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Method for Dealing with Fatigue of Reinforcing Steel in Concrete Codes

Prise en compte de la fatigue des aciers d'armature dans les normes de béton

Berücksichtigung der Ermüdungsfestigkeit von Bewehrungsstählen in Stahlbaunormen

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SUMMARY
In the report basic parameters affecting the fatigue strength of reinforcing steel are revealed. Attention is concentrated on the common presentation of both static and fatigue strength of reinforcing steel in concrete codes.

RESUME
L'exposé met en évidence les paramètres de base influençant la résistance à la fatigue des aciers d'armature. L'accent est placé sur la présentation ordinaire des deux résistances statique et à la fatigue des aciers d'armature dans les normes de béton.

ZUSAMMENFASSUNG
Der Beitrag behandelt den Einfluss der Hauptparameter auf die Ermüdungsfestigkeit von Bewehrungsstählen. Als Diskussionsgrundlage dient die übliche Darstellung der statischen Festigkeit und der Ermüdungsfestigkeit in den Stahlbetonnormen.

1. INTRODUCTION

Many countries have in their reinforced concrete codes introduced the princip of limit states design. This has been done in the CEB model code too. The implementation of limit states design in fatigue problems have however not always been adapted in a proper way. With this I mean a user minded code.

Earlier when codes were usually based on deterministic methods that is methods based on permissible stresses, the fatigue strength was presented by means of a permissable stress amplitude. On the other hand constructions were at that time more massive and their self weight was dominating. In these circumstances the fatigue problems were not usually as important as they might be today.

When drawing limit states codes, the principles that had been used in the permissable stresses codes were often used as a basis for the limit states method. This has been done by more or less artificially changing it to fit the limit states design. The result has been an increasing amount of design work without any improvement of the construction.

In this report a new way of drawing requirements for fatigue design in codes is presented. The intention is that the designer is not caused increased extra work. The princip of limit state design is applied in the same way in the design for both static and fatigue loading.

2. SAFETY PRINCIPLES IN FATIGUE DESIGN

All that is valid for safety consideration in common is also valid in fatigue loading. The difference lies in the combination of time and loading in material parameters ie. in the characteristic material values. The reduction of characteristic stresses as a function of time and number of loading cycles must be taken into account.

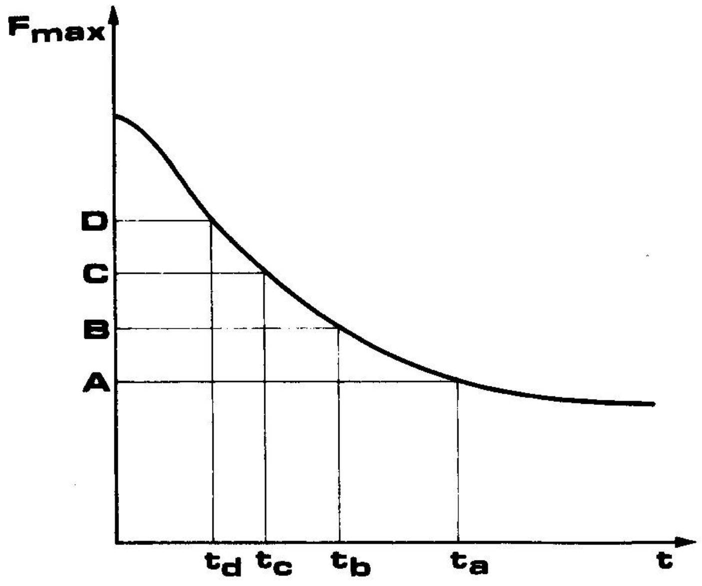

Fig. 1 Schematic limit states as a function of time

The problem have to be simplified by assuming the loading cycles to be of constant size. These constant loading cycles are presented in figure 1 by horizontal lines A, B etc. For example if the loading cycles are of size C, then the effective life time of the construction in question is t_C. In this way the curve is drawn. The curve resembles a Wöhler curve, but is a curve showing the effective life time not for the material but for the construction or a part of it.

The level of the minimum stress in the reinforcing steel is one important determining parameter too. In order to take this into account figure 1 must be expanded in space by introducing a new dimension, the minimum stress level, as has been done in figure 2.

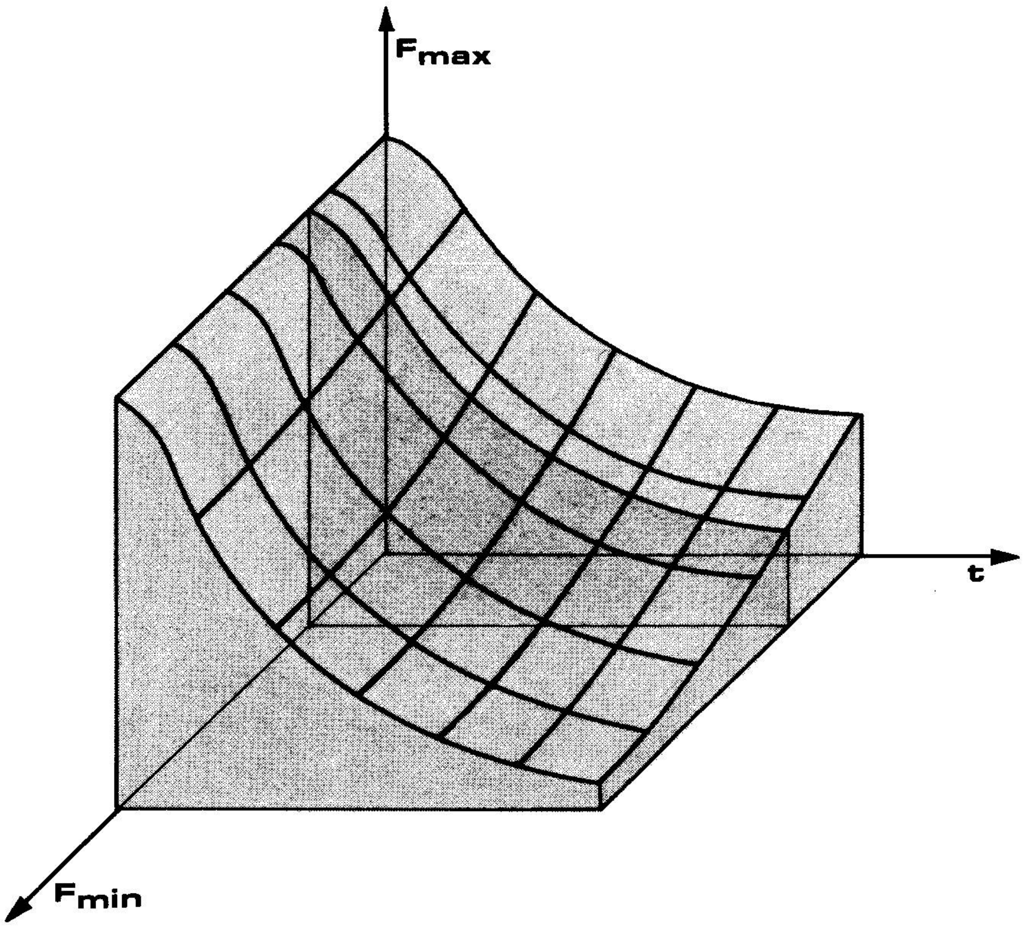

Fig. 2 Schematic limit states as a function of time and F_{min} and F_{max}

By taking the above mentioned things into account in code-writing the problem of fatigue design by limit states can be presented in a simplier way. The simplicity required by the codes can be achieved by simplifying figure 2 by cutting the three-dimensional figure from a point which can be considered as not normally exceeded.

The smooth curved lines in figure 2 are at the same time modified into straight lines in order to additionally simplify the figure. This results in figure 3, where level A corresponds to static loads and level B to loads causing fatigue.

Level A can be used up to 10^4 loading cycles as supposed in figure 3. 10^3 has also been suggested as the limiting value, but this value is considered to be too low as it increases considerably the number of situations when the designer has to take the fatigue into consideration as there are quite a lot of constructions which during their supposed life time achieve more than 10^3 but less than 10^4 loading cycles.

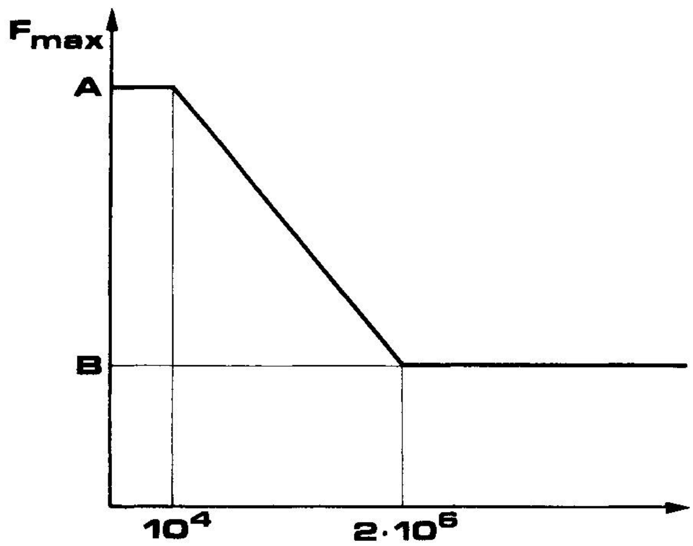

Fig. 3 Simplified effective life of the construction

The reduction of the overall safety of the construction due to considering 10^4 loadings still as a static loading can be considered to be covered by the reduced probability for loads to appear 10^4 times compared with the probability of appearing only one time.

Level B can be used without restricting the number of loading cycles. The values between these two levels can be interpolated linearly. With this modification of figure 2 the same design method can be used for loads both in static and fatigue design. The difference is that the loading parameter F becomes dependant of the amount of loading cycles $F\{N\}$ and the material parameter f becomes respectively dependant of both the number of loading cycles and the minimum stress $f\{N,\sigma_{min}\}$ (or the stress amplitude $f\{N,\sigma_A\}$).

The point where figure 2 is cut must be selected on the basis of two things; the highest commonly in practice used minimum stress level and the suitable reduction of material stress amplitude due to changing the minimum stress level from zero to the above mentioned highest commonly used level.

3. CHARACTERISTIC MATERIAL STRENGTH

The characteristic material strength is determined in such a way that it corresponds to results obtained by test specimens which are designed according to averige construction elements. Such elements are for example ordinary straight beams. When elements of other format, for example in some way bent or twisted ones are used, consideration must be taken to the effect of the size and format of the actual construction compared to the test specimen.

Characteristic material strength can be given in form of a Wöhler curve by selecting some adequite cutting point in figure 2. In this article I have chosen the cut at a point where the minimum stress level is 30 % of the yield stress of reinforcing steel.

For special cases, when the characteristic strength as a function of minimum stress level is needed, can in an explanatory note or in design handbooks a modified Goodman diagram (standardized to correspond to a certain number of loading cycles, usually $2 \cdot 10^6$) be given.

In order to be able to use the same load factors for both static and fatigue loadings, it is not convinient to give the characteristic material strength alone without corresponding material safety factor. They have to be linked together in one figure.

4. MATERIAL SAFETY FACTORS

The starting point in choosing material safety factors is the load safety factors given in loading codes. These vary in national codes for self weight between 1,0...1,3 and for variable load between 1,3...1,6. In the following it has been assumed that these factors are 1,2 for self weight and 1,6 for variable load.

In fatigue loading the load safety factors must be reduced as the probability for the design load to appear many times in order to cause fatigue is smaller than to appear only one time. It is however more convinient to reduce the material safety factor than to reduce the load safety factor, as the latter method causes the designer to recalculate the design loads after finishing the design for static loadings.

By reducing the material safety factor as the number of load cycles increases it is possible to present the design strength of the material in one and same figure both for static and for fatigue loadings. The safety factors can be adapted in such a way that on a simplified Wöhler curve on level A the safety factors are the same as in static design including the variation due to safety classes, quality control, workmanship etc., but on level B the factors are all equal to 1,0 as the fatigue loading includes more uncertain elements and cannot be presented in such refined system as for static loading. With the above mentioned principles figure 4 is drawn.

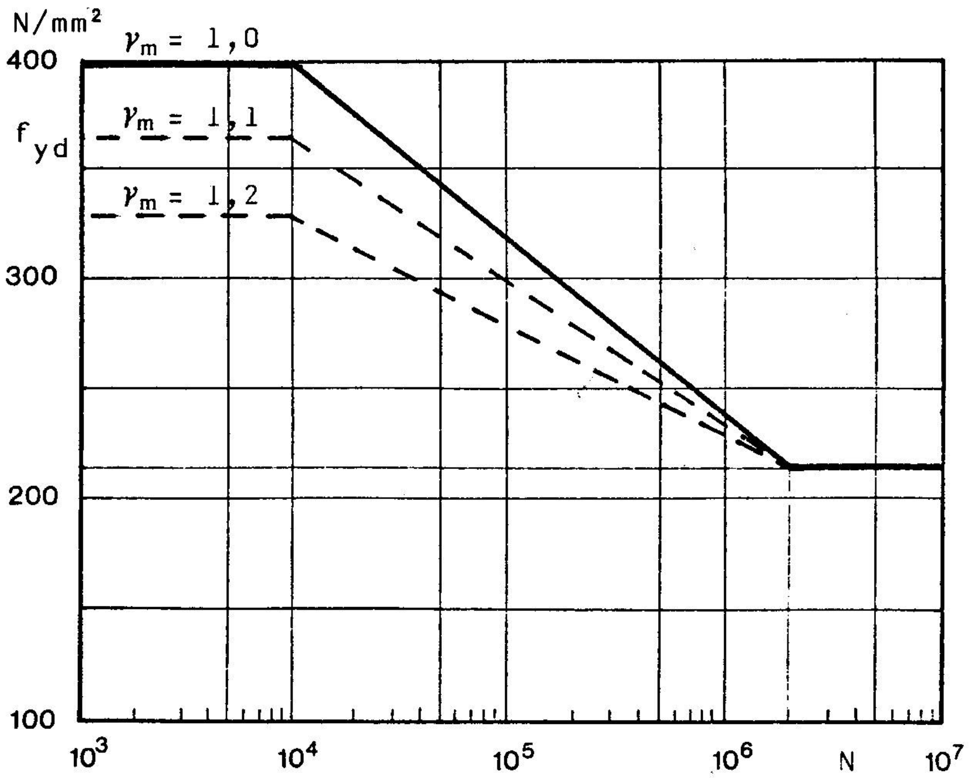

Fig. 4 Material parameter supposed to be presented in codes

For such situations, where the minimum loading exceeds 30 % of the yield stress a simplified modified Goodman diagram can be given in some explanatory publication or in design handbooks as mentioned above. One possible simplified Goodman diagram is presented on next page in figure 5. The figure contains two alternative lines i and ii. The first line i gives more exact information, but on the other hand is somewhat more complicated as line ii.

Bearing in mind that codes ought to be as short and pithy as possible and cover only normally appearing design situations, it is not necessary to go into detailed refined text. It is not the purpose of a code to give the designer all the information that he might need in his practice. The code is in a simple form written common rules between the designer and the authorities. In code writing one has to assume that the designer can handle more complicated design situations with the help of his education and available technical handbooks.

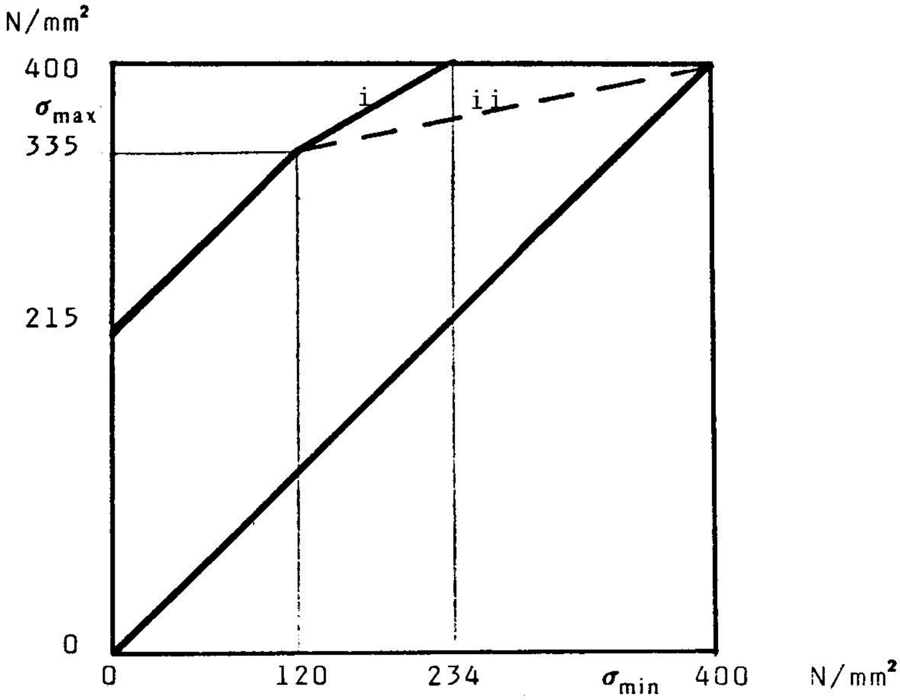

Fig. 5 Siplified modified Goodman diagram with two alternatives i and ii.

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