CORRESPONDENCE

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" Creep of High-Tensile Steel Wire " †

by

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Mr A. J. Harris, referring to the Authors' mention of the high creep values found by Simon and Xercavins, observed that those values were employed in practice by S.T.U.P. (" Société Technique pour l'Utilisation de la Précontrainte ") in estimating stress relaxation when using the type of French steel in question.

There was a reason for supposing that creep values were closely connected with the degree of homogeneity of the crystalline structure and internal stress of the steel. According to that theory, creep consisted of plastic strains being reached in limited zones of the wire; those zones transferred stress to other zones which were still elastic and a slight extra elongation resulted. Thus the greater the homogeneity and the smaller the " locked-up " stresses in the unloaded state, the smaller the creep; the high values found by Simon and Xercavins were probably to be explained by features in the manufacturing process—for example, too small a number of passes through the dies.

It should be remarked that a new type of process developed in France especially for prestressing wire, and which combined cold-drawing with heat-treatment, appeared to give lower results than those quoted by the Authors, though more work was needed to give conclusive results.

Mr J. L. Bannister, observed that the Authors had claimed to have investigated two variables, namely, diameter and ultimate strength. The characteristics of drawn wire were not a simple function of either diameter or ultimate strength, but were dependent upon the basic material and its treatment, and the extent and manner of subsequent cold reduction. The resultant properties, as the Authors had pointed out, were " a function of

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the amount of drawing which takes place, and any work- or age-hardening which may occur." A variation in diameter of a drawn wire inferred both a variation in the diameter of the basic material prior to drawing, and a variation in the rapidity of the total reduction in cross-sectional area.

The condition of the 0·2-inch-diameter wire in " small " and " large " coils immediately prior to testing was not made clear, and before making any comparison between the creep losses on the basis of coil diameter, it was essential to know that condition. The stress/strain curves shown in *Fig. 7* indicated that both the " small " and " large " coil wires exhibited elastic characteristics in the initial stages of stressing, which suggested that both had received some form of treatment subsequent to cold-drawing. Otherwise they would exhibit the plastic characteristics of wire in the as-drawn condition.

It was well known that drawn wire would strain-age at ordinary temperatures. By artificially strain-ageing the drawn wire at higher temperatures, the behaviour of the wire under tensile stresses was more elastic and stable, but the creep losses were increased. It had also been demonstrated, by Magnel, Strycker, and others, that by stressing the wire in tension to a value higher than the service stress for a short time, the creep losses were decreased. Thus it was clear that the behaviour of the wire with stress and time was dependent upon treatment subsequent to drawing, and if the " small " coil had been strain-aged and the " large " coil had been previously tensioned, that would explain the difference in behaviour of the two coils.

Would the Authors say whether the coils used in their experiments had received such treatment subsequent to drawing ? If so, what precisely had been the nature of such treatment ?

Whilst from the Authors' tests it was apparent that the 0·2-inch-diameter " large " coil had smaller creep losses, it could be seen in *Fig. 7* that for the same concrete deformation the loss of steel stress from 200,000 lb. per square inch was greater for the " large " coil than for the " small " coil.

Mr W. O. Everling, of Cleveland, Ohio, observed that the apparatus used by the Authors in making their tests was ingeniously contrived.

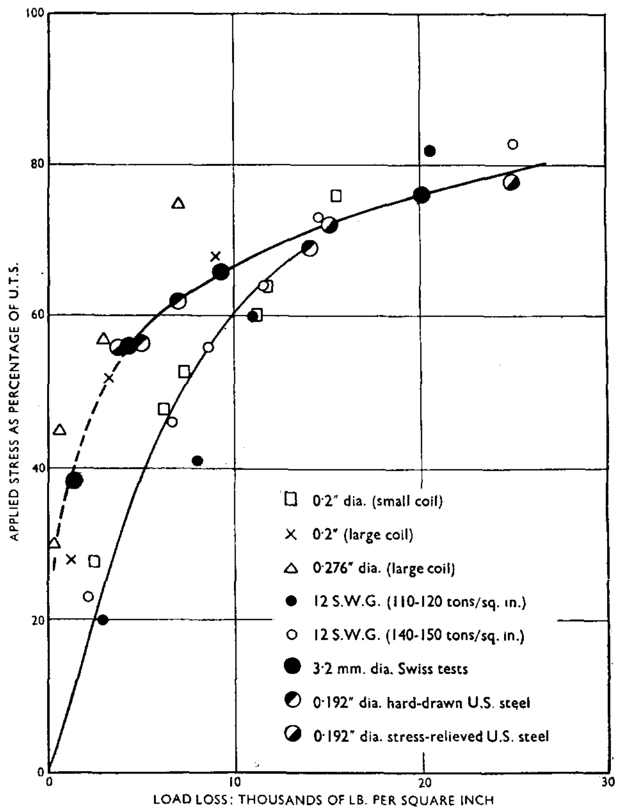
The research laboratory of the American Steel and Wire Division of the United States Steel Corporation had been making similar tests on a 100-foot-long test-bed constructed about 8 months previously. The wire was suitably supported at frequent intervals and the progression of stress relaxation tested with a specially designed load cell. Needless to add, those researches were by no means complete.

A comparison of results with those of the Authors was the more interesting because they agreed so well with a part of them, and so poorly with another part.

The most popular wire used for prestressing in the United States had 0·75 to 0·80 carbon, medium manganese, and was cold-drawn to a tensile strength of about 250,000 lb. per square inch. The most common diameter was 0·192 inch, both for single wires and for heavy strands (larger than 0·600 inch diameter).

In the state in which such wire came off the final wire-drawing block it had a free coil set of about 36 inches. Its stress/strain relationship was typically soft; that was to say, it yielded plastically and quite measurably at stresses as low as 60,000 to 80,000 lb. per square inch.

Fig. 25



During recent years it had become popular in the United States to give such wire a final "time-temperature" or "stress-relieving" treatment, which increased the original elongation of about 2½ per cent to the minimum of 4 per cent measured in a gauge length of 10 inches. It also affected the stress/strain curve, making the wire substantially elastic up to at least 50 per cent, and perhaps slightly more of its ultimate strength.

Incidentally, that treatment did not change the original strength significantly, while at the same time it straightened the wire itself quite well. The final curvature was approximately one foot in a length of 12 feet.

That relative straightness had become an important consideration because it facilitated handling in the field and the higher apparent elastic limit had suggested that it might have higher creep resistance, particularly at very high stress.

The U.S. test programme was designed to compare the resistance against stress relaxation of the wire in the hard-drawn state with the same type of wire in the stress-relieved state. In the light of the Authors' programme, it also afforded an opportunity to compare wire with a free coil set of only 36 inches with almost straight wire.

Fig. 25 showed the results of the American investigation. Somewhat unexpectedly, both the stress-relieved wire as well as the wire in the as-drawn state, showed about the same degree of stress relaxation between the limits tested, namely 55 to 75 per cent of ultimate strength. It was also remarkable to see the close agreement with the Authors' 0·2-inch (large coil) and the Swiss 3·2-millimetre wire, as well as a part of the Authors' 0·276-inch wire.

On the other hand, the American researchers found it difficult to explain the rather wide discrepancy between their results and those obtained from the Authors' small-coil wires. It would be interesting to have more details of those wires regarding analysis and elongation, particularly in comparison with the large-coil wires. One effective way of determining elongation was to measure what was called in America the uniform elongation. That was done by marking a gauge length of perhaps 20 inches at intervals of 1 inch. The sample was then broken under tension and the percentage elongation determined on a piece of the wire which did not include the necked-down zone of the actual break.

It had also occurred to Mr Everling and his associates that the handling of the small-coil wire might have presented considerable difficulties A certain amount of hand straightening might have had to be done. The possibly resulting faint " kinks " might have affected the relaxation results considerably, particularly in the lower stress-range.

Mr Everling hoped that it would be possible to continue to compare results as time progressed.

Mr S. C. C. Bate observed that reference was made in the Paper to the investigation of the properties of hard-drawn wire for prestressed concrete, which was being carried out at the Building Research Station. That investigation included a number of relaxation tests on different samples of wire of British manufacture, in which some of the specimens had been under load for more than 2 years. The results for relaxation at 1,000 hours were of the same order as those obtained by the Authors, although the difference between the behaviour of the straight wire from the large-diameter coils and the unstraightened wire from small-diameter coils was not so distinct. The results for relaxation after 10,000 hours gave some indication of the errors introduced by extrapolation from the results of tests of short duration. For the wires from small-diameter coils, the errors through extrapolation appeared to be of little practical importance, and an approximate value for the relaxation during that period might be obtained from tests of much shorter duration than 1,000 hours. The errors involved in extrapolation were, however, greater for the relaxation of the particular samples of straight wire from large-diameter coils, which were being tested at the Building Research Station. It had been found that, as the duration of the tests increased, the difference between the relaxation of the wires from the coils of small diameter and of those from the coils of large diameter became less marked for initial stresses between 60 per cent and 70 per cent of the tensile strength and negligible at higher initial stresses. The range of values for relaxation over a period of 10,000 hours for three different samples of wire from small coils and two different samples of straight wire from large coils was $3\frac{1}{2}$ to 7 tons per square inch, for an initial stress of 60 per cent of the tensile strength, and 6 to $9\frac{1}{2}$ tons per square inch for an initial stress of 70 per cent of the tensile strength.

The Authors had suggested that the effects of relaxation could best be offset in practice by permanently overstressing the wires as an alternative to the slower process of temporarily overstressing for a few minutes before anchoring. The results of several tests made at the Building Research Station on the effect of temporarily overstressing the wires had shown that the subsequent reduction in relaxation was the result of a reduction in the rate of relaxation during the first few days only and thereafter the rate was unaffected. As a result of temporarily over-stressing by 10 per cent for 1 minute, the relaxation of a sample of wire in 1,000 hours was reduced from 5·3 tons per square inch to 3·6 tons per square inch for an initial stress of 70 per cent of its tensile strength. The reduction in relaxation was therefore only a small proportion of the applied stress and could be more conveniently offset in practice by a permanent increase in the initial stress, as suggested by the Authors.

During recent years the creep and relaxation of steels for prestressed concrete had attracted considerable attention, and since the Authors had started their tests more published information had become available. Strict comparisons between the results of different investigations could only be made if details of the experimental technique were given; the rate of stressing and the method of establishing the initial condition for the test might have a considerable influence on the results obtained subsequently. It would, therefore, appear desirable to give the details of the stress- and strain-history of the material in presenting the results of creep or relaxation tests.

The Authors, in reply, stated that they were glad that the figures quoted in the opening remarks to the Paper concerning the French figures for relaxation were not generally applicable. In their view it was too early to say whether the new type of steel, referred to by Mr Harris, would have superior properties to the present wire used in Great Britain.

In reply to Mr Bannister, the Authors would agree that the two variables referred to were meaningless in themselves, since both sizes and strengths of wire would not be drawn from the same original wire. " Investigated " was too strong a word ; they had used the wires described to cover a range of ultimate tensile strength and diameter. The condition of the 0·2- and 0·276-inch-diameter wire in the large coils had now been made clear by Mr Brereton's contribution ; the condition in the small coils was, so far as the Authors were aware, in the as-drawn state. They were not aware that relaxation losses were increased by strain-ageing at higher temperatures since that was the treatment of the wire on the large coils which showed a marked decrease in relaxation. The wire in the large coils had not been previously tensioned. The Authors were not clear about the reference to *Fig. 7*. It seemed to them merely to show that the strain at a stress of 200,000 lb. per square inch in the wire from the large coils was smaller than for the wire in the small coils.

They were interested to learn from Mr Everling's contribution of the work of the American Steel and Wire Division of the United States Steel Corporation. They were surprised to see that the same relaxation was obtained with stress-relieved wire as with wire in the as-drawn state, but were pleased to see that their results were of the same order of magnitude as those described in the Paper. They looked forward to seeing further results from the American tests in due course.

They were grateful to Mr Bate for his contribution, and only wished that it could have been amplified, because it was clear that he had much valuable data. They were surprised to learn that the rate of stress loss for the wire from large coils did not decrease as quickly as they had estimated, and would be glad to know what the difference between the relaxation of the two types of wire was at 10,000 hours for an initial stress of 60–70 per cent of their ultimate strength. It was encouraging to learn that his tests confirmed that the best method of taking care of the relaxation was permanently to overstress the material initially. They agreed with Mr Bate as to the necessity of providing full data when presenting the results of similar experiments ; reconciling experimental data often proved impossible because of lack of data.

A general point which emerged from the discussion which should be emphasized was the necessity for the designer in prestressed concrete to have a knowledge of the treatment to which the wire he proposed to use had undergone. When that information was obtained it should be possible for him to know into which category he should place the wire and so have an idea of the possible relaxation which could take place.

In conclusion, the Authors would like to thank all the contributors to the discussion. They felt that the interest which had been aroused had justified the presentation of their Paper, and hoped that it would stimulate others to carry out further work on a relatively new subject so that a definite result may be arrived at which would be of direct service to designers in prestressed concrete.