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Autor: Abeles, P.W.

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Fatigue resistance of prestressed concrete beams *

Der Widerstand von Spannbetonbalken gegen dynamische Beanspruchung

Resistência à fadiga de vigas de betão preesforçado

Résistance à la fatigue de poutres en béton précontraint

P. W. ABELES
London

With most materials it is usual to investigate the endurance limit based on a resistance of one million or several millions of repetitions for a range from zero to the maximum loading. This applies to parts of machines or structures of relatively small dead weight, (e. g. railway sleepers). However, for ordinary constructions in civil and structural engineering the range of loading is greatly reduced in view of the substantial permanent dead load. It will, therefore, suffice for road and railway bridges to ascertain whether the required factor of safety against failure is still available in a static loading after a fatigue loading for the range of the ordinary static live load had previously been applied. Where an increase in loading may be expected in the future, it might be of interest to ascertain, in addition, the endurance limit of the structure based on the lower limit of the range equalling the dead weight. However, such a test is for the present state of the structure only of secondary importance, since the safety against static failure load after a fatigue loading in the range of the present live load is of primary importance. Investigations about ultimate load resistance after previous fatigue loading were carried out on most specimens at the tests of British Railways at Liège 1951 [1] and Derby 1954 [2].

These fatigue tests of British Railways have definitely proved that freedom from visible cracks can be obtained for a range of approx. 750 lb/in^2 for a maximum tensile stress of 650 lb/in^2, even if short microscopic cracks may have developed already at a load corresponding

(*) Another contribution presented at the same time under the title «Impact Resistance of Prestressed Concrete Masts» will appear in the 17th Volume of the Publications.

to a tensile stress of 500 lb/in². These microscopic cracks of short length will open and close millions of times without the occurrence of visible cracks, as has been shown in paper [2]. If the range of loading is increased from 750 lb/in² to, say, 2,000 lb/in², the maximum tensile stress will be reduced from 650 lb/in² to, say, 400 to 500 lb/in², if freedom from visible cracking is to be obtained. This will have to be ascertained by tests.

The tests [1] and [2] have also proved that after visible cracks have developed, many millions of repetitions of loading may be applied, during which the cracks open and close and still the full serviceability of the construction is retained, as seen in Figure 1. This shows 3 load deflection curves, one at the first loading, the other after 583,000 and

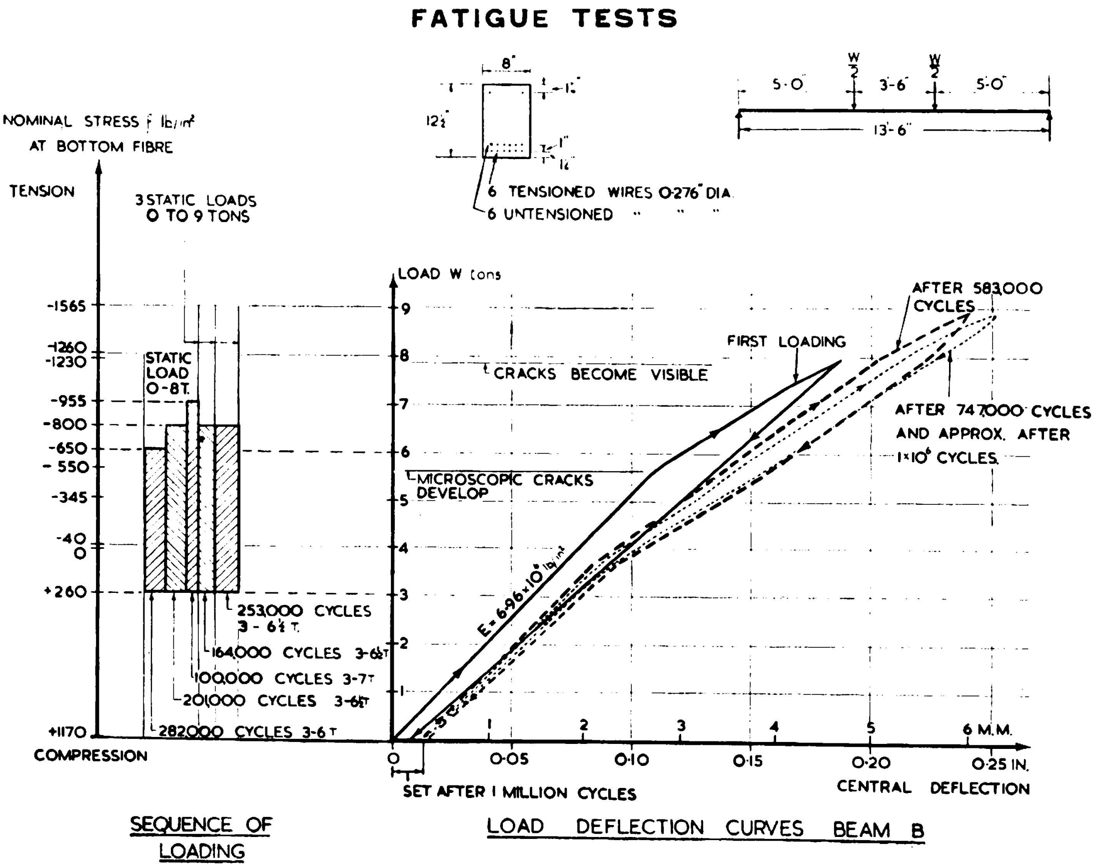

FIG. 1

the third after 747,000 cycles, the last curve approximating also that after 1 million cycles. The modulus of elasticity at the first loading is 6.96×10^6 lb/in² and after 1 million cycles the elastic modulus in the range of effective prestress is 6.68×10^6 lb/². In spite of this dynamic loading of varying range and individual static overloadings, as shown in Fig. 1, the secant moduli of elasticity, including the set, for loads of 6 and 7 tons (corresponding to nominal tensile stresses of 650 and 955 lb/in²) amount to 5.38×10^6 and 5.31×10^6 lb/in² respectively, which high values prove the very high degree of serviceability after the previous history with its severe loading . Both the deflection and the maximum width of cracks, which determine serviceability are very small.

These facts are in great contrast with the views expressed by Prof. Freudenthal in [3] and [4] based on the assumption that non-linear creep may occur. Non-linear creep would occur only if the compressive stress exceeds approximately 1/3 of the concrete strength. Prof. Freudenthal advocates higher prestress to avoid cracking, although he says himself on page 927 «The principal advantage of prestressing, i. e. the raised limit of serviceability, may thus be partly lost when the prestress is too high». This shows the crucial point. There is a vicious circle. A too high prestress causes excessive creep and thus a great part of the prestress may become ineffective. It is, therefore, important to assess the losses correctly with a safe, but not excessive, margin and to avoid too high compressive stresses under working load or the use of non-bonded post-tensioned steel.

With regard to the influence of sustained loading upon deformation, certain precautions appear to be advisable in view of the lack of research data, but the conditions cannot be worse than those due to a corresponding fatigue loading. In fact, the influence of sustained loading may be compared with that of dynamic loading, and it is suggested that comparative tests be carried out which would give a key to obtain the influence of a long sustained loading by a short dynamic test. When relating serviceability to cracking, as Prof. Freudenthal does, the great advantage of prestressed concrete as a ductile heterogeneous material when approaching failure (i. e. its reversibility) would be disregarded and brittle constructions obtained, like the monoliths in stone used as beams by our early ancestors, but only with the difference of reduced depth. It would appear that Prof. Freudenthal has arrived at his idea of considering cracking as the limit of serviceability from an entirely theoretical basis on the lines of rheology, thinking of a newly created, homogeneous material as originally presented by M. Freyssinet. However, it is just the combination of an elastic behaviour under ordinary conditions with a ductile behaviour under excessive load which makes prestressed concrete a particularly attractive material. It is the reversibility of ductile behaviour, even after heavy fatigue loading, which is its outstanding advantage.

Great ductility is of utmost importance in an atomic age when explosions may occur and the structures ought to be capable of absorbing shock. It is a marked advantage of prestressed concrete as compared with ordinary reinforced concrete that the serviceability is retained even if at an occasional overloading cracks develop, since these cracks will close even after many million repetitions, as already stated.

BIBLIOGRAPHY

1. ABELES, P. W. — *Fatigue Tests on Partially Prestressed Concrete Members.* Final Report 1953, Fourth Congress, I. A. B. S. E.
2. ABELES, P. W. — *Cracks in Prestressed Concrete Beams.* Preliminary Report V (a) (1) 1956, Fifth Congress IABSE.
3. FREUDENTHAL, A. M. — *The Safety of Prestressed Concrete as affected by Creep and Fatigue.* V (c) (1) Preliminary Report, 1956, Fifth Congress I. A. B. S. E.
4. FREUDENTHAL, A. M. — *Creep - Effects in the Analysis of Reinforced Concrete Structures.* I (a) (B) Preliminary Report, Fifth Congress 1956, I. A. B. S. E.

SUMMARY

The essential features of prestressed concrete under dynamic loading are discussed. Freedom from visible cracks has been obtained for a range of 750 lb/in² and a maximum tensile stress of 650 lb/in². Many millions of loadings may be applied with hair cracks opening and closing, without the secant modulus of elasticity being appreciably reduced, as compared with the tangent modulus at first loading.

ZUSAMMENFASSUNG

In diesem Beitrag sind die wesentlichen charakteristischen Merkmale des Verhaltens von Spannbeton bei dynamischen Beanspruchungen besprochen. Sichtbare Risse waren nicht wahrnehmbar für ein Belastungsbereich entsprechend einer Spannung von 52.5 kg/cm² mit einer grössten Zugspannung von 45.5 kg/cm². Viele Millionen Lastwechsel können erfolgen, wobei sich Haarrisse öffnen und schliessen, ohne dass der auf die Gesamtverformung bezogene Elastizitätsmodul wesentlich geringer als derjenige bei erstmaliger Belastung ist.

RESUMO

O autor discute as características principais de comportamento do betão preesforçado submetido a cargas dinâmicas. Nota a ausência de fissuras visíveis para um intervalo de 52,5 kg/cm² e uma tensão máxima de tracção de 45,5 kg/cm². As solicitações podem repetir-se muitos milhões de vezes, provocando a abertura e fecho de fissuras muito finas, sem por isso diminuir de maneira apreciável o módulo de elasticidade em relação ao módulo correspondente à carga inicial.

RÉSUMÉ

L'auteur discute les caractéristiques essentielles de comportement du béton précontraint soumis à des sollicitations dynamiques. Il remarque l'absence de fissuration visible pour un intervalle de 52,5 kg/cm² et une contrainte maximum de traction de 45,5 kg/cm². Les sollicitations peuvent être répetées plusieurs millions de fois, en provoquant l'ouverture et la fermeture de fissures très fines, sans réduire de manière appréciable le module d'élasticité par rapport au module correspondant à la charge initiale.