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Lessons to be Learned from the History of Suspension Bridge Suspenders

Leçons tirées des expériences réalisées avec les suspentes de ponts suspendus

Lehren aus den Erfahrungen mit Aufhängungen in Hängebrücken

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SUMMARY
A review of laboratory results as compared with stress ranges in current use over many years suggests a relaxation in the conservative approach to design for fatigue.

RÉSUMÉ
L'auteur présente une rétrospective de résultats de laboratoire comparés aux tendances pratiquées depuis plusieurs années. Il suggère d'assouplir la méthode conservatrice du dimensionnement à la fatigue des câbles de suspension.

ZUSAMMENFASSUNG
Eine Rückschau auf Labortestergebnisse im Vergleich zu den Spannungsniveaus, die tatsächlich über viele Jahre auftreten, legt nahe, das konservative Vorgehen bei der Ermüdungsbemessung von

LESSONS TO BE LEARNED FROM THE HISTORY OF SUSPENSION BRIDGE SUSPENDERS

In reflecting on the subject of fatigue, as related to cyclic axial tension on wire tension members, the writer has been impressed by the inexactitude of the data base on which design judgments are made. The results of laboratory tests typically show a wide scatter of cycles to "failure". (Here "failure" is in quotation marks because each researcher has his own criterion for failure, or for discontinuance of a test). Also, the number of cycles selected for design purposes on a given structure is, at best, an educated guess.

In the presence of all these uncertainties, it is not surprising that designers take a very conservative approach, selecting an S-N curve which is at or near the lower boundary of the scatter of test results, and then applying a factor of safety by limiting the maximum permissible stress range to a percentage (e.g. 75% or 80%) of the range taken from the curve.

As more and more experience gets into the record, and better testing procedures are developed, designers will probably be inclined to relax this conservatism to some degree. The writer has also been impressed that, although thousands of tons of suspender ropes on suspension bridges have been undergoing millions of cycles of stress during more than 100 years of service, there has not come to his attention a single case of wire fracture or retirement from service which has been attributed to the results of cyclic axial tension. Admittedly, the cyclic stress range in this service has been relatively small. On the other hand, the writer suspected that the scatter of test results for this construction of wire rope (galvanized wire assembled in six helically wound strands wound helically about a core consisting of another strand or a small stranded wire rope) would demonstrate a relatively low endurance limit. (Defined as the maximum stress range which can be repeated indefinitely without failure.) Some researchers have even concluded that a rope of such construction has no endurance limit.

The original intended purpose of this paper was that of placing on the record a full review of test results and a wide spectrum of design and actual stress ranges on existing bridges. However, the task turned out to be so time consuming that, when the time came to draw the line on further research in order to meet the deadline for submission of papers, it had been far from finished to the writer's satisfaction. Thus, this will, to some extent, be in the nature of an interim report, presented in the hope that some institution devoted to research will agree that the intended result has validity, and will decide to finish the job.

In search of test results, an attempt was made to achieve a full review of literature on the subject, with the aid of many persons, whose generous responses are gratefully acknowledged. The literature abounds with fatigue tests on individual wires, spiral strands, and parallel wire strands, but relatively little appears for stranded cables, which are the subject of this paper. However, it was possible to uncover seven research projects whose results are pertinent. The sources are given below under "References". Correlation of these results was difficult. There was no consistency in the method of plotting (i.e. logarithmic vs. natural). Where stress ranges are expressed as percentages, the question "percentage of what?" is often not clearly answered. The criterion for failure or discontinuance of test is often not clear. Making reasonable assumptions, where necessary, and making a careful attempt to reduce all data to natural scale, the writer has produced seven curves, numbered from one to seven, corresponding to the number of the "Reference" from which each was obtained. For ease of reading, these curves are first presented on three separate charts, as indicated below:

Figure 1: This presents curves 1 & 2.

Curve 1 is taken from Fig. 4 of reference 1, It represents the only two lines on that chart which deal with ropes of the subject type, It is an average of those two lines, which are very close and similar. Failure is defined as the failure of 5% of the wires. This line represents an average of test results, not a bottom boundary of scatter.

Curve 2 is taken from Fig. 9 of reference 2. It represents the dashed line and is the boundary of test results based on failure defined as "5 broken wires".

It is interesting to note that, although separated vertically by approximately 10% of ultimate strength, the curves have very similar forms. This implies the likelihood of a failure to correlate data adequately well (e.g. ultimate strengths or failure criteria). There is also the difference between "average of scatter" and "lower boundary".

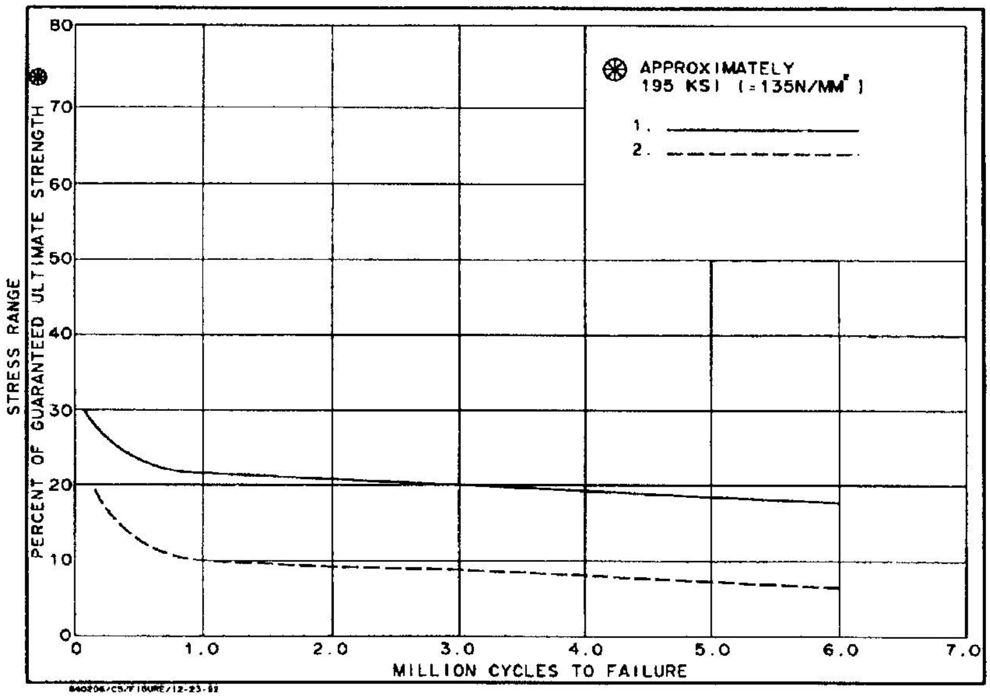

FIGURE 1

Figure 2: Here are presented curves 6 & 7.

Curve 6 is taken from Fig. 8 of reference 6. It represents the curve for 5% wire breakage and is the average of test scatter.

Curve 7 is taken from Fig. 9 of reference 7. It represents the average of test results and the criterion for failure is not given. Again we have two curves of similar form, separated by almost 10% of ultimate strength, and, again, the most likely cause is imperfection of correlation of data.

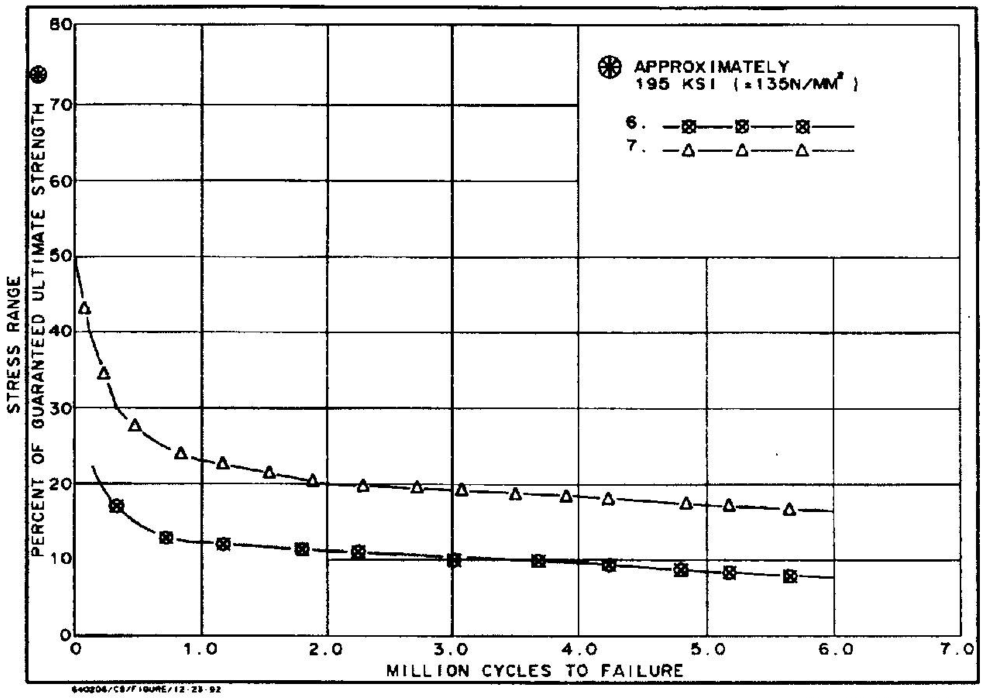

FIGURE 2

Figure 3: Here are presented Curves 3, 4, & 5.

Curve 3 is taken from Fig. 8 of reference 3. It represents an average of test results wherein the criterion for failure was the fracture of one strand.

Curve 4 is taken from Fig. 4 of reference 4. It represents a judgmental statement of the safe lower boundary of a fatigue spread developed from the study of many ropes including the suspenders of the Golden Gate Bridge.

Curve 5 is taken from Fig. 4 of reference 5, It represents the average of test results on the suspenders of the George Washington Bridge. The criterion for failure seems to have been excess elongation.

It can be seen that these results represent a scatter between the extremes of curves 1 & 7 on the high side, and curves 2 & 6 on the low side.

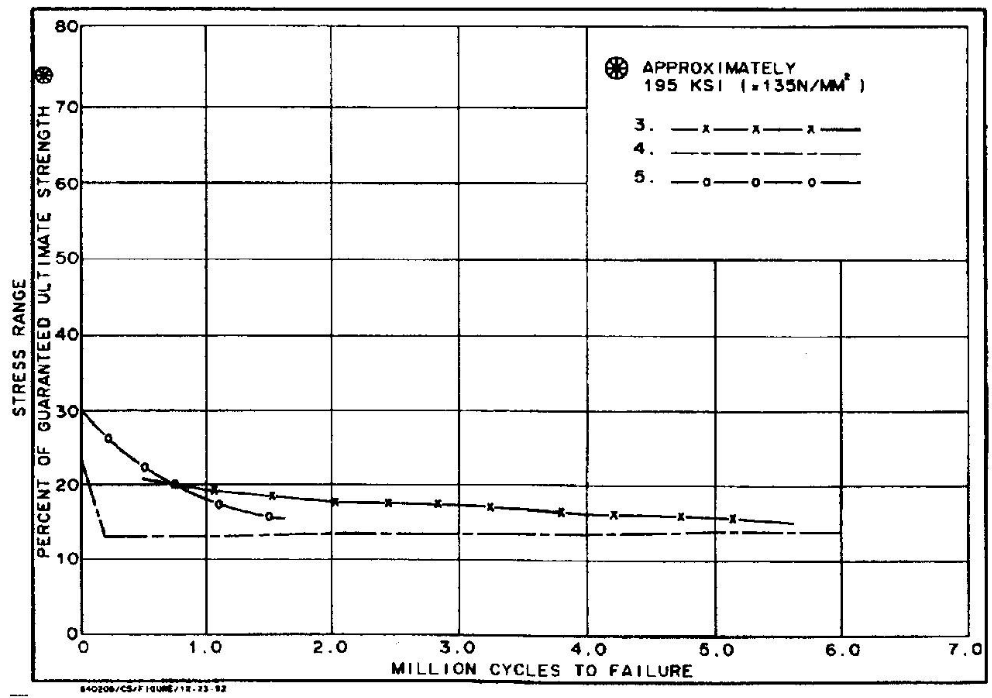

FIGURE 3

Figure 4: Here all 7 curves have been plotted to pro-vide the visual representation of the range of all the data,

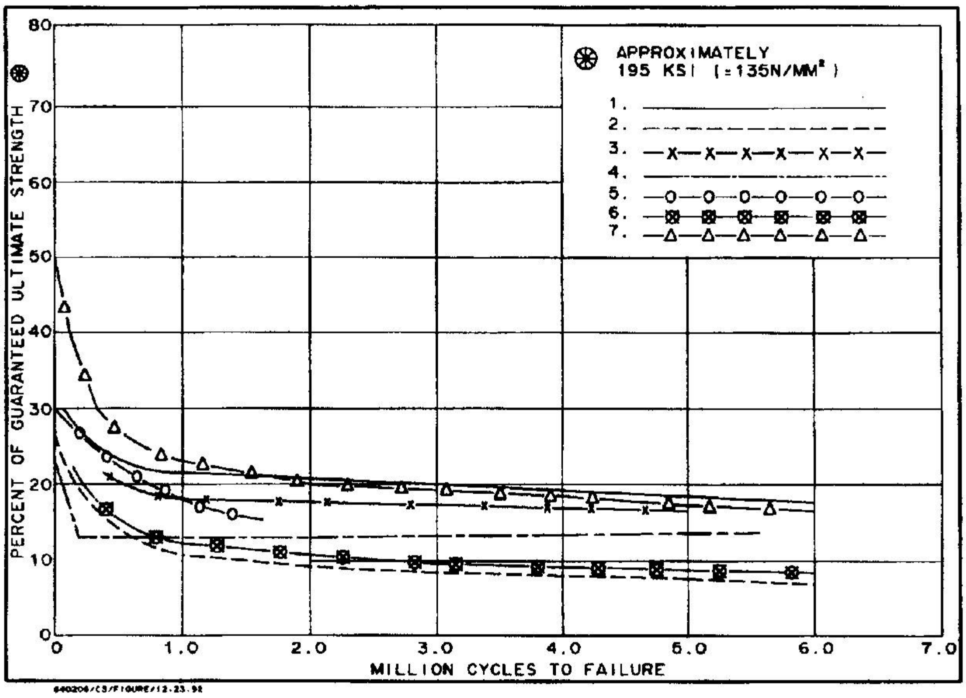

FIGURE 4

The above represents the limit of the data which the writer has been able to collect and analyze in the available time. It probably represents a fair sampling of currently existing reports and literature. What is needed from further research is a fine tuning of this type of data, -- either by going into greater depth in the analysis of existing data, in order to make sure that it is properly correlated and comparable, or by additional experimental research aimed specifically at obtaining data which is germane to the subject of this paper, or both,

Now let us turn to the input representing existing practice in the design stress range of suspenders. A partial list is presented in Table 1. This, also, is not as complete as the writer would like. It turned out to be very difficult to dig up this data out of old files. However, the spread of values seems to be broad enough to reach some tentative conclusions from this study.

TABLE 1

DESIGN STRESS RANGE OF SUSPENDER ROPES OF SEVERAL BRIDGES

BRIDGE	LOCATION	STRESS RANGE*
George Washington	New York	5
Walt Whitman	Philadelphia	10
Throg's Neck	New York	10
Maysville	Kentucky	12
Odgenburg	N.Y.-Canada	14
Davenport	Iowa-Illinois	14
Verrazano	New York	8
Forth Road	Scotland	12

*Percent of guaranteed strength (from several sources, including the writer's own files)

Figure 5 is a repetition of Figure 4, with the addition of the cross-hatched band which represents the above spread of extant stress ranges. This indicates that many suspenders have been operating successfully, without known fatigue breaks, at stress ranges above the minimum values for fatigue life developed from the literature. This does not mean, of course, that one should consciously take such liberties with experimental fatigue life. There can be many reasons for this apparent overlap. It is likely that serious consideration of fatigue was not included in the design. If the subject was given any consideration, it would probably have been discounted because of the low range of stress. The overlap could mean simply that the actual incidence of the maximum design stress range was not great enough to require dependence on the endurance limit.

However, it does lead one to believe that it would be adequately conservative to accept the lower portions of the test scatter as permissible design stress ranges, without the application of any further factor of safety. Hopefully, further tests and experience may lead to an even more relaxed approach.

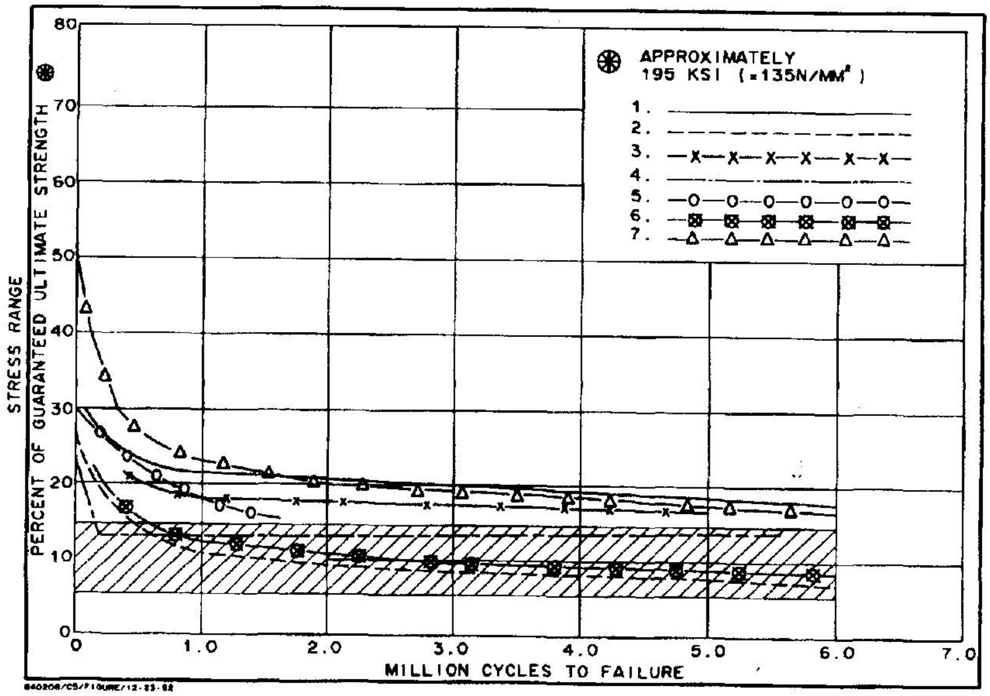

FIGURE 5

CONCLUSIONS AND RECOMMENDATIONS.

This study leads the writer to make the following suggestion for determining safe design stress range for cyclic axial tension on any type of steel wire tension member, be it a single wire, a bundle of parallel wires for use in a cable stayed bridge, spiral strands, or stranded cable:

Find the static stresses for the member, using all the criteria for loadings and allowable stresses selected for the design of the particular structure. Using the widest spectrum available of test data for the type of member, find the lower border of the scatter of test results which contains 95% of the test results. (This is suggested to avoid being misguided by the occasional extreme apparent test result.) If the design stress range is equal to, or below, the range obtained from the border curve, accept the design without further factor of safety.

It is the writer's hope that this discussion will motivate others to think along the same lines, and that a consensus will develop eventually in favor of a less ultra-conservative approach than many are taking now.

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