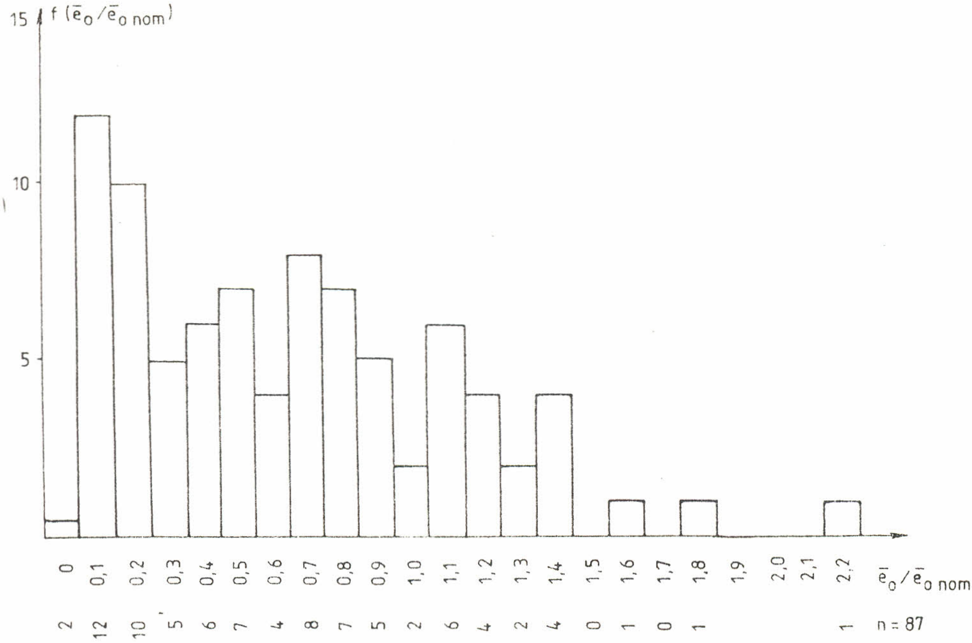

***Fig. 3**: The histogram of the random variable* φ_e .

4. Statistical acceptance of the compression plates

The general relation (2) for the compression plates is better to modify into the form

$$R_C = \rho_n \cdot f_y \cdot \varphi_a \ , \tag{9}$$

where

$\rho_n = \sigma_n / f_y$ is the real value of the buckling factor of the isotropic plate ($\rho_n \leq 1{,}0$),

$$\rho_n = \rho_n(k_{wo}, b/t, f_y, \sigma_r) \ , \tag{10}$$

σ_n is the limit average stress with respect to the plate buckling.

The buckling factor ρ_n is a function of several random variables, mainly of imperfection factor k_{wo} , slenderness of plate b/t, yield stress f_y and residual stress σ_r. Considering all values in (10) as random variables leads to very complicated relations. As a first step the assumption that only k_{wo} is random variable, was accepted. This variable can be expressed by the formula

$$k_{wo} = 200 \cdot \Delta w_o \cdot \frac{\sqrt{245 / f_y}}{b}, \tag{11}$$

where Δw_o is the main component of the isotropic plate buckling which depends on the measurement methods and on the evaluation of the results of measurement [7].

The dependence of ρ_n on the imperfection factor k_w is shown in Fig. 4 for sterderness of plate b/t = 40, yield stress f_y = 240 MPa and 3 levels of residual stresses σ_r (see Fig.4).

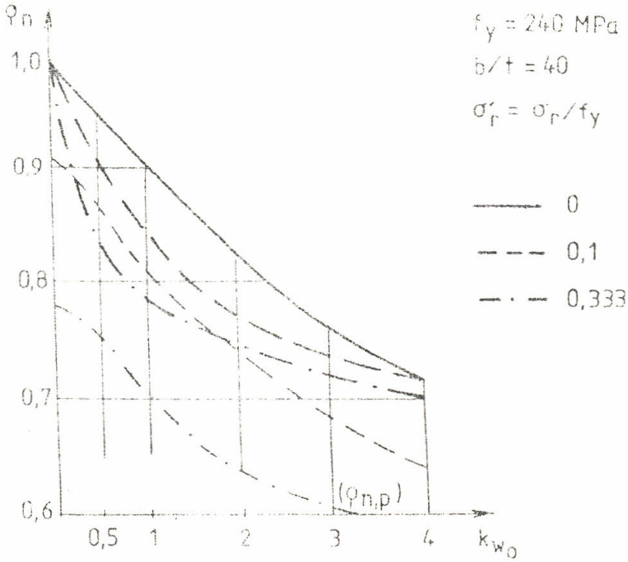

***Fig. 4**: The dependence of the buckling factor ρ_n on the imperfection factor k_{wo}.*

Using the plot in Fig.4 the histogram of the buckling factor ρ_n can be determined. Then applying the Monte Carlo method according to (9) the random values of the resistance of plates can be generated.

The quality of the set of products from the view point of the statistical acceptance is again determined by the relation (3).

The described method has been verified by testing isotropic plates with b/t = 40 fabricated from the steel 11375 which belongs to the orthotropic plate of a road box girder. The longitudinal stiffeners are perfectly rigid in the sense of [5]. The histogram of real measured values of initial deflection amplitude according to (11) is shown in Fig. 6. The probability density function of the yield stress is shown in Fig. 5.

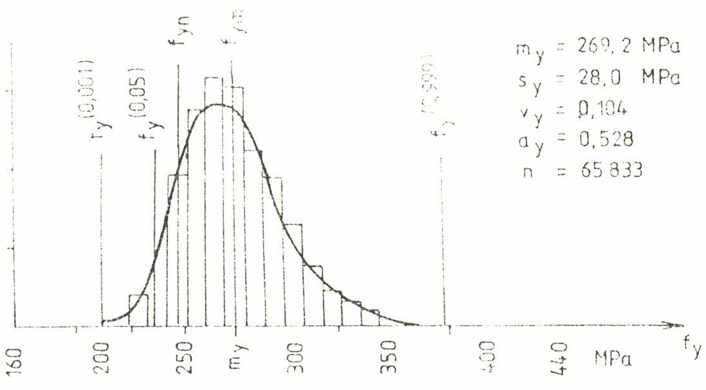

***Fig. 5**: The histogram and probability density function of the yield stress of isotropic plates.*

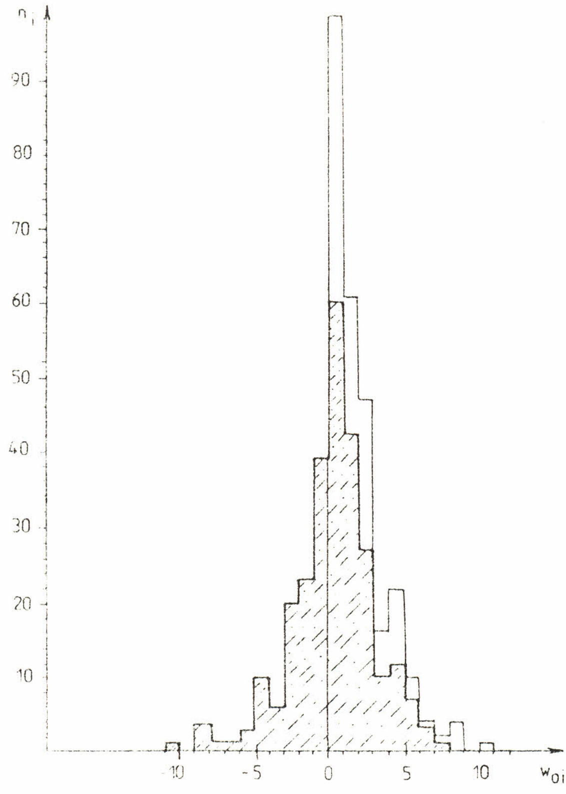

***Fig. 6**: The histogram of real measured values of initial deflection amplitude of isotropic plates.*

The parameters of φ_a are: μ_a = 1,0 , σ_a = 0,03 for normally distributed random variable φ_a .

The design resistance value of the isotropic plate according to [5] is R_{dc} = 0,85 · 210 = 178,5 MPa.

Using Fig. 4 for σ_a = 0,1 f_y the histogram for ρ_n has been developed and the resistance of the investigated set of plates has been determined. For the failure probability $P_f = 10^{-3}$ the resistance R_C = 160,7 MPa has been found.It means that the condition (3) was not satisfied. The condition holds for $P_f = 2.10^{-2}$. The value of $P_f = 10^{-3}$ could be reached only by excluding the plate sheets with initial deflections $k_{wo} > 1{,}4$, it is for w_o > 4 mm.

5. Conclusions

Two examples were shown to demonstrate the method of the statistical acceptance of compression members from the view point of their reliability.

The realisation of the statistical acceptance by this method enables to determine the failure probability of the resistance of the set of products with high accuracy.

Lektoroval: Prof. Ing. Pavel Novák, DrSc.
Předloženo v únoru 1995.

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Summary

THE STATISTICAL ACCEPTANCE OF THE STEEL BRIDGE STRUCTURE MEMBERS

Hynek ŠERTLER, Josef VIČAN, Jiří SLAVÍK

The paper presents a new statistical approach to the acceptance of steel bridge structure members based on their reliability. Two exaples are shown to demonstrate this methods for the acceptance of compression members.

The described methods anables to determine the failure probability of the set of members with higher accuracy.

Zusammenfassung

DIE STATISTISCHE ÜBERNAHME DER STAHLBRÜCKENELEMENTEN

Hynek ŠERTLER, Josef VIČAN, Jiří SLAVÍK

Der Beitrag befaßt sich mit dem neuen statistischen Zutritt für die Übernahme der Stahlbrückenelementen, der an iher Verläßichkeit gegründet ist. Zwei Beispiele sind angeführt, um die Methode für die Übernahme der druckbelasteten Elementen vorzustellen. Diese Methode vermägt die Wahrscheinlichkeitsverletzung der Tragfähigkeit der Stahlelementen mit höher Genauigkeit bestimmen.

Resumé

STATISTICKÁ PŘEJÍMKA PRVKŮ OCELOVÝCH MOSTNÍCH KONSTRUKCÍ

Hynek ŠERTLER, Josef VIČAN, Jiří SLAVÍK

Článek presentuje nový statistický přístup k problematice přebírání prvků ocelových mostů vycházející z jejich spolehlivosti. Jsou uvedeny dva příklady, které demonstrují uvedenou metodu při přejímce tlačených prvků. Popsaná metoda umožňuje stanovit pravděpodobnost poruchy souboru zkoumaných prvků s větší přesností.