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Fatigue Behaviour of Riveted Joints

Comportement à la fatigue d'assemblages rivetés

Ermüdungsverhalten genieteter Verbindungen

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SUMMARY

Previously, most dynamically loaded steel structures, such as bridges and cranes, were designed in accordance with the specifications in force at that time. The increasing of loads has posed the question of expected reserve life. In order to assemble more information concerning fatigue life prediction, a review of data available in current literature is given in this paper with regard to the fatigue behaviour of riveted joints and the variables affecting fatigue strength.

RESUME

De nombreuses constructions métalliques actuelles, telles que ponts et ponts-roulants, soumises à des charges dynamiques, ont été dimensionnés sur la base des normes de calcul d'alors. L'augmentation des charges dynamiques, ont été dimensionnées sur la base des normes de calcul d'alors. L'augmentation des charges met en question la durée de vie restante de l'ouvrage. Afin de fournir une meilleure information fatigue d'assemblages rivetés et aux paramètres influençant la résistance à la fatigue.

ZUSAMMENFASSUNG

Viele bestehende, dynamisch beanspruchte Metallkonstruktionen wie Brücken und Kranbahnträger sind aufgrund älterer Bemessungsgrundlagen erbaut worden. Infolge der Belastungszunahme im Laufe der Zeit stellt sich heute die Frage bezüglich der Restlebensdauer. Um bessere Informationsgrundlagen für die Vorhersage der Lebensdauer zu erhalten wird hier ein Überblick über Angaben aus neuerer Literatur betreffend das Ermüdungsverhalten genieteter Verbindungen sowie die Einflussparameter auf die Dauerfestigkeit gegeben.

1. INTRODUCTION

Extensive fatigue tests of riveted joints were carried out in Germany in the 1930's. Well known are the testseries of O. Graf [5] and K. Klöppel [3].
In the USA there were studies conducted at the University of Illionois and Northwestern University [8]. Several investigations in the USA were reported in AREA Proceedings and Transactions ASCE [4], [7], [11].

The variables studied by the investigators were the effect of the clamping force, bearing-tension ratio (B/T) and the shear-tension ratio (S/T) on the fatigue strength of double lap and single lap riveted joints.
Also were studied the influence of the ratio R = min.stress /max.stress and the effect of paint on the contact surfaces (red lead).
The specimens were made of mild steel (A7, St37) or low alloy steel (A242, St52).

The results of the fatigue tests of riveted joints show a great scatter.
In his contribution to the AREA Seminar of 1968 [1] W.H. Munse gives a scatterband of riveted joints. In the present paper the scatterband for the ratio R = 0 of the study of W.H. Munse is used as a reference in all presented figures to establish the influences of the variables mentioned above.
In a double logarithmic network the upper bound has a slope of k = 8,3, the slope of the lower bound is k = 6,1. Fig. 1 shows these bounds, and gives also as a reference the results of fatigue tests on specimens with new drilled open holes.

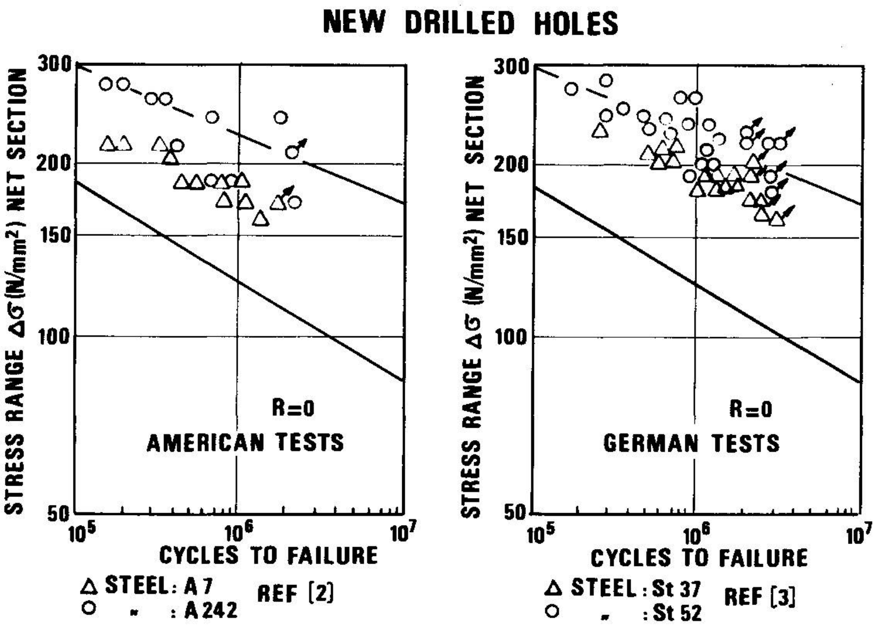


Fig. 1 Comparison new drilled holes

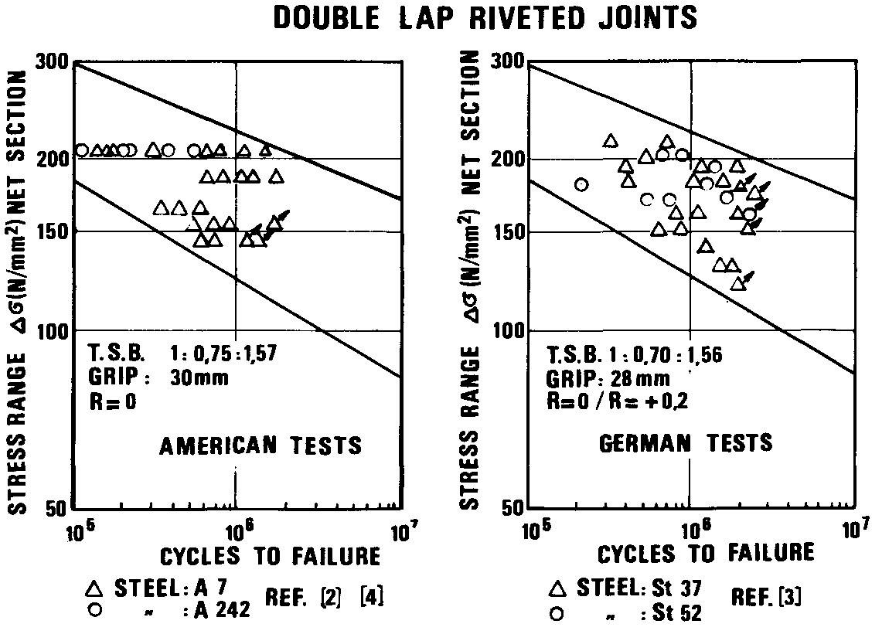


Fig. 2 Comparison riveted joints

The data of the fatigue behaviour of riveted joints presented in this paper concern connections with hot driven rivets.
The experimental data obtained from American and German double lap fatigue tests having a tension : shear : bearing ratio (T : S : B) of about 1,00 : 0,75 : 1,60, according to the standard specification for design of riveted structures, are given in fig. 2.
These data are lying within the scatterband.

2. EFFECT OF VARIABLES

2.1 Clamping force

One of the most important factors affecting the fatigue strength of a riveted joint is the clamping force. When the clamping force is great the main part of the load is transferred by friction between the plates and the rivets are less in bearing. The resulting stress concentrations near the holes are in that case much less severe.
An increase in the clamping force of the rivets results in an increase in the fatigue strength of the joint.
Theoretically the clamping stress in the rivet is independent of the length of grip. However shrinkage after driving causes some deformation of the rivet heads through which the clamping stress decreases. For a longer grip this deformation is a smaller part of the total length shrinkage of the rivet than for a shorter grip.
That is why the clamping force of hot driven rivets increases with the length of grip.

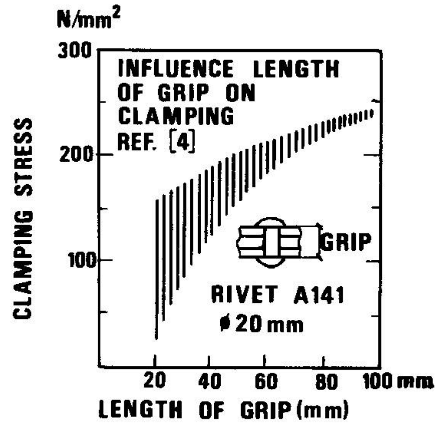


Fig. 3 Clamping stress

For a grip of about 100 mm the clamping stress approaches the yield stress (fig. 3). The shorter grips show a wide spread with lower clamping stresses. There is no assurance that a long grip will always develop a high clamping force in the whole joint.
The clamping stresses given in fig. 3 concern rivets of low carbon steel (A141) which has more or less the same properties as steel St.34.
Rivets of alloy steel may develop in some cases a very low clamping force.

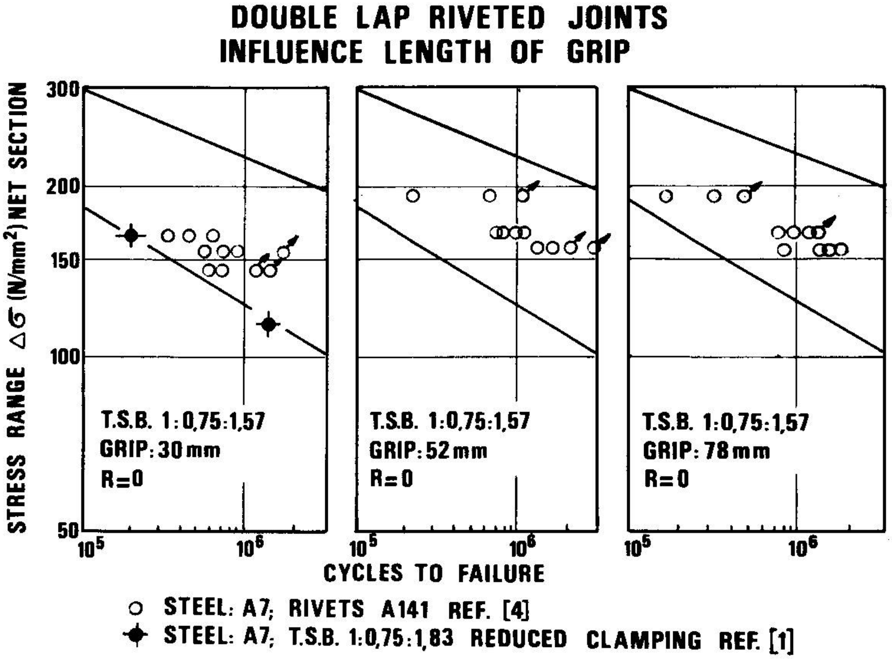


Fig. 4 Influence length of grip

Fig. 4 shows the influence of variable grip length on fatigue. The results of the tests with reduced clamping are lying at the lower bound.

2.2 Tension : Shear : Bearing ratio (T : S : B)

For a proper design the American specifications require a tension-shear-bearing relationship of 1 : 0,75 : 1,50.

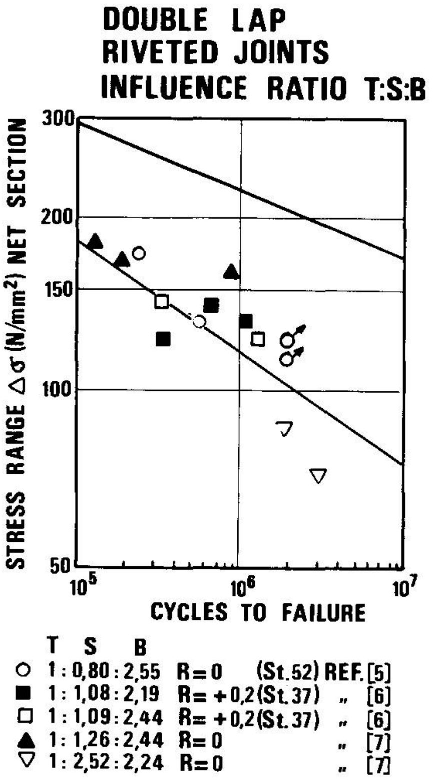


Fig. 5 Influence ratio T:S:B

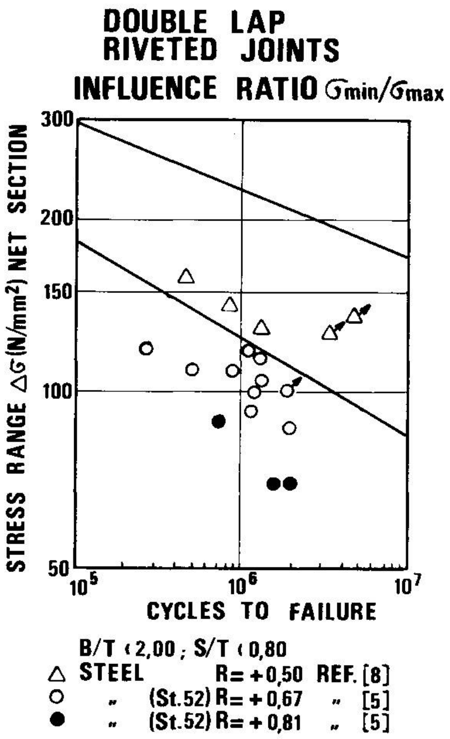


Fig. 6 Influence ratio R

The German specifications allow for this ratio 1 : 0,8 : 2,00.
The results of fatigue tests on double lap joints with these ratios are concentrated within the mentioned scatterband.
Having a ratio of S/T = 0,8, the fatigue strength will decrease byond ratios of about B/T = 2,0. This is much severe in proportion to less clamping. Combined high bearing and high shear stress will further reduce the fatigue strength.
Fig. 5 shows some examples.

2.3 Ratio R = σ min/σ max

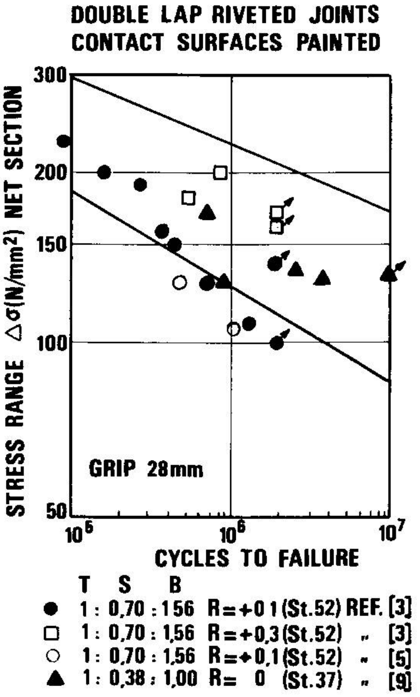
The adopted scatterband of Munse [1] for zero to tension (R = 0) represents the scatterband of the stress range for this ratio.
A comparison of the testdata shows that when the ratio R increases the stress range decreases.
This behaviour can be explained by the absence of residual stresses.
The largest stress range is found for R = -1,0.
Fig. 6 shows that the plotted data of the example for R = +0,5 with ratios B/T $<$ 2,0 and S/T $<$ 0,8 are within the scatterband of the stress range for R = 0.
Byond the ratio R = +0,5 the stress ranges decreases rapidly.

2.4 Painting of the contact surfaces

Most of the tested riveted specimens were assembled without painting of the contact surfaces and had the mill scale intact.
There are some experiments with riveted joints of which the joined parts were painted with red lead prior to assembly.
The coefficient of friction of surfaces with mill scale varies from about 0,30 to 0,40. The friction coefficient of surfaces with red lead is about 0,10.
Low frictional resistance brings the rivets in more bearing and causes a decrease of the fatigue strength.
Results of fatigue tests on specimens with painted contact surfaces are shown in fig. 7.

2.5 Drifting of holes

When holes for connection do not coincide and are drifted by a pin, there is an elongation at one side of the holes that may develop initial cracks.
Drifting of holes during manufacturing and construction greatly reduces the fatigue strength.
Fig. 8 shows the results of fatigue tests on specimens with drifted open holes, coming from removed parts of an existing bridge [9].
One result is given of a fatigue test on a specimen with drifted holes containing bolts in bearing with no clamping [11].
Punching of holes has a similar effect as drifting.



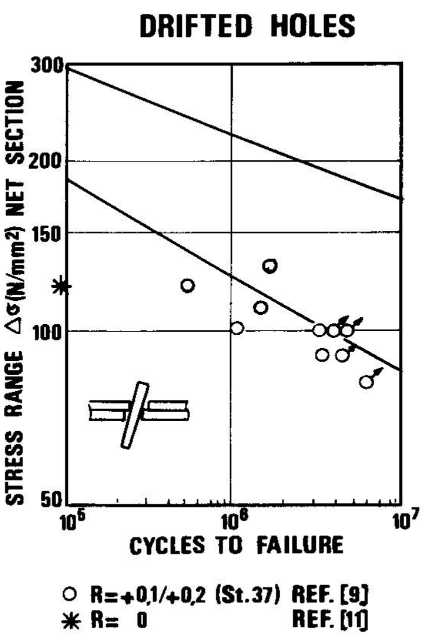


Fig. 7 Influence paint Fig. 8 Influence drifting

2.6 Single lap joints

In the middle of the 1940's fatigue failures were found in floorbeam hangers of railway bridges in the USA. These failures all occured in riveted single lap joints.
An extensive investigation was started in 1947 and continued to 1954.
The failures were explained by the fact of eccentric bearing, causing high stress concentrations at the edge of the holes, coupled with low clamping. This was proved by fatigue tests of Wyly and Carter with single lap connections having bolts in bearing with no clamping [11]. The results of these tests are shown in fig. 9b.
Single lap connections as beams with riveted cover plates and connections of beams to gusset plates always have some eccentricity. Even in the case of sufficient clamping the effect of the addition of bending will reduce the fatigue strength. Fig. 9a presents some examples.

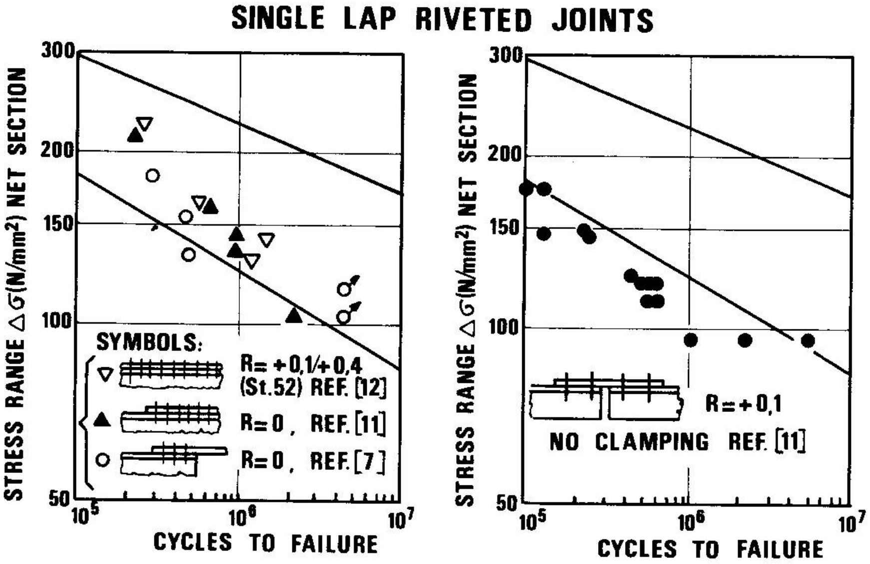


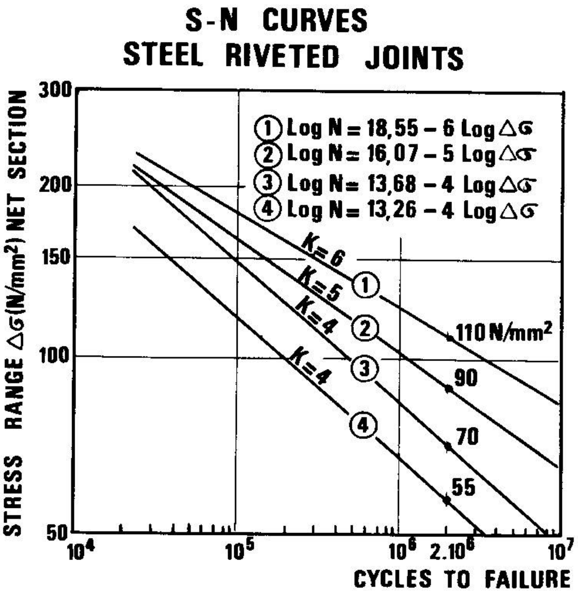
Fig. 9a - Fig. 9b Single lap riveted joints

2.7 Grade of steel

There is no significant difference between the fatigue strength of riveted joints of steel A7 and A242, and St.37 and St.52 respectively.

3. CHOISE OF S-N CURVES

In order to get a more reasonable prediction of fatigue life the various types of riveted steel joints are distinguished.
Fig. 11 shows four S-N curves. The S-N curve for double lap joints ① is similar to the lower confidence limit of the study of Munse [1] and has a slope k = 6.
The S-N curves ②, ③ and ④ also represent more or less lower confidence limits and have with respect to higher stress concentration steeper slopes with values assumed k = 5 and k = 4 respectively.
To take in account the influence of the ratio R, a difference is made between R = 0 and R = +0,5
The choice between the two S-N curves for the single lap joints depends on the rate of stiffness of the sustaining parts. Not all cases are covered by these S-N curves. When there are severe secondary stresses due from



CHOISE S-N CURVES STEEL RIVETED JOINTS S/T‹0,8 ; B/T‹2,0		
TYPE OF JOINT	R=0	R=~+0,5
DOUBLE LAP	①	②
DOUBLE LAP (PAINTED)	②	③
SINGLE LAP	② ③	③ ④

Fig. 10 S-N curves steel riveted joints

eccentricity, these stresses have to be taken in account.

4. WROUGHT IRON RIVETED JOINTS

Most of the bridges built in the 19th century have been made of wrought iron.
During the last decennia in various countries fatigue tests were carried out on specimens of wrought iron. Fig. 12 shows the results of testseries in the Netherlands [10].
For comparison the scatterband of the steel riveted joints as used previously is plotted in this figure.
As one can see the results illustrate in comparison to steel a lower fatigue strength for the wrought iron specimens with new drilled open holes. The same tendency show the results of the tests with the wrought iron riveted joints taken from old bridges.
To determine the lower confidence limit the results of the test on the riveted joints are assimilated in a modified Goodman diagram for 2.000.000 cycles (Fig. 12).

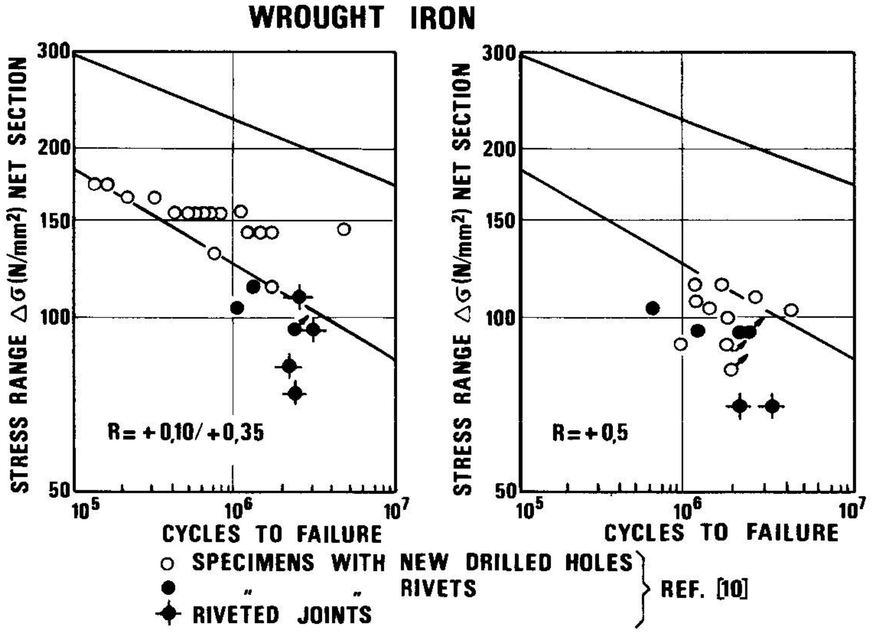
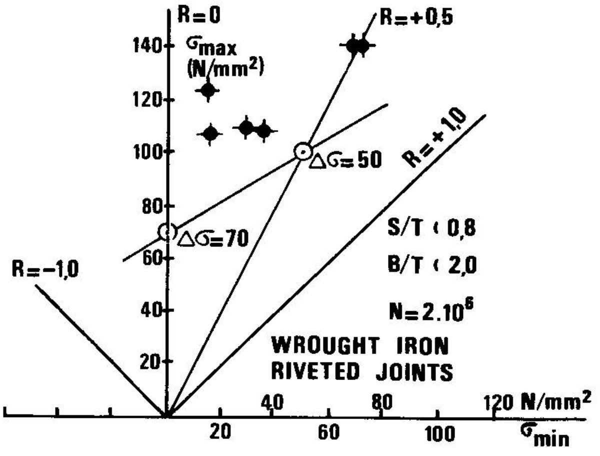


Fig. 11 Fatigue tests wrought iron

An assumption of the lower limit is obtained dividing the mean values by a factor of 1,4.
Fig. 12 also shows the corresponding equations of the S-N curves.



5. FINAL REMARKS

The fatigue strength of riveted joints was shown to be affected by several factors.
One of the dominant factors is the clamping force of the rivets.
Most sensitive to fatigue are the single lap connections.

WROUGHT IRON RIVETED JOINTS S/T ‹ 0,8; B/T ‹ 2,0 S-N CURVES	
R=0	R= +0,5
Log N=15,52-5Log Δσ	Log N= 14,80-5Log Δσ

Fig. 12 Fatigue behaviour wrought iron riveted joints

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ASCE = American Society of Civil Engineers
AREA = American Railway Engineer Association