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SUMMARY

Fatigue tests have been carried out on lugs of BS 2L65 aluminium alloy loaded by steel pins under constant amplitude (CA) and narrow band random (NBR) loading over a range of mean stresses and for different values of pre-stress. Life estimations for the NBR tests were made using Miner's rule.

The relative fatigue performance under CA and NBR loading as expressed by the Miner summation $\sum n/N$ was consistent with the fatigue damage accumulation being markedly affected by observed changes in residual stress at the point of crack initiation due to local yielding under the higher load levels.

* Replaces RAE Technical Report 77167 - ARC 37840

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1 INTRODUCTION

In a pin-loaded lug the occurrence of fretting between the pin and the hole at a fairly high stress concentration can lead to the early onset of cracking. It is thus a feature for which the designer requires reliable fatigue data together with guidance on how to apply this data to the service situation.

Basic fatigue performance is usually evaluated for constant amplitude loading only whereas components in service usually experience load spectra which are random in nature. It is therefore important to have some knowledge of how a particular feature behaves under variable amplitude loading and how accurately fatigue life can be estimated using available rules.

This Report presents the results of fatigue tests on pin-loaded lugs of BS 2L65 aluminium alloy under constant amplitude (CA) and narrow band random (NBR) loading over a range of mean stresses, and under the two types of loading with and without a pre-stress. Although NBR loading does not accurately simulate most service situations, it does contain many of the essential features found in service load spectra, and thus is useful for demonstrating trends of behaviour under such loading.

The performance under NBR loading is compared with Miner's rule predictions and it is shown that residual stresses induced by local yielding have a major influence on damage accumulation.

2 MATERIAL AND SPECIMENS

All lug specimens were manufactured from extruded bars of BS 2L65 aluminium alloy obtained from the same melt. Table 1 gives the chemical composition as stated by the manufacturers and shows the tensile properties.

Fig 1 shows the lug specimen which was loaded by pins of BS 94 steel with a clearance in the hole of between 0.0003 and 0.0021 of diameter. Components were degreased and assembled dry prior to testing.

3 FATIGUE TESTS AND RESULTS

The fatigue tests were carried out in a modified Schenck PP60/12 resonant machine which was capable of both constant amplitude and narrow band random loading in the load range 300 ± 300 kn at approximately 27 Hz. Loads were monitored throughout the tests by measuring their root mean square value and displaying this on a trace recorder. In addition the amplitude distribution of the random loading was measured as described in Appendix A.

The following testing programme was carried out:

(a) Tests under constant amplitude loading over a range of stress amplitudes at three levels of tensile mean stress.

(b) Constant amplitude testing following two values of pre-stress, defined as a single large tensile stress applied at the beginning of the test and then reduced to the mean stress of the subsequent fatigue test.

(c) Tests under narrow band random loading over a range of stress amplitudes at two levels of tensile mean stress.

(d) Narrow band random testing following two values of pre-stress.

Specimens were tested to failure or 10^7 cycles, whichever occurred first. It was observed that cracks initiated at regions of fretting between the pin and the bore of the hole and led to failure through the net section. Typical failures are shown in Figs 2 and 3.

The following table defines the programme and indicates the locations of the tabulated results and the associated S-N curves. The stresses quoted in the table and throughout this Report are pin bearing stresses, with values of net stress in brackets where:

$$\text{Pin bearing stress} = \frac{\text{Load}}{\text{lug thickness} \times \text{pin diameter}}$$

and

$$\text{Net stress} = \frac{\text{Load}}{\text{lug thickness} \times (\text{lug width} - \text{hole diameter})}$$

Form of loading	Mean stress MN/m^2	Pre-stress MN/m^2	Table No.	Fig No.	Fig No. of comparison
Constant amplitude	111(69)	0	2	4	
" "	155(96)	0	3	5	13
" "	277(172)	0	4	6	
" "	155(96)	390(242)	5	7	14
" "	155(96)	500(310)	6	8	
Narrow band random	155(96)	0	7	9	15
" " "	277(172)	0	8	10	
" " "	155(96)	390(242)	9	11	16
" " "	155(96)	500(310)	10	12	

The S-N curves are based on a faired line passing as close as possible to the log mean endurances at each stress level. All failed specimens are indicated on these figures by a circle and a dot, whilst a circle with an arrow indicates an unbroken specimen.

In Figs 13 to 16 where comparisons are made of results under different mean stresses and pre-stresses, individual test points are omitted for clarity.

4 LIFE ESTIMATIONS AND COMPARISONS WITH ACHIEVED PERFORMANCES

Miner's rule is the most common method of predicting the life of components under service loading using data obtained in the laboratory under constant amplitude loading. Basically it sums linearly the damage accumulated at the various levels of alternating stress contained in the service spectrum.

For the various narrow band random tests Miner's rule was used to predict the life from constant amplitude data as described in Appendix B and outlined in the following table.

Narrow band random test		Constant amplitude data used in prediction		
Mean stress MN/m^2	Pre-stress MN/m^2	Mean stress MN/m^2	Pre-stress MN/m^2	Fig No.
155(96)	0	155(96)	0	17
155(96)	390(242)	155(96)	390(242)	18
155(96)	500(310)	155(96)	500(310)	19
155(96)	390(242)	155(96)	0	20
155(96)	500(310)	155(96)	0	21
277(172)	0	277(172)	0	22

It will be noted that for the narrow band random tests with pre-stress, the predictions have been based on the results of constant amplitude tests both with and without pre-stress. The former predictions using pre-stressed constant amplitude data were made to see if the benefits of pre-stressing were found to the same degree under random loading. The latter predictions using unpre-stressed data were made because this is a possible situation a designer would be faced with; using simple constant amplitude data to predict the life of a component which is subjected to a high proof stress before entering service.

5 DISCUSSION

5.1 Effect of mean stress on constant amplitude performance

Fig 13 demonstrates the usual effect of mean stress under constant amplitude (CA) loading, *ie* an increased mean stress reduces endurance at a given level of alternating stress. It will be noted that the three curves converge at long lives unlike the 'standard' fatigue strength of lugs curves plotted by Heywood[1].

5.2 Effect of pre-stress on constant amplitude performance

Fig 14 shows that the effect of a large pre-stress was a general increase in life under subsequent CA loading, the larger pre-stress producing the greater benefit. There is a tendency towards an inflection in the curve at about 3×10^5 cycles for the high pre-stress case.

The observed increase in life due to a pre-stress is most likely to be the result of a reduction in the local mean stress at the point of crack initiation due to the creation of a compressive residual stress by local yielding in tension[2]. Local stress measurements have been made in a previous investigation[3] to study the effect of pre-stress; the specimens were of identical design and batch to those reported here and they were tested under loading of mean stress 153(95) MN/m^2 and rms alternating stress 64.4(40) MN/m^2. The effect of pre-stress on local mean stress was as follows:

Pre-stress MN/m^2	Local mean stress MN/m^2
0	237
412(256)	103
486(302)	17

The applied stress levels were comparable with those in the present investigation and showed substantial reductions in the local mean stress which would be expected to have a beneficial effect on life.

5.3 Effect of mean stress on narrow band random performance

The effect of mean stress is difficult to evaluate for NBR loading from tests in a resonant machine as, for a given level of rms alternating stress, the amplitude distribution tends to vary with mean stress. This arises from the change in stiffness of the double pinned lug, as the load passes through zero during large negative-going amplitudes, resulting in truncation of the largest amplitudes; therefore truncation of the high alternating stress will be more pronounced for lower values of mean stress. Thus although Fig 15 indicates only a small effect of mean stress under NBR loading, the effect may be disguised by the difference in amplitude spectrum at a particular level of alternating stress. The question of relative sensitivity of CA and NBR performance to mean stress level will be examined further in section 5.5 by studying life predictions based on actually achieved spectra.

5.4 Effect of pre-stress on narrow band random performance

The effect of pre-stress on life under NBR loading, as shown by Fig 16, demonstrates similar trends to those under CA loading. The lower pre-stress had only a fairly small effect, except at the lower levels of alternating stress where it produced greater endurances than the high pre-stress. However, the amount of scatter in the low pre-stress results was sufficient to cast some doubt on the significance of the faired curve (see Fig 11). The higher pre-stress had a much larger effect on the higher levels of alternating stress. It should be noted that both values of pre-stress were greater than the maximum stress which occurred subsequently under NBR loading and therefore the pre-stress always governed the maximum reduction in local mean stress. This is confirmed by the local stress measurements[3] referred to earlier. The only beneficial effect that the peaks in the NBR spectrum could have had was the restriction of any fading of residual stress, in contrast to the tests without pre-stress where they governed the reduction in local mean stress. Therefore it would be expected that the effect of pre-stress under NBR loading would not be as great as under CA loading, which is in agreement with the test results.

5.5 Life estimations using Miner's rule

As outlined in section 4, Miner's rule was used to estimate the endurances in the random loading tests using the constant amplitude data as indicated in the table in that section.

The accuracy of Miner's rule is usually judged by the ratio

$$\sum n/N = \frac{\text{achieved life}}{\text{predicted life}}$$

for which values >1 represent a conservative or safe prediction, and values <1 an unsafe prediction.

Considering first the NBR loading at a mean stress of 155(96) MN/m^2, Fig 23 presents the variation in $\sum n/N$ with rms alternating stress for tests with three values of pre-stress viz 0, 390(242) and 500(310) MN/m^2, in each case using CA data with the appropriate value of pre-stress. It can be seen that in all cases, apart from that of the high pre-stress at low alternating stresses, Miner's rule based on nominal stresses was conservative. With no pre-stress $\sum n/N$ varied from 1.5 to 2.75, which could be explained by the argument that the fatigue performance under NBR loading was beneficially influenced by the lowering of the local mean stress due to local yielding under the highest load level, whereas the predicted performance was based on CA data for which the residual stress condition was generally less beneficial. The effect of pre-stress was to reduce values of $\sum n/N$ over most of the alternating stress range, but to increase them at the highest alternating stresses. $\sum n/N$ was still greater than unity except for the higher pre-stress at low alternating stresses where it fell to 0.7. The general reduction in $\sum n/N$ from introducing pre-stress is consistent with the influence of residual stress which has already been discussed. The pre-stress induced a high level of residual stress prior to the start of both the CA and NBR tests, and because all subsequent load cycles fell below the level of the pre-stresses they could have little further beneficial effect in either case in contrast to the no pre-stress tests. Thus $\sum n/N$ would be expected to be lower than in the case without pre-stress.

In Fig 24 $\sum n/N$ values are plotted for the three pre-stress cases discussed above, but this time the basis of the life estimation for all conditions was constant amplitude data at the same mean stress with no pre-stress. This procedure, apart from its analytical value, could represent a possible situation in which a designer used simple CA data to predict the life of a component which is subjected to a proof test before entering service. In view of the preceding discussion it is not surprising that the effect of pre-stress is now seen to increase the values of $\sum n/N$.

The effect of mean stress level on NBR loading performance was discussed earlier in section 5.3, where it was stated that the direct comparison of test results (Fig 15) was unreliable due to differences on the achieved spectra. These differences have however been taken into account in Fig 25 which shows the variation in $\sum n/N$ at two mean stresses. It is seen that over the alternating stress range tested $\sum n/N$ was appreciably higher for the higher mean stress. The net result is that the detrimental effect of mean stress is less under NBR loading than under CA loading. This comparative insensitivity of NBR performance to mean stress is presumably due to the marked lowering of the local stress by the highest loads in the spectrum.

6 CONCLUSIONS

Cumulative fatigue damage behaviour of pin-loaded lug specimens has been studied by tests under constant amplitude (CA) and narrow band random (NBR) loading at a number of tensile mean stress levels and for different values of tensile pre-stress.

The relative fatigue performance under CA and NBR loading, expressed by the Miner summation $\sum n/N$, was consistent with the fatigue damage accumulation being markedly affected by observed changes in residual stress at the point of crack initiation due to local yielding under the higher load levels. Hence:

(1) The occasional high peak loads in NBR loading maintained a low level of local mean stress and $\sum n/N$ was greater than unity.

(2) A large tensile pre-stress prior to NBR tests only, reduced the local mean stress even further and gave increased values of $\sum n/N$.

(3) A large tensile pre-stress prior to both NBR and CA tests diminished the relative benefit to the NBR performance as the local mean stress was reduced in both cases and thus $\sum n/N$ was reduced, although still greater than unity over most of the rms stress range.

(4) The detrimental effect of increased mean stress on performance was less marked under NBR loading due to lowering of local mean stress by the higher loads in the spectrum, resulting in an increase in $\sum n/N$ with mean stress level.

Appendix A

FATIGUE TESTING FACILITY AND LOAD SPECTRA

The fatigue tests were carried out on a modified Schenck PP60/12 resonant machine for which the original out-of-balance mass exciter was replaced by an electrohydraulic exciter and control was provided in a similar manner to that described by Edwards[4].

In the case of random loading the spectrum shape was measured using a levels crossed counter[5]. These measurements were made at a later date than the fatigue tests by which time the electrohydraulic exciter had been replaced by an electromagnetic type, but it was considered that this did not affect the response of the machine. The levels crossed counter measured the cumulative number of exceedings of a series of amplitude levels, equally spaced over the range of the spectrum. In this Report the results of these measurements are plotted in the form of cumulative number of exceedings on a logarithmic scale against the non-dimensional quantity

$$\left(\frac{\text{amplitude level}}{\text{root mean square value of waveform}}\right)^2 \quad \text{or} \quad \left(\frac{F}{\sigma\ \text{rms}}\right)^2 .$$

Plotted in this way true Gaussian narrow band random loading would produce a straight line. In practice it can be seen in Figs 26 and 27 that there was truncation of the higher levels of load, arising from mechanical damping, which is dependent on specimen stiffness and stress level.

Appendix B

THE PALMGREN-MINER CUMULATIVE DAMAGE HYPOTHESIS (MINER'S RULE)[6]

Miner's rule states that if a component is subjected to a variable amplitude loading sequence containing stress amplitudes σ_q ($q = 1, 2, 3 \ldots P$), then the fraction of the total life used up by any single stress cycle at stress amplitude σ_q is given by $1/N_q$ where N_q is the expected number of cycles to failure of the component under stress amplitude σ_q alone.

Therefore the total fraction of the fatigue life used up by the variable amplitude waveform is

$$\sum_{q=1}^{q=P} \frac{n_q}{N_q}$$

where n_q is the number of cycles of stress amplitude σ_q contained in the variable amplitude waveform.

The rule predicts failure when

$$\sum_{q=1}^{q=P} \frac{n_q}{N_q} = 1 \quad .$$

The accuracy of the rule is generally judged by computing the ratio

$$\sum_{q=0}^{q=P} \frac{n_q}{N_q} : 1$$

for specimens which have been tested to failure. Since the rule predicts failure when

$$\sum \frac{n}{N} = 1 \; ,$$

the computed value of the ratio at failure is equal to the ratio

$$\frac{\text{achieved life}}{\text{predicted life}} \; .$$

When carrying out the predictions in this Report the actual measured load spectrum for the particular condition and stress level was used in all cases.

It was necessary in carrying out the predictions to use S-N curves which extended above the stresses actually tested. This was done by extrapolating to the static failure point.

Table 1

CHEMICAL COMPOSITION AND TENSILE PROPERTIES OF BS 2L65 ALUMINIUM ALLOY

Chemical composition (nominal) % by weight 4.4 Cu, 0.7 Mg, 0.7 Si, 0.6 Mn, balance Al

Tensile properties (measured)	UTS	517 MN/m^2
	0.1% proof stress	462 MN/m^2
	Elongation	10%

Table 2

FATIGUE TEST RESULTS

Constant amplitude loading

Mean stress = 111(69) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
66	11.1	6.9	847	
76	11.1	6.9	79.5	414
116	11.1	6.9	631	
117	11.1	6.9	694	
94	13.9	8.6	312	
93	16.7	10.3	199	
77	22.2	13.8	79.5	77.4
104	22.2	13.8	75.3	
113	27.8	17.2	32.2	
98	33.3	20.7	22.3	
78	44.4	27.6	14.2	
81	44.4	27.6	17.2	15.1
100	44.4	27.6	14.0	
85	55.5	34.5	8.17	
86	55.5	34.5	8.5	7.86
102	55.5	34.5	7.0	
106	66.6	41.4	5.47	5.37
123	66.6	41.4	5.28	
90	77.7	48.3	4.05	
108	77.7	48.3	4.12	4.06
124	77.7	48.3	4.00	

Table 3

FATIGUE TEST RESULTS

Constant amplitude loading

Mean stress = 155(96) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
63	11.1	6.9	508	
64	11.1	6.9	1220	765
65	11.1	6.9	725	
9	16.7	10.3	167	
27	16.7	10.3	207	165
1005	16.7	10.3	130	
3	22.2	13.8	94	
28	22.2	13.8	40.7	60.1
35	22.2	13.8	62.5	
157	22.2	13.8	54.5	
6	27.8	17.2	30.2	
29	27.8	17.2	23.9	25.8
38	27.8	17.2	23.8	
1001	31.1	19.3	18.4	16.6
1003	31.1	19.3	15.0	
1	33.3	20.7	15.6	
39	33.3	20.7	23.4	18.0
608	33.3	20.7	16.0	
4	44.4	27.6	7.83	7.73
32	44.4	27.6	7.63	
5	55.5	34.5	4.72	
33	55.5	34.5	4.37	4.31
606	55.5	34.5	3.63	
607	55.5	34.5	4.59	
2	66.6	41.4	3.31	
31	66.6	41.4	2.64	3.03
42	66.6	41.4	3.02	
1000	66.6	41.4	3.18	
7	77.7	48.3	2.49	
34	77.7	48.3	2.27	2.43
40	77.7	48.3	2.53	

Table 3 (concluded)

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
601	79.9	49.6	3.06	
602	79.9	49.6	2.24	
603	79.9	49.6	2.47	2.40
604	79.9	49.6	2.28	
605	79.9	49.6	2.08	
8	88.8	55.2	1.52	
30	88.8	55.2	1.36	1.67
41	88.8	55.2	2.25	
10	94.4	58.6	1.31	
36	99.9	62.1	1.20	
37	99.9	62.1	1.03	
11	99.9	62.1	1.03	1.12
1006	99.9	62.1	1.16	
1007	99.9	62.1	1.19	

Table 4

FATIGUE TEST RESULTS

Constant amplitude loading

Mean stress = 277(172) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
91	11.1	6.9	513	
95	11.1	6.9	404	436
111	11.1	6.9	401	
10	13.9	8.6	328	
92	16.7	10.3	43.4	
120	16.7	10.3	39.9	68.2
121	16.7	10.3	124.0	
122	16.7	10.3	101.0	
114	19.4	12.1	66.0	40.8
115	19.4	12.1	25.2	
82	22.2	13.8	22.2	18.0
105	22.2	13.8	14.6	
112	27.8	17.2	11.3	
97	33.3	20.7	6.28	6.84
99	33.3	20.7	7.45	
79	44.4	27.6	4.48	
80	44.4	27.6	5.40	4.70
101	44.4	27.6	4.28	
83	55.5	34.5	0.40	
84	55.5	34.5	0.59	3.28
103	55.5	34.5	2.88	
107	66.6	41.4	2.48	
87	77.7	48.3	1.92	
88	77.7	48.3	1.22	
89	77.7	48.3	1.92	1.73
109	77.7	48.3	1.72	
125	77.7	48.3	2.01	
126	88.8	55.2	1.62	1.45
127	88.8	55.2	1.29	
128	99.9	62.1	0.76	
129	99.9	62.1	1.27	0.97
130	99.9	62.1	0.95	

Table 5

FATIGUE TEST RESULTS

Constant amplitude loading with a pre-stress

Mean stress = 155(96) MN/m^2 pre-stress = 390(242) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
392	13.9	8.6	600	
391	16.7	10.3	309	371
169	16.7	10.3	447	
299	19.4	12.1	196	217
168	19.4	12.1	239	
161	22.2	13.8	191	
295	22.2	13.8	103	153
296	22.2	13.8	180	
292	27.8	17.2	73.8	61.8
167	27.8	17.2	51.8	
164	33.3	20.7	28.4	28.3
293	33.3	20.7	28.1	
158	44.4	27.6	11.7	14.3
288	44.4	27.6	17.5	
165	55.5	34.5	6.83	8.13
287	55.5	34.5	9.67	
159	66.6	41.4	4.41	4.58
291	66.6	41.4	4.76	
289	77.7	48.3	3.36	3.27
166	77.7	48.3	3.19	
160	88.8	55.2	2.54	2.59
290	88.8	55.2	2.64	

Table 6

FATIGUE TEST RESULTS

Constant amplitude loading with a pre-stress

Mean stress = 155(96) MN/m^2 pre-stress = 500(310) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
187	16.7	10.3	971	769
1044	16.7	10.3	609	
394	22.2	13.8	185	
182	22.2	13.8	248	362
1206	22.2	13.8	1040(UB)	
186	27.8	17.2	110	
395	33.3	20.7	124	99.0
184	33.3	20.7	79.0	
398	38.9	24.1	50.2	50.4
180	38.9	24.1	50.6	
173	44.4	27.6	45.6	
396	44.4	27.6	51.9	44.0
183	44.4	27.6	36.0	
181	50.0	31.0	22.1	
400	50.0	31.0	24.2	25.2
185	50.0	31.0	22.5	
1151	50.0	31.0	33.5	
174	55.5	34.5	12.7	12.9
397	55.5	34.5	13.2	
399	66.6	41.4	7.45	
177	66.6	41.4	8.17	8.0
1091	66.6	41.4	7.43	
1028	66.6	41.4	9.05	
393	77.7	48.3	5.54	5.18
172	77.7	48.3	4.85	
170	88.8	55.2	4.50	4.13
171	88.8	55.2	3.79	
1018	99.9	62.1	2.17	

UB - unbroken

Table 7

FATIGUE TEST RESULTS

Narrow band random loading (see Fig 26)

Mean stress = 155(96) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
59	11.1	6.9	594	
26	11.1	6.9	419	518
60	11.1	6.9	558	
55	16.7	10.3	203	
20	16.7	10.3	121	198
56	16.7	10.3	326	
22	16.7	10.3	193	
48	22.2	13.8	126	
21	22.2	13.8	85.2	82.7
58	22.2	13.8	50.7	
23	22.2	13.8	86.1	
19	27.8	17.2	76.2	
53	27.8	17.2	53.3	65.1
54	27.8	17.2	67.8	
15	33.3	20.7	37.4	
51	33.3	20.7	48.3	39.4
25	33.3	20.7	33.8	
52	38.9	24.1	35.4	
16	38.9	24.1	22.8	27.8
17	38.9	24.1	26.7	
50	44.4	27.6	22.7	
18	44.4	27.6	24.4	21.9
62	44.4	27.6	19.0	
49	50.0	31.0	14.3	
12	50.0	31.0	13.0	14.7
61	50.0	31.0	17.1	

Table 8

FATIGUE TEST RESULTS

Narrow band random loading (see Fig 27)

Mean stress = 277(172) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
652	11.1	6.9	293.4	297.4
707	11.1	6.9	301.5	
642	22.2	13.8	78.5	
667	22.2	13.8	66.5	70.5
613	22.2	13.8	67.2	
621	33.3	20.7	31.9	
627	33.3	20.7	29.5	36.2
677	33.3	20.7	50.4	
637	44.4	27.6	23.6	
657	44.4	27.6	22.9	23.3
692	44.4	27.6	23.4	
632	55.5	34.5	9.70	
647	55.5	34.5	10.6	9.04
672	55.5	34.5	7.17	
662	66.6	41.4	4.63	
682	66.6	41.4	2.76	3.47
687	66.6	41.4	3.26	

Table 9

FATIGUE TEST RESULTS

Narrow band random loading with a pre-stress

Mean stress = 155(96) MN/m^2 Pre-stress = 390(242) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log mean life 10^4 cycles
792	16.7	10.3	835	
737	22.2	13.8	117	
767	22.2	13.8	215	170
777	22.2	13.8	196	
717	27.8	17.2	121	
727	27.8	17.2	58.8	81.1
757	27.8	17.2	149	
812	27.8	17.2	41.0	
703	33.3	20.7	81.9	
802	33.3	20.7	28.0	40.2
807	33.3	20.7	28.3	
722	38.9	24.1	63.8	
762	38.9	24.1	56.6	47.5
797	38.9	24.1	29.6	
697	44.4	27.6	3.67	
732	44.4	27.6	21.5	23.1
742	44.4	27.6	13.9	
752	44.4	27.6	25.8	
712	50.0	31.0	23.1	28.2
747	50.0	31.0	34.5	

Table 10

FATIGUE TEST RESULTS

Narrow band random loading with a pre-stress

Mean stress = 155(96) MN/m^2 Pre-stress = 500(310) MN/m^2

Specimen No.	Rms pin bearing stress MN/m^2	Rms net stress MN/m^2	Life 10^4 cycles	Log_4 mean life 10^4 cycles
423	11.1	6.9	1110(UB)	
413	14.4	9.0	600	
414	14.4	9.0	1150(UB)	
404	16.7	10.3	326	365
410	16.7	10.3	408	
411	22.2	13.8	225	272
412	22.2	13.8	330	
422	27.8	17.2	113	131
425	27.8	17.2	152	
406	33.3	20.7	94.3	85.9
421	33.3	20.7	78.3	
408	38.9	24.1	66.7	60.0
409	38.9	24.1	54.0	
402	44.4	27.6	75.0	
419	44.4	27.6	47.2	62.0
420	44.4	27.6	67.2	
415	50.0	31.0	61.4	60.5
418	50.0	31.0	59.6	

UB - unbroken

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No.	Author	Title, etc
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2	P.R. Edwards	Cumulative damage in fatigue with particular reference to the effects of residual stresses. ARC CP No.1185 (1971)
3	J.E. Moon B.H.E. Perrett	A study of local stress histories in structural elements and their implications to fatigue life estimation. Paper presented at the SEE Fatigue Group International Conference 'Fatigue Testing and Design' held at the City University, London, England 5-9 April 1976
4	P.R. Edwards	A controller for random and constant amplitude loading on resonant and electrohydraulic fatigue machines. RAE Technical Report 72226, ARC 34525 (1973)
5	E.M. Power	The analysis of random data for fatigue testing. Paper presented at the SEE Symposium 'Statistical Aspects of Fatigue Testing' held at Warwick University, 12 February 1975
6	M.A. Miner	Cumulative damage in fatigue. J. Applied Mechanics, Vol 12, 3, pp A159 - A164 (1945)

Scale $\frac{3}{4}$
Nominal dimensions in mm
Material – BS 2L65 aluminium alloy

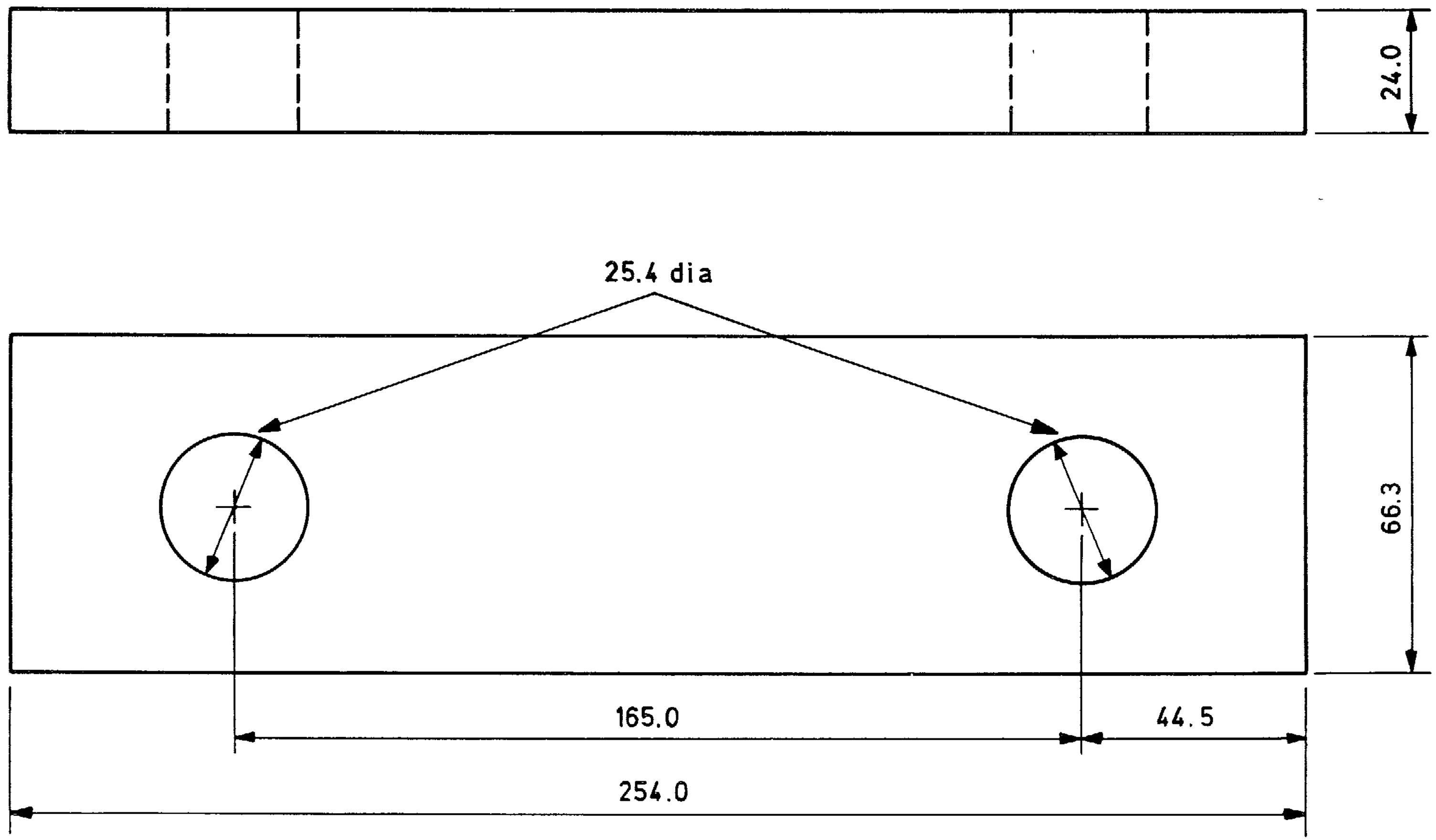

Fig 1 Pin-loaded lug specimen

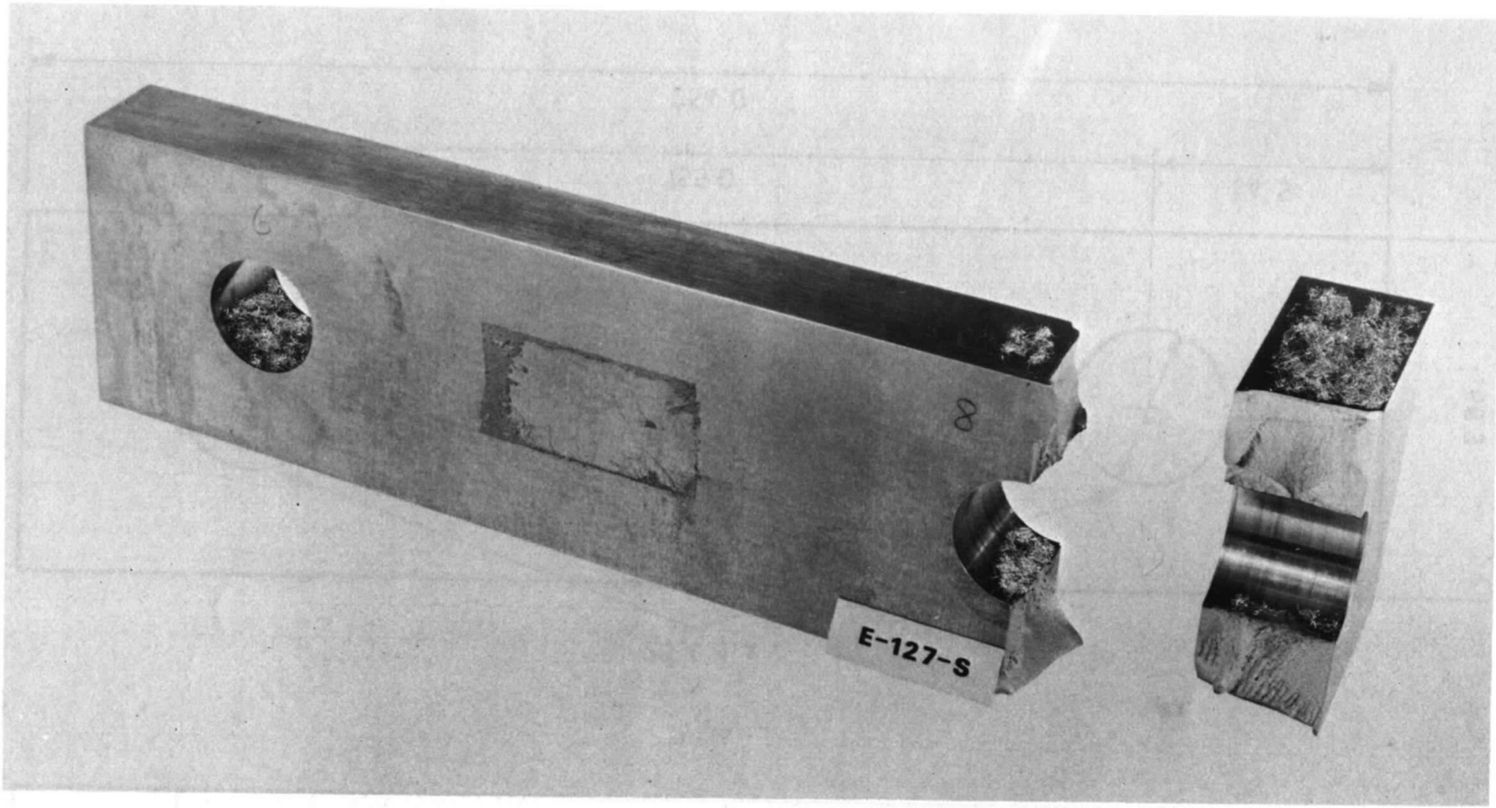

Fig 2 Failed specimen. Constant amplitude loading at mean stress = 155(96) MN/m^2, with a prestress = 390(242) MN/m^2, at rms stress = 33.3(20.7) MN/m^2

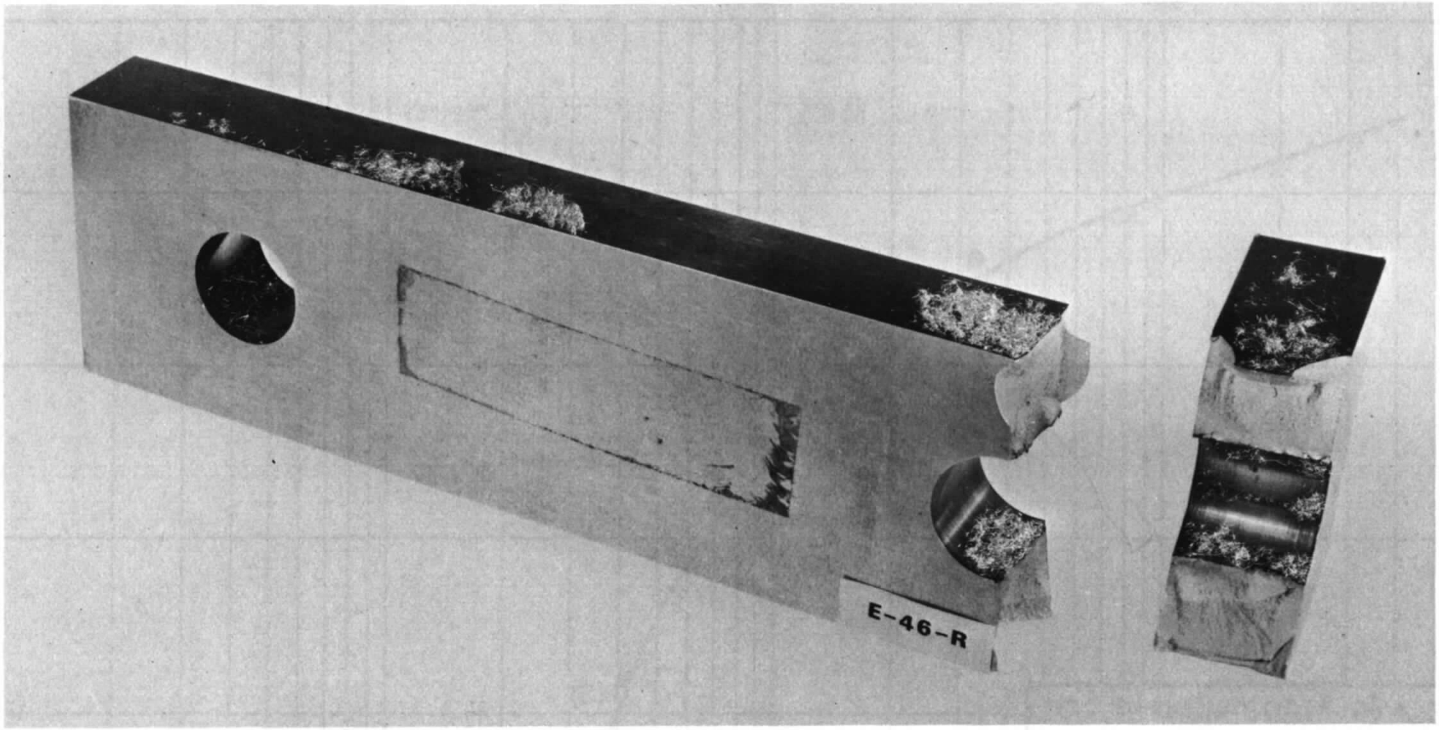

Fig 3 Failed specimen. Narrow band random loading at mean stress = 155(96) MN/m^2, at rms stress = 27.8(17.2) MN/m^2

Fig 3

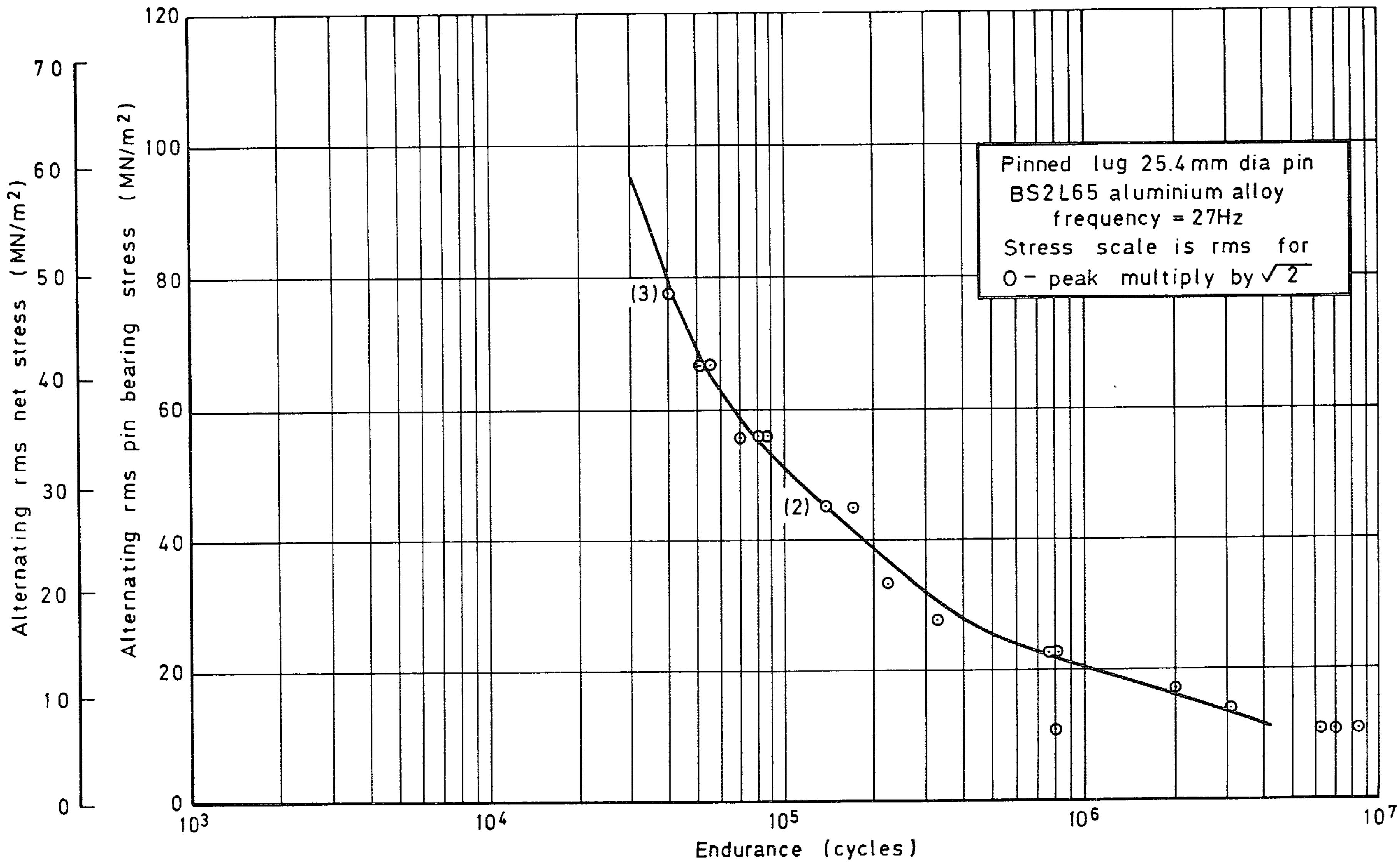

Fig 4 Constant amplitude loading at mean stress = 111(69) MN/m^2

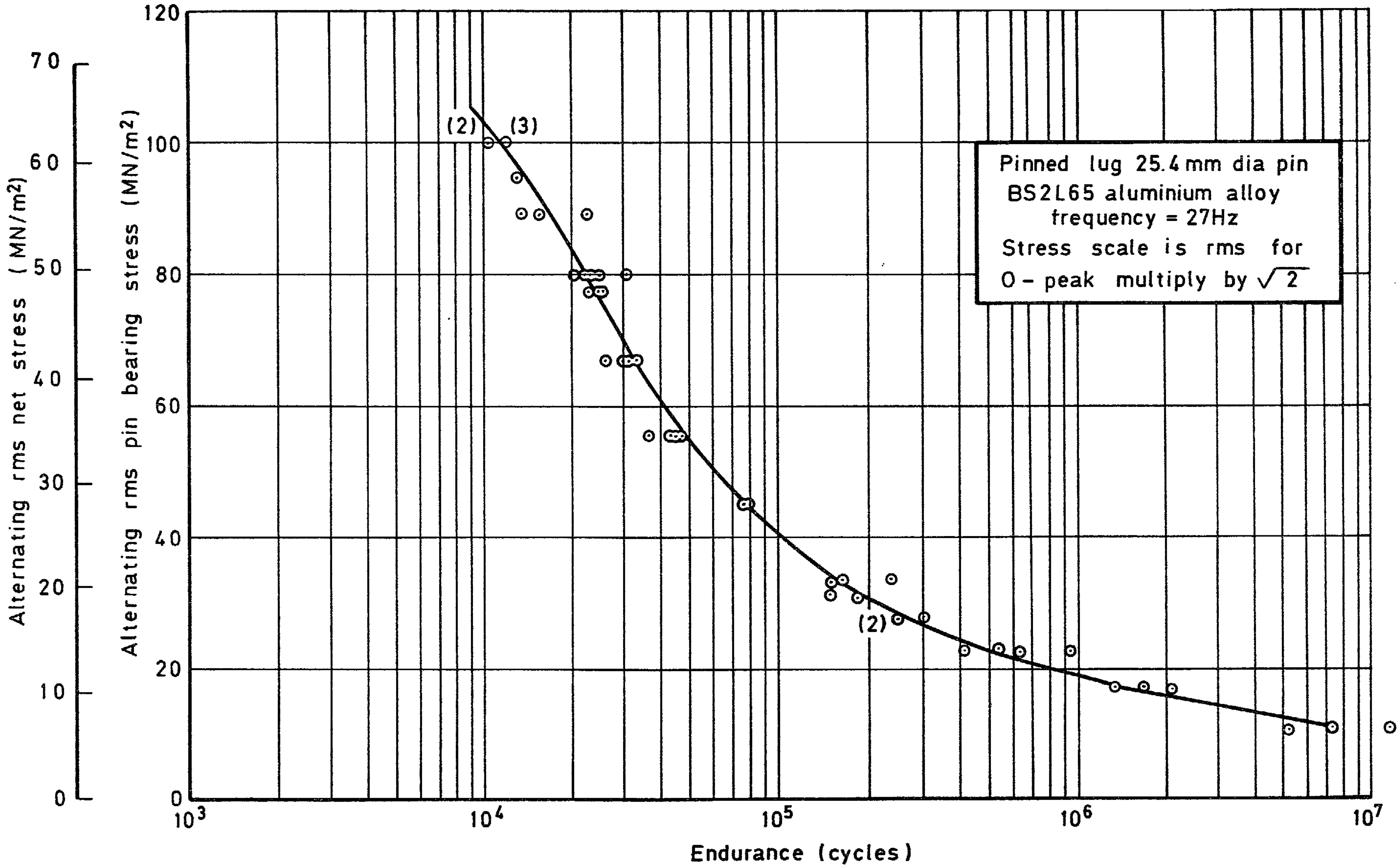

Fig 5 Constant amplitude loading at mean stress = 155(96) MN/m²

Fig 5

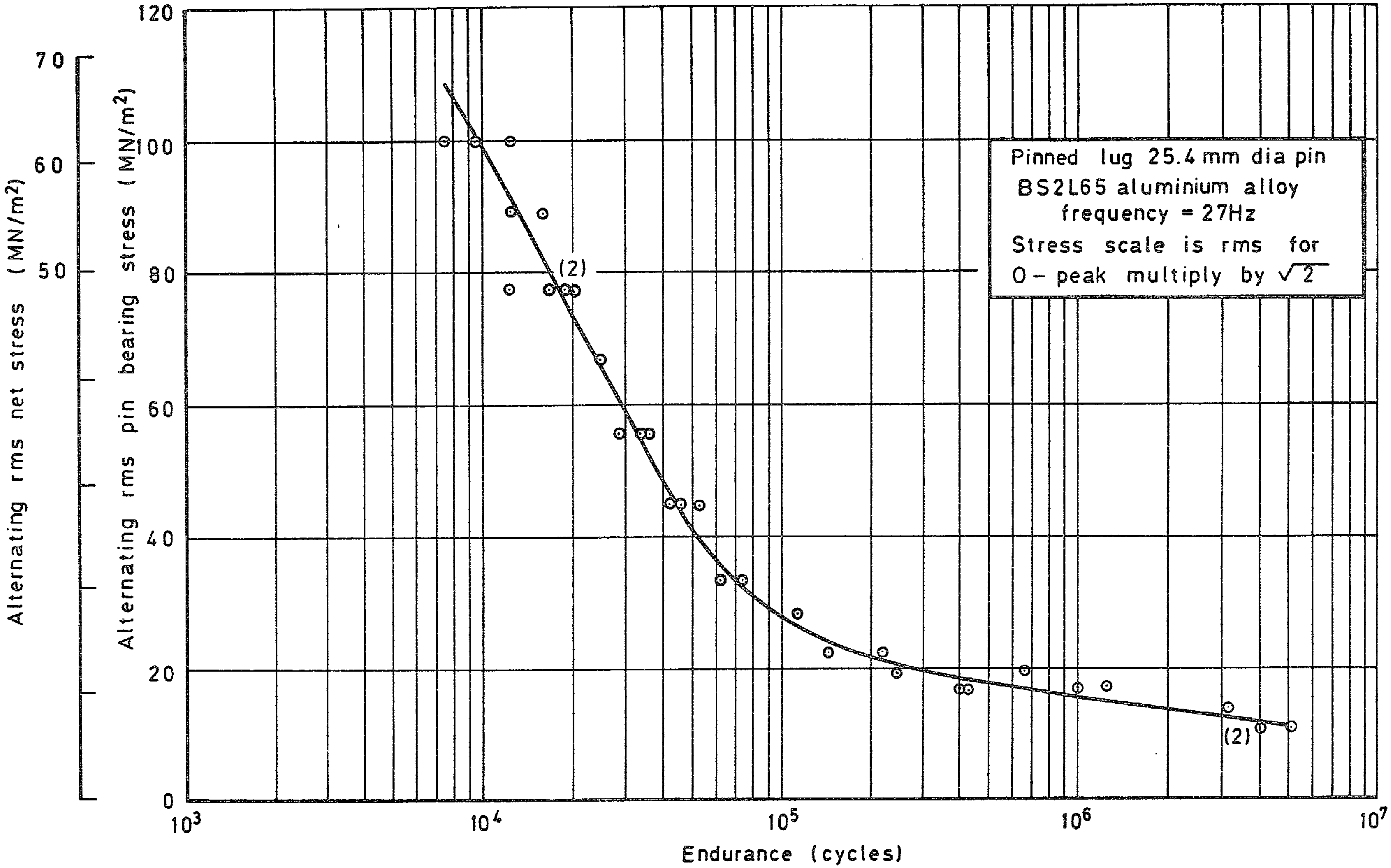

Fig 6 Constant amplitude loading at mean stress = 277(172) MN/m^2

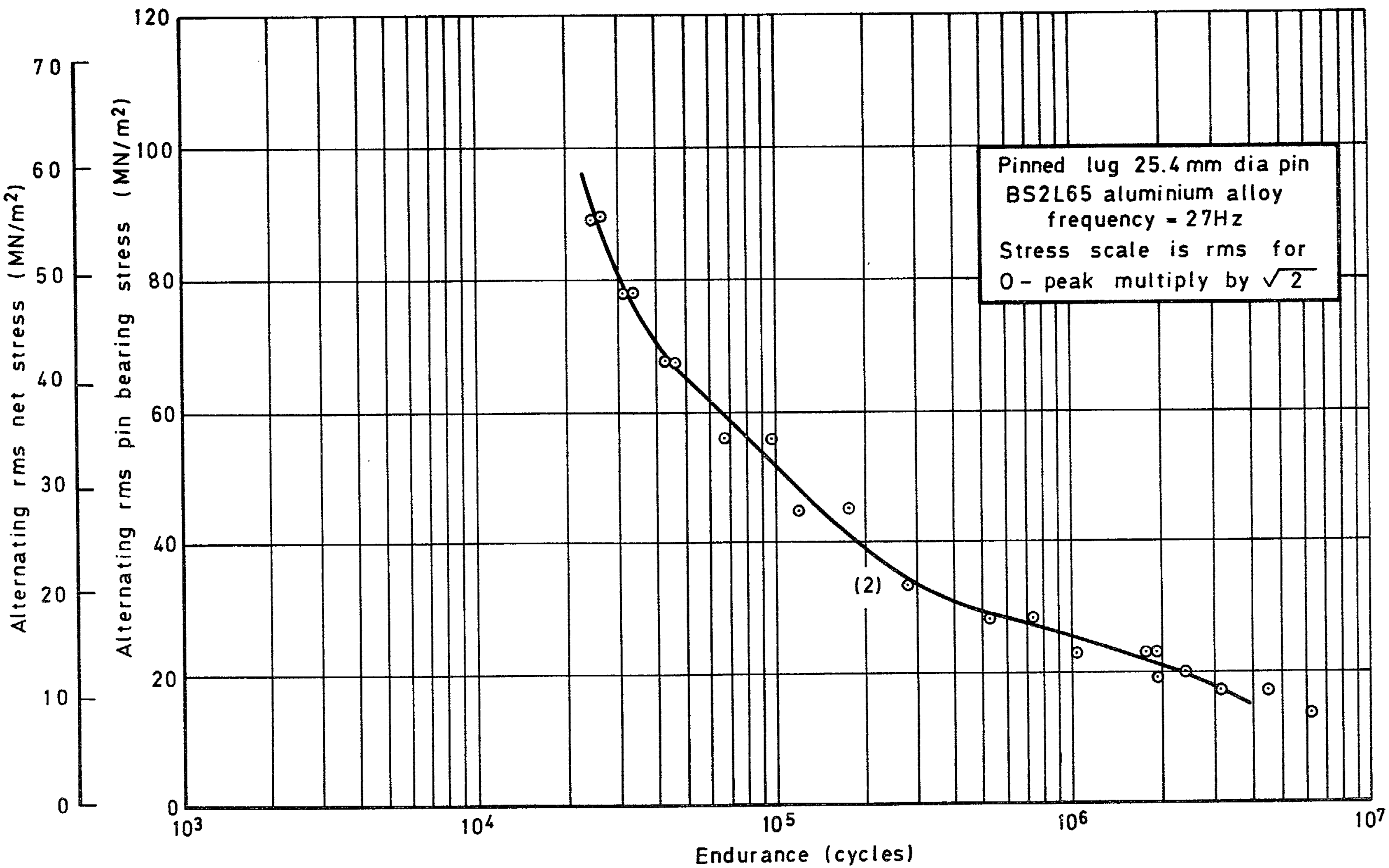

Fig 7 Constant amplitude loading at mean stress = 155(96) MN/m²
with a prestress = 390(242) MN/m²

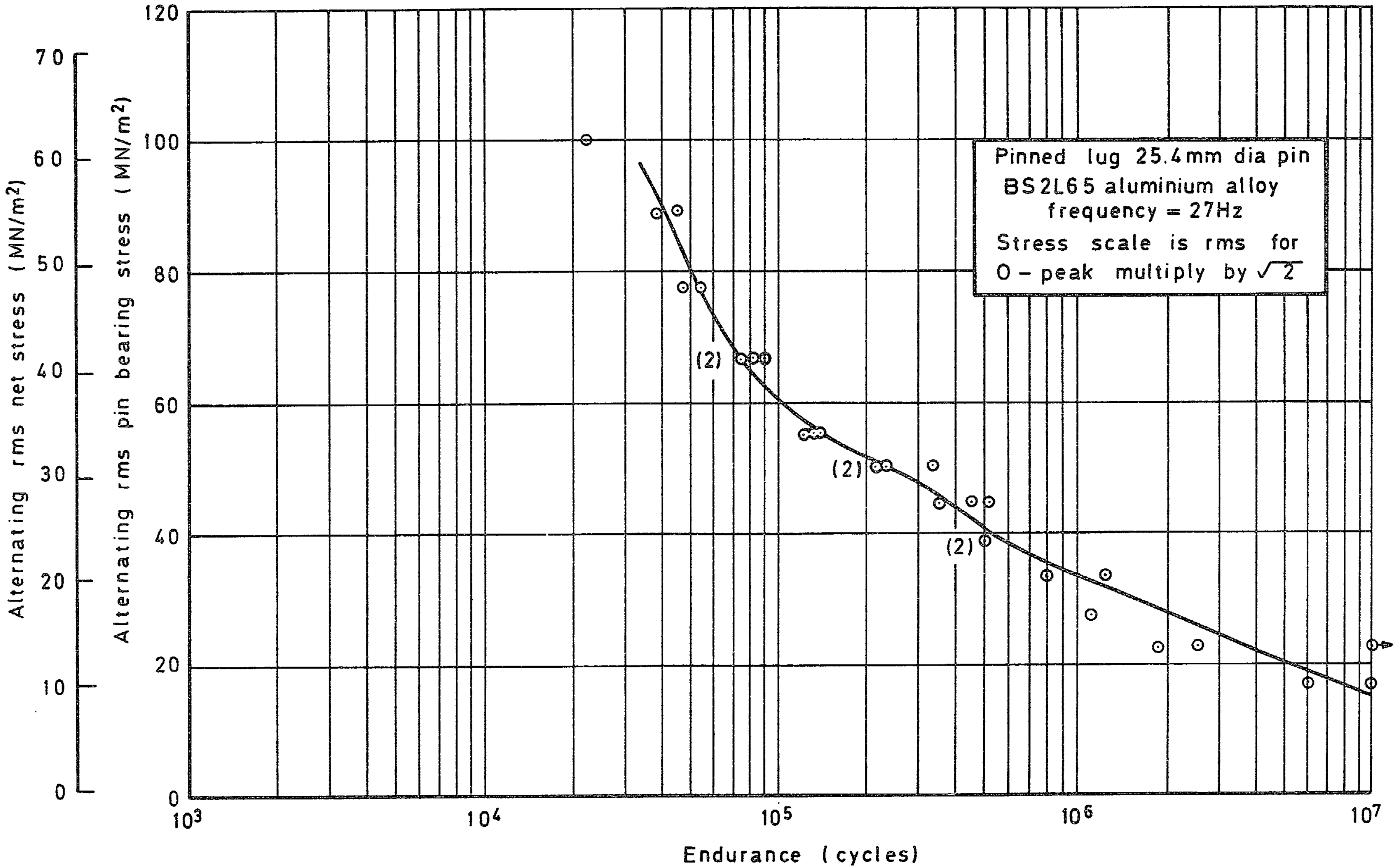

Fig 8 Constant amplitude loading at mean stresss = 155(96) MN/m^2
with a prestress = 500(310) MN/m^2

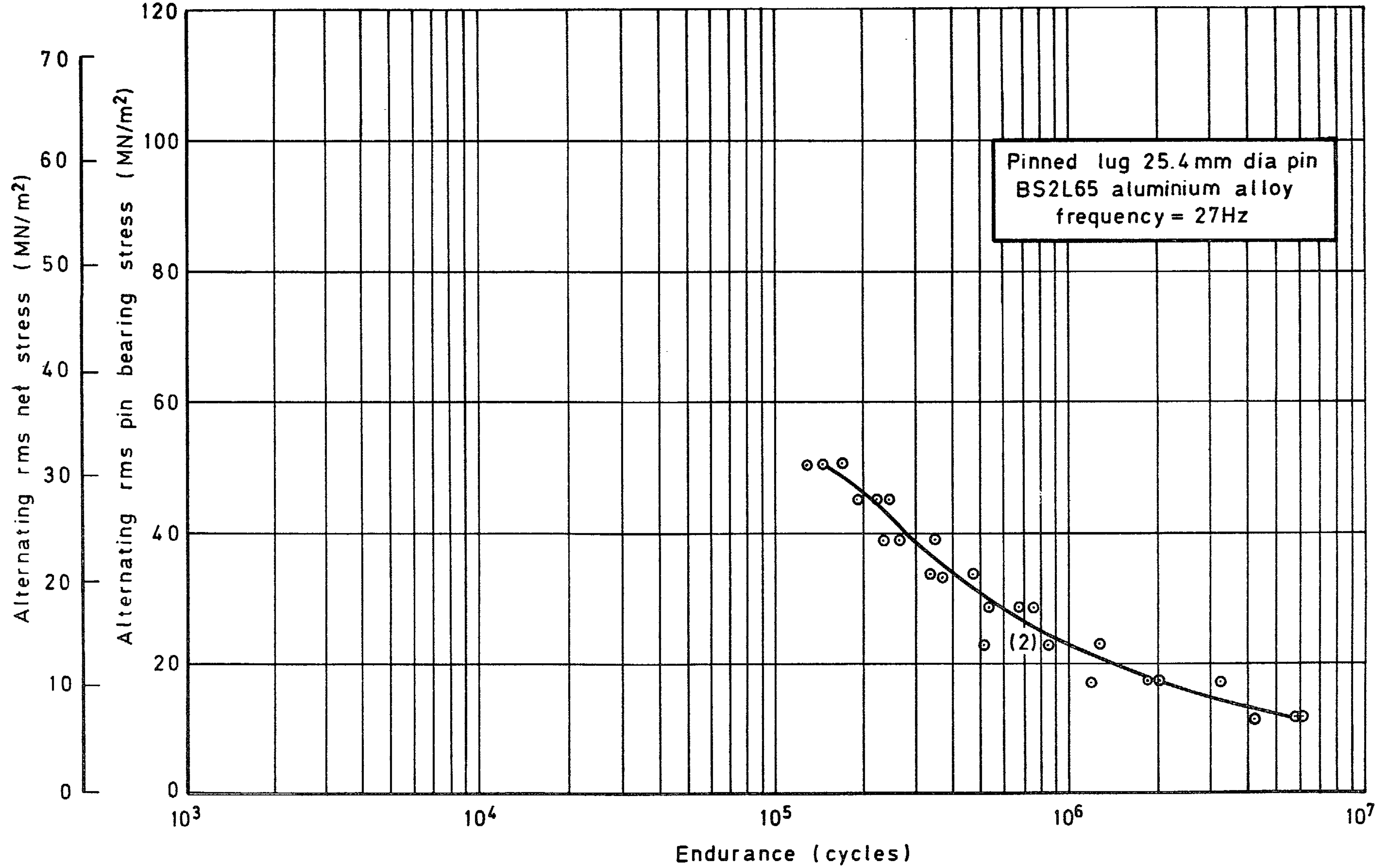

Fig 9 Narrow band random loading at mean stress = 155(96) MN/m^2

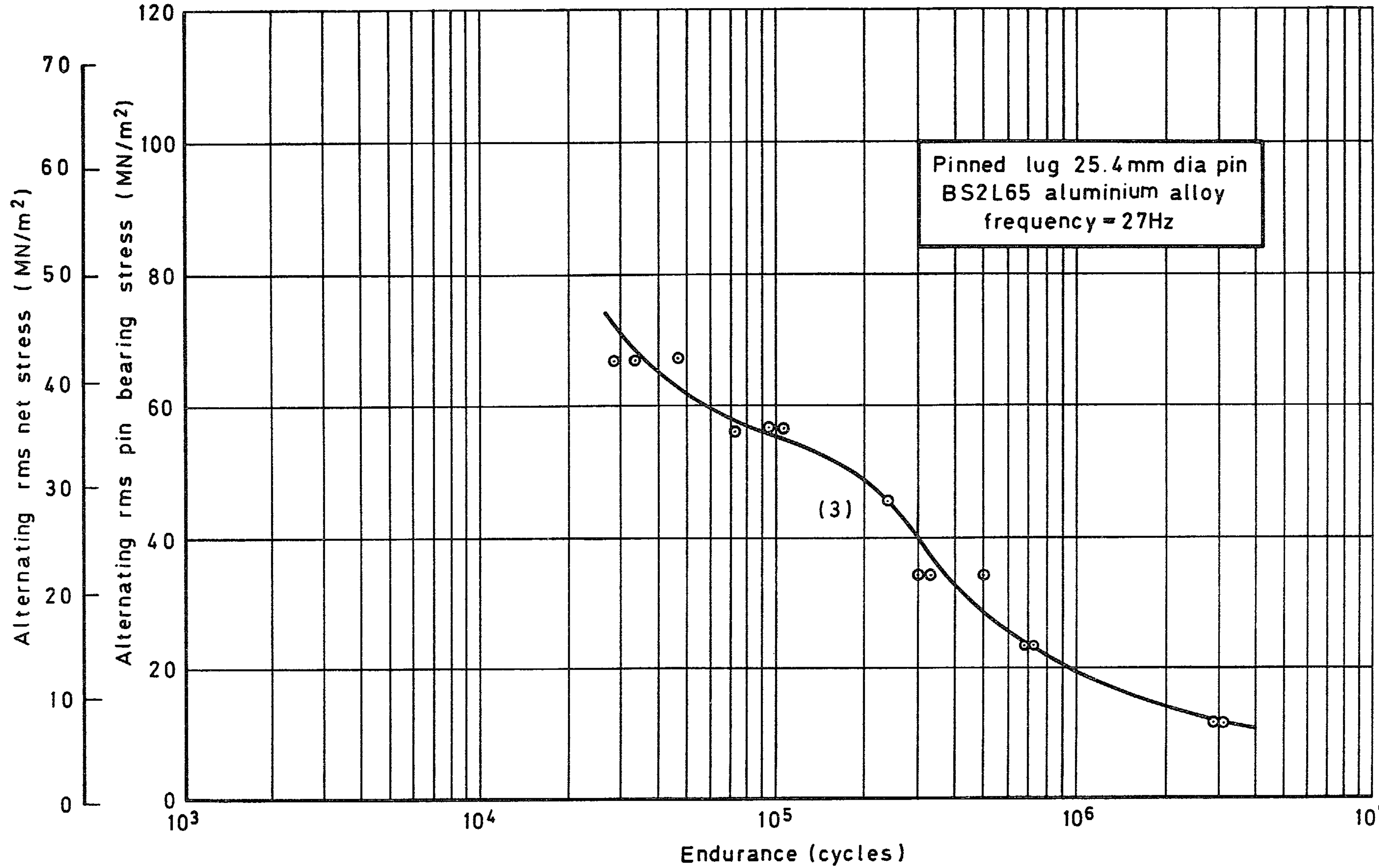

Fig 10 Narrow band random loading at mean stress = 277(172) MN/m^2

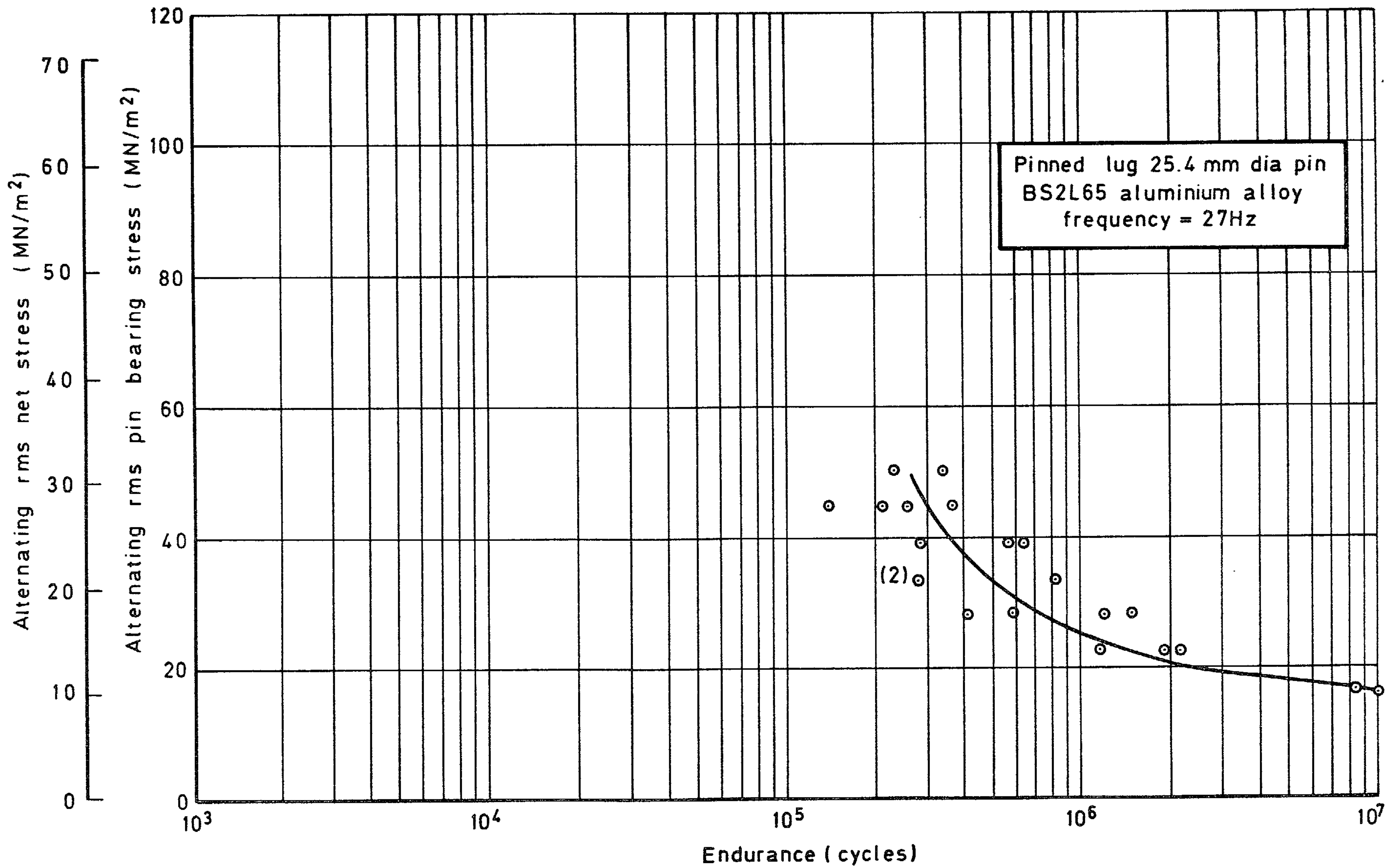

Fig 11 Narrow band random loading at mean stress = 155(96) MN/m^2 with a prestress = 390(242) MN/m^2

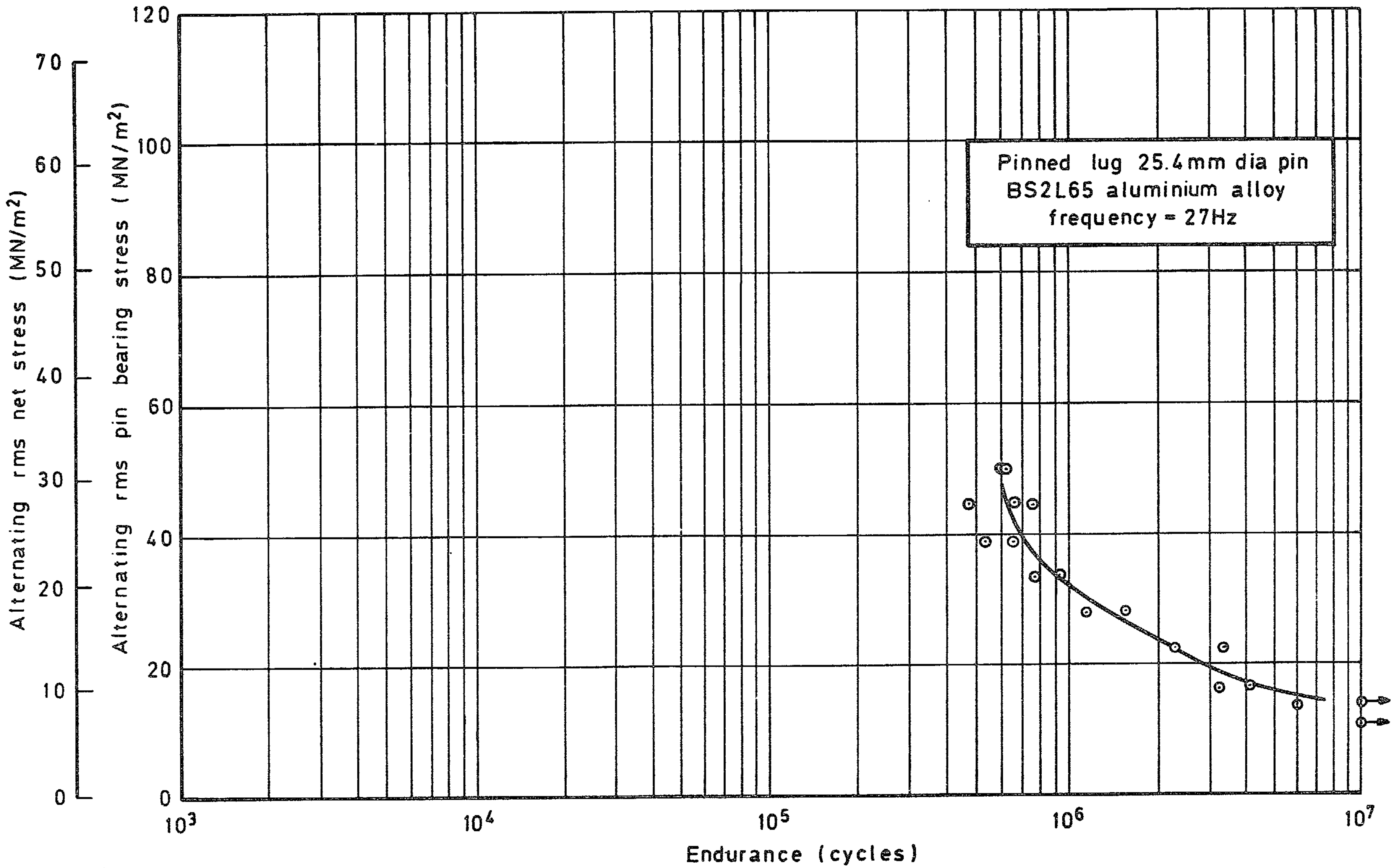

Fig 12 Narrow band random loading at mean stress = 155(96) MN/m^2 with a prestress = 500(310) MN/m^2

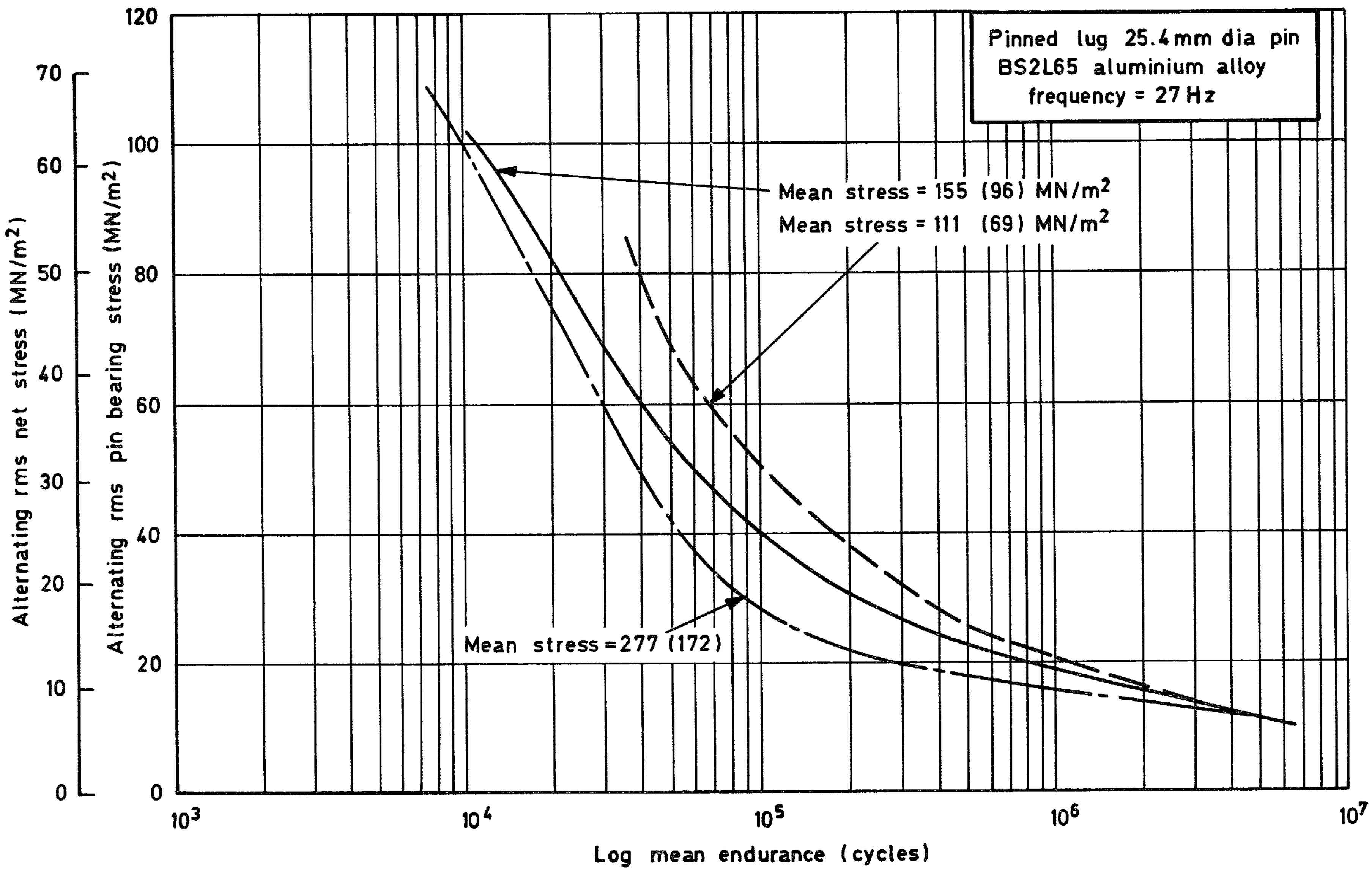

Fig 13 The effect of mean stress on constant amplitude performance

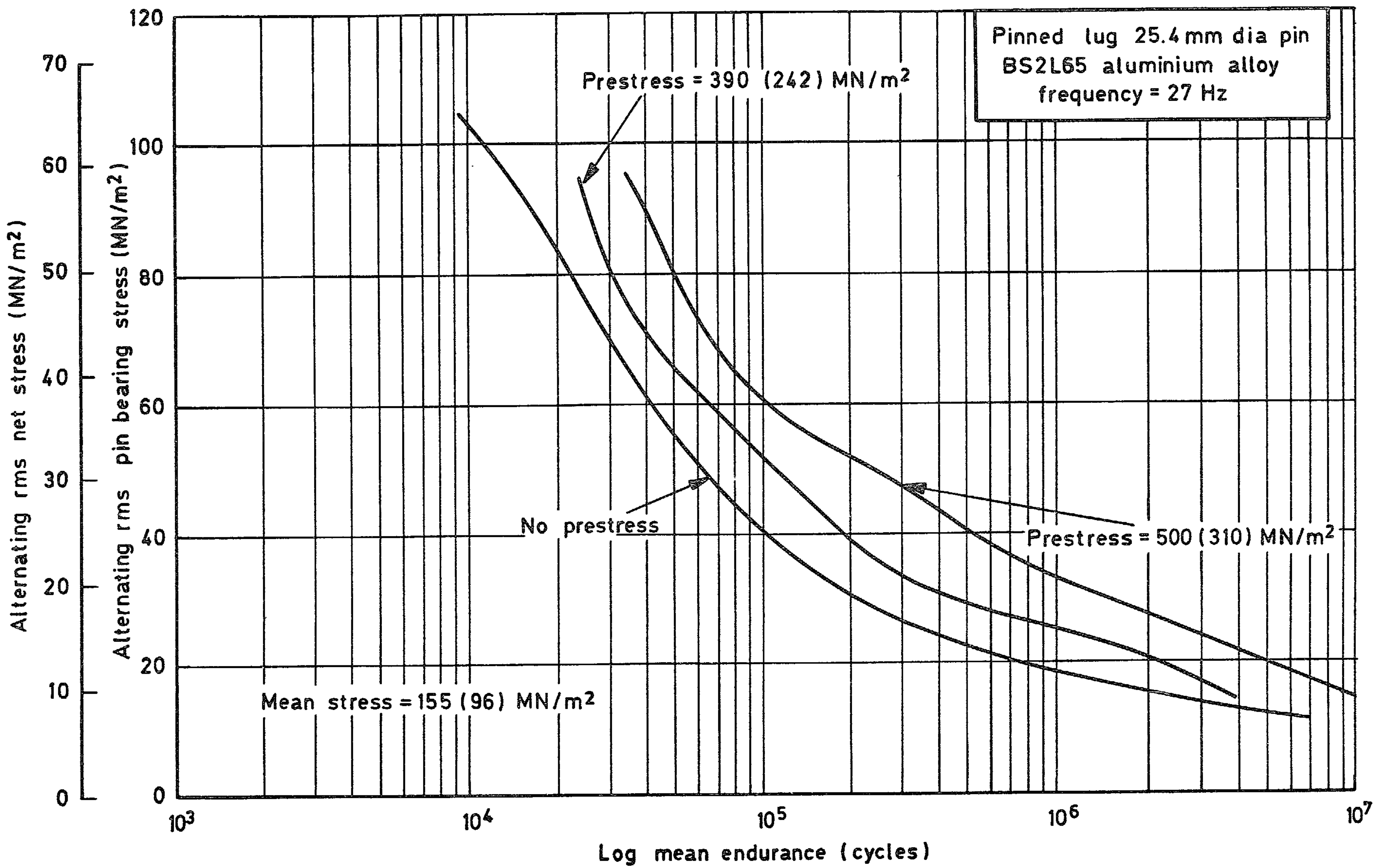

Fig 14 The effect of a prestress on constant amplitude performance

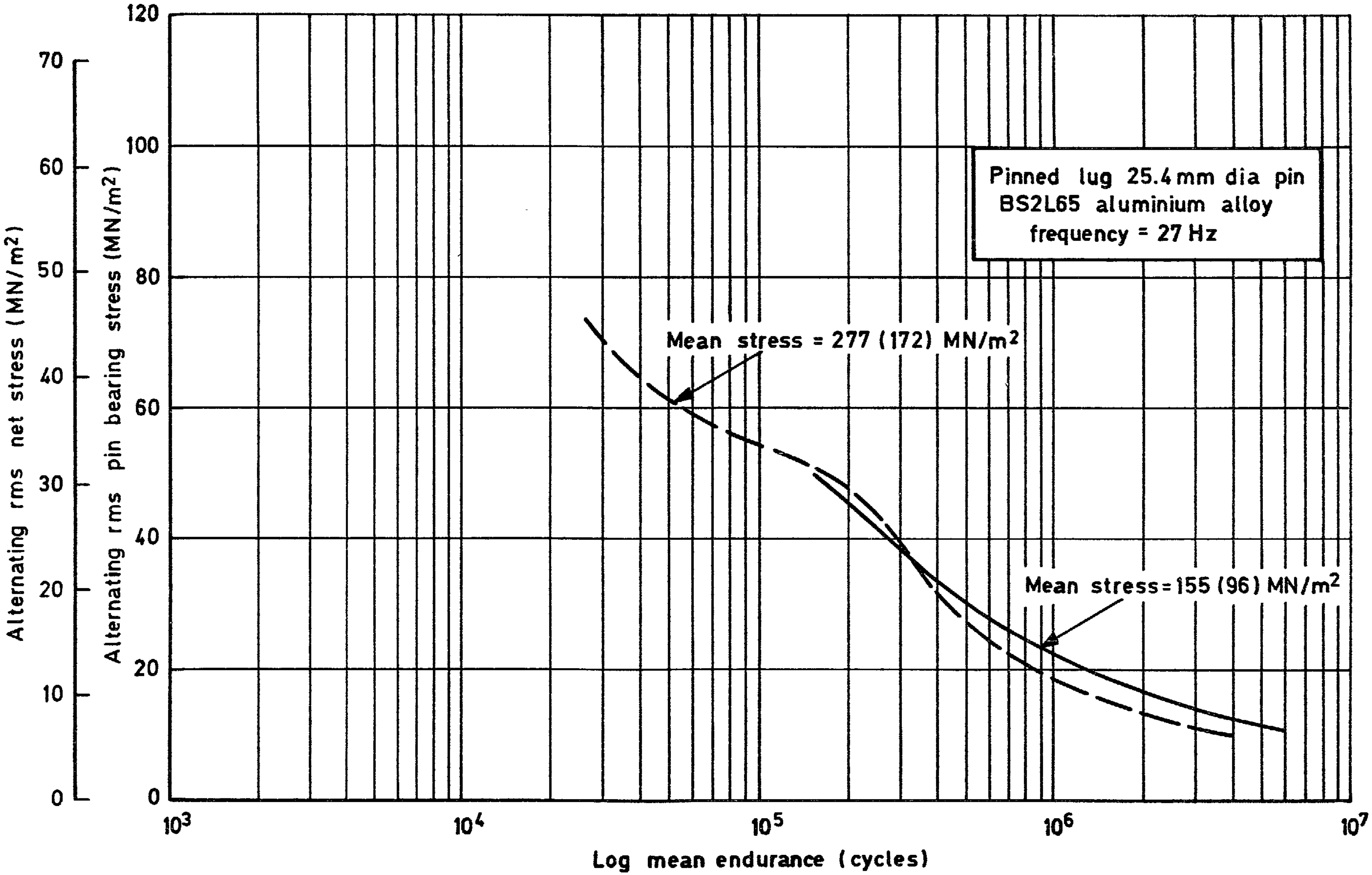

Fig 15 The effect of mean stress on narrow band random performance

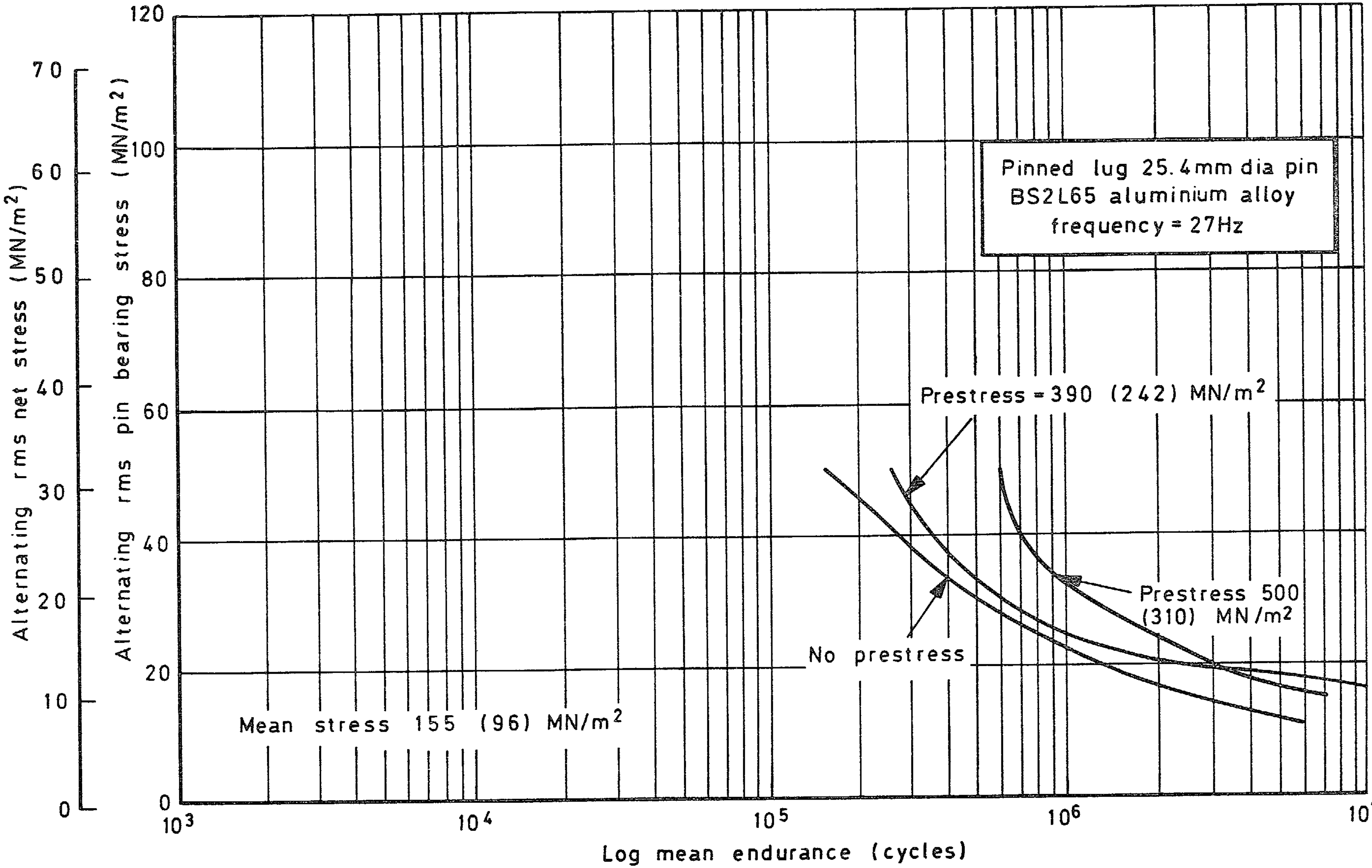

Fig 16 The effect of a prestress on narrow band random performance

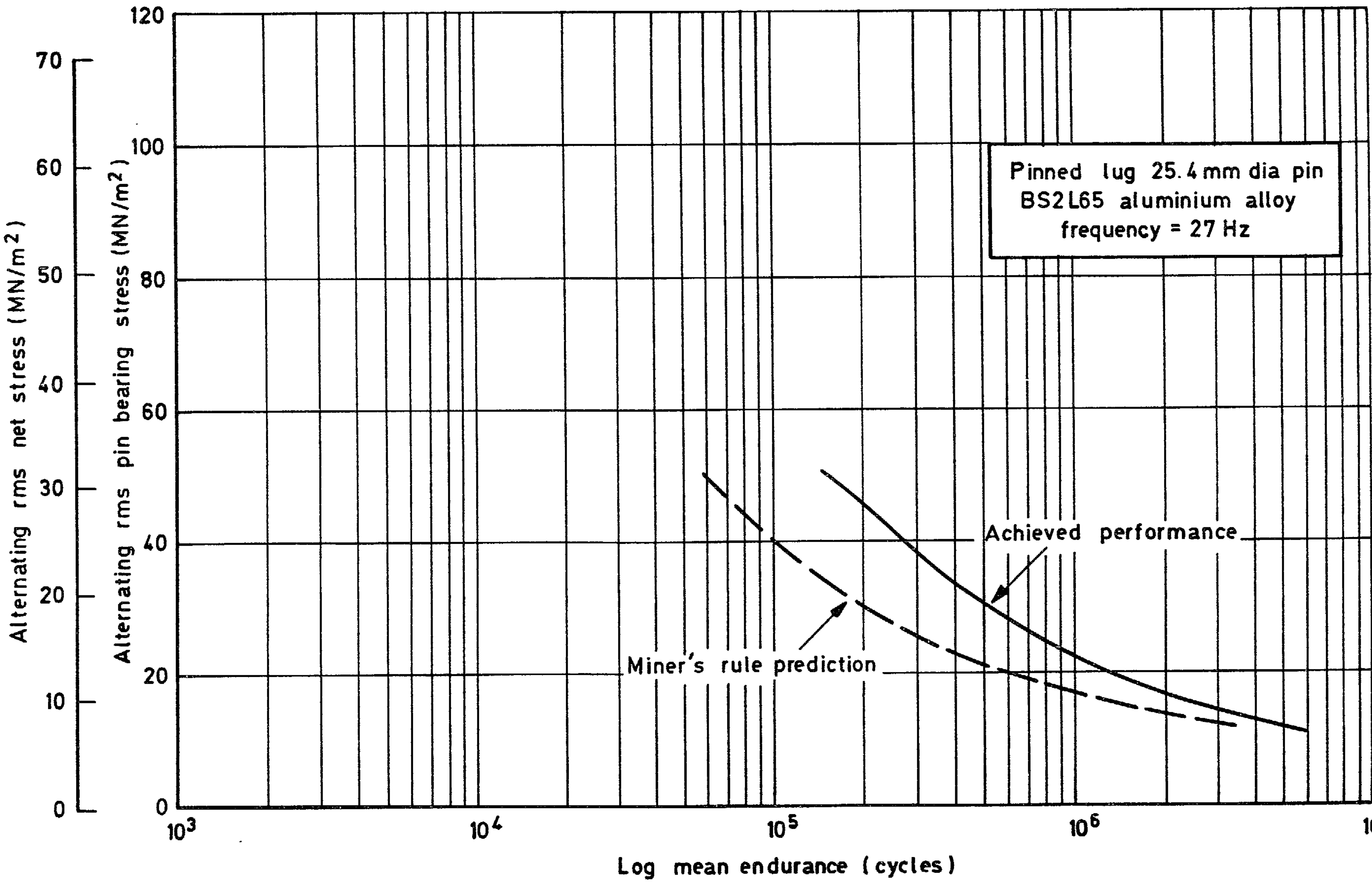

Fig 17 Accuracy of Miner's rule for NBR loading at mean stress = 155(96) MN/m^2

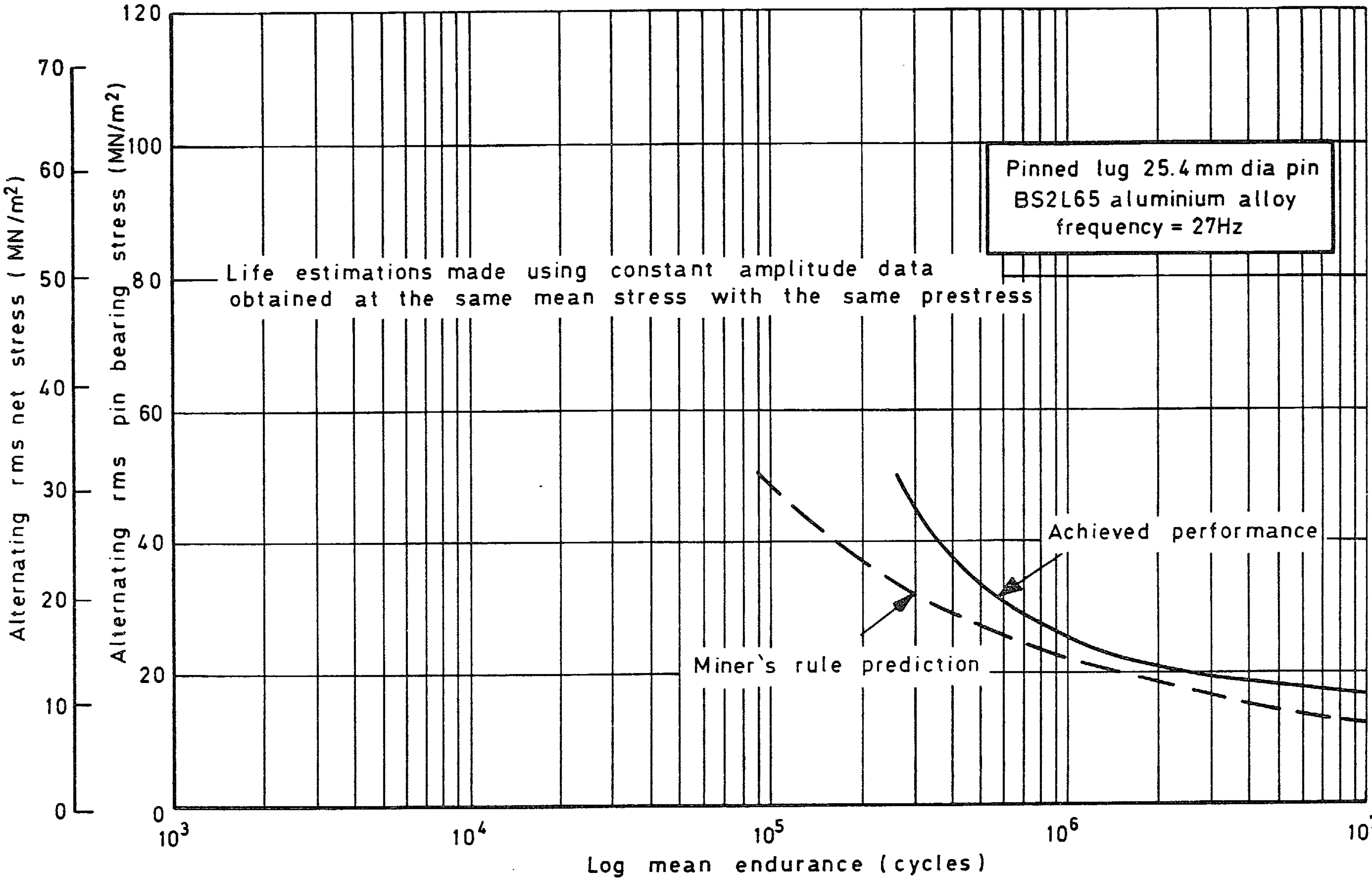

Fig 18 Accuracy of Miner's rule for NBR loading at mean stress = 155(96) MN/m^2 with a prestress = 390(242) MN/m^2

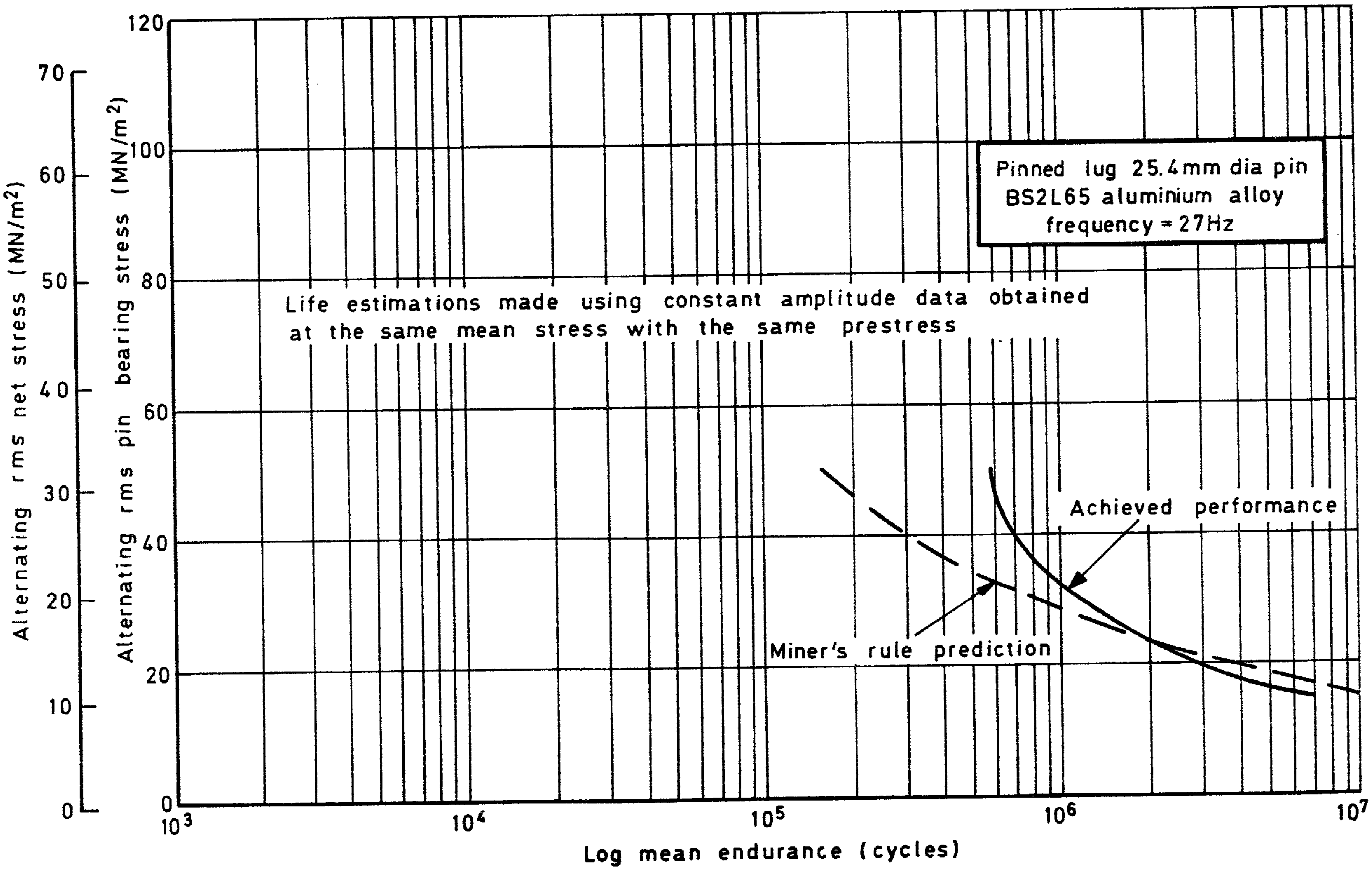

Fig 19 Accuracy of Miner's rule for NBR loading at mean stress = 155(96) MN/m^2 with a prestress = 500(310) MN/m^2

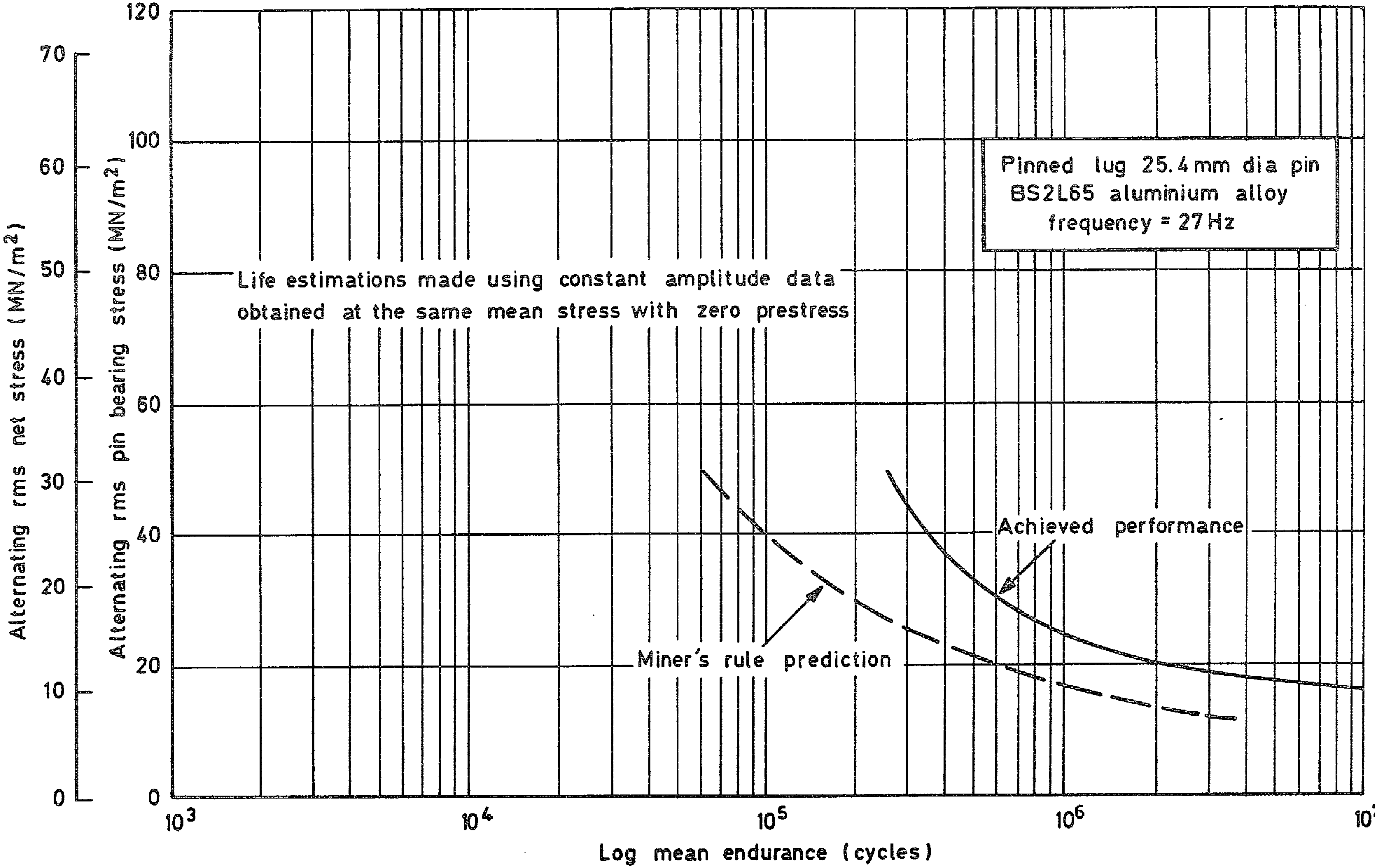

Fig 20 Accuracy of Miner's rule for NBR loading at mean stress = 155(96) MN/m^2 with a prestress = 390(242) MN/m^2

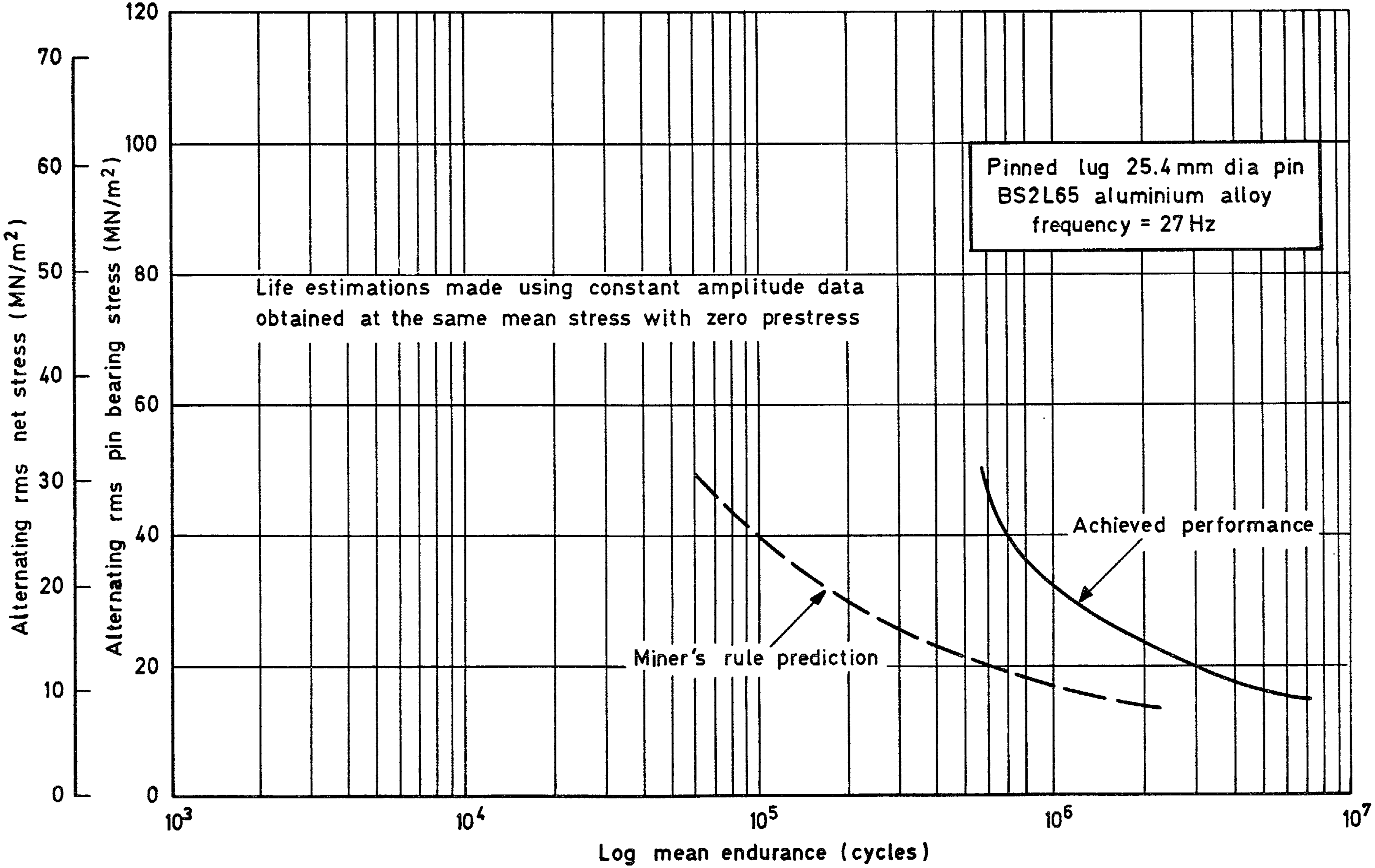

Fig 21 Accuracy of Miner's rule for NBR loading at mean stress = 155(96) MN/m^2 with a prestress = 500(310) MN/m^2

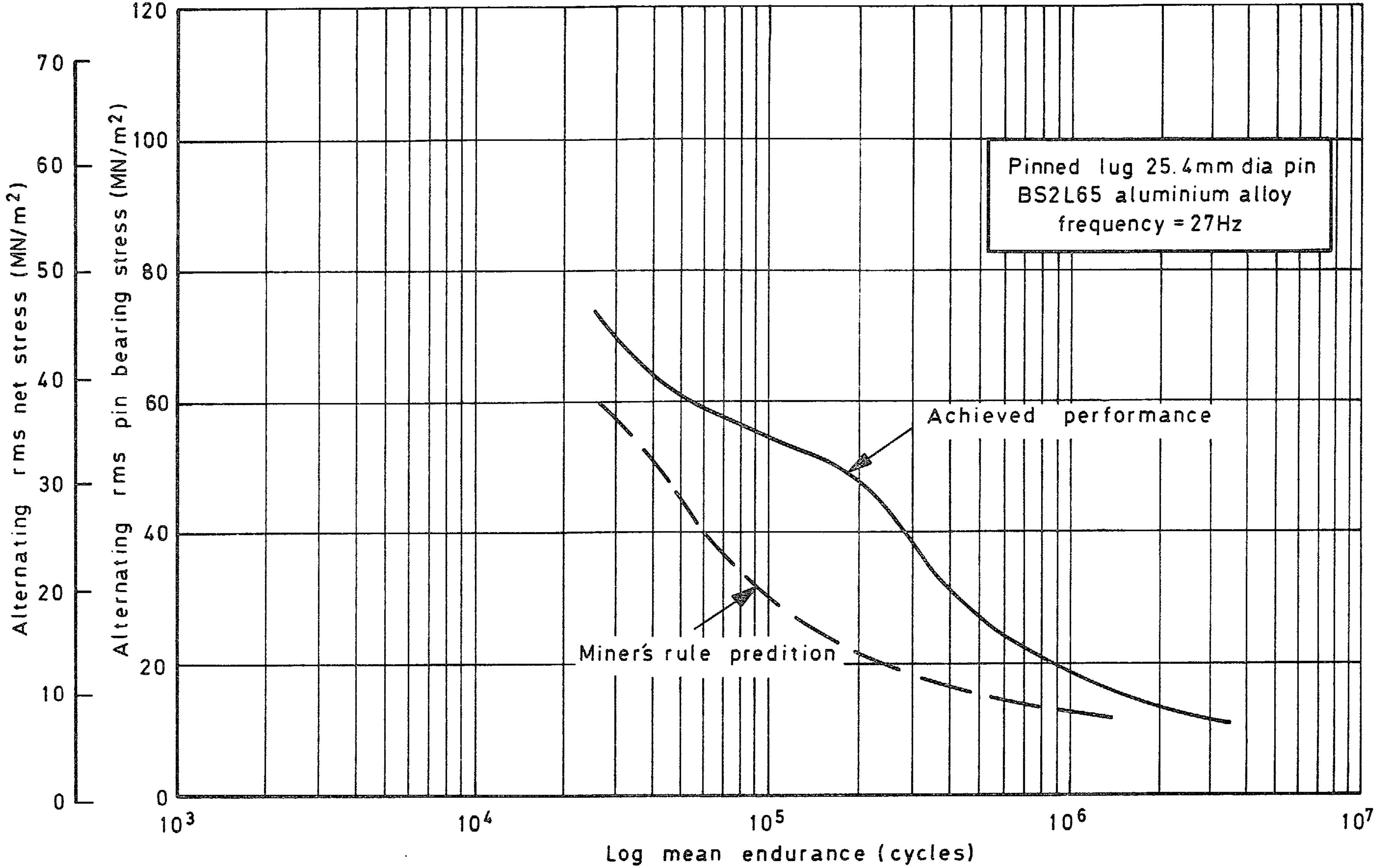

Fig 22 Accuracy of Miner's rule for NBR loading at mean stress = 277(172) MN/m²

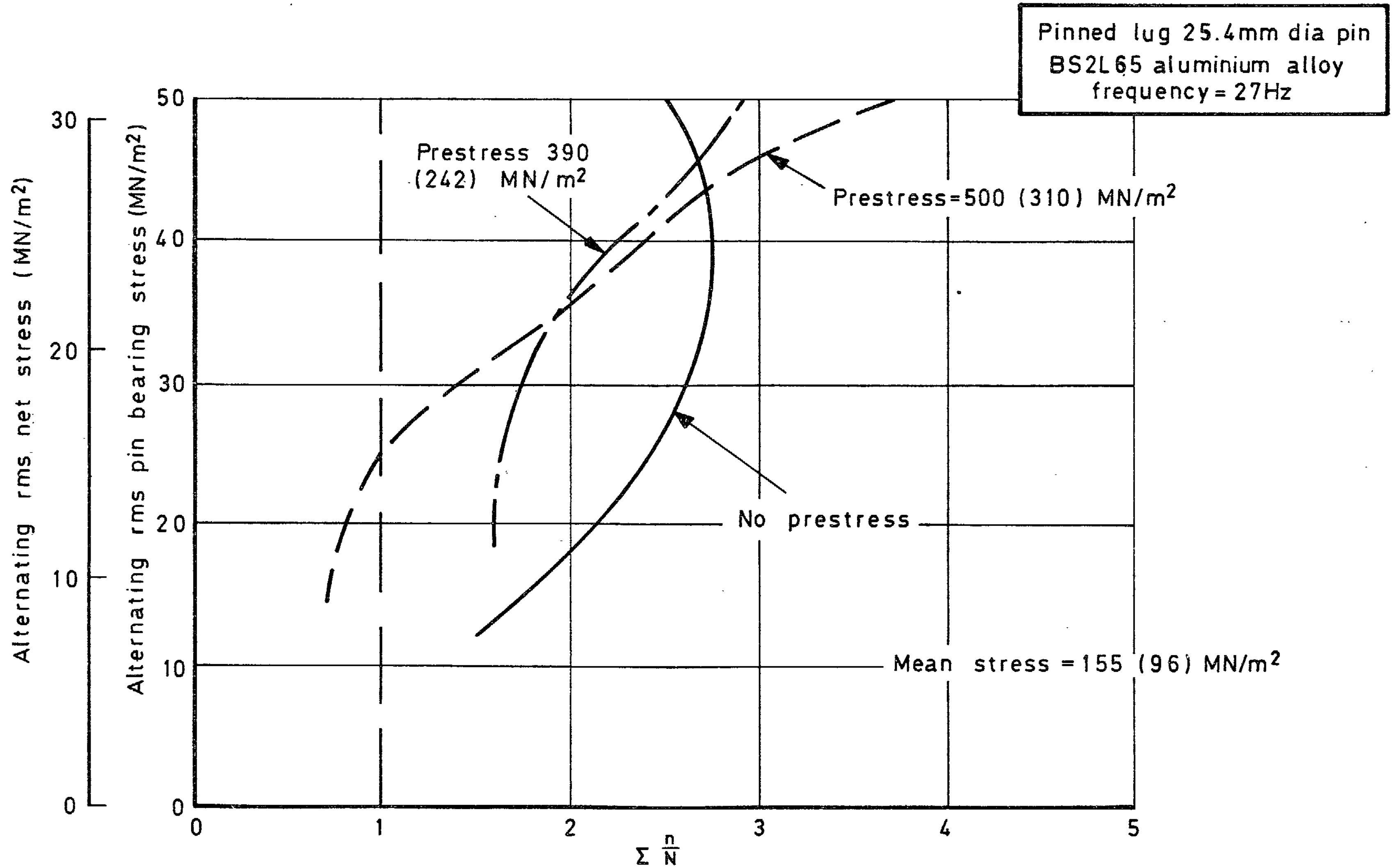

Fig 23 Σ n/N values for lugs with and without prestress based on constant amplitude data with the appropriate value of prestress

Fig 23

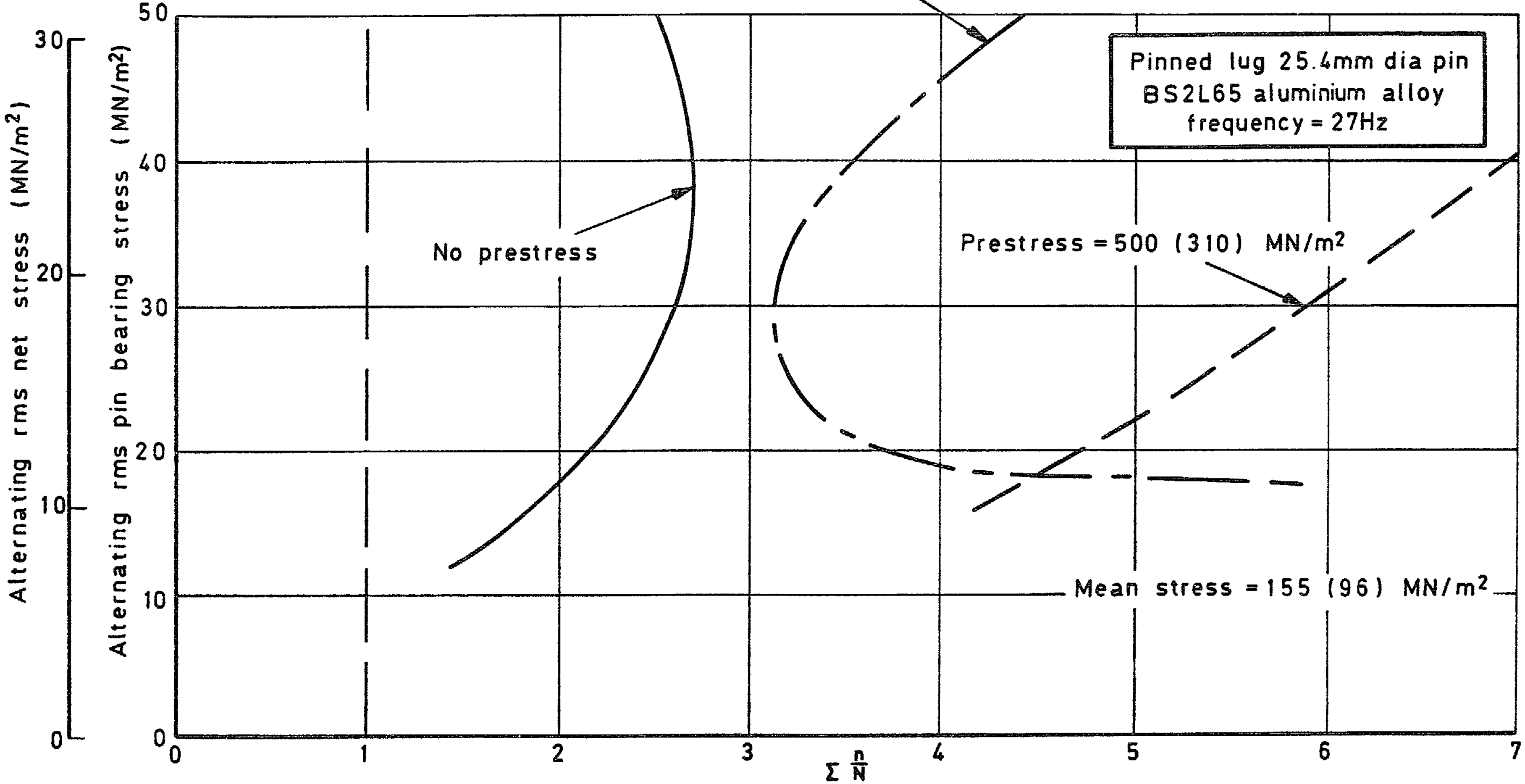

Fig 24 Σ n/N values for lugs with and without prestress based on constant data with no prestress

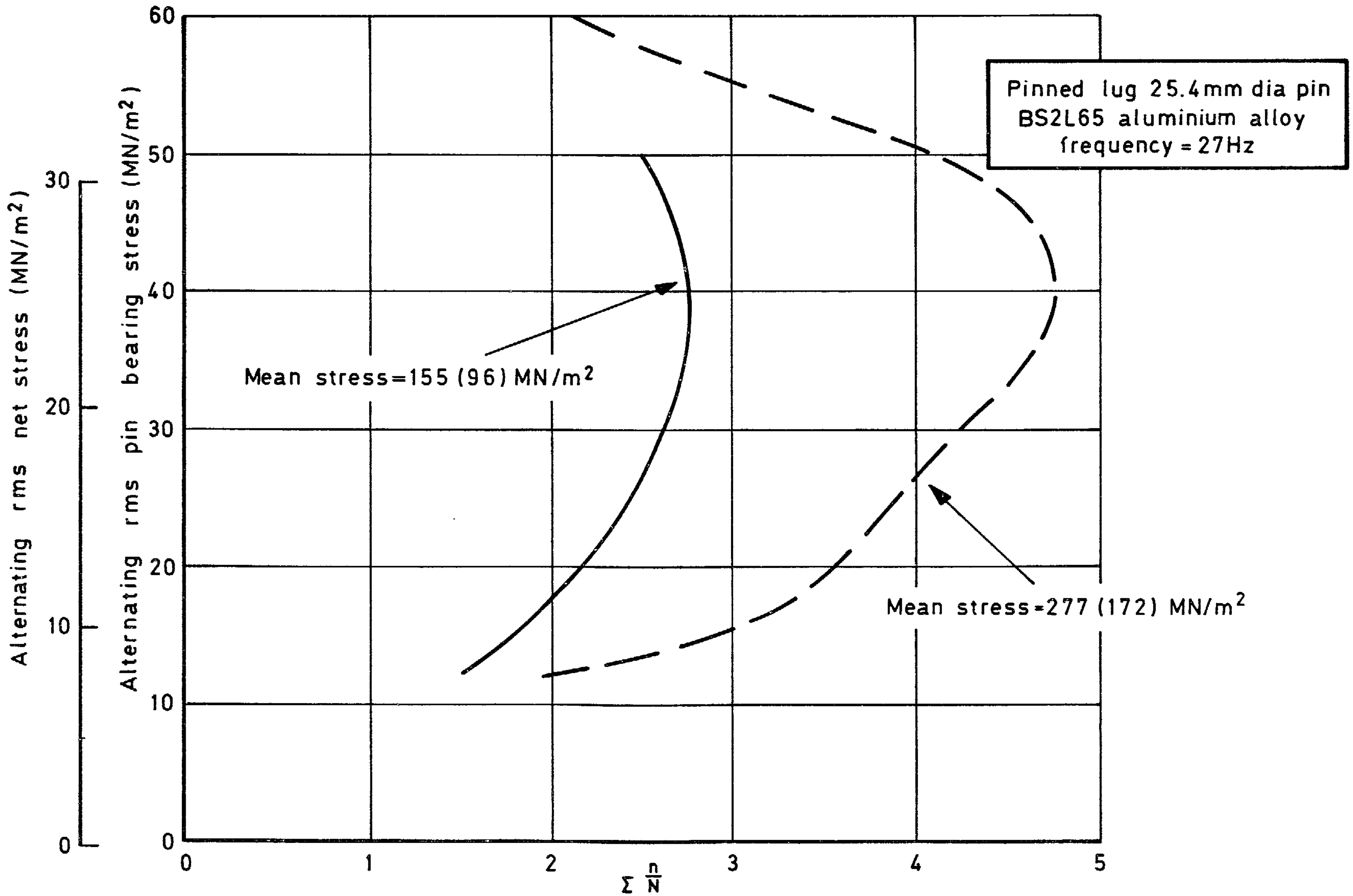

Fig 25 Σ n/N values for lugs at two mean stresses

Fig 25

Fig 26

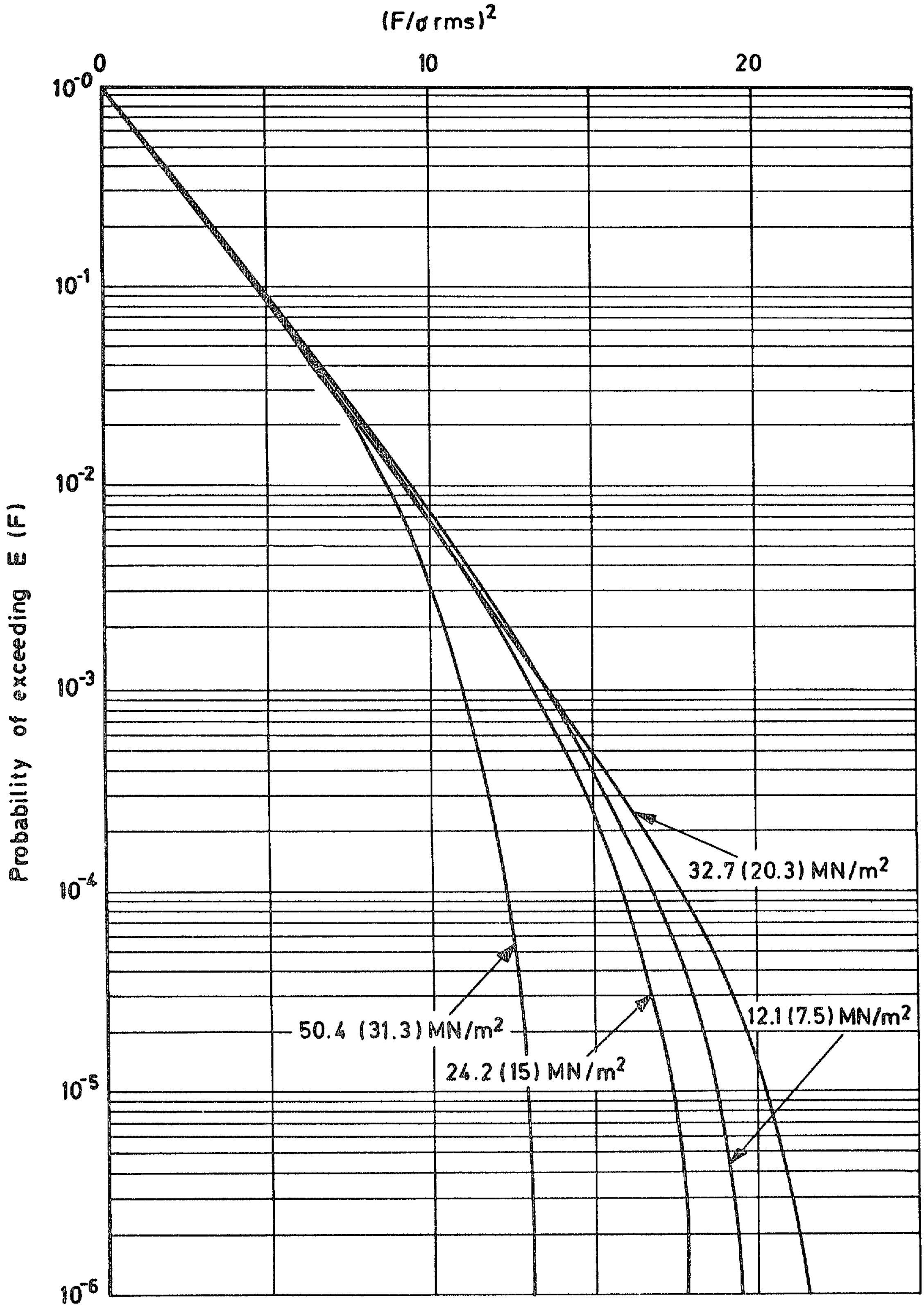

Fig 26 Measured load spectra at mean stress = 155(96) MN/m^2 at various rms alternating stress levels

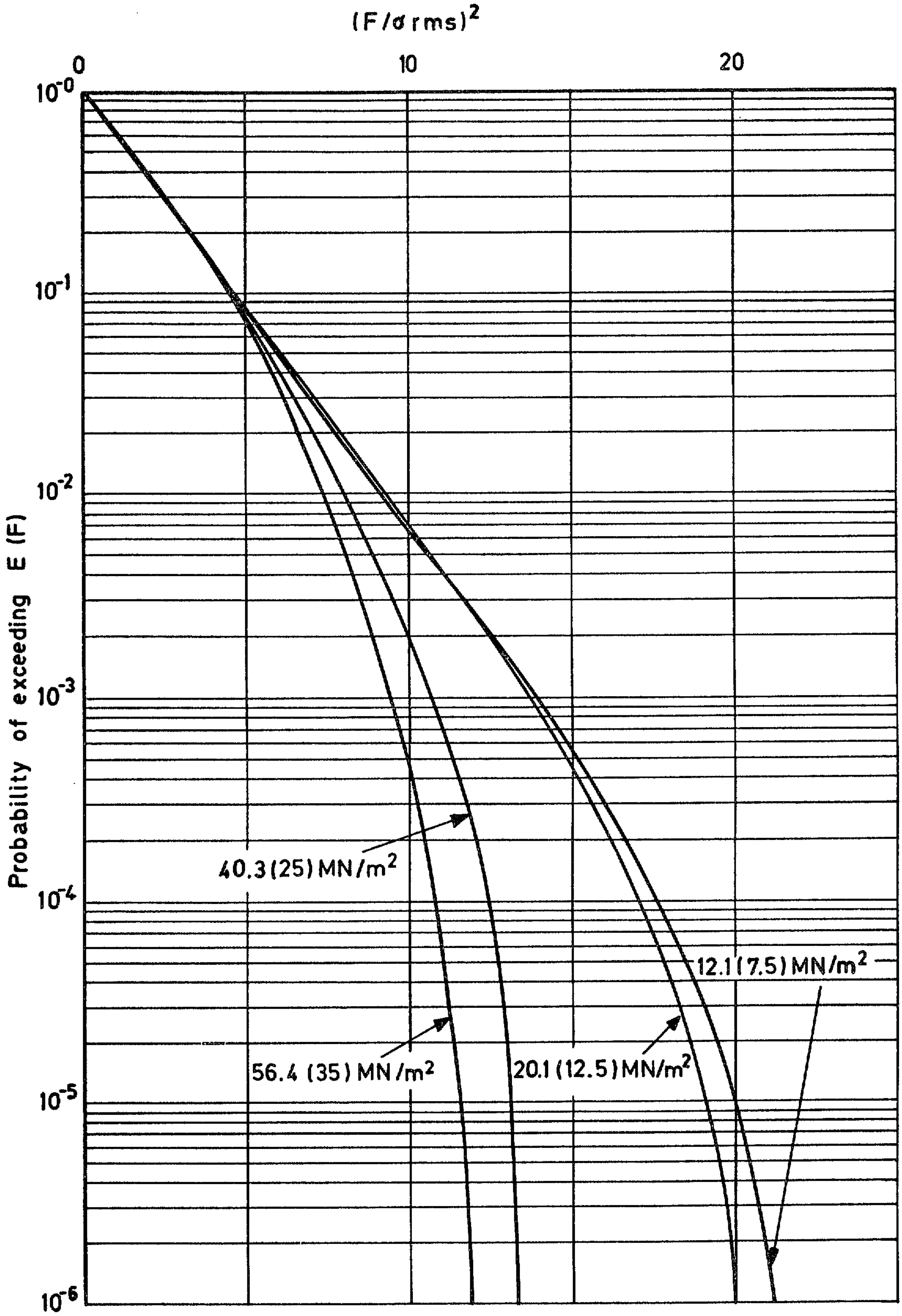

Fig 27 **Measured load spectra at mean stress = 277(172) MN/m² at various rms alternating stress levels**

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