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Brief Overview of ASCE-Related Fatigue Studies in USA

Bref aperçu des études sur la fatigue aux USA en relation avec l'ASCE

Kurze Übersicht der Studien über die Ermüdung in den USA in Zusammenhang mit dem ASCE

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SUMMARY
The paper presents a review of ASCE participation in fatigue studies and some comments are made on the current U.S. fatigue research activity nationally. Future needs, directions and possibilities for research are also discussed.

RESUME
L'article donne un aperçu de la participation de l'ASCE aux études sur la fatigue et fait quelques remarques au sujet des recherches sur la fatigue actuellement en cours aux USA. Besoins futurs, orientations et possibilités pour la recherche sont également discutés.

ZUSAMMENFASSUNG
Der Artikel gibt einen Überblick über die Teilnahme des ASCE in Ermüdungsuntersuchungen und macht einige Bemerkungen über die laufende aktuelle Ermüdungsforschung in den USA. Zukünftige Bedürfnisse, Richtungen und Möglichkeiten der Forschung werden diskutiert.

INTRODUCTION

This author has been appointed as the official representative of the American Society of Civil Engineers (ASCE) to the IABSE Colloquium on "Fatigue of Steel and Concrete Structures", and this brief overview is made to acquaint the readers with the status of fatigue studies in the United States. The task is made difficult by two factors : 1) the author is not a specialist in the study of fatigue problems, and 2) the ASCE is not the main focus of research in this field in the U.S. However, in such a Colloquium where experts from around the world come to share the results of their special efforts, it may be interesting to see how an outsider views the field.

ASCE COMMITTEE ACTIVITIES

There are two committees specifically charged with fatigue studies within the ASCE technical committee structure ; both are part of the Structural Division :

1) Fracture and Structural Fatigue (within the Technical Committe on Metals) ; chairman Prof. Pedro Albrecht.

2) Fatigue and Fracture Reliability (within the Technical Committee on Structural Safety and Reliability) ; chairman Prof. Paul Wirsching.

Total membership of the two committees is 40, with a ten percent overlap in members. The primary function of ASCE technical committees is dissemination of current information (conference sessions, papers and State-of-the-Art reports), stimulation of research, and implementation in design practice. The main difference between the two ASCE fatigue committees is one of emphasis : one is concerned with all aspects of metal fracture and fatigue, especially the evaluation of the test data in order to develop design methods, while the other is involved in the development of probability-based design and analysis methods. Such committees are a good thing, representing the mature stage of development (education, evaluation, codification, etc.), but they are not, as a group, on the cutting edge of research even though individual members themselves are operating at that level.

RECENT ASCE PAPERS ON FATIGUE

A review of the ASCE Publications Abstracts for the period 1978 through 1981 revealed the rather small number of 25 papers, indicating that ASCE is not a very active outlet for fatigue and fracture studies. Nine of the papers dealt with experimental investigations, the remainder being about equally divided between general papers, design methods, theoretical analyses (including three papers on reliability topics), and evaluations of specific field failures.

RESEARCH DIRECTIONS

Looking as a relative non-expert on the scene of fatigue and fracture research in the U.S., it would seem that far too little effort is being extended on these problems for civil engineering structures. Considering the sophistication of the analytical techniques which are available, the importance to our economy to solve the problems, the availability of advanced laboratory and field testing equipment, and the advances made in other fields (e.g., aircraft and machine design), it appears that more should be done. To be sure, work in going on on fatigue problems which have occured in real structures, and there is fundamental research being conducted on corrosion fatigue and on various details and materials pertinent to bridges and off-shore platforms. An exciting area of research which has as yet received far too little application in fatigue and fracture is the use of the methodology probability-based design. Some efforts in this direction are underway, but support for such work seems to be inadequate. In the opinion of this author, fatigue and fracture research for civil engineering structures on both the fundamental and the applied side is grossly underfunded, resulting in a possible decline in solutions to many of our pressing engineering problems.

However, it is not necessary to base this paper on a pessimistic note. Traditional research on fatigue has, is, and will continue to provide basic data on various materials and details with which we are concerned. This is important work and should continue, but in a new direction : to provide meaningful data for use in methodologies of design yet to be completely defined. Many possibilities for these analytical methods are being investigated from various points of view : first-order, second-movement probabilistic methods, various approaches involving ideas of damage, and the just evolving methodologies using fuzzy logic. In the opinion of this author it is imperative that first a commonly agreed upon rational model, or a set of interrelated models, be developed and tested for use in solving fatigue and fracture problems. Laboratory and field research should then be performed to provide the necessary data so that the models can be implemented for use in practice. While such a scheme is not formally operative at present, there are still a number of developments underway which leads to the hope of the emergence of a rational and consistent method in the near future.

Fatigue Design Concept of the ECCS

Concept du dimensionnement à la fatigue de la CECM

Konzept des Ermüdungsnachweises gemäss der EKS

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SUMMARY
The scope and aims of the European Convention for Constructional Steelwork (ECCS) are indicated, its technical activities are outlined, the interactive efforts with other organizations and its contribution to the development of Eurocodes 1 and 3 are shown. The main portion of the paper is devoted to describe the major options retained for the ECCS Recommendation for the Fatigue Design of Structures: stress range concept, parallel S-N curves, cumulative damage rule, fatigue load models for highway and railroad bridges, safety concept.

RESUME
Cet exposé résume les différents domaines d'activité de la Convention Européenne de la Construction Métallique (CECM), ses buts, ses activités techniques, ses actions réciproques avec d'autres organisations et sa contribution au développement des Eurocodes 1 et 3. La majeure partie de l'exposé est une description des principaux paramètres retenus dans la Recommandation de la CECM, soit: différence de contraintes, courbes de résistance à la fatigue parallèles, lois du cumul des dommages, modèles de charges pour ponts-routes et ponts-rails, concept de sécurité.

ZUSAMMENFASSUNG
Umfang und Ziele der Europäischen Konvention für Stahlbau (EKS) sowie ihre technischen Tätigkeiten, die interaktiven Bemühungen mit anderen Organisationen und ihr Beitrag zur Entwicklung von Eurocode 1 und 3 sind dargestellt. Im weiteren werden die wesentlichen Parameter umschrieben, welche für die EKS Empfehlung gewählt wurden: Konzept der Spannungsdoppelamplitude, Parallelität der Ermüdungsfestigkeitslinien, kumulative Schädigungshypothese, Lastmodelle für Strassen- und Eisenbahnbrücken, Sicherheitskonzept.

1. SCOPE AND AIMS OF ECCS

Founded in 1955, on the initiative of Switzerland and France, the European Convention for Constructional Steelwork comprises at present, 15 European member countries and two non-European associate member countries, Japan and the United States of America.

Among its aims, which were defined in its constitution over a quarter of a century ago, the most important are :

- the undertaking of common research and investigation leading to the publication of results in a form directly applicable by designers and structural steel manufacturers for the advancement of the steel construction industry,
- the preparation of recommendations and guidelines with a view to an international harmonisation of standards and codes in the field of steel construction,
- the promotion of coordination and co-operation with other European and international organisations concerned with construction, standardisation and testing of materials.

Since its very beginning, the ECCS has worked on technical matters relevant to the quality, safety and economy of steel construction. This still constitutes the main part of its activity today.

Among the main considerations that have guided ECCS activities are :

- the conviction that technical progress leading to up-to-date methods of design and fabrication is the key to efficient and economic structures,
- the awareness of the need for international, unified rules in view of the increasing inter-penetration of markets,
- the wish to put together the experience, knowledge and working capacity of experts from various countries in order to obtain the most rational recommendations in the field of structural design.

In this perspective technical committees and working groups have been formed to deal with specific subjects. Their members are experts chosen from the professions, the academic or research wórld and in many cases, government departments. These committees have always worked together most successfully and responded to the demands of our time.

It would not be in line with the theme of this Colloquium to give a complete description of the activities of ECCS in the technical field. Therefore, only a few of its main objectives and achievements shall be mentioned before presenting the ECCS involvement and activity on fatigue.

2. TECHNICAL ACTIVITIES OF ECCS

The following lists the ECCS Technical Committees that are actively dealing with structural problems and related matters :

TC1 Structural Safety
TC2 Aluminium Alloy Structures
TC3 Fire Safety
TC6 Fatigue
TC7 Cold-Formed Thin-Walled Sheet Steel in Buildings
TC8 Structural Stability
TC10 Bolted and Welded Connections
TC11 Fabrication and Erection
TC12 Wind
TC13 Seismic Actions

As an example, the field of structural stability, which is of fundamental importance for the study of steel and other metal structures may be mentioned. To put an end to the enormous discrepancy which existed between the column curves of various countries, a large experimental (more than 1'000 columns) and theoretical research programme was carried out by TC8 with the aim of obtaining the best possible unified treatment of the problem. The results were presented at the International Colloquium on Column Strength, sponsored by IABSE, ECCS, CRCJ and SSRC, in Paris in 1972 [1] and in the Introductory Report to the Second International Colloquium on Stability [2] Tokyo 1976, Liège, Washington, Budapest 1977). Three noteworthy aspects of the whole research, that are also common to other ECCS programmes, are :

- for the first time a probabilistic approach has been adopted for a major experimental investigation on structural stability,
- the strict international co-operation between laboratories of eight countries under the supervision of the ECCS Technical Committees,
- the success of the whole co-operation as shown by the improvements in most national codes.

The ECCS technical activities have also covered certain fields that are not specifically related to steel structures, but nevertheless relevant to structural design. The best example is the preparation and the publication of "The Recommendations for the Calculation of Wind Effects on Buildings and Structures" [3] which is a most up-to-date document on this matter. It contains a specially studied wind map of Western Europe, which ignores national borders, as wind does, and has a full set of aerodynamic factors. An ISO Recommendation on wind loading, currently under preparation, follows closely this Recommendation, as do various National Standards also under preparation.

These two examples, stability and wind, illustrate the type of activities of ECCS and their influence upon national and international codes or recommendations.

Most of the studies carried out by ECCS have been included in the "European Recommendations for Steel Construction" published in 1978 [4] in the format of a practical code with commentaries on each article. These recommendations had a great influence on the preparation of many national codes and formed the basis of the "European Code for Steel Construction" (Eurocode 3). This has been prepared in the framework of the harmonisation of codes for structural design promoted by the Commission of the European Communities. In connection with this I would like to mention another ECCS publication "Composite Structures" [5] prepared in the format of a model code by a Joint CEB, ECCS, FIP committee which will certainly be the major reference for the "European Code for Composite Construction" (Eurocode 4).

3. ECCS RECOMMENDATION FOR FATIGUE DESIGN

The 1978 ECCS Recommendations [4] covered only statically loaded structures. A great effort with regard to fatigue was therefore still necessary on a European level to include bridges, crane girders, and other structures subjected to fatigue. A new technical committee, TC6 "Fatigue", was founded in 1979 under the chairmanship of Prof. Dr. Manfred A. Hirt, Switzerland. The task of this committee is to harmonize the available modern concepts, to have a common set of rules applicable to various types of structures and to have a philosophy of safety in line with statically designed structures.

When this new committee started its work, a first proposal [6] was already available that had been prepared by committee TC9 "Welded Connections". This proposal was restricted to welded elements, but it included the results of much of the modern research. It had not yet obtained general acceptance mostly because of a large discrepancy in the state of knowledge and historically motivated differences in points of view of some member countries.

Committee TC6 has already come up with a new proposal [7] retaining many ideas of the previous document, adding new elements, and taking advantage of the progress achieved in other organizations, such as UIC, IIW, and a few national codes. This international co-operation, which is instrumental from the point of view of achieving harmonization, acts mainly as a means to dispense information on an international level. All this ensured that the new document [7] would achieve wide acceptance. In addition, it was the basis for the chapter on fatigue incorporated in the first draft of Eurocode 3 [8].

3.1. Scope and goals of the fatigue recommendation

The aim of the fatigue recommandation is to give detailed information not only on the fatigue strength of welded and bolted structural details but also to include a basic safety concept as well as load models that can be used for general fatigue evaluations. It is obvious that this is a very ambitions intention since not all information needed is available to date. Therefore, the recommendations are divided in two distinct parts : the basic chapters and the appendices. The chapters contain the major rules and clauses based on generally accepted concepts where as the appendices provide detailed information and numerical values. These appendices may be adapted more easily and more rapidly with improved knowledge.

It is beyond the scope of the present paper to describe in detail all clauses of the ECCS Recommendations for fatigue design, so only some of the basic concepts shall be mentioned. Much input information was obtained from References [9] [10] [11], as well as from various working documents prepared by members or guests of Committee TC6.

It might be interesting to add that committee TC2 "Aluminium Structures" participates actively in the preparation of these fatigue recommendations through its TWG 2.4. The main purpose of this co-operation being to adopt, as far as possible, the same concept for aluminium structures.

3.2. Constant amplitude fatigue strength

After almost a century of research in this field, it was only around 1970 that, for the first time, the results of statistically evaluated test data of a comprehensive study were published [12]. These were immediately introduced in some USA specifications. The results were based on beam tests and provided a new insight into the fatigue strength of structural elements. In particular, it was found that :

- stress range is the governing parameter for the fatigue life of structural details,
- the type of structural detail used is of prime importance for the fatigue strength,
- minimum stress, stress ratio, and even grade of steel do not significantly affect the fatigue strength, in the vast majority structural applications.

In the wake of these findings, many analyses and re-analyses of the USA and additional European data yielded similar fatigue strength curves. Everybody believed his curves to be the true ones and it became readily apparent that no harmonization was possible. It is to the merit of Prof. Siebke to have proposed, mostly through his work in the UIC code writing, a different approach : define a set of equidistant fatigue strength curves which can accommodate fatigue test data as well as national differences of workmanship or even interpretation or classification of structural details.

At the present time, the curves shown in FIGURE 1 are proposed to become the "European Fatigue Strength Curves" similarly to the buckling curves. It is most fortunate that IIW [12] has opted to include these same curves, permitting thus an international agreement.

The classification of the structural details has yet to be finalized and will probably follow quite closely the proposal by IIW. However, it is the aim of ECCS to show the structural details in such a way that the designer realizes rapidly whether a detail is good or bad, and what corrective measures have to be taken to improve a bad detail. The structural details will be grouped as welded or non-welded and the former divided into non-load and load transmitting welds. Such a presentation is schematically shown in FIGURE 2. In short, the designer should be motivated to design and not to go into extreme lengths of sophisticated computations.

3.3. Cumulative damage rules

It is proposed that stress-time histories be evaluated using Rainflow counting or any other method which permits adequate definition of stress ranges. Cumulative damage is calculated according to Palmgren-Miner's rule and based on the fatigue

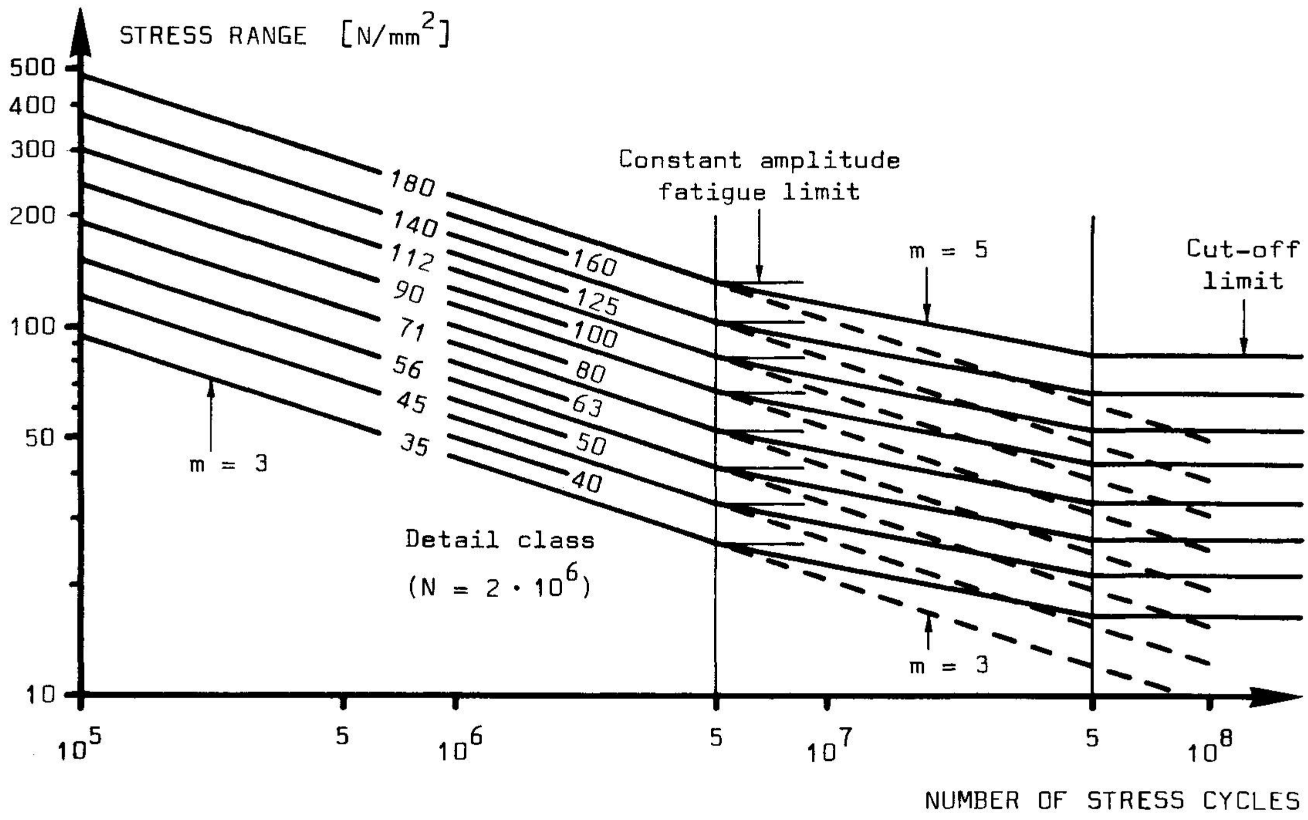


FIGURE 1 : ECCS proposal for "European Fatigue Strength Curves" representing mean minus two standard deviations [7].

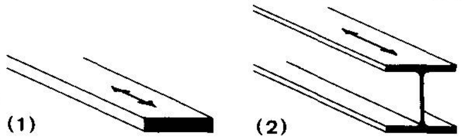
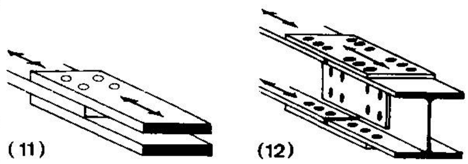
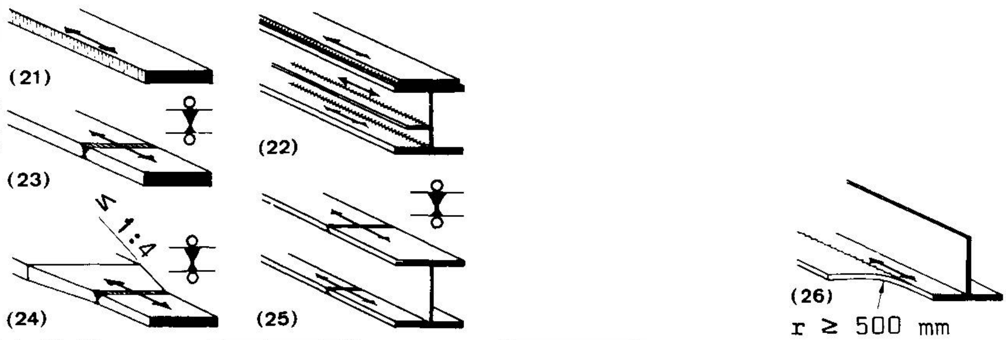
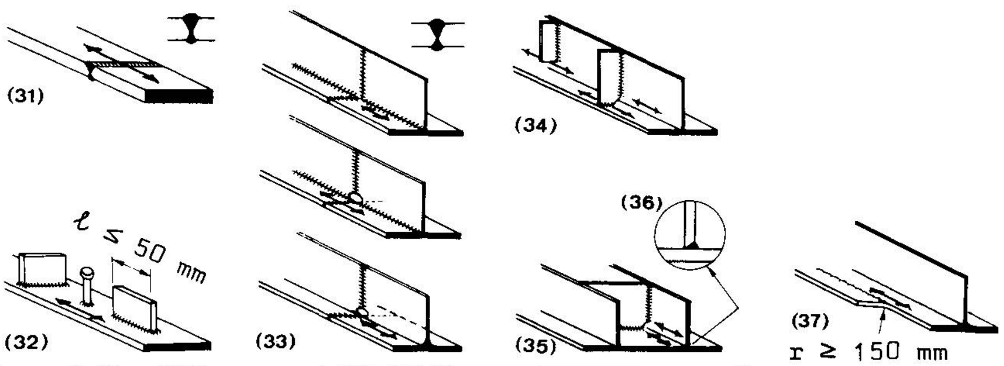
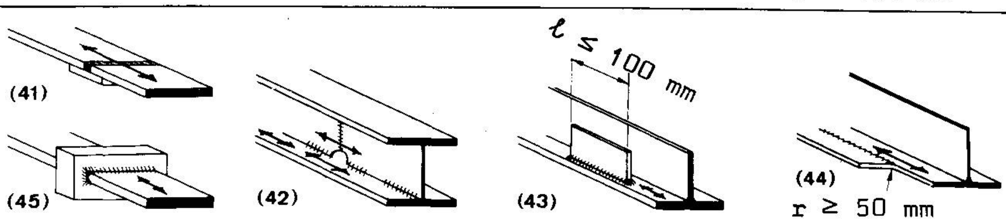
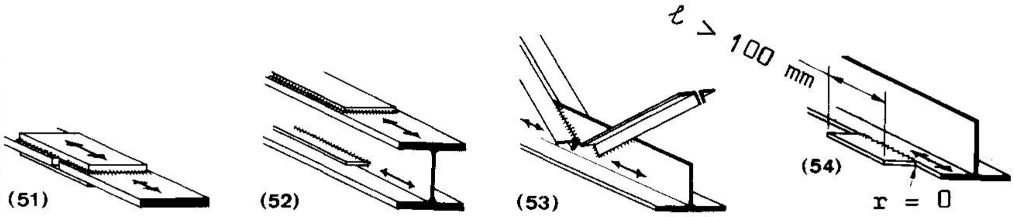
CATEGORY	CONSTRUCTIONAL DETAILS The arrow indicates the location and direction of the stresses, acting in the base material, that have to be determined for the calculation of the stress range.
A_0	
A_1	
B	
C	
D	
E	

FIGURE 2 : Example for the classification of typical constructional details in fatigue categories [10].

strength curves defined in FIGURE 1. One should note that the fact of having parallel lines greatly simplifies the designer's work.

If all stress cycles fall below the fatigue limit, it is assumed that no fatigue damage will occur. When the spectrum is such that a part of it lies above the fatigue limit, three approximations are possible :

1.- A simplified approach, being on the safe side, which disregards the fatigue limit and uses fatigue curves extended below the limit.

2.- A modified curve, having a slope of 5, below the fatigue limit, which may be used for this part of the spectrum.

3.- Fracture mechanics methods may be used.

It should be stressed that fatigue strength and cumulative damage are only a part of the problem and thus the simplifications given are acceptable. This becomes even more obvious when considering all the other assumptions with regards to loads and impact factors.

3.4. Fatigue loads

The description of loads has long been a neglected part of fatigue codes. In fact, much more research has been done, and is still being done, to establish strength rather than investigating loads and load effects. This, incidentally, is equally true for statically loaded structures. Nevertheless it seems possible to describe generalized load models for railway bridges, highway bridges and crane gantry girders, among others. More information on this will be provided in other sessions of this Colloquium.

It should be recognized that it is much more sensible to define loads and load models instead of directly imposing stress range spectra. In fact, a given load, say a train, will cause completely different stress spectra when crossing long or short span bridges. Thus for any given bridge, different stress spectra will be obtained for different structural elements. The same is true for highway bridges where sometimes the total vehicle weight, or the axle loads, or a combination of both become dominant.

All this does not imply that the engineers have to calculate stress spectra in all circumstances. It is feasible to give standard correlation functions for typical influence lines of typical structures based on standard statical analysis. This work can be done, and has been done, in different national codes [9] [10] and the results are available.

3.5. Safety concept

This is probably still the most difficult problem of modern fatigue codes. Much research has recently been done in the fields of safety and reliability of statically loaded structures. However, only a little information is available for structures under fatigue loading. Early attempts to solve the problem have used statistical distributions of equivalent stress ranges and fatigue strength. Recent studies should provide us with additional information to specify numerical values for load and strength factors applicable for fatigue design.

4. CONCLUSIONS

The present draft of the ECCS fatigue recommendations [7] will be modified in some details. However, the main concept can probably be retained since it represents a general concensus of most of the advanced research groups and code writing bodies. ECCS would like to express its thanks to all national and international organizations for their willingness to co-operate and to harmonize their concepts. Special thanks are extended to the many persons inside and outside of ECCS who have spent much time and effort to improve the quality of the recommendations. It is hoped that the final draft will be available by the end of 1982.

It is of prime importance that Europe is not flooded with a multitude of different, or different looking codes, edited by various groups or organizations. The task of design engineers, working at home or abroad, has to be simplified. One way of achieving this goal is to give one, and only one set of rules. We hope that IABSE may continue to provide an adequate platform for discussion which will eventually lead to the desired harmonization.

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Fatigue of Concrete Structures

Fatigue dans les structures en béton

Ermüdungsverhalten von Betonelementen

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SUMMARY
The paper presents a general view of fatigue failures of concrete structures and discusses the object and scope of RILEM activities. The RILEM Committee report on "Long Term Random Loading" of concrete structures, completed in 1981, is summarised. This includes comments on fatigue life, fatigue strength, accumulated damage, analytical service-life functions and the results of both experiments and analyses.

RESUME
L'article présente une vue générale des cas de rupture par fatigue des structures en béton et discute les buts et la portée des activités de la RILEM. Le rapport du comité de la RILEM sur "les charges de longue durée aléatoires" dans les structures en béton a été achevé en 1981 et est résumé dans cet article. Il traite de la durée de vie, de la résistance à la fatigue, de dommages accumulés, des fonctions analytiques de durée de service et des résultats tant expérimentaux qu'analytiques.

ZUSAMMENFASSUNG
Ein allgemeiner Überblick über das Ermüdungsverhalten von Betonelementen ist in diesem Artikel gegeben; zugleich werden die Zielsetzungen und der Umfang der Aktivitäten des RILEM vorgestellt. Der Kommissionsbericht "Long Term Random Loading" von Betonelementen, welcher 1981 fertiggestellt worden ist, wird in zusammengefasster Form präsentiert. Dieser Bericht enthält Kommentare über das Ermüdungsverhalten, die Ermüdungsfestigkeit und die Schadensakkumulation sowie über analytische Funktionen für die Lebensdauer. Zudem werden Resultate von Experimenten und Analysen diskutiert.

1. INTRODUCTION

Fatigue of concrete structures never created the widespread interest as has been the case for steel structures. While fatigue failures of steel structures have caused catastrophic failures, no such fatigue failure has been reported for concrete structures, although there have been speculations in some cases whether the failure might be due to fatigue. Minor damage to concrete supporting machinery is not included. Research on concrete, however, indicates that the effect of repeated loading may be more damaging to concrete structures than realized at present. The interest for fatigue of concrete structures has also increased in recent years because of a higher degree of utilisation of the capacity of the materials, which increases the stress-variations and brings the working stress range closer to the failure stress.

2. FATIGUE PROPERTIES OF REINFORCED CONCRETE

The fatigue properties of reinforced concrete are related to the component materials, reinforcement and concrete. The bond between the components may be the critical factor for the fatigue life of a structure. During fatigue loading the structure undergoes local and overall deformations which leads to a continuous redistribution of stresses. In a structural member, concrete in compression may be critical at static load and at a few repeated loads, while many repeated, smaller loads relieve the concrete stresses and the final failure may be due to fatigue of reinforcement |19|. This illustrates the complexibility of the problem, which is significantly increased by the fact that the variable loads are usually stochasticly distributed in time.

From experimental investigations, considerable information has been achieved on the fatigue of steel and also steel reinforcement. Some knowledge is also available on fatigue of concrete. Several proposals for mathematical expressions of the fatigue life have been presented. Realizing that these formulae give inaccurate results, new research programs have been initiated to find better correlation between theory and test results. Gradually, better results have been obtained for the components of reinforced concrete. These results from research on steel bars and plain concrete are basic factors in systematic investigations of the combined response of the the components of a structural member subjected to fatigue loading. Such comprehensive investigations are not carried out to such an extent that the lifetime of a structure can be predicted with a degree of accuracy that may be said to be satisfactory.

3. FATIGUE FAILURE MODES OF STRUCTURAL MEMBERS

Shear failure may occur with the same mode of failure as observed at static tests. However, in some cases, beams which have failed in shear after repeated loadings would have failed in bending under static load, |1,22|. Fig. 1 compares test results of beams without shear reinforcement subjected to a dominant bending moment or shear force.

Interesting observations are indicated in |2|. A beam is such loaded that the shar force is approximately constant between supports and loading points. The shear reinforcement is not strained according to the shear force, but according to the crack-formation. Repeated loadings lead to the shear force, but according to the crack-formation. Repeated loadings lead to a greater crack zone and wider cracks. The strains in the stirrups increase irregulatly. Further loadings increases the bond slip, which results in greater deformations. Finally the compression zone of the concrete may fail, or it may happen that the repeated stresses in the stirrup bends have increased so that the stirrups fail in fatigue, or the wide cracks crossing the longitudinal bars introduce local repeated bending of the bars until they fail. All these failure developments have been reported.

Bond properties are also of major importance at overlapped spliced bars and for anchoring capacity of bars. Again there are two aspects involved: bond fatigue capacity and deformations resulting from the repetitions of loadings. The latter may cause fatal stress-redistribution in the member. Some observations from investigations |3| are illustrated in Fig. 2.

The fact that we are far from having a general, reliable, analytical model for estimating the fatigue life of a reinforced concrete structure, should not prevent steps towards such a model. A model requires knowledge of the properties of each of the components of the composite reinforced material under repeated random loadings. In addition, the interaction properties of the components are needed. Deformations during the loading period and the fatigue capacity are equally important.

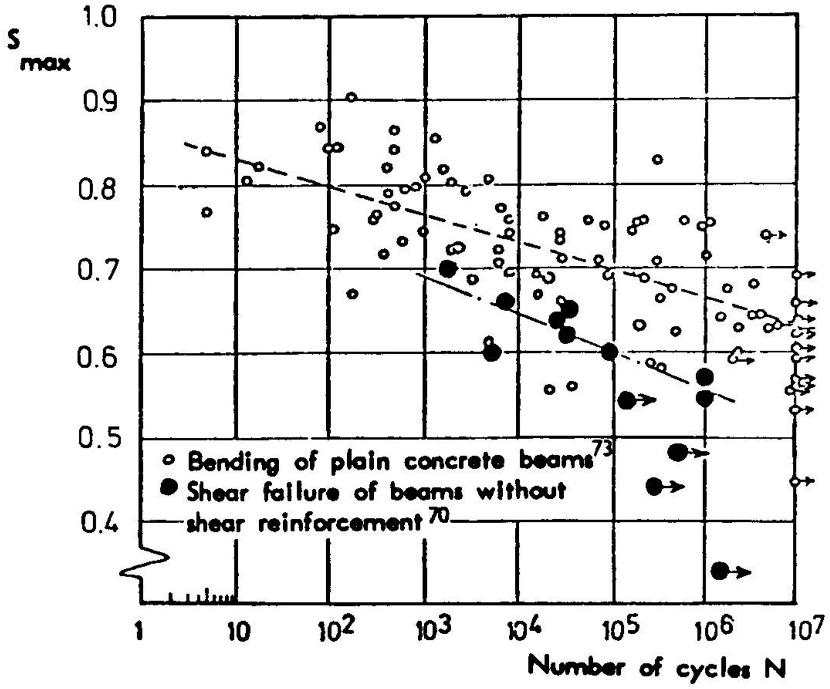


Fig. 1 Comparison between strength in shear of beams without shear reinforcement and fatigue strength in bending of plain concrete beams

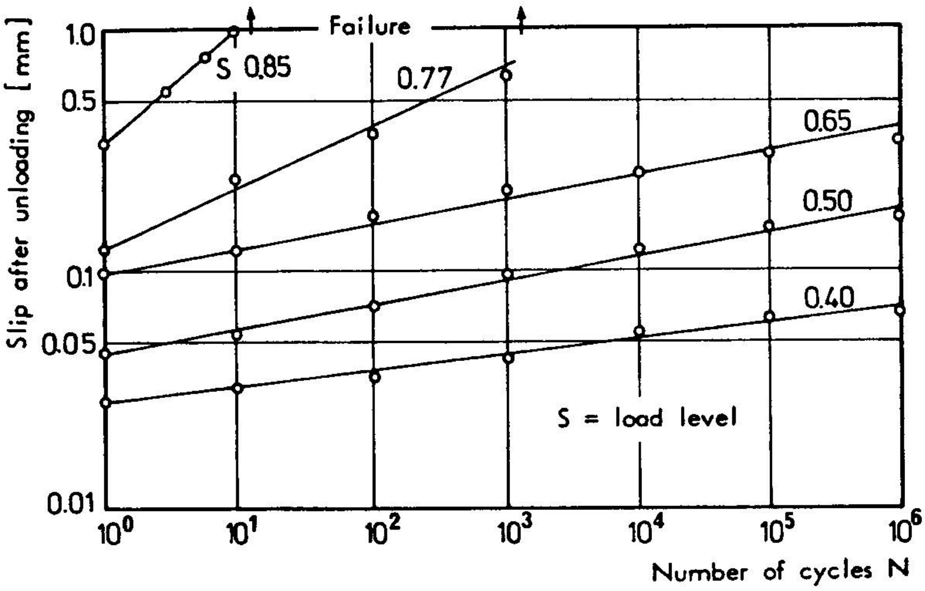


Fig. 2 Increase of slip at the free bar end during cyclic load as a function of the number of load reversals n(f_c = 23.5 MPa, d = 14mm, bond length 30d)

4. BRIEF COMMENTS ON REINFORCEMENT

Reinforcement steel is relatively well covered due to the extensive research on fatigue of steel within mechanical, naval and aeronautical engineering |4,5,6,7,8,9,10,11,12,13,14,15,19|. This paper will primarily deal with fatigue of concrete. Because the investigations and discussions on fatigue of concrete have followed the same lines as for steel, some main properties of steel bars subjected to fatigue loading will be briefly mentioned. It is important to be aware of both similarities and differences between steel and concrete.

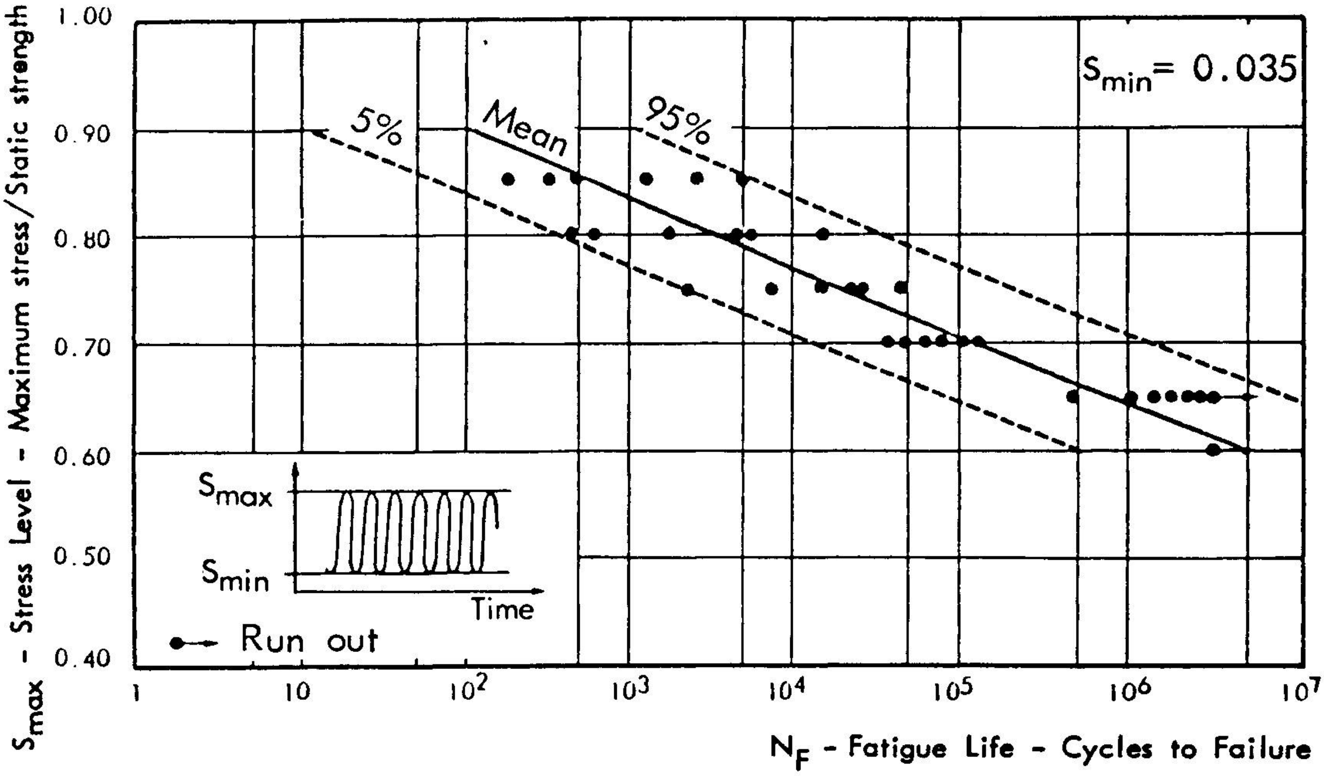


Fig. 3 Typical S-N relationship for concrete i compression

The surface geometry of the steel bar has a marked influence, for instance the shape of the ribs |10,11,12|. The effect of the concrete surrounding the reinforcement has been investigated in a number of projects with contradicting results. A reasonable conclusion is that reinforcement bars in a structure have approximately the same fatigue life as the twin naked bars although the scatter of the test results is greater in the first case. Bent reinforcement bars can have a drastic reduction of fatigue strengh compared with straight bars |16,17,18,22|. In relation to the pin diameter, P, and the bar diameter, d, it is reported that the fatigue strengh of a 45^0 bend is reduced with 1/5 to 2/3 as the ratio D/d is decreased from 15 to 5.

5. CONCRETE UNDER COMPRESSION

For concrete, there is a better correlation between the ratio max. stress/ static strength and the fatigue strength, than between stress range and fatigue strength, as experienced with steel. Therefore the S-N-diagram for concrete is presented as shown in Fig. 3. The minimum stress of the load cycle, or in other words the stress range, is also significant for fatigue of concrete. Examination of fatigue of concrete requires that many factors should be considered, such as: aggregates and proportions of concrete, humidity and temperature conditions, stress rate and load frequency, tri-axial conditions, stress gradient and eccentric loading - and other factors |20|.

In the following the load aspect will be given most attention. The results reported are primarily generated in a recent investigation at our research institute |21|.

Previously it has been reported a significantly greater scatter of fatigue testing than at static testing. However, the mean standard deviation, expressed in units of stress, is not significantly different for static strength and for fatigue strength. This is also reported in a research paper by TNO in Delft |23|. It might be added that an extrapolation of the S-N-

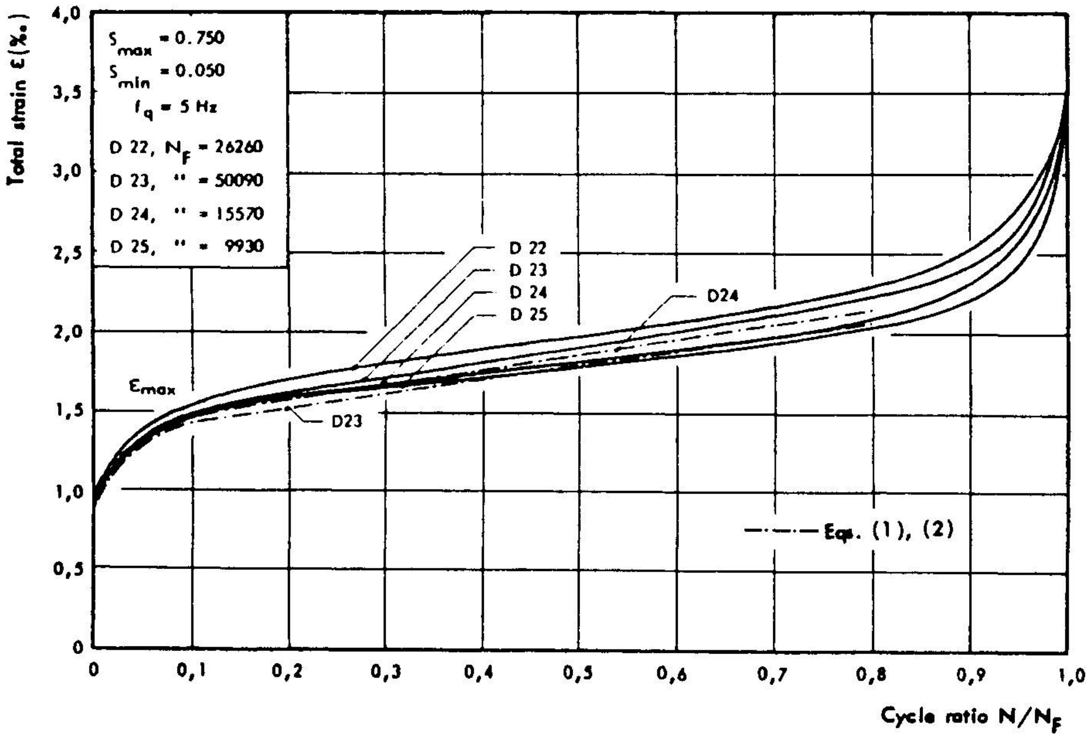
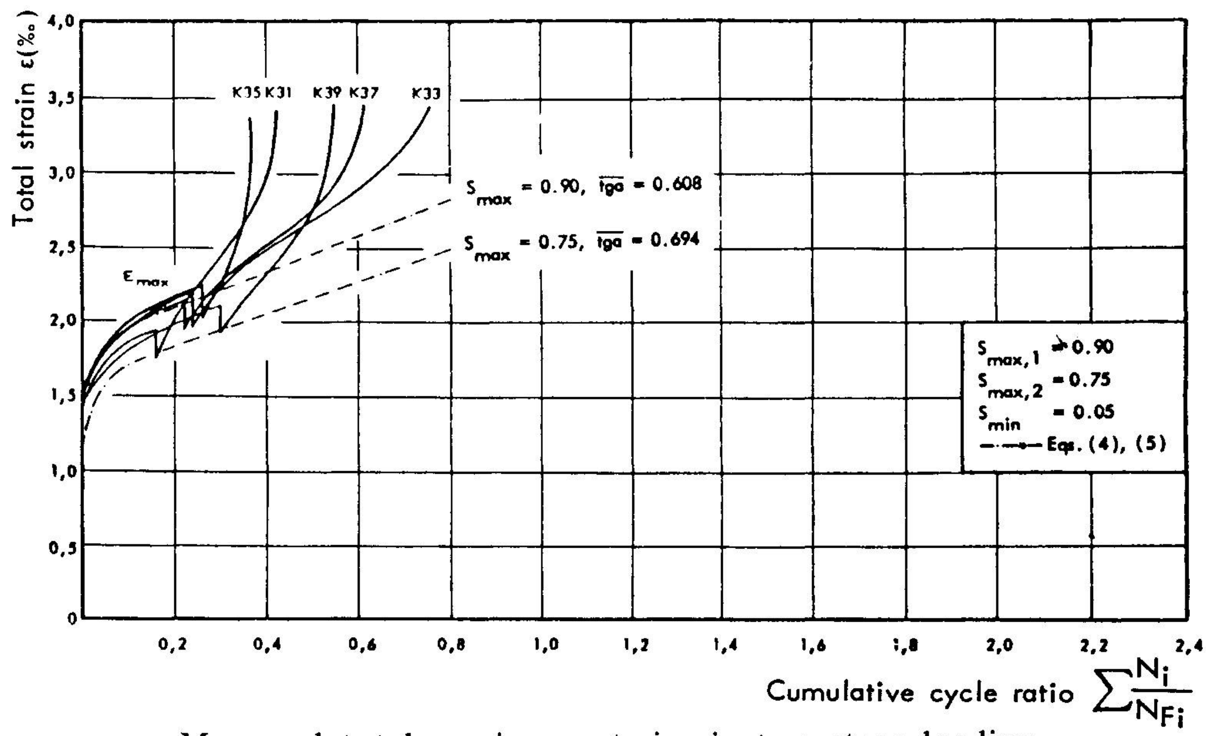
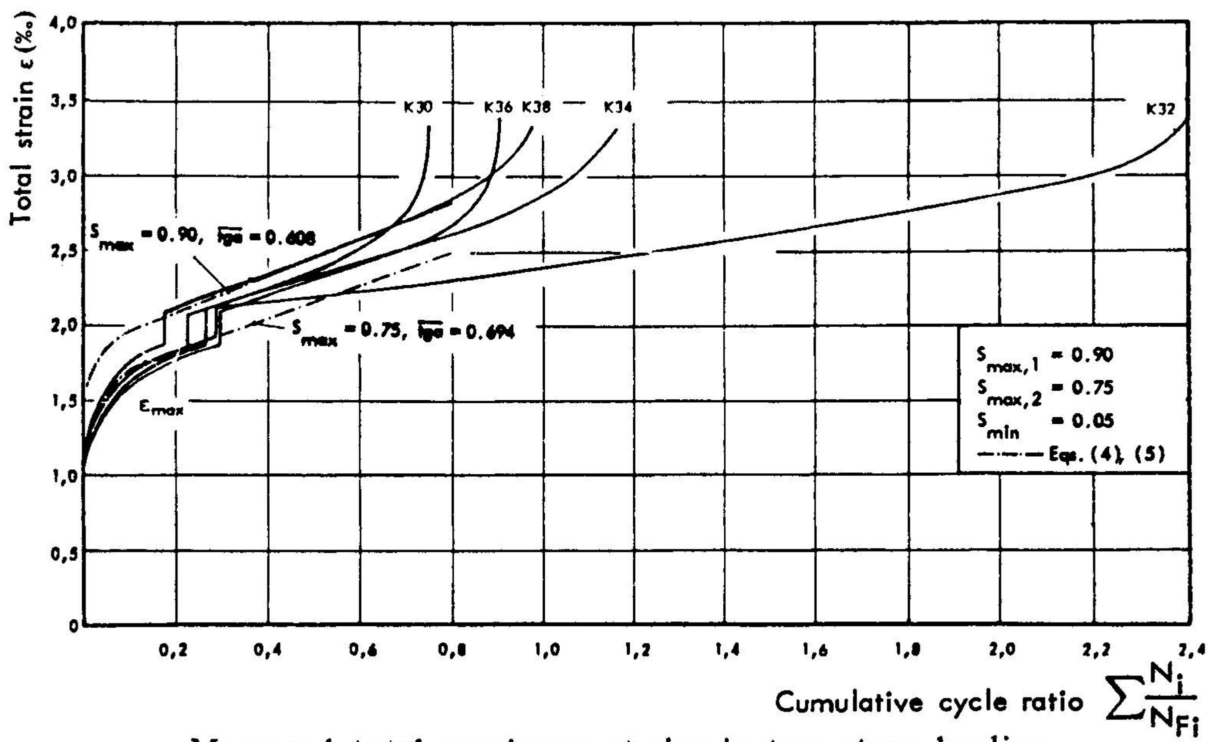


Fig. 4 Measured and calculated variation of total maximum strain with the cycle ratio



Measured total maximum strains in two stage loading compared with eqs. (4), (5)



Measured total maximum strains in two stage loading compared with eqs. (4), (5)

Fig. 5

curve in Fig. 3 towards a smaller number of loadings would give a strength higher than the static strength. It has to be noted that the rate of the dynamic loading in this case is approximately 2000 times higher than the prescribed rate for the static tests. According to other tests, an increase of approximately 25% in "static" strength is to be expected by such a high rate of loading as mentioned above |23|.

The importance of the deformation during the fatigue loading has been more and more realized. In Fig. 4 typical test results from tests of short duration are shown |19|. The trend is the same for all test specimens. The first loadings greatly increase the deformation. After a while the increase in deformation is reduced and the specimen enters a more stabilized period until an excessive deformation starts a short while before the final failure - if the specimen fails in fatigue. The relation between the number of loadings and the strain can, according to the experiments, be expressed by

$0 < \frac{N}{N_F} \leq 0,1$:

$$\varepsilon_{e_1} = \text{cotan}\alpha(3.76-2.18\ S_{max})\sqrt{\frac{N}{N_F}} \qquad (1)$$

$0.10 < \frac{N}{N_F} < 80$:

$$\varepsilon_{e_2} = \text{cotan}\alpha(1.11+0.75\ \frac{N}{N_F}) \qquad (2)$$

where: ε_e = total maximum strain (o/oo)

ε_0 = total maximum strain in the first cycle (o/oo)

S_{max} = maximum stress/static ultimate strength

$\text{cotan}\alpha = \varepsilon_0/S_{max}$

The α-value is to be considered as a material property. The strain or the deformation at constant amplitude loading is dependent on the fatigue life, N_F, of the concrete at that loading. Since N_F is not directly known, the equations 1 and 2 may not be practical for estimating the strain. However, if a specimen is subjected to fatigue loading and the strain and number of loadings are recorded, the remaining fatigue life can be found.

For dynamic loading with long duration a part of the total strain is due to the dynamic action, and the other part is due to creep of the same nature as for long time static load. Many proposals have been presented for a representative creep function, mostly for static permanent load. For alternating loads with long duration, tests indicate that the creep is higher than for a permanent static load equal to the average alternating loads. For creep calculations under alternating loads the so-called RMS-value, root mean square-value, seems to be a good equivalent permanent load

$$RMS = \sqrt{\frac{1}{T_0} \int_0^{T_0} x^2(t)dt}$$

where $x(t)$ = alternating stress

T = total time, duration of the cyclic loading

This RMS-value is also used for random loading. The mean stress level plus the RMS-value is called the characteristic stress level, S_c. The equations 1 and 2 are extended to include the creep:

$0 \leq \frac{N}{N_F} < 0.10$:

$$\varepsilon_{max} = \text{cotan}\alpha(3.76-2.18\ S_{max})\sqrt{\frac{N}{N_f}} + 0.143\ S_c^{1.184}\ln(t+1) \qquad (4)$$

$0.1 < \frac{N}{N_F} < 0.80$:

$$\varepsilon_{max} = \text{cotan}\alpha(1.11+0.75\ \frac{N}{N_F})+0.143\ S_c^{1.184}\ln(t+1) \qquad (5)$$

where $S_c = S_m + RMS$

S_m = mean stress

t = duration of alternating load in hours

The simple time-dependent creep function proved suitable for the laboratory climate.

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Reflections on the Presentation of Fatigue in Design Codes

Considérations sur la prise en compte de la fatigue dans les règlements

Überlegungen bezüglich der Behandlung von Ermüdungsproblemen in Vorschriften

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SUMMARY
Some thoughts are presented on the transformation of scientific research findings into a form suitable and acceptable for use in practice. With regards, in particular, to fatigue the paper discusses both the load processes involved and the general structural requirements to be fulfilled. The ways and means of meeting these requirements are mentioned for planning, design, execution and inspection in order to outline the considerations to be made in preparing practical guidelines.

RESUME
L'article présente quelques considérations relatives à la transformation nécessaire des connaissances scientifiques en règles pour l'application pratique. Il rappelle d'abord les différents types de charges répétées, puis il discute les performances exigées pour les structures; il analyse les mesures à prendre lors de l'étude et de la réalisation d'un ouvrage pour assurer qu'il fournira les performances exigées. Les informations indispensables qui doivent figurer dans les textes réglementaires sont ainsi mis en évidence.

ZUSAMMENFASSUNG
Es werden einige Überlegungen mitgeteilt, die die notwendige Umsetzung wissenschaftlicher Erkenntnisse in praktische Anwendungsregeln zum Gegenstand haben. Durch Betrachten der Einwirkungskollektive, der Bauwerksanforderungen und der Massnahmen, die bei Entwurf, Bemessung, Ausführung und Kontrolle zu einer zufriedenstellenden Realisierung des Bauwerks zur Verfügung stehen, werden die Informationen herausgestellt, die zu einer Ausarbeitung praktischer Regeln unumgänglich sind.

To contribute on an international level to the development and evolution in structural engineering and to provide the necessary prerequisites for technological and economical progress in planning, design and execution of engineering structures belongs to the mission of all associations assembled at this Colloquium. CEB's particular interest in this mission has always been directed toward the two following objectives:

1) To elaborate on a structural engineering level a synthesis of existing theoretical knowledge and practical experience.

2) To derive from this synthesis practical guidance for planning, design, execution and maintenance of concrete structures.

Working toward these aims means that CEB clearly defines its position as link between scientific research and practical application.

One particular field in which we consider this link to be of special importance is the problem area to which this colloquium is partly devoted: Fatigue of concrete structures. Observing the development in this field one can realize a growing gap between scientific findings and practical guidance.

Due to many characteristics distinguishing the load bearing behaviour of concrete structures their sensitivity to fatigue has been in general of less decisive importance in design considerations. A fact which explains the minor priority which had been given to fatigue problems in many national and international codes and recommendations [see also (1)]. However actual practice and future developments are showing that this will not necessarily be so in future. The choice of structural concrete for a wider range of applications (sleepers in railroads, road and air-field pavements, wind-power plants and off-shore structures etc) and the design of more slender members, particularly in modern transport facilities (resulting among other things from a higher exploitation of the structural resistance at the ultimate limit state) may lead to time dependent stress variations resulting in local stress histories which in fact can affect the fatigue resistance. It is therefore important to provide univocal guidance which allows the structural engineer to identify those cases where fatigue can be decisive and which offers to him adequate information for their correct treatment.

An indispensable step toward the preparation of practical guidance is the elaboration of a synthesis of knowledge from the designer's point of view. This requires the consideration of the state of the art in all subject matters involved: Action models, material science, experimental techniques, performance and design criteria, production technologies, execution experiences etc. It is this state of the art to which we expect the colloquium will contribute.

On which particular problem areas do we have a hope to gather information? I will try to identify these by presenting some conceptional considerations which may be appropriate when preparing practical guidance for the treatment of fatigue problems in concrete structures.

Semantic clarity - one of the fundamental prerequisites for rationally derived regulatory documents - leads us to a first important question requiring a clear definition of "Fatigue".

The expression fatigue is related to a change in material performance under repeated loads - expressed e.g. in time dependent properties -. It is therefore desirable to define reasonable classifications which relate particular alterations in the material properties to relevant types of dynamic loads. Since dynamic loads by definition comprise all arbitrary variations of actions in time, including e.g. repeated actions exerted on foundations by machines, on bridges by traffic and on off-shore facilities by waves, ground motions caused by earthquakes or shocks induced by impact and explosions, a classification - allowing a clear definition of what is meant by fatigue - may reasonably be based on the nature how the performance of structural members is changed under the different kinds of dynamic actions.

One possible interpretation limits the meaning of fatigue to the reduction in resistance due to a sufficiently large number of load oscillations between critical lower and upper limits. It should be noted that this interpretation relates the actions leading to fatigue to the transient situations (as they result under normal use) rather than to accidental situations [see (2)]. In this way it also allows to distinguish fatigue from phenomena resulting from accidental actions as explosions, impact or high intensity ground motions. Some clarification in the univocal definition of fatigue is expected from this colloquium.

A very large problem area is related to the modelling of representative load processes as they result from the various dynamic loads acting e.g. on rails for cranes, bridges, off-shore facilities etc. It is hoped that this colloquium will particularly contribute to this field of necessary information.

A further consideration with regard to the preparation of practical guidance leads us to the requirements a concrete structure is expected to fulfill.

Limiting the scope to the structural behaviour under normal use, the requirements shown on the following page have been defined [see also (3)]. Please note that "fatigue" is related to the local resistance in a section or an element of the structure as it results from the actual e.g. time dependent mechanical and geometrical properties.

The formulation of semantically correct regulations calls for the translation of these requirements in performance criteria which are technical expressions - containing quantitative limits - of the required performance.

Which of the required performances are directly affected by frequent load repetitions causing fatigue in concrete structures? In general safety as well as serviceability and durability. Safety through the possible reduction of the resistances of the constitutive materials concrete and steel, furthermore through the loss of bond e.g. at anchorages and splices but also through the possible decrease of ductility caused by the increasing tendency to brittle rupture of reinforcing and prestressing steel. Serviceability may, among other things, be affected by the increase of deformations, in particular due to the loss of bond and to the increase in concrete strains etc. Finally, durability can be affected by a possible acceleration in crack development and propagation which then may initiate physical or chemical deterioration processes (e.g. corrosion of reinforcement).

Having outlined the effects exerted on the structure we come to a third consideration concerning possible measures to be taken in order to assure the required structural performance. These will comprise measures related to the design and the dimensioning of the structural members, but also to their structural detailing, to the execution procedures and finally to the possibilities of adequate observation and maintenance under service. Regulatory documents will have to provide the appropriate design criteria guiding the different steps. In order to assure well performing structures much importance must be given to the necessity to treat all criteria as a whole [performance,design (dimensioning, detailing), execution, control and maintenance] in a way which reflects their contribution to the realization of concrete structures sufficiently reliable against fatigue. For example stress concentration may often be avoided or at least reduced when all influencing factors from planning and design via detailing and execution are appropriately studied.

PERFORMANCE REQUIREMENTS (Normal Use)		
SAFETY	STABILITY	RIGID BODY EQUILIBRIUM
		SYSTEM STABILITY
		MEMBER STABILITY
	RESISTANCE	STRENGTH
		FATIGUE
	DUCTILITY	STRAIN-, ROTATION CAPACITY
SERVICEABILITY	Limitation of DEFORMATIONS	
	Limitation of VIBRATIONS	
	TIGHTNESS (Liquids, Gas)	
	THERMAL INSULATION CAPACITY	
	ACOUSTICAL INSULATION CAPACITY	
DURABILITY	Limitation of STRUCTURAL DETERIORATIONS	

Completeness, uniqueness and correctness of the criteria formulated in regulatory documents require a clear understanding on how the structural performance will be affected by frequent load repetitions. It is expected that advanced information on that subject matter will be presented at this colloquium.

The formulation of criteria treating fatigue problems in design, detailing, execution, control and maintenance of concrete structures demands a competent understanding of the structural behaviour which must be based on scientifically sound theoretical models and proved by extensive practical experience. It is essential to dispose of sufficient information allowing a consistent modelling of the material behaviour as a basis for a mechanically and statistically clear definition of the parameters involved (concrete, reinforcement and their bond interactions). Furthermore behaviour models concerning structural elements (beams, slabs, joints, anchorage devices etc) need to be available and their interaction within the overall structure should be well understood.

Finally the a-priori verification of adequate resistance against fatigue requires a consistent reliability concept. The variation in time of the actions and the resulting effects on safety, serviceability and durability of structures will favour concepts based on design service life considerations. Although intellectually appealing, such a concept requires profound considerations concerning its technical and legal implications.

This very general tour d'horizon from the standpoint of CEB raises many questions. Certainly more than we are able to answer at this colloquium. Scientific research will have to go on and practical experience will have to be made. However we hope that this colloquium will evidence sufficient knowledge which allows CEB to improve practical guidance for the treatment of fatigue problems. This improvement should include the separation of those cases where fatigue phenomena need not to be considered from those where safety, serviceability and durability may be affected by repeated loadings. In order to treat the problem with appropriate simplicity, it should be possible to subdivide the second class in cases where a simplified treatment may be sufficient and in cases where more refined load histories and corresponding fatigue processes considering damage accumulations should be taken into account in order to assure the required structural performance at economical conditions.

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