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Effect of Mean Stress on the Fatigue Strength of D.T.D.364 Round Bars with and without Transverse Holes

By

G. M. Norris

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ROYAL AIRCRAFT ESTABLISHMENT

Effect of Mean Stress on the Fatigue Strength of D.T.D.364 Round Bars With and Without Transverse Holes

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SUMMARY

Endurance curves for zero mean stress and for tensile mean stresses of 5 tons/in^2 and 10 tons/in^2 were determined for round specimens machined from extruded D.T.D. 364 bar. Endurance curves were determined also for similar specimens with a transverse hole. Variations in surface roughness caused some scatter in results and an attempt is made to correlate degree of surface finish with fatigue strength.

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1 Introduction

The fatigue tests reported here were made by R.A.E. as an extension to the fatigue programme[1] of Vickers-Armstrongs Ltd., Weybridge.

Two groups of round specimens were used; bars with a transverse hole, and bars with no hole. It was intended to determine the effect of tensile mean stress on fatigue strength, and to assess the influence of the hole, at an endurance of 2×10^6 cycles.

2 Description of Specimens

All specimens were made from D.T.D. 364B extruded bar. Drawings of each type of specimen are given in Figs. 1 and 2 and it is convenient to call those specimens with a hole 'drilled bars', those without 'plain bars'. Each plain bar had a nominal diameter of 0.700", each drilled bar a nominal diameter of 0.832", with a 0.1875" diameter hole in the middle of the length. These dimensions ensured that the minimum cross-sectional area was the same for plain and drilled bars (i.e. 0.385 square inches).

The plain bars had a turned surface. Preliminary fatigue tests indicated that the turning grooves were having undue influence on the results, and it was decided to smooth the remaining bars*. The drilled bars had a much smoother finish and were tested in their original manufactured condition. The 0.1875" diameter holes had a reamed finish and the edges of each hole were slightly chamfered.

3 Tests made

3.1 Static Control Tests (Vickers-Armstrongs)

Three static tests were made on each type of specimen.

	0.1% Proof Stress tons/in^2	Maximum Stress tons/in^2	Average Ultimate Strength tons/in^2
Plain bar	-	32.21	32.15
	-	32.23	
	27.54	32.00	
Drilled bar	-	32.96	33.04
	-	33.16	
	-	33.01	

3.2 Fatigue Tests

The fatigue tests were made under axial loading at zero mean stress and at tensile mean stresses of 5 tons/in^2 and 10 tons/in^2, the testing machine being a 20-ton Avery-Schenck pulsator.

4 Results

The results from the fatigue tests are given in Tables I and II and plotted in Figs. 3 and 4. In drawing the endurance curves the following results were neglected in the case of the plain bar (Fig. 3):-

---

* Appendix I.

(1) Points 'A' and 'B'. It was found that the fractures coincided with pronounced turning marks.

(2) Point 'C'. This result was obtained from a specimen which failed in the head (Fig. 6).

The effect of mean stress is shown in Fig. 5, in which mean and alternating stresses are expressed in terms of the static strength.

5 Failures

Four positions of failure occurred in the plain bars; in the parallel portion, in the radius at the end of the parallel portion, in the head fillet, and in the head (Fig. 6). Some typical fractures are shown in Fig. 7. Fatigue nuclei may be located from the points of convergence of the curved wrinkle formation.

6 Discussion

The fatigue stress-concentration factor[2] (K_f) is a measure of the effect of the hole and is defined as follows:-

$$K_f = \frac{\text{Fatigue strength of plain bar}}{\text{Fatigue strength of drilled bar}}$$

At an endurance of 2×10^6 cycles values for K_f have been calculated:-

Zero mean stress $K_f = 1.81$

5 tons/in^2 stress $K_f = 2.28$

10 tons/in^2 stress $K_f = 2.31$

The geometric stress-concentration factor[3] (K_e) has been determined experimentally, and for the present case is about 2.75.

7 Conclusions

(1) Mean stress has a greater effect on the fatigue strength of the drilled bar than on that of the plain bar.

(2) At the endurance of 2×10^6 cycles, the fatigue stress-concentration factor is approximately constant over the mean stress range 5 tons/in^2 to 10 tons/in^2.

REFERENCES

No.	Author	Title, etc.
1	Vickers-Armstrongs Ltd.	'Interim Report on Fatigue' VTO/M/182, Issue 2. January, 1950
2	P.B. Walker and R.B. Heywood	Fatigue nomenclature for aircraft structural workers Report No. Structures 102, February 1951 ARC 13.960.
3	R.B. Heywood	Page 273 of 'Designing by Photoelasticity', to be published by Chapman and Hall in 1952

Appendix I

Effect of Surface Finish

In the tests by Vickers-Armstrongs the usual method of removing transverse scratches was not employed because the firm desired results from bars having a typical production finish. The scatter in their results shown plotted in Fig. 3 is believed to be due mainly to the rough-turned surface of the plain bars, and the hand-smoothing* done by R.A.E. largely responsible for the reduction in scatter. After the R.A.E. tests on the plain bars the surface roughness near to each fracture was measured; two typical records are given in Fig. 8. As there was not sufficient evidence of a consistent relationship between roughness and fatigue strength this method was abandoned.

A visual examination was made, which enabled the roughness of each bar to be classified. The results obtained are given in Table III. From this table emerges a number of cases where poor surface finish is associated with low fatigue strength.

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* Using 00 grade emery paper. The bars could not be described as 'highly polished', however.

Table I

Results of Plain Specimens

Specimen Number	Mean Stress tons/in^2	Alternating Stress tons/in^2	Endurance cycles $\times 10^{-6}$
12	zero	10.0	0.131
1	"	12.0	0.129
6	"	11.1	0.443
13	"	10.68	0.794
14	"	10.2	1.15
19	"	9.7	3.58
23	"	9.5	7.29
20	5	9.5	0.083
10	"	10.0	0.154
16	"	9.6	0.285
22	"	9.2	0.863
21	"	9.0	12.35
24	"	8.5	18.84*
7	10	7.6	0.316
15	"	7.7	0.158
17	"	7.75	0.172
4	"	8.5	0.196
25	"	9.0	0.222
2	"	7.05	0.123
18	"	7.9	0.465
3	"	7.8	0.655
9	"	8.0	2.04
8	"	9.0	2.53
11	"	7.15	2.58
5	"	7.3	4.41

* Specimen unbroken

Table II

Results of Notched Specimens

Specimen Number	Mean Stress tons/in^2	Alternating Stress tons/in^2	Endurance cycles $\times 10^{-6}$
30	zero	8.0	0.177
26	"	6.0	0.695
29	"	5.77	1.26
27	"	6.0	1.427
28	"	5.0	10.9*
34	5.0	6.5	0.156
31	"	5.0	0.334
38	"	5.5	0.374
32	"	4.0	0.76
39	"	4.0	2.17
35	"	3.0	17.56*
33	10	4.0	0.146
40	"	3.5	0.321
37	"	3.25	0.98
36	"	3.0	11.63*

* Specimen unbroken

Table III

Correlation of Surface Roughness with Fatigue Strength

No. of Specimen	Mean Stress ($tons/in^2$)	Fatigue strength variation ($tons/in^2$)		Degree of Surface Finish	No. of Specimen	Mean Stress ($tons/in^2$)	Fatigue strength variation ($tons/in^2$)		Degree of Surface Finish
		Above* Curve	Below* Curve				Above* Curve	Below* Curve	
12	0	-	2.18	4	25	10	0.69	-	2
1	"	-	0.25	2	4	"	0.10	-	3
6	"	0.14	-	1	18	"	0	0	2
13	"	0.18	-	2	3	"	0.05	-	2
14	"	-	0.05	1	17	"	-	0.75	3
23	"	0	0	2	15	"	-	0.86	2
19	"	0	0	3	7	"	-	1.05	3
10	5	0.20	-	2	5	"	0.09	-	2
16	"	0.07	-	3	11	"	-	0.17	2
20	"	-	0.60	3	2	"	-	1.10	3
21	"	0.14	-	1	8	"	1.65	-	1
22	"	0	0	2	9	"	0.6	-	1

* Positions of individual points with respect to particular endurance curve.

From the visual examination made of the surface of each specimen the degree of finish was graded as follows:-

1. No tool marks
2. Short residual tool marks
3. Tool marks visible all round specimen

} Smoothed with 00 grade emery paper

4. As machined

Wt.2078. CP120.K3. Printed in Great Britain.

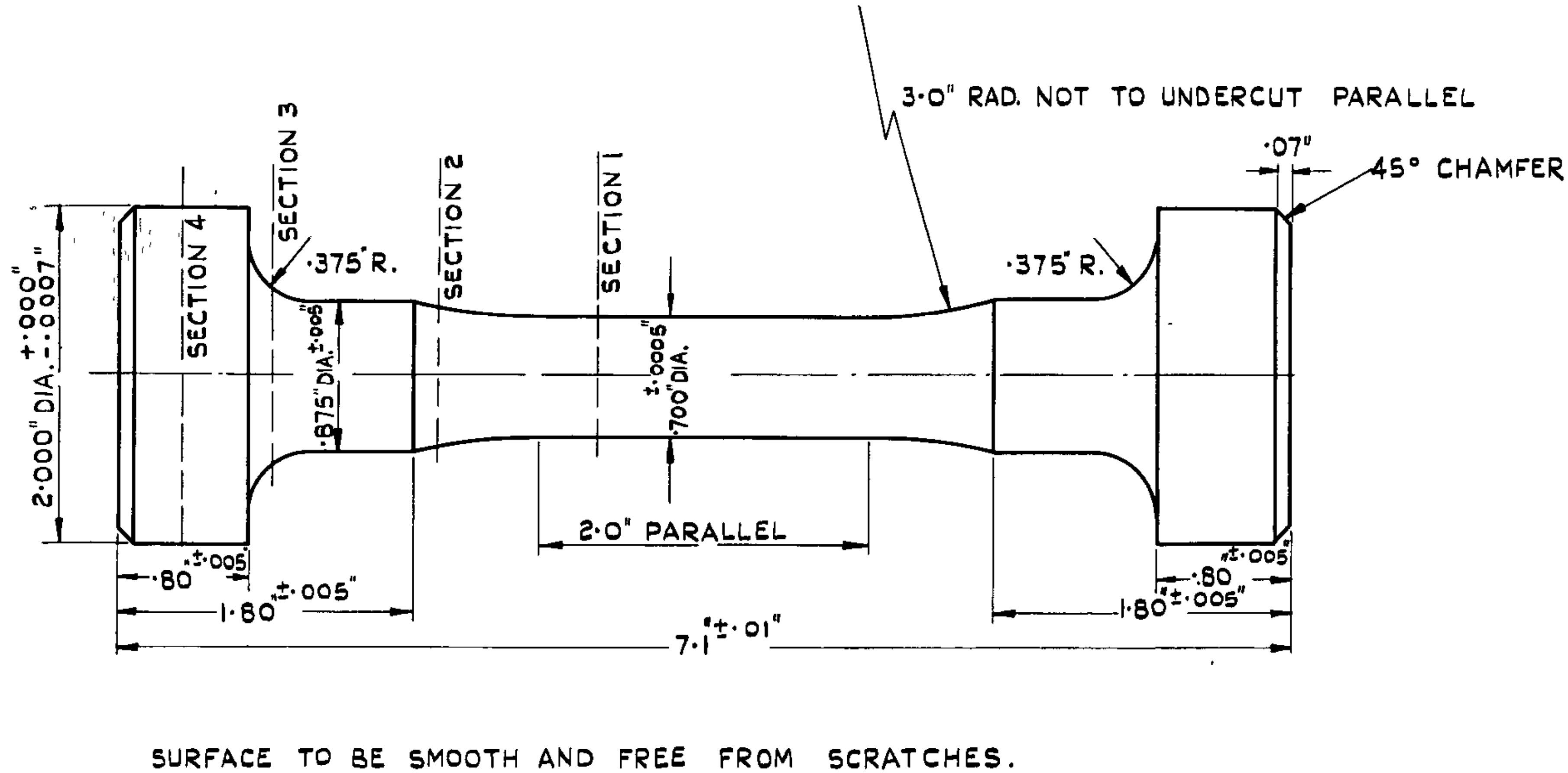

FIG.1. PLAIN BAR TEST PIECE.

FIG.1.

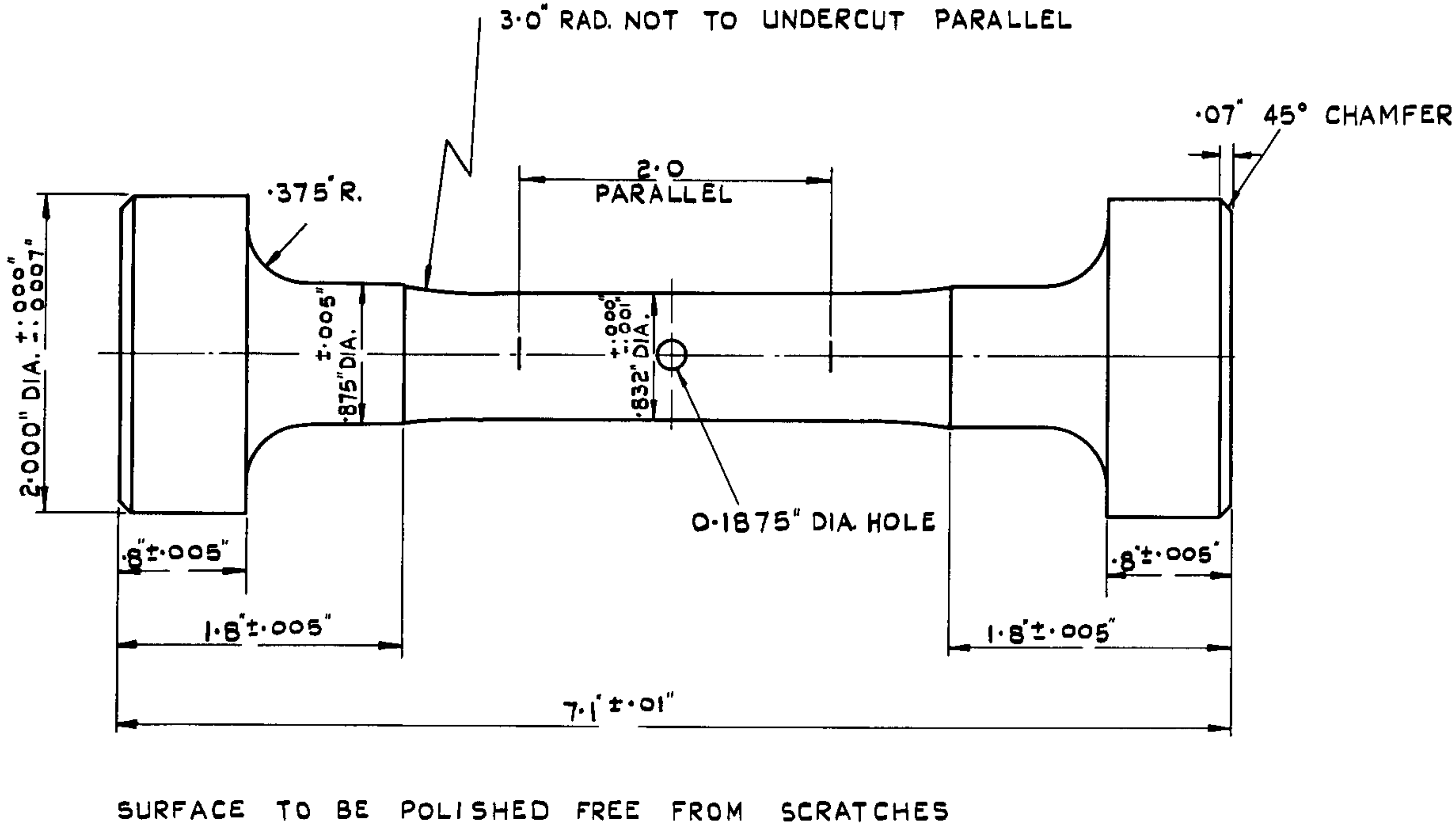

FIG. 2. DRILLED BAR TEST PIECE.

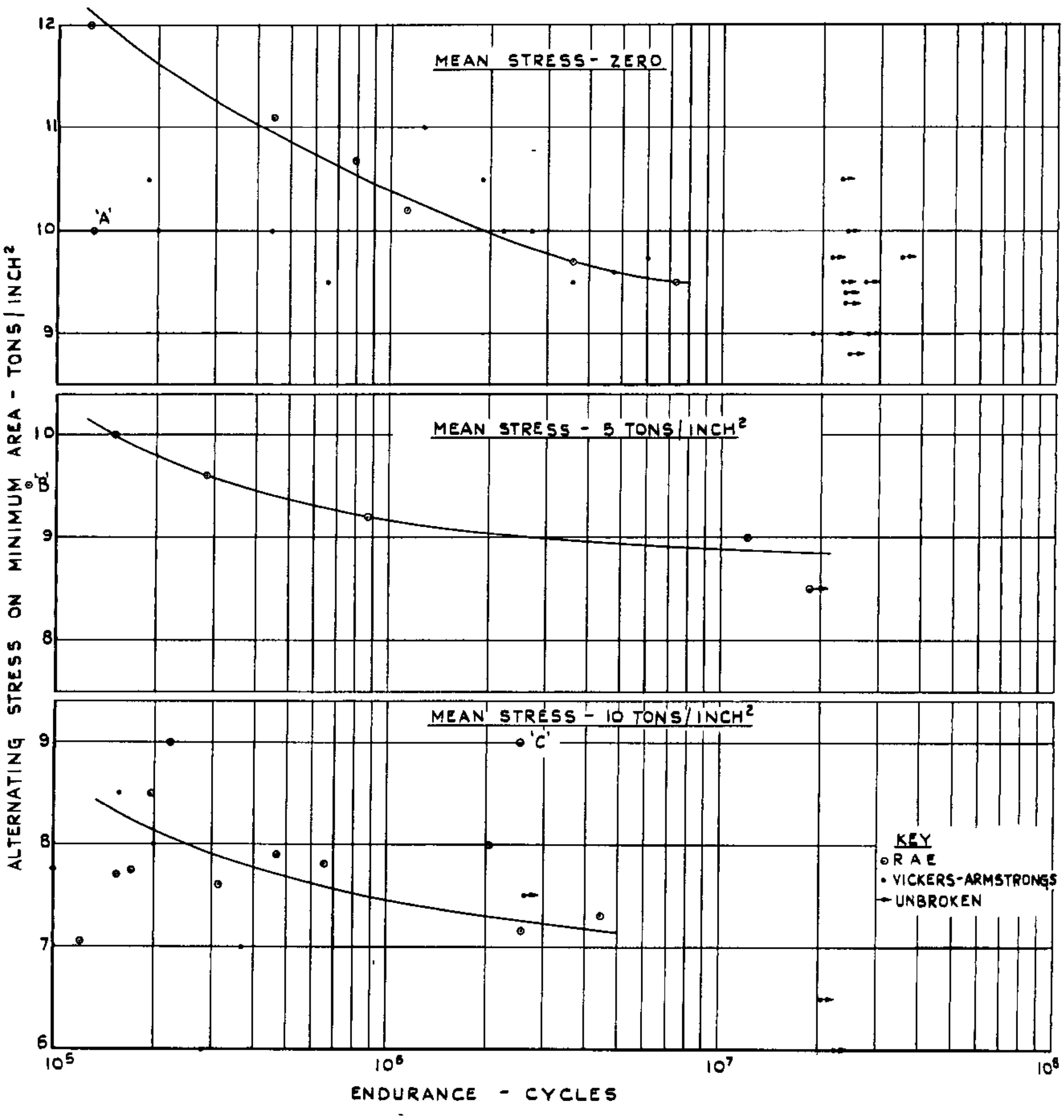

FIG.3. RESULTS FROM PLAIN SPECIMENS.

FIG.4.

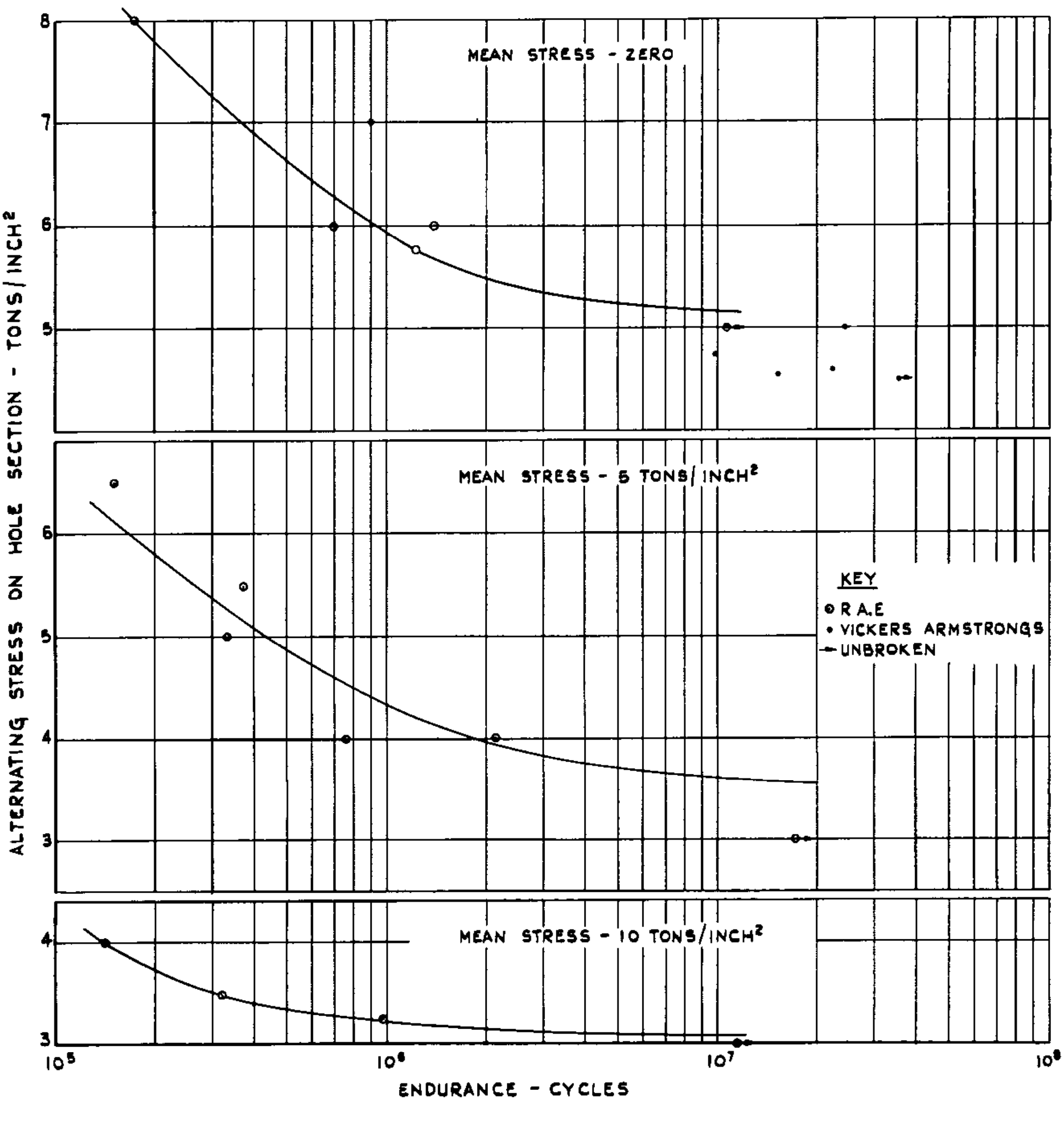

FIG.4. RESULTS FROM DRILLED SPECIMENS.

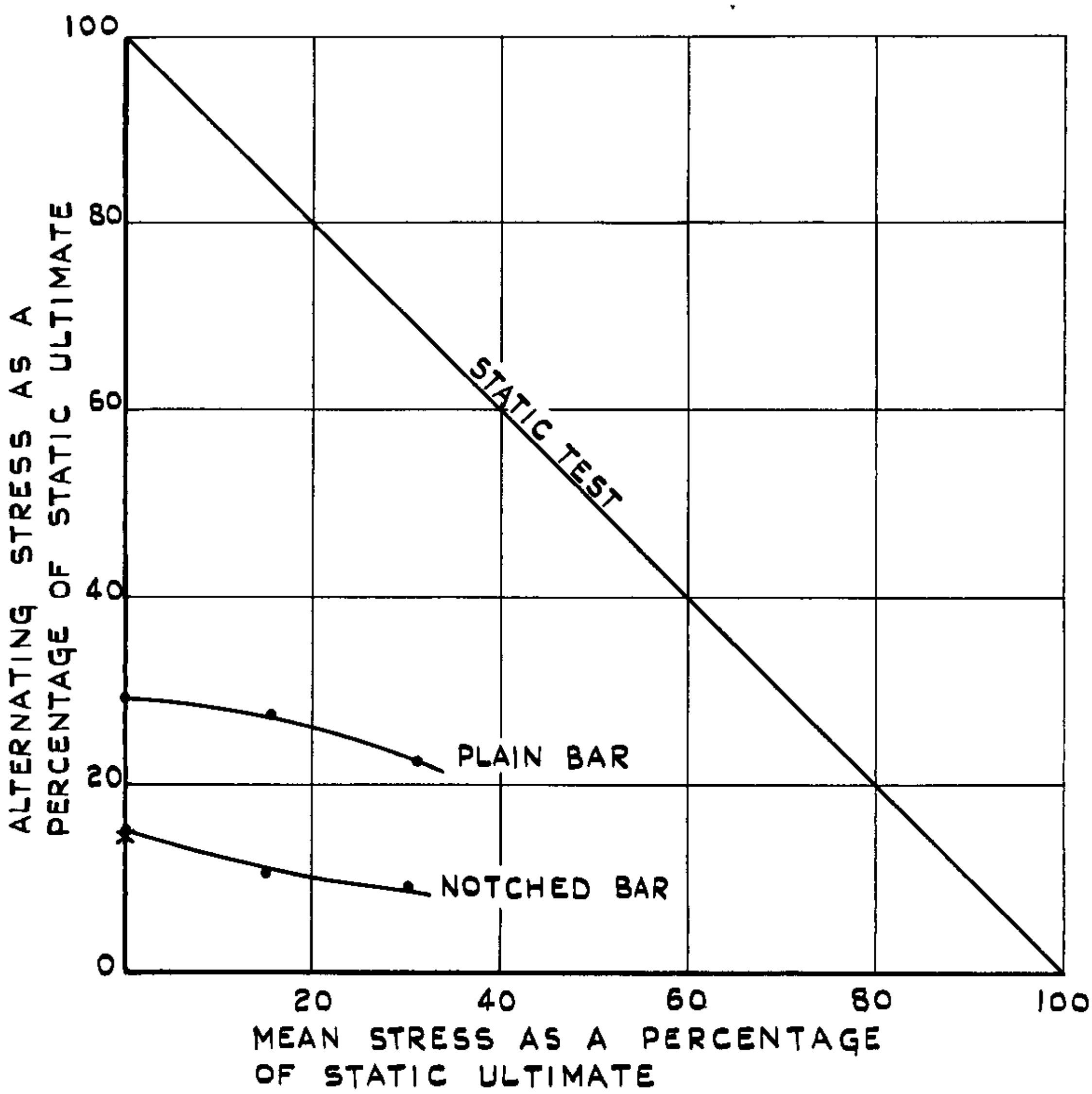

FIG.5. 'CONSTANT ENDURANCE' DIAGRAM (FOR 2 MILLION CYCLES)

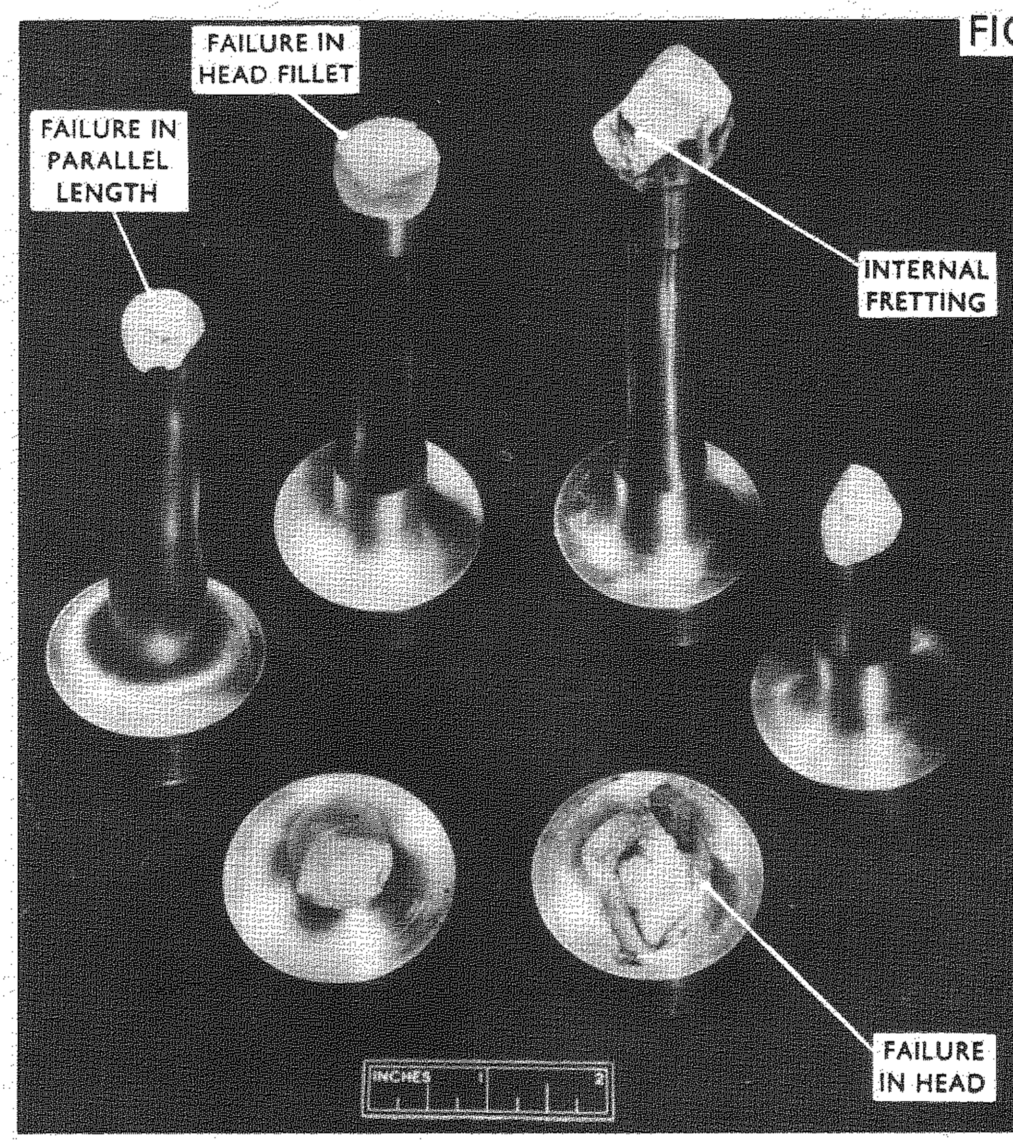

FIG.6. POSITIONS OF FAILURE

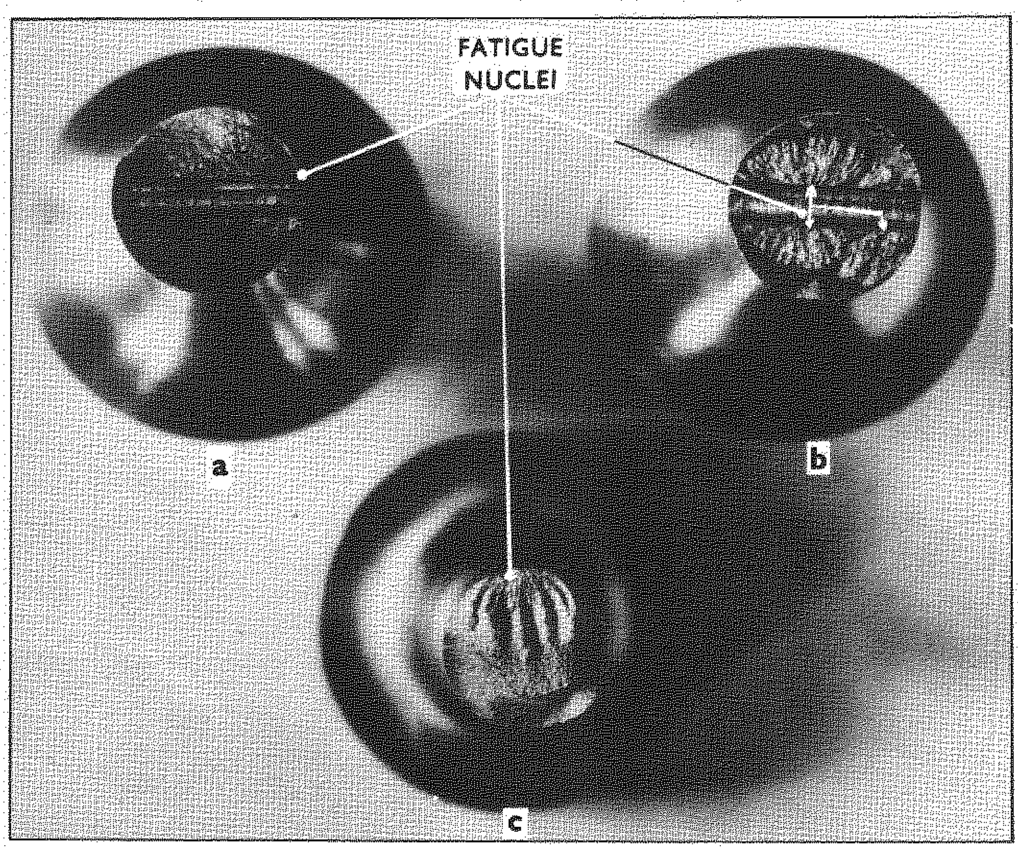

FIG.7. FATIGUE NUCLEI

FIG.8

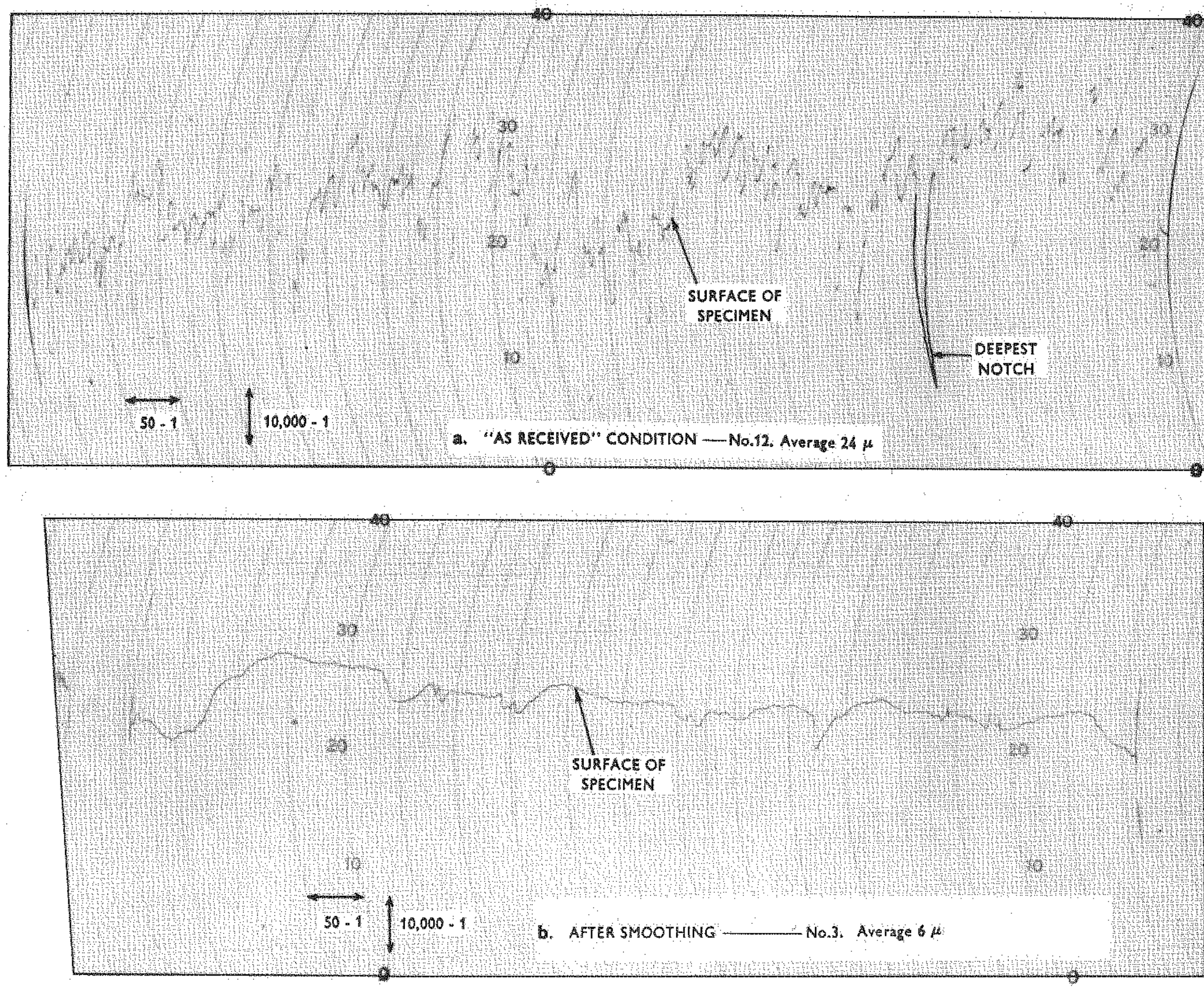

FIG.8. TYPICAL RECORDS TAKEN BY TALYSURF RECORDER

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