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Residual Fatigue Life of Railway Bridges

Durée de vie résiduelle des ponts de chamin de fer

Restnutzungsdauer von Eisenbahnbrücken

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SUMMARY
The paper presents a unified approach to fatigue design with theoretical background data and experimentally defined characteristic values. A step by step procedure for the assessment of residual fatigue life of existing structures and bridges in particular is also given. These provisions form part 6 of the new specifications DS 804 of the German Federal Railway.

RESUME
L'article présente une méthode unifiée pour calculer la résistance à la fatigue avec des bases théoriques et des caractéristiques déterminées expérimentalement. Un procédé pas à pas pour la détermination de la durée de vie résiduelle des structures existantes et principalement des ponts est également présenté. Ces règles constituent la partie no 6 du nouveau règlement DS 804 des chemins de fer fédéraux allemands.

ZUSAMMENFASSUNG
Eine einheitliche Methode zur Erfassung der Ermüdungsfestigkeit, theoretische Grundlagen und experimentell bestimmte Kenngrössen sowie Verfahren zur schrittweisen Ermittlung der Restnutzungsdauer bestehender Tragwerke, hauptsächlich Brücken, werden dargestellt. Diese Regeln entsprechen Teil 6 der neuen Vorschrift DS 804 der Deutschen Bundesbahn.

Part no. 6 of the specifications of the Deutsche Bundesbahn "Bewertung der Tragfähigkeit bestehender Bauwerke - Vorschrift für Eisenbahnbrücken und sonstige Ingenieurbauwerke (VEI) 1980" which was introduced about a year ago demonstrates a method, particularly for bridges, to predict damage accumulation and residual life of a structure and of parts thereof and to localize areas with particularly high accumulation of damage. On the basis of such a predetermination it is then possible to examine the structure specifically in situ.

There may be quite a number of bridges, especially in South Germany, performing adequately for more than 80 years and which will possibly soon reach or may already have exceeded their theoretical fatigue life. These specifications, however, are not only applicable to the "veterans" among the bridges, for each structure having been built in the meantime or to be built in future, which is subjected to dynamic loads, some day will reach the limits of its service life and then have to undergo such an investigation.

To achieve an optimized service of a bridge from the economic and safety point of view one needs to compare the design loads with the actual working loads and if necessary to determine once more the residual life at any time during service. Today, it is an advantage for the residual life of many old bridges, that in the past the design loads were far higher than the actual loads.

Not only in order to take full advantage of the fatigue strength, but also for further aspects of increasing the efficiency of a bridge, such as

- increase of engine loads, car loads and train loads,
- increase of train speed,
- increase of train frequency,

or in other cases, such as

- reinstatement works,
- replacement of longitudinal girders or cross girders or of other parts of the runway,
- collision or other damage etc.

a new assessment of the structure is necessary to achieve coherent safety and efficiency of all parts.

As one can see, this is a very important task for the future, a solution for which has already been worked out. The procedure is explained in the following (see fig. 1):

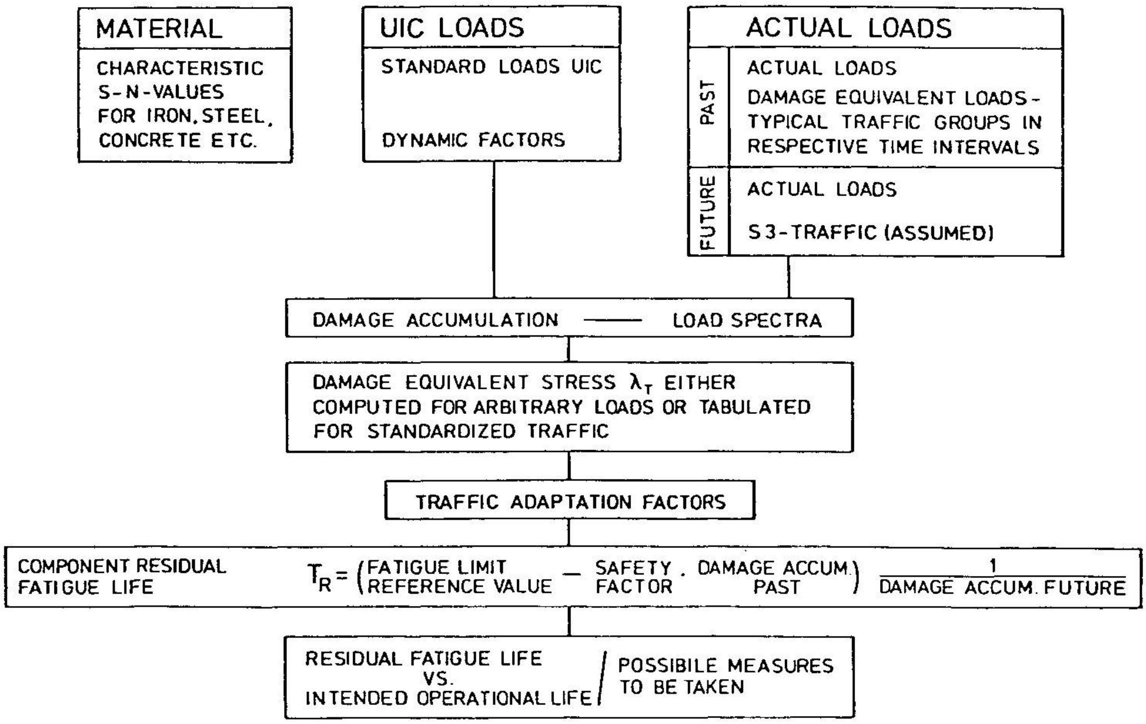


Fig. 1: Computation scheme for residual fatigue life

1. After documentation of the current state of the structure and its environmental conditions it is necessary to analyze as exactly as possible the past and the future working loads (actual trains = BLZ) regarding

   - load configuration including engine loads, car loads and axle loads, axle arrangements, distances between axles,
   - train frequency,
   - train velocity

   classified according to different service periods.

2. When all data of actual train passage in the past - and correspondingly for the future - are known, effective working load trains (E BLZ) or standardized working load trains (T BLZ) can be obtained by transforming actual train loads according to the data defined above. These standardized working load trains substitute one ore more of the actual trains in the calculation of the structure. Depending on the required accuracy of the residual life estimation either one standardized working load train covering all actual trains of the past and the future (level 1) ore more T BLZ each covering a set of actual trains are taken into account (higher level).

3. The travelling speed, the influence length and, above all, the specific passage period as well as the loading pattern are connected with the vibration factor.

This factor can be taken from previous or current regulations or determined on the basis of exact calculations or it can be evaluated from measurements (ref. /1/ and /2/). As a multiplication factor for the loads or for the internal forces it has a direct and considerable influence on the stresses.

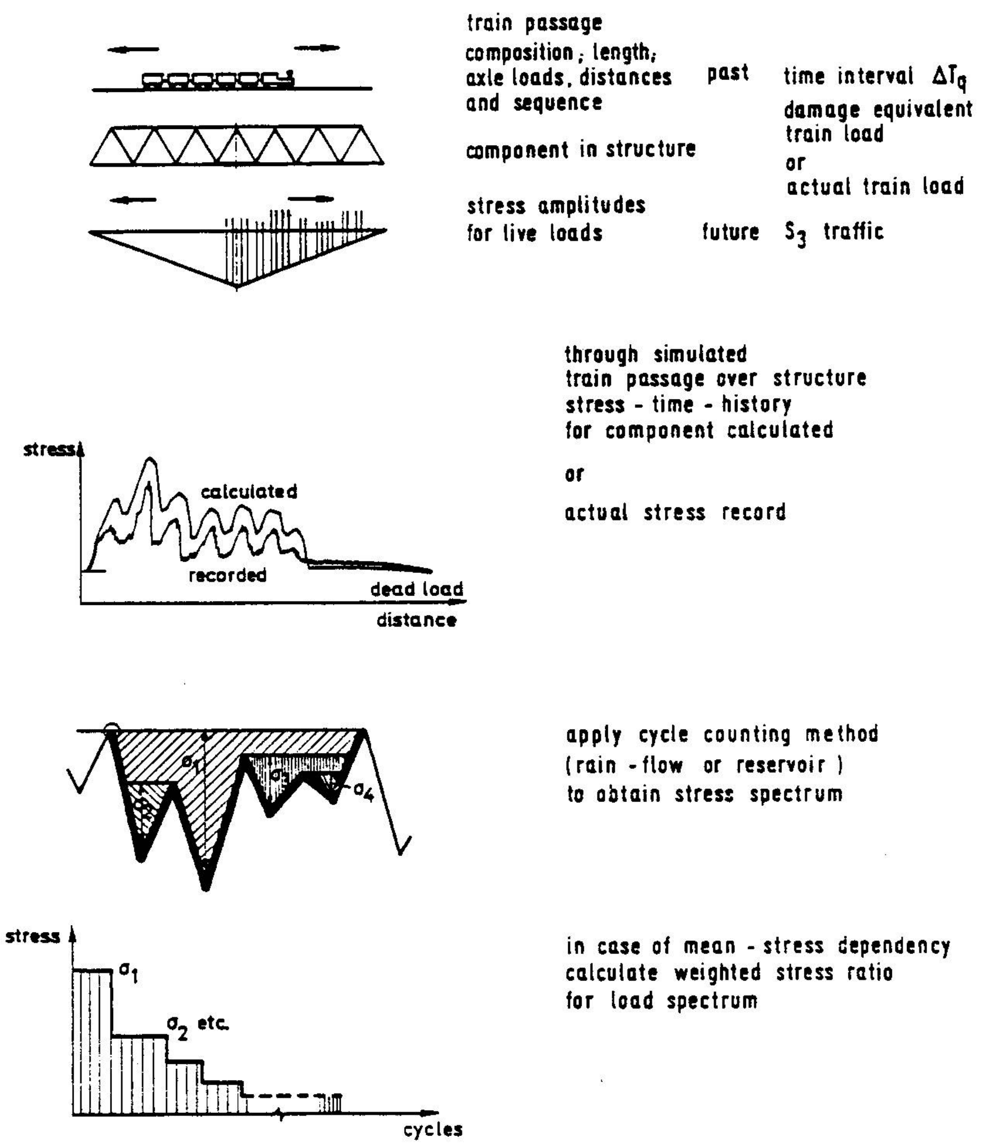
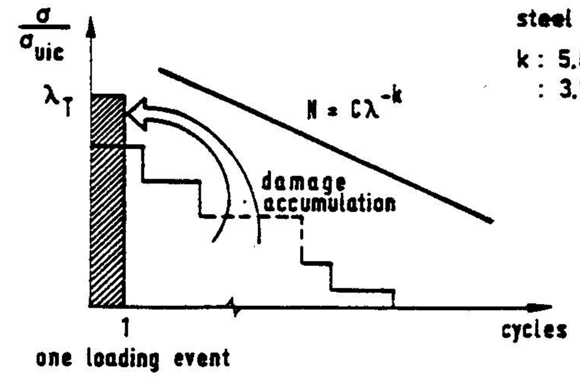


Fig. 2: Computation of load spectrum for structural component

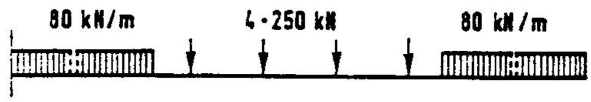
4. On the basis of the actual cross sectional data the stresses have to be calculated according to the elastic theory or, respectively, the load carrying capacity can be achieved by means of the ß-method (ref. /3/ and /4/). This ß-method is a simplified way to compare the stresses in the members of a railway bridge under the standardized train S 1950 with any other train.

5. The working stresses, which are decisive for the fatigue life, are either calculated from effective working load trains (E BLZ) with respect to the elastic theory and by means of computer programs of the Bundesbahn-Zentralamt, München, for induvidual damage equivalent stress λ_{Tqj}-values of each E BLZ_j, or the damage equivalent stress λ_{Tqj}-values of the standardized working load trains T BLZ_j can be taken directly from tables prepared by the Bundesbahn-Zentralamt, München. The λ_{Tqj}-values can be introduced into the calculation of cumulative damage. The computation of the λ_{Tqj}-values is based on Miner's rule (see fig. 2 and 3) and takes into account the stress spectrum of the working load train j $(BLZ)_j$ within the time intervall q, the Wöhler line for the corresponding material and the notch case in question, or, respectively, the regulations of DS 804 regarding adm. $\Delta\sigma_{Be}$ are important (ref. /5/ to /7/).



steel structures after DS 804
k : 5.00 material and connections
: 3.75 welds

UIC 71 specifications load



representative traffic S_3

type 1 rapid rail - car train
type 2 passenger train
type 3 passenger train
type 4 general freight train
type 5 general freigth train
type 6 heavy freight train
with respective frequencies

Fig. 3: Damage equivalent stress λ_T

The safety factors are:

1.65 against the mean value of the Wöhler line and
1.33 against the 90 % probability of survival of the Wöhler line.

The residual life finally results from the following equation:

$$\gamma_{s,v}^{k} \sum_{q}\sum_{j} N_{qj} \lambda_{Tqj}^{k} \Delta T_q + \gamma_{s,z}^{k} \sum_{j} N_j \lambda_{Tj}^{k} T_R = 5\,480\ \lambda_R^{k},$$

where

$\gamma_{s,v}$ safety factor for past loads (load enhancement factor),
N_{qj} number of passings per day of the BLZ_j within the time intervall q,
q parameter for the time intervall in question,
j type of the standardized or effective working load trains (T BLZ or E BLZ),
λ_{Tqj} damage equivalent stress as ratio between internal forces of the chosen T BLZ_j or E BLZ_j of the past within the time intervall q and the corresponding internal forces from UIC 71 (ref. /8/ and /9/),
k slope of the Wöhler line depending on material and notch case,
ΔT_q time intervall (in years) within which the T BLZ_j or E BLZ_j ran,
$\gamma_{s,z}$ safety factor for future loads (load enhancement factor),
N_j number of passings per day of the T BLZ_j or E BLZ_j in the future; here also the S3-traffic can be taken which was determined by the Deutsche Bundesbahn, it is a combination of 6 different types of trains and stands for the modern traffic on railway lines (ref. /10/),
λ_{Tj} damage equivalent stress as ratio between internal forces of the T BLZ_j, E BLZ_j or S3-traffic of the future and the corresponding internal forces from UIC 71,
T_R residual life,
λ_R = $adm.\Delta\sigma_{Be}/\Delta\sigma_{UIC\ 71}$,
$adm.\Delta\sigma_{Be}$ admissible stress amplitude of the notch case in question according to ref. /8/,
$\Delta\sigma_{UIC\ 71}$ stress amplitude from the load diagram of the UIC 71. Virtually all effects of other load trains are referred to the effects of this load diagram UIC 71, so that the tables for UIC 71 can be used.

The above equation with the load on the left side and the strength on the right side consists of three parts. The first part on the left covers the cumulative damage from the past loads, it can be determined numerically. The second part on the left covers the cumulative damage from the future loads, it contains the value T_R, the unknown residual life. The third part on the right considers the strength aspects, in this part the Wöhler line of the material under consideration, the respective notch case and the required safety factor are taken into account.

The value 5480 results from the assumption, that the bridge is in service on 365 days per year and that the damage equivalent stress λ_{Tqj} of a T BLZ_j or E BLZ_j within the time intervall q are referred to a characteristic fatigue strength value λ_R for a life limit of $2 \cdot 10^6$ cycles.

The investigations and the result of the calculation lead directly to those areas in a structure where residual life is insufficient or which may, theoretically, already have reached the end of their service life. In this case and depending on the results measures have to be taken, one of the most important is the local crack inspection.

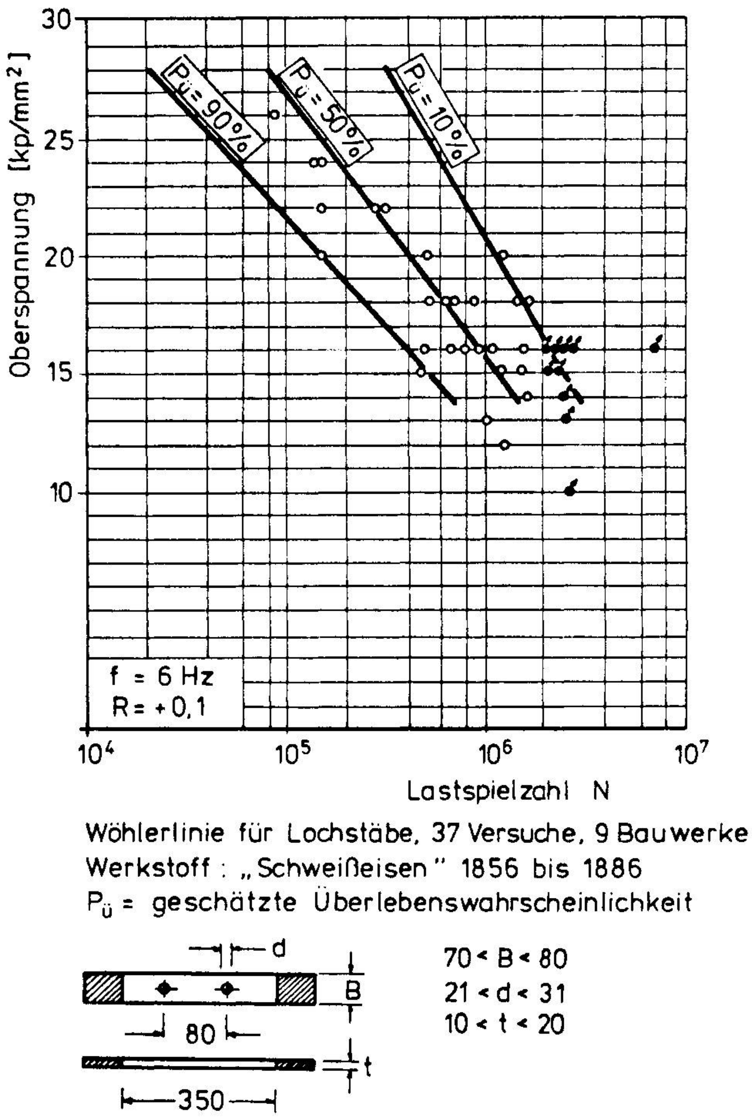


Fig. 4: Wöhler lines for iron bars from 1856 to 1886 (ref. /5/)

Problems arose with old steels since their Wöhler lines were unknown. In many years co-operation with Deutsche Bundesbahn the Versuchsanstalt für Stahl, Holz und Steine of the University of Karlsruhe performed fatigue tests in order to obtain general information on the fatigue behaviour of steel fabricated before the end of the last century and specific information on the fatigue behaviour of the steel of the structure under discussion. Whenever an old bridge was pulled down the "Versuchsanstalt" made every effort to secure material such as plain bars, bars with old or re-drilled holes, riveted bars with old or newly driven rivets. The fatigue test results obtained so far are compiled and commented in ref. /11/ to /15/ (see fig. 4). For steels fabricated after 1905 more fatigue test results are available.

Summing up, however, it must be said that further research and efforts are necessary to

1. confirm the validity and to improve Miner's rule of damage accumulation,
2. obtain more detailed information on the fatigue behaviour of members of very old, old and new steel with their connections and other notch effects under realistic stress distribution and
3. develop the regulation DS 804/6 from experience gained by application to existing structures and to obtain a good knowledge of the residual life of existing railway bridges.

The draft for the code was compiled as a joint effort of the authors of this paper Prof. Steinhardt, Prof. Valtinat, Prof. Kosteas and the Deutsche Bundesbahn, represented by Dept.-President Dipl.-Ing. Stier and Dipl.-Ing. Kirstein of the Bundesbahn-Zentralamt, München.

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