On the load capacity of stiffened plate girders

On the Load Capacity of Stiffened Plate Girders

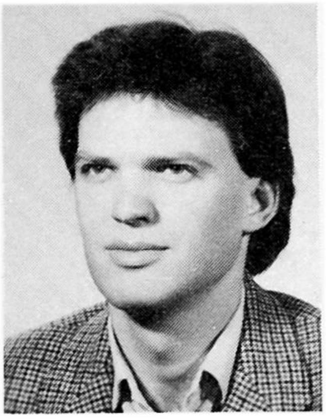
Sur la capacité portante des poutres à âme pleine raidie

Zur Regelung der Tragfähigkeit versteifter Blechträger

Joachim SCHEER
Civil Engineer
TU Carolo-Wilhelmina
Braunschweig, FRG

Joachim Scheer, born 1927, obtained his Ph.D. in 1958. As a Consulting Engineer he was involved in the design of bridges, masts and scaffolding. Since 1971 he has been a professor for Steel Structures, first in Hannover. and from 1976 in Braunschweig, working mainly on plate stability, masts and code development.

Hartmut PASTERNAK
Civil Engineer
TU Carolo-Wilhelmina
Braunschweig, FRG



Hartmut Pasternak, born 1954, obtained his Ph.D. in 1981. As a research engineer he was involved in the design of industrial steel buildings, silos and cranes. Since 1986 he has been a research worker at the Institute of Steel Structures in Braunschweig, working on load capacity and load modelling problems.

SUMMARY
Since 1935 over 200 experiments on stiffened plate girders, subjected to shear and bending loads, have been carried out worldwide. It is now to be determined, using a probabilistic approach whether, by means of the above mentioned experiments, the tension field model of the Eurocode 3 is verified for transversely stiffened girders and whether it may be extended to longitudinally stiffened ones.

RÉSUMÉ
Depuis 1935, plus de 200 expériences ont été effectuées sur la capacité portante des poutres à âme pleine raidie, soumises à des efforts tranchants et fléchissants. L'objet de cette publication est de déterminer, de façon probabilistique, si le modèle de champ de traction de l'Eurocode 3 est vérifiable pour les poutres à âme pleine raidie transversalement et s'il peut être étendu aux poutres à âme pleine raidie longitudinalement, en tenant compte des expériences mentionnées auparavant.

ZUSAMMENFASSUNG
Weltweit wurden seit 1935 über 200 Versuche zur Tragfähigkeit ausgesteifter Vollwandträger unter Schub- und Biegebeanspruchung durchgeführt. Jetzt wird auf probabilistischer Grundlage untersucht, ob damit das Zugfeldmodell des Eurocode 3 für querversteifte Träger verifiziert und auf längsversteifte Träger ausgedehnt werden kann.

1. INTRODUCTION

In the past three decades, various tension field models were developed in order to predict the ultimate load capacity of stiffened plate girders subjected to shear and bending loads [1].

From time to time this development has been the target of fundamental questioning. Recently, a design model, based on the fully plastic shear load of the unstiffened web, has been presented [2].

Parallel to this, the number of experiments on stiffened plate girders has continually increased; in 1968, approximately 50 experiments were carried out, ten years later about 140 and nowadays there are more than 200.

However, experiment and theory only have their meaningfulness if full attention is paid to the stochastic character of the load capacity, and its influence quantities, in the experimental evaluation as well as in the calculations.

Since 1986, the Institute for Steel Structures in Braunschweig is working on the documentation, evaluation and recalculation of all available experiments. The work is performed - in an unprecedented extensive manner - using the programmable database system dbaseIII+. Moreover, it was attempted to estimate the uncertainty in the experiment execution and in the load capacity prediction.

In the context of the revision of the EC3, a few new questions arise, that may now be answered:

- is it allowable, in the Eurocode safety concept to apply the tension field models to transversely stiffened plate girders?
- could the application of these models, within the same safety concept, be extended to longitudinally stiffened girders? Which of the established models is optimal, taking into account the results of the experiments that were analysed in this study?

2. EVALUATION PROCEDURE

After compiling all experimental data into databases for transversely and longitudinally stiffened girders, the experiments containing parameters outside of the EC3 definition domain were rejected. The most frequent reason therefore were end post failures.

The test analysis described below (Fig. 1) was derived from the outline of the Eurocode paper "Procedure for the determination of the design resistance from tests" published in September 1987.

For the remaining i tests, the measured values of load capacities $V_{ue,i}$ (for the moment considered as exact), are compared with the calculated values $V_{ut,i}$ using model factors M_i, whose mean value $\overline{M}$ as well as the error terms δ_i are calculated. The scattering of the measured values with respect to the theoretical ones can be estimated by means of v_δ.

The variation coefficient v_{Vut} of the calculated load capacity is to be estimated from the randomization of the design models according to sections 3 and 4, in which the input values (basic variables) are to be formulated with variation coefficients normally used for steel structures:

yield stress	– v_{fy}	= 0.06...0.08
modulus of elasticity	– v_E	= 0.04
plate thickness	– v_t	= 0.02

The authors have no data concerning the scattering of the buckling coefficient k_s (mainly because of the scattering of the boundary conditions). It is assumed that v_{ks} = 0.03. The scattering of the other input values is negligible. From the computational model, the variation coefficient of the load capacity is then calculated to be v_{Vut} = 0.08.

Until now it has not been taken into account, that vaguely defined experimental data must also have been introduced into the data base: e.g. the yield stress was often not measured or measured inaccurately, the modulus of elasticity was often not measured at all, and in some cases, only the nominal plate thicknesses were given. The scattering for the whole set of experiments may be estimated with $v_{\delta exp}$ = = 0.10.

1. Measure $V_{ue,i}$
2. Calculate $V_{ut,i}$ (from EC3 or [1])
3. $M_i = \dfrac{V_{ue,i}}{V_{ut,i}}$
4. $\overline{M} = 1/n \sum M_i$
5. $\delta_i = \dfrac{M_i}{\overline{M}}$
6. $v_\delta = \sqrt{\dfrac{1}{n-1}\left(\sum_{i=1}^{n} \delta_i^2 - n \cdot 1\right)}$
7. Estimate v_{Vut}
8. Estimate $v_{\delta exp}$
9. $v_{Vu} = \sqrt{v_{Vut}^2 + v_\delta^2 - v_{\delta exp}^2}$
10. $V_{u,k} = \overline{M}\, V_{ut} \exp(-1{,}645\, v_{Vu} - 0{,}5\, v_{Vu}^2)$ for LN-distributed load capacity
11. $\gamma_m = \exp\left((0{,}8\,\beta - 1{,}645)\, v_{Vu}\right)$, $\beta = 3{,}8$

Fig.1 Algorithm

The variation coefficient v_{Vu}, characteristic value $V_{u,k}$ as well as the partial safety factor γ_m of the ultimate load capacity may then be calculated.

3. TRANSVERSELY STIFFENED GIRDERS

The EC3 contains simplifying assumptions for the load capacity calculations of transversely stiffened girders: bending moment and longitudinal force are taken up by the flange, transverse

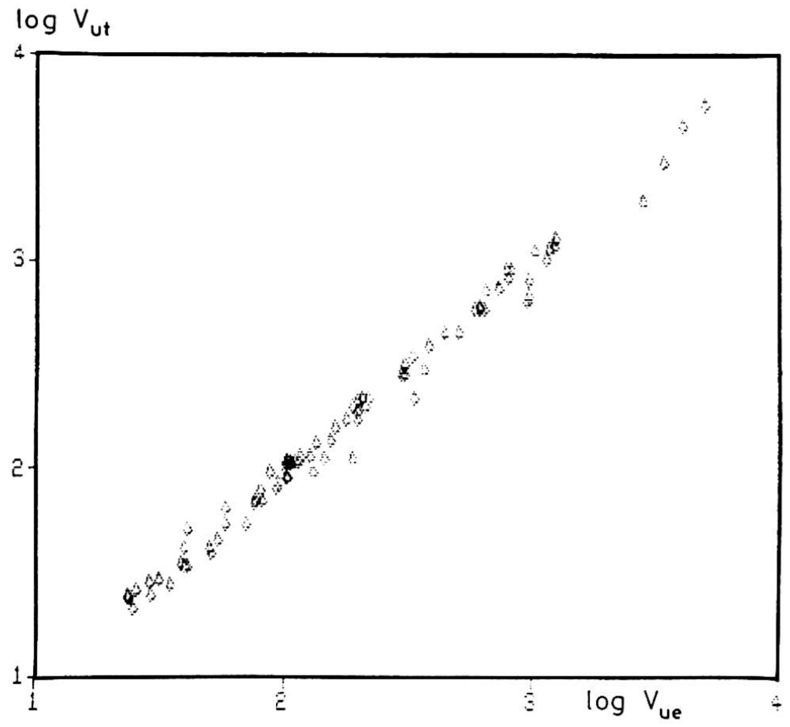


Fig.2 Correlation between calculation and experiment

forces are transfered to the web through the tension field and the shear field mechanism.

Fig.2 shows the satisfactory agreement between calculated and experimental results.

Fig.3 gives the frequency distribution of the model factor.

Characteristic value and partial safety factor of the load capacity may be read off Fig.4.

4. LONGITUDINALLY STIFFENED GIRDERS

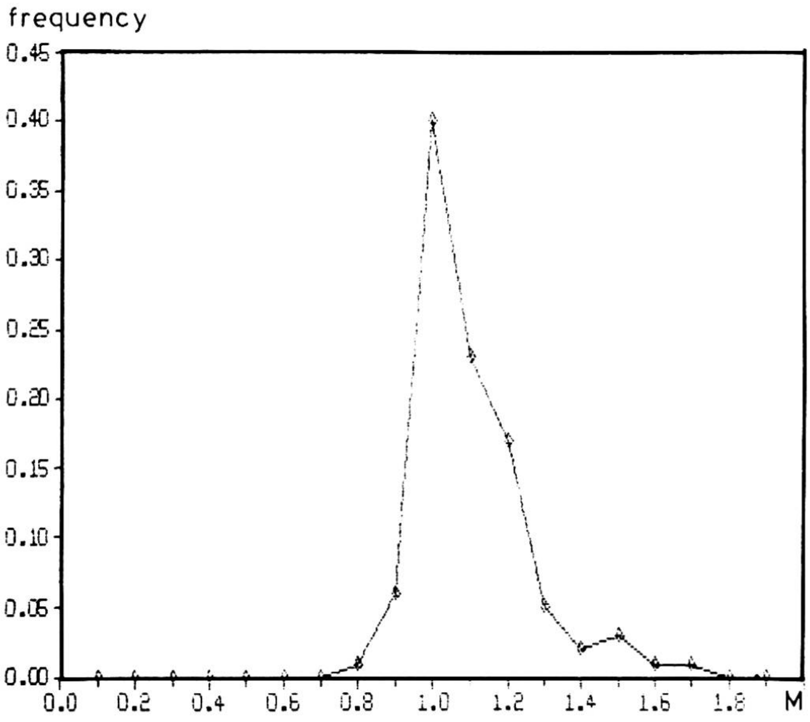


Fig.3 Frequency distribution of the model factor

The limit load capacity of longitudinally stiffened girders could be determined within EC3, in the same way as for transversely stiffened girders. The assumption of the tension field mechanism, however, still has to be determined. During the comparison of competing models, it was possible to substantially increase the number of evaluated experiments, relative to earlier investigations described in [1]. Fig.4 gives the results for various models.

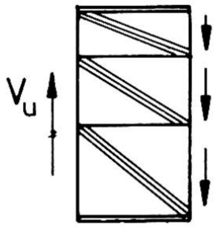
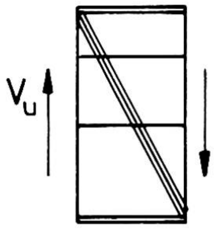
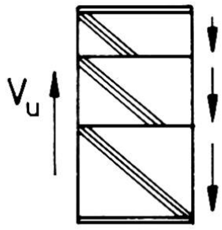
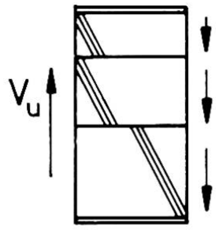
	Transversely stiffened girders (n = 98)	Longitudinally stiffened girders (n = 59)			
		1	2	3	4
					
		Separate tension field bands	Single tension field band	Separate tension field bands	Separate tension field bands
		Each a function of subpanel τ_i and aspect ratio α_i	A function of full panel aspect ratio α	Each a function of subpanel τ_i and common aspect ratio α_{min}	Each a function of subpanel τ_i and common panel aspect ratio α
$\bar{M}$	1,10	1,15	1,17	1,12	0,99
v_δ	0,16	0,13	0,10	0,12	0,08
$V_{u,k}$	0,85 V_{ut}	0,95 V_{ut}	0,94 V_{ut}	0,94 V_{ut}	0,91 V_{ut}
γ_m	1,23	1,17	1,12	1,16	1,08

Fig.4 Characteristics of various computational models

5. CONCLUSIONS

The first two questions of section 1 can in priciple be answered positively. However, the characteristic values of the load capacities are a few percent lower than the theoretical values; the partial safety factors are mostly greater than the code value of $\gamma_m = 1.1$.

Moreover, it is noticeable that even the models having an average model factor above 1, with consideration of all the scattering originating from experiment and calculation, do not lie on the safe side any more. Considering this result, one might be tempted to jump to conclusions, but should rather be prompted to further investigate the experimental assessment of computational models.

Model 2 seems to be optimal for describing the behaviour of longitudinally stiffened girders; the model is simpler and does not yield worse characteristics than the other models.

The method in [2] is characterized by scattering in the model factors, that is larger than that of the models discussed in section 3 and 4. From our experience, this yields a lower bound of the load capacity.

All of the experimental data and detailed results of the evaluation are available from the authors.

6. ACKNOWLEDGEMENT

The Authors wish to thank the Federal Ministry of Civil Engineering for financial support, all scientists who have sent their research papers, as well as Mr. O. Kroth for his support in setting up the data base.

REFERENCES

1. Dubas P., Gehri E.: Behaviour and Design of Steel Plated Structures, ECCS publication n.44, Zurich 1986

2. Herzog M.: Tragfähigkeit und Bemessung unversteifter und versteifter Blechträger auf Schub in einfachster Näherung, Bauingenieur 63 (1988)