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Checking the Reliability and Durability for Corrosion

Evaluation de la fiabilité et de la durabilité d'élements soumis à la fatigue par corrosion

Kontrolle der Zuverlässigkeit und Dauerhaftigkeit gegen Ermüdung bei Korrosion

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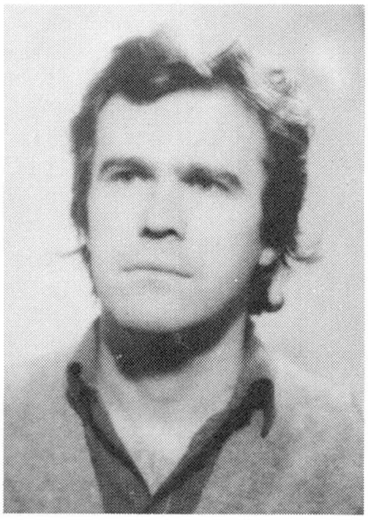

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SUMMARY

This paper deals with reliability and durability assessment procedure for engineering components with respect to corrosion fatigue. The problem of safety concept is treated as the probability of bearing capacity failure, expressed with its operative value safety index. The objective of these results, where fatigue is analysed phenomenologically, is to use the known facts as a basis for a quantitative estimate of the risk level at corrosion fatigue.

RÉSUMÉ

L'article traite l'évaluation de la fiabilité et de la durabilité d'éléments structuraux soumis à la fatigue par corrosion. On a assimilé le problème de sécurité à la probabilité de renoncement de la capacité portante exprimée par la valeur de l'indice de fiabilité. Le but de cette étude où la fatigue est analysée de façon phénoménologique, est d'appliquer ses résultats pour l'estimation quantitative du niveau de risque de fatigue par corrosion.

ZUSAMMENFASSUNG

Im vorliegenden Bericht werden Zuverlässigkeits- und Dauerhaftigkeits-Bewertungsverfahren von Konstruktionselementen bei Korrosionsermüdung behandelt. Das Sicherheitskonzept wird als Versagenswahrscheinlichkeit gegeben und durch ihre operative Grösse, den Sicherheitsindex, ausgedrückt. Die Absicht dieses Vorgehens besteht darin, bekannte Tatsachen als Grundlage für quantitative Schätzungen des Risikoniveaus bei Korrosionsermüdung zu verwenden.

1. INTRODUCTION

Causes that bring about failure due to fatigue in steel structures take place on micro-structure level and are subject to local defects due to fabrication and erection process ,and are also subject to corrosion during service.Already small changes in local properties of material have been found to influence the results even in strictly controlled conditions of laboratory sample testing,so the problem of fatigue safety can be adequately treated only with mathematical statistic models by applying fracture mechanics.

This paper concentrates on steel railway bridge structures with fatigue due to corrosion.Numerous inspections have detected corrosion process on steel bridge parts. Corrosion on steel bridge structures is mainly due to two reasons.The former is underestimation of corrosion fatigue,and the latter is lack of access to different parts of the structure for repeated corrosion protection.

The objective of this paper is to use the facts known so far as a basis for estimating the influence of corrosion fatigue by means of an operating engineering procedure where safety is treated as probability of bearing capacity failure.

2.INFLUENCE OF CORROSION ON FATIGUE

The fatigue damage increases with the duration of exposure to corrosion or factors causing it.The decreased fatigue strength depends on the kind of stress,category of the part, chemical composition and mechanical properties of the steel, aggressiveness of the corrosion medium,and corrosion protection system.If fatigue strength is analysed phenomenologically by means of the Wohler's line,it can be concluded that,in the case of corrosion fatigue,there is no area of indefinite amplitudes that the element can bear,but the $\Delta\sigma$-N line continues to zero as seen in Fig.1.

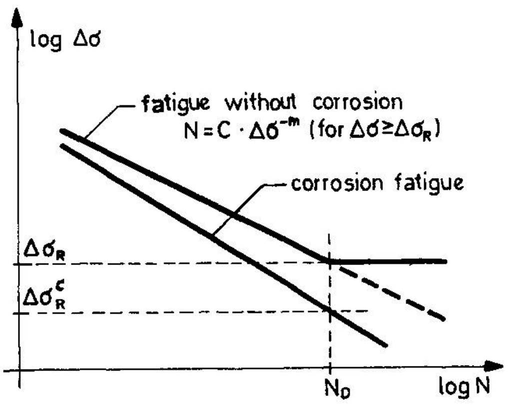

Fig.1 Phenomenological analyses of corrosion fatigue

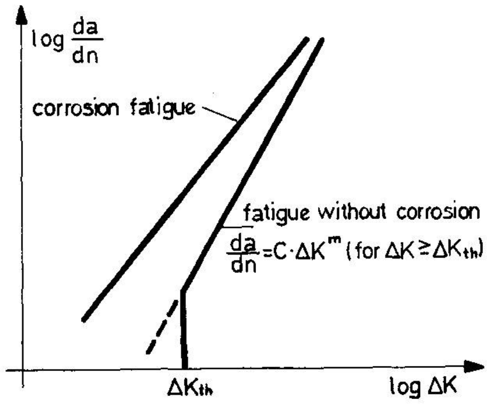

Fig.2 Corrosion fatigue expressed by fracture mechanics

Similar considerations can be applied in fatigue analysis by applying fracture mechanics,where in diagram $\frac{da}{dn}-\Delta K$ in the case of corrosion fatigue one can notice a decreased critical stress intensity ΔK_{th} (Fig.2.)Test results [1]in steels with the strength of 400 to 700 N/mm2 have shown an average drop in strength at corrosion fatigue.

3.DURABILITY AND RELIABILITY OF ELEMENTS SUBJECTED SIMULTANEOUSLY TO BOTH FATIGUE AND CORROSION

Durability and reliability at fatigue can be estimated probabilistically with the Hasofer-Lind method,where some statistical values of loads and strength are known.Density functions of these values change with time,which means that reliability ,i.e. its operational value(safety index β), also changes with time.This explanation is shown in Fig.3.

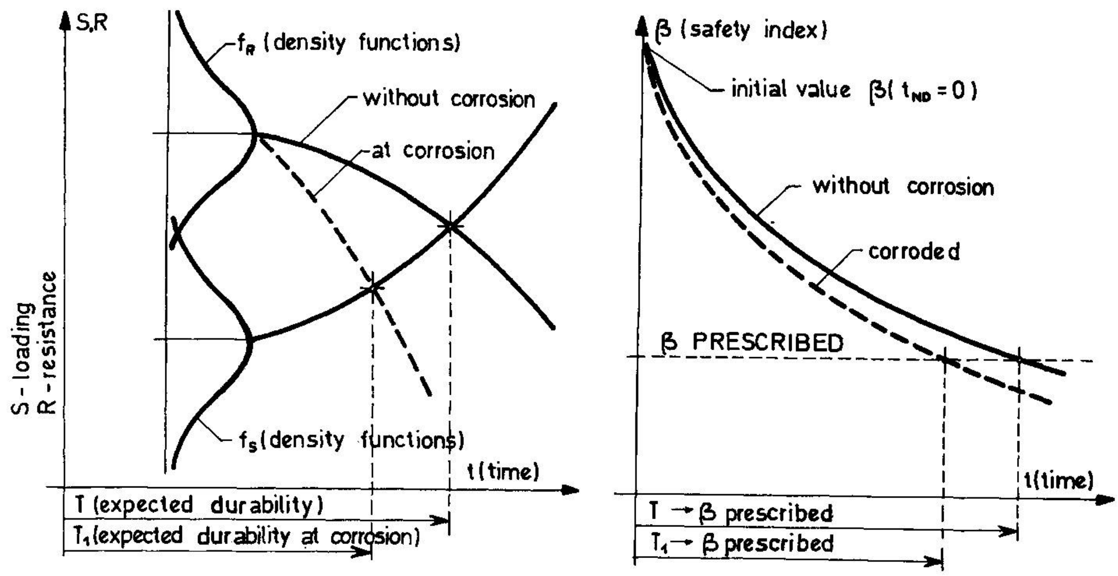

Fig.3 Relation of reliability and durability at corrosion fatigue

A general expression for the limit state equation for an n-dimensional vector space can be written in the following form:

$$Z=G[\vec{X}(x1,x2.....xn);\ \vec{K}(k1,k2....kn)] \qquad /1/$$

where

Z - safety margin

G - bearing capacity value function(mechanical model)

$\vec{X}$(x1,x2.......xn) - basic variables vector and its components

$\vec{K}$(k1,k2 kn) - deterministic parameters vector and its components

n - vector space dimension

Expression /1/ in the case of fatigue can be written in the following form:

$$Z = D(t) - \int_{r_d}^{r_g} \int_{\Delta\sigma_d}^{\Delta\sigma_g} \frac{n(t,\Delta\sigma,r)}{N(\Delta\sigma,r)}\, d\Delta\sigma \cdot dr = 0 \qquad /2/$$

where

D(t) - total damage in time t

rd,rg, $\Delta\sigma_d,\Delta\sigma_g$ } - lower and upper limits of double integral

$n(t, \Delta\sigma, r)$ - random number of stress variation in time t with stress difference $\Delta\sigma$ and the stress ratio r

$N(\Delta\sigma, r)$ - random number of stress variations with parameters $\Delta\sigma$ and r from Wohler's experiment (specimen fracture with constant amplitude)

If corrosion is present at fatigue,lower limit of double integral can be zero.

4.RESULTS FROM PRACTICE

Reliability of four different detail categories was analysed on a steel bridge element (Fig.4).

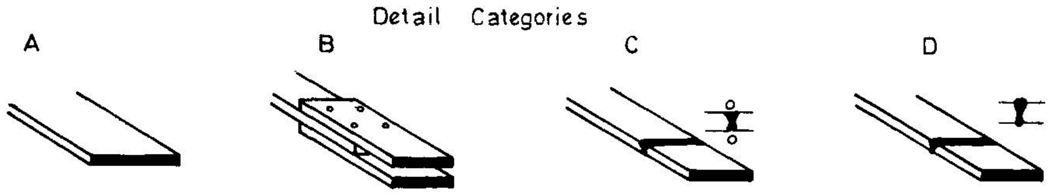

Fig.4 Analysed detail categories

The calibration procedure of existing railway bridges on the Zagreb-Karlovac railway line provided the safety indices for uncorroded details A,B,C and D according to[2].

SAFETY INDICES β									T(YEARS) l(SPAN)			
$\alpha = \frac{\Delta\sigma_R^c}{\Delta\sigma_R}$	T=10 l=4m				T=10 l=10m				T=50 l=10m			
	DETAIL				DETAIL				DETAIL			
	A	B	C	D	A	B	C	D	A	B	C	D
1.0	7.51	5.10	3.79	2.68	9.43	7.16	5.36	4.33	6.71	4.60	3.34	2.32
0.9	7.30	4.81	3.60	2.46	9.31	6.98	5.21	4.16	6.62	4.39	3.29	2.16
0.8	6.96	4.44	3.36	2.17	9.15	6.74	5.07	3.95	6.35	4.13	3.01	1.96
0.7	6.58	3.97	3.04	1.82	8.81	6.43	4.84	3.69	6.04	3.81	2.78	1.72
0.6	6.09	3.28	2.59	1.35	8.56	6.02	4.56	3.32	5.67	3.37	2.49	1.40
0.5	5.38	2.18	1.92	0.74	8.05	5.43	4.16	2.76	5.16	2.74	2.06	0.96

Table 1 Decrease of safety indices due to corrosion fatigue

The method and way of computer processing as well as the input data are presented in the paper [3].If corrosion circumstances appear,the basic variable of fatigue strength is lowered.Table 1 presents the drop of reliability index depending on assumed different percentages of fatigue strength drop.

The following numerical analyses comprise the relationship of the reliability index and the life span of railway bridges from corrosion fatigue aspect.Fig. 5 shows this relationship for various detail categories,i.e.$\alpha = \frac{\Delta\sigma_R^c}{\Delta\sigma_R} = 1$ (uncorroded detail fatigue) and $\alpha = 0.8$ (corrosion fatigue strength if decreased by 20%).

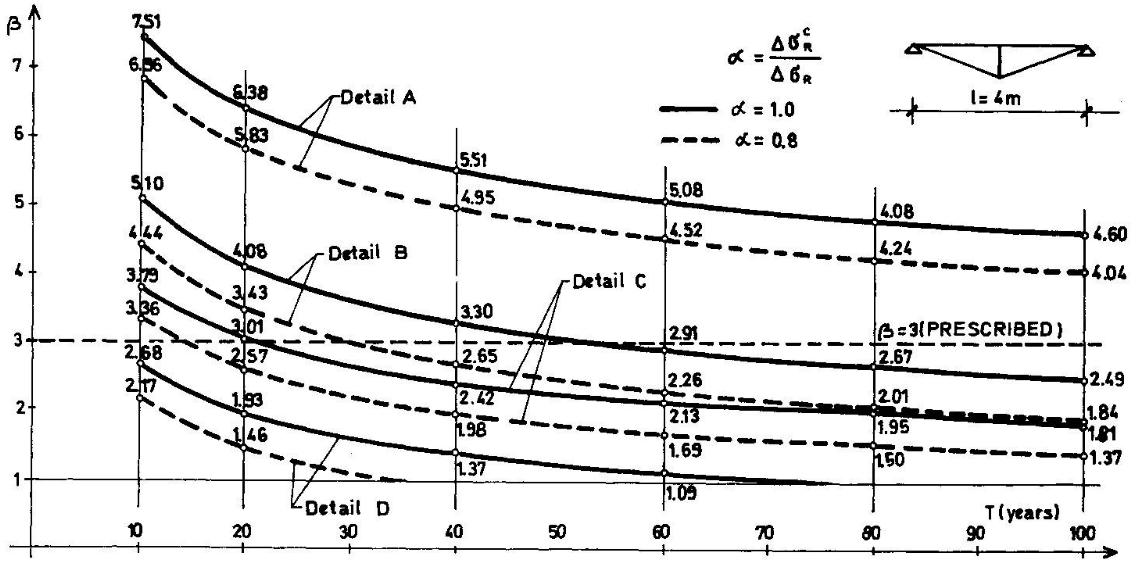

Fig. 5 Durability decrease at corrosion fatigue (α =0.8)

Fig. 6 shows the durability decrease of detail B for various coefficients.These analyses relate to our oldest bridges because rivets were the commonest way of linking the parts.It is highly probable that corrosion process was present here due to negligence or inability to renew the protection.

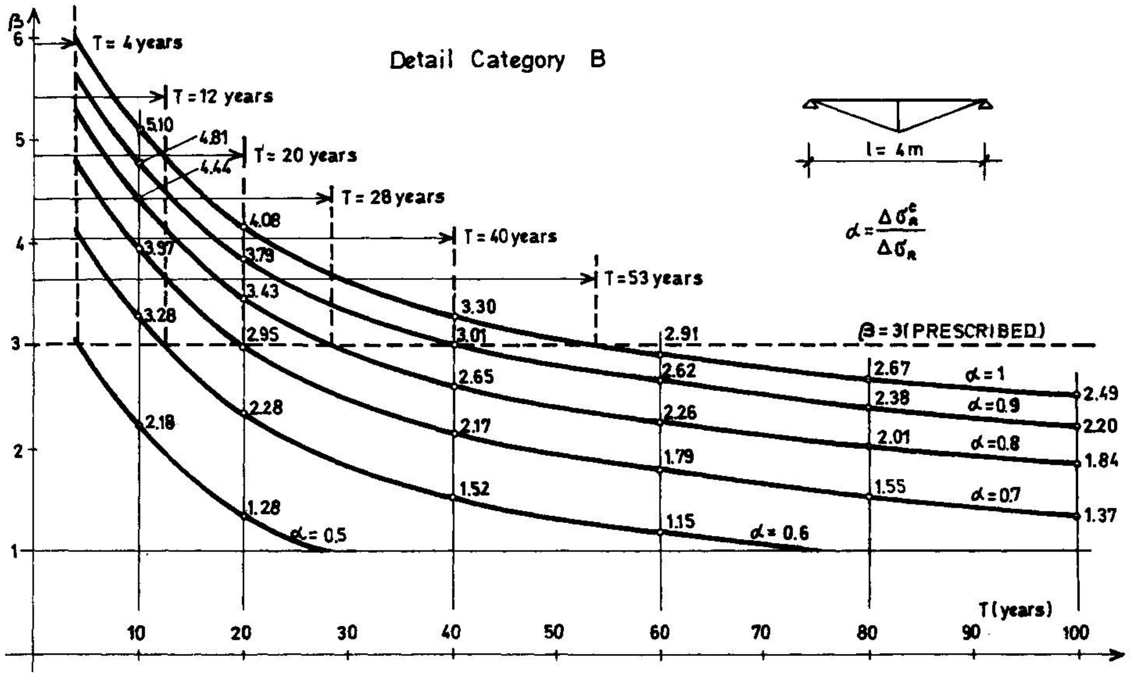

Fig.6 Durability decrease of detail B for various coefficients

The required safety index is $\beta \geq 3.5$ according to recommendations in [4] .Final adoption of safety index is the subject of further discussion.

5.DISCUSSION

The safety of steel structures exposed to corrosion fatigue shows a drastic drop of safety index β .The results of the analyses shown in Table 1 made on a practical example have shown that already after 10 and 50 years of service ,the safety index β can drop far below the recommended values $\beta \geq 3.5$ [4] .In this paper,the required value of safety index will be taken as $\beta = 3$ since there is a tendency to lower the safety index prescribed by ECCS recommendations in [4].In other words,preserving the required safety index,the service life is decreased.In the case of fatigue strength basic variable drop by 50% ($\alpha = 0.5$) [1] in the limit state equation,the service life is greatly decreased,as shown for detail B in Fig. 6.The problem is increased if correlation of basic variables $\Delta\sigma_R^c$ and m is considered.It has,namely,been found that slope regression line shows greater values at lower fatigue strength.

6.CONCLUSION

Corrosion fatigue greatly increases the probability of failure as compared to fatigue without the corrosion process,and the following facts should be noticed on the basis of phenomenological findings:

a) the structure should be designed so that corrosion protection can be regularly repeated and maintained,and every corrosion process should be prevented before it starts.

b) in cases where corrosion has been detected,and the structure has been in service for some time,service life is decreased,and the structure should be inspected more often than is usual for uncorroded structures exposed to fatigue.Obtained safety indices will provide a quantitative estimate of the risk level and compare it to the prescribed value.

The results should start a further discussion of safety problem at corrosion fatigue.The objective of such discussions is to reach decision for codification of the problem.

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