Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 5 (1956)

Artikel: Cracks in prestressed concrete beams

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DOI: https://doi.org/10.5169/seals-6007

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Cracks in prestressed concrete beams

Risse in vorgespannten Betonbalken

Fissuração das vigas de betão preesforçado

Les fissures dans les poutres en béton précontraint

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I. *Introduction (various kinds of cracks in prestressed concrete beams).*

With regard to the individual causes, the following kinds of cracks may be considered: (1) shrinkage cracks; (2) settlement cracks; (3) bending-tensile cracks; (4) shear cracks at ends of beams; (5) principal tensile and shear cracks; (6) torsion cracks; (7) cracks due to impact; and (8) cracks due to faults in connection with prestressing [1].

Cracks (1) may develop if the concrete is insufficienttly cured before the prestress is applied. Once having occurred, they may open under loading whenever the bending tensile stress exceeds the effective pre-compression. By sufficient curing until application of the prestress, shrinkage is delayed and thus the development of such cracks avoided.

Cracks (2) may occur before prestressing due to insufficient spreading of the self weight to the ground or due to vibrations caused by traffic. It depends on their position whether they are later closed by compression due to bending or prestressing.

Cracks (3) will develop when the actual tensile stress due to load exceeds the effective pre-compression plus, if available, the tensile resistance of the concrete. These cracks disappear entirely when the load is reduced and compression is re-established. They may also temporarily develop in a zone which is normally in compression (e. g. during handling) and will close on discontinuation of the loading. However cracks may not close if they occur in a zone without compression due to prestress or bending, e. g. at the upper side of a beam near the supports.

Cracks (4) along the web at the end of an I-shaped section may

[1] Surface cracks causing so-called crazing have not been considered in this paper, nor cracks which occur due to excessive compression at crushing.

develop due to excessive shear stresses where the prestress is tranferred from the bottom flange to the web. Without vertical stirrups the web may split and with insufficient stirrups fine haircracks may occur. Cracks may develop also near the anchor ends of post-tensioned cables if insufficient reinforcement is provided.

Cracks (5) occur when the maximum principal and shear stresses exceed the tensile resistance. Normally there is no prestress available to close these cracks on removal of the load. Consequently they should be avoided altogether. Torsion cracks (6) are similar to cracks (5), and the same considerations apply. Cracks (7) are unpredictable; they may be harmless or not.

Quite different kinds of cracks listed under (8) may develop; e. g. in beams with pre-tensioned top and bottom wires, tensile cracks at the top flange may occur if the prestressing force is released first at the bottom alone or if the concrete is less well vibrated at the top than at the bottom. In these cases the prestress is effective only in the bottom flange and not in the top flange either temporarily or locally. Cracks may also develop when the selfweight is prevented from counteracting the prestress contrary to the design assumptions.

In this paper under II tensile bending cracks according to (3) are investigated to show that for monolithic beams with well-bonded tensioned steel fine cracks are entirely harmless. They close completely on removal of the load after previous static loading, not exceeding 80 to 95 % of the failure load, or after millions of repetitions of loading, as long as the latter does not exceed two-thirds of the failure load. In particular, it is shown that cracks are unlikely to develop under fatigue conditions or sustained loading as long as the tensile stress does not exceed two-thirds of the tensile resistance of the concrete. Some of these conclusions were stated by the author already on the occasion of the 3rd [1] and 4th [2] Congress. They will be amplified in this paper by some descriptions of new fatigue tests carried out jointly by the Chief Civil Engineering Dept., Eastern Region and the Research Dept. of British Railways, 1954 [3], and by other investigations.

Cracks (4) at the ends of beams are discussed under (III), together with the provision of shear reinforcement necessary to prevent their development. In this connection also the danger of corrosion is considered, which question the author had investigated for high strength reinforced concrete already in 1937 [4].

In (IV) accidental impact cracks (7) are described, together with the application of accelerated autogeneous healing under special temporarily applied prestress. This has been successful though the cracks had developed at positions where there was no compression.

II. *Bending tensile cracks.*

1. – *Cracks in ordinary reinforced concrete and in prestressed concrete beams.*

In ordinary reinforced concrete cracking is unavoidable [4, 5]. Shrinkage can be delayed by moist curing until the concrete is capable of taking up higher tensile stresses, but then cracks may develop. Tensile bending cracks will occur due to ordinary loading when the elongation of the steel exceeds the extensibility of the concrete. They become wider with increasing stress in the steel, particularly if the bond is destroyed between the reinforcement and concrete, e. g. with ordinary mild steel bars of large diameter. This is the reason why permissible steel stresses for ordinary reinforced concrete have been limited.

If, however, the bond between reinforcement and concrete is improved (which is obtained by the use of concrete of higher strength, the choice of steel bars of smaller diameter and/or the provision of indentations), the bond is destroyed only in the immediate neighbourhood of a crack and consequently the pattern is changed since individual cracks develop much more closely than with smooth round bars. In two cracks of the same width the steel stress in one crack may be much greater than in the other (1) if the concrete properties are in both cases the same and (a) the steel is deformed or indented instead of smooth surface or (b) of smaller size, and (2) if the steel is of the same size and properties and the concrete strength is greater. Obviously, the entire elongation is much greater with a higher steel stress. It is, however, not the *entire* elongation but the *maximum* width of the individual crack which matters from the point of view of corrosion, as was shown by Dr. F. v. Emperger [6], Dr. F. G. Thomas [5] and the author [4] some twenty years ago. The distance of cracks depends entirely on individual circumstances, i. e. shape of cross-section, dimensions, arrangement of steel reinforcement, bond conditions (strength of concrete, type of reinforcement, steel stress) and arrangement of loading; it seems therefore impossible to compute the distance between cracks on general lines as claimed by some research workers.

Prestressed concrete was originally limited, according to Freyssinet, to structures in which the development of cracks must be avoided under all circumstances. This view appeared to be entirely justified when Freyssinet, some thirty years ago, was the first to suggest that a very high tensioning stress be applied to ensure that the prestress remains effective. Without special investigation it was doubtful whether a crack under extraordinarily high steel stress would not become dangerously wide. Subsequent tests by the author have proved that they remain very narrow and close completely on load reduction, when the pre-compression becomes again effective [1, 2, 6].

The stipulation that freedon from cracks must be guaranteed has been introduced in the French Draft Code of Practice [8]. In this it is stated that only such structures in which freedom from cracking is ensured can be considered as prestessed. This is contrary to the views presented in the British First Report on Prestressed Concrete [9] and the German Code of Practice [10], in which there is no such limitation.

2. – *Various types of prestressed concrete beams and the factor of safety against cracking.*

Three different types may be considered, (1) monolithic beams, (2) beams assembled from blocks with satisfactory mortar joints, and (3) cracked beams or as (2) but without, or with unsatisfactory, mortar joints, representing pre-formed cracks which open when the bending tensile stresses exceed the pre-compression. Three different arrangements may be used which affect the behaviour of cracks, (a) fully bonded wires or bars (always with pre-tensioning and sometimes with post-tensioning when excellent grouting is ensured); (b) partially bonded cables or bars (mostly with post-tensioning when optimum bond cannot be ensured); and (c) non-bonded wires, cables or bars (with post-tensioning without, or with inefficient, grouting). Thus, 9 different types of construction may occur with appreciable differences.

When the safety against cracking is considered, the great difference between Type 1a and Types 3a to 3c ought not to be ignored. If the working load tensile stress is just balanced by the effective pre-compression, the factor of safety against cracking with Type 1a amounts to 2 or 1.5 for a respective effective prestress of 1,000 or 2,000 psi (70 and 140 kg/cm²). However, with Type 3 this factor is in both cases only 1. Between these extremes, Type 1a representing the optimum and Types 3 the minimum resistance against cracking, there are many intermediate cases. Thus, quite different considerations should apply to these different types with regard to the permissible stress under working load.

With arrangement (a) the bond is destroyed only in the immediate neighbourhood of any crack, whereas with (c) the steel elongates over its entire length, and permanent deformation may remain. Thus, cracks may not close completely on removal of the load as they do with (a). Arrangement (b) is an intermediate case between (a) and (c).

3. – *Visible and Microscopic cracks.*

A crack may be considered as visible when noticeable to the unaided eye of a skilled research worker. It depends entirely on his experience and the instruments he uses whether development of a crack is detected earlier or later. Its visible width may be taken as 0.01 mm. (1/2500 in.) if the position is known and 0.02 mm. (0.0008 in.) if it is unknown. The concrete stress computed for a homogeneous section at which a visible crack develops is called the modulus of rupture and also bending tensile or flexural strength; but this nominal stress differs greatly from the direct tensile strength of the concrete (2). The modulus of rupture is approximately twice the direct concrete tensile strength. Recent research has proved that microscopic (i. e. invisible) cracks develop earlier.

Professor R. H. Evans [11] was, to the author's knowledge, the first to ascertain the development of such microscopic cracks at bending stresses which correspond to the direct tensile strength and not to the modulus of rupture.

Similar results were obtained in the tests [3] from electric strain

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(2) It is difficult to ascertain this strength correctly since fracture may occur in the test specimen at the grips of the testing apparatus and any eccentricity affects the result. Thus, mostly the modulus of rupture is ascertained by beam tests. The results depend greatly on the beam dimensions and loading arrangement. A single point load or two point loads may be applied either to a long or a short beam, and quite different results may thus be obtained for the same concrete quality. A satisfactory comparison with the stress condition in a beam would be obtained only if the cross section of the specimen were equal to, or of similar proportions to the actual beam. With regard to direct tensile tests, briquettes have, in the author's experience, resulted in some uniformity, when tested by the same person, but the value thus obtained is greater than the direct concrete tensile strength because of stress concentration. However, a certain basis of comparison is obtained.

gauge measurements. Load deflection diagram, Figure 1, shows diagrammatically the three stages which ought to occur with all prestressed monolithic concrete beams with bond. (Stage 1: full homogeneity before cracking; Stage 2: larger deflections in cracked state without permanent deformation; Stage 3: large deflections, a part of which remains permanent). An enlargement of part of this diagram shows that there is not a sudden change from Stage 1 to Stage 2 by two straight lines, but

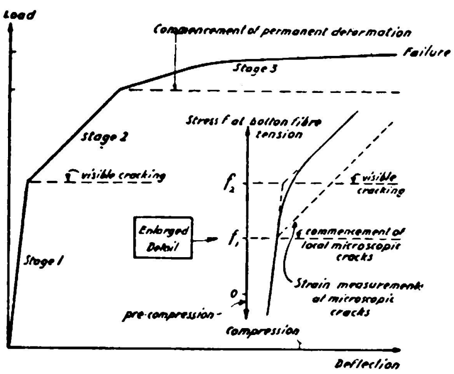

FIG. 1. Typical load deflection diagram

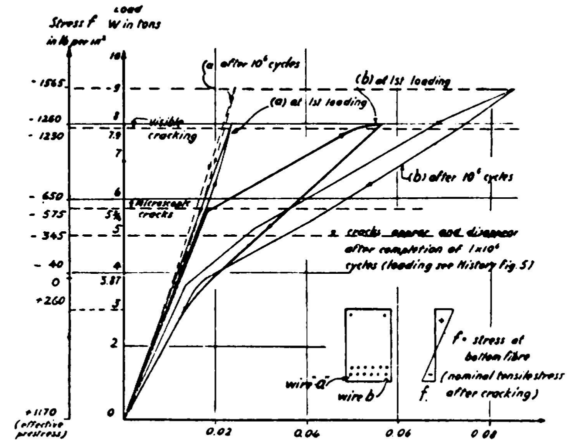

FIG. 2. Strain measurements

by a curved portion commencing at the concrete tensile stress f_1. In the curved part apparently plastic deformation takes place in the concrete tensile zone. Visible cracks are noticeable only when the stress f_2 equalling the modulus of rupture is reached where the curved portion of the diagram is rather pronounced.

In the tests [3] similar curves to those of Figure 1 were obtained from most of the strain gauge readings; but in a few instances already at the first loading a sudden change was noticed in the tensile zone at the stress f_1 approximating the tensile strength, as indicated in the enlarged part diagram of Figure 1. Microscopic cracks of limited size must, therefore, have developed already at that load at certain points of measurements. However, no visible cracks were noticed by careful search before the ordinary cracking load was reached, corresponding to the stress f_2.

Figure 2 shows diagrams based on strain gauge readings from the tests [3] obtained at two wires «a» and «b» in loading cycles at the first static loading up to visible cracking, and a second cycle after fatigue loading. Zero stress corresponded to a load of approximately 3.87 tons and, in spite of careful search, cracks became visible not before a load of 7.9 tons was reached (tensile stress 1,230 psi, i. e. 86 kg/cm^2). From the kink in the stress-strain diagram for wire «b» at a load of 5 $^3/_4$ tons, (tensile stress of 575 psi, i. e. 41 kg/cm^2), it can be assumed that a microscopic crack occurred already at that load near wire «b»; but no kink occurred in the stress-strain diagram for wire «a», at which the strain gauge was in a different section from that of wire «b».

The phenomena discussed in Figure 2 and in the following Figures 4 and 5 relate to 3 beams of cross sections, length and testing arrangement shown in Figure 3. All beams contained 6 tensioned wires 0.276 in. diameter (7 mm.) of a strength of 218,000 psi (153 kg/mm²) and the beam B also 6 non-tensioned smooth wires of the same diameter. In all 3 beams the effective prestress at the bottom fibre of the beam was approximately equal (1,170, 1,200 and 1,230 psi, corresponding to 82, 84 and 86 kg/cm² respectively), as was ascertained from strain measurements between tensioning and testing, and checked by many load-strain and load-deflection diagrams at various stages of loading. Beams A1 and B were loaded statically to failure after previous application of 1 million repetitions of loading in a cracked state applied at 250 cycles

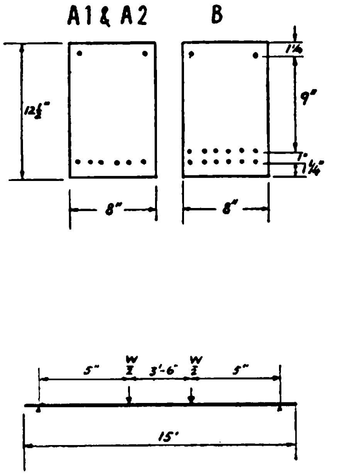

FIG. 3. Particulars about 3 fatigue tests

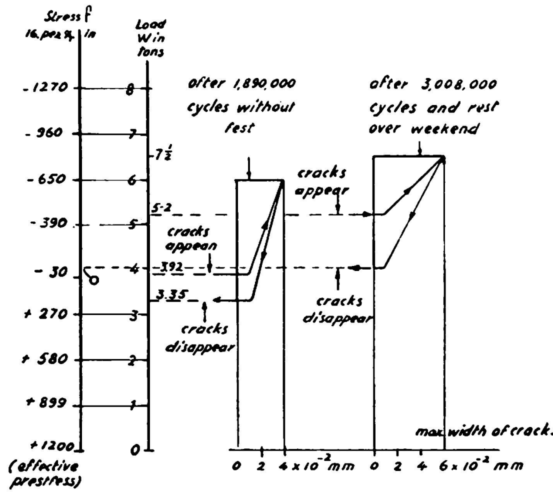

FIG. 4. Influence of rest on visibility of cracks beam A 2

per minute with many rest periods and beam A2 was loaded to failure by fatigue, which occurred at a load slightly exceeding two-thirds of the static failure load in this special instance. Over 10 million repetitions were applied at 500 cycles per minute with very little rest. The beams of the Type A reached their entire tensile resistance at static loading, the wire fracturing at failure, but the beam B attained only 83 % of the maximum tensile resistance owing to slipping of single non-tensioned smooth (3) wires 0.276 in. diameter. However, the beneficial effect of the non-tensioned wires with regard to the limitation of cracks is seen in Figure 5.

Microscopic cracks were observed similarly also in beam A2 previously to a fatigue loading and they did not become visible after the completion of one million cycles between an upper limit corresponding to approx. two-thirds of the usual modulus of rupture and a lower limit of approx. zero stress. After a relatively small number of cycles at an increased range of loading cracks became visible.

From these observations it can be concluded that local microscopic cracks develop as soon as the concrete stress exceeds the tensile strength. In spite of such local microscopic cracks which do not extend through

(3) From this it has been concluded that only indented wires or pairs of twin-twisted wire 0.276 in. diameter should be used as non-tensioned reinforcement to use fully their tensile strength.

the entire section and are harmless, visible cracks occur only when the concrete stress reaches in a static loading the modulus of rupture or in a fatigue loading either when this is within the tensile range and the concrete stress exceeds two-thirds of the modulus of rupture or when the range is further increased.

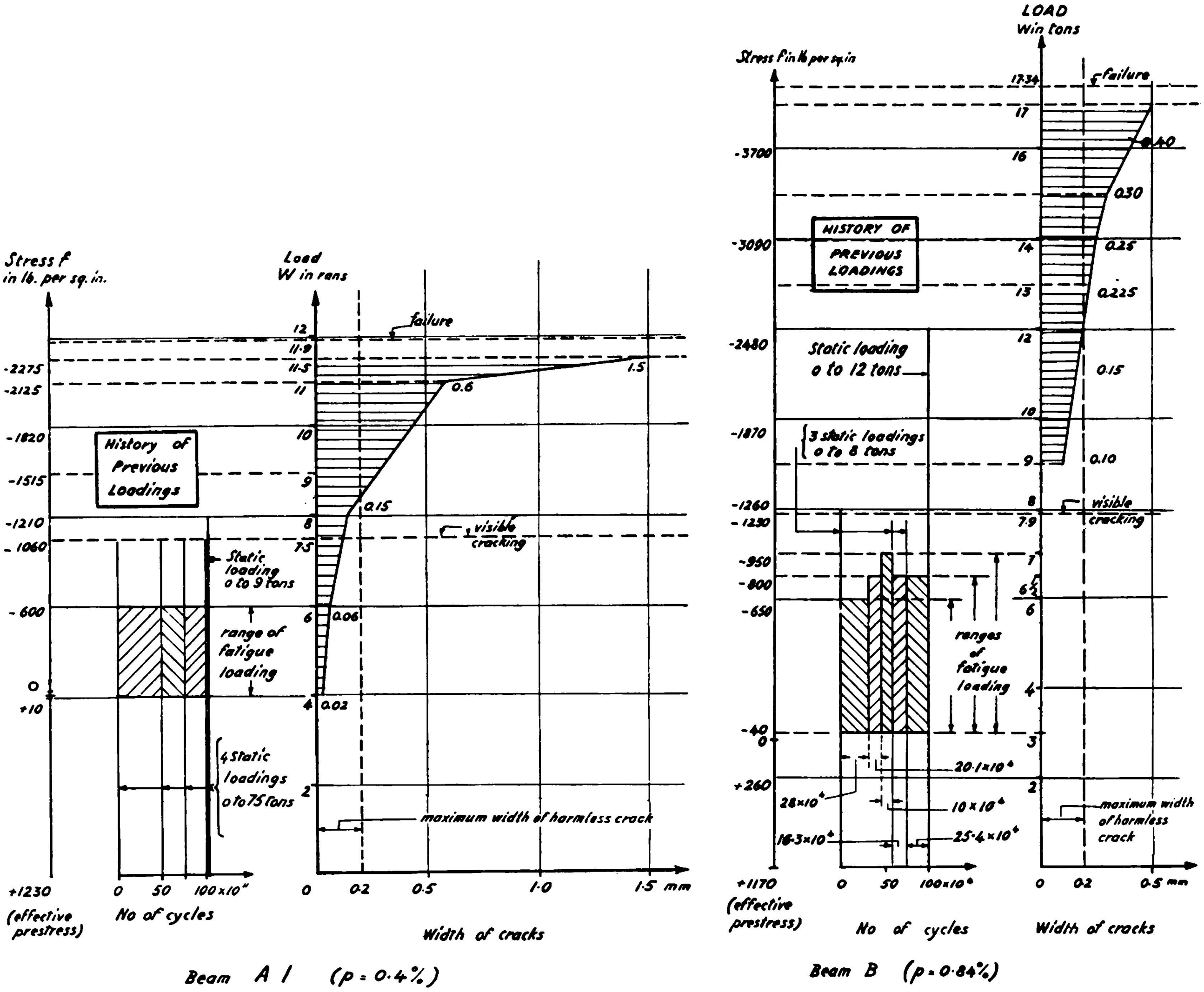

FIG. 5. Widths of cracks at final static loadings to failure (with history of previous static and fatigue loadings)

4. – *Visible cracks.*

It was already mentioned that cracks of known position become noticeable to the skilled eye at a width of approximately 0.01 mm. (0.0004 in.), when the nominal concrete tensile stress in a homogeneous section equals the modulus of rupture. The writer has found very good uniformity of this stress from numerous tests on precast beams with pre-tensioned wires, i. e. a modulus of rupture of 1,000 to 1,200 psi (70 to 84 kg/cm^2) [12]. As already stated, in the tests [3] the shortening was measured between initial tensioning and testing, and thus the effective prestress in each beam A1, A2 and B ascertained. It was thus possible to obtain sufficiently exact tensile stresses at cracking which varied between 1,060 and 1,230 psi (74 and 86 kg/cm^2). In many publications much lower stresses are related to the cracking load.

Great variations in the tensile stresses at craking at tests are also given by Guyon [13]. The writer is convinced that other causes accounted for these discrepancies, e. g. the development of shrinkage cracks before prestressing. The writer noticed once in an acceptance test [12] that a shrinkage crack became visible at a tensile stress of 300 to 400 psi (21 to 28 kg/cm^2). Further shrinkage cracks were avoided in all future production of the prestressing works in question by moistening (by sprinklers). Another cause may be due to increased losses resulting in lower effective prestress. Unfortunately it is the general practice to underestimate the losses. Also the initial prestress may be less owing to errors in the manufacture; last but not least there may be differences in observation of cracking.

Undoubtedly, beside the actual concrete tensile strength also the cross-section and the arrangement of the tensioned steel is of great influence on the noticeability of cracks. They will be observed earlier if the percentage of the tensile reinforcement is small. The same applies if concentrated prestressing cables are provided rather far apart which are not well distributed in the tensile zone. In such a case shrinkage cracks will develop even if there is nominal compression over the entire section as the pre-compression is not well distributed by cables far apart.

Sometimes the effective prestress is ascertained by the observation at which load the cracks disappear or appear again, based on the assumption that a crack having once occurred will close or open when the zero stress is reached. However, this is not always the case, as will be discussed in (5).

It can, therefore be definitely stated that visible cracks will not develop in a beam with well-bonded tensioned steel well distributed in the tensile zone, before the loading corresponds to a concrete tensile stress of approx. 1,000 to 1,200 psi (70 to 84 kg/cm^2), for concrete of a cube strength of approximately 7,500 to 10,000 psi (525 to 700 kg/cm^2). Provided that the effective prestress is assessed correctly and shrinkage cracks have not occurred before transfer of the prestress.

5. – *Closing and opening of cracks.*

Cracks close completely even after considerable deformation, as long as Stage 3 in Figure 1 was not previously reached. Immediately on removal of the load some deformation may remain and cracks may still be temporarily visible, but they close after certain rest periods. Such a recovery occurred, e. g. in a static test in 1949 [14], when the deformation disappeared completely after a previous loading approaching nearly the failure load.

Figure 4 shows the influence of rest periods upon the load at which cracks appear at loading and disappear on removal of the load. This relates to beam A2, to which 1 million cycles had been applied in a non-cracked state between the loads 4 and 6 tons, corresponding to tensile stresses of 30 and 650 psi respectively (2 and 45 kg/cm^2), after previously microscopic cracks were detected at a load of approx. 5.5 tons (tensile stress of 500 psi, i. e. 35 kg/cm^2). Visible cracks were noticed when the range was increased and the cycles applied between 3 and 6 tons. Immediately after 890,000 cycles of this loading in a static loading the cracks became visible at approximately zero stress and disappeared at a load of 3.35 tons (compressive stress of 160 psi, i. e. 11 kg/cm^2). However, after the application of the 3rd million of loading between 3 and 6 $^1/_4$ tons (tensile stress (4) of 730 psi, i. e. 51 kg/cm^2) and a rest over the weekend, the cracks became apparent only at a load of 5.2 tons and closed at a load of 4 tons. Under otherwise equal conditions, cracks disappear and appear again at a higher nominal concrete tensile stress if the percentage of reinforcement is greater, and in each case if there is no rest period they appear at a higher stress than they disappear. After 7,707,000 cycles, at each million the upper limit being increased by $^1/_4$ ton, the cracks became visible to the unaided eye at zero load. After sufficient rest period, recovery would most likely have taken place, but the upper limit which was at the 8th million cycles 7 $^1/_2$ tons (tensile stress 1,115 psi, i. e. 78 kg/cm^2) was further increased. One wire fractured at 9,638,000 cycles at an upper limit of 8 tons (tensile stress 1,270 psi, i. e. 89 kg/cm^2) and failure occured after a further 33,000 cycles at an upper limit of 8 $^1/_4$ tons (tensile stress 1,500 psi, i. e. 105 kg/cm^2).

Reference may be made also to Figure 2. After completion of the fatigue loading in a cracked state, details of which are shown in Figure 5 (history of beam), the cracks appeared and disappeared at a load of 5 tons, corresponding to a concrete tensile stress as high as 345 psi (24 kg/cm^2). Another interesting feature is seen in Figure 2 by the strain diagram for wire «a» after fatigue loading. This phenomenon indicates that wire «a» was in a non-cracked portion, whereas wire «b» was within a microscopic crack which became later visible; apparently some stress re-distribution must have taken place.

6. – *The width of cracks.*

Figures 5 (a) and (b) show the widths of the maximum cracks at static loadings to failure of beams A1 and B, together with the history of the previous static and fatigue loadings. From these diagrams it is seen that even after previous high loadings corresponding to nominal tensile stresses of 1,060 and 1,560 psi (74 and 108 kg/cm^2) respectively at beams A1 and B, the maximum widths were within the harmless range up to high proportions of the failure loads. The test results according to Figure 5 are very encouraging and allow to consider the possibility of permiting cracks in prestressed concrete of the type discussed. For example, with beam B half the harmless width was reached at a nominal tensile stress of 1,400 psi (98 kg/cm^2), and it must not be forgotten that the cracks close up on reduction of the load.

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(4) *After cracking* such a stress computed for a homogeneous section is obviously only a *nominal* tensile stress.

Tests are being carried out by the Chief Civil Engineer's Dept., Eastern Region, British Railways, to investigate again the influence of the width of cracks upon corrosion. Prestressed sheet piles were loaded nearly to failure and cracks of various widths were kept open by wedges. A specimen was placed into the sea between low and high tide in June 1953. In January 1955 two wires, were cut out from the specimen (see Figure 6) and the remaining part again placed in the sea. No trace of corrosion was noticed where the cracks were fine and thus this has confirmed previous results. It seems to be proved that a capillary action does not tacke place if the width of a crack is less than say 0.008 in (0.2 mm) provided that the concrete is dense, which is essential with prestressed concrete.

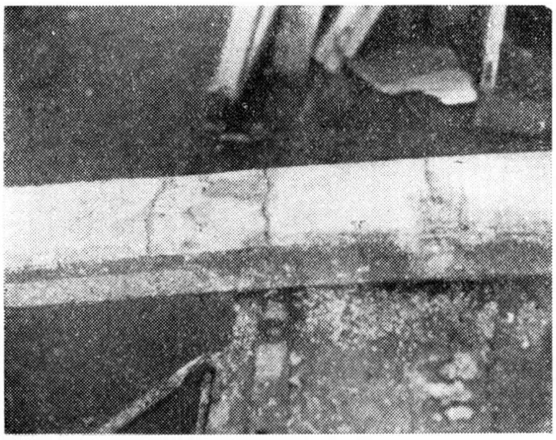

FIG. 6

It is not within the scope of the present paper to investigate the development of the crack pattern during loading and particularly before, and at, failure. It may only be mentioned that in under-reinforced beams failure is not imminent before the width of the largest crack exceeds 2 mm.

III. *Horizontal shear cracks at the ends of beams with pre-tensioned wires.*

With pre-tensioning the wires are generally straight along the entire length of a beam and not bent up towards the ends. The centroid of the wires must, therefore, be in such a position that at transfer the stress at the bottom fibre does not exceed the permissible compressive stress, and that at the top does not reach too high tensile stresses but preferably approximates zero.

There are two ways of complying with this condition. Either the tensioned wires are placed uniformly over the section, or the greater part of the tensioned steel is placed in the bottom flange so as to ensure maximum tensile resistance at failure and the remaining steel is in the top flange. Some research workers suggest that only the former solution is satisfactory and prevents splitting at the ends. However, this solution is less satisfactory from the point of view of ultimate resistance and handling, and the second alternative seems therefore to be more practical.

In order to avoid splitting of the web, usually with I-shaped beams, stirrups and end stiffeners are provided similar to the end blocks used for anchorages of post-tensioned cables. Near their anchorages, stirrups must be provided in two directions to take up the tensile and shear stresses. With pre-tensioning the prestress is not transferred at the anchorage but gradually over a certain length, and rather different trajectories occur from those relating to post-tensioned cables. The transmission length of pre-tensioned wires depends on the diameter as on the surface conditions of the wire and on the concrete strength. The usual end stiffeners are often awkward as they require special mould ends for different lengths of beams. To avoid this the author has investigated whether stirrups alone in the web would suffice without concrete end stiffeners. Particulars of the test beams of a wide bottom flange and a narrow web are seen in Figure 7a, (stress diagram Figure 7b). After preliminary tests on similar beams in which sufficient stirrups were provided and no cracks developed, tests with different shear rein-

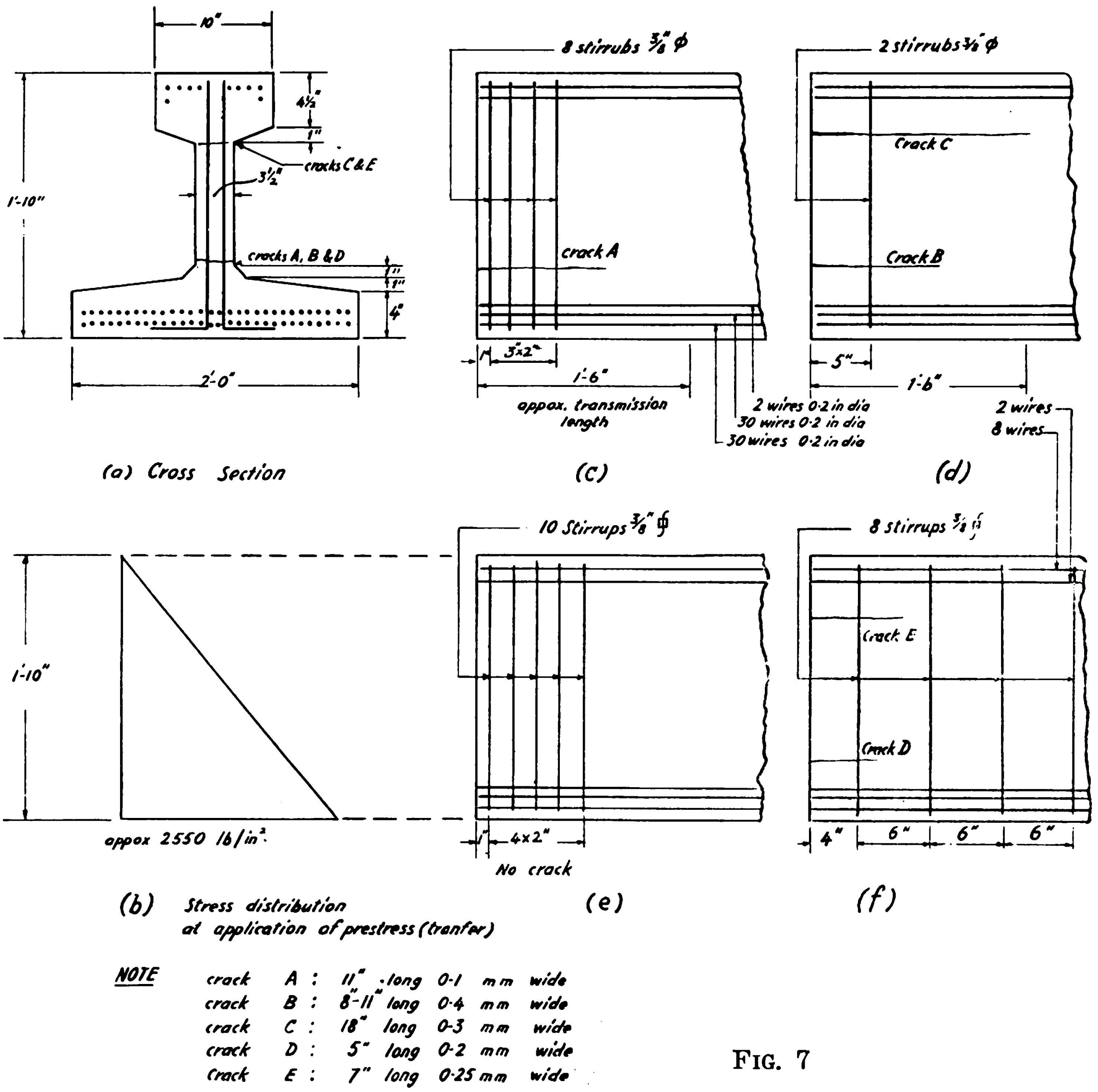

FIG. 7

forcement were carried out close to the releasing end where the impact is greatest, and in this case cracks developed in the specimens tested.

From Figure 7c and d it is seen that the cracks did not become very long even at ends where only two arms $^3/_8$ in. mild steel bars were provided. At this rather weakly reinforced end of the beam the cracks were obviously much wider than those at the much heavier reinforced end. None of the cracks really interfered with the development of the prestress of the wires 0.2 in. (5 mm.) diameter, which was gradually introduced over a length of approximately 18 in. in all the cases in question as proved by strain measurements.

Figures 7 (e) and (f) show particulars of further test specimens in which square twisted bars $^3/_8$ in. (approx. 0.95 cm.) were used as shear reinforcement.

IV. *Impact cracks and accelerated autogeneous healing of cracks.*

It is known that fine cracks heal in the course of years if there is a possibility of hydration. This can be accelerated if the healing process is carried out under pressure, as the author noticed by the following

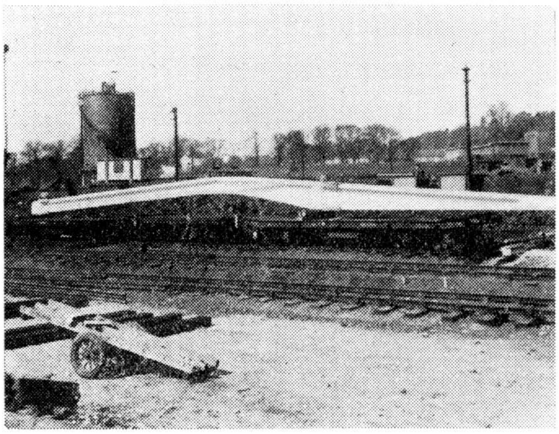

FIG. 8

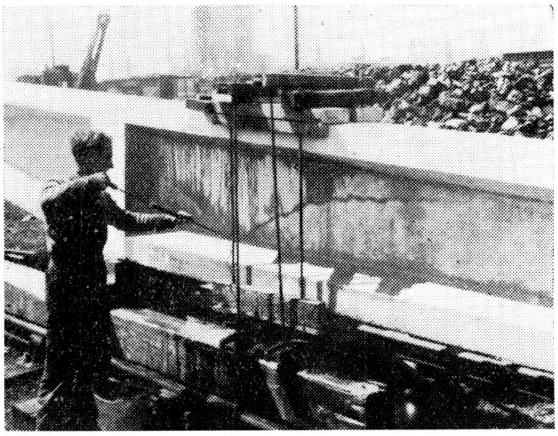

FIG. 9

practical experiment in 1953 and was later shown also in the paper [14]. Prefabricated roof beams for the engine shed, Ipswich, of 102 ft. (30.9 m.) length containing post-tensioned cables, had a free span of 64 ft. (19.4 m.) and at one side a cantilever of 37 ft. (11.21 m.) length (Fig. 8). When the first beam was lifted from the casting platform it was accidentally dropped, the cantilever end heavily hitting the ground. Thus, an impact force was applied to the cantilever in the opposite direction to the load for which it was designed. By this accident a considerable crack developed, as seen in Fig. 9. It began as a tensile crack across the bottom flange and forked into two branches, one of which formed within the web along the beam as a typical shear crack. By loading the canti-

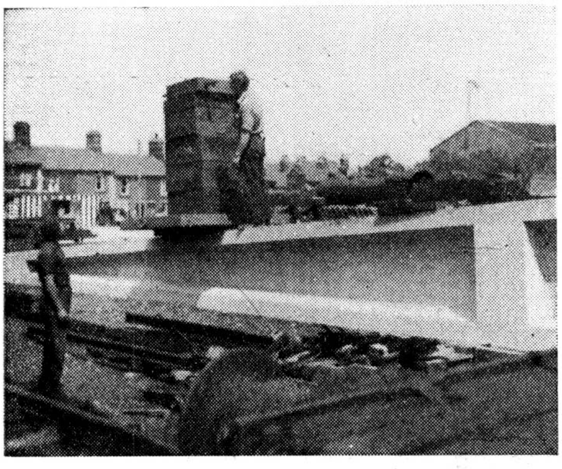

FIG. 10

lever, the vertical tensile crack closed and by temporary vertical prestressing shown in Figure 9 the horizontal portions along the crack were pressed together. Previously the faces of the crack were thoroughly moistened with the use of a bicycle pump. Where the crack was particularly fine, pure water was injected and where the crack was slightly wider a composition of water and cement was used. The loading of the cantilever and the vertical prestressing by pressing together the top and bottom flange continued for three weeks, and during all this time the crack was kept moist. After termination of this healing process, a test loading was applied to the cantilever and sustained for 24 hours, as seen in Figure 10. At this loading tensile stress of approx. 300 psi (21 kg/cm²) occurred. Obviously, before this loading was applied the temporary prestressing had been terminated. This loading test was successfully repeated two months later before the beam was placed in position. At erection the stresses in the beam were further increased owing to impact, without opening of the cracks.

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ACKNOWLEDGMENT

The author expresses his thanks to the Chief Civil Engineer, Eastern Region, British Transport Commission, for the permission to include in this paper the latest research carried out by British Railways, and to the Assistant Engineer, New Works, for his support of these investigations. The fatigue tests with the interesting strain gauge measurements were carried out by the Engineering Division of the Railways Research Dept., Derby.

SUMMARY

The author examines, in the light of his own experiments, problems dealing with crack formation, the behaviour of cracked prestressed concrete beams and the closing and healing of different kinds of cracks.

The author also deals with: visible and microscopic cracks under statical and fatigue loading in the presence of pretensioned steel; cracks in prestressed concrete beams subjected to impact; opening of cracks under fatigue and statical loading; maximum permissible width of cracks to avoid corrosion of reinforcement; flexural and shear cracks; closing of cracks by autogeneous healing by pretensioning.

These consideration are illustrated with practical examples.

ZUSAMMENFASSUNG

Dieser Beitrag zeigt, auf Grund der eigenen Erfahrung des Autors, einige Gesichtspunkte über die Entstehung von Rissen, das Verhalten von vorgespannten Betonbalken mit Rissen und das Ausbessern und Wiedergutmachen einiger Risse.

Feine mikroskopische und sichtbare Risse unter statischer und Ermüdungs-Beanspruchung von Balken mit vorgespannten Drähten. Das Auftreten von Rissen in vorgespannten Balken bei stossartiger Beanspruchung; Vergrösserung der Rissebreite unter statischer und Ermüdungs-Beanspruchung. Grenze der Rissbreite um jede Möglichkeit der Korrosion zu vermeiden, Biege- und Schubrisse, autogenes Schliessen von Rissen unter Vorspannung, mit einigen praktischen Beispielen.

RESUMO

O autor apresenta, baseando-se nos ensaios que efectuou, algumas considerações sobre a fissuração, o comportamento de vigas de betão preesforçado fissuradas e a correcção de algumas fissuras.

O autor trata ainda de fissuras microscópicas e fissuras visíveis sob a acção da fadiga e das cargas estáticas, em presença de armaduras em tensão; a fissuração das vigas de betão preesforçado submetidas ao choque; o aumento da fissuração sob à acção da fadiga e das cargas estáticas; largura limite das fissuras para evitar a corrosão das armaduras; fissuras de flexão e de corte; fecho de fissuras por correcção autogénia por pretensão.

Ilustram-se estas considerações com exemplos práticos.

RÉSUMÉ

L'auteur présente, en se fondant sur des essais qu'il a réalisés, quelques considérations sur la fissuration, le comportement de poutres en béton précontraint fissurées et la correction de quelques types de fissures.

L'auteur s'occupe également de: fissures microscopiques et fissures visibles sous l'effet de la fatigue et des charges statiques, en présence d'armature pré-tendues; la fissuration de poutres en béton précontraint soumises aux chocs; l'ouverture des fissures sous l'effet de la fatigue et des charges statiques; la largeur limite des fissures pour éviter la corrosion des armatures; fissures de flexion et de cisaillement; fermeture des fissures par correction autogène par pré-tension.

Ces considerations sont illustrées par des exemples pratiques.

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