Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 37 (1982)

Artikel: Fatigue strength of screwed fastenings

Autor: Strnad, Milan

DOI: https://doi.org/10.5169/seals-28970

Fatigue Strength of Screwed Fastenings

Résistance à la fatigue d'assemblages vissés

Ermüdungsfestigkeit geschraubter Verbindungen

MILAN STRNAD
Eng., CSc.
Building Research Institute
Praha, Czechoslovakia

SUMMARY
The present paper is concerned with the analysis of the behaviour of screwed fastenings subjected to repeated loading that can lead to fatigue. On the basis of statistical evaluation of experimental results empirical formulae are set up that make it possible to establish the design shear strength of screwed fastenings in light gauge steel structures subjected to repeated shear fluctuating loading.

RESUME
La présente contribution traite de l'analyse du comportement à la fatigue d'assemblages vissés de constructions en tôles minces soumises à l'action de charges répétées. Il décrit les différents cas de fatigue d'assemblages de tôles minces au moyen de vis, sous chargement répété. Sur la base de résultats statistiques, des formules empiriques sont établies pour le calcul des forces de cisaillement sous l'action de sollicitations variables de tels assemblages.

ZUSAMMENFASSUNG
Der Beitrag informiert über Forschungsergebnisse auf dem Gebiet der Schraubenverbindungen bei dünnwandigen Stahlkonstruktionen. Er beschreibt das Ermüdungsverhalten solcher Verbindungen unter wiederholter Belastung. Aufgrund statistischer Ergebnisse werden empirische Berechnungsformeln für die Bemessung von Blechschraubenverbindungen aufgestellt.

1. INTRODUCTION

One of the most widely used ways of connecting light gauge steel structures nowadays is by means of screwed fastenings. They differ from bolted fastenings primarily in the fact that they need no nuts since they make their own nut thread in the connected elements.

Very early, experimental research [1], [2] established essential differences in the behaviour of screwed fastenings in light gauge steel structures and that of bolted fastenings in thick steel structures. Therefore it was not possible, with regard to safety and economy of design, to apply the design formulae that were known only for bolted fastenings of thick steel structures to screwed fastenings. Lack of knowledge about the behaviour of the highly advantageous screwed fastenings on the one hand and growing pressure on their application on the other hand, stimulated extensive research in this field. Initially, this research was focused on cases of non-repeated loading [1], [2], [3], [4], [5], [6], later it grew in scope to include cases of repeated loading which can often lead to fatigue [7], [8], [9], [10], [11], [12], [13], [14].

The purpose of this contribution is
- a brief outline of the research carried out so far;
- a description of the typical behaviour of screwed fastenings subjected to repeated loading leading to fatigue;
- information about tentative formulae for characteristic loading range in repeated cyclic loading leading ta fatigue.

2. AN OUTLINE OF PAST EXPERIMENTAL RESEARCH

The primary aim of research in this field was to establish the actual behaviour of screwed fastenings of light gauge steel structures in different conditions. The result aimed at was principles and recommendations for design including design formulae.

On the basis of the materials available to us it can be said that as early as in 1971 the results of the first detailed research were published [2] describing the behaviour of screwed fastenings, including rupture modes, and giving the design formulae for the cases of non-repeated loading. Of great importance was the coordination of research in this field by European Convention for Constructional Steelwork. First recommendations for testing of connections in light gauge steel components were worked out [5] and then attention was turned to a whole range of problems connected with the design of fastenings [13]. This work also involved some problems of repeated wind loading that may, in some case, lead to fatigue of fastenings. For the sake of simplicity of design formulae, the effects of multi-level repeated wind loading were simulated by reduction of design loading observed in non-repeated loading [11], [12], [13].

In the course of the research into screwed fastenings subjected to repeated loading [9], [10] the importance of the influence of the development of plastic deformations on the fatigue strength of the fastening was observed.

3. THE RESPONSE OF A FASTENING TO REPEATED LOADING

The behaviour of screwed fastenings subjected to repeated loading, fatigue failure and failure mode are dependent on a number of conditions which can be summed up into four basic categories

- material parameters;
- parameters of manufacturing technique;
- design parameters;
- load parameters.

The influence of these conditions on fastening fatigue is generally recognised and also the experiments performed are evaluated from this point of view. However, there still exists a group of problems important for the determination of fatigue [14] : in contrast to the other elements of steel structures, screwed fastenings of thin steel sheets generally exhibit considerable plastic deformations from the very beginning of loading. In the process of repeated loading, considerable discrepances in the behaviour of identical fastenings can be observed which cannot always be accounted for in terms of loading data alone. They are due to the different character of the development of plastic deformations in the process of loading which determines whether the failure observed is

- high-cyclic fatigue rupture;
- low-cyclic fatigue rupture;
- an increase of plastic deformation.

High-cyclic fatigue occurs if no plastic deformations are observed during loading or if initial plastic deformation gives rise to such residual stresses that shakedown occurs and the fastening continues to behave elastically. High-cyclic fatigue rupture is mainly characterised by an increase of fatigue cracks at a great number of loading cycles.

Low-cyclic fatigue occurs in the case of reversed plastification which leads to continual increase in plastic deformations. Rupture at a small number of loading cycles is also caused by an increase of fatigue cracks.

An increase of plastic deformations occures if there is no shakedown after the initial plastic deformation or if there are slips in the plastically deformed screw hole caused by repeated reversed loading. Plastic deformations here make the fastening useless even before contingent rupture.

4. TENTATIVE FORMULAE OF FATIGUE STRENGTH OF SCREWED FASTENINGS

Experimental establishement of fatigue for each particular variant of fastening is very time-consuming and expensive. Therefore attempts are made at setting up empirical formulae with a more general validity that could be used as a substitute for experiments and could reduce their role to a mere verification of a chosen variant.

On the basis of experimental results obtained in Czechoslovakia, a model of design formulae was set up involving, in the first stage, screwed fastenings subjected to shear fluctuating loading.

Research has shown [10] that failure is commonly caused by high fatigue rupture or by increase of plastic deformations and that fatigue strength is well characterized by the loading range. The following formulae do not hold for cases of shear of fastener and end failure which we usually try to eliminate in advance through the design parameters chosen. The formulae proposed for repeated loading follow up the earlier empirical formulae for ultimate load in the case of non-repeated loading [4] :

$$F_{max} = K \times t \times R_m \times (D + 5), \text{ where} \qquad (1)$$

$$t = 0.5\left[t_1 (\varkappa - 1) + t_2(3 - \varkappa)\right] ; \; R_m = 0.5\left[R_m^{t_1}(\varkappa - 1) + R_m^{t_2}(3 - \varkappa)\right]$$

If $\varkappa > 2$, we substitute $\varkappa = 3$.

In order to set up a model of the formulae expressing the relation between the loading range and the number of loading cycles achieved at the moment of fatigue rupture, it has been necessary to divide this dependence into two intervals characterized by different failure modes. These intervals are evident from log-log graph in Figure 1.

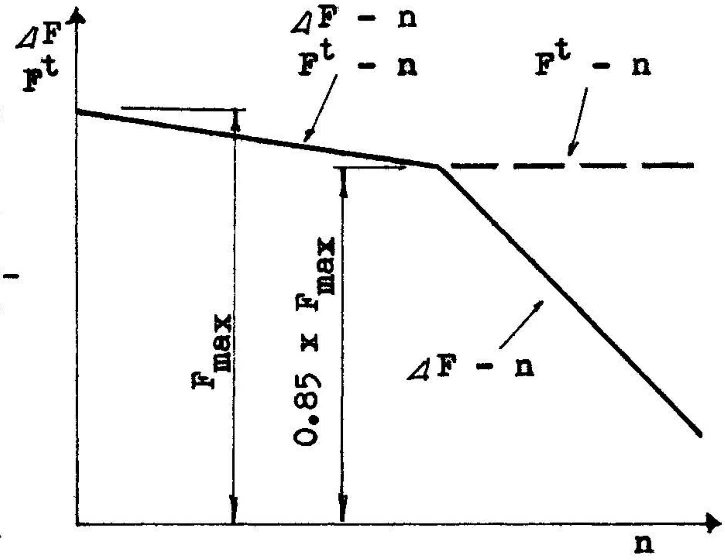

Fig. 1

In the first interval, the top value of repeated loading F^t is greater than $0.85 \times F_{max}$. In such cases plastic deformations increase considerably in the course of repeated loading. For this interval, the following dependence between F^t, ΔF and n is proposed :

$$\Delta F \leq F^t = F_{max} \frac{1}{n^C} \quad . \qquad (2)$$

The practical value of this formula is rather small, for two reasons. First, the difference $F_{max} - F^t$ is relatively small compared with the possible scatter of F_{max} in actual fastenings, and thus the precision of the formula is small. Second the actual design of a fastening must, in this cases, take into account plastic deformations which impair the fastening long before rupture.

Typical of the second interval is the occurrence of high-cyclic fatigue. For the dependence of the loading range and the number of loading cycles achieved at rupture the following formula has been proposed :

$$\Delta F = 0.85 \times F_{max} \frac{1}{\left(\frac{n}{A}\right)^B} \quad . \qquad (3)$$

This relation holds on condition that $F^t \leq 0.85 \times F_{max}$.

On the basis of earlier [4], [14] and recent experimental research in Czechoslovakia, the factors in (1), (2), (3) are proposed to be as follows :

$K = 0.80 + 0.35\ (\varkappa - 1)$

$A = 10^{5 - (R_m - 300) \times 0.007}$

$B = 0.08 + 0.05\ (\varkappa - 1)$

$C = 0.016$

Table 1 presents a comparison of some experimentally determined values with those calculated according to formulae (1), (2), (3). The experimental data given have been obtained by statistical evaluation of six identical samples. Owing to considerable scatter of results of identical tests found both in Czechoslovakia [14] and Sweden [9] we find advisable in future research to use more identical samples.

Formulae (1), (2), (3) relate to cases of rupture. Design values for calculations in limit states design are then determined according to Czechoslovak standards and regulations, as follows:

- In the case of non-repeated loading, design load is obtained by dividing characteristic load in (1) by material factor $\gamma_m = 2.05$. Also, plastic deformations must be kept within acceptable limits.
- In the case of repeated loading leading to high-cyclic fatigue, design loading range is obtained by dividing loading range in (3) by material factor $\gamma_m = 1.20$.
- In the case of repeated loading leading to an increase of plastic deformations, formula (2) cannot be generally applied; instead, plastic deformations must be kept within allowable limits. It is advisable to choose the design loading range so that plastic deformations at a given number of loading cycles do not exceed 0.30 mm.

5. CONCLUSION

From the numerical comparison that has been carried out it can be concluded that the proposed model of formulae is in good agreement with the actual behaviour of the fastenings in which fatigue failure occurs. However, further research should bring the particular factors to greater precision and possibly include cases of cyclic repeated reversed loading which brings about a response of a fastening quite different from the response to fluctuating loading.

In fastenings subjected to repeated tensile loading, fatigue strength is influenced by a great variety of fastening parameters. Therefore it seems that it will be better to test each case separately, rather than to set up complicated formulae.

NOTATIONS

F	shear load per fastening	n	number of loadin cycles at failure
F_{max}	ultimate shear load per fastening		

Table 1

CONNECTION: SCREW DIAMETER	CONNECTION: SCREW TYPE	CONNECTION: SHEET t_1 / t_2 [mm]	CONNECTION: SHEET $R_m^{t_1}$ / $R_m^{t_2}$ [MPa]	$\varkappa$	NON-FATIGUE STRENGTH F_{max} [kN] EXPERIMENT	NON-FATIGUE STRENGTH F_{max} [kN] THEORY Formula (1)	FATIGUE OF CONNECTION ΔF [kN] (F^t) [kN]	FATIGUE OF CONNECTION $n \times 10^{-6}$ EXPERIMENT	FATIGUE OF CONNECTION $n \times 10^{-6}$ THEORY Formulae (2) (3)
6.3	Thread forming	0.84 / 5.00	339 / 369	>3	5.87	4.83	4.05 (4.50)	0.0888	0.0575
							3.15 (3.50)	0.1477	0.2324
							2.75 (5.00)	0.6330	0.4941
							2.52 (2.80)	1.0188	0.8028
							2.50 (5.00)	1.1593	0.8391
							2.12 (4.25)	1.8548	2.0970
4.0	Thread cutting	0.57 / 5.00	316 / 369	>3	2.35	2.43	2.00 (2.15)	0.0706	0.0924
							1.45 (1.60)	0.5843	0.5516
							1.00 (1.60)	3.0158	4.3465
6.3	Thread forming	0.84 / 0.84	339 / 339	1	3.24	2.57	2.02 (2.25)	0.2621	0.1419
							1.94 (2.75)	0.2293	0.2352
							1.80 (2.00)	0.7246	0.5998
							1.75 (2.50)	3.6226	0.8529
							1.40 (2.01)	11.8853	13.8770
4.0	Thread forming	0.63 / 0.63	325 / 325	1	1.41	1.47	1.30 (1.30)	0.0009	0.0021
							1.00 (1.10)	0.5143	1.0819
							0.81 (0.90)	12.9763	15.0708
6.3	Thread forming	0.57 / 0.82	316 / 327	1.49	2.66	2.70	2.45 (2.45)	0.0001	0.0004
							2.00 (2.25)	0.1866	0.2550
							1.75 (2.25)	0.4315	0.9208

F^t top value of repeated load

F^b bottom value of repeated load

ΔF loading range ($\Delta F = F^t - F^b$)

D nominal diameter of screw

$\varkappa$ stress-thickness ratio

$$\left(\varkappa = \frac{t_2 \times R_m^{t_2}}{t_1 \times R_m^{t_1}} \right)$$

t_1, t_2 thickness of the thinner, thicker steel sheet

$R_m^{t_1}$, $R_m^{t_2}$ ultimate stress of the thinner, thicker steel sheet

K, A, B, C experimentally de - termined factors

REFERENCES

1. Bryan, E. R. - ElDakhakhni, W. M. : Shear flexibility and strength of corrugated decks. Jour. Struct. Div., Proc. A. S. C.E. Vol. 94, No. ST 11, November 1968, p. 2549.

2. Baehre, R. - Berggren, L. : Hopfogning av tunnväggiga stål-och aluminiumkonstruktioner (Jointing of thin-walled steel and alu - minium structures), Byggforskningen Sammanfattningar R 30 : 1971, Stockholm, Statens institut för byggnadsforskning, 1971.

3. Grossberndt, H. - Kniese, A. : Untersuchung über Querkraft- und Zugkraftbeanspruchungen sowie Folgerungen über kombinierte Schraubenverbindungen bei Stahlprofilblech-Konstruktionen (Investiga - tion into screwed connection subjected to shear or tensile loading; implications for tensile and shear load combinations). Der Stahlbau, Vol. 44, October 1975, p. 289, November 1975,p.344.

4. Strnad, M. : Smyhem namáhané šroubové spoje tenkých ocelových plechů (Screwed fastenings of thin sheets subjected to shear). Stavebnícky časopis, Vol. 24, No.6, VEDA, 1976, p. 523.

5. European Convention for Constructional Steelwork : European recommendations for the testing of connections in profiled sheeting and other light gauge steel components. No. 21, ECCS - XVII - 77 - 3E, 1978.

6. Grimshaw, J. A. : Shear tests on mechanical connections in light gauge steel components. University of Salford, Department of Civil Engineering, Report Ref. No. :79/121, July, 1979.

7.Guidlines for the testing and evaluation of products for cyclone-prone areas. Experimental Building Station, Department of Construction, Australia, Technical record 440, February, 1978.

8. Tomà, A. W. : Fastening of steel sheets for walls and roofs on steelstructures. Institute TNO for Building Materials and Build - ing Structures, Report No. BI - 78 - 43/63.5.5461, Delft, June, 1978.

9. Nissfolk, B. : Fatigue strength of joints in sheet metal panel (2), Screwed and riveted connections, Statens råd för byggnads - forskning, Stockholm, Document D 15:1979.

10. Strnad, M. : Screwed connections in profiled sheeting. VIth International Scientific and Technical Conference Metal Constructions, Katowice, May-June, 1979, p. 177.

11. Klee, S. - Seeger, T. : Vorschlag zur vereinfachten Ermittlung von zulässigen Kräften für Befestigungen von Stahltrapezblechen (Proposal for the simplified determination of allowable forces for connections in profiled sheeting). Institut für Statik und Stahlbau der Technischen Hochschule, Darmstadt, Report No. 33, 1979.

12. Strnad, M. : Únavová pevnost šroubových spojů tenkých plechů

(Fatigue strength of thin sheet screwed connections). Stavebnícky časopis, Vol. 28, No. 2, VEDA, 1980, p. 125.
13. European Convention for Constructional Steelwork: European recommendations for connections in thin walled structural steel elements, Part I : Design of connections, September, 1980.
14. Strnad, M. : Fatigue strength of screwed fastenings in thin sheet components. The Structural Engineer, Vol. 59B, No. 3, September, 1981.