

Further discussion

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An appreciation of the work carried out on fatigue in prestressed concrete structures*

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The author has omitted from his review much of the fundamental information on the strength of hard-drawn wire and of heat-treated wire under fluctuating tensile stress. The evidence⁽¹⁻³⁾ shows that the limiting range of tensile stress in fatigue is little influenced by the minimum of the range for minimum values up to 60% or more of the static tensile strength for these types of wire. This characteristic is displayed in prestressed concrete and is demonstrated by the results obtained by Xercavins [reference (14) of the paper], who showed that the fatigue strength of prestressed concrete was increased by increasing the initial tension in the steel; thus an increase in the minimum stress in the steel in a prestressed concrete beam increased the maximum stress that could be sustained under repeated loading. Further fundamental data on the fatigue strength of wire do not appear to be required; quantitative information on the fatigue properties of marketed prestressing wires is, however, essential, as the results of fatigue tests on wire reported by Levi⁽⁴⁾ have shown that the use of some types of wire in structures subjected to heavy repeated loading may give little margin of security against failure.

The investigation at the Building Research Station, to which the author refers, was designed to assess the fatigue strength of plain and indented hard-drawn wires of British manufacture. The wires were incorporated in prestressed concrete beams, which were stressed by pre-tensioning the wires, and tested under repeated loading. The fatigue tests on the wires were made in this way as research^(1, 3, 5) has shown that surface condition and environment have an important influence on strength. Some of the results of this investigation dealing with plain smooth wires from coils of large diameter have already been reported⁽⁶⁾ and have shown that wires of this type can sustain a range of repeated stress of at least 20 tons/in² when the minimum stress is about 55

tons/in²; for deformed wires the range of stress may be a little smaller. This range of stress in the steel is normally sufficient to ensure that the fatigue strength of a prestressed concrete beam is not less than 70% of its strength under static loading.

Since the preparation of this paper, further tests have been made on prestressed concrete beams with post-tensioned cables which have shown that failure can occur as a result of fatigue of the concrete when the wires are of 0.276 in. diameter and the depth/span ratio for the beams is relatively high. In such beams, the bond with the concrete is less effective than with pre-tensioned wires and thus the stress in the steel is less critical in defining fatigue failure. The degree of bond between the steel and the concrete would also seem to be of importance where post-tensioned bars are used as, although no tests appear to have been carried out on beams, evidence from tests reported by Quade⁽²⁾ suggests that threading the bar at the anchorage leads to greatly reduced fatigue strength; the capacity of prestressed concrete beams stressed with post-tensioned bars to sustain severe repeated loading may, therefore, be largely governed by the adequacy of grouting in establishing bond.

The author has made reference to safety factors, and in his general observations states "safety factors against fatigue failure appear to be in the region of 2". No definition of the term "safety factor" is given, and it is evident that this factor is often related to the design live load only. Such a factor has some value when it relates to a specific structure, but when it is used in a generalization it may be misleading. It would seem preferable to use the term "load factor" and to relate the factor to the total design load. The effect of this may be seen by examining, for example, the results quoted for the first of the beams tested by Magnel [reference (11) of the paper]. The safety factor against fatigue failure given in the paper is 2.05 and is based on the design live load only; this figure is equivalent to a load factor on total design load of 1.8, which has some fundamental meaning and may be compared with other results similarly obtained. The generalization that can be made for normally designed prestressed concrete beams is that the load factor against fatigue failure is usually not less than 1.5, al-

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though it may sometimes have a value of 1.8 or more.

As there are relatively few results of fatigue tests on prestressed concrete beams with post-tensioned cables, it may be useful to give details of some tests which did not form part of a series but served to provide preliminary data for use in the investigations at the Building Research Station. The beams were similar and were of composite T section consisting of a rectangular member 14.4 in. deep and 8 in. wide stressed by a post-tensioned cable with 24 wires of 0.2 in. diameter and an *in situ* reinforced concrete slab 4.8 in. deep and 32 in. wide. The wires, which had a tensile strength of 114 tons/in², were stressed initially to 65 tons/in². At the time of test, when the beams were about one and a half years old, it was estimated that the maximum precompression in the concrete was 1,760 lb/in². The design working load, W , was taken as the total load including dead load to reduce the precompression to zero. The first beam was subjected to one million repetitions of load fluctuating from $\frac{1}{2}W$ to W , and the effect of these repetitions was to increase the deflexion at the maximum load by 4%. The second beam cracked under static loading at $1.4W$; it was then loaded one million times between $\frac{1}{2}W$ and $1\frac{1}{2}W$, when the maximum width of cracks increased from 0.005 in. to 0.019 in.; finally the beam was loaded to failure under static loading, failing at $2.3W$, which was 2% less than the strength of a similar beam in a static loading test. The final beam was subjected to repeated loading, fluctuating between $\frac{1}{2}W$ and $1\frac{1}{2}W$, until failure occurred after 615,000 repetitions; this range of loading represented a range of stress in the steel of about 30 tons/in² with a minimum value of about 54 tons/in². The main conclusions that may be drawn from these particular tests are that repeated loading within the range of design working load has little effect on prestressed concrete beams and that severe over-loading may be repeated many times without reducing the strength under static loading.

The author refers to the importance of rest periods in permitting recovery from the effects of fatigue. The evidence shows that marked recovery of deformation occurs during a period of rest, but no data are available to indicate that endurance to failure is extended by rest. Such recovery of deformation as may take place is soon completely offset when the repeated loading is resumed.

The most difficult problems yet to be tackled in relation to the fatigue resistance of prestressed concrete structures are, first, as the author suggests, the assessment of the conditions of loading occurring in practice, secondly, the investigation of ways in which cumulative damage resulting from these conditions of loading may be evaluated, and finally the influence of corrosive environments.

Reply by the author

Dr Bate's contribution to the discussion of my paper

is very valuable since he has been responsible for the large amount of work carried out by the Building Research Station on this subject. My omission of much of the fundamental information on the strength of hard-drawn wires and heat-treated wires under fluctuating tensile stresses was because I considered that further work was not required and that it was the behaviour of the wires in prestressed units that was of importance. This opinion is supported by the approach to the problem adopted by Dr Bate.

I would agree with Dr Bate that the term "safety factor" is misleading and that the use of the term "load factor" is preferable; this would enable a more rational assessment of fatigue tests to be made.

With reference to the fatigue strength of prestressed units incorporating high-tensile bars it should be mentioned that Eastwood and Rao⁽⁸⁾ report contrary evidence to that of Quade⁽⁷⁾ indicating the need for further tests to clarify this point.

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