Experimental and theoretical investigations of existing railway bridges

Experimental and Theoretical Investigations of Existing Railway Bridges

Recherche théoriques et expérimentales sur des ponts de chemin de fer existants

Experimentelle und theoretische Untersuchungen an bestehenden Eisenbahnbrücken

Friedrich MANG
Prof. Dr.-Eng.
Univ. of Karlsruhe
Karlsruhe, Fed. Rep. of Germany

Friedrich Mang, born 1934, received his civil engineering degree at the University of Karlsruhe.

Oemer BUCAK
Dipl.-Eng.
Univ. of Karlsruhe
Karlsruhe, Fed. Rep. of Germany

Oemer Bucak, born 1947, received his civil engineering degree at the University of Karlsruhe.

SUMMARY

This paper describes an investigation of a complete bridge structure of the «museum railway» in the community of Blumberg as well as two bridge structures of the «Deutsche Bundesbahn». Results of component tests are compared with data taken from the literature as well as other results of similar investigations.

RÉSUMÉ

Cet article présente une recherche effectuée sur une structure complète d'un pont du «musée du chemin de fer» de la commune de Blumberg, ainsi que sur deux structures de ponts de la «Deutsche Bundesbahn». Les résultats des essais effectués sur ces éléments sont comparés avec les valeurs provenant de la littérature, ainsi qu'avec celles tirées d'autres essais de recherches similaires.

ZUSAMMENFASSUNG

Der Bericht handelt von Untersuchungen an einem kompletten Brückenbauwerk der «Museumsbahn» der Gemeinde Blumberg sowie an zwei Brückenelementen der «Deutschen Bundesbahn». Die Resultate werden mit bekannten Angaben aus der Literatur sowie mit weiteren Ergebnissen ähnlicher Untersuchungen verglichen.

1. PRELIMINARY REMARKS

All over the world the industrialization starting early in the 20th century paved the way for numerous constructions, particularly for steel railway bridges. Still today we find bridges dating from the end of the last century, i.e. about 1850. These bridges are mainly riveted constructions designed for low external loads. The standard service lives of these constructions were short compared to current designs. In many cases, however, they have been exceeded by far. All over Europe we find bridges which have been continuously in service for more than 100 years. Most of these buildings are classified as historical monuments or shall be preserved for economical reasons.

In most cases it is impossible to make a definitive judgement as to whether a construction under fatigue loading can be used further after its standard service life has been reached or exceeded. Further problems occur when the safety of an old bridge has to be recalculated due to increased design loads (e.g. new load spectra for trains) or when the safety of a building damaged in an accident has to be estimated. This can be explained by the poor knowledge of the static strength and the fatigue strength of steels (wrought iron, puddled iron) and constructional details (X lattice girders, rivet joints) used in the 19th century.

The judgement of old bridges is based on results of material tests on specimens taken from areas under low loading conditions, such as bracings and support areas. Up to the present, these data have been reduced by high safety factors to obtain a safe estimation. The structural design of the connections has a considerable influence on the load-carrying capacity of the whole construction. Till today tests on whole constructions and their connections have been carried out only sporadically.

"Damage" or "fatigue" incurred during the service life are determined by means of hypotheses the reliability of which is not quite indisputed. Data on the load history of bridges built during the two world wars and in early post-war times are not available. The judgement is therefore based on mean values and estimated load histories. In order to be on the safe side, we try today to obtain the required data by tests on all structural components under high loading conditions.

2. DETERMINATION OF THE REMAINING SERVICE LIFE OF A FATIGUE-LOADED CONSTRUCTION

Up to a short time ago, the procedure to determine the remaining service life of a bridge was as follows:

- visual inspection of the bridge, outward appearance (corrosion), with some bridges this was the dominating point of judgement
- specification of repairs or reinforcement measures (e.g. due to increased loads from engine and cars)
- determination of points under maximum stress (by means of the design calculation or by new calculation e.g. according to BE 804); determination of points governing the safety of the construction (e.g. tensile members); for highway bridges see DIN 1072 and DIN 18809 taking account of impact loads and crash barrier spacings
- taking of specimens from uncritical, but representative areas of the construction
- tests, e.g. chemical analysis, tension test and fatigue tests, on the original material
- additional calculations based on actual material properties
- determination of the previous load history and future loads

- determination of the remaining service life using Miner's linear cumulative damage rule and fixing of a safety factor for the respective bridge construction
- fixing of inspection intervals
- fracture-mechanical tests, e.g. COD tests, determination of the critical crack size, previous damages.

Defective structural components (damaged e.g. by corrosion, by accident (see Fig. 1) or by bullets) may cause a considerable reduction of the life of a construction depending on the situation of the defect and on the stress level. We therefore recommend to attach special importance to these points when visiting a construction.

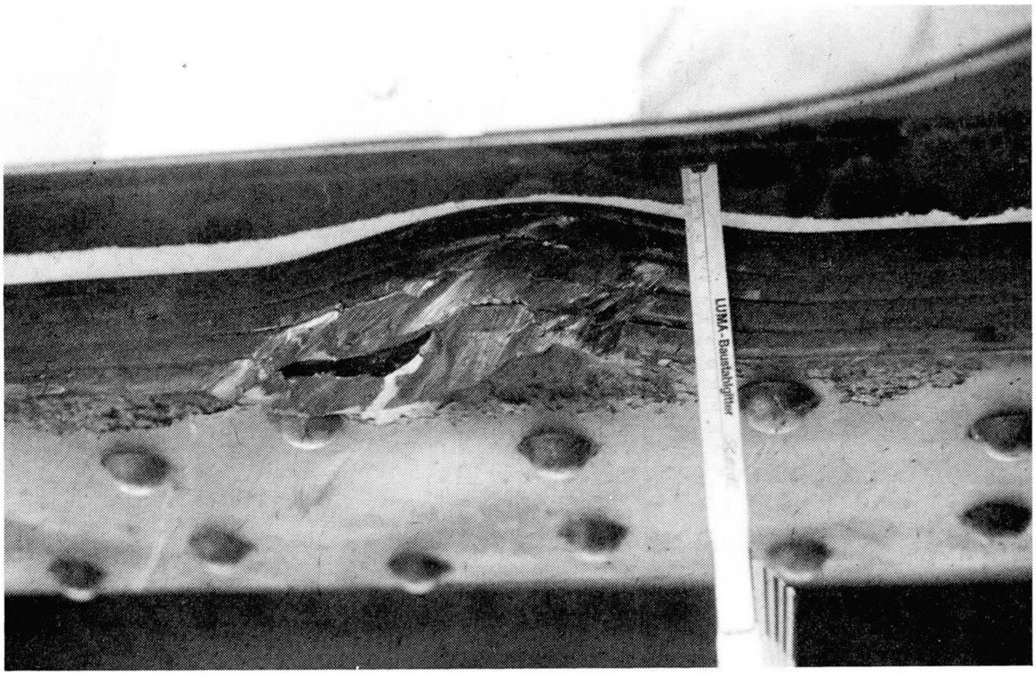

Fig. 1 Bridge damaged by impact

Certificates on various constructions under high-cycle fatigue loading and tests carried out for a research program |1| supplied sufficient data on the material properties thus allowing a preliminary estimation. Therefore, only few tests in the final stage are necessary to confirm these presumptions. The load-carrying behaviour of such constructions as a whole and the load-carrying capacity of structural components in the original state are not yet sufficiently known. The points in question are: rivet slip, rivet preloading, displacement under shear load, distribution of the load to other elements of a structural component. Large structural components should therefore be investigated as a whole.

At the "Versuchsanstalt für Stahl, Holz und Steine" tests were carried out on a whole bridge built in 1887 which had been chosen from different bridge systems of the "Museumsbahn" (Fig. 2).

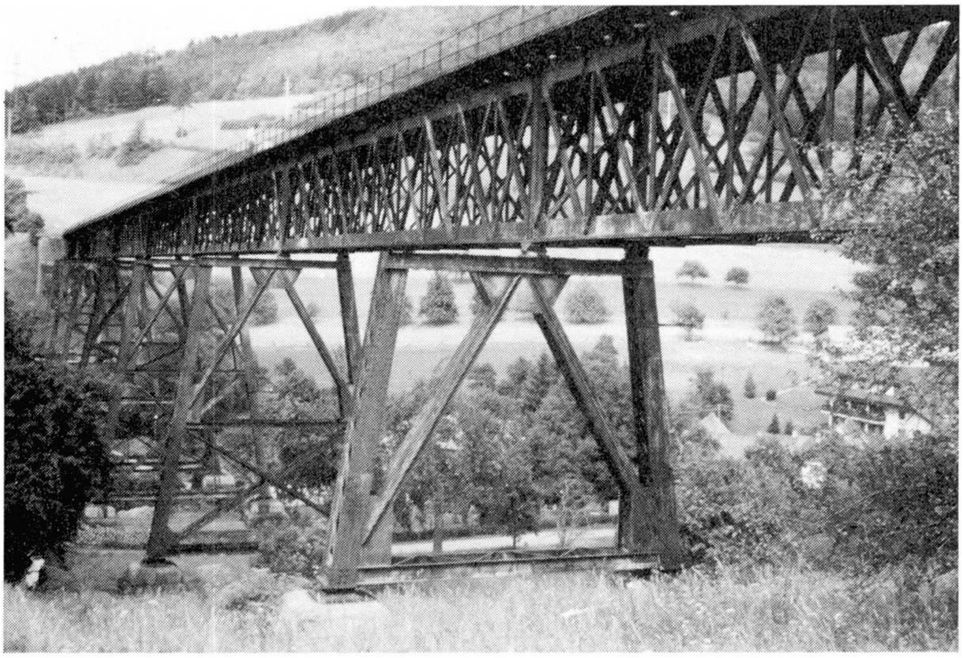

Fig. 2 Bridge of the "Museumsbahn"

3. FATIGUE TESTS AND RESULTS

3.1 Tests on the whole bridge

The whole bridge was built in the 50 MN power press of the institute. Fig. 3 shows the bridge built in according to load configuration LF 1.

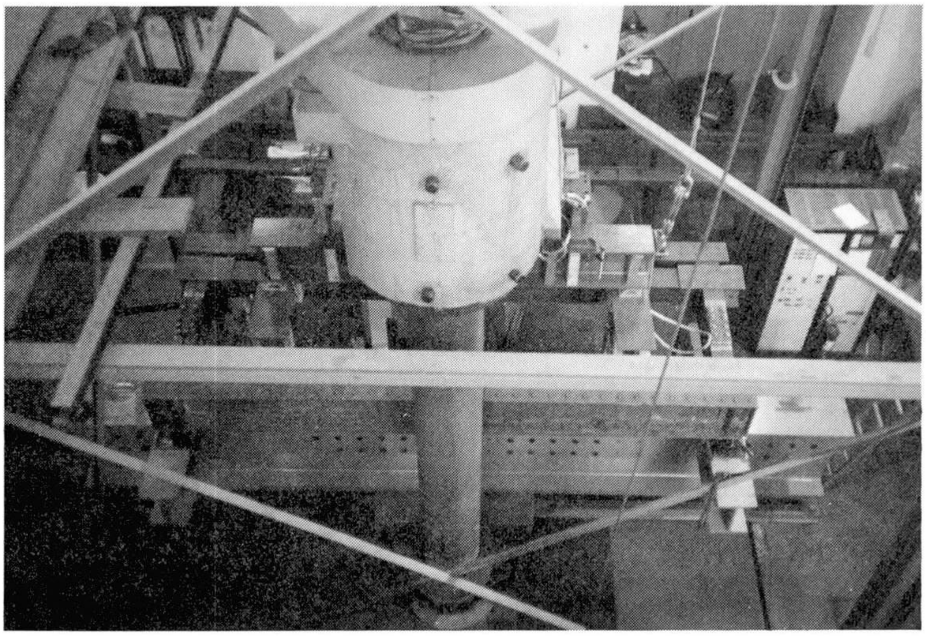

Fig. 3 Bridge of the "Museumsbahn" in the 50 MN power press

The test was interrupted at 108 070 stress cycles as a correct load application was no longer possible due to a large crack in the connection between transverse girder and main girder. Fig. 4 shows the point of failure.

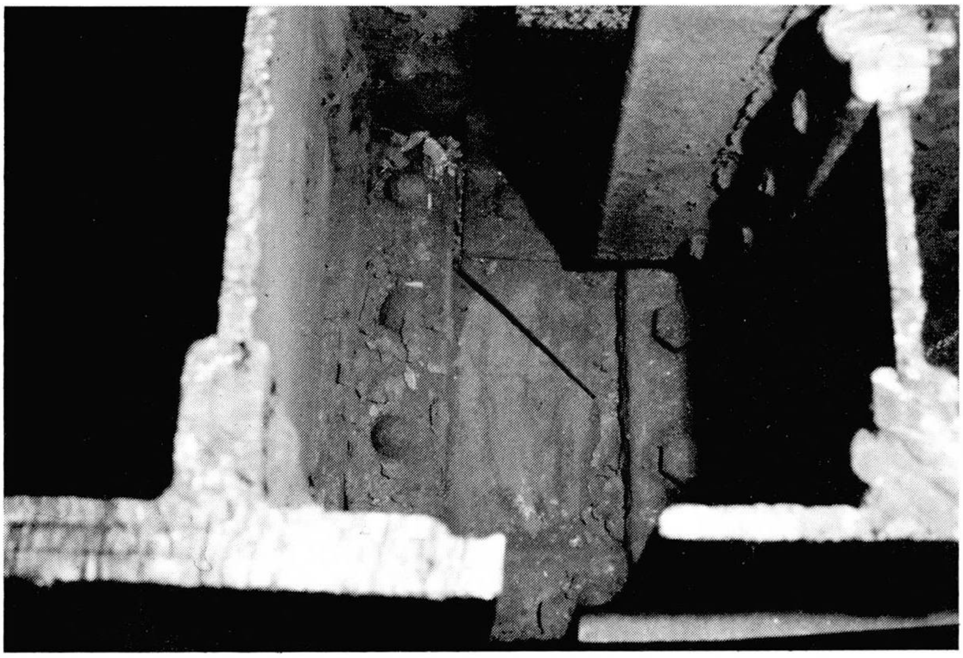

Fig. 4 Connection between transverse girder and main girder, crack in web plate

Afterwards, the bridge was sawed up (see Fig. 5) to carry out seperate tests on components (main girder, longitudinal girder) and connections (transverse girder, main girder).

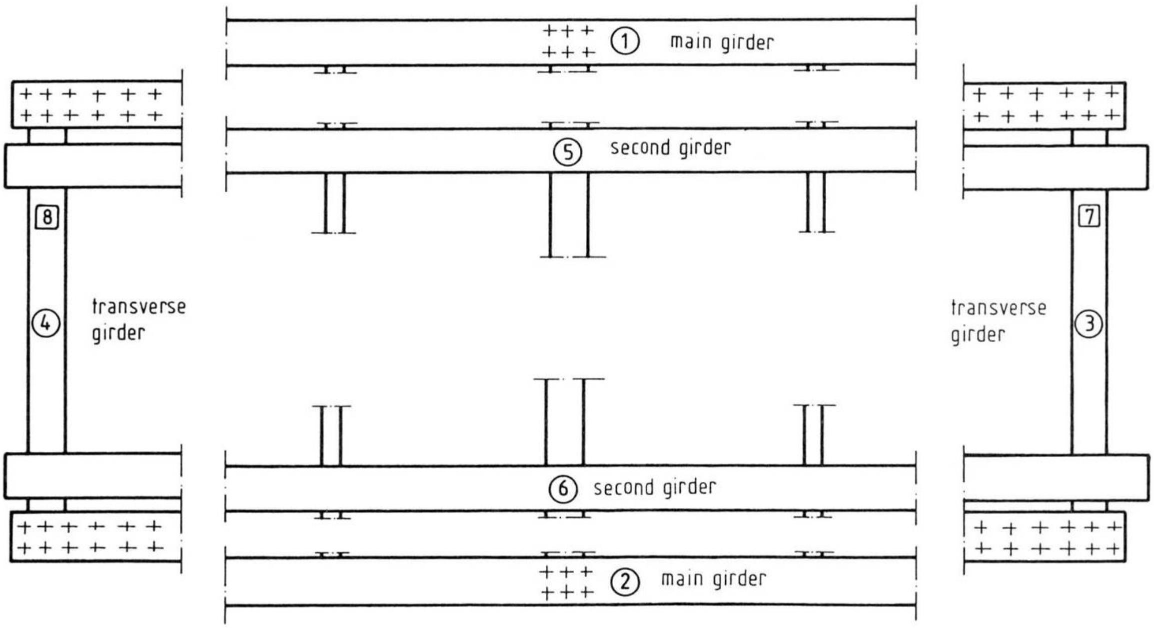

Fig. 5 Blumberg bridge - designation of specimens

Analogously, the Stahringen bridge dating from 1895 was sawed up to investigate the two main girders and the connections between main girder and transverse girder. Fig. 6 shows the components of one half of the bridge. Punched specimens, riveted specimens as well as specimens of the plain web plate material were taken from the remaining bridge parts.

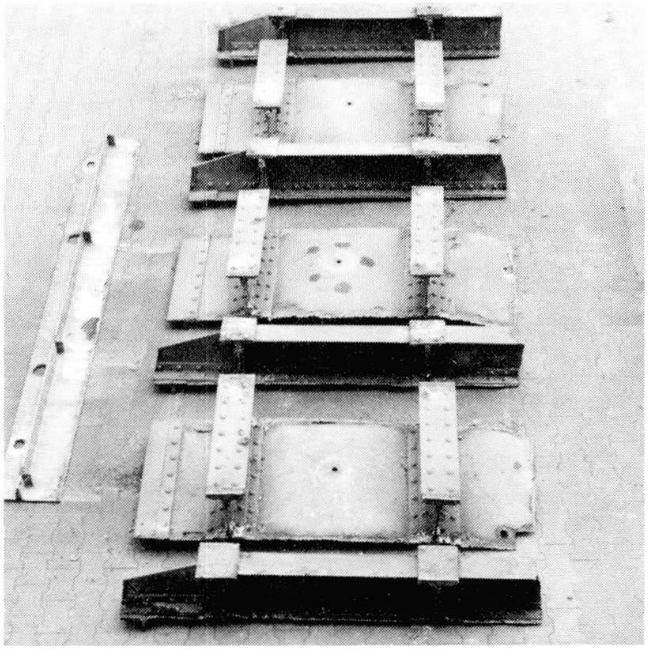

Fig. 6 Stahringen bridge - structural components

3.2 Tests on the main girder

The main girders of the two bridges were subjected to four-point-bending tests with a span of 3300 mm. The spacing between the two points of load application was 800 mm. The tests were carried out on two stress levels (135 N/mm^2 and 165 N/mm^2) with an ultimate stress ratio of R = + 0.2.

In these cases the fatigue crack usually started from a rivet hole in the tension chord due to a stress concentration in the hole rim. The punching and riveting procedures as well as corrosion may also cause damages in the hole rim. An exception to this rule are those cases where components have been seriously damaged e.g. by impact or by bomb splinters.

Under a maximum stress of 165 N/mm^2 and at 1 534 000 stress cycles the crack occurred in the web of main girder I of the Blumberg bridge. Despite the crack, the main girder carried the full load and the test was continued until the two angles and the cover plate of the main girder tensile chord failed at a total number of stress cycles of 1 572 600. This means that the minimum number of stress cycles between crack appearance and total failure of the main girder was 38 600 (see Fig. 7).

Fracture first occurred in the web, then in the angle section and finally in the cover plate. The cracks were not situated on one level.

Subsequently, the main girder II of the Museumsbahn bridge and the two main girders of the Stahringen bridge were tested under the same conditions. The first crack occurred in the main girder web. The numbers of stress cycles between crack appearance and total failure of the main girder ranged up to 100 000.

Three additional specimens were taken from the uncracked main girder parts of the Blumberg bridge. These specimens were subjected to three-point-bending tests with a span of 1500 mm. The maximum loads were 450 kN and 600 kN, the ultimate stress ratios were R = + 0.35 and R = + 0.1. These test results will help in judging the influence of the mean stress.

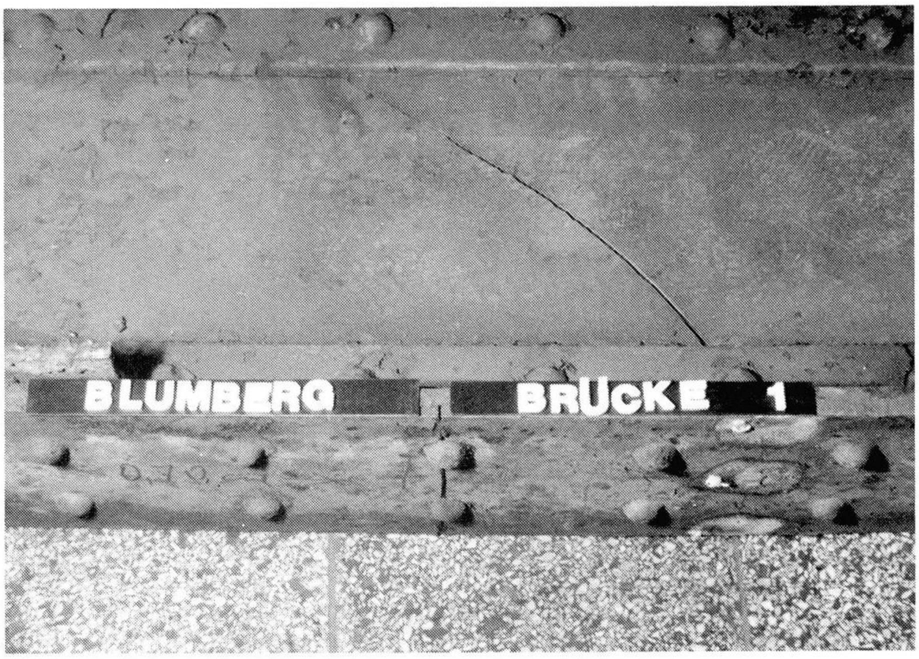

Fig. 7 Points of fracture of main girder I

Fig. 8 shows the test results in comparison with earlier data obtained by tests on punched specimens of puddled iron. The diagram shows that the results of the main girder and transverse girder tests are within the range of scattering of results for small-scale specimens.

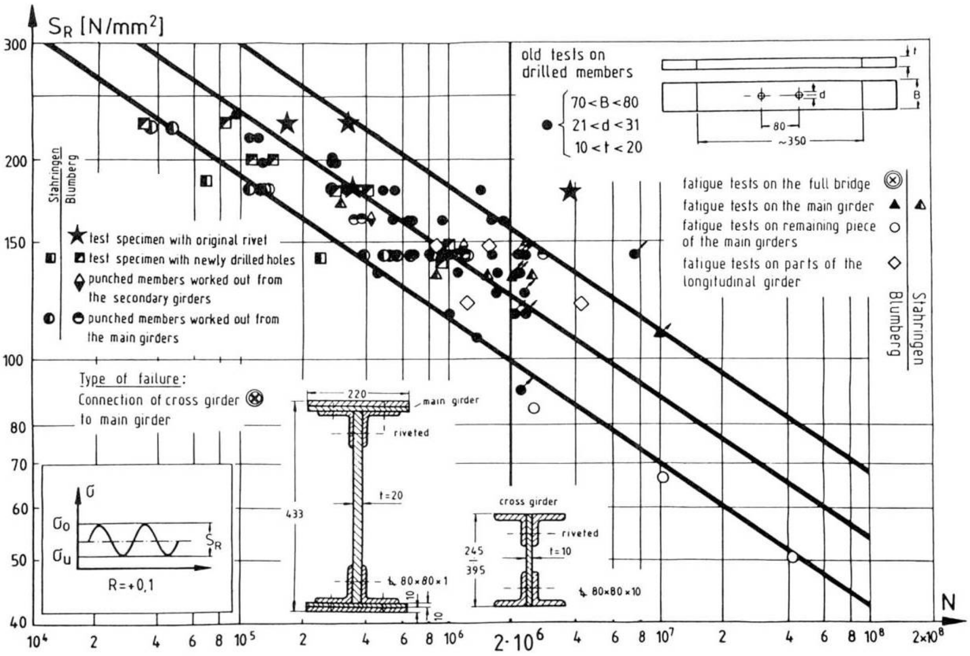

Fig. 8 Results of tests on components of the Blumberg bridge compared to earlier test results of punched specimens

The results of the specimens taken from the remaining parts of the main girder are slightly beyond the $P_{ü}$ = 97.5 % line which is due to previous fatigue loads endured during service and during the girder tests (1.6 to $2.0 \cdot 10^6$ stress cycles).

3.3 Tests on transverse girder connections

In the tests on the whole bridge failure occurred at the transverse girder connections. These connections were therefore a point of major consideration in the investigation of the service life of bridges. Full details of these investigations are given in |10|.

3.4 Tests on parts of the longitudinal girders

Four specimens were taken from the longitudinal girders of the Museumsbahn bridge and subjected to three-point-bending tests with a span of 1500 mm. For two specimens the maximum stress was 165 N/mm², for the other ones 135 N/mm². The ultimate stress ratio was R = + 0.1. The test results are shown in Fig. 8 in comparison with earlier data for flat plate specimens of similar age. The cracks usually started at a distance of about 600 mm from the point of support and proceeded diagonally through the web. In some specimens further cracks occurred in the angle sections. Fig. 9 gives an example of the failure mode.

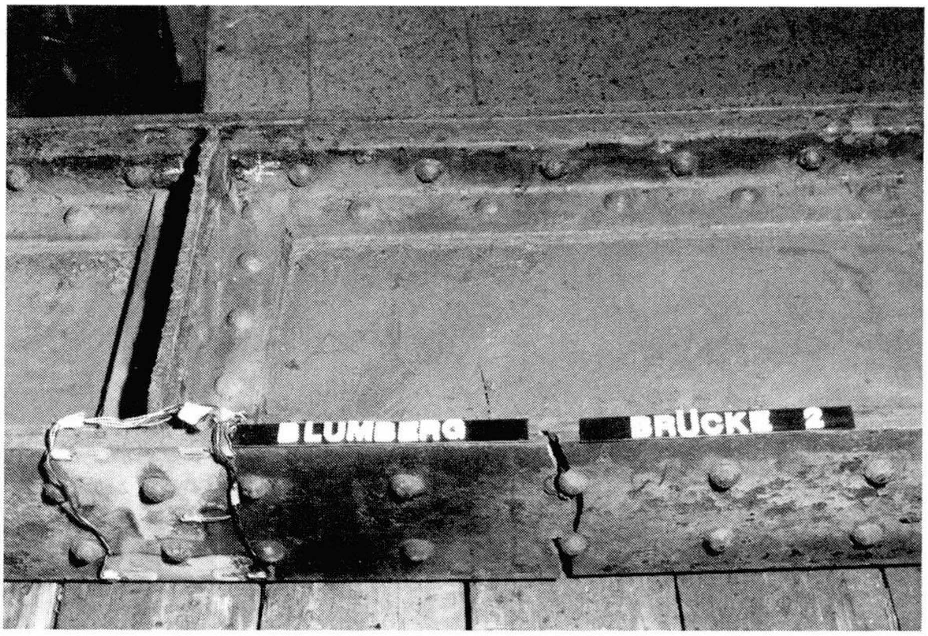

Fig. 9 Failure mode for the longitudinal girder of the Blumberg bridge

3.5 Tests on riveted and punched specimens

The central parts of wind bracings of the bridge were fatigue tested in the original state (with rivets) in a pulsator.

The remaining material of the bracings was used for punched specimens, i.e. specimens with new holes Ø 20 mm, which were fatigue tested at different stress levels.

Further specimens with original holes were taken from remaining parts of main girders and longitudinal girders. The results of these tests are plotted in Fig. 10.

It is evident that the test results are in good agreement with earlier data, although the data of the Stahringen bridge are comparatively low. The scattering of the results is comparatively large, as is the rule with old constructions.

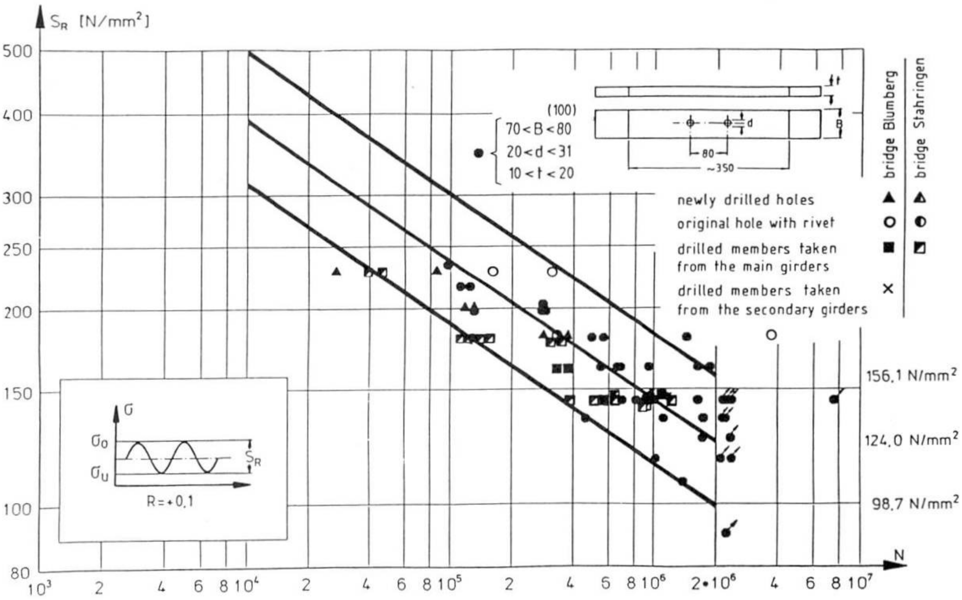

Fig. 10 Results of tests on punched specimens and specimens with original rivets

Two specimens taken from the web area are also in good agreement with earlier test data. As expected, the fatigue cracks started from rivet holes. Fig. 11 shows the specimens taken from the main girder of the Stahringen bridge after failure. After the first crack had occurred the specimens were re-fixed until a second or a third crack started from another rivet hole.

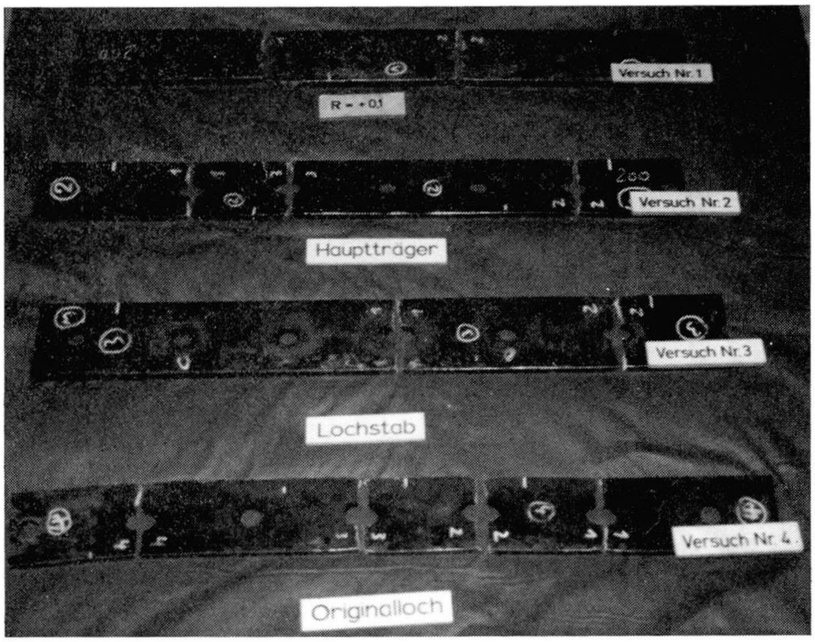

Fig. 11 Specimen after failure (punched specimen from Stahringen bridge)

4. COMPARATIVE TEST DATA FROM THE LITERATURE

As mentioned before, information on the fatigue behaviour of old steels, particularly from the 19th century is very scarce. Hirt and Brühwiler |3| were the first researchers to carry out a methodical evaluation for two old bridge components. They compared their results to those of three other reports. For comparison the test results of the Blumberg bridge and the Stahringen bridge were entered into the diagrams of Figs. 12 and 13.

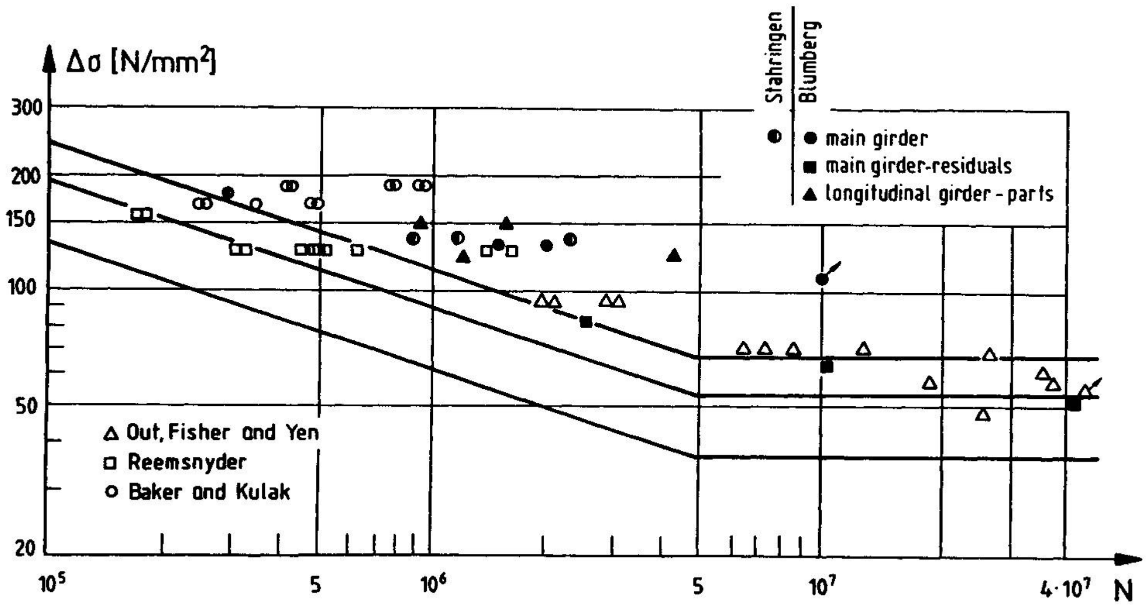

Fig. 12 Test results and data from |3|

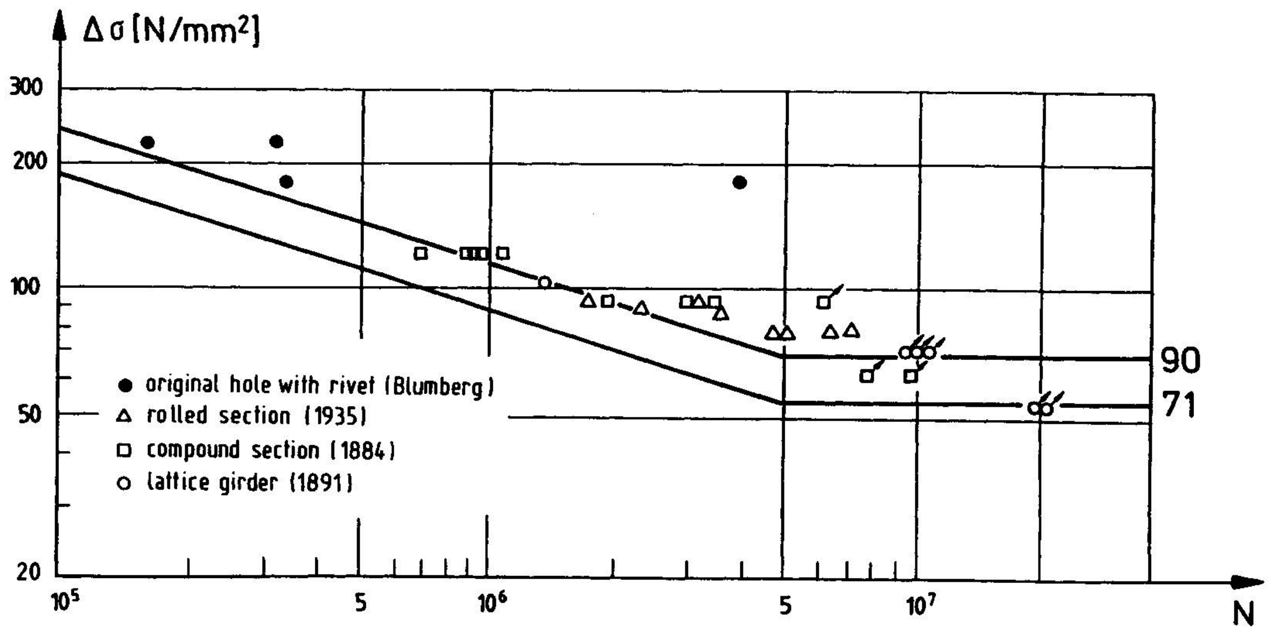

Fig. 13 Test results and data from |3|

In Figs. 14 and 15 our test results are compared to data for plain specimens dating from 1880 |3|. These diagrams are completed by data for punched and riveted specimens and for original structural components. Fig. 16 includes results of tests on structural components of the Blumberg bridge.

The annual of SFB 315 (special research program) |11| includes further comparisons particularly with the data of the draft standard DS 805 "Bewertung der Tragfähigkeit bestehender Eisenbahnbrücken" from July 1987.

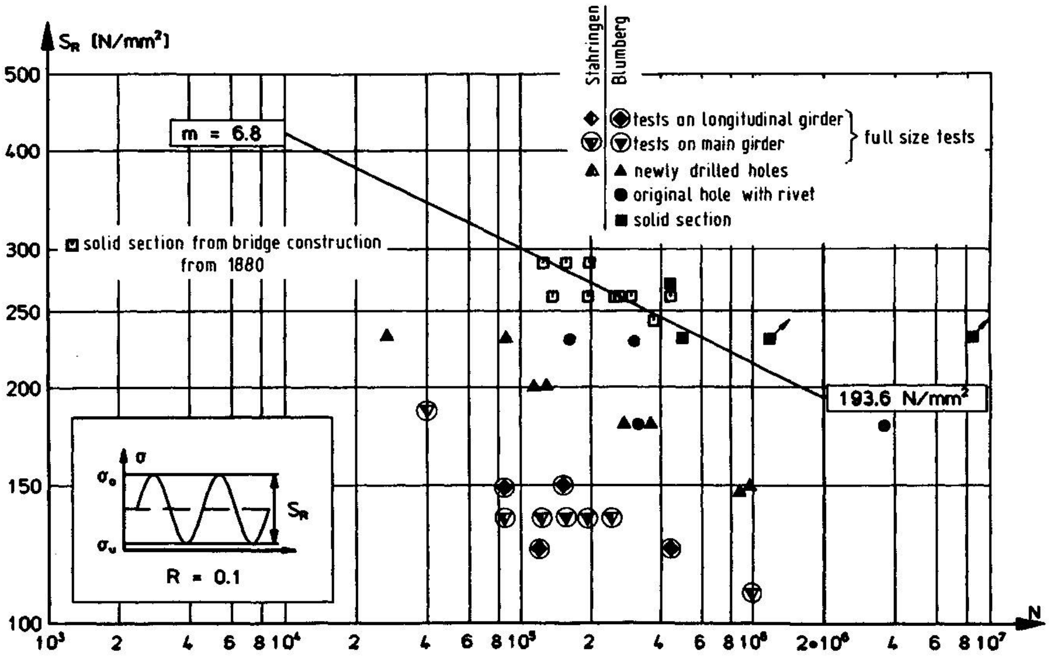

Fig. 14 Test results and data from |5|, bridges dating from 1880, plain material

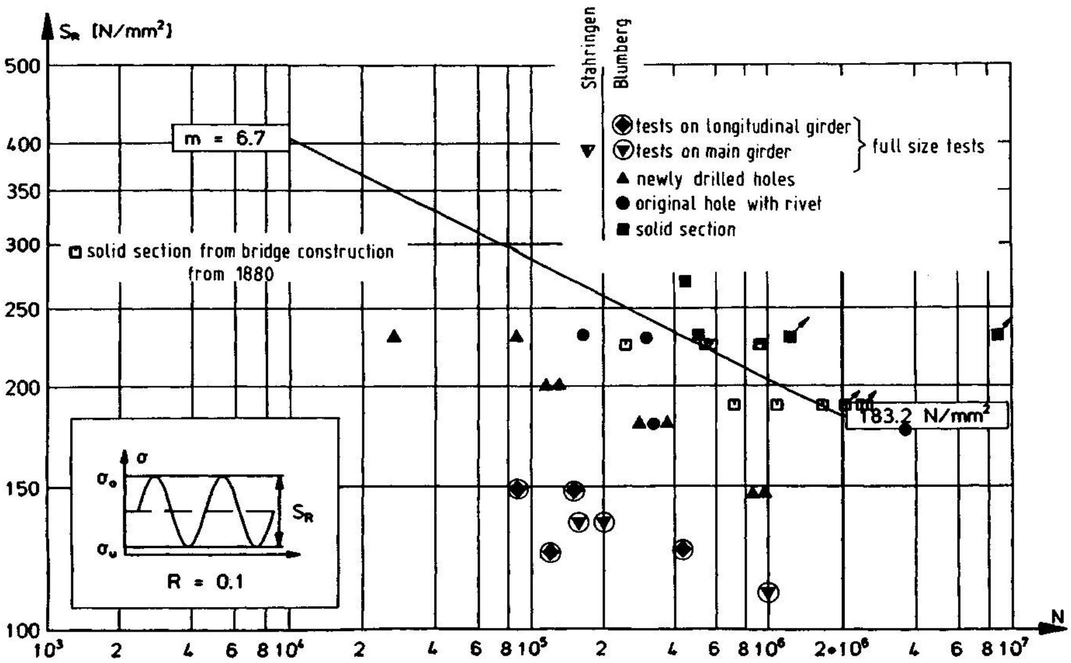

Fig. 15 Test results and data from |5|, bridges dating from 1880, plain material prestressed by 290 N/mm² and 10^5 stress cycles

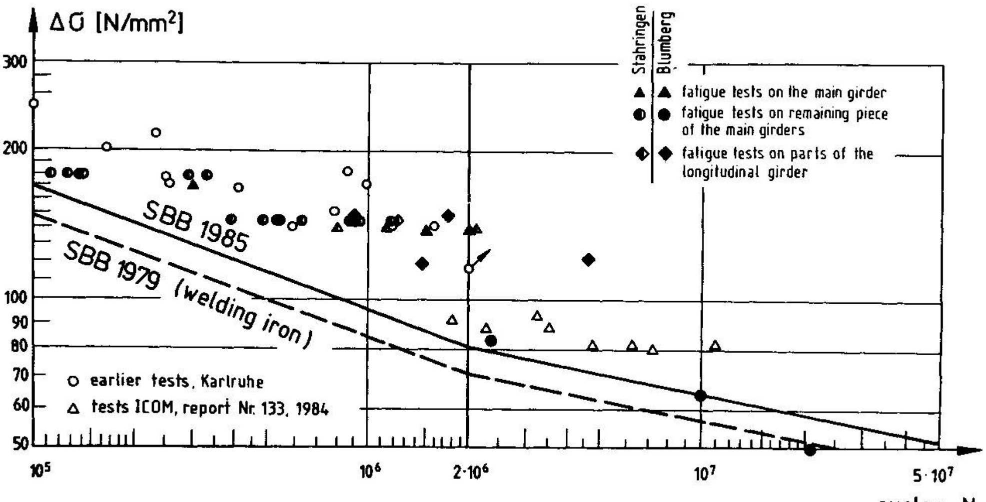

Fig. 16 Test results and data from |4|

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