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Remaining Fatigue Life of Old Steel Bridges

Capacité de résistance à la fatigue des vieux ponts en acier

Beurteilung der Restlebensdauer alter Stahlbrücken

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SUMMARY

Because of the large number of existing old steel bridges, the evaluation of the remaining fatigue life of these bridges is a very important economic problem and also an interesting one from the engineering point of view. For investigating old steel bridges, crack growth tests have been added to the well established types of investigation. To verify the established procedure of investigation and rating traffic load will be simulated on dismantled bridges in the laboratory.

RÉSUMÉ

Etant donné le grand nombre de vieux ponts en acier existants, l'évaluation de leur capacité de résistance à la fatigue est un problème économique de grande importance et un problème de grand intérêt pour l'ingénieur. Aux méthodes classiques d'inspection des vieux ponts en acier, il est possible d'ajouter l'étude du développement de la fissuration. Afin de pouvoir vérifier et étalonner la procédure d'inspection établie, les cas de charge de trafic ont été simulés en laboratoire sur des ponts démantelés.

ZUSAMMENFASSUNG

Die Ermittlung der verbleibenden Nutzungsdauer alter Stahlbrücken stellt wegen der grossen Anzahl dieser Brücken ein beachtliches wirtschaftliches Problem dar und ist zugleich eine interessante ingenieurwissenschaftliche Aufgabe. Bei Untersuchungen alter Stahlbrücken wurden die üblichen Untersuchungen um Rissfortschrittsversuche an standardisierten Proben erweitert. Zur Bestätigung der Beurteilungsverfahren werden alte ausgebaute Brücken simulierter Verkehrsbelastung bis zum Auftreten von Rissen unterworfen.

1. INTRODUCTION

In Germany as well as in other countries, there are many old riveted steel bridges which are approaching their design life after about hundred years of service. The replacement of all these bridges far exceed the available financial resources. However, even if the funds existed, replacement would be the least acceptable option in several cases because many of the bridges are historic structures [1]-[4].
Being concerned with the rating of old steel bridges, we added a further component to the procedure of investigation. We performed crack growth tests on samples of the material of some high stressed structural elements of the bridge shown in fig. 1, thus determining data to define the fatigue behaviour of the material [5].

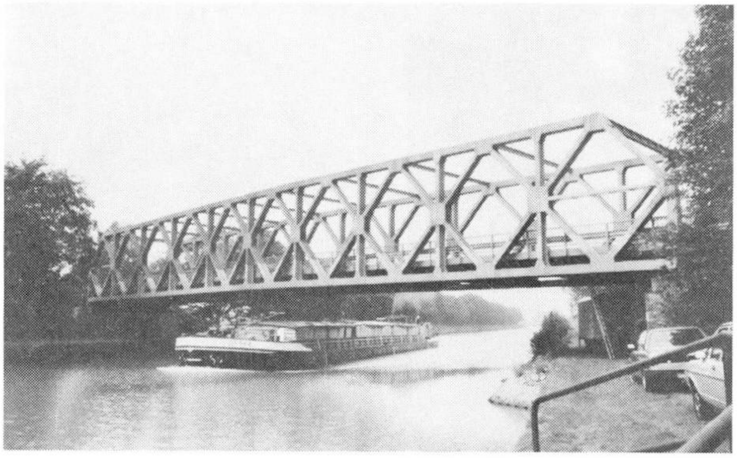


Figure 1. Riveted highway bridge of 59 m span in north-west Germany

However, faced with the problem of rating old bridges, the need of further research is recognized in order to calibrate the results of the rating procedure with experience. This calibration can only be done by simulating traffic load on old removed bridges the stresses in which are well-known from measurements before removing. Research is under way in BAM on bridges one of them is shown in Fig. 2.

2. BRIDGES UNDER INVESTIGATION

Two bridges are under investigation (fig. 1, fig. 2). In the following, a brief description about the investigation and their results are presented.

2.1 Truss Bridge Crossing a Canal in North-West Germany

The load bearing elements of the bridge (fig. 1) that crosses the Dortmund-Ems-Kanal near Osnabrück, are outlined in fig. 3. It was built in 1953, the rolled girders were produced in the thirties. During an inspection, cracks have been detected at some of the cross girders near the connection to the principal load bearing elements, trusses of 59 m span (fig. 4). The investigation of the bridge included strain measurements at longitudinal and cross girders under static load and under traffic flow and tests on the

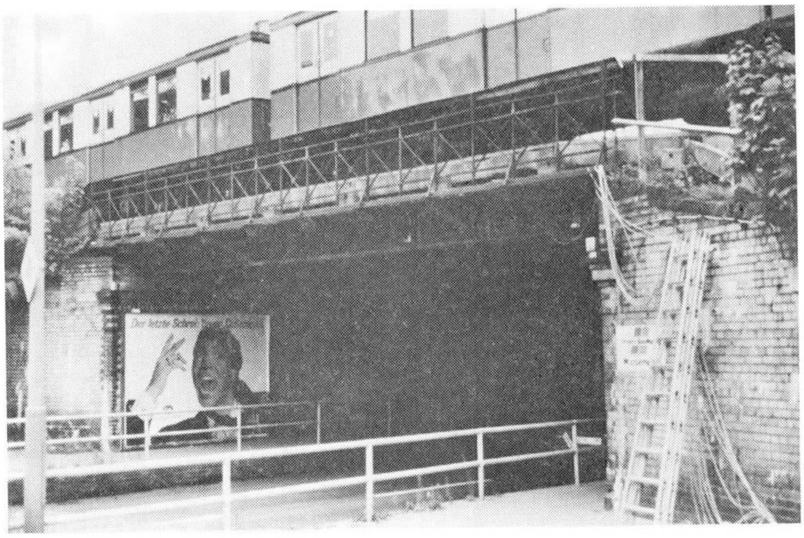


Figure 2.
Girder Bridge of Berlin Metropolitan, replaced in 1988

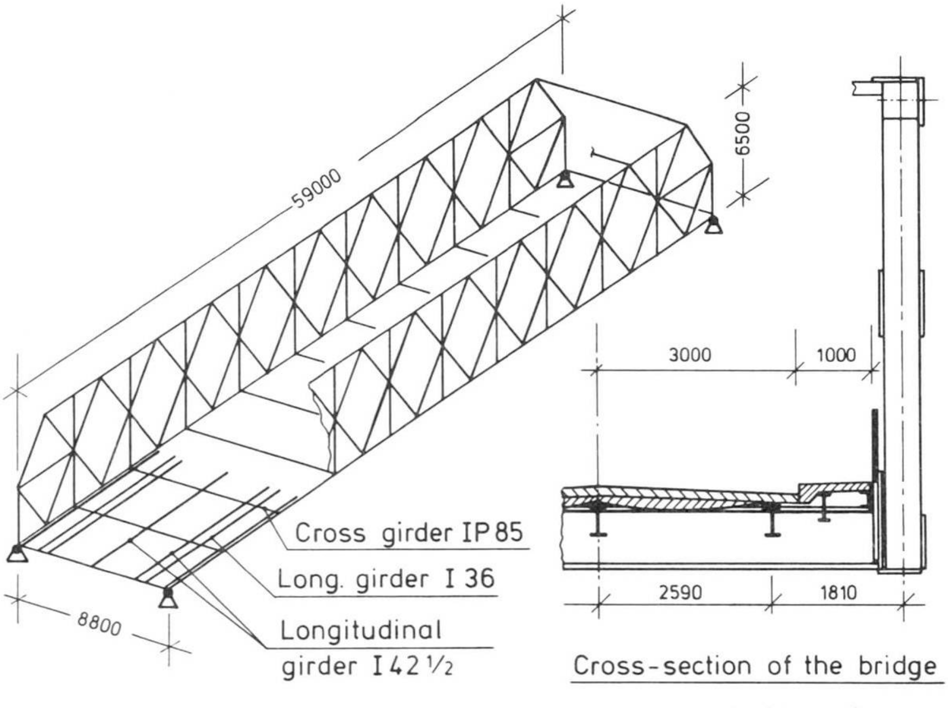


Figure 3: Load bearing elements of the bridge of fig. 1

material of the structural elements in question. The measurements under defined static load by a two-axle truck of about 20 t weight showed that the calculated stresses at the points of maximum stressing are considerably higher than the measured ones. From the measurements under traffic we obtained that only in very few cases of passing of heavy trucks, stresses exceeded the cut-off limits of the standardized fatigue curves [6] (fig. 5). In addition to the standardized material investigation, we performed crack growth tests on CT-specimens as recommended in ASTM E-647-83. The results in terms of the representing Paris equation (fig. 6)

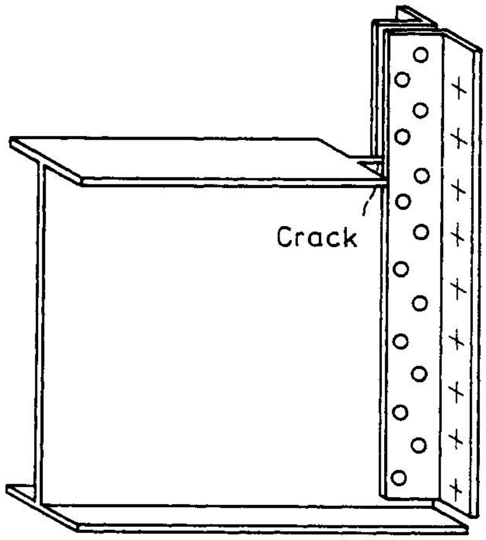
$$\frac{da}{dN} = C \, \Delta K^n \qquad (1)$$

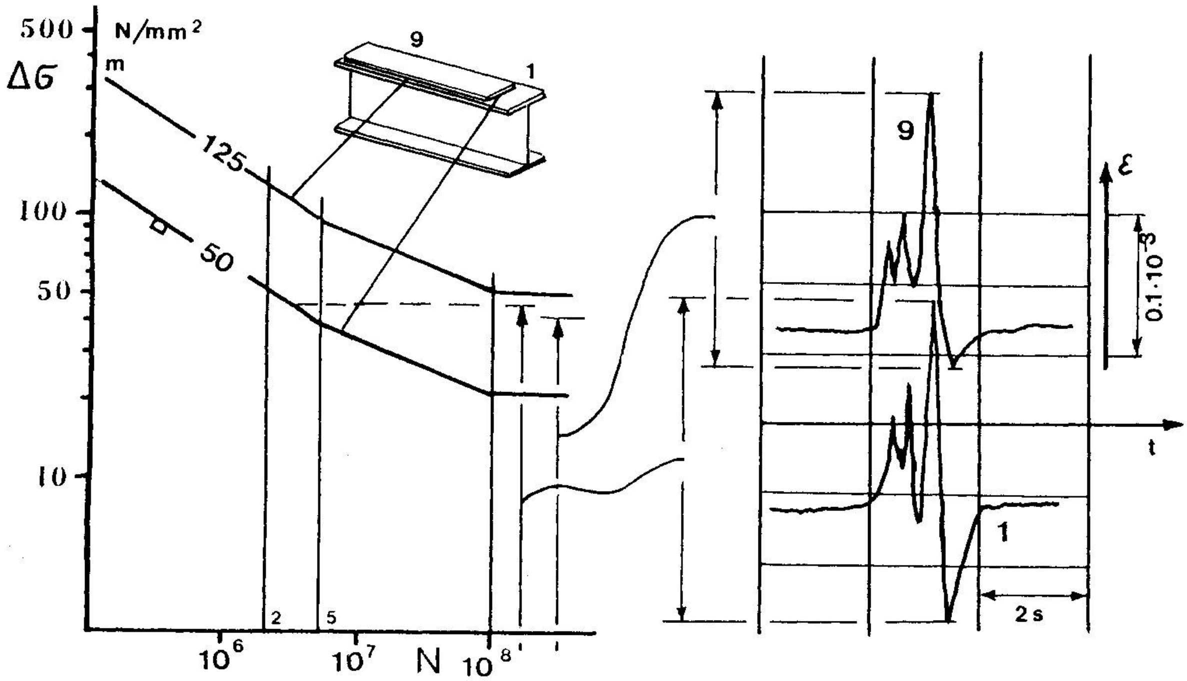
a crack length
N number of loading cycles
ΔK cyclic stress intensity factor
C;n material parameters of crack growth

confirmed that the material could be regarded as mild steel concerning the fatigue behaviour.

Figure 4.
Structural detail at the connection of the cross girders to the main truss girder and the location of cracks

Figure 5 (below).
Fatigue strength curves (categories 125 and 50) and maximum measured stress cycle at two measuring points at the central longitudinal girder during passing of a heavy vehicle.





The crack growth tests offered the possibility to assess the amount of growing of a crack of a certain length which was not detected during an inspection within the time interval up to the next inspection (3 years). From the measurements, it turned out that the cracks (fig. 4) were caused by residual forces.

2.2 Riveted Girder Bridge of Berlin Metropolitan

The single-track bridge (fig. 2) with a span of about 12 m was built in 1896. It had to be replaced because the road it crosses had to be widened.
Before the bridge was removed, we performed strain measurements at several points of the structure, at elements of the main girders and of cross girders. The stresses during the hours of measurement did not reach the cut-off limits of the standardized European Fatigue Strength Curves[6]. However, we do not know accurately which type of traffic passed the bridge during the nearly 100 years of the bridge's life in an eventful history.

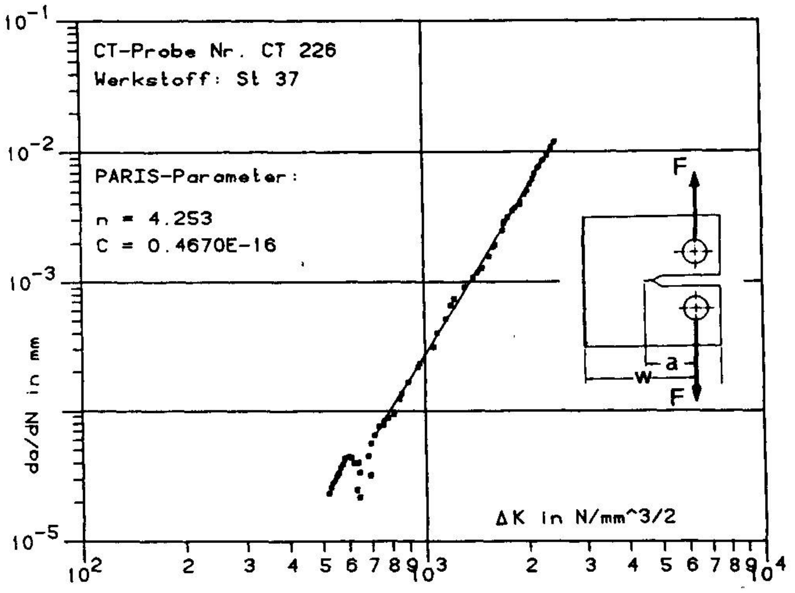


Figure 6: Diagram of crack growth rate da/dN versus cyclic stress intensity ΔK as elaborated for a compact tension (CCT) specimen (ASTM E 647-83)

It is intended to simulate traffic load on this bridge and another one similar to it in the laboratory to confirm the assessment of remaining fatigue life by the evaluation procedure that is common practice.

3. PROBLEMS OF APPLICATION OF CRACK GROWTH INVESTIGATION

The application of fracture mechanics in the evaluation of remaining fatigue life implies the modelling of cracks in structural elements which can probably occur, fig. 7. The crack growth is only governed by the stress intensity at the crack's tip as expressed by the Paris equation (1). It is an advantage of the concept of fracture mechanics that it leads to a deeper insight into the problem of survival of structural members under cyclic loading than only the application of fatigue strength curves after calculation of cummulative damage by collectives of stresses. Fracture mechanics procedures are recommended when cracks have been observed, because the shape and the dimensions of the cracks are known as well as the surrounding stress fields.

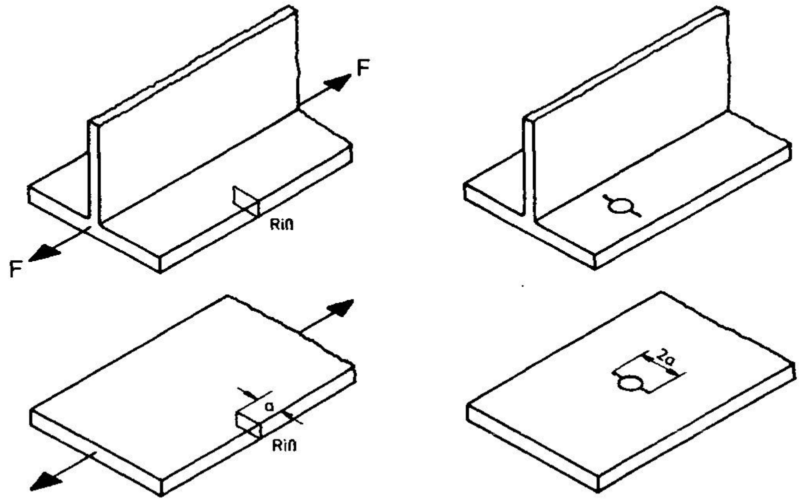


Figure 7:
Crack pattern for evaluating stress intensity factors and crack propagation

4. CONCLUSION

The evaluation of the remaining fatigue life of old riveted steel bridges is a very important task of structural engineering and comprises several different investigations. Faced with the problem to give an estimation of the remaining fatigue life of a certain bridge, which had cracks in a few structural elements, we extended the commonly used evaluation procedure by crack growth tests. The results of these tests made it possible to identify the material in terms of fatigue strength and gave the fundament to determine the propagation of postulated or observed cracks within the inspection period of time.

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