THE SPRING RESEARCH ASSOCIATION

THE EFFECT OF SOLID STRESS ON THE FATIGUE BEHAVIOUR OF SPRINGS MANUFACTURED FROM BS 1408C

by

G. C. Bird, B.Sc.

Report No. 219

SEPTEMBER 1973

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SUMMARY

Springs were made from a single bundle of 2.3 mm diameter wire to BS 1408C Range 3 with three solid stresses, 1000 N/mm^2, 1150 N/mm^2 and 1300 N/mm^2. Fatigue tests were carried out on the springs in both the unpeened and shot peened conditions with different initial stress levels to produce six Goodman Diagrams.

It was found that springs with a higher solid stress had superior fatigue properties. A linear relationship was found to exist between the values of Solid Stress - Initial Stress and Solid Stress - Final Stress for both shot peened and unpeened springs, which can be used to determine the minimum solid stress necessary for any required fatigue performance. From this relationship it is possible to predict a Goodman Diagram with a range of solid stresses once a diagram has been determined at any particular solid stress.

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1. INTRODUCTION

The prestressing or scragging operation is used on compression springs to obtain a greater load carrying capacity by improving the stress distribution in the spring. The operation consists of coiling the spring to a length greater than the free length desired and then compressing the spring to solid a number of times, hence causing a reduction in the free length of the spring. The Spring Research Association has recently investigated and report in Research Report No. 208 the number of prestressing operations which are required to stabilize springs and has also determined the reduction in solid stress brought about by the prestressing operation as a function of initial solid stress.

The purpose of this investigation is to determine the effect which solid stress of a spring has on the fatigue properties for springs in both the peened and unpeened conditions.

2. MATERIALS

The wire selected for this investigation was to BS 1408C range 3 with a diameter of 2.3 mm (0.092 in). The torsional properties of the wire were measured in the 'as received' condition on a Tinius Olsen Torsion Testing Machine. The results obtained are recorded in Table I.

3. SPRING DESIGN AND MANUFACTURE

Three spring designs were used each with the same mean coil diameter and number of coils, but the free length values as coiled were selected to give solid stresses after prestressing of 1000 N/mm^2, 1150 N/mm^2, and 1300 N/mm^2. Details of the designs are given in Table II.

In order to produce springs with a high degree of consistency, all the springs were coiled on an automatic coiling machine. After coiling, the springs were given a low temperature heat treatment of 280°C for ½ hour followed by end grinding.

4. PRESTRESSING AND SHOT PEENING

The free length of each spring was measured before prestressing. For each design of spring, the number of prestressing operations was determined such that no further reduction in length occurred upon further prestressing. The number of prestressing operations for each design of spring was as follows:

Solid Stress	Number of prestressing operations
1000 N/mm^2	1
1150 N/mm^2	3
1300 N/mm^2	5

The springs were divided into two equal batches, one batch for fatigue testing in the unpeened condition, the springs in the second batch were shot peened in a Tilghman Wheelabrator plant with S 330 shot for 30 minutes to an Almen Arc of 0.018/0.022 A2. After shot peening the springs were given a low temperature heat treatment of 220°C for 30 minutes.

After all the springs had been prestressed by the number of prestressing operations previously determined, the free length of each spring was remeasured, hence enabling the loss in length to be calculated.

5. FATIGUE TESTING

Fatigue testing was carried out on the Spring Research Association's forced motion valve spring testing machines. Load tests were carried out on individual springs to establish the necessary fatigue machine strokes to give the required stress ranges. Unpeened springs were tested at three initial stress values of 100 N/mm^2, 300 N/mm^2 and 500 N/mm^2, peened springs were only tested at the two lower initial stress values since, with an initial stress of 500 N/mm^2, the stress range was insufficient for failure to occur. In the case of springs which survived 10^7 cycles without failure, the load at the minimum compressed length was remeasured, hence enabling the relaxation which occured during the fatigue testing to be calculated. All fatigue testing was carried out at room temperature. The S/N curves for the unpeened springs are reproduced in Figs. 1-8 and for the peened springs in Figs. 9-14.

The relaxation data is tabulated in Table III.

6. RESULTS AND DISCUSSION

The S/N curves Figs. 1-14 contain a varied amount of limited life data but in all cases the fatigue limit has been estimated and tabulated in Table IV. It can be seen that the effect of shot peening is to raise the fatigue limit by between 11 and 15%. It will also be observed that the springs with the higher solid stresses also exhibit the superior fatigue properties, this can be more clearly seen in Figs. 15 and 16 where Goodman Diagrams have been constructed from the data in Table IV for springs in both the peened and unpeened condition. It might be considered that the increase in measured fatigue performance of springs with the higher solid stress could be attributed to these springs relaxing to a greater extent during the testing procedure. From the relaxation data presented in Table III, it can be seen that this is not the case since the variation in relaxation data is not sufficient to explain the differing fatigue performance and hence it can be assumed that the effect of solid stress on fatigue performance is real. In order to rationalise this behaviour, an alternative method of presentation was explored. From the results in Table IV, the values of (Solid Stress - Initial Stress) were plotted against the values of (Solid Stress - Final Stress), the data being presented in Table V and Fig. 17 where two lines have been drawn through the data for springs in the peened and unpeened conditions. In a Goodman Diagram the initial and final stresses are measured from zero, while in the presentation in Fig. 17 they are measured relative to the solid stress of the spring. The new presentation therefore takes into account the solid stress of the spring but is not so convenient to use for design purposes as the normal Goodman Diagram. However, it does enable the minimum value of the solid stress to be calculated for a specified fatigue performance if the initial and final stresses are known. This is best done by writing the equation for either of the two lines in Fig. 17. If, for example, we consider springs in the unpeened condition, the equation to the line is:

$$\mathrm{SS} - \mathrm{IS} = \frac{4}{3}(\mathrm{SS} - \mathrm{FS}) + 500$$

or

$$\mathrm{SS} = 4\mathrm{FS} - 3\mathrm{IS} - 1500$$

where the stresses are $\mathrm{N/mm^2}$.

Hence if FS and IS are known, the solid stress required can be calculated.

Similarly, for the shot peened springs:

$$\mathrm{SS} = \left(\frac{7\mathrm{FS} - 5\mathrm{IS}}{2}\right) - 2500$$

7. EXTENSION OF THE PRINCIPLE TO OTHER MATERIALS

If the presentation adopted in Fig. 17 has a universal validity, which will have to be substantiated by further experimental results, it will have the important consequence of enabling a Goodman Diagram, which has been determined for springs at one solid stress, to be used to construct further Goodman Diagrams for any desired solid stress. Consider, for example, the data on En 45A material reported in Research Report No. 210(1), and in particular the infinite life data for unpeened material. The springs used in the investigation had a solid stress of 1220 N/mm^2 and from the data in Table III of Report No. 210 the values of SS - IS and SS - FS can be determined and are tabulated in Table VI and displayed graphically in Fig. 18.

In order to construct a Goodman Diagram for springs with a solid stress of (say) 920 N/mm^2, the data can be determined from Fig. 18 and recorded in Table VI, and a Goodman Diagram for a solid stress of 920 N/mm^2 constructed, Fig. 19.

8. CONCLUSIONS

(i) The effect of solid stress on the fatigue resistance of springs made from BS 1408C Range 3 has been determined for springs in both the shot peened and unpeened condition.

(ii) It has been shown that a linear relationship exists between the values of (Solid Stress - Initial Stress) and (Solid Stress - Final Stress) for both shot peened and unpeened springs.

(iii) A method had been developed for determining the minimum solid stress which will permit a given stress range to be used at a required fatigue performance.

(iv) If the relationship in (iii) is of universal application, it enables a family of Goodman Diagrams to be constructed for a range of solid stresses, from a Goodman Diagram experimentally determined for one solid stress.

9. REFERENCE

1. Owen, A.P. "The Fatigue Properties of Heavy Helical Compression Springs - Phase I En 45A".

S.R.A. Report No. 210

TABLE I TORSIONAL PROPERTIES OF WIRE

TORSIONAL YIELD STRESS	540 N/mm^2
0.05% PROOF STRESS	902 N/mm^2
0.1% PROOF STRESS	992 N/mm^2
0.2% PROOF STRESS	1083 N/mm^2
TORSIONAL STRENGTH	1534 N/mm^2

TABLE II SPRING DESIGNS

	DESIGN A	DESIGN B	DESIGN C
WIRE DIAMETER (mm)	2.3	2.3	2.3
MEAN COIL DIAMETER (mm)	18.7	18.7	18.7
TOTAL No. OF COILS	5.5	5.5	5.5
ACTIVE No. OF COILS	3.5	3.5	3.5
FREE LENGTH (AFTER PRESTRESSING) (mm)	28.0	31.9	34.1
SOLID STRESS (AFTER PRESTRESSING) (N/mm^2)	1000	1150	1300

TABLE III DYNAMIC RELAXATION

UNPEENED	INITIAL STRESS		
	100 N/mm^2	300 N/mm^2	500 N/mm^2
DESIGN A	1.5%	1.3%	-
DESIGN B	1.2%	1.1%	1.4%
DESIGN C	0.7%	0.6%	2.0%
SHOT PEENED			
DESIGN A	1.1%	2.6%	-
DESIGN B	0.6%	1.2%	-
DESIGN C	0.3%	0.6%	-

TABLE IV FATIGUE LIMITS AT 10^7 CYCLES

UNPEENED	INITIAL STRESS		
	100 N/mm^2	300 N/mm^2	500 N/mm^2
DESIGN A	690	860	-
DESIGN B	750	880	1040
DESIGN C	780	910	1060
SHOT PEENED			
DESIGN A	780	960	-
DESIGN B	860	980	-
DESIGN C	900	1010	-

TABLE V MODIFIED FATIGUE DATA

UNPEENED

SOLID STRESS	INITIAL STRESS	FINAL STRESS	SS - IS	SS - FS
1000	100	690	900	310
1150	100	750	1050	400
1300	100	780	1200	520
1000	300	860	700	140
1150	300	880	850	270
1300	300	910	1000	390
1150	500	1040	650	110
1300	500	1060	800	240

SHOT PEENED

1000	100	780	900	220
1150	100	860	1050	290
1300	100	900	1200	400
1000	300	960	700	40
1150	300	980	850	170
1300	300	1010	1000	290

All Stresses in N/mm^2

TABLE VI FATIGUE DATA FROM REPORT No. 210

TEST DATA:

SOLID STRESS	INITIAL STRESS	FINAL STRESS	SS - IS	SS - FS
1220	100	560	1120	600
1220	300	720	920	500
1220	600	1000	620	220

DERIVED DATA:

920	100	520	820	400
920	300	700	620	220
920	450	830	470	90

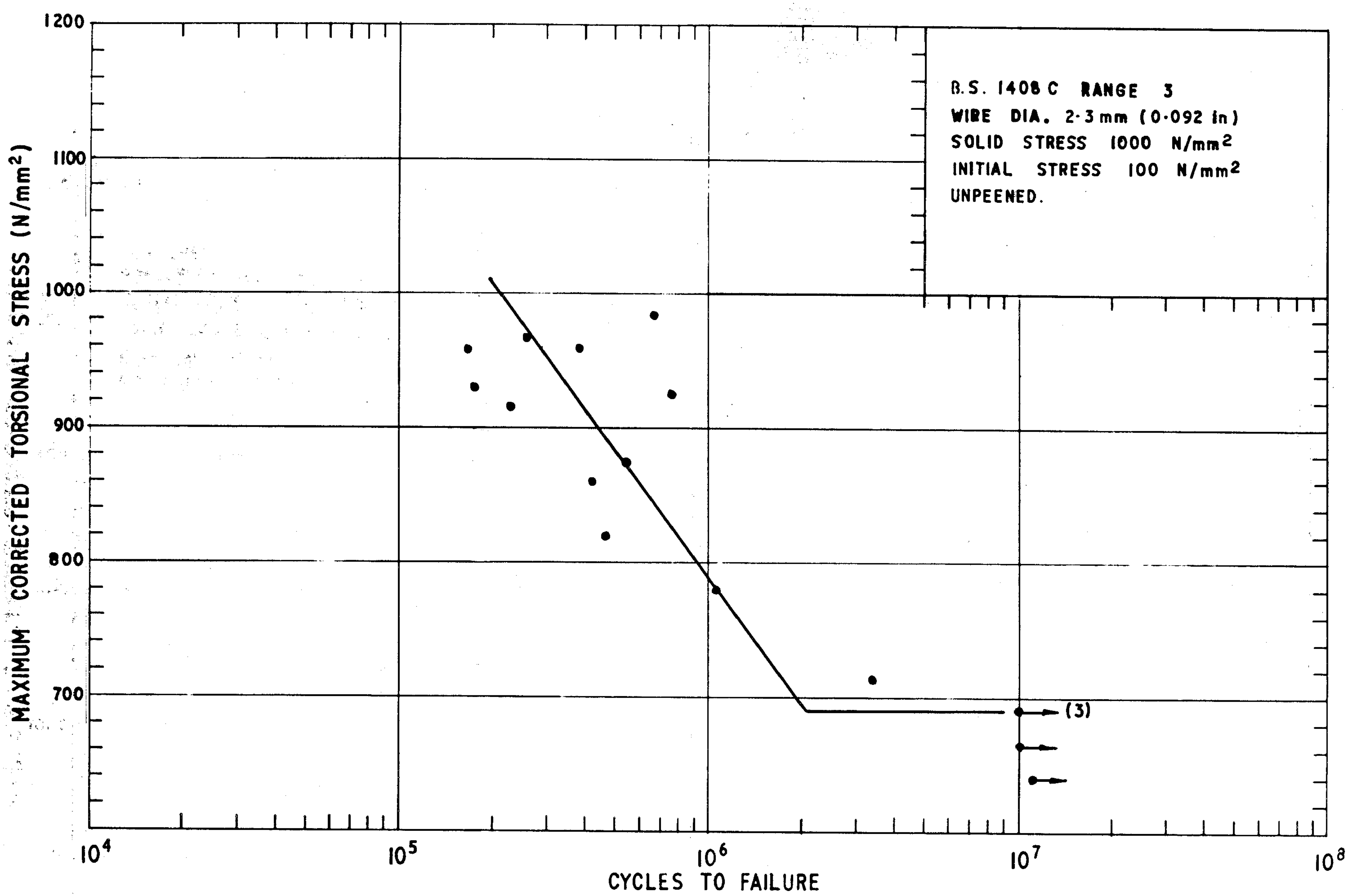

FIG. I. S/N CURVE FOR UNPEENED SPRINGS DESIGN A. INITIAL STRESS 100 N/mm²

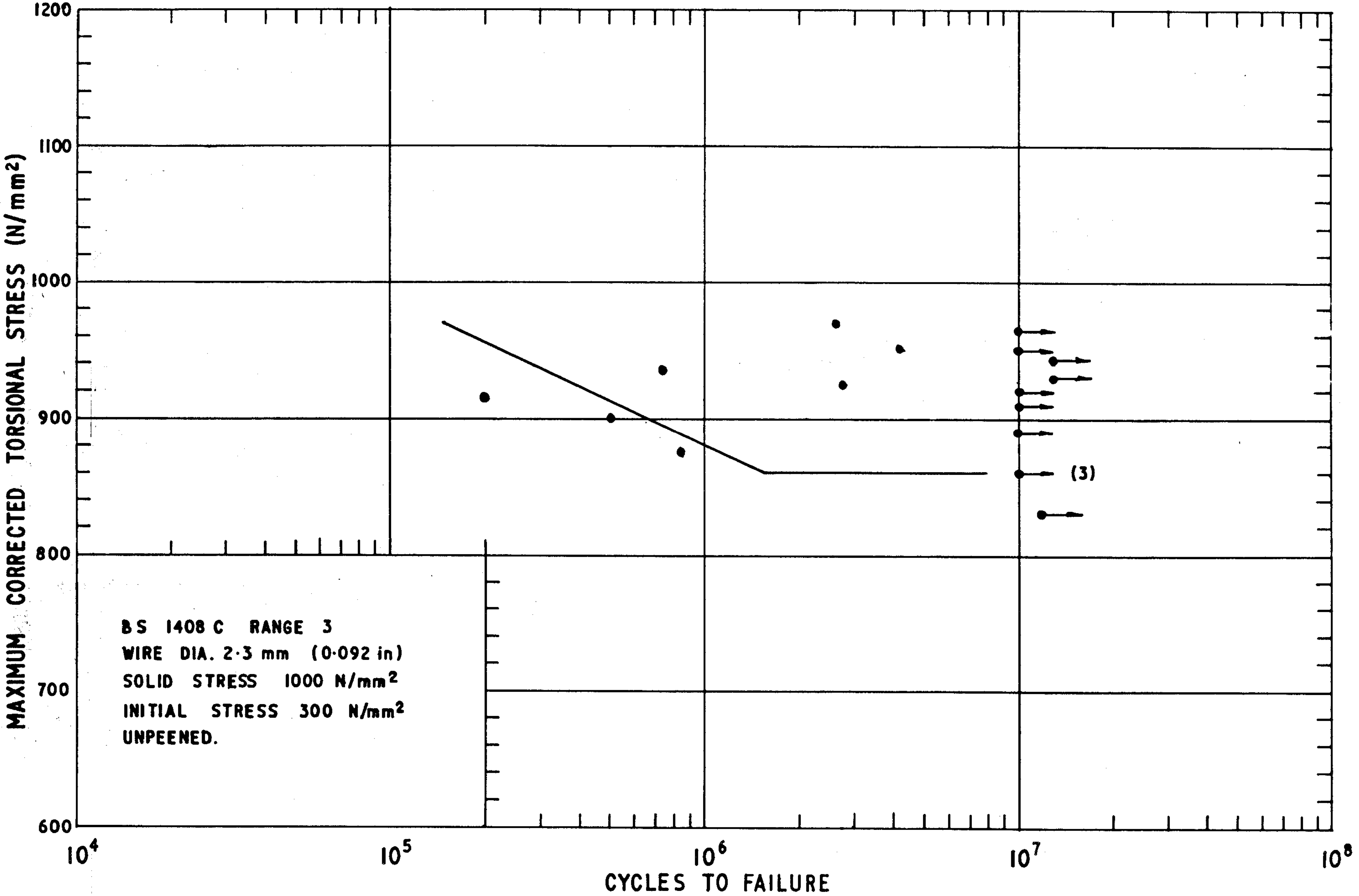

FIG. 2. S/N CURVE FOR UNPEENED SPRINGS DESIGN A INITIAL STRESS 300 N/mm²

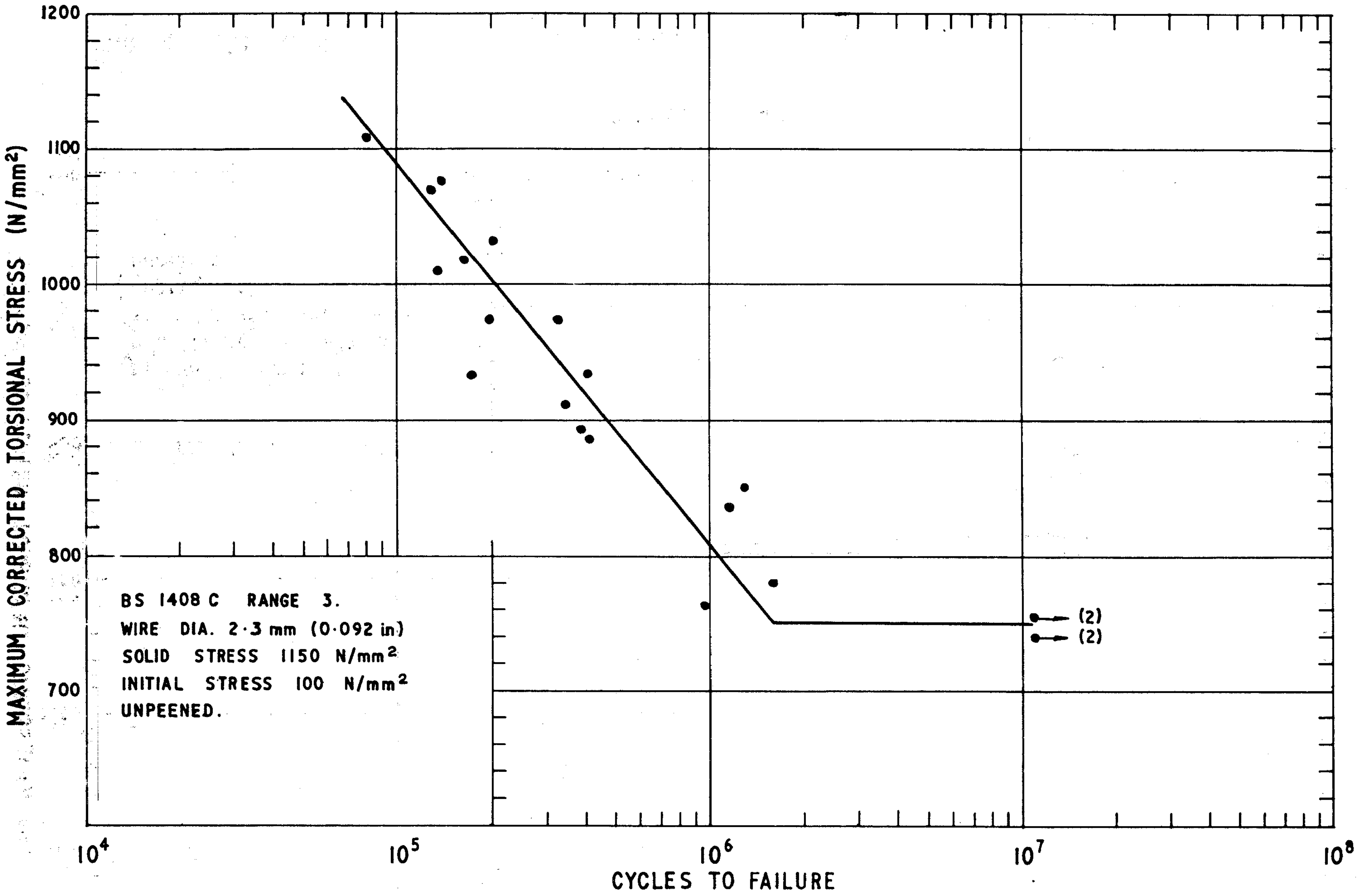

FIG. 3 S/N CURVE FOR UNPEENED SPRINGS DESIGN B INITIAL STRESS 100 N/mm²

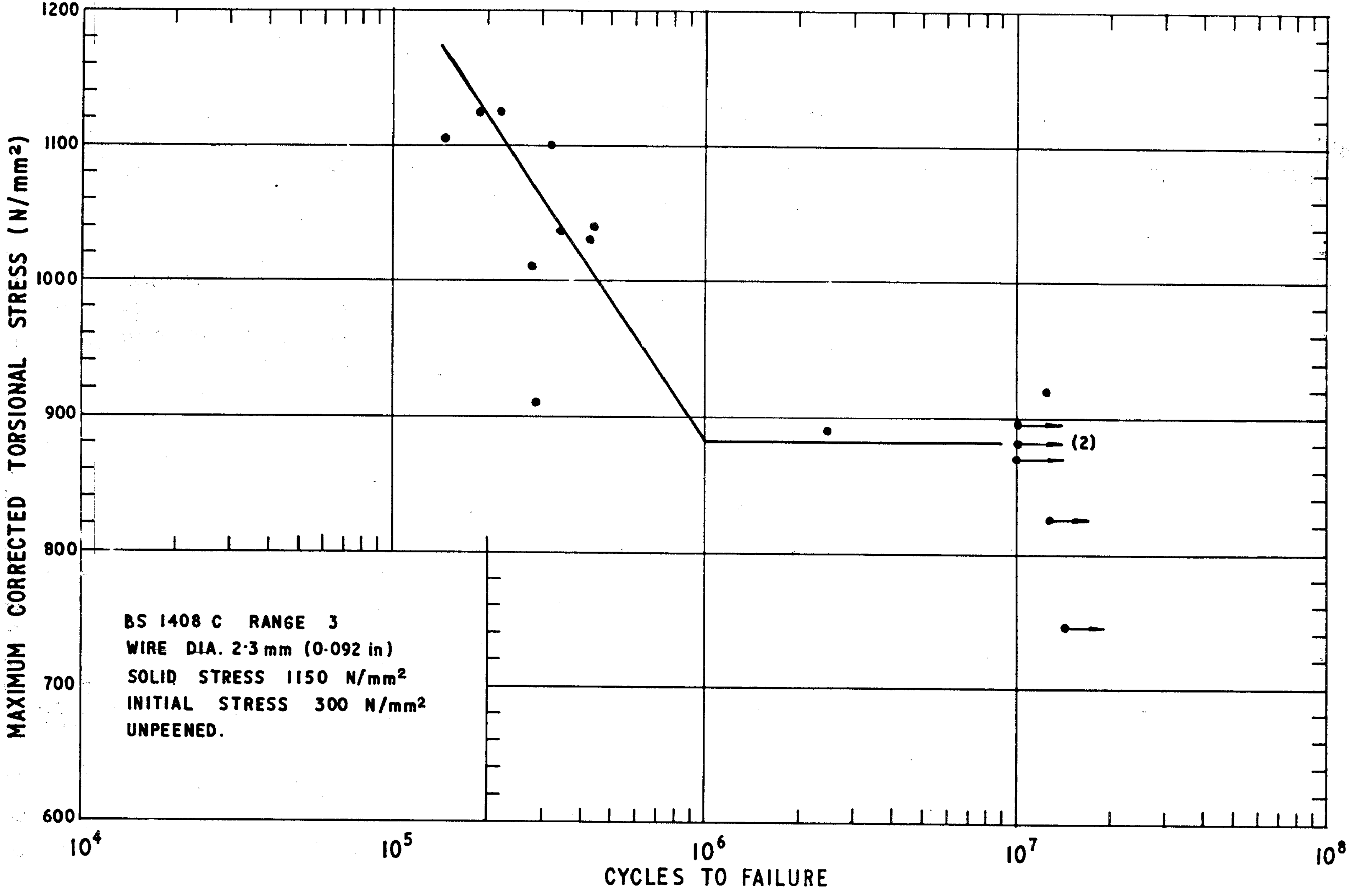

FIG. 4. S/N CURVE FOR UNPEENED SPRINGS DESIGN B INITIAL STRESS 300 N/mm²

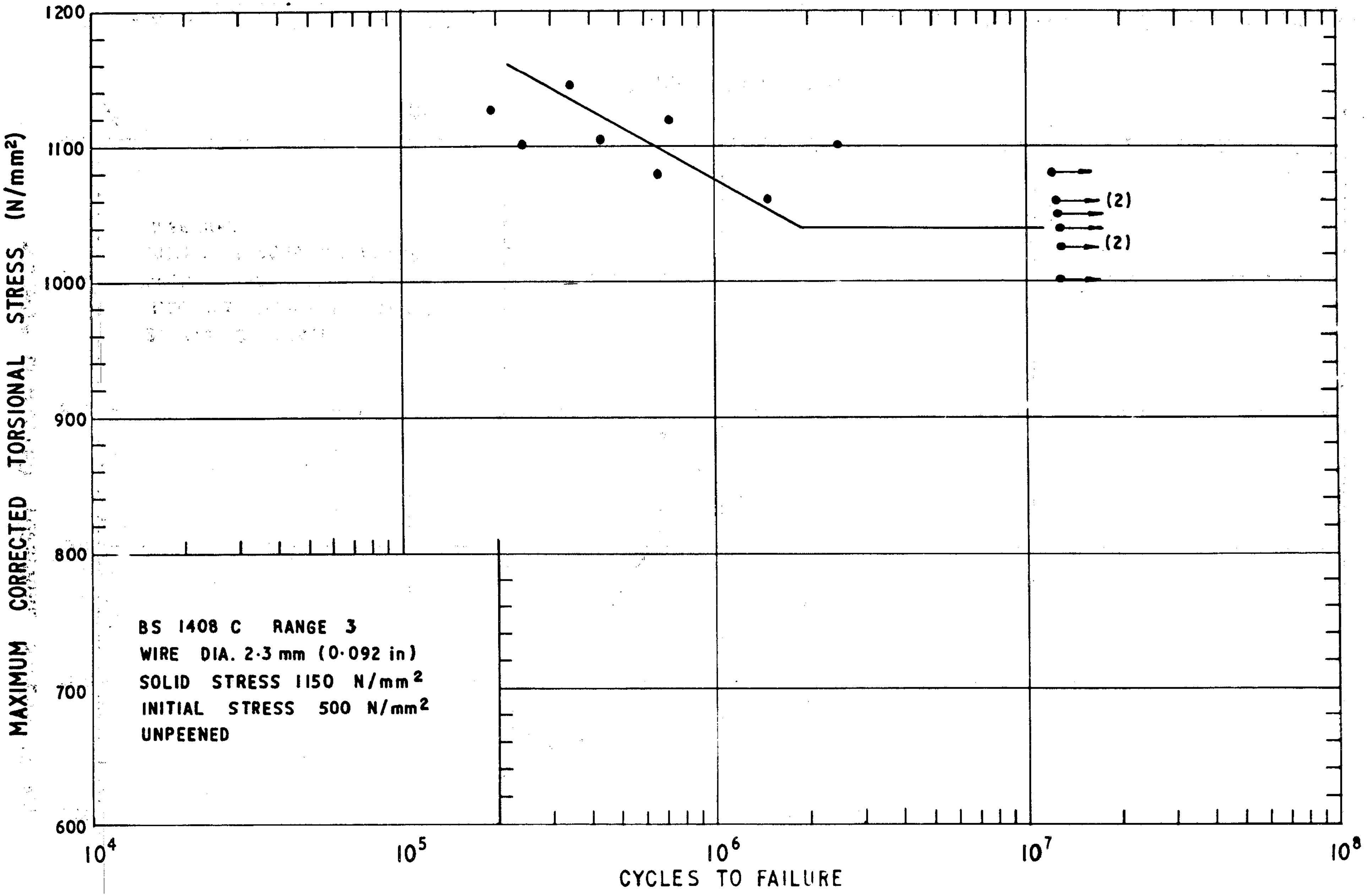

FIG. 5 S/N CURVE FOR UNPEENED SPRINGS DESIGN B INITIAL STRESS 500 N/mm²

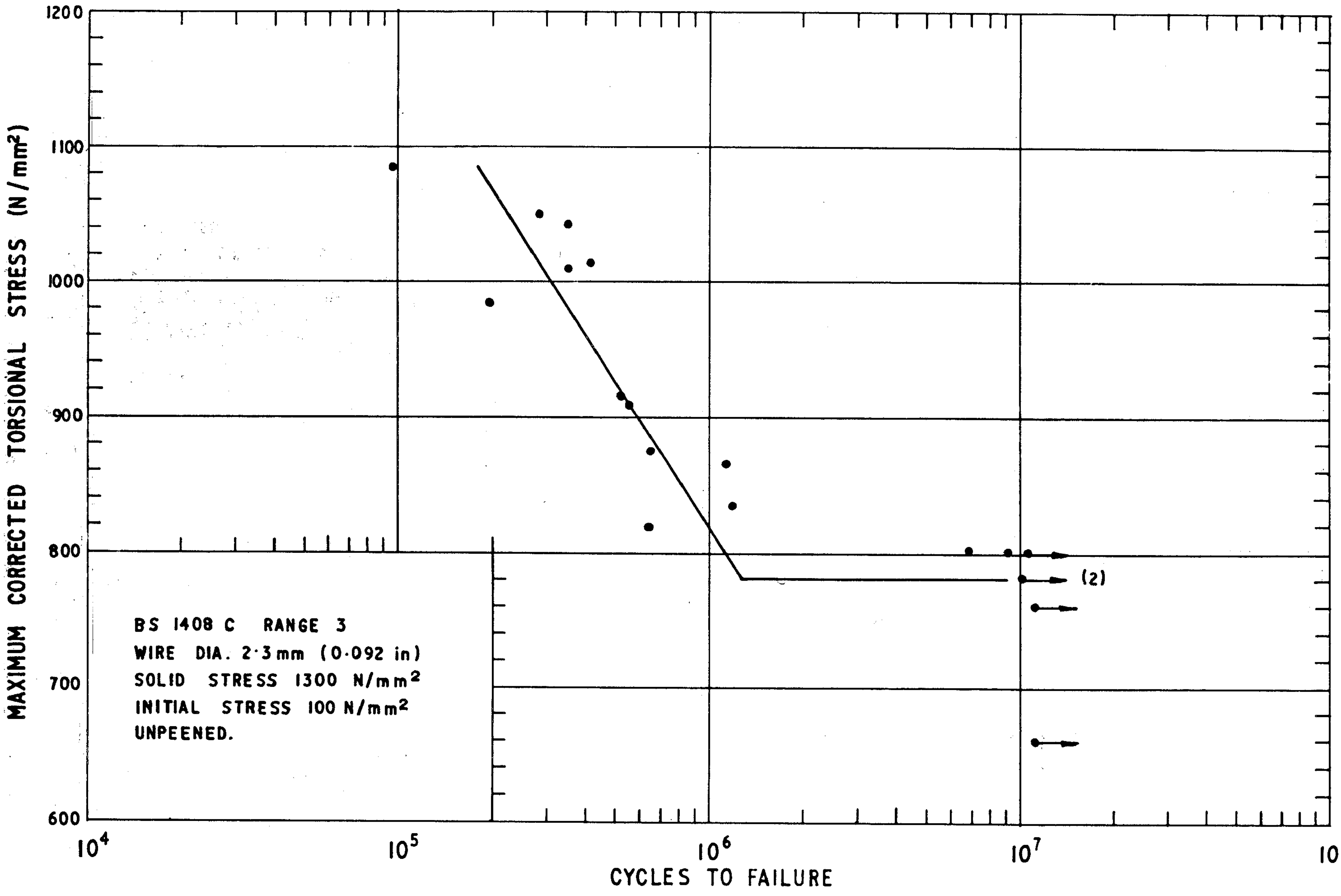

FIG. 6 S/N CURVE FOR UNPEENED SPRINGS DESIGN C INITIAL STRESS 100 N/mm²

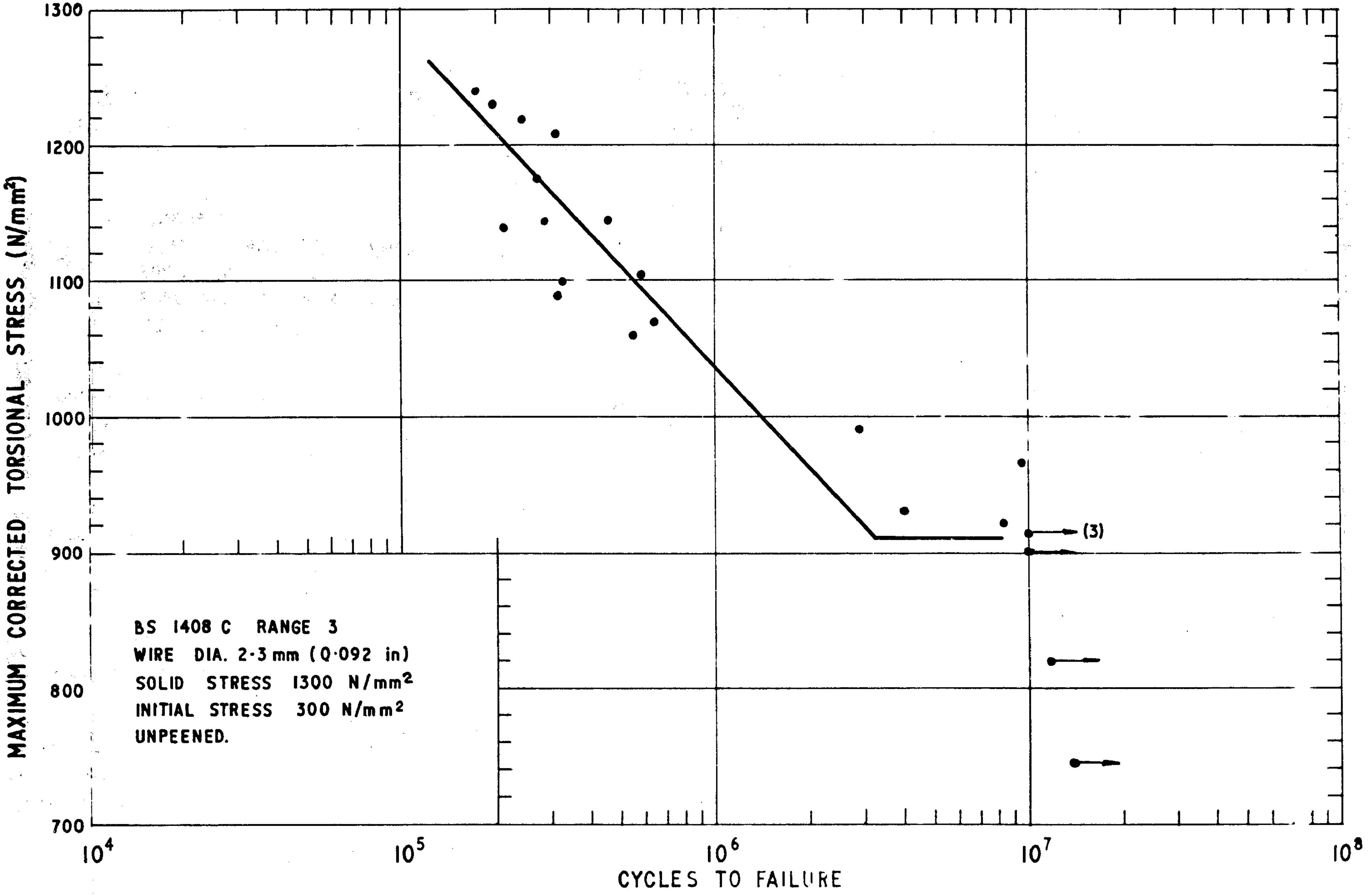

FIG. 7 S/N CURVE FOR UNPEENED SPRINGS DESIGN C INITIAL STRESS 300 N/mm²

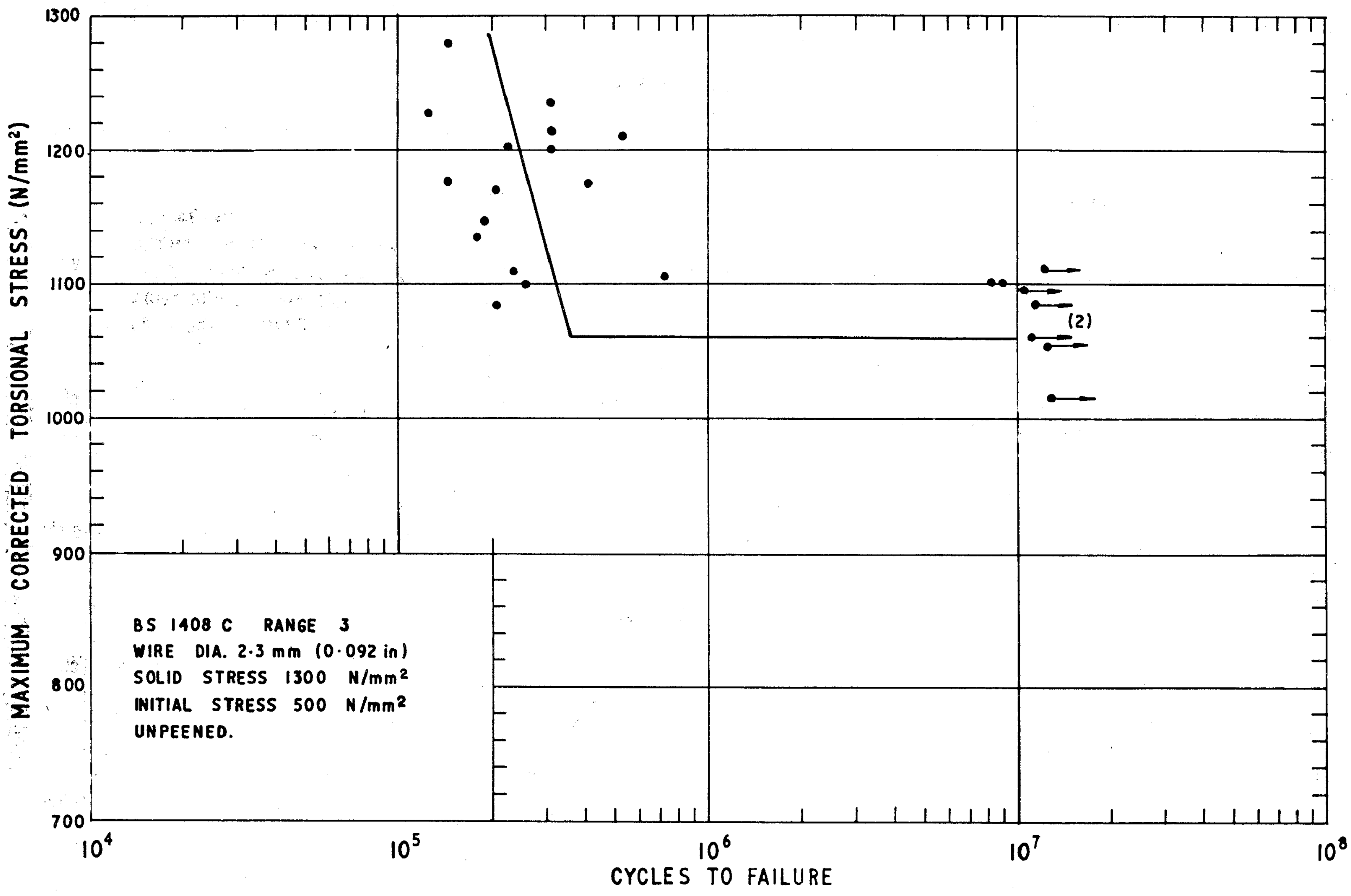

FIG. 8 S/N CURVE FOR UNPEENED SPRINGS DESIGN C INITIAL STRESS 500 N/mm²

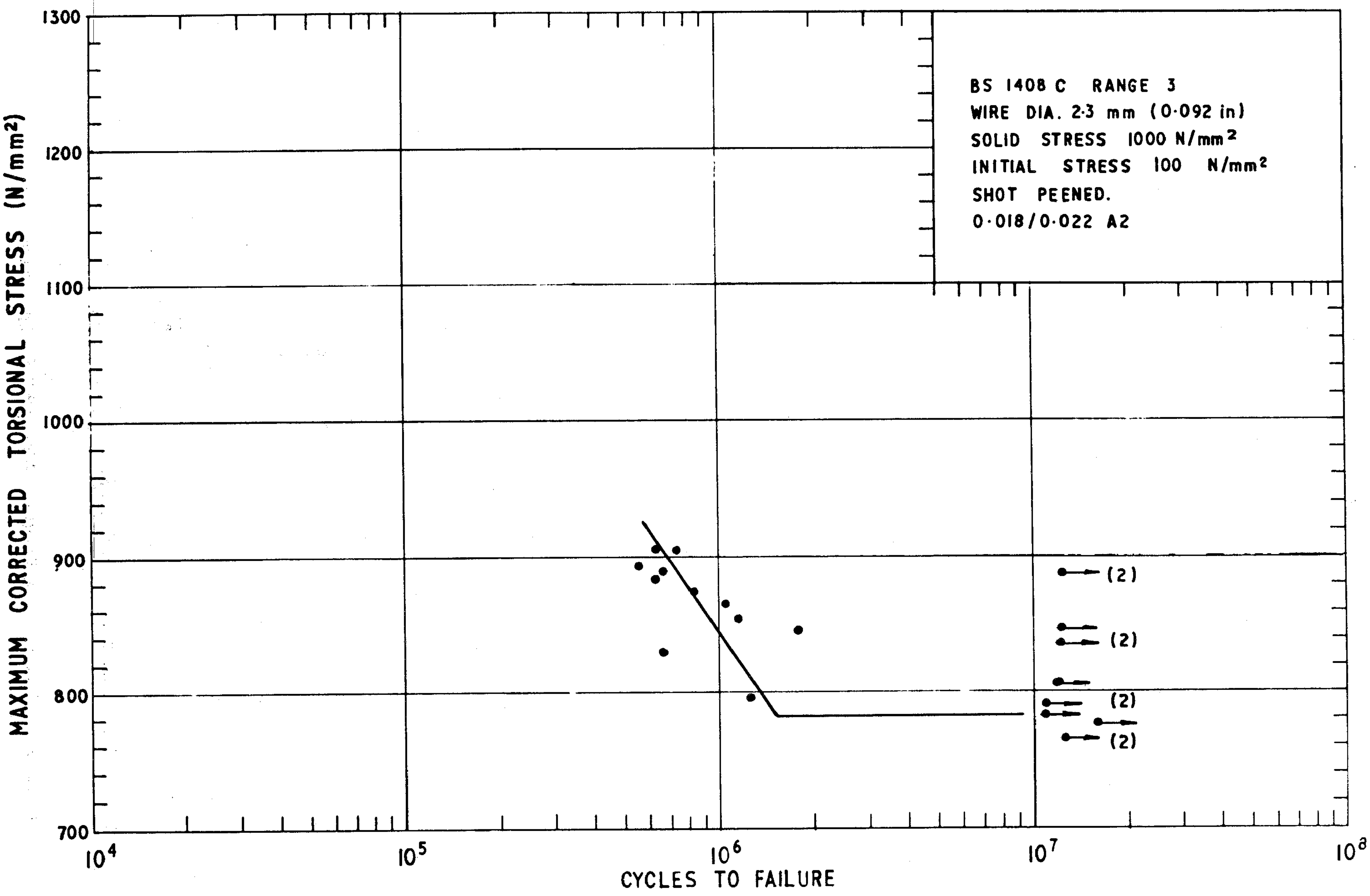

FIG. 9 S/N CURVE FOR SHOT PEENED SPRINGS DESIGN A INITIAL STRESS 100 N/mm²

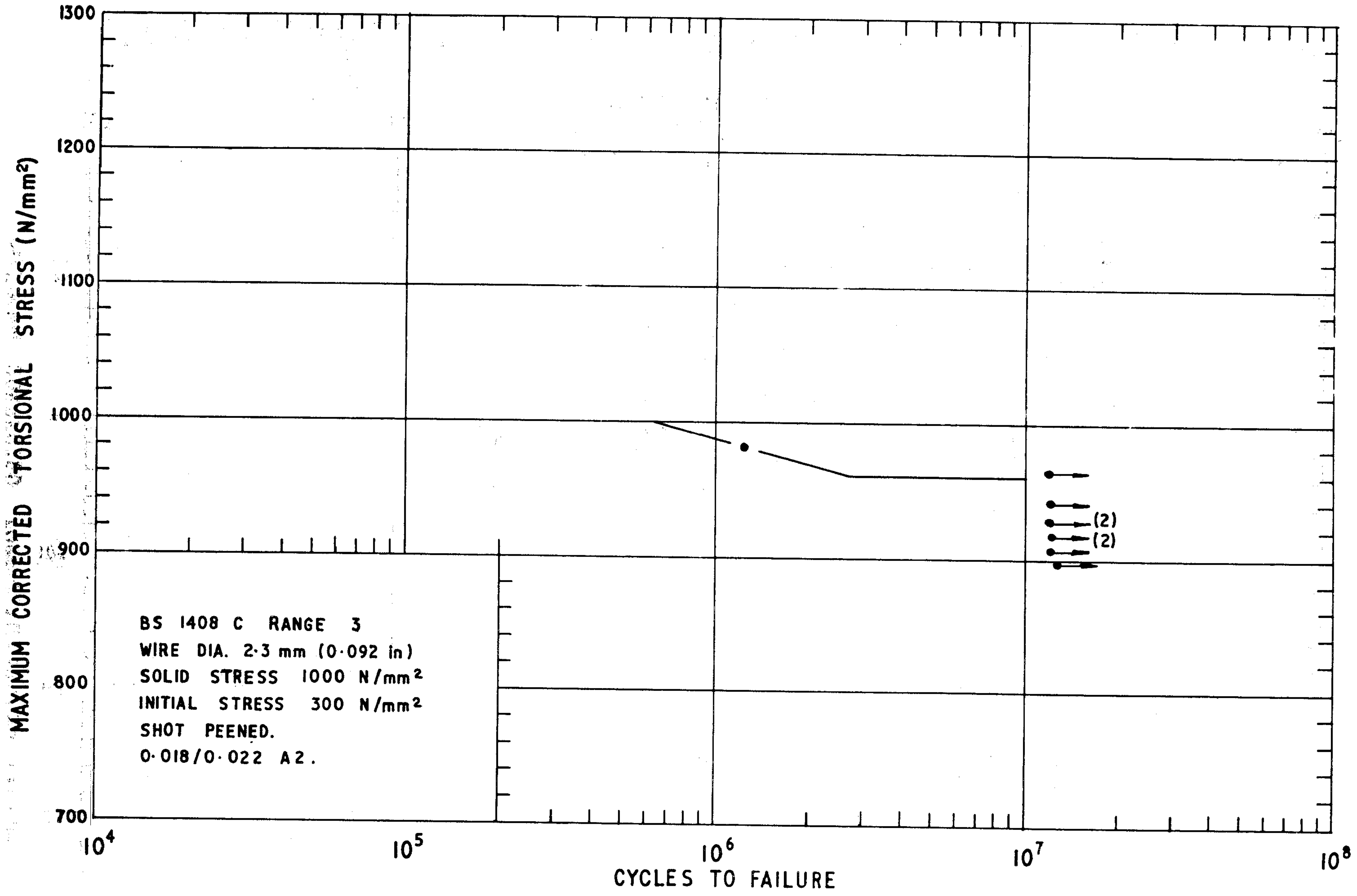

FIG. 10. S/N CURVE FOR SHOT PEENED SPRINGS DESIGN A INITIAL STRESS 300 N/mm²

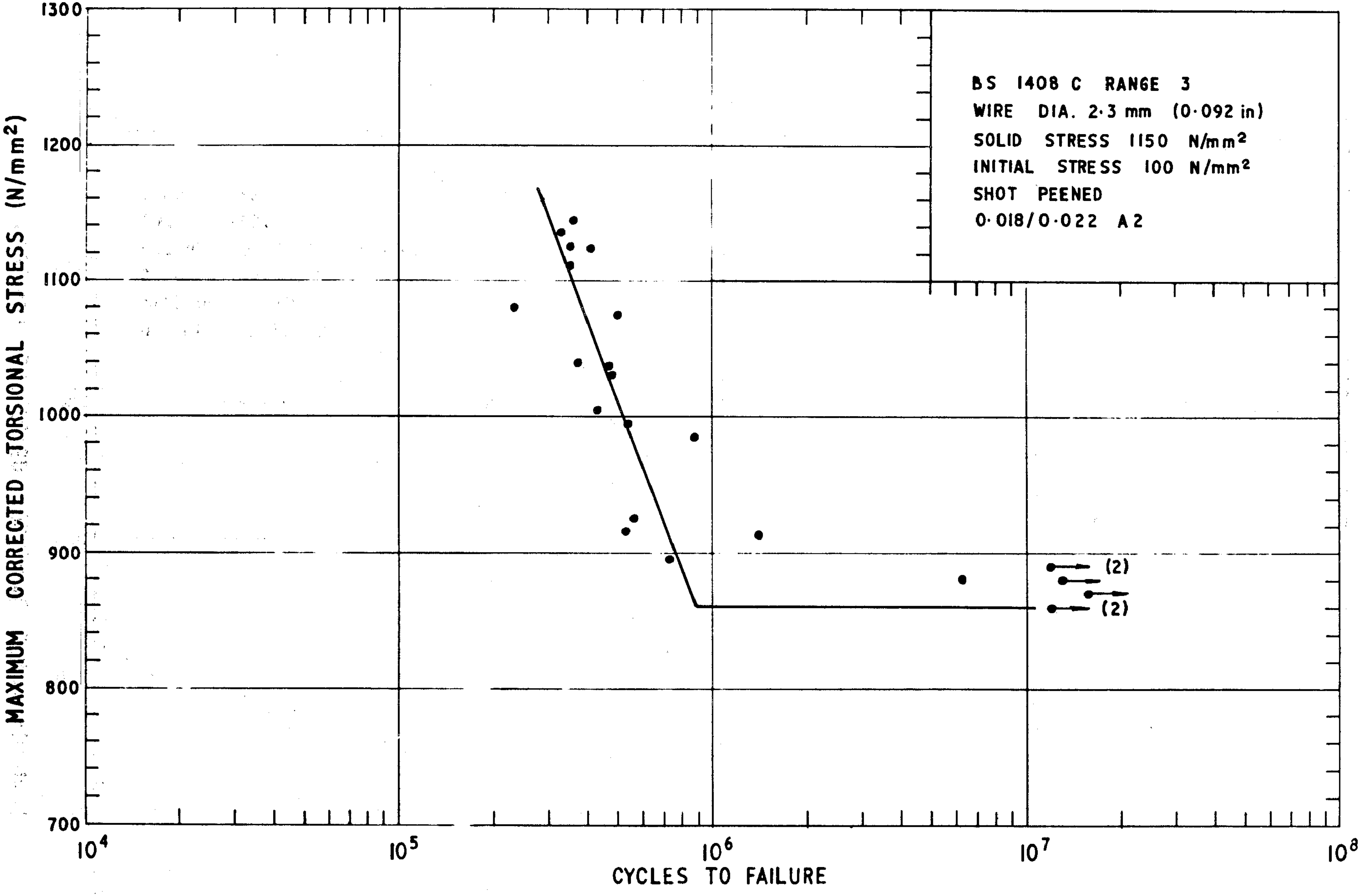

FIG. 11 S/N CURVE FOR SHOT PEENED SPRINGS DESIGN B INITIAL STRESS 100 N/mm²

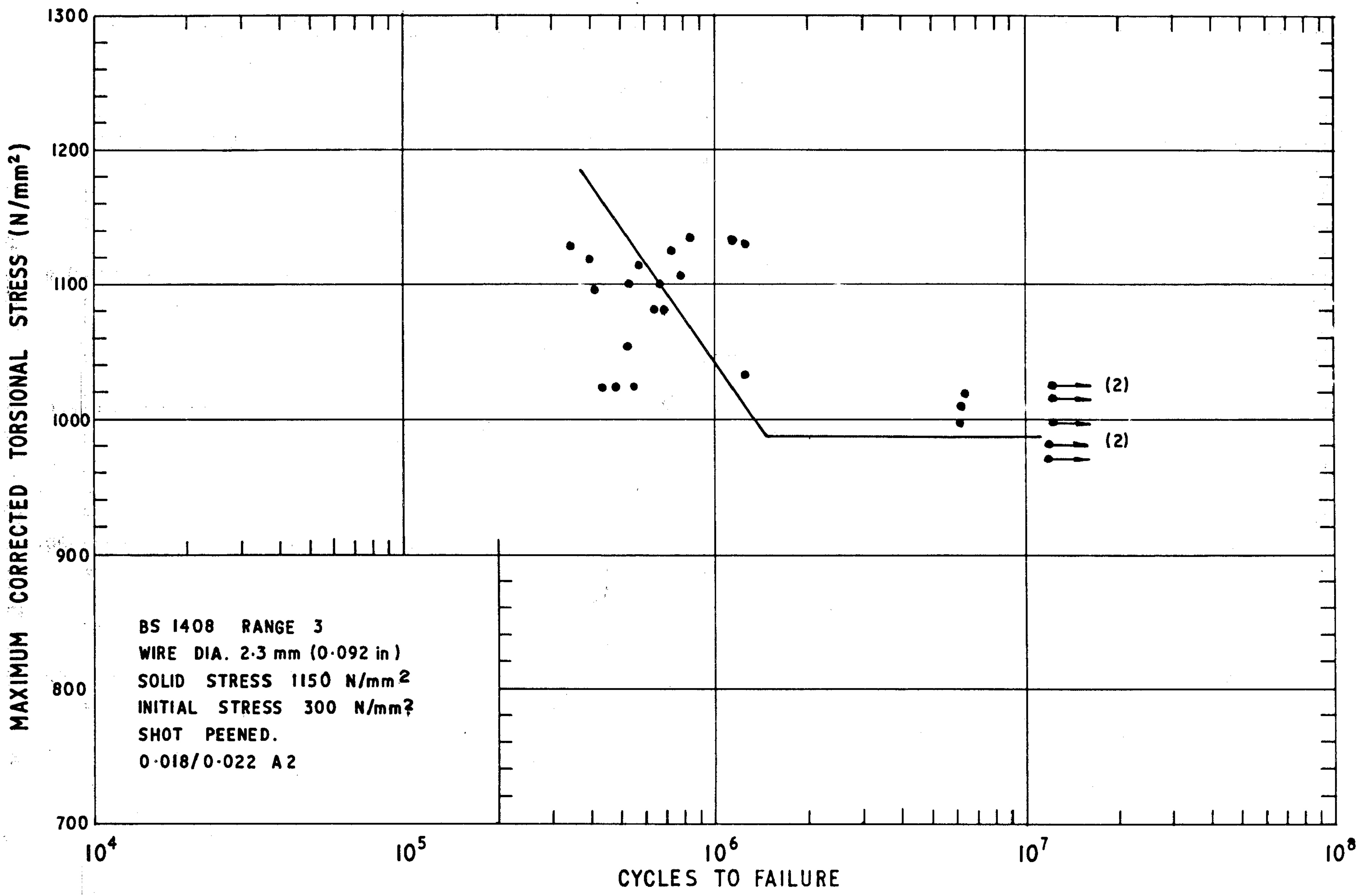

FIG. 12. S/N CURVE FOR SHOT PEENED SPRINGS DESIGN B INITIAL STRESS 300 N/mm²

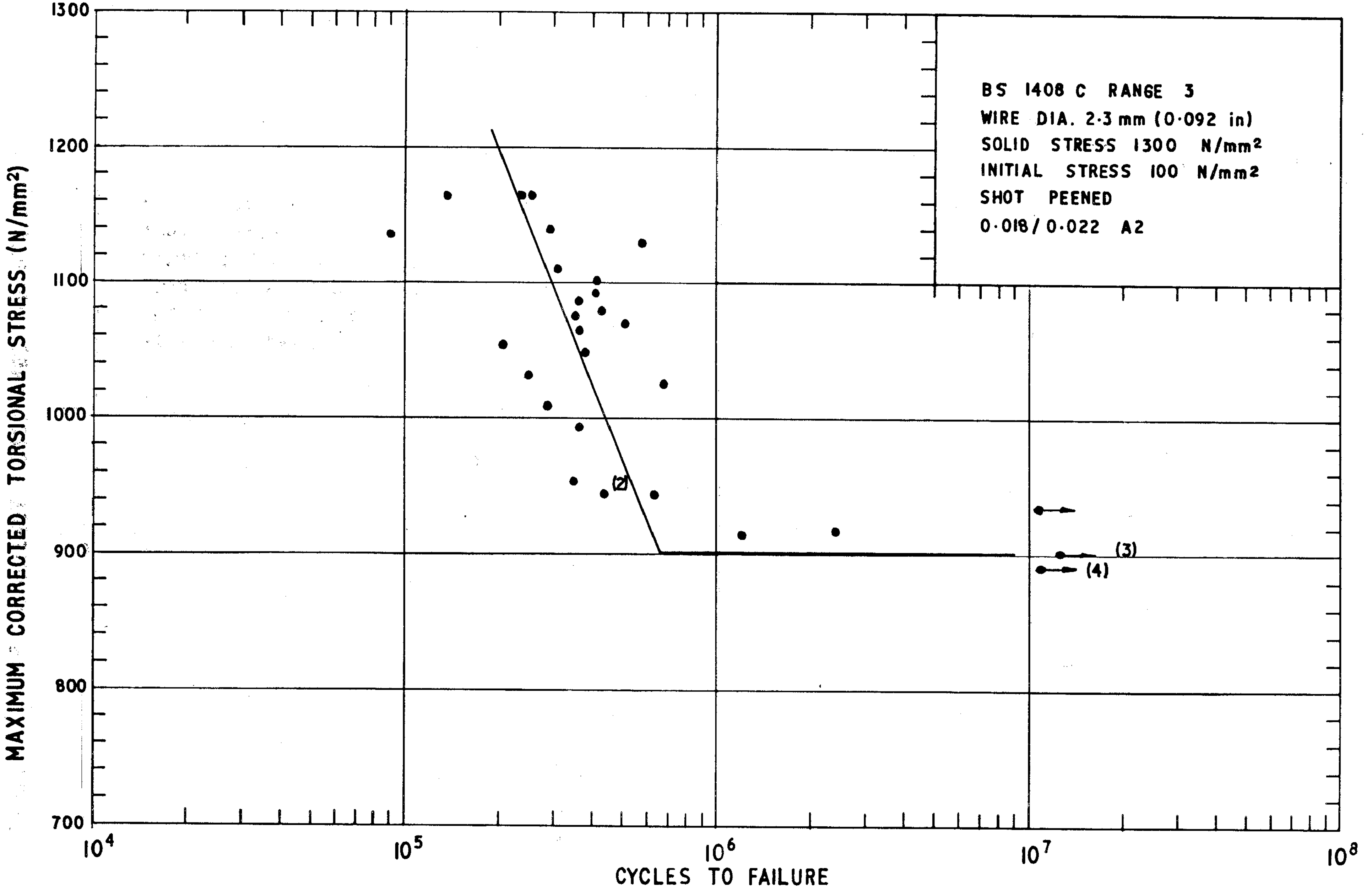

FIG. 13 S/N CURVE FOR SHOT PEENED SPRINGS DESIGN C INITIAL STRESS 100 N/mm²

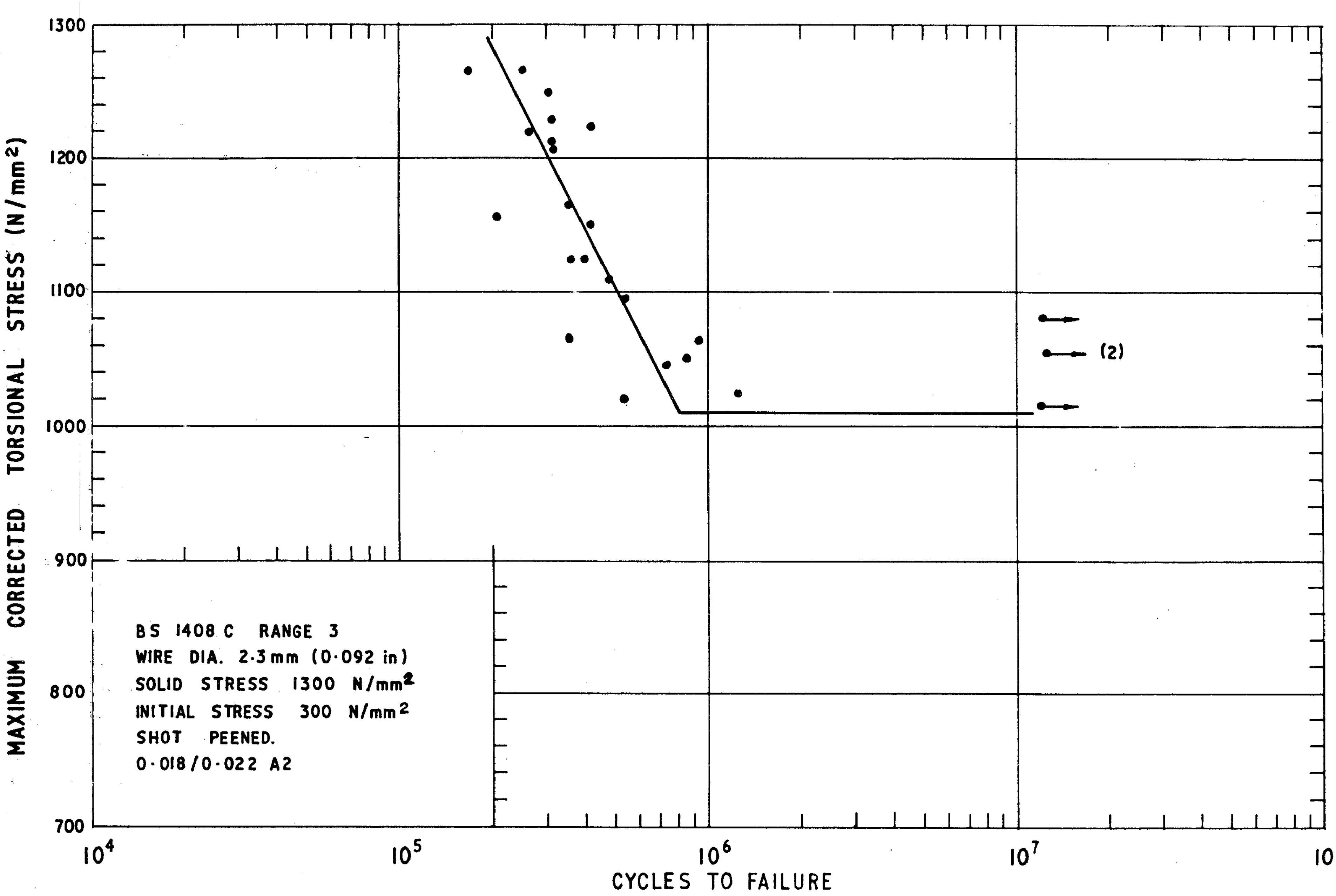

FIG. 14 S/N CURVE FOR SHOT PEENED SPRINGS DESIGN C INITIAL STRESS 300 N/mm²

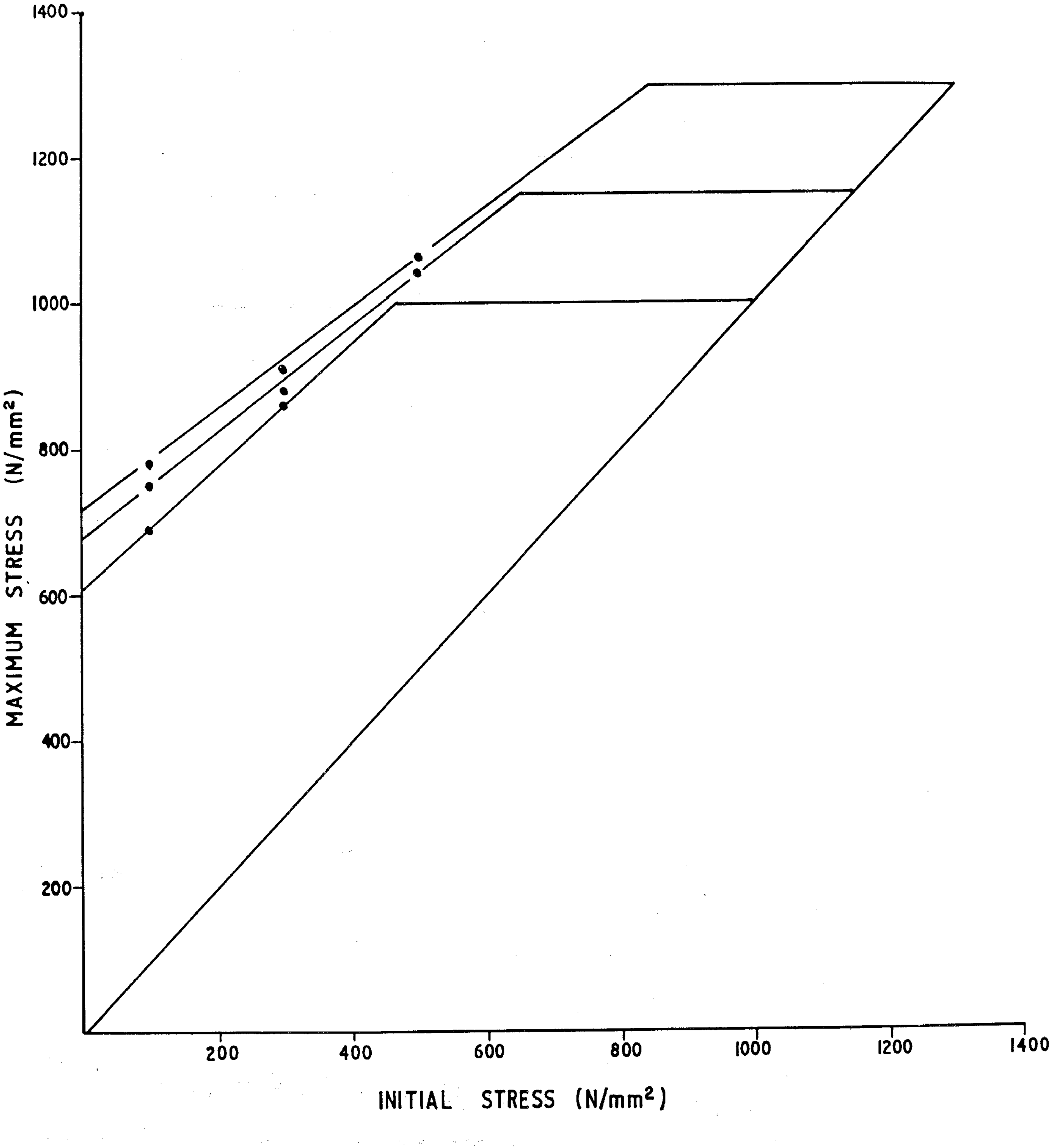

FIG. 15 MODIFIED GOODMAN DIAGRAM FOR UNPEENED SPRINGS

10^7 CYCLES

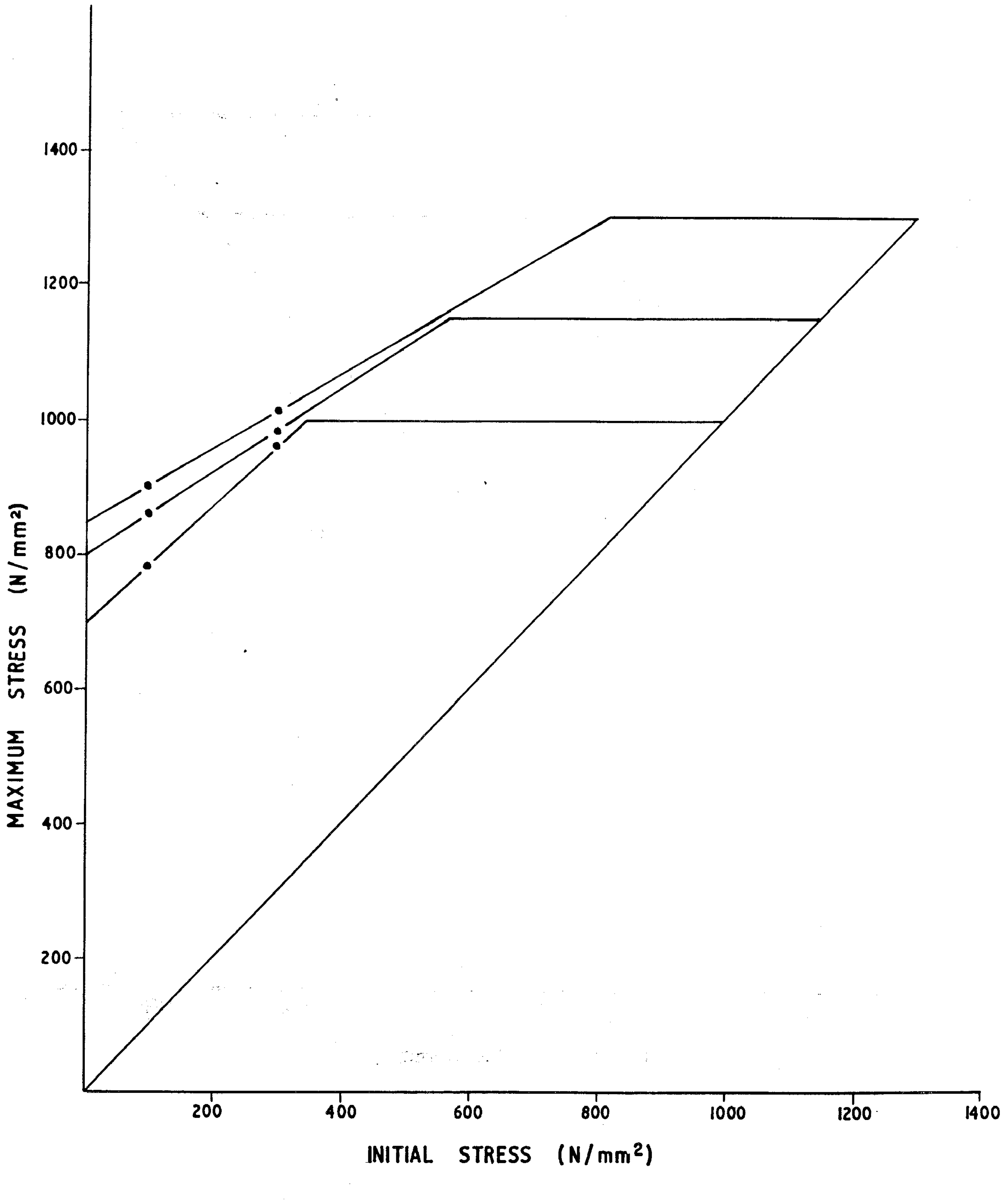

FIG. 16. MODIFIED GOODMAN DIAGRAM FOR SHOT PEENED SPRINGS

10^7 CYCLES

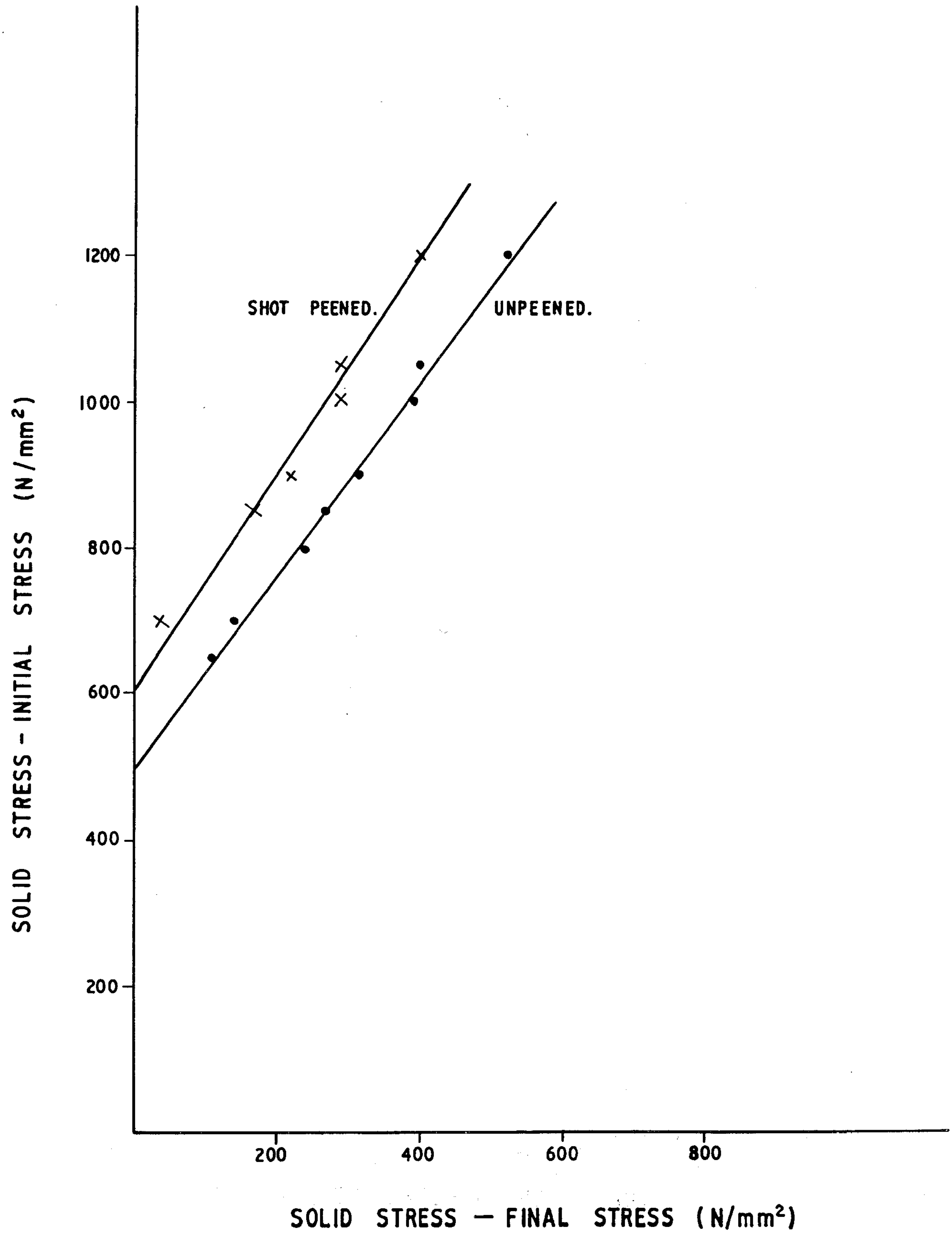

FIG. 17. MODIFIED PRESENTATION OF FATIGUE DATA.

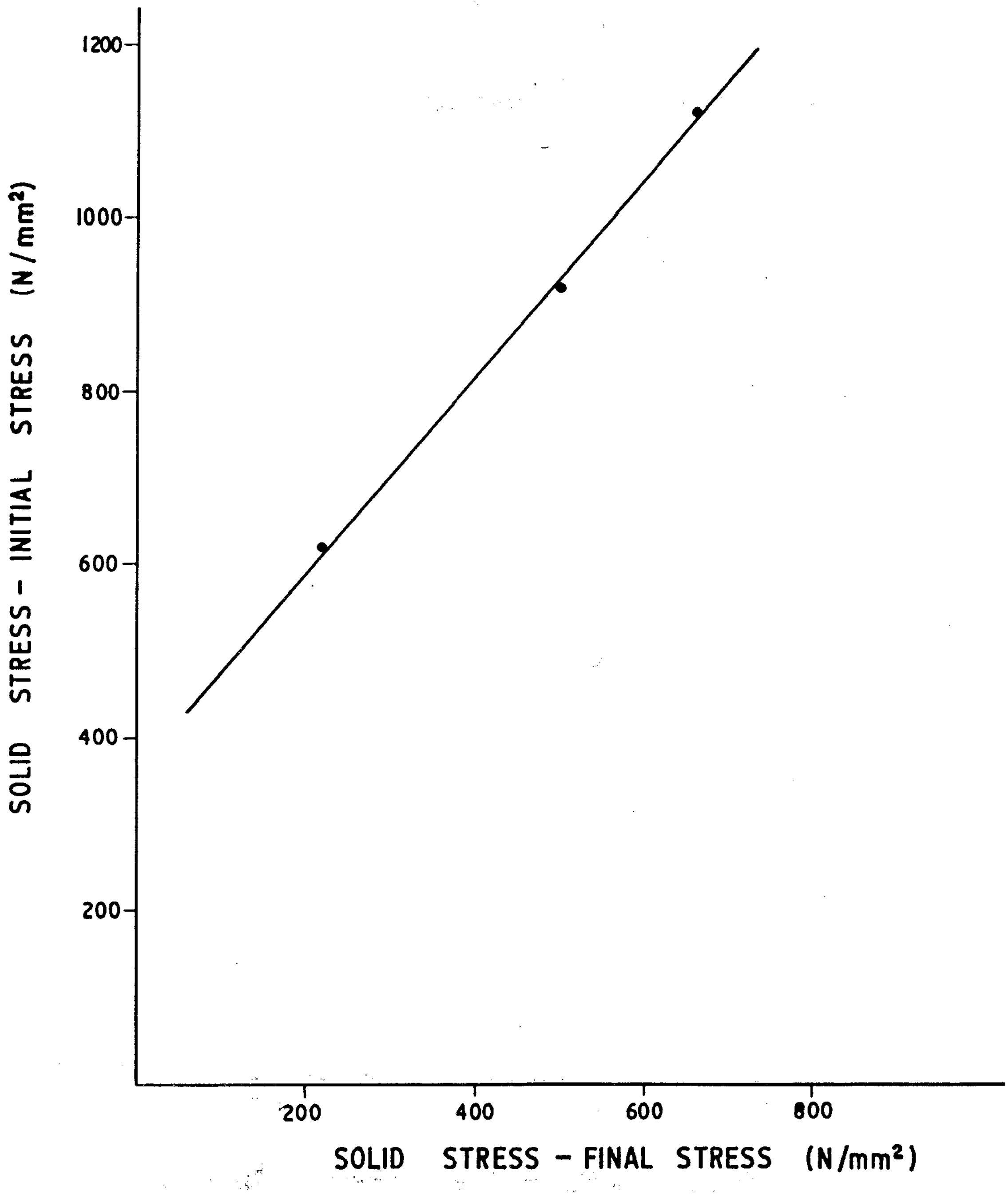

FIG. 18. FATIGUE DATA FROM REPORT R 210.

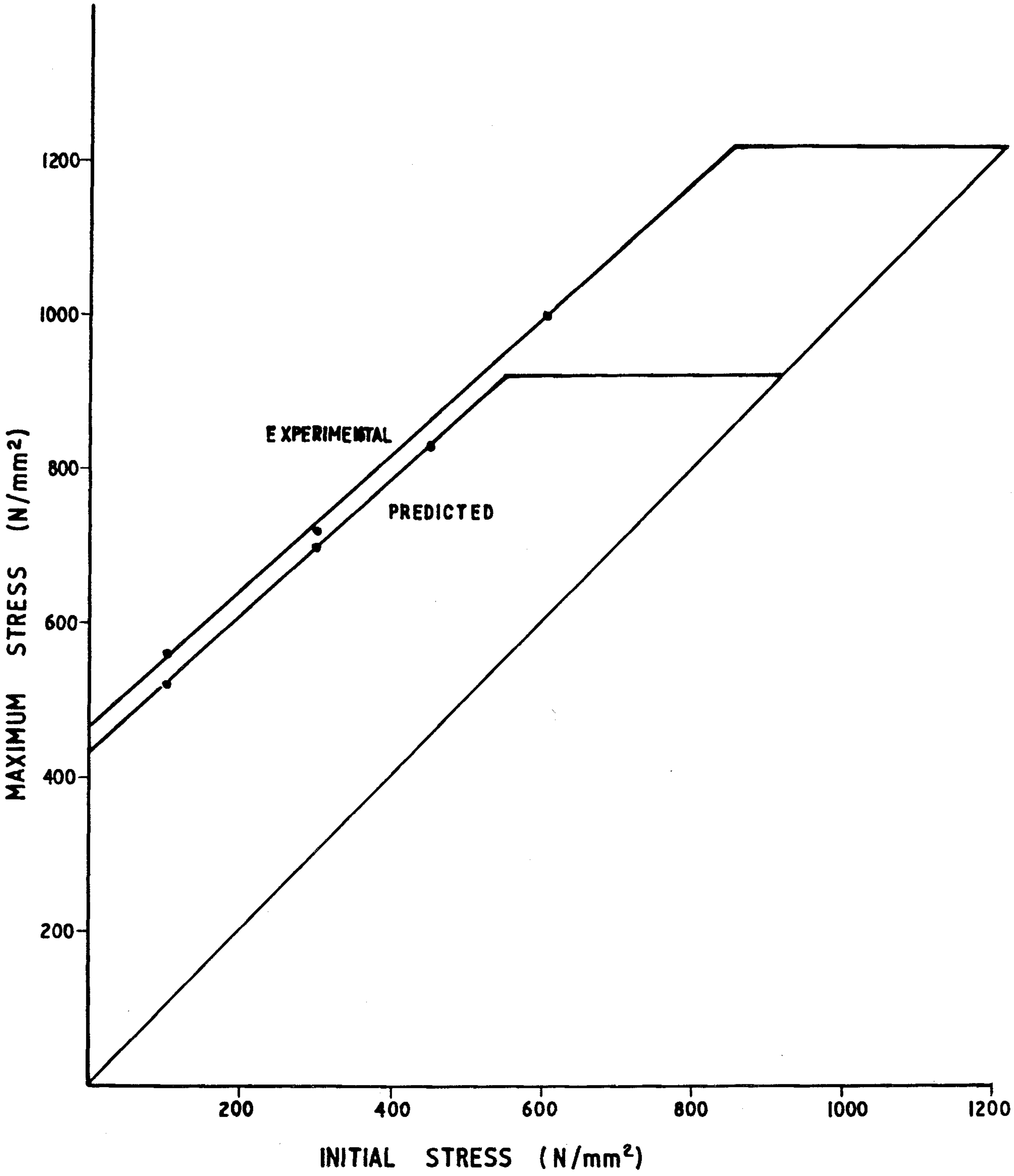

FIG. 19 GOODMAN DIAGRAMS OBTAINED FROM REPORT R 210 SHOWING EFFECT OF SOLID STRESS.