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The safety of prestressed concrete as affected by creep and fatigue

Die Sicherheit beim vorgespannten Beton unter Berücksichtigung des Kriechens und der Materialermüdung

Efeito da fluência e da fadiga sobre a segurança das estruturas de betão preesforçado

Influence du fluage et de la fatigue des matériaux sur la sécurité du béton précontraint

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The safety of prestressed concrete beams differs in certain important aspects from the safety of simply reinforced beams This difference warrants a short discussion of the factors involved in the analysis of safety and in the establishment of rational safety factors for the two types of structures.

The safety of any structure must be considered in terms of the dual aspect of unserviceability and of collapse [1]. A structure may be reasonably safe with respect to collapse in terms of the probable maximum loading conditions but unserviceable, as in the case of structures that deform excessively under service loads in spite of relatively low stresses; or it may be serviceable but unsafe as, for instance, in the case of structures with inadequate internal mechanisms for rapid energy absorption, which might be subject to rather infrequent, but still possible, dynamic loads of high intensity.

The ratio between the collapse load and the limiting service load represents a rational «overloading factor» which is characteristic of the structure, but unrelated to the intensity and variation of the applied loads. Neither of the critical loads can be specified as a definite figure, but only as a probability function of service-and of collapse-carrying-capacities, in terms of load capacities associated with various probabilities of being exceeded (probability of «survival») or of not being reached (probability of «failure»). Their ratio can therefore be specified only as a probability

function, indicating the various likelihoods of occurence of certain values of this ratio, and thus the probability of a specific ratio, i. e. of a specific value of the «overload factor». Any satement concerning this factor can therefore be made only in terms of the probability of a structure to have a factor of not less than a certain specified value. While the safety factor, which is related to a certain spectrum of applied loads, governs the design of a structure with respect to this load, the «overload factor» represents the critical ratio for the rating of an existing structure.

The discussion of the safety of simply reinforced concrete structures is complicated by the fact that, primarly, collapse may be due either to failure of the concrete or to failure of the reinforcement; structures in which failure occurs simultaneously in both materials, because of the relatively high percentage of reinforcement involved in the creation of such conditions, are the exceptions rather than the rule. Unserviceability, which is usually associated with excessive deformation and objectionable cracking in the tension zone of the concrete, can be related to a critical strain in the tension zone and thus to the stress-level, under service conditions, in the reinforcement; the concrete strength properties, with the exception of the rather uncontrollable tensile strength, are not involved in the consideration of unserviceability.

The use of prestress in a reinforcement of adequate yield point increases, for a given concrete section and percentage of reinforcement, the applied load that is likely to cause unserviceability (cracking load); it does not, to any significant degree, affect the ultimate failure (collapse) load of the structure except in the infrequent case when collapse is primarily due to concrete failure or where, as in continuous beams, some «plastic» redistribution of stresses in the simply reinforced structure may result in a partial redistribution of moments which, because of the imminent collapse of a «plastically yielding» prestressed section, may not be possible in the prestressed structure. This fact results in an automatic reduction of the ratio between the collapse-and the unserviceability-loads, and thus in the «overload factor» of the prestressed in relation to the simply reinforced structure. It is the possibility of this reduction which, under the assumption of an adequate collapse capacity, constitutes the principal incentive to the use of prestressed concrete.

It should be kept in mind, however, that although the reduced overloading capacity is not in itself objectionable, provided the remaining safety factor is adequate, and the probability of failure by collapse is sufficiently low with respect to the spectrum of possible loads, there are certain features characteristic of prestressed concrete which tend to reduce the safety of such structures in relation to that of simply reinforced concrete. Particularly under conditions of repeated loading these effects may increase the probability of collapse beyond an acceptable figure, and thus endanger the life of the structure. These critical features are the creep of the concrete at the relatively early age when the prestress is applied, and the fatigue resistance of the highly prestressed reinforcement. The significance of both effects increases with increasing level of prestress and thus with increasing quality of the reinforcing wire used.

Recent investigations have demonstrated the pronounced non-linearity, with respect to stress, of the creep rate of concrete under sustained

stresses exceeding about one quarter of the 28 day compressive strength f_c [2]; such non-linearity produces non-linear stress distributions, as well as stress-relaxation in the reinforcement which, during the early stages, is far more rapid than under conditions of linear creep. It appears that in order to produce, in the extreme fibers, the level of prestress estimated on the basis of elastic theory, as required to eliminate concrete tension and to balance excessive loss of prestress by relaxation, a higher prestress would have to be applied than would appear necessary on the strenght of linear (elastic and creep) theories if the theoretical stress were to exceed the limit of linearity of about $0.25f_c$. The principal advantage of prestressing, i. e. the raised limit of serviceability, may thus be partly lost when the prestress is too high. Moreover, the creep rate of concrete varies rather widely with the type of cement, content of aggregate, water-cement ratio and curing procedure; it also varies between nominally identical test specimens. Hence, the prediction of concrete creep and prestress-relaxation is subject to a rather large range of error, which must be compensated by an increase in the required safety factor with respect to the condition of unserviceability. This, however, can only be achieved either by a reduction of the permissible maximum service load at the price of the economy of the structure, or by a commensurate increase in the prestress, a fact which will provide a further incentive for the use of high prestress.

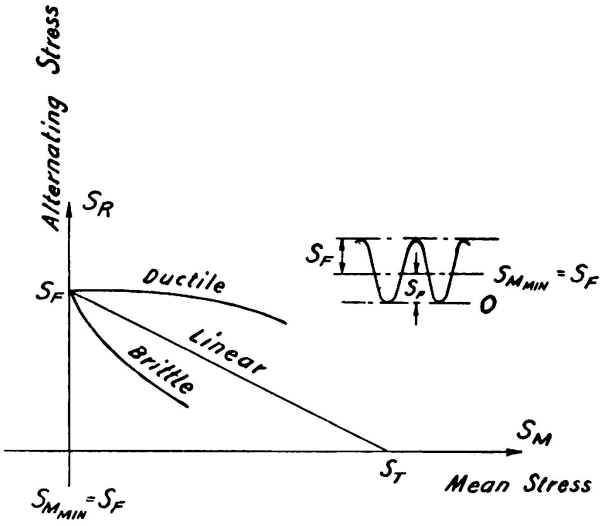

FIG. 1. Typical Fatigue Diagram showing the Relation between Amplitude of Reversed Stress S_R and Mean (Sustained) Stress S_M for Range of Stress Pulsation ($S_M > S_R$).

Considering, however, a typical fatigue diagram, as indicated in Fig. 1, it becomes evident that an increase in prestress seriously reduces the stress amplitude which can repeatedly be applied to the prestressing wire without causing fatigue fracture after a certain number of load applications. While very few fatigue test data for prestressing wires are available, particularly under the high mean stress representative of prestress, it may be assumed that, as is generally the case, the higher the static strength of a metal alloy, the higher its fatigue sensitivity. Considering, moreover, that the application of the prestress inevitably

induces severe stress-concentrations at the wire ends, such as screw-threads, sharp reentrant corners or tight grips with discontinous distribution of shear stresses, all of which seriously reduce the fatigue resistance of the wire, it appears likely that the collapse-capacity of a prestressed structure under repeated service loads might be decisively limited by the fatigue strength of the prestressing wire under the high mean stress induced by prestress and dead load and the stress-concentration effects of specific gripping arrangements applied.

The effective use of prestressed concrete for structures subject to dynamic loads will therefore largely depend on the results of investigations of the fatigue strength and notch-sensitivity of the prestressing wire under conditions of high mean-stress.

REFERENCES

1. A. M. FREUDENTHAL — *Proceedings, Am. Soc. Civil Engrs.*, vol. 80 (1954), No. 468.
2. A. M. FREUDENTHAL — *Preliminary Publication IABSE* (1956), Contribution to Question Ia.

SUMMARY

The concept of safety of prestressed concrete is discussed in terms of service and failure capacity, considering the effects of creep of concrete and of the fatigue sensitivity of the reinforcement at the high levels of prestress. The importance is discussed of the non-linearity with respect to stress of the creep-rate of concrete, as well as of the reduction, with increasing prestress, of the safe range of repeated load amplitudes.

ZUSAMMENFASSUNG

Der Verfasser behandelt das Sicherheitsproblem bei vorgespanntem Beton bezüglich Gebrauchs- und Bruchsicherheit. Dabei werden der Kriechvorgang und die Materialermüdung als Folge der hohen Vorspannungswerte berücksichtigt.

Als wesentliche Tatsache ist zu erwähnen, dass das Kriechmass des Betons nicht linear zum Druck verläuft und dass die Sicherheit für wiederholte Belastungsschwankungen mit erhöhter Vorspannung abnimmt.

RESUMO

O autor discute o conceito de segurança nas estruturas de betão preesforçado em relação às cargas de serviço e de rotura, considerando o efeito da fluência do betão e da sensibilidade à fadiga das armaduras, para prétensões elevadas. Discute também a importância da não-lineari-

dade da variação da fluência do betão em relação às tensões e da diminuição do limite de segurança da amplitude das cargas repetidas com o aumento da prétensão.

RÉSUMÉ

L'auteur discute la définition de la sécurité des structures en béton précontraint par rapport aux charges de service et de rupture, en tenant compte de l'effet du fluage du béton et de la sensibilité à la fatigue des armatures pour des valeurs élevées de la précontrainte. Il discute l'importance de la non-linéarité de la variation du fluage du béton par rapport aux contraintes ainsi que l'importance de la diminution de la limite de sécurité de l'amplitude des charges répétées avec l'augmentation de la précontrainte.

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