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Synergetic Effects of Environment Actions and Fatigue

Effets synergétiques des influences extérieures et de la fatigue

Synergetische Auswirkungen von Umgebungseinfüssen und der Ermüdung

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SUMMARY

As far as reinforced concrete and prestressed concrete bridges are concerned, the importance of fatigue damage is progressively increasing. In the present paper stochastic action effects are considered together with experimental and theoretical methods for their evaluation. The methods for the assessment of safety for durability are discussed. The influence of corrosion on the laws for constitutive materials is properly taken into account.

RÉSUMÉ

Dans les ponts en béton armé et/ou précontraint, l'importance des dommages dûs à la fatigue est en progression. Les effets des actions stochastiques de même que les méthodes expérimentales et théoriques sont étudiées. L'article traite les méthodes de sécurité, tenant compte d'une manière appropriée de l'influence de la corrosion sur les lois des matériaux constitutifs.

ZUSAMMENFASSUNG

Es wird eine gleichzeitige Zunahme der Schadenfälle durch Ermüdung sowohl bei schlaff bewehrten als auch bei vorgespannten Brücken festgestellt. Sowohl die Betriebsbeanspruchung infolge Zufallslasten als auch die experiementellen und theoretischen Methoden ihrer Auswertung werden betrachtet. Weiter werden die Methoden zur Sicherheitsanalsyse diskutiert; der Einfluss der Korrosion der Materialien wird zweckmässig abgewogen.

1. INTRODUCTION

The present work is part of a systematic research, coordinated between the Universities of Pavia and Rome, devoted to the study of damage and reliability of bridges during their service lives.
First results of the research, limitedly to the case of materials damage due to repeated loads by means of nominal "stress spectra" were presented at the 25th Plenary Session of CEB in Treviso [4]. the research continued on one hand with the execution of field measurements of the response of an highway bridge, called "Pecora Vecchia", to directly get the "stress spectra", on the other taking into account other concurrent sources of damage.
The investigation is here extended to the study of environmental effect over the duration of service life, with special reference to the interaction between reinforcement's corrosion and fatigue strength. A calculation procedure is presented which fits in the philosophy of the "Generalized Design Space", proposed by Tassios [6].

2. STATEMENT OF THE PROBLEM

The durability of a given structure comes from the stability of thermodynamic state functions of its constitutive materials during the design service life.
Setting up calculation procedures for the design vs. durability of reinforced concrete and prestressed concrete bridges asks for evaluating the effect of instability-generating phenomena over the performance of resisting sections.
When progressive damage of materials is not present, the evaluation of ultimate safety of a structural member is expressed by the symbolic relation:

$$S_d \leq R_d$$

where S_d is the effect of the design mechanical action and R_d is the design strength, whose invariability during service life is tacitly supposed as a rule.
When damage of materials is present (corrosion,fire, abrasion,..) the term R_d is modified and subsequent reduction changes the state of safety, in the same manner as S_d would increase.
The quantitative evaluation of damage asks for a suitable mathematical model, able to take into account of the decrease of material performance.
When damage is due to the fatigue of reinforcement, the safety check is carried out by means of well known procedures, using SN law of material and the cumulative curve of stress - stress collective - applying a criterion of cumulative damage, generally the linear one due to Palmgren-Miner.
When steel reinforcement is subjected both to fatigue damage and to corrosion damage, corrosion's effects interact unfavorably with those due to repeated loads.
As it was experimentally shown that S-N curve in this case undergoes some changes, it is possible to evaluate the effect of corrosion on safety using modified S-N curves in the classical procedure for fatigue checking.

3. THE EFFECT OF REPEATED LOADS: THE STRESS COLLECTIVE

In order to evaluate the safety vs fatigue it is essential the knowledge of the cumulative curve of the amplitudes of the stress cycles, sometimes called more shortly "stress collective".
It can be obtained by field observation of the response of existing bridges, as in the case of the "Pecora Vecchia" bridge (on the highway Florence-Bologna near Barberino del Mugello), or it can arise from a code of practice, or it can be evaluated in an analytic way.
In the last case applied load is conveniently simulated, in its essential features, as a random process and the stress collective is evaluated by the standard analysis methods both in the time domain and in the frequency domain.

4. MATERIAL'S PERFORMANCE VS FATIGUE AND CORROSION : THE MODIFIED S-N LAW

In the case of phenomena of wet corrosion, the zone of metal's anodic dissolution is seat of "craters", which are very little discontinuities, which can lead to stress concentrations in the bars and decrease the length of fatigue life of material.
The onset of cracks is favoured by other forms of localized corrosion, and the subcritic crack propagation is facilitated by stress corrosion. When the stress corrosion is excluded, a decrease of the threshold value of the stress-intensity factor is noted (true corrosion fatigue).
As a consequence of corrosion the S-N law of materials is modified.[2]
In the field of mechanical and offshore engineering it is generally acknowledged that the corrosion leads to the progressive disappearance of the horizontal branch of S-N law and also to the variation of the slope of the oblique branch, which becomes more steep.[3]
Nevertheless as the opinions are not unanimous, it seems suitable to deepen the investigation and, in the meanwhile, to proceed cautiously.

5. THE CRITERION OF ACCUMULATION OF MECHANICAL DAMAGE

When the stress collective is not constant, the liner Palmgren-Miner criterion is usually applied to evaluate the damage due to variable amplitude stress cycles.
It is considered an acceptable compromise between the ease of use and the quality of its output informations, and it is consented by most codes [1].
In the presence of corrosion, which can lead to strong variations of materials' properties with an evolution during time different from the case of cyclic loads, the problem of modelling the interaction "corrosion-fatigue" arises. It is possible to deal with it by means of criteria of additivity or synergism.
In this paper, waiting for further studies, the Palmgren-Miner criterion is applied, meanwhile the corrosion-fatigue interaction was directly considered by means of the overall effects observed in experimental tests to get S-N law.

6. THE SAFETY ANALYSIS VS DAMAGE IN THE CASE OF CORROSION-FATIGUE

The safety analysis can be carried out working at Level 1 or at Level 2.
In the first case, Level 1, [1] there are two ways to perform the check. In the first one it is performed comparing the stress due to external loads with the allowable one for corrosion-damaged material. In the second one the cumulative damage is computed and it is compared with the allowable one, that is unity.
In the second case, Level 2, the safety index β is computed: the damage is included in the limit-state surface in the space of design variables by means of a proper S-N law.
The Level 2 is a powerful tool of investigation and is applied hereafter in the following numerical analyses.

7. NUMERICAL EXAMPLES

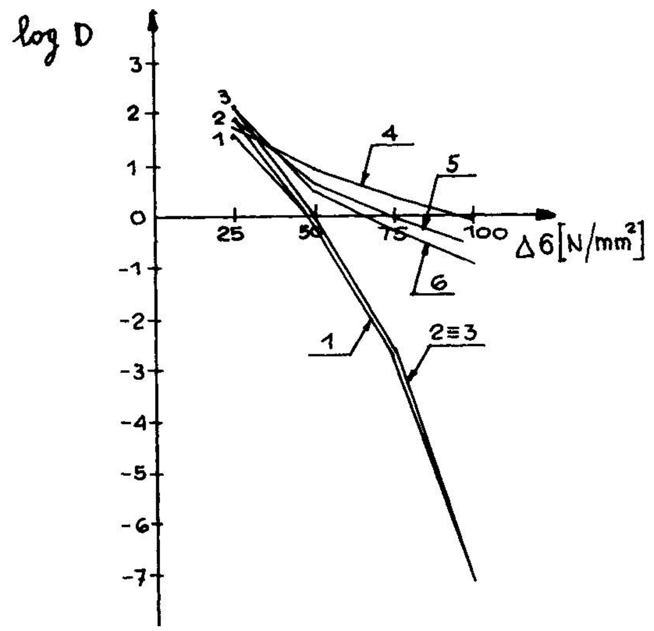
On the basis of previous concepts numerical applications were carried out.
A steel bar belonging to the deck of a prestressed concrete bridge was considered. Its behavior in the case of corrosion-fatigue was compared with the behavior in the case of conventional fatigue.
Corrosion was introduced in computations modifying the S-N law of material: first the horizontal branch was removed, then the slope of the curve was gradually increased, that corresponds to increase the exponent n in the crack growth law : $da/dN = C(\Delta K)^n$.
A parabolic stress collective (in semi-logarithmic scale) was used. This is the case of narrow-band structural response.
Its maximum level was supposed to be constant and equal to 100 N/mm^2.
The total number of stress cycles was modeled as a log-normal random variable, having mean value equal to $100x10^6$ and c.o.v. equal to 0.05.
For the S-N law, a linear trend in logarithmic scale was used, fully described by:

a) ordinate at $2x10^6$ cycles;
b) slope;
c) presence or absence of the horizontal branch after $2x10^6$ cycles.

The ordinate at $2x10^6$ cycles was considered as a log-normal random variable, having c.o.v. equal to 0.10.
Its mean value, the slope, and the presence/absence of the horizontal branch were submitted to a parametric analysis.
Four cases of the ordinate were considered (100,75,50,25 N/mm^2), three values of the exponent of the S-N law (3,4,5) and two cases of the trend of the S-N law for $N>2x10^6$ cycles (presence or absence of the horizontal branch), for a total of 4x3x2=24 cases.
For every case the deterministic damage D was first computed using the characteristic values of random variables (Fig.1), then Level 2 analysis was performed (Fig.2).

8. COMMENTS ON THE RESULTS OF NUMERICAL EXAMPLES

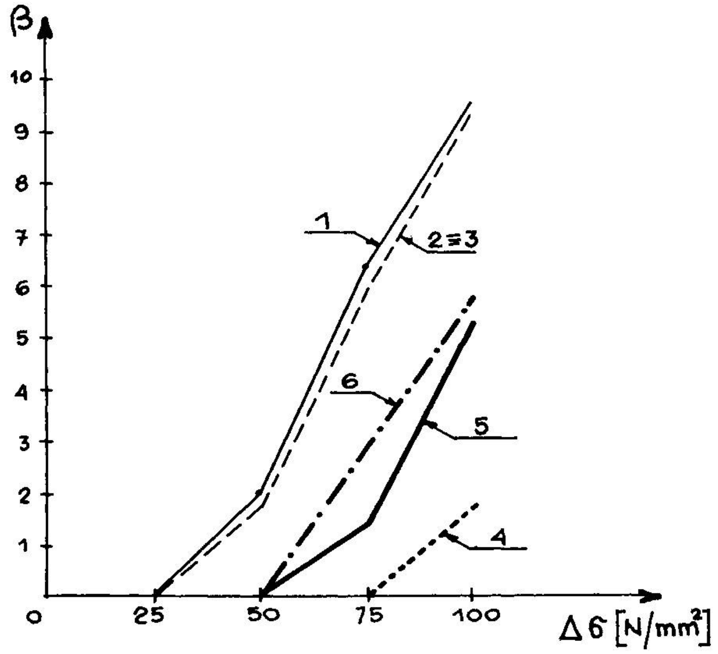
The effect of the presence of the horizontal branch in the S-N law seems to be prevailing over the variation in slope both in the



Parameters of S-N law: $NS^m=C$

Line	exponent	horiz. branch
1	3	yes
2	4	yes
3	5	yes
4	3	no
5	4	no
6	5	no

Fig.1 Deterministic damage D (Palmgren-Miner sums) for the 24 cases considered in numerical examples versus the ordinate of S-N law at $2x10^6$ cycles.



ameters of S-N law: $NS^m=C$

e exponent	horiz. branch
3	yes
4	yes
5	yes
3	no
4	no
5	no

Fig.2 Values of the safety index β for the 24 cases considered in numerical examples versus the ordinate of S-N law at $2x10^6$ cycles.

results of deterministic damage and in Level 2 computations.
In the case of S-N law with horizontal branch computed values of D and β are practically independent from the slope.
On the contrary in the case of S-N law without horizontal branch the values of are not greater than the half of the corresponding ones computed with the horizontal branch, even in the case of the most unfavorable slope.
Anyway the differences between the cases with higher exponents (4 and 5) are smaller than those between the cases with lower exponents (3 and 4).

9. CONCLUSIONS

A methodological approach for the evaluation of safety of bridges exposed to chemical-physical-mechanical damage was described.
In this frame a simplified method was presented which takes into account the corrosion even in the classical time-tension space. It is a first step toward the general approach in the hyper-space of all the design variables.
The numerical investigation performed showed a strong sensitivity of the procedure to the variations of the S-N law of reinforcing steel due to corrosion.
For this influence and on account of the limited number of reliable data on the actual behaviour of reinforcement vs. corrosion-fatigue, it is desirable to promote a systematic theoric-experimental research to get lacking data, as shown by proposed computation procedure.

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REFERENCES

1. CEB-FIP Model Code 1990 (First predraft 1988). Bulletin d'information CEB No. 190, Sept. 1988.

2. Fatigue of concrete structures. Bulletin d'information CEB No. 190, Sept. 1988.

3. JASKE C.E.; PAYER J.H.; BALINT V.S., Corrosion fatigue of metals in marine environments. Springer-Verlag, 1981.

4. MACCHI G.;RADOGNA E.F.;MAGENES G.;MATERAZZI A.L., Probabilistic analysis of safety of bridges versus fatigue. CEB 25th Plenary Session, Treviso, May 12-15 1987.

5. POURBAIX M., Lectures on electrochemical corrosion, Plenum Press, New York, 1973.

6. TASSIOS T.P., Prolegomena to a generalized design space. Bulletin d'information CEB No. 152, April 1984.