Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 66 (1992)

Artikel: Tensile fatigue of very short samples of stranded wire rope

Autor: Chaplin, Richard

DOI: https://doi.org/10.5169/seals-50698

Tensile Fatigue of Very Short Samples of Stranded Wire Rope

Fatigue à la traction de courts échantillons de câbles toronnés

Zugermüdung sehr kurzer Proben von Drahtlitzenseilen

Richard CHAPLIN
Senior Lecturer
University of Reading
Reading, UK

Richard Chaplin graduated from Cambridge University in 1966 in Mechanical Sciences followed by a PhD on composite materials. He has worked in a structural consultants office and in an aircraft design office. His current preoccupation is with the endurance of ropes.

SUMMARY

This paper describes the outcome of a series of tension-tension fatigue tests on samples of six strand wire rope with lengths from one to four rope lay lengths. Despite expectations to the contrary, it is found that following good practice in the preparation of terminations, and with an initial overload at the start of each test, consistent high fatigue lives can be obtained with no length effect apparent.

RÉSUMÉ

L'auteur fournit les résultats d'une série d'essais à la fatigue, sous sollicitation pulsatoire de traction, effectués sur des échantillons de câbles comportant six torons, et dont la longueur variait de un à quatre pas de torsade. Contrairement à toute attente, l'expérience a montré que, dans le cas d'une bonne préparation des extrémités et d'une surcharge initiale au début de chaque essai, il était possible d'atteindre des valeurs de durée de vie élevées sans entraîner des effets apparents sur la longueur des échantillons.

ZUSAMMENFASSUNG

Der Beitrag beschreibt die Ergebnisse einer Versuchsserie mit Zugschwellbelastung an Proben von Seilen aus sechs Litzen, deren Länge von einer bis zu vier Seilschlaglängen variiert wurde. Trotz gegenteiliger Erwartung wurde beobachtet, daß bei sorgfältiger Bearbeitung der Enden und Anfangsvorbelastung zu Versuchsbeginn durchgängig hohe Ermüdungsstandzeiten ohne auffälligen Längeneinfluß erreicht werden können.

1 INTRODUCTION

In response to an invitation to participate in the IABSE Workshop on Length Effects on Fatigue of Wires and Strands, since the author's main area of interest has been stranded ropes, a short investigation has been made of the influence of sample length on the tensile fatigue endurance of such a construction. The investigation has not been intensive and only a limited set of results has been obtained within the time available, but these are never the less considered to be worth reporting.

Over recent years there has been considerable interest in the tensile fatigue of wire ropes for use in offshore applications, especially as components in mooring systems for oil exploration, production, and accommodation platforms [1]. This interest has stimulated numerous investigations at different levels, on various different issues, but the question of length has not been addressed specifically. For the majority of these investigations there has been a tacit acceptance that, provided samples tested have lengths of at least six lay lengths, but preferably more than ten lay lengths, then results will be representative of the very much longer ropes employed in service. The unstated basis for this acceptance is that while service lengths of rope (which may be as much as 2 km long) are different in statistical terms, any increased probability of failure at a given level of loading associated with high length, is counterbalanced by additional loading components (bending near terminations, imbalance etc,) that are exacerbated by shortness.

The guideline for sample length based upon "lay length" translates for a typical six strand rope to 40 diameters as an absolute minimum or 60 diameters as a preferred length. These translations into lengths defined as diameters have then been taken as more generally applicable to other constructions. Whilst this may seem reasonable for fairly conventional spiral strands or multi-strand ropes, real problems are likely to arise with some of the more specialised constructions now being considered for taut vertical mooring systems which have very long lays.

Therefore having resolved some of the more basic issues affecting fatigue, the length effect issue is one which is likely to become of greater significance to offshore applications, and in this context the IABSE initiative is most timely.

2 BACKGROUND

2.1 Stranded Rope Constructions

The essentially helical construction of a traditional rope provides the mechanism that gives the rope its essential quality of bending flexibility under high tensile load. This flexibility is achieved in practice by a geometry that permits the wires to slide in relation to one another, as described by Gibson [2] and quantified by Nabijou [3], to equalise the strains otherwise associated with distance from the rope axis when bent. But, when the rope is clamped in a way which locally prevents any relative sliding, the capacity to escape these bending strains is restricted in a way recently described in detail by Andorfer [4].

Such problems can be especially acute when there are two effective clamps close to each other. In this context clamping can be achieved by an attachment, such as a pendant chair on an aerial ropeway, or clearly by a termination, but also, to a degree, by the transverse loading associated with the rope running onto a sheave or a drum. As discussed by Andorfer, the effect on bending behaviour of such clamps will be influenced by proximity in a nonlinear way that reflects the amplitudes of the helical features of the construction. So that, assuming that strand lay (i.e. the pitch of a wire in a strand) is comparatively low, then clamps effectively located at exactly one rope lay length will not reduce bending compliance from that of the unclamped rope. However clamping at say a half lay length, but also at one and a half lay lengths, will lead to appreciable reductions in compliance.

By a similar argument it will be apparent that different spacings between clamps put on a rope in a bent state, will have different consequences for mean axial wire stresses when the rope is pulled straight. Clamps spaced at integral numbers of lay lengths should have no effect, and the worst effects must be expected for intermediate spacings. But the greater the distance between clamps the greater the length for redistributing the imbalances associated with clamping at lengths which are not integral numbers of lays, and so the less the effect.

The magnitude of the wire length inequalities associated with straightening a bent rope is dependent on the non integral part (the residue after subtracting the integral part) of the number of lay lengths between clamps. The magnitude of the resulting strains and stresses will fall with increase in the length over which the inequalities are redistributed.

These observations clearly have relevance for bending fatigue of ropes running on and off sheaves or drums: there are alsoevident implications for tensile fatigue.

2.2 Geometrical influences on rope endurance in bending

The "bending over sheaves" fatigue testing of ropes (BOS fatigue) has been the subject of considerable investigation starting with Albert in 1828 [5] but really only being put on a scientific basis by Scoble in 1920 [6]. Various investigators have considered rope length effects in the context of BOS fatigue. There are two length parameters which profoundly influence endurance:

(i) bending length [2, 5, 6, 7] (the amplitude of rope movements on and off the test sheave);

(ii) contact arc length [2, 5, 6] (the length of rope in contact with the test sheave).

In broad terms the effects of both these parameters are that endurance at constant load tends towards infinity as either length tends to zero, but the effects have been found to correspond in terms of the lay length of the rope. This is especially apparent with the effect of contact arc length, where endurance falls to a minimum at about one half a lay length [5, 6], but is approximately constant for lengths greater than one lay length, though there is a suggestion in Muller's results [6] of a periodic fluctuation in phase with lay length.

2.3 Parameters influencing fatigue endurance in tension

In fatigue testing of wire ropes under a tensile load which fluctuates at constant amplitude, a significant number of parameters in addition to the mean and range of the load can influence the result. These include:

(i) overall class of construction e.g. six strand with IWRC, spiral strand, multi strand, etc.

(ii) details of construction, e.g. 6×36 or 6×19, 1×147 or 1×292, 35×7 or 57×7, but also including the lay angles and details of wire diameters;

(iii) quality of manufacture, i.e. the dimensional consistency and balance between similar elements;

(iv) wire grade, essentially the minimum strength;

(v) wire quality, including ductility, residual stress distribution and surface finish;

(vi) lubrication;

(vii) diameter scale effects (though these are largely encompassed effectively by other parameters);

(viii) definition of what constitutes failure (ranging from say the detection of five broken wires to total destruction);

(ix) sample preload;

(x) type and quality of termination;

(xi) test length.

Of these eleven parameters, the first eight are a function of the rope itself, (viii) is an arbitrary decision depending on the way in which the data are intended to be used, but the last three are likely to contribute to "scatter" in the results for a given rope.

A fact to emerge very clearly from a detailed examination of published research in this area [1] is that carefully conducted tests on samples taken from the same length of rope perform with a high degree of consistency, and results can be expected which fall within a very narrow band of scatter, generally conforming to a simple single power "s-N" equation. The implications of this observation are that, from the designer's point of view the problem is much more that of allowing for variation between ropes, even those that are nominally the same, than variation in fatigue performance of any given rope; but there is also the problem of defining what constitutes a "carefully conducted" test.

This last point has special significance in relation to the last three parameters listed above. Length is the main topic under discussion here, but usually any one set of tests is likely to have been performed on samples of equal length. Preloading is significant in that it has been shown to enhance endurance significantly [8], but reportedly only when the overload is applied to the sample as terminated for test, and only with loads in excess of 60% of rope strength. The implication of this is that the function of the preload has more to do with the termination than any other possible effects although the potential for such a procedure to improve unequal load sharing induced by geometrical imbalance will be discussed below.

The influence of the terminations is of course well known as the greatest source of problems when trying to characterise the tensile fatigue behaviour of a rope. One of the reasons for this being such a problem is that the great majority of conventional stranded ropes are employed in applications where there is always some feature associated with the manner of use, most commonly bending over sheaves, that concentrates the degradation mechanisms away from the ends: the ends of the rope and therefore the terminations are not seen as being critical in determining life. When tension fatigue is significant, that is no longer true, but, in the author's experience, a resistance to following precise specifications for termination procedures is encountered in the industry. Such difficulties are becoming significantly less common, and much better procedures with better control of quality seem to be in use, especially for the larger specialised ropes.

When assessing tensile fatigue data for a given rope, significant scatter is usually a sign of termination problems. Any characterisation of the fatigue behaviour of the rope must employ termination procedures that eliminate end effects, and in these terms rejection of data points associated with end failures is justified. But the use of the resulting characteristic in relation to establishing safe service life for ropes in service, must only be on the basis that actions are taken to ensure that the ropes in service will not suffer end effects.

3 EXPERIMENTAL PROCEDURE

3.1 Objective

The objective of the experimental work was to investigate the effect on the endurance of a stranded rope in tensile fatigue of very short test lengths. The particular area of interest was from one to about four lay lengths.

3.2 Sample Preparation

The rope selected for the tests was a six strand rope with independent wire rope core that had already been the subject of extensive testing in a programme of work [9,10] investigating "bending-tension" fatigue (small amplitude bending in phase with fluctuating tension). A detailed specification for the rope is given in Table 1.

Rope Construction:	13 NAT 6(12 + 6F + 6 +1) + IWR(6(6 + 1) + IWS(6 + 1)) 1770 ZS 111 67.3 6x19 filler IWR
Actual Rope Diameter d :	13 mm
Actual Cross Section A_m :	85.7 mm^2
Nominal Wire Grade:	1770 N/mm^2
Nom. Tensile Strength R_o :	111 kN
Actual Breaking Load F_m :	122.55 kN
Lubrication:	Bri-Lube 60 ®

Table 1: Specification of test rope.

One of the reasons for selecting this rope was that its fatigue behaviour had already been assessed from tests on samples of 750 mm length, without overload [10]. The resulting equation, at a mean of 20% (F_m), was: $N = (113 / range\%)^{9.63}$

The procedure used for terminating the samples is one that has been developed over an extended period of investigations. A filled polyester resin cone is cast over the wire brush using a split mould. The sample when removed from the mould and associated supporting fixture is assembled into a conical collet with split conical spacers, on the test frame. The significant features of the moulding system are a clamp which supports the sample over the full length between terminations, and a mould which permits injection of the resin from the base of the cone, as shown in Figure 1. This arrangement ensures that as the resin rises around the wires all air is effectively excluded, and injection ceases when the resin reaches the neck. The clamping fixture ensures that the rope is located axially and concentrically.

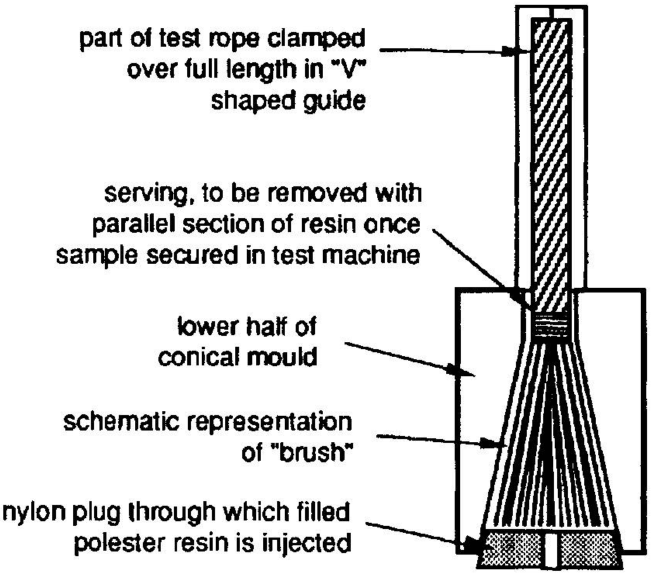

Figure 1: Arrangement employed for moulding conical ends of test samples, injecting resin vertically upwards into the mould.

3.3 Testing

Testing was performed using a 100 kN servo-hydraulic testing system under closed loop load control at a frequency of 1 Hz, ensuring that rope temperature was maintained below 35° throughout all tests.

A decision was made at the start of the programme that in order to minimise the influence of termination inaccuracies, an overload would be applied to every sample at the start of the fatigue test. The magnitude selected for this load was 50% of the actual ultimate breaking load, F_m. This was considered as sufficiently high in relation to the maximum load to be beneficial, but not so high as have too much influence on life [8].

The mean load for the tests was chosen as 20% F_m, since that was the same as used in the earlier tests. The range was initially set at 34% (i.e. 20 ±17%) because on the basis of the previous results that should give a life of about 10^5 which would be convenient for testing. The first test at this level resulted in a life which was a factor of five greater than the estimate, so the load range was increased to 36% F_m to reduce the endurance to a more convenient level.

4 RESULTS

4.1 Test data

Table 2 lists details of all the tests performed.

Test No.	Sample Length		Cycles to Failure	Comment
	mm	rope lays		
1	304	3.58	567683	discounted - load range 34%
2	334	3.93	136892	OK
3	262	3.08	144457	OK
4	234	2.75	168304	OK
5	200	2.35	122530	OK
6	164	1.93	132384	OK
7	133	1.56	151904	OK
8	370	4.35	102060	discounted - end failure *
9	93	1.09	199945	discounted - initial overload 64%
10	136	1.60	50114	discounted - end failure *
11	148	1.74	113766	discounted - end failure *
12	163	1.92	174701	OK
13	96	1.13	188686	OK
14	238	2.80	231085	OK
15	202	2.38	204716	OK
16	269	3.16	182695	OK

Table 2: Test results. Note all tests, except No. 1, conducted at 20 ± 18% F_m, with a single initial overload to 50% F_m. Test samples 8, 9, 10 & 11 were incorrectly terminated with the "brush" positioned outside the cone.

The first test, as mentioned above was at a different load range from those which followed, and should not be considered as part of the set. Test numbers 8, 9, 10 & 11 were incorrectly terminated with the "brush" positioned outside the cone to varying degrees, and should also be discounted. Of these four test 9 also received an additional accidental overload to a level of 64% F_m.

4.2 Distribution of results

Figure 2 shows the selected set of endurances ("OK" in Table 2) plotted as a function of the sample length, measured between the socket faces after initial overload, but before commencing fatigue.

In an effort to uncover some indication of a trend in the data, and following the argument in Section 2.1 relating to the straightening a curved rope, the results have also been plotted as a function of the "residual" length, defined as the remainder after subtracting the integral part of the sample length (in rope lay lengths) from the full length (also in rope lays).

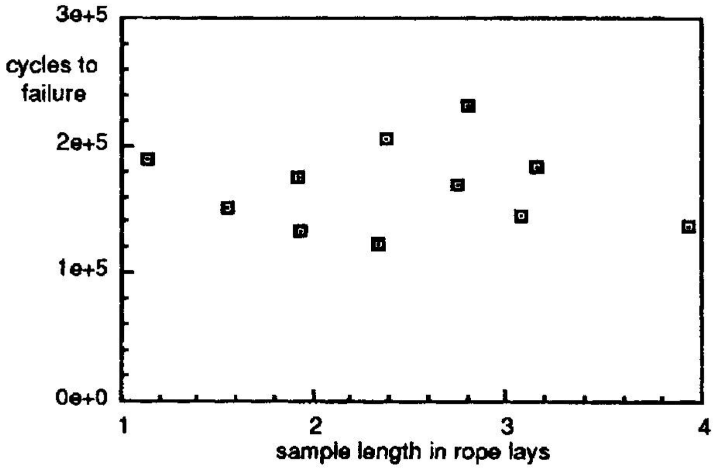

Figure 2: Valid test results plotted in terms of length between socket faces, in rope lay lengths.

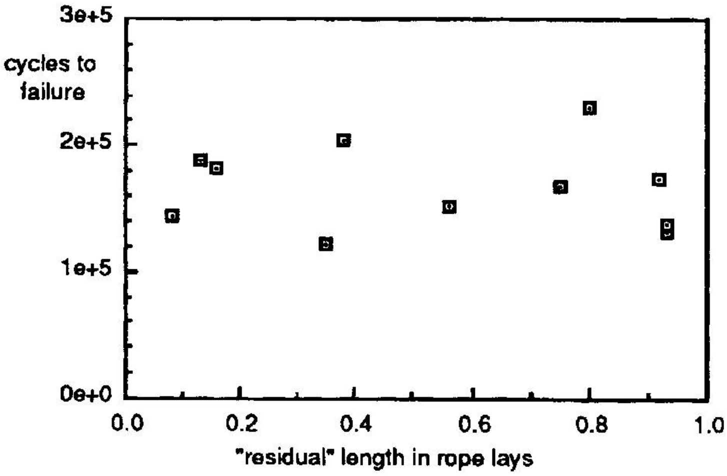

Figure 3: Valid test results plotted in terms of "residual" length, defined as the remainder of length between socket faces, in rope lay lengths, after subtracting the integral part of the length.

5 DISCUSSION

There are two worthwhile observations that can be made from these results, the first of which concerns the effect of preload on the endurance measured. The initial overload to 50% of the rope breaking load has dramatically improved the performance from what had been measured previously, at the same load levels, for the same rope. The previous analysis of fatigue performance was based on exactly the same procedures for preparation (with minor modifications to accommodate length differences), gripping and testing, and the analysis was based on data that excluded any termination failures with the results very closely spaced about the mean line

Data for the previous tests performed without pre-load have been plotted together with the new data in Figure 4. The clear distinction between the two sets can be seen. It can also be noted that one test result in the previous series, on a rope that had received an accidental overload of unknown magnitude prior to test exhibited an even greater life enhancement than indicated here. This tends to suggest that the difference between the two sets of results cannot be associated with length, but attributed to the overload.

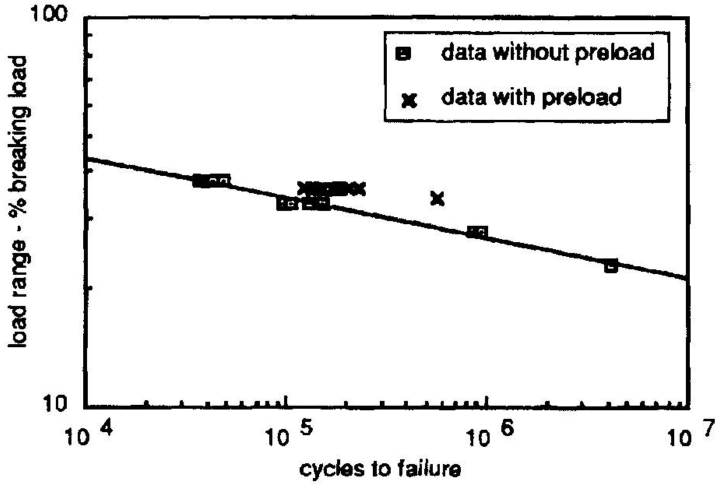

Figure 4: Comparison of test results obtained both with and without pre-load (data for no pre-load obtained from ref. [10])

The results for the tests on samples of different lengths, plotted in Figures 2 & 3 show no sign of any length effect, whether absolute or residual, at all. To seek further explanation results have been replotted in Figure 5 in the order in which the ropes were tested. Some suggestion, though not at a high level of significance, is present that there is a progressive improvement. This could possibly be associated with a learning process for terminating unfamiliar length samples.

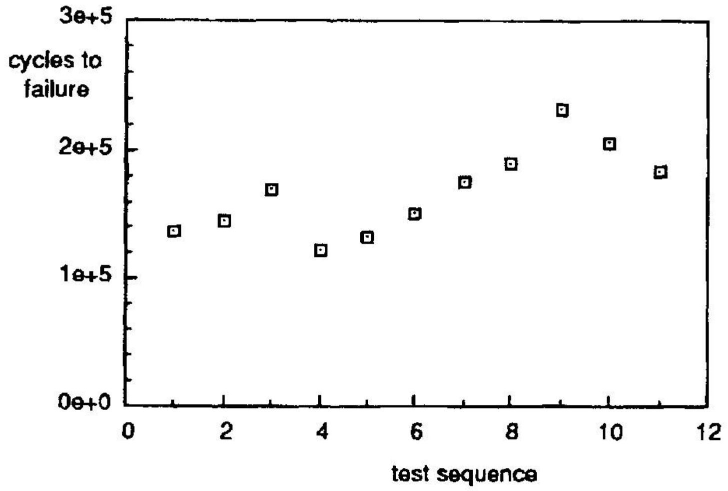

Figure 5: Valid test results plotted in terms of the order in which they were performed, which corresponds to the sequence of preparation.

6 CONCLUSIONS

1 Length effects in tensile fatigue of very short test ropes have not been found.

2 The beneficial influence of an initial overload in significantly extending the endurance of a stranded rope in tensile fatigue has been demonstrated to be applicable to very short samples.

3 The benefits of preload are most probably due to eliminating geometrical imbalances, whether associated with rope manufacture or termination, and as such could be responsible for the observed absense of the expected adverse length effects in very short samples.

4 Further work is clearly needed to clarify these issues, investigating:

(i) the effects of similar preloads on longer samples;

(ii) the influence of preload magnitude;

(iii) the length effects on short samples without preload (not easy).

7 REFERENCES

1 Chaplin, C. R. & Potts, A. E. *Wire Rope Offshore – a Critical Review of Wire Rope Endurance Research Affecting Offshore Applications* University of Reading Research Report for Dept. of Energy, HMSO Publication OTH 91 341, 1991.

2 Gibson, P. T. *Wire Rope Behaviour in Tension and Bending* Proc. First Annual Wire Rope Symposium. Pub. by Engineering Extension Service, Washington State University, Pullman, Washington, March, 1980.

3 Nabijou, S. *Frictional Behaviour and Fatigue Performance of Wire Ropes over Small Sheaves* PhD Thesis, Imperial College of Science, Technology and Medicine, University of London, 1990.

4 Andorfer, K. *The influence of short grips on the wire and strand mobility in round strand ropes running over sheaves* OIPEEC Bulletin No. 63, June, 1992.

5 Muller, H. *The Properties of Wire Rope under Alternating Stresses* Wire World International, Vol. 3, No. 5, October, 1961.

6 Scoble, W. A. *Fourth Report of the Wire Ropes Research Committee* Proc. I.Mech.E., May, 1930.

7 Feyrer, K. *Effect of Bending Length on Endurance of Wire Ropes* Wire World International, Vol. 23, July/August, 1981.

8 Stonesifer, R. & Smith, H. L. *Tensile Fatigue in Wire Rope* Proceedings of 11th Annual Offshore Technology Conference, Paper No. OTC 3419, May, 1979.

9 Ridge, I. M. L., & Chaplin, C. R. *Bending-tension fatigue – the influence of fluctuating load on the safety of ropes in bending* OIPEEC Bulletin No. 62, December, 1991.

10 Ridge, I. M. L. *Bending-Tension Fatigue of Wire Rope* PhD Thesis, University of Reading, June, 1992.

8 POSTSCRIPT

Following the discussion of this paper it is apparent that there are some important points which are not really given enough emphasis:

(i) tension-tension fatigue data for any given stranded wire rope or spiral strand, provided tests are conducted with adequate care on samples of reasonable proportions, are invariably tightly grouped with remarkably little scatter;

(ii) short samples have a greater tendency to premature termination failures, and, largely as a consequence, show more scatter and a lower mean life;

(iii) the fatigue performance of a given rope can be radically modified, for example by initial over-load;

(iv) nominally similar ropes from different manufacturers, or even from the same manufacturers, can have a radically different fatigue performance.

"Reasonable proportions" in this context would be a test length which is at least forty diameters (six lay lengths of a typical stranded rope), but sixty diameters would be preferred. Any test piece with a length of less than forty diameters must be considered too short. However the implications of the work described here are that the problems of a short rope can be overcome by preload, but tha inturn is likely to distort the behaviour.

In translating from laboratory test data to the endurance prediction of ropes in service, it is first necessary to eliminate the adverse effects of poor termination and short samples by adoption of good practice. Then the important point to conclude from the above observations is that the distribution of endurances obtained for any one rope, compared with the distribution of mean endurances obtained for different ropes, is such that the statistical modelling of the influence of service length is likely to be of minimal significance compared with the problem of modelling the differences between ropes.

This conclusion implies that "length effects" are not really an issue. The issue that must be resolved however is that of statistically modelling the differences between ropes, acknowledging that the fatigue results for a rope at the lower end of that distribution will *all* tend to be low.

Leere Seite
Blank page
Page vide