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Incremental Collapse of Thin Webs subjected to Cyclic Concentrated Loads

Rupture des âmes minces soumises à des charges cycliques concentrées

Kollaps von dünnen Stegen unter zyklischer Belastung durch Einzellasten

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Some comments and complements are here given to the problem treated in the paper by P. Novák and M. Škaloud [1] on the above subject.

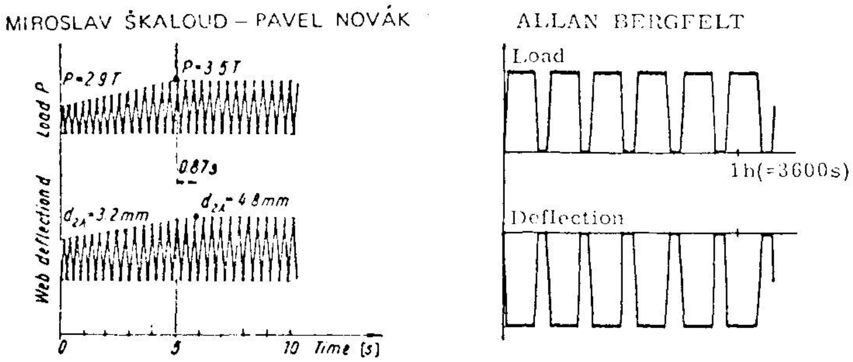

Fig. 1. Different shape of loading cycles.

The authors have performed tests, where the maximum load in every cycle has been attained during a very short time only, fig. 1. In each cycle, load values causing plastic deformations, seem to have been kept during a few hundredths of a second only, in the "fast" cycles, or during a few seconds in the "slow" cycles. In my tests the maximum load has been kept for several minutes in every cycle as is illustrated by fig. 1.

My test results agree, in principle, with those of Novák and Skaloud (except for the girders with very small flange stiffness factor). That is, the reduction of the load carrying capacity caused by repeated loading was found to be very small. In figure 2 the failure loads after 2 cycles – circular points – or after many cycles (up to about 1000) – triangular points – are plotted against the flange-to-web thickness ratio. The failure loads are divided by web crippling load under monotonously increasing loading. These failure load ratios are very close to 1, althogh in most cases a little less than 1, 0. Even the lowest ratios are not less than 85 à 90 %, which I have reported earlier [2].

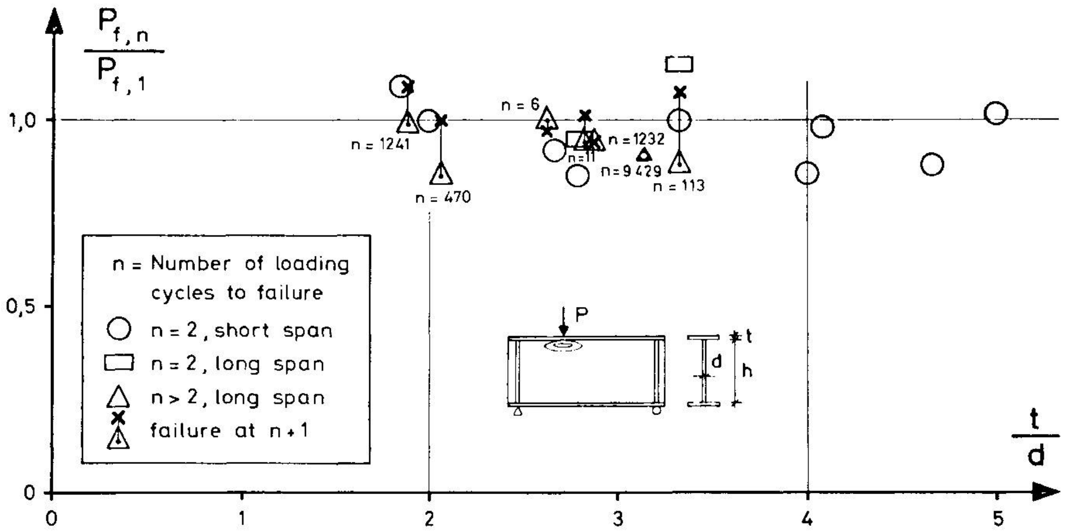

Fig.2. Ratios of failure load under repeated loading to failure load under monotonous loading.

As usual the greatest difference in deformation is measured between the first and second loading. A repeated loading that goes on for hundreds of cycles causes only a slight further increase. From these tests it was hard to find any difference in failure load between the 2 cycle tests and the tests with up to about 1000 loading cycles. Of course the scatter of the results is rather great, depending on initial deformations and initial stresses.

One test was however performed to about 10 000 loading cycles with a maximum load of 90 % of the foreseen crippling load under monotonously increasing loading. Here a crack appeared in the web after about 5000 cycles. The crack was mainly horisontal and about 3 cm below the flange right under the load with slightly bents upwards at each side until a total length of about 10 cm. No significant increase of vertical deformation was observed. Nothing more happened during the following 4 000 loading cycles than that the length of the crack increased to about 20 cm. Soon thereafter at 9 429 cycles a buckling failure occured. The girder was of ordinary carbon steel with a yield stress $\sigma_y \approx 3300$. Flange 18 x 350 mm, web 6 x 700 mm. Max.load 31,5 tons was for the somewhat shortened cycles of just this test, held during nearly 30 sec. in every cycle. The max.vertical stress was about 3000 kp/cm^2 and the breathing under the loading cycles caused bending strains of similar magnitude. The crack was visible on both sides of the web. Its maximal width was largest on one side at max.load and on the other side at unloading.

The local crack demonstrates that even if the girder can bear a certain load in one point during many cycles, this repeated load will cause a collaps if it is movable along the span.

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The most important new results in my investigation is however that girders both of ordinary carbon steel and of high strength steel have been tested [3]. The results for high strength steel are in fig.3 marked with filled dots (or partly filled dots).

It is seen - which is quite obvious - that the girder can carry higher concentrated loads when the yield point of the steel increases. (This is true also for such a hybrid girder with high strength steel in the web only). It is also seen that the increase of failure load is not directly proportional to the yield stress which is quite normal as buckling is dominating. The lines of the diagram illustrates what in the case of direct proportionality should have been expected for an ordinary steel with yield points of σ_y = 2000 or 3000 and a high strength steel of 6000 kp/cm^2. It is seen that for example the filled dots for 6000 kp/cm^2 fall much below the corresponding theoretical line. The failure loads seem to be approximately proportional to $\sqrt{\sigma_y}$ (or still better to $\sigma_y^{2/3}$) and not directly proportional to σ_y. Of course this concerns only those tests where $t/d \gtrsim 2$ and thus buckling is dominating.

In a diagram (fig.4) where the load is divided by $\sqrt{\sigma_y}$ the results for different steel qualities fall rather near the theoretical lines. (As is pointed out in [2] the flange thickness t ought to be corrected to $t_i = t\sqrt[4]{b/25\,t}$, which is however not done in this discussion resport).

Of special interest for this symposium are the results for repeated loads. These points are marked with dots completed with two small upward

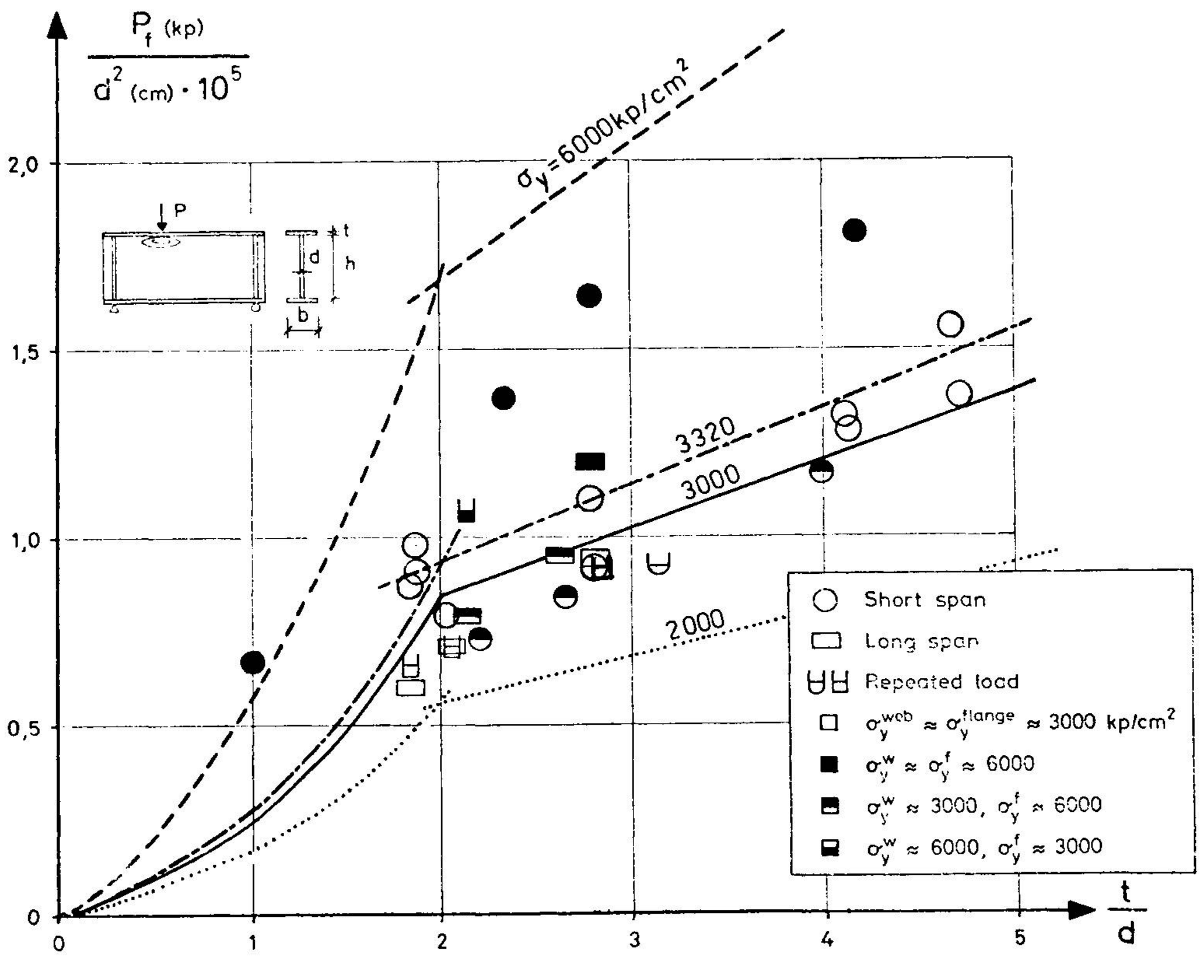

Fig.3. Failure loads (crippling) for different steel qualities.

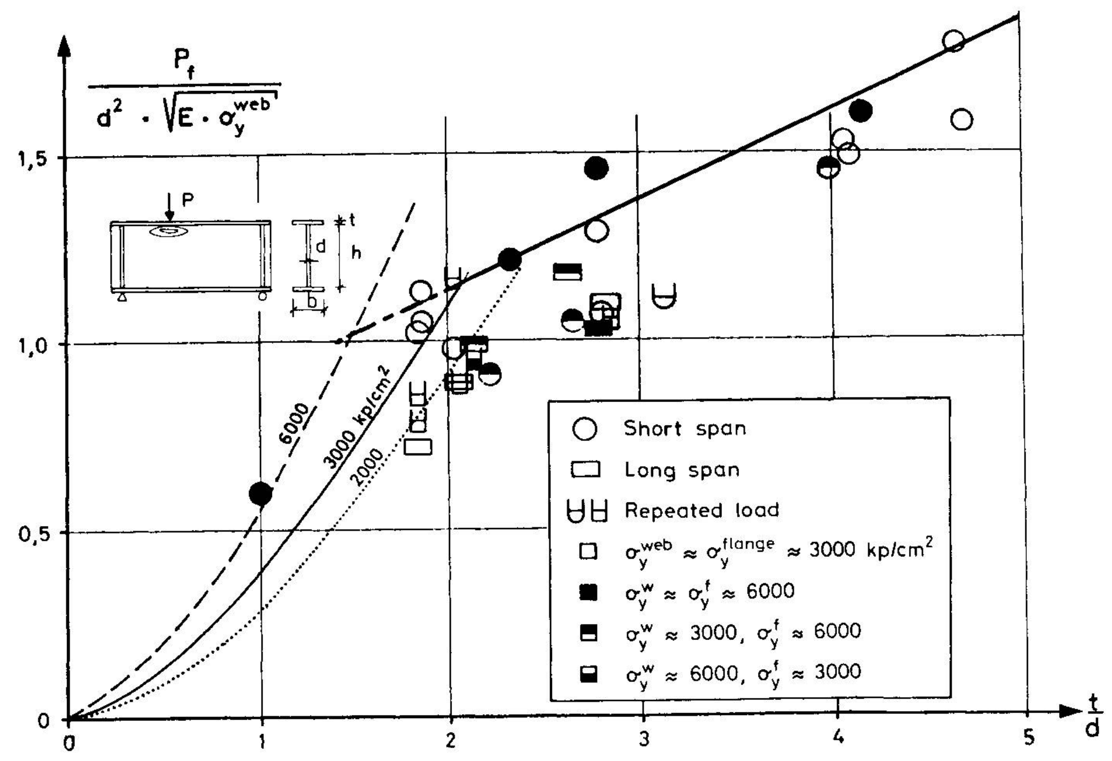

Fig.4. Failure load (crippling) divided by $\sqrt{\sigma_y}$ and for different steel qualities.

lines. It is seen that also these results fall within the scatter region. The points fall, however, generally in the lower part of this region.

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References :

[1] P.Novák - M.Škaloud : Incremental collapse of thin webs subjected to cyclic concentrated loads. IABSE Symposium Lisboa 1973, Preliminary report p.179.

[2] A.Bergfelt : Post-buckling behaviour of webs under concentrated loads. IABSE, Ninth Congress, Amsterdam 1972, Final report p.83.

[3] A.Bergfelt - S.Lindgren : Livintryckning vid slanka I-balkar vid upprepad belastning och speciellt vid höghållfast stål (Web crippling for repeated loadings and specially for high strength steel). Nordiske Forskningsdager for Stålkonstruksjoner, Oslo 1973. Rapport II.2/4.

SUMMARY

The new test values according to Škaloud and Novák [1] for local web crippling under a concentrated load, are compared to values from tests with loading cycles where the loading period is rather long.

Both static and repeated loadings have been made with girders both of ordinary carbon steel and of high strength steel. Previously given dependance on flange-to-web thickness ratio is completed with the dependance on the yield stress.

RESUME

Les résultats d'essais selon Škaloud et Novák [1] concernant la ruine locale de l'âme soumise à une force concentrée variant périodiquement sont comparés à ceux avec des périodes de charges assez longues.

Des essais statiques et avec des charges périodiques ont été réalisés sur des poutres en acier normal et en acier de haute résistance. La dépendance du rapport entre l'aile et l'âme donnée auparavant est complétée par la dépendance de la limite d'élasticité.

ZUSAMMENFASSUNG

Die Versuchsergebnisse nach Škaloud und Novák [1] für lokales Stegblechbeulen unter periodisch variierender Einzellast werden mit Ergebnissen unter Wechsellasten mit langer Zeitdauer verglichen.

Die Balken wurden mit statischer Einzellast und mit Wechsellasten geprüft. Sie waren sowohl aus normalem Stahl als aus hochfestem Stahl gefertigt. Die früher gegebene Abhängigkeit der Flanschdicke von der Stegdicke wird hier durch die Abhängigkeit von der Fliessgrenze vervollständigt.

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