

Paper No. 6300

The relative merits of plain and deformed wires in prestressed concrete beams
 under static and repeated loading †

by

Stephen Charles Clavell Bate, Ph.D., B.Sc.(Eng.), A.M.I.C.E.

Discussion

Dr Paul Abeles (Assistant to the Chief Civil Engineer, British Railways, Eastern Region) pointed out that the design indicated in Fig. 3, was based on an arbitrary assumption that the concrete tensile stress in the added concrete was limited to 250 lb/sq. in. That meant that concrete of a depth of 2.66 in., according to Fig. 12, was assumed to be non-existent in bending, but available in shear. Such an arbitrary assumption did not appear to be justified, as extensive tests have proved.^{9, 10}

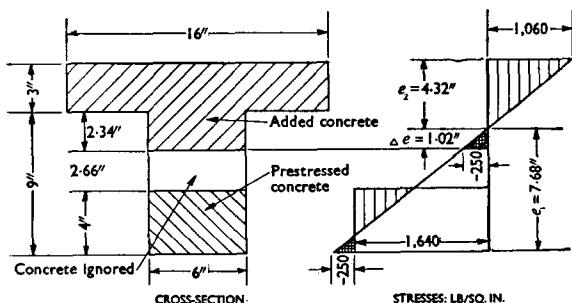


FIG. 12

54. Stress redistribution was expected to occur before cracks had become visible in the prestressed concrete only if the maximum tensile stress in the added concrete exceeded that at which *visible* cracks normally developed. Consequently, if before cracking the greatest tensile stresses did not appreciably differ from the maximum tensile stress at which visible cracks developed, there seemed to be no need to consider a stress redistribution or non-co-operation of part of the section. It was true that microscopic cracks occurred much earlier. However, tests had proved¹¹ that when they developed, they did not influence the stress at which cracks became visible, even after these microscopic cracks had previously opened and closed a million times.

55. Evans and Bennett¹² had reached the conclusion that the design should be made for the entire composite section, provided that the resultant stress in the prestressed part did not exceed the modulus of rupture. Moreover, it was stated in the Draft Code of Practice for Prestressed Concrete Buildings that prestressed and added concrete were "deemed to co-operate".

56. The two stress diagrams, Fig. 13, for working load ($W=9$ tons) and for average cracking load ($W=13.6$ tons) were based on a residual precompression of 1,640 lb/sq. in. These stresses had been computed on the lines observed by the Civil Engineer's Department, British Railways, Eastern Region, since 1949, when the first tests on such

† Proc. Instn civ. Engrs, vol. 10, p. 473 (Aug. 1958).

⁹ References 9 to 12 are given on p. 225.

composite beams had proved the full co-operation and confirmed that the entire section acted homogeneously.⁹ This had been established not only before cracks developed, but also after cracking, but obviously on condition that any possibility of separation between prestressed and added concrete was prevented.

57. As seen in Fig. 13, just before cracking, a slight stress redistribution might have taken place, resulting in a tensile stress higher than 904 lb/sq. in. at the bottom edge and a tensile stress slightly lower than 1,151 lb/sq. in. in the added concrete.

58. If a nominal residual prestress was considered, based on maximum losses, such as 1,570 lb/sq. in. according to Table 9, then the tensile stress at the tensile skin amounted to 974 lb/sq. in. at cracking, which value agreed very well with that of 1,000 lb/sq. in. obtained from numerous tests as a safe value, provided that high-strength concrete with well distributed pretensioned wires was employed.

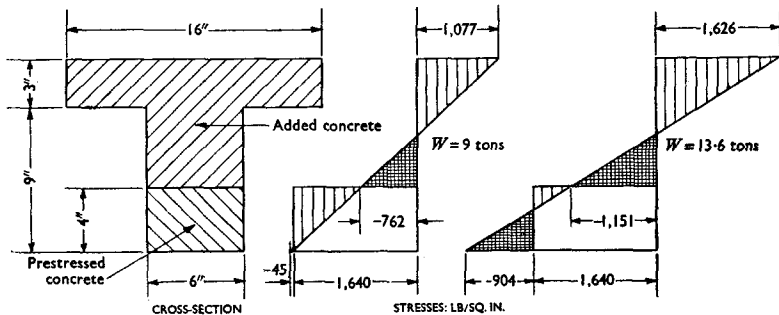


FIG. 13

59. It was generally agreed that failure and working load should be considered separately and more steel added where required. Hence, Fig. 10 might be somewhat misleading with regard to the factor of safety against failure. This factor was seen to be greater than the required minimum, if no tensile stress was permitted under working load, for in this case the steel area, corresponding to the required prestressing force, was large. With increasing permissible tensile stresses, obviously the area of the tensioned steel, A_{st} , and also the factor of safety against failure were reduced. This situation could not be avoided, but it was possible, without affecting the degree of prestress, to obtain the required factor of safety by adding non-tensioned wires.

60. Fig. 14 showed a revision of Fig. 10 for the design assumption in Fig. 13. The permissible working load W_{perm} had been plotted as well as the factors of safety against failure and visible cracking. In this diagram also the required additional cross-sectional area of non-tensioned steel A_{sn} was indicated, for a factor of safety against failure of at least 2, by the ratio A_{sn}/A_{st} .

The Author, in reply, stated that the section of beam selected for the tests had been chosen from considerations of experimental convenience in fulfilling the main function of the investigation, which was a study of the performance of the prestressing wires under repeated loading. Calculation of the working load had therefore followed from the choice of dimensions rather than the calculation of the dimensions following from the assessment of working loads as in normal design. In those circumstances, the limitation of the permissible bending tensile stress to 250 lb/sq. in. meant that part of the concrete section had to be ignored although it was agreed that full composite action was obtained and that visible cracking did not develop generally until the bending tensile stresses exceeded 900 lb/sq. in. as illustrated in Fig. 13 for the average cracking load of 13.6 tons. The stress distribution under a load of 9.0 tons might well have been closer to that shown in Fig. 13 than to that shown in Fig. 12, but the higher bending tensile stresses for the former were not compatible with a limitation of 250 lb/sq. in., and the latter stress distribution was therefore a compromise. This compromise would

probably not arise in practice as a choice of dimensions for the section, which did not use the full concrete section, would be uneconomic.

62. At the time the investigation had been started, it was unlikely that a bending tensile stress in excess of 250 lb/sq. in. for prestressed concrete beams subjected to frequently repeated loads would have been generally acceptable. That higher values were now accepted was largely due to Dr Abeles's work during the past few years, and the results of this investigation described in the Paper suggested that even higher values might be used.

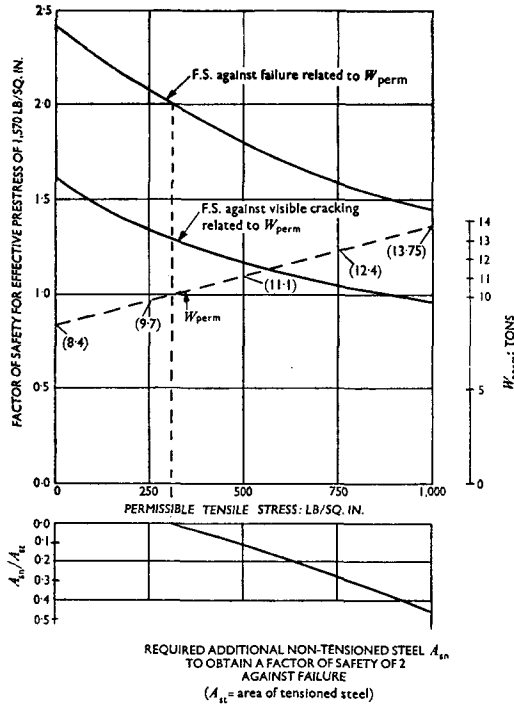


FIG. 14

63. It was agreed that working and ultimate conditions should be considered separately in design, particularly in composite construction where the addition of un-tensioned steel was a valuable method for increasing the load factor against failure when necessary. Fig. 10 was primarily intended to relate to conditions leading to fatigue failure. General conclusions on the performance of composite prestressed concrete beams should not be drawn from tests on one form of section only, especially when that form was adopted with a rather different purpose in mind.

REFERENCES

9. P. W. Abeles, "Some new developments in prestressed concrete". Struct. Engr, vol. 29 (1951), p. 259.
10. P. W. Abeles, "Fatigue tests on partially prestressed concrete members". Int. Ass. Bridge Struct. Engrg, Fourth Congress, Cambridge, Final Report, 1953.
11. P. W. Abeles, "Fatigue resistance of prestressed concrete beams". Int. Ass. Bridge Struct. Engrg, Fifth Congress, Lisbon, Final Report, 1957.
12. P. H. Evans and E. W. Bennett, "Pre-stressed Concrete". Chapman & Hall, London, 1958, p. 180.