Safety against cracking and permissible stresses in prestressed concrete

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Safety against cracking and permissible stresses in prestressed concrete

Rissicherheit und zulässige Spannungen im Spannbetonbau

Segurança contra a fissuração e tensões admissíveis no betão preesforçado

Sécurité contre la fissuration et contraintes admissibles dans le béton précontraint

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London

At the 3rd Congress at Liege 1948 the author presented two contributions [1, 2], in which the behaviour of prestressed concrete, after cracking, was described and the resultant economy of partial prestressing was expounded. Special reference was made to a bridge design of British Railways, Eastern Region, in partially prestressed concrete which provides for freedom from cracks. Such a design had originally been excluded at the Congress from the definition of prestressed concrete, but on the author's suggestion it was eventually embodied in the wording of the «Conclusions and Suggestions» of the Final Report, 1949.

The British «First Report on Prestressed Concrete» [3] which appeared in 1951 was very progressive with regard to new developments. In this Report three types of structures are distinguished (see Fig. 1). Type (iii) should be used only where there is no danger of fire, corrosion or fatigue. There are two alternatives of type (i) : (A) fully prestressed structures in which tensile stresses are not permitted (e. g. railway underbridges with heavy impact) ; and (B) partially prestressed structures in which tensile stresses below the modulus of rupture are allowed by the «First Report». The present contribution deals mainly with type (i) (B) which has been developed by the Chief Civil Engineer's Dept., British Railways, Eastern Region, since 1948. An interim report appeared in the 2nd Volume of the Publications about the experience gained from 1948 to 1952 [4] (1).

(1) In this paper a composite partially prestressed bridge design was described which has been used for 14 bridges 1949-1952 and in three standard sizes for approximate spans of 20, 30 and 50 ft. They were designed for a permissible tensile stress of 500 lb/in², but freedom from visible cracking was ascertained by acceptance tests at which the test load corresponded to a tensile stress of 750-800 lb/in².

After fatigue tests [5] had proved that for a range of 750 lb/in², visible cracks do not develop even after 1 million cycles between loads corresponding to a compressive stress of 100 lb/in² and a tensile stress of 650 lb/in², the permissible tensile stress under working load was increased to 650 lb/in² in 1952, and since then approximately some further 50 bridges have been built and a great number will be built in the near

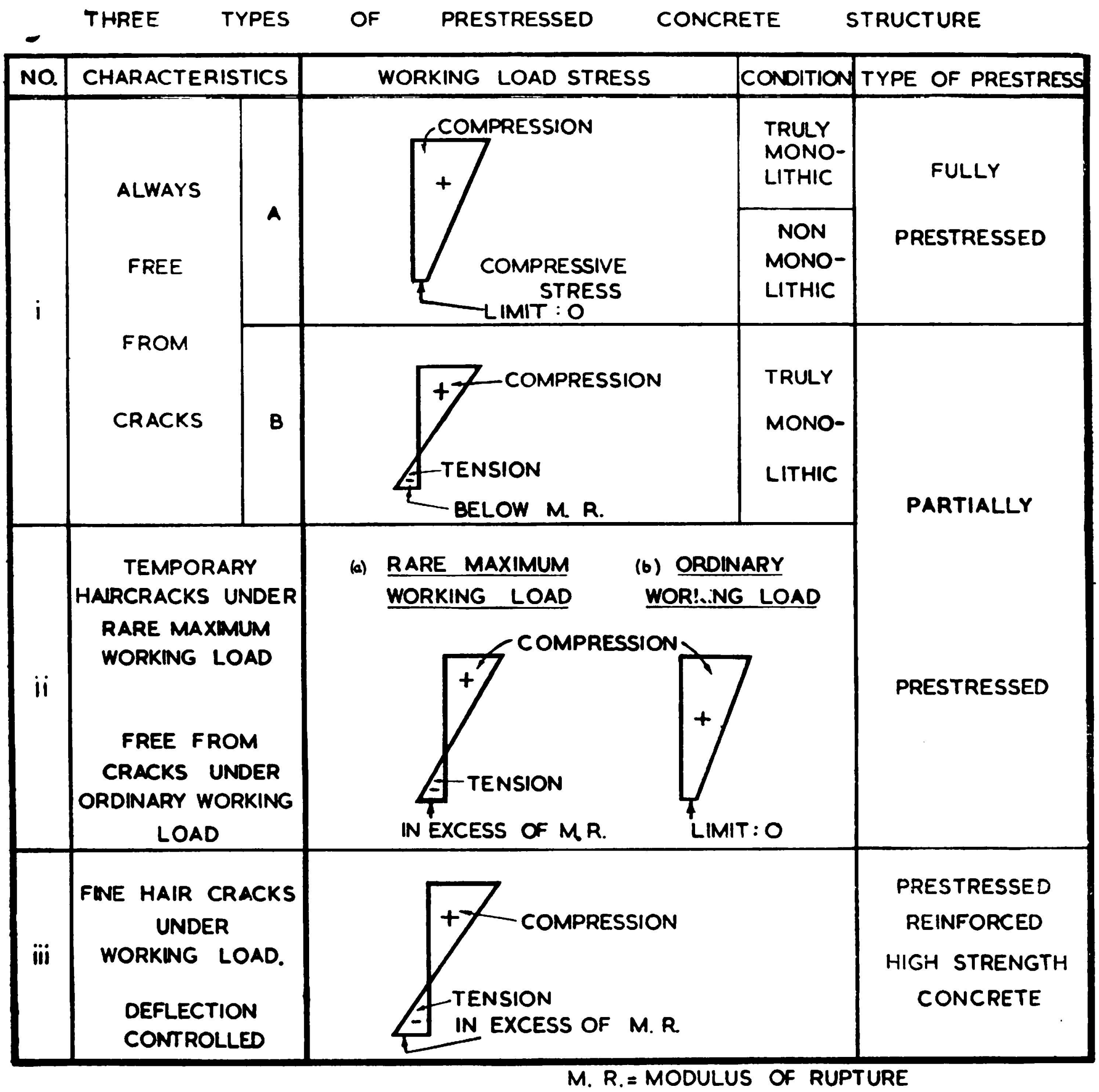


FIG. 1

future. The design has been standardised and employed also for bridges under railways (Fig. 2); in this case under working load, tensile stresses do not occur at the soffite but appear in the additional concrete which fully co-operates and is prevented from the development of visible cracks because the tensile skin is still compressed and the composite slab deforms only slightly at that stage.

Already in the paper [4] the use of partially prestressed concrete for roof construction was shown. Tensile stresses of 750 lb/in^2 were permitted under working load for factory made members with pre-tensioned wires and 650 lb/in^2 for beams with post-tensioned well grouted cables. The same permissible stresses, which are in accordance with the «First Report», have been used also for later work carried out since 1952.

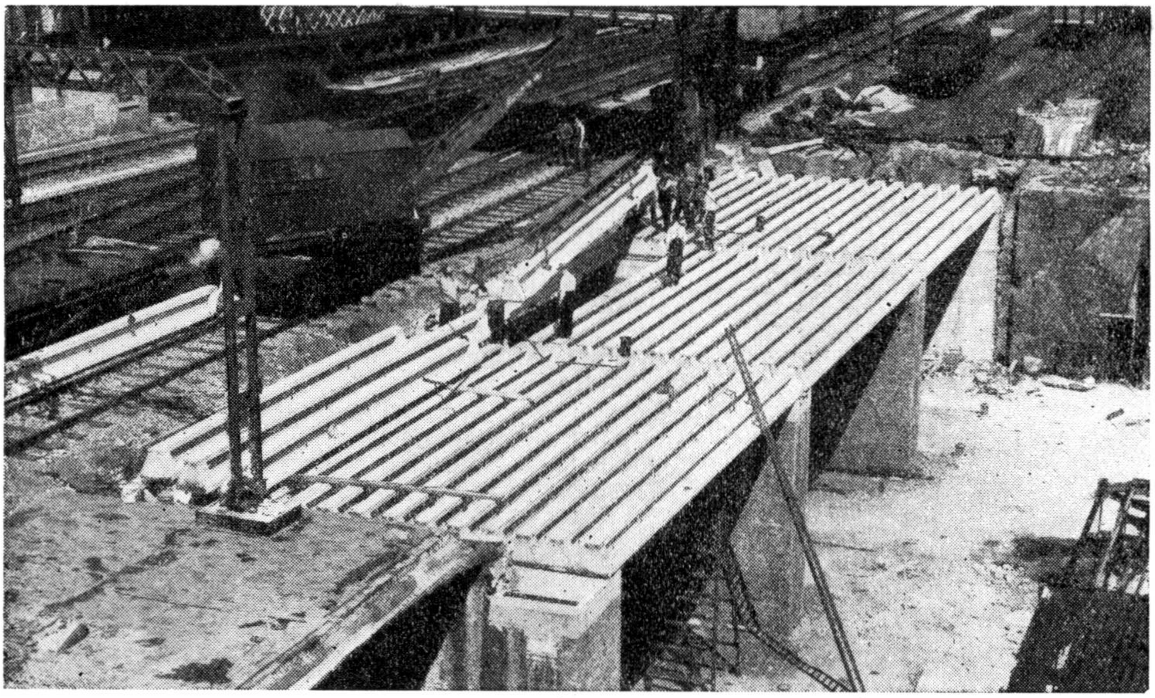


FIG. 2. Bridge under Railway siding at Fenchurch Street Station, London

Among the constructions, the precast roof beams for Sheffield Victoria Station of 85 ft. span is shown in Fig. 3.

Under [6] a report appears about the conditions of bridges and roof structures after several years use, based on inspections carried out in the autumn 1954 and spring 1956. These constructions have proved to be entirely satisfactory, and comprehensive experience has been gained between 1948 and 1956; it seems, therefore, to be appropriate to investigate the margin of safety against cracking of such partially prestressed structures and to enquire into the reason why this type of structure is viewed with disfavour by some authorities, whilst approbation is expressed only when constructions appear, in a calculation, to be fully prestressed though based on certain assumptions, quite disregarding whether they are fulfilled or not (e. g. whether the proper losses have been taken into account or monolithic behaviour is obtained).

A partially prestressed structure according to type (i) (B) (Fig. 1) must be monolithic, (i. e. any shrinkage cracks before prestressing must be avoided or any mortar joints must have a definite strength) (2).

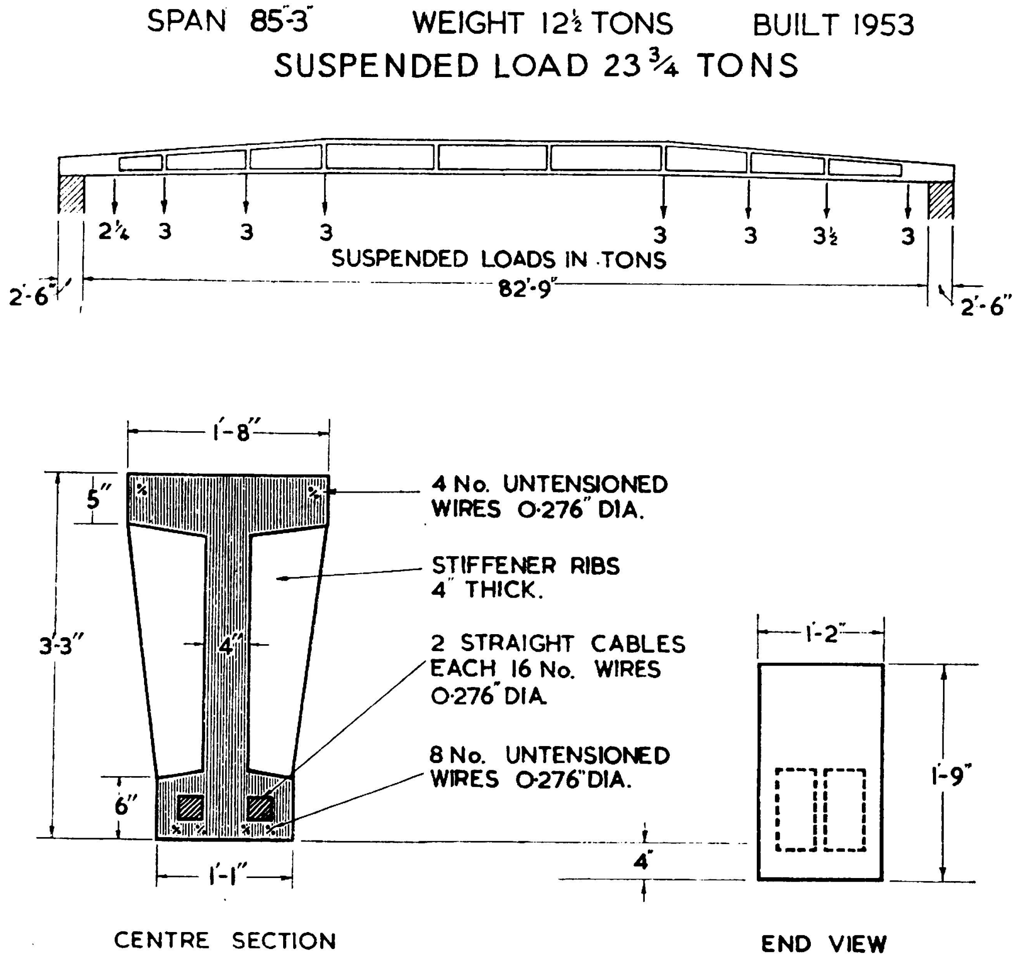


FIG. 3. Roof beams Sheffield, Victoria Station

In Figure 4 a comparison is shown between a non-monolithic type (i) (A) and a monolithic type (i) (B), each designed for the same factor of safety against cracking, or opening of cracks, of 1.25 (3) and a range of live load corresponding to a stress of 1,000 lb/in². In the first case residual compressive stresses of 250 and 1,250 lb/in² are required under live and dead load respectively, whereas with the partially prestressed

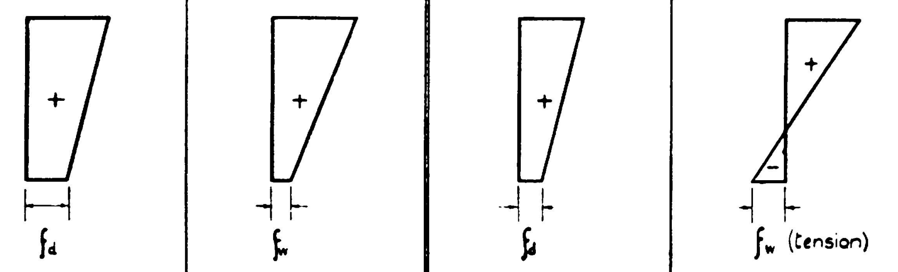
(2) If this is ascertained by loading tests carried out on a number of specimens selected at random, then a certain factor of safety against cracking can be obtained. On the other hand, unless such performance tests are carried out no safeguard against cracking is obtained, notwithstanding that only compressive stresses appear in a calculation.

(3) A factor of safety of 1.25 does not appear to be very large, but it is fully sufficient to ensure full freedom from cracks. The ratio of the two factors of safety against failure and cracking should be large, say 2, if the structure is to be capable of absorbing impact; Factors of 1.25 on the one hand and 2.5 on the other hand might be recommended. Obviously, it is also possible to provide a greater factor of safety against cracking if at the same time also the factor of safety against failure is increased, (e. g. 1.5 and 3 respectively).

type (i) (B) a tensile stress of 750 lb/in^2 is permissible under live load and the resultant compressive stress under dead weight is 250 lb/in^2.

Relatively small pre-compression combined with great ductility are advantageous to obtain a great resilience, particularly with bending moments of opposite direction, as may occur with overhead masts and

FACTORS OF SAFETY AGAINST CRACKING



TYPE	A. (NON-MONOLITHIC)		B. (MONOLITHIC)	
	DEAD LOAD	WORKING LOAD	DEAD LOAD	WORKING LOAD
STRESS DISTRIBUTION	f_d	f_w	f_d	f_w (tension)
LIMIT	$f_w = 0$		$f_w = f_r$ f_r = rupture stress (Modulus of Rupture)	
RANGE	$f_d - f_w$		$f_d + f_w$	
FACTOR OF SAFETY	$\frac{f_d}{f_d - f_w}$		$\frac{f_d + f_r}{f_d + f_w}$	
	LIMIT $f_w = 0$	F. of S.=1	LIMIT $f_w = f_r$	F. of S.=1
EXAMPLE	f_d = 1250; (87½ kg/cm^2) F. of S. = $\frac{1250}{1000}$ = 1·25	f_w = 250 lb/in^2 (17½ kg/cm^2)	f_d = 250; (17½ kg/cm^2) f_r = 1,000 lb/in^2 (70 kg/cm^2) F. of S. = $\frac{250+1000}{250+750}$ = 1·25	f_w = 750 lb/in^2 (52½ kg/cm^2)

FIG. 4

cantilever sheet piles (Fig. 5). In the event of an unforeseen slip of the retained earth of greater extent than anticipated, a re-adjustment would take place and the safety of the construction would not be impaired. All these constructions have been designed for the condition that only compressive stresses occur under dead load. Thus, any cracks which may develop in a member due to an unforeseen excess loading will close on removal of the load, that is after the slip has been corrected.

In view of the satisfactory use of partial prestressing during the last eight years, when tensile stresses from 500 to 750 lb/in² were allowed, as permitted by the «First Report», and freedom from cracking obtained, any objections to these stresses for type (i) (B) would not be justifiable, and it is to be hoped that further progress in this direction will not be hindered by unrealistic restrictions.

If rare maximum working load and ordinary working load are considered for type (ii) (Fig. 1), there is obviously no safety against cracking

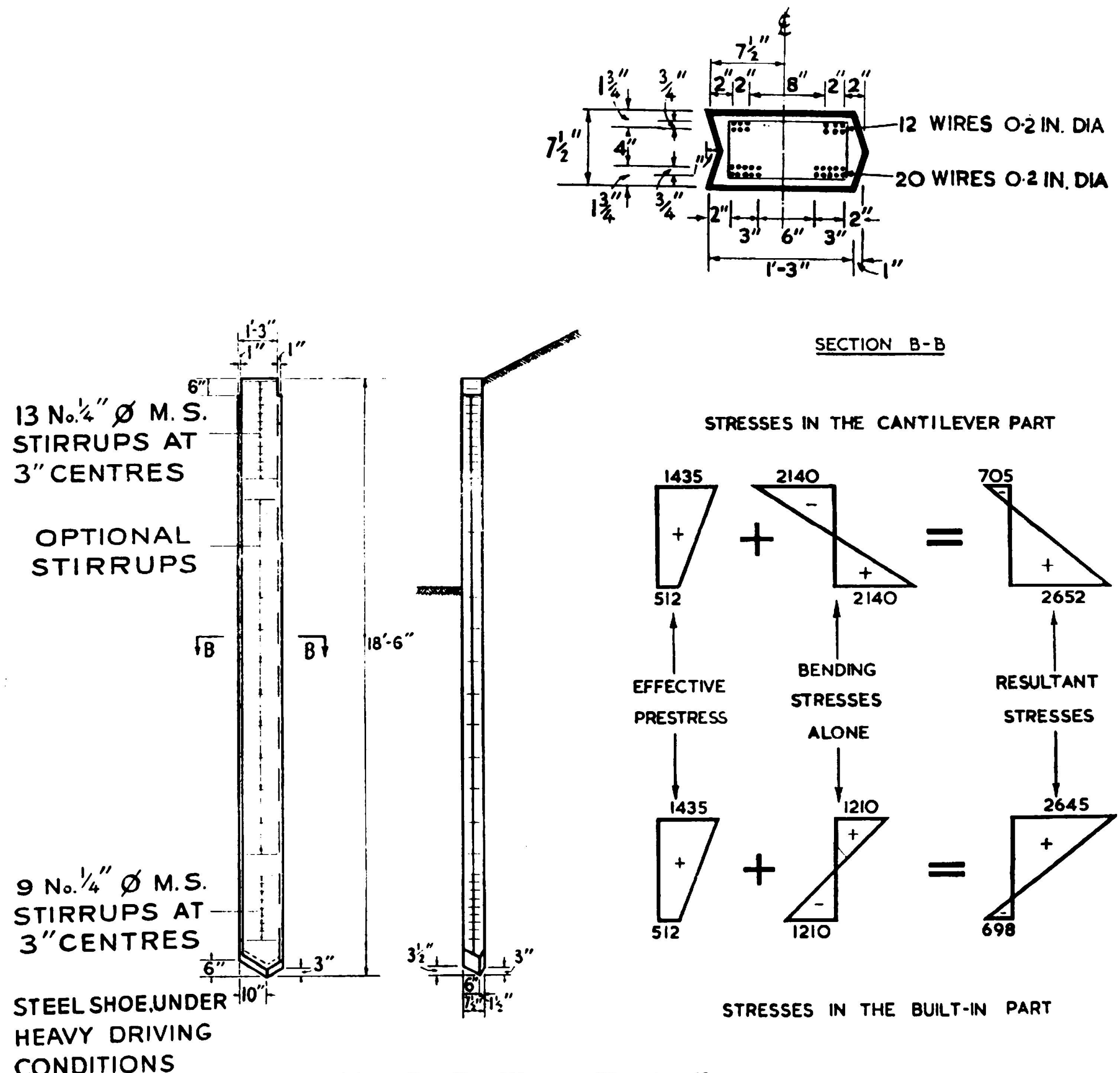


FIG. 5. Cantilever Sheet piles

with regard to the rare load: but an effective though small residual compressive stress is obtained under load, and consequently any fine hair cracks which might have occurred under the rare load will remain completely closed under ordinary load. Consequently, type (ii) represents a very important development of prestressed concrete, since full freedom from visible cracks is obtained under ordinary conditions and full advantage is taken of the greatest phenomenon of prestressed concrete, i. e. its complete reversibility of behaviour. It depends now entirely on the designer what he considers as «rare» maximum working load. Based on the test results discussed before, the cracks will close completely even after millions of repetitions, as discussed above. Thus, there need not be too great an anxiety about the definition of what is considered as «rare» loading It seems, however, advisable to provide suf-

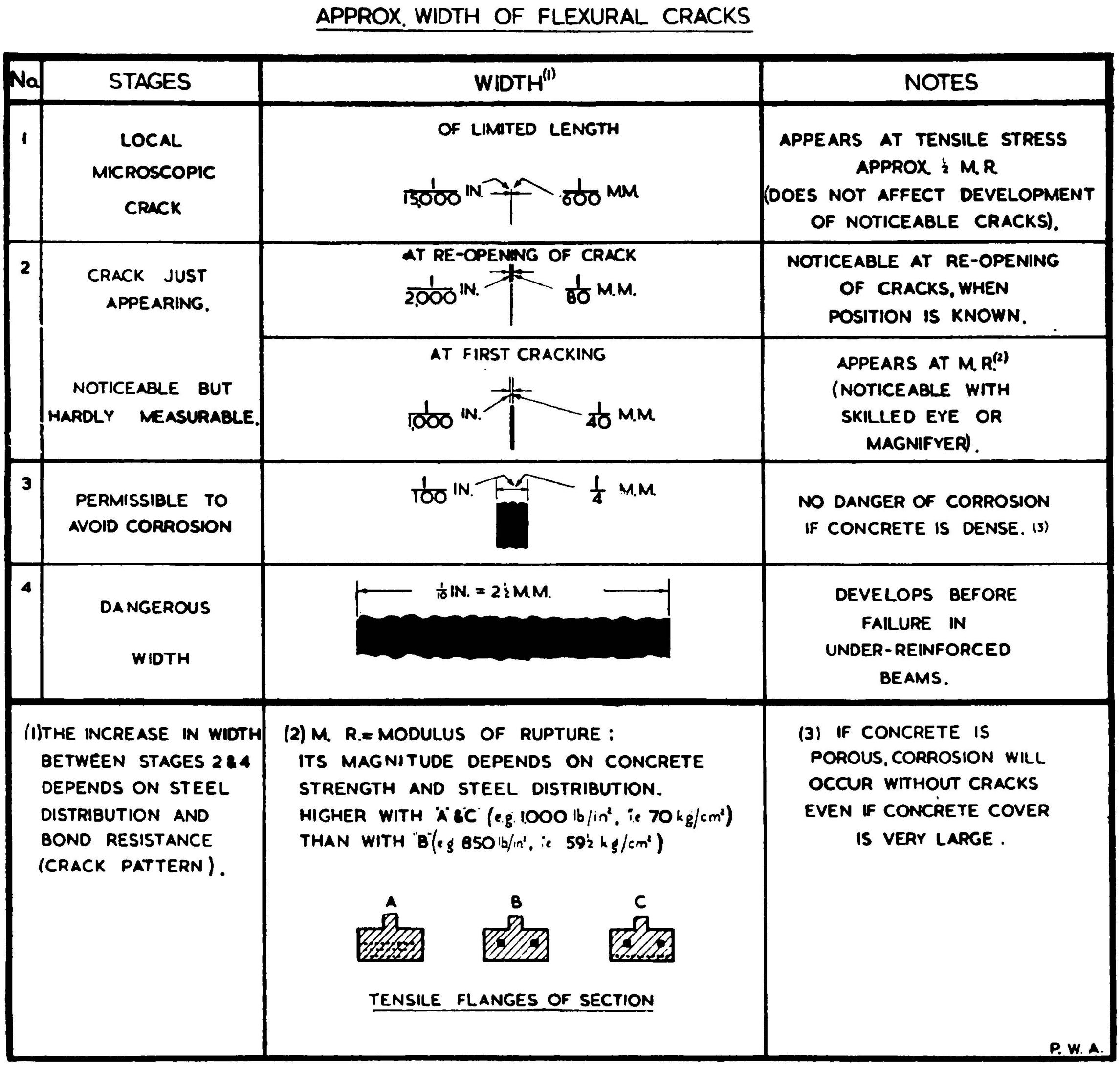


FIG. 6

ficient steel reinforcement by supplementary non-tensioned wires to obtain the required factor or safety against failure related to the «rare» loading. By such an arrangement the width of cracks is reduced as seen from Figure 5 of publication [7].

Fig. 6 shows various widths of cracks. Visible cracks occur when the modulus of rupture is reached which is not affected by the previous development of microscopic cracks.

There is obviously no safety against cracking for type (iii), but the position is, in any case, better than with ordinary reinforced concrete ([4]). It would be possible to base the design of type (iii) on a limited maximum width of cracks and controlled maximum deflection, although the average working load steel stress in a cracked section would be as high as 80,000 – – 100,000 lb/in². Such a structure would be more economical than prestressed concrete and preferable to ordinary reinforced concrete, particularly when compared with concrete structures containing non-tensioned high tensile reinforcement which in some countries is stressed up to 60,000 lb/in². (In the latter case a satisfactory crack pattern may be achieved, but the deformation is likely to be excessive).

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SUMMARY

Safety against cracking is obtained in truly monolithic structures for appreciable concrete tensile stresses under working load, as ascertained by British Railways, 1948-56; but with non-monolithic structures a residual compressive stress under working load would be required to obtain the same safety. The subject of the contribution is discussed for various types of structures.

([4]) Reference may be made to the satisfactory experience with spun concrete poles [8] exposed in the open air to atmospheric influences during the last 20-40 years. It may be pointed out that these spun concrete masts contain relatively thin high strength steel reinforcement (yield point approximately 88,000 lb/in², diameter 0.2-0.3 in.). The development of permanently visible hair cracks cannot be avoided with such masts and these cracks do not close, as is the case with prestressed concrete. Nevertheless, the masts have stood up very satisfactorily even in districts where chemical influences occur in industrial districts.

ZUSAMMENFASSUNG

In wirklich monolithischen Konstruktionen kann selbst bei bedeutenden Biegezugspannungen Rissicherheit unter Gebrauchslast erzielt werden, wie Versuche der Britischen Bahnen 1948-56 bewiesen haben. Aber in nicht monolithischen Konstruktionen würde eine bedeutende bleibende Druckspannung nötig sein, um denselben Sicherheitsgrad zu erzielen. Diese Frage ist für verschiedene Typen von Konstruktionen besprochen.

RESUMO

Observações efectuadas pelos Caminhos de Ferro Britânicos em 1948--1956 mostram que as estruturas verdadeiramente monolíticas apresentam, para valores apreciáveis das tensões de tracção no betão correspondentes às cargas de serviço, um bom coeficiente de segurança contra a fissuração; em estruturas não-monolíticas tornar-se-ia necessário dispor, sob a carga de serviço, de uma tensão de compressão residual para obter o mesmo coeficiente de segurança. Este problema é discutido no caso de vários tipos de estruturas.

RÉSUMÉ

Des observations effectuées par les Chemins de Fer Britaniques en 1948-56 montrent que les structures vraiment monolithiques présentent, pour des valeurs appréciables des contraintes de traction dans le béton correspondant aux charges de service, un bon coefficient de sécurité contre la fissuration; dans le cas de structures non-monolithiques, il serait nécessaire, pour obtenir le même coefficient de sécurité, de disposer, sous la charge de service, d'une contrainte de compression résiduelle. Ce problème est discuté pour divers types de structures.