Updated service life evaluation of bridges through measurements

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Updated Service Life Evaluation of Bridges through Measurements

Meilleure estimation de la durée de vie de ponts par des mesures in situ

Durch Messungen verbesserte Einschätzung der Nutzungsdauer von Brücken

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SUMMARY

An improved estimation of the service life of a structure with respect to fatigue is possible if measured stress spectra are used. Based on a safety index, the influence of the effective traffic loading on structures compared to design loading is determined. The methodology shows a consistent combination of computer calculations and long-term measurements and can be used for structural monitoring. Results are given for an old steel bridge and a new composite bridge.

RÉSUMÉ

La durée de vie d'une construction dépend fortement de phénomènes de fatigue. Cette durée peut être mieux estimée si des mesures de spectres de contraintes sont faites. L'influence de la charge réelle de trafic sur la structure est exprimée avec un coefficient de sécurité permettant une comparaison avec la charge de trafic calculée lors du projet. La démarche proposée résulte d'une combinaison efficace entre des calculs automatisés et des mesures permanentes sur l'ouvrage. Les résultats sont présentés pour un ancien pont métallique et pour un pont mixte récent.

ZUSAMMENFASSUNG

Eine Einschätzung der Nutzungsdauer von Ingenieur-Bauwerken wird wesentlich verbessert, wenn gemessene Spannungskollektive verwendet werden. Auf der Basis eines Sicherheitsindex kann der Einfluss der tatsächlichen Verkehrslasten hinsichtlich der Materialermüdung, verglichen mit normierten Lastannahmen, berücksichtigt werden. Die vorgestellte Methode zeigt eine konsequente Nutzung von Rechnung und Langzeitmessung und kann zur Bauwerksbeobachtung eingesetzt werden. Es werden Ergebnisse für eine alte Stahlbrücke und eine neue Verbundbrücke vorgestellt.

1. INTRODUCTION

To do service-life evaluations for civil engineering structures in the state of planning models have to be used for the static system as well as for the loading. Whereas there are reliable statistical data available for the structural model (geometry, material behaviour), the modeling of the load is relatively uncertain, especially for the traffic loading covering the whole time of its service-life, e.g. 80 years. When fatigue-life is decisive, the choice of the parameters of the load model yields, besides the material parameters, the most important influence on the safety index ß. The decrease of ß due to fatigue caused by traffic loading for existing constructions can be updated by the use of measured stress spectra.
A lot of theoretical and experimental effort was spended during the last years with the aim to integrate field measurements and inspection results to bridge assessment (e.g. Zhao et al. 94, Moses et al 94).

2. METHOD

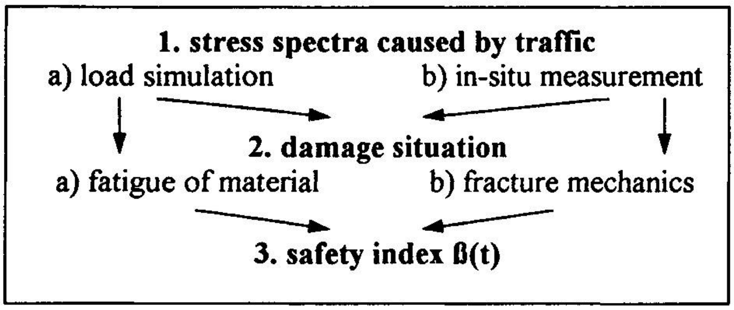

Fig. 1 Possibilities to estimate the safety-index ß(t)

The method we use to estimate structures (i.e. old bridges) with respect to their residual service-life, offers four possibilities to derive a safety index as a function of time ß(t) (fig. 1). Additionally adapted inspection intervals for various structural members can be recommended. As the different sensibility with respect to damage of the structural members is characterized by ß, inspection personnel can work with more efficiency.

The innovative concept of the presented methodology is:
- using a comfortable computer program to do (1a) traffic simulations and calculations of stress spectra, (2) damage calculations and (3) assessments of the safety index ß and the derived residual service life and
- the consequent integration of in-situ measurements (1b).

2.1 Estimation of stress caused by traffic (stress spectra)

Calculating stress spectra using a structural model based upon **statistic traffic load simulation** with appropriate programs running on a PC (Geissler 95) is an economic method to get a first estimation of stress spectra for chosen points of a structure. Different parameters concerning defined load spectra and details of the structure can be studied.

In-situ measurements give a much better estimation for the stresses at the observed points, thus the real loading and the real behaviour of the structure are taken into account. The measurement program we are using (Baumgärtner 90) is running permanently and classifies the stress ranges in real-time.

In combination of the two mentioned methods we can calibrate traffic load models according to the measured stress spectra and therefore we can adjust stress spectra of structural members not measured.

2.2 Evaluation of accumulated damage

Based on the stress spectra, the **damage caused by fatigue** can be evaluated, e.g., using the Palmgren-Miner method. In connection with permanent measurements we also use different accumulation hypotheses which take into account the time history of the stress ranges(Baumgärtner and Waubke 93).

Especially when cracks are detected or hidden cracks have to be taken into account, e.g. when cracks cannot be observed under rivets, the **theory of fracture mechanics** can be applied in a very successful manner to get an estimation of the residual service life. The use of fracture mechanics could also be necessary when the fatigue calculation yields a damage value D greater than 1, or in the case when no information of the stress history is available.

2.3 Safety index ß(t)

The safety index ß is a defined value for an estimation of the probability of failure. To calculate the safety index we use FORM (First Order Reliability Method) and Monte-Carlo-Simulation.

1. Stress range ($\Delta\sigma$)	0.60 .. 0.80
Crack prop. exponent (m)	0.60 .. 0.80
2. Crack prop. factor (C)	0.20 .. 0.25
3. Initial crack length (a_0)	0.15 .. 0.20
4. Fracture toughness (K_c)	0.03
5. Yield strength (f_y)	0.001

Fig. 2 Influence values α_i with regard to fatigue life

Our interest in the safety index ß idoes not only concern its absolute value, but also as an operative value. With the determination of influence values α_i, the dominant influence of the loading assumptions on the safety index and on the residual service life can be shown. Results of systematic calculations, based on fracture mechanics, yielded a rank of sensibility of the parameters with regard to remaining fatigue life, given in fig. 2. One consequence should be, to put greater attention on the estimation of the stress of existing constructions, e.g. by doing measurements (Waubke and Baumgärtner 93).

3. APPLICATION TO BRIDGES

3.1 Bridge „Fischerdorf", bridge „Kaditz"

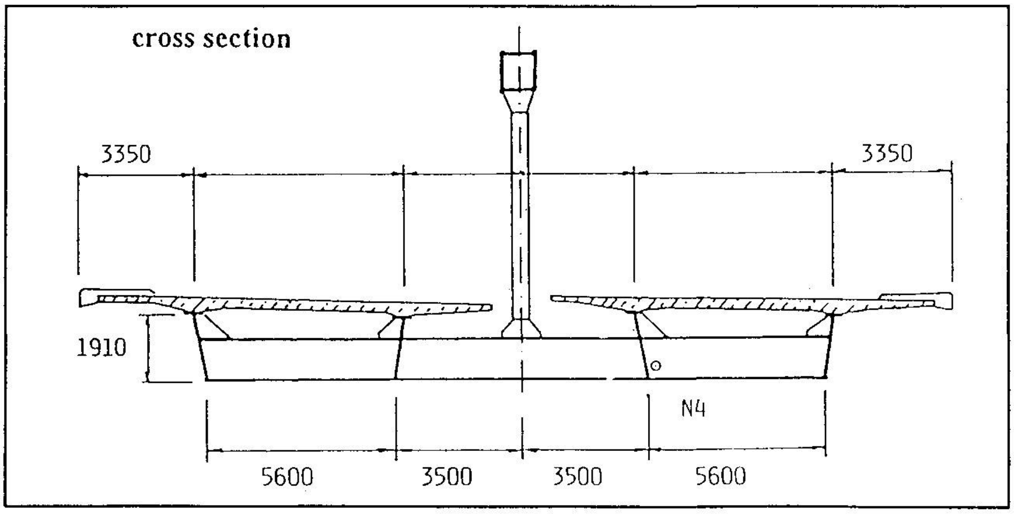

Fig.3 Bridge „Fischerdorf", cross-section

The static system of the **motorway bridge „Fischerdorf"** consists of one middle-arch, eight hangers and cross-beams made of steel and two longitudinal beams made of steel and concrete (fig.3). The span is 102.5 m. The decision to do stress measurements was made, to get better information about the effective stress due to traffic loading with respect to the spatial load bearing system and the influence of the interaction of steel and concrete. Due to the different welded members of the bridge 40 measurement points had been supplied with strain gages.

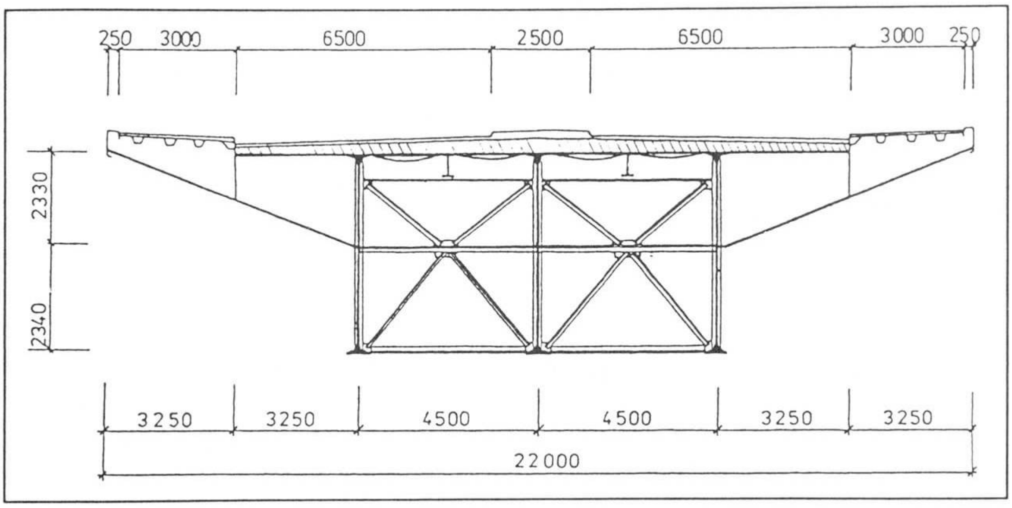

Fig. 4 Bridge „Kaditz“, cross-section

The **road bridge „Kaditz“** is about 50 years old and crosses the Elbe river near Dresden. The bridge is a riveted construction and has 4 spans with a main span of 115 m. The cross section (fig. 4) shows the 3 steel girders (4.7 m high) and the concrete slab. The degree of interaction of steel and concrete is unknown because there are no designed links. Investigations were decided to ensure future safe performance with respect to increased traffic loading. Based on measurements we can say, that there is a nearly full composite effect in parts of the fields.

3.2 Results for bridge “Fischerdorf“

A measurement system was developed to get representative stress spectra for a long time interval. This system, consisting of a measurement device and computer programs, is able to do permanent stress measurements with parallel evaluation of stress ranges using the „rain flow“ method in real time.

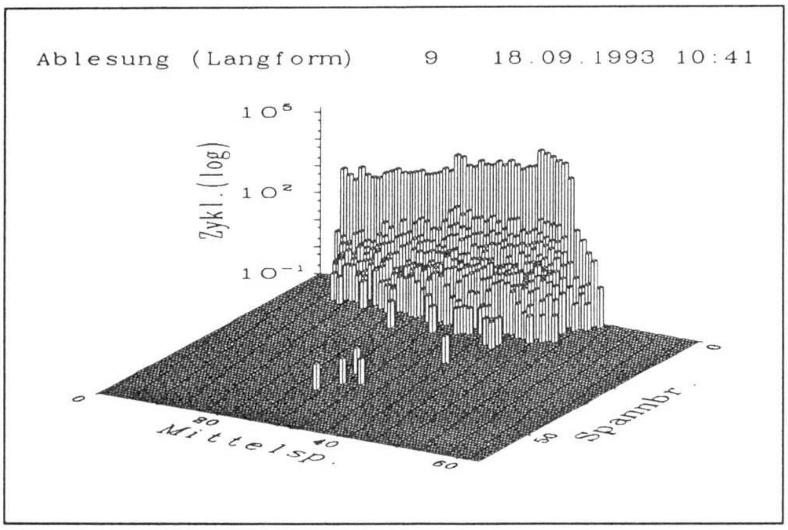

Fig. 5 Number of stress ranges, classified with respect to amplitude and mean value (bottom of main girder)

A measurement point at the bottom of a longitudinal beam was selected to present some results. The few extraordinary high stress-ranges in fig. 5 are caused by the change of temperature. Using standardized S-N-curves (e.g. Eurocode) the accumulated fatigue D(t) can be recorded at given time intervals, e.g. 2 hours. In fig. 6 the development of D(t) is shown for different detail categories to realize their influence. Fig. 7 shows an extrapolation of ß(t) for a cross-beam based on stress spectra received by a one month measurement. The detail category 71 (Eurocode) was applied. A factor of 1.5 was multiplied on the measured stresses to take into account some increase in the weight of the trucks and that the strain gage is pasted in some distance to the point of interest.

Further development of D(t) and ß(t) will be observed at the bridge, to study the alteration of the traffic and the roughness of the lanes, accompanied by calculations with a FE model. Measurements covering three years show, that the stress spectra under traffic are much “smaller“ than calculated ones under design loading. Till now, fatigue is not relevant for the instrumented members.

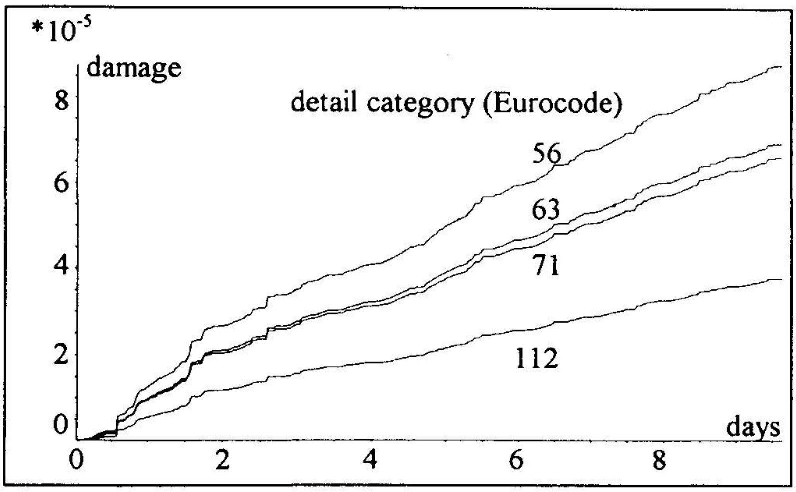

Fig. 6 Damage accumulation ("Fischerdorf")

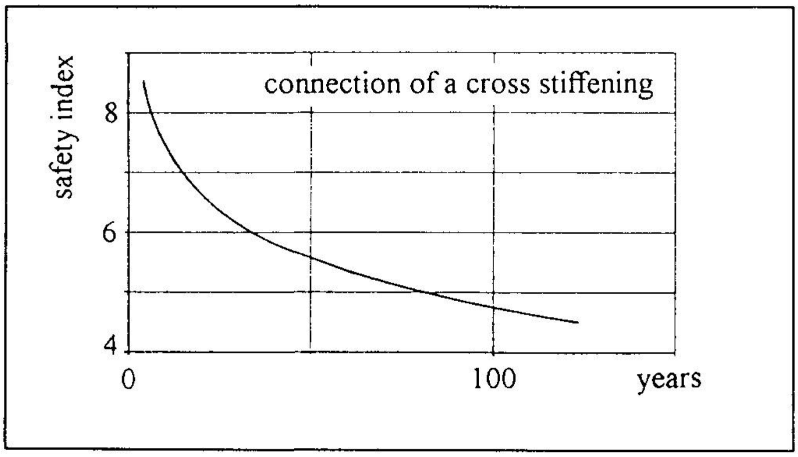

Fig. 7 safety index ß(t) ("Fischerdorf")

3.3 Results of bridge „Kaditz"

The loading is simulated considering three different traffic situations and the stress spectra were calculated for a critical point of the main beam (bottom flange). Hidden cracks on both sides of a rivet hole were evaluated as the worst crack situation. The development of calculated crack lengths confirm the great influence of the different traffic loadings (fig. 8).

To do a reliability analysis based on fracture mechanics we can calculate with the developed computer program the decrease of the safety index ß as a measure for the increase of the probability of failure. In fig. 9 a comparison is given between ß(t) based on measurements lasting several weeks and based on the traffic load model „medium distance traffic". As long as the observed traffic situation does not change the fatigue-life doubles for the same level of the safety index. The theory of crack propagation and the assumptions of the crack situation may be very conservative for this safety evaluation. As the stress

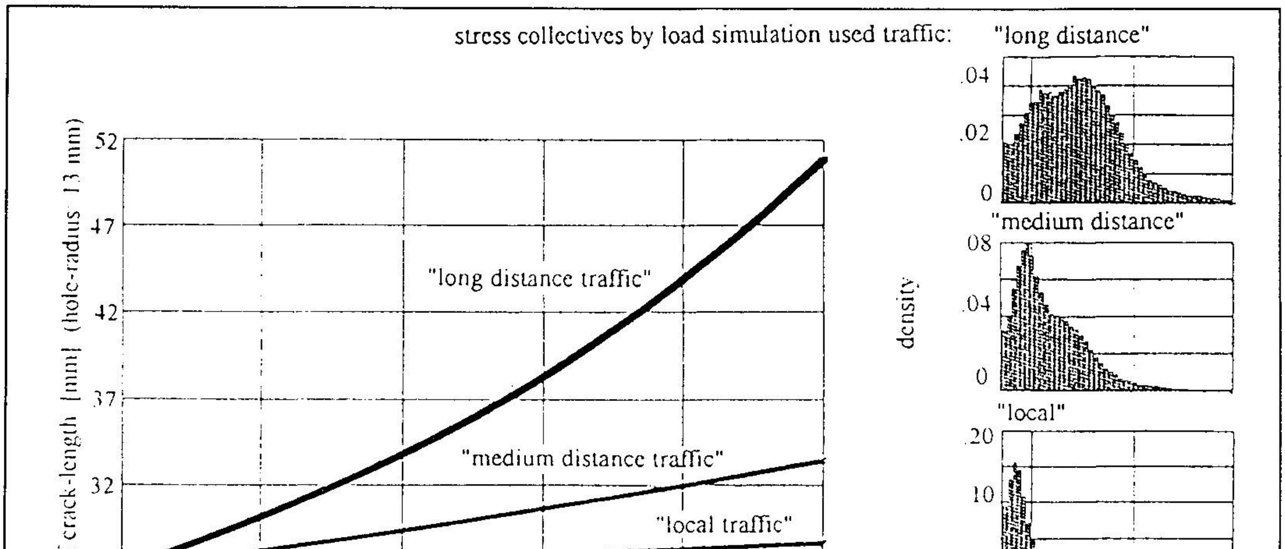

Fig. 8 right: Stress spectra based on traffic simulations ("Kaditz")
left: Crack lengths by time

level is not very high and no cracks are detected until now, the safety situation can be accepted. Additional material tests also confirmed a sufficient safety level during the inspection intervals.

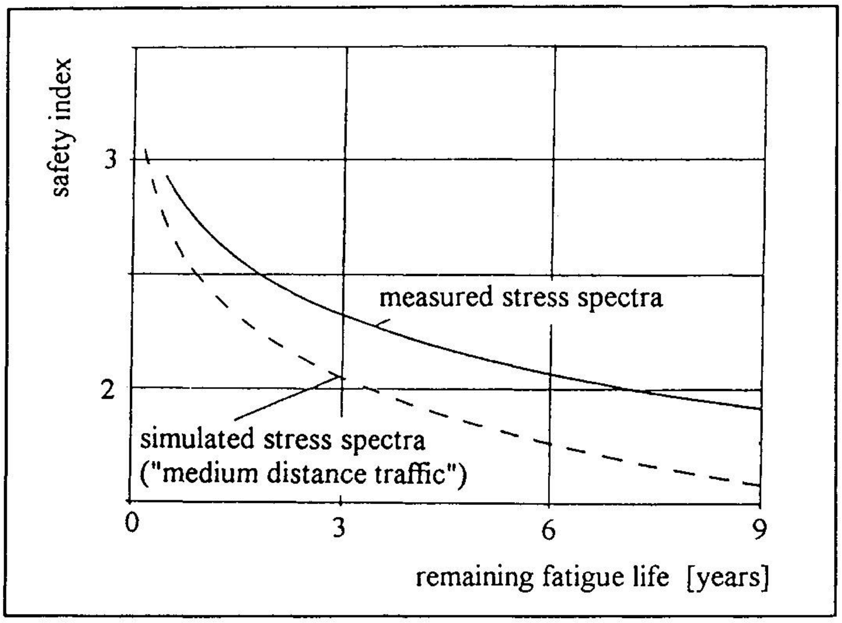

Fig. 9 Safety index ß(t) (bridge „Kaditz"), based on
a) simulated traffic b) measured stress spectra

4. FINAL REMARKS

The presented results show in a clear manner that the utilization of measured stress spectra can give a considerable improvement for the assessment of bridges. The applied methodology is very efficient as one can do numerical comparisons between fatigue accumulation and crack propagation and one can also calibrate traffic models by field measurements, if necessary and available.

To give some support for the installation of monitoring systems on constructions the „Deutsche Gesellschaft für Zerstörungsfreie Prüfung (DGfZP, „German Society for Nondestructive Testing") is going to develop an instructional pamphlet with the title „Automatisierte Dauerüberwachung - Dynamische Messungen" („Automatized Permanent Monitoring - Dynamic measurements", to be published summer 95).

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