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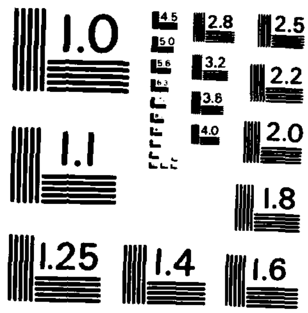

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MELBOURNE, VICTORIA

Structures Technical Memorandum 348

FOREMAST VIBRATIONS ON HMAS PARRAMATTA

A. GOLDMAN AND PETRA M. COX

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FOREMAST VIBRATION ON HMAS PARRAMATTA

A. GOLDMAN AND PETRA M. COX

SUMMARY

Tests have been carried out to determine the shapes of the natural modes of vibration, up to 20 hertz, of the new foremast fitted to HMAS Parramatta. Subsequent sea trials were undertaken to determine the amplitudes of vibrations under various operating conditions. A mathematical model of the mast has been developed to determine the modes of vibration. Results of the tests, and comparisons with the model, are presented.

POSTAL ADDRESS: Director, Aeronautical Research Laboratories,
P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

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1. INTRODUCTION

As part of a refit programme, a new lattice mast has been fitted to HMAS Parramatta. The mast is constructed, generally, from aluminium alloy tubing and carries radar, radio, and other navigation equipment. Aeronautical Research Laboratories had been requested to measure the resonant frequencies and mode shapes of the mast in the frequency range 0 to 20 hertz.

Figures 1 and 2 show the general construction of the mast and provide the major dimensions.

At this time, A.R.L. had taken delivery of the PAFEC computer programme for use in dynamic structural analysis. PAFEC stands for Programme for Automatic Finite Element Calculations and was developed by PAFEC Ltd. of Nottingham, U.K. It was decided to use this programme to model the mast and compare the results with those measured on the physical mast.

2. VIBRATION MODES

2.1 Description of Method

Two electromagnetic shakers were used to excite the structure. These were seismically mounted as shown in Fig. 3 and attached to the platform at level 7 on the mast. For excitation of transverse modes of vibration the shakers were attached on opposite sides of the platform with the push rods acting against the base of the pole mast. For excitation of the fore-aft and torsional modes of vibration the shakers were attached to the platform, forward of the pole mast, with the push rods acting against brackets clamped to the platform. Figs 4a and 4b show the two arrangements used. The shakers were controlled by high-impedance amplifiers driven from a common oscillator. Vibration was measured by means of eight accelerometers fixed to the mast at eight levels, the output being measured on a transfer-function analyser (TFA) using the forcing current as reference. Initially the accelerometers were located to measure vibrations in the transverse direction only. On completion of modal measurements in this direction they were relocated to measure vibrations in the fore-aft direction. Following this, they were again moved to observe torsional modes of vibration.

The outputs of two accelerometers were also displayed on an oscillascope as Lissajous figures as an aid to tuning for resonance.

Tables 1 to 9 present the measurements taken at each resonant frequency, and Figs 5 to 13 are the mode shapes obtained by plotting the quadrature component measured. The table indicates the units of acceleration in terms of g, the acceleration due to gravity. The force input was not measured.

Mode shapes are not plotted for the torsional resonances, or for the resonances observed of the horizontal arms. A summary of all resonant frequencies noted or measured is presented in Table 10.

2.2 Discussion of Results

Several of the modes of vibration fall within the range of propeller shaft rotation or propeller blade passing frequencies. The ease with which relatively large amplitudes of vibration had been excited, with quite small input force levels, led to the inclusion of mast vibration measurements in the coming sea trials.

3. SEA TRIALS

3.1 Description of method

Because the modes of vibration were known, it was considered unnecessary to use accelerometers at all levels in both directions. Accelerometers were fixed at level 8, on the small platform part way up the pole mast; and at level 7, at the top of the lattice structure. At each location two accelerometers were used, one in the fore and aft plane, and one in the transverse direction. The signals from the accelerometers were recorded on two two-track instrumentation recorders. The signals were monitored continuously on an oscilloscope and a dual-channel spectrum analyser.

Vibrations were observed at several propeller shaft speeds, and the amplitudes, the frequencies of the modes previously measured, were noted. From a knowledge of the mode shape, the amplitudes at the pole mast top, and other locations, may be easily calculated.

3.2 Discussion of results

Figs 14 to 29 present some of the frequency spectra produced on the analyser from the records taken at the different locations. Those presented are selected to demonstrate that the only significant acceleration amplitudes were experienced at a narrow band of speeds, and only at the frequencies of the fundamental bending modes. From these spectra, and the others produced but not presented here, data was obtained to plot displacement versus propeller shaft speed for the pole mast top and the top of the lattice mast. These plots are presented in Figs 30 and 31. The vibration modes of most concern were the fundamental bending modes in both directions.

The transverse bending mode, which was measured earlier as having a frequency of 3.08 hertz was observed to have a maximum peak-to-peak displacement at the top of the pole mast of 46 millimetres at a shaft speed of 180 revolutions per minute. At this speed, the amplitude at the top of the lattice mast was 4.4 millimetres peak-to-peak. On Fig 30 it may be seen that this amplitude falls away rapidly at speeds above and below 180 R.P.M.

The fundamental bending mode in the fore-aft direction, which was measured earlier at 3.23 hertz, was observed to have a peak-to-peak displacement of 39 millimetres at the top of the pole mast at 190 R.P.M. Fig 31 shows that the amplitude was greatly reduced at speeds below 190 R.P.M., and was reduced at 200 R.P.M., but, as this was the maximum speed permitted during these trials, the falling trend could not be investigated further.

The previously measured higher frequency modes were all detected during the sea trials, but all had acceleration levels significantly smaller than the fundamental bending modes, and consequently, much smaller displacement amplitudes.

Two other frequencies were noted during the sea trials. At 100 R.P.M. of the propeller shaft, a vertical motion was observed at a frequency of 1.6 hertz. This is believed to be the fundamental vertical bending of the ship hull. At 140 R.P.M. a similar transverse motion was observed with a frequency of 2.2 hertz. This is believed to be transverse bending of the hull.

4. MATHEMATICAL MODEL

4.1 Description of Model

The mast was modelled on the A.R.L. DEC System 10 computer using the PAFEC 75 computer programme.

The mast was broken into 319 simple beam elements, 4 eight-noded shell elements, 4 four-noded shell elements, 41 mass elements, and 8 spring elements. The model has 888 degrees of freedom and the computing time to calculate the first 60 modal frequencies, and provide details of the first 20 modes is approximately 30 minutes.

Construction details were taken from Department of Defence (NAVY) Drawing Number 120P-0225-002G and the values of the masses to be added were obtained at the construction site. The eight spring elements were introduced to allow for flexing of the deck. Another refinement was introduced to overcome the difference between the idealised construction, used in the model, and the actual construction shown in Fig 32. To correctly model the mast would have involved the introduction of 8 more nodes at each mast level, and the reduction of the simple beam elements into many shorter elements. An analysis was carried out on one section of the model to determine the change caused by this difference between ideal and actual construction. The change was a reduction in stiffness. The same reduction in stiffness was achieved in the model by reducing the modulus of elasticity for the material from 0.7×10^{11} to 0.6×10^{11} Newtons/metre^2. The effect of this reduced stiffness was to lower all the resonant frequencies. Fig 33 shows the distribution of masses and springs on the model.

4.2 Discussion of Results

The first 20 calculated modes of vibration are listed in Table 11. These modes were calculated in detail by the computer, were plotted out, and are presented in Figs 34 to 53. In Table 11 the equivalent measured modes are shown against the calculated modes. The table includes modes of vibration which were not observed during the initial vibration tests. This results from the simple test method adopted. The use of two accelerometers in fixed locations to provide the sole indication of resonance for one direction of excitation is certain to miss those modes having nodes at these locations. The calculated modes of vibration which have large amplitudes at the locations of accelerometers show good correspondence to measured modes.

5. GENERAL DISCUSSION AND CONCLUSION

The overall test programme has been successful and it has been established that there is significant mast vibration excited at the shaft frequency but only outside the normal operating range. There is no significant vibration at the blade-passing frequency.

The method used to excite the modes of vibration was relatively simple and quite effective. Each shaker with its seismic mount has a mass of approximately 100 kilogrammes which restricted the choice of locations to those with easy access and sound mountings. This restriction of choice of location for the shakers prevented excitation of all the modes possible. This applied particularly to the 3-node modes of vibration which have a node close to level 7 where the shakers were located. The modes excited at 10.87 hertz and 13.37 hertz were both thought to be predominantly torsion because the exciting forces were being applied in a torsional manner and the accelerometers had been located to observe torsional modes. What was observed may well have been the two calculated 3-node transverse bending modes, illustrated in Figs 46 and 50, both of which show slight torsion at level 7.

The use of the portable spectrum-analyser, in conjunction with the earlier obtained modal analysis details, provided on-site analysis of vibrations during sea-trials.

The fact that the model provided several modes of vibration that were not observed during testing is an indication of the limited scope of the tests carried out. With a larger number of accelerometers, on a wider spread location grid, some of the other modes may have been observed. It was not feasible to use a travelling accelerometer on this project because of the time and effort required for the operator to climb up and down the mast for each reading. The mass of the operator would have introduced a significant error as he moved about the mast structure.

The mast model appears to be a close representation and could now be used with some confidence to determine effects of future modifications.

TABLE 1

Measurements of acceleration at resonant frequency
of 3.08 hertz in transverse direction
Illustrated in Fig 5

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	12	-217	218	272
" 8	0	- 72	72	268
" 7	0	- 16	16	276
" 6	0	- 10	11	280
" 5	-0.4	- 9.1	9.2	268
" 4	-0.4	- 6.8	6.8	269
" 3	+0.2	- 3.8	3.8	274
" 2	0	0		

<u>TABLE 2</u>

Measurements of acceleration at resonant frequency
of 3.23 hertz in fore and aft direction
Illustrated in Fig 6

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	-34.0	807	808	92
" 8	2.0	278	278	90
" 7	2.6	49.0	50.6	82
" 6	2.0	37.6	37.7	87
" 5	1.8	27.7	27.8	86
" 4	1.6	20.8	21.0	86
" 3	0.8	12.8	13.0	88
" 2	0.4	5.8	6.0	90

TABLE 3

Measurements of acceleration at resonant frequency
of 5.19 hertz in transverse direction
Illustrated in Fig 7

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	1	113	111	90
" 8	1.3	- 9.5	9.6	276
" 7	5.2	-43.3	43.6	276
" 6	1.4	-34.5	34.6	271
" 5	0	-27.7	27.7	269
" 4	-0.2	-23.0	23.0	269
" 3	0.2	-15.8	15.8	270
" 2	0	- 7.6	7.6	272

TABLE 4

Measurements of acceleration at resonant frequency
of 5.43 hertz in fore and aft direction
Illustration in Fig 8

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	-8.3	-99.1	99.6	216
" 8	1.0	2.6	2.8	25
" 7	-4.9	28.5	31.3	96
" 6	-3.7	26.7	29.4	101
" 5	2.4	22.8	23.0	84
" 4	1.4	19.4	19.6	87
" 3	0	16.0	16.2	91
" 2	-0.2	6.4	6.4	91

TABLE 5

Measurements of acceleration at resonant frequency
of 7.68 hertz in fore and aft direction
Illustrated in Fig 9

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	8.1	-32.7	36.3	281
" 8	0.2	13.6	13.7	90
" 7	0.4	21.7	21.7	89
" 6	-3.1	19.6	19.9	98
" 5	-2.9	15.9	16.2	99
" 4	-2.0	13.4	13.6	96
" 3	-1.4	8.0	8.2	97
" 2	-0.8	4.4	4.6	95

TABLE 6

Measurements of acceleration at resonant frequency of 9.25 hertz in the transverse direction Illustrated in Fig 10

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	2.01	57.5	57.5	88
" 8	0.48	-27.6	27.6	271
" 7	1.63	-31.2	31.2	273
" 6	0	-39.5	39.5	270
" 5	1.13	-32.4	32.4	272
" 4	0	-32.0	32.0	270
" 3	1.38	-19.8	19.8	274
" 2	0.96	-10.9	11.0	275

TABLE 7

Measurements of acceleration at resonant frequency
of 10.29 hertz in the fore and aft direction
Illustrated in Fig 11

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	-2.1	-69.0	69.0	240
" 8	-0.2	32.4	32.4	106
" 7	1.4	31.6	31.8	73
" 6	1.0	25.5	26.4	67
" 5	-0.6	20.6	20.2	91
" 4	-0.8	11.6	11.8	92
" 3	0.4	10.0	10.0	90
" 2	0	5.8	6.0	94

TABLE 8

Measurements of acceleration at resonant frequency
of 17.76 hertz in the transverse direction
Illustrated in Fig 12

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	-17.0	-34.4	37.4	243
" 8	5.0	9.5	10.1	60
" 7	5.4	-41.5	41.9	277
" 6	- 2.5	-10.1	10.4	257
" 5	1.5	- 0.2	1.5	352
" 4	9.2	13.2	16.2	55
" 3	9.6	15.4	18.2	59
" 2	6.6	11.0	12.8	60

TABLE 9

Measurement of acceleration at resonant frequency
of 18.85 hertz in fore and aft direction
Illustrated in Fig 13

LOCATION	IN-PHASE COMPONENT $g \times 10^{-3}$ r.m.s.	QUADRATURE COMPONENT $g \times 10^{-3}$ r.m.s.	MODULUS $g \times 10^{-3}$ r.m.s.	PHASE DEGREES
LEVEL 9	-2.6	19.2	19.4	97
" 8	0.1	- 6.8	6.9	270
" 7	-1.0	23.6	23.7	92
" 6	-5.5	10.8	12.1	116
" 5	-6.3	- 1.3	6.4	192
" 4	-8.0	-14.4	16.4	242
" 3	-7.6	-17.4	19.0	247
" 2	-5.4	-13.8	14.8	250

TABLE 10

Summary of resonant modes measured or noted

FREQUENCY HERTZ	DESCRIPTION	FIG.	CALCULATED Hz	EQUIVALENT FIG.
3.08	Transverse bending of mast	5	3.16	34
3.23	Fore-aft bending of mast	6	3.38	35
5.19	Transverse bending two-node mode	7	4.75	36
5.43	Fore-aft bengind two-node mode	8	5.84	37
5.48	Horizontal arm at level 4, starboard side	N.I.	8.64	40
6.02	Horizontal arm at level 6, port side	N.I.	9.11	41
6.44	Horizontal arm at level 4, port side	N.I.	8.64	40
6.95	Torsion	N.I.	6.67	38
7.68	Fore-aft bending, two-node mode	9	8.38	39
9.25	Transverse bending, two-node mode	10	11.09	45
10.29	Fore-aft bending, two-node mode	11	10.95	44
10.87	Torsion	N.I.	11.67	46
13.37	Torsion	N.I.	13.98	50
17.76	Transverse bending, four-node mode	12	15.52	53
18.85	Fore-aft bending, four-node mode	13	-	-

N.I. = Not illustrated

TABLE 11

Vibration modes calculated by PAFEC programme

FREQUENCY HERTZ	DESCRIPTION	FIG.	OBSERVED Hz	EQUIVALENT FIG.
3.16	Transverse mast bending	34	3.08	5
3.36	Fore-aft mast bending	35	3.23	6
4.73	Transverse mast bending, two-node mode	36	5.19	7
5.84	Fore-aft mast bending, two-node mode	37	5.43	8
6.67	Torsion mode	38	6.95	N.I.
8.36	Symmetric vertical bending of lower horizontal arms	39	7.68	9
8.64	Symmetric vertical bending of lower horizontal arms with vertical bending of platform at level 7	40	5.48 or 6.44	N.I.
9.11	Vertical bending of upper horizontal arms	41	6.02	N.I.
9.19	Torsion of mast with antisymmetric bending of horizontal arms	42	10.87	N.I.
9.42	Antisymmetric bending of lower horizontal arms	43	-	-
10.95	Fore-aft bending of upper horizontal arms with slight fore-aft mast bending	44	10.29	11
11.09	Antisymmetric horizontal bending of upper horizontal arms, with slight transverse mast bending	45	9.25	10

TABLE 11 (CONT.)

FREQUENCY HERTZ	DESCRIPTION	FIG.	OBSERVED Hz	EQUIVALENT FIG.
11.67	Three-node transverse mast bending with large vertical bending of horizontal arms	46	10.87	N.I.
12.51	Symmetric vertical bending of upper horizontal arms	47	-	-
12.55	Antisymmetric vertical bending of upper horizontal arms	48	-	-
13.72	Fore-aft mast bending, three-node mode	49	-	-
13.98	Transverse mast bending, three-node mode	50	13.37	N.I.
14.95	Symmetric vertical bending of lower horizontal arms	51	-	-
15.04	Symmetric vertical bending of lower horizontal arms	52	-	-
15.52	Four-node transverse mast bending with lower horizontal arm bending	53	17.76	12

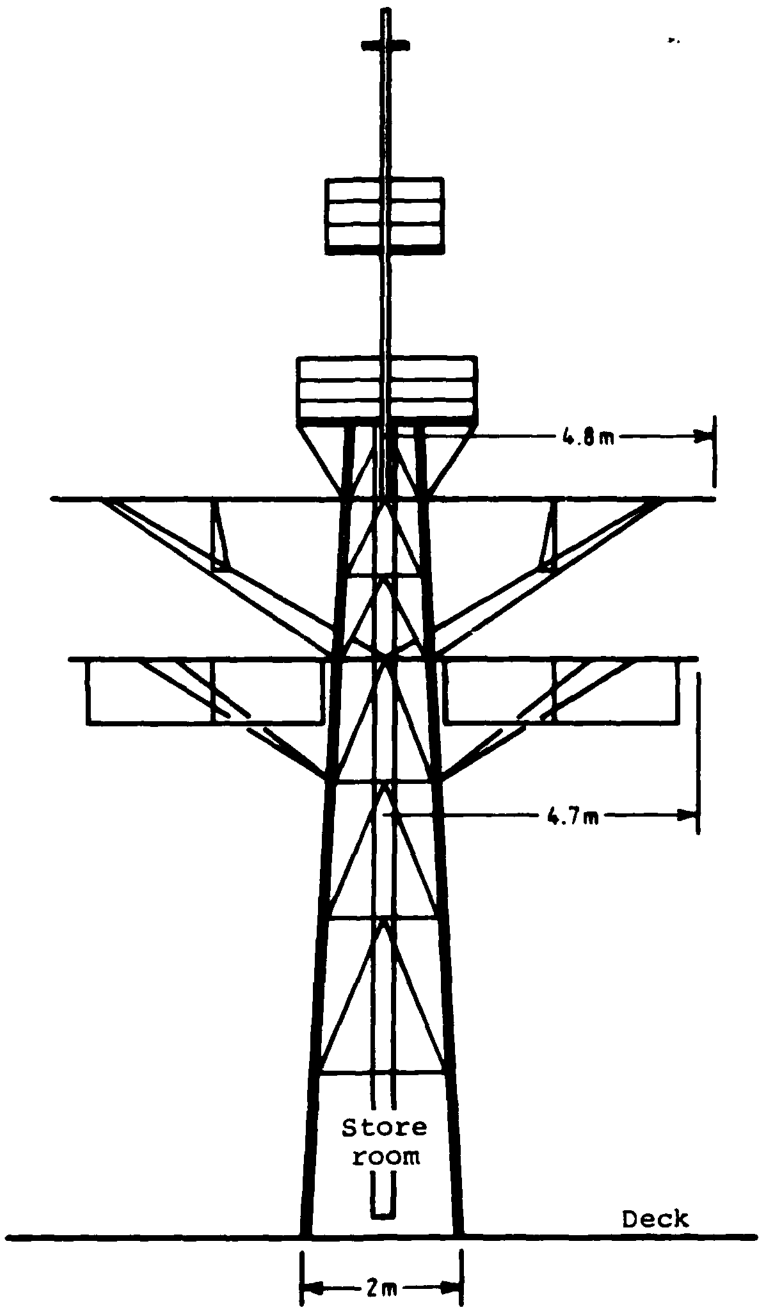


FIG. 1 VIEW OF MAST LOOKING AFT

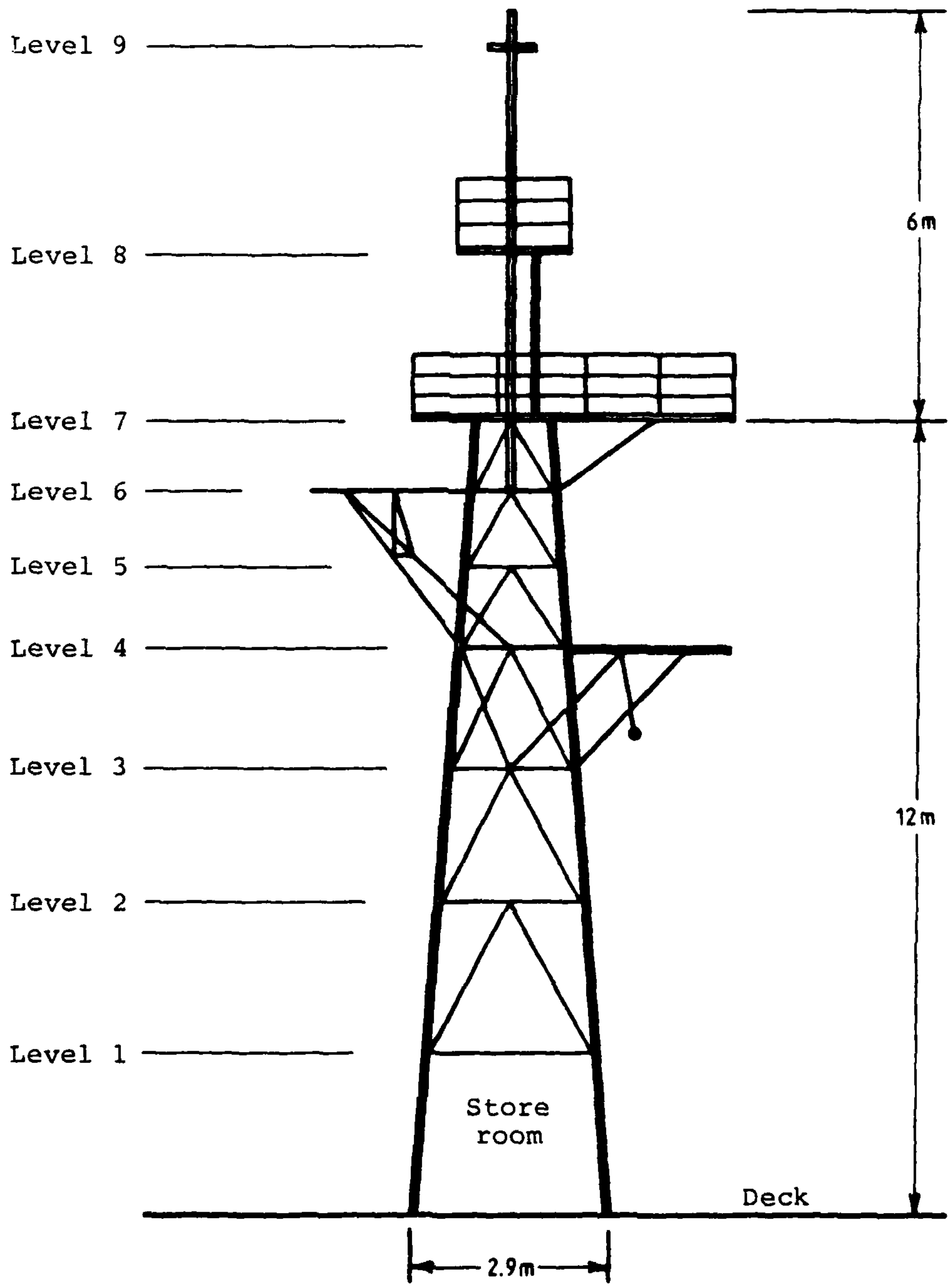


FIG. 2 VIEW OF MAST LOOKING TO PORT

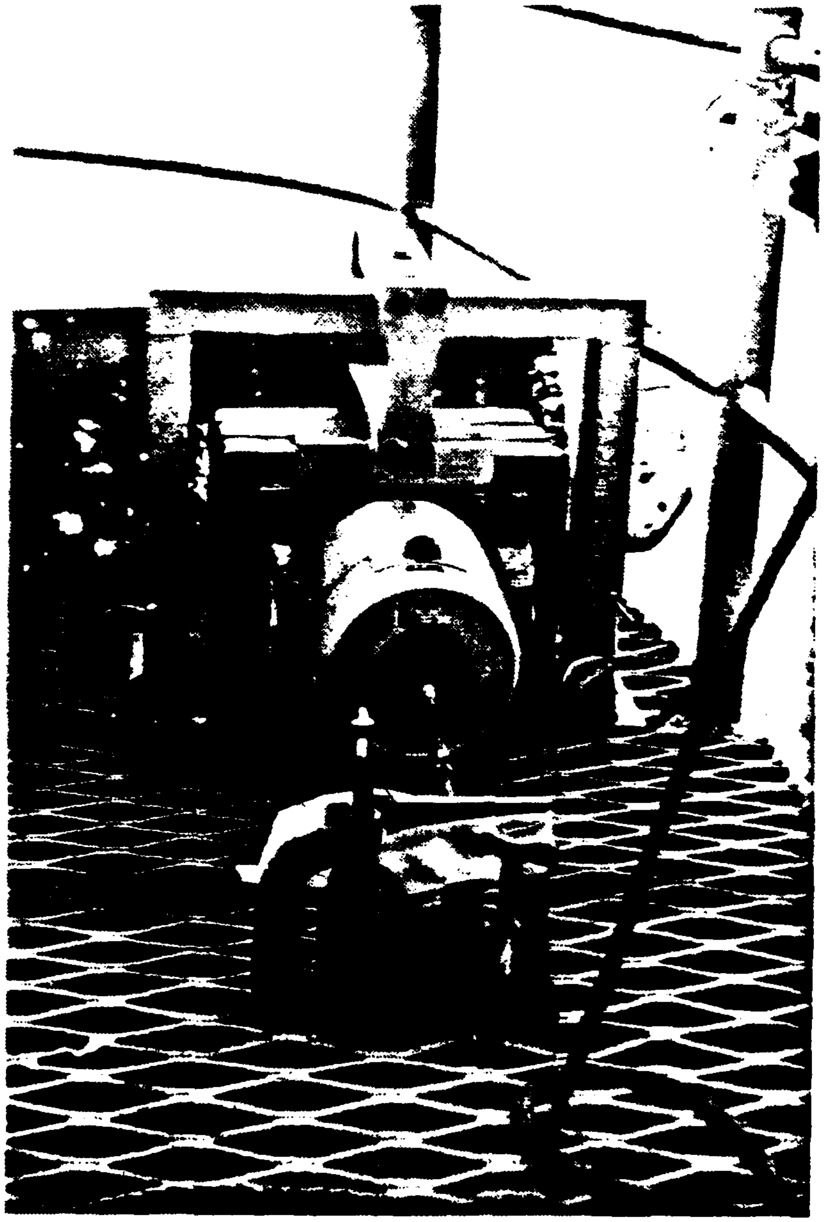


FIG. 3 ELECTRO MAGNETIC SHAKER SEISMICALLY MOUNTED ON MAST

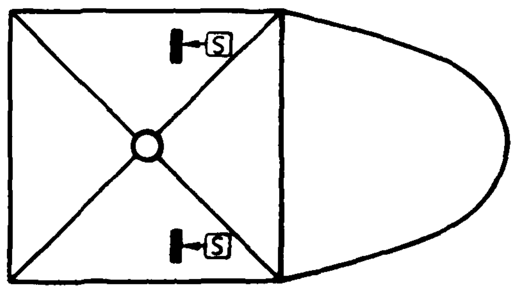


FIG. 4(a) LOCATION OF SHAKERS AT LEVEL 7 FOR FORE AND AFT VIBRATION EXCITATION

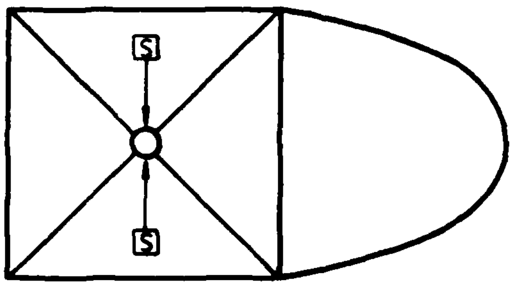
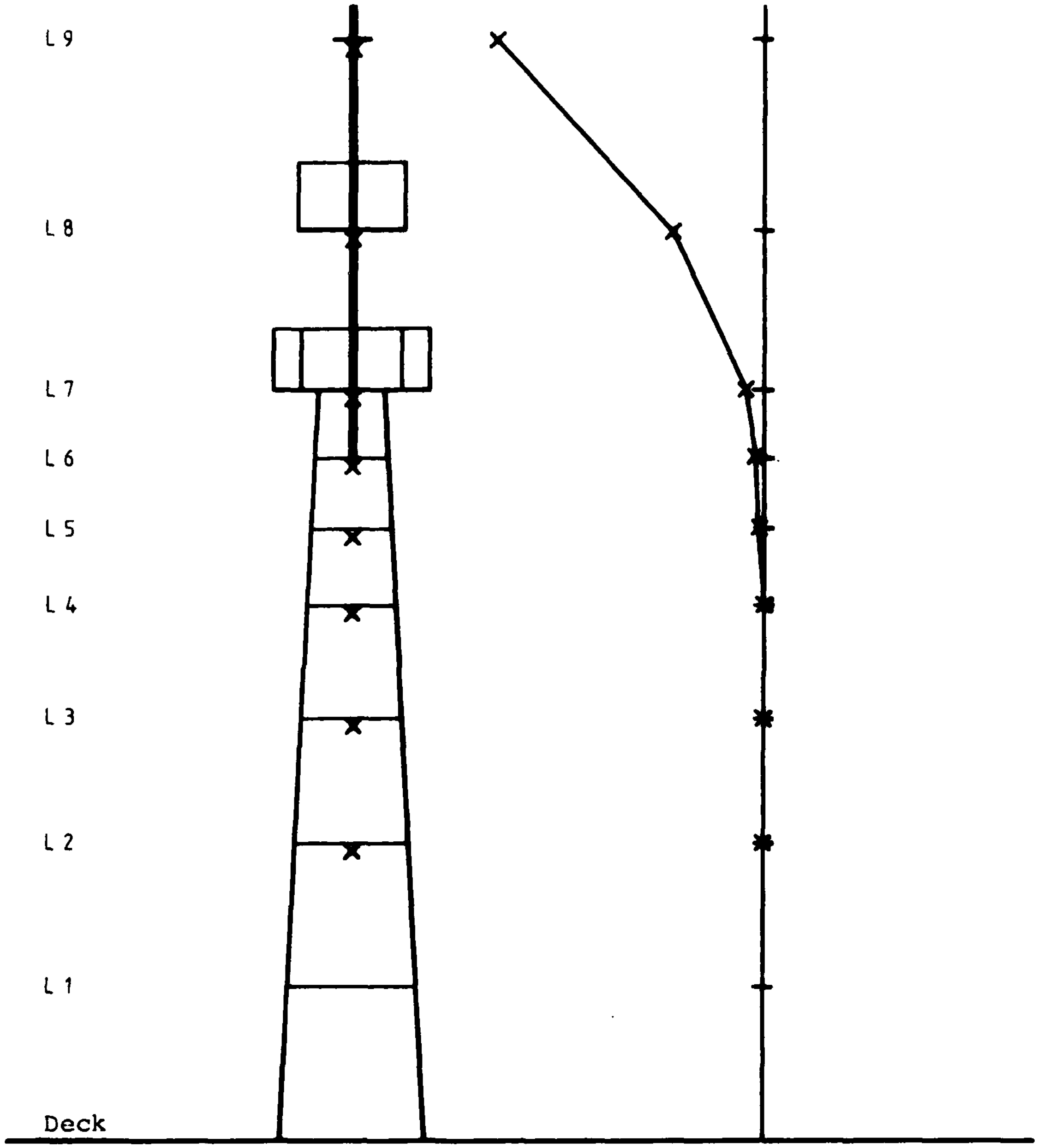


FIG. 4(b) LOCATION OF SHAKERS FOR TRANSVERSE VIBRATION EXCITATION



Direction - Transverse
Frequency - 3.08 Hz

× Accelerometer location

FIG. 5 MEASURED TRANSVERSE MODE AT 3.08 Hz

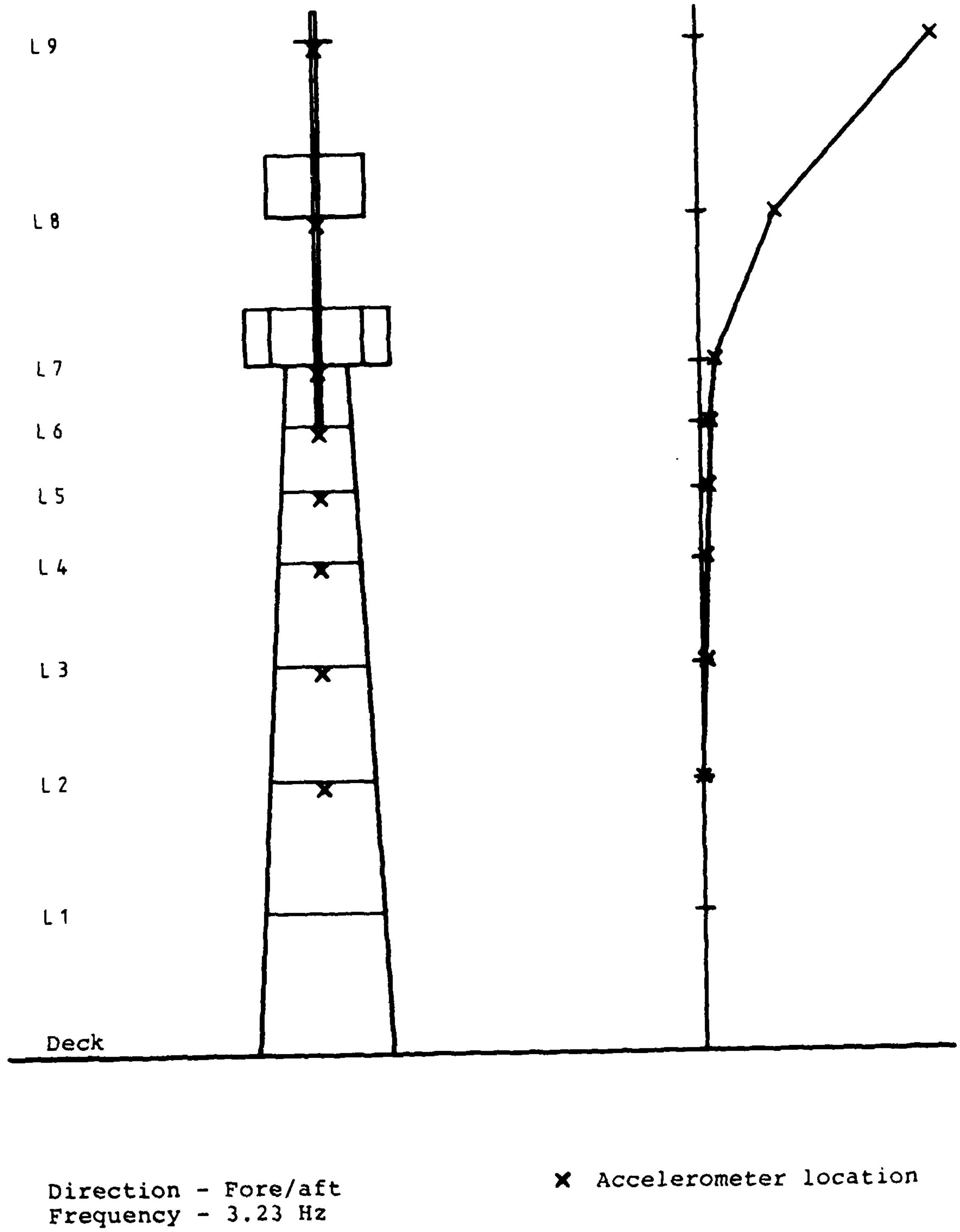


FIG. 6 MEASURED FORE/AFT MODE AT 3.23 Hz

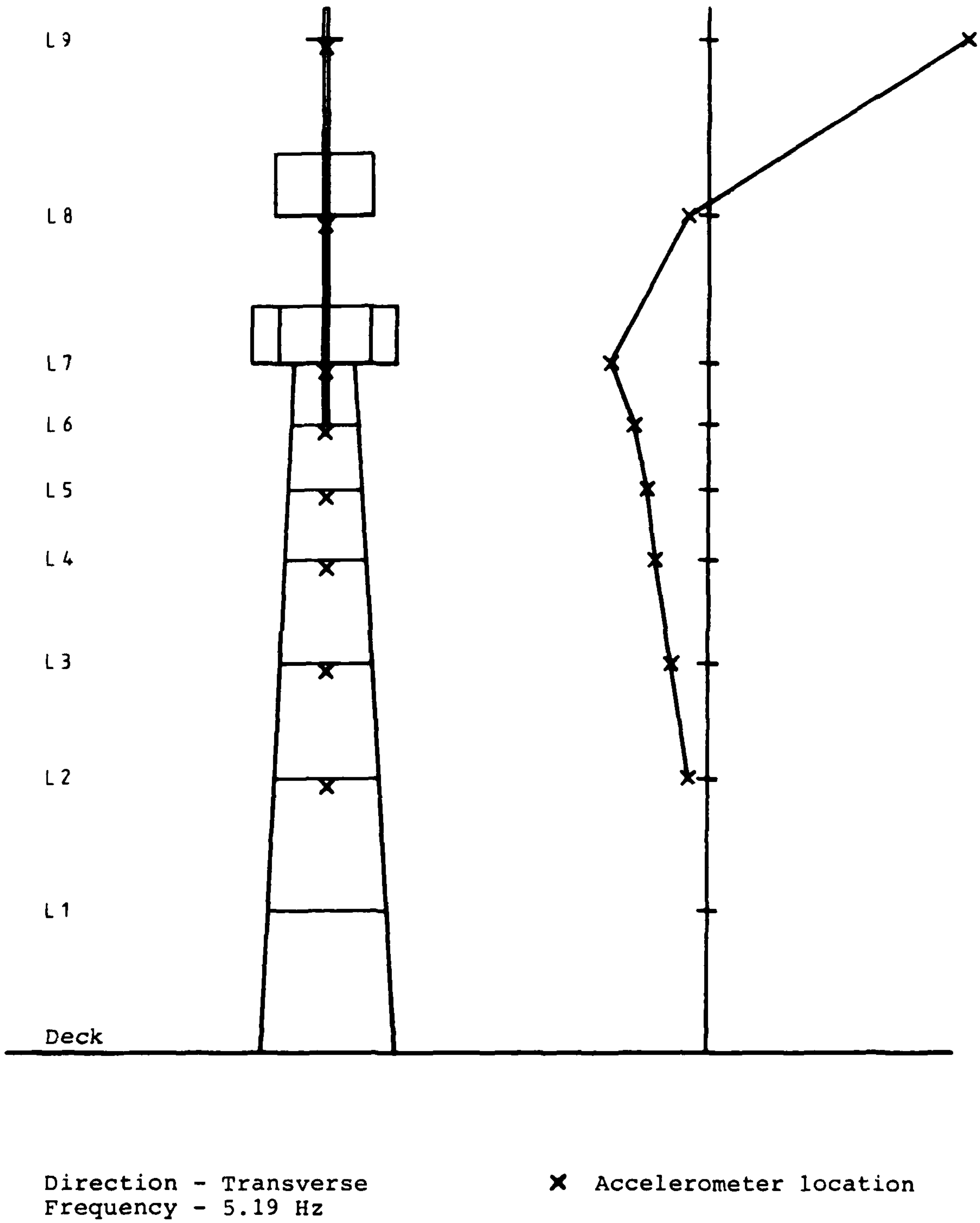
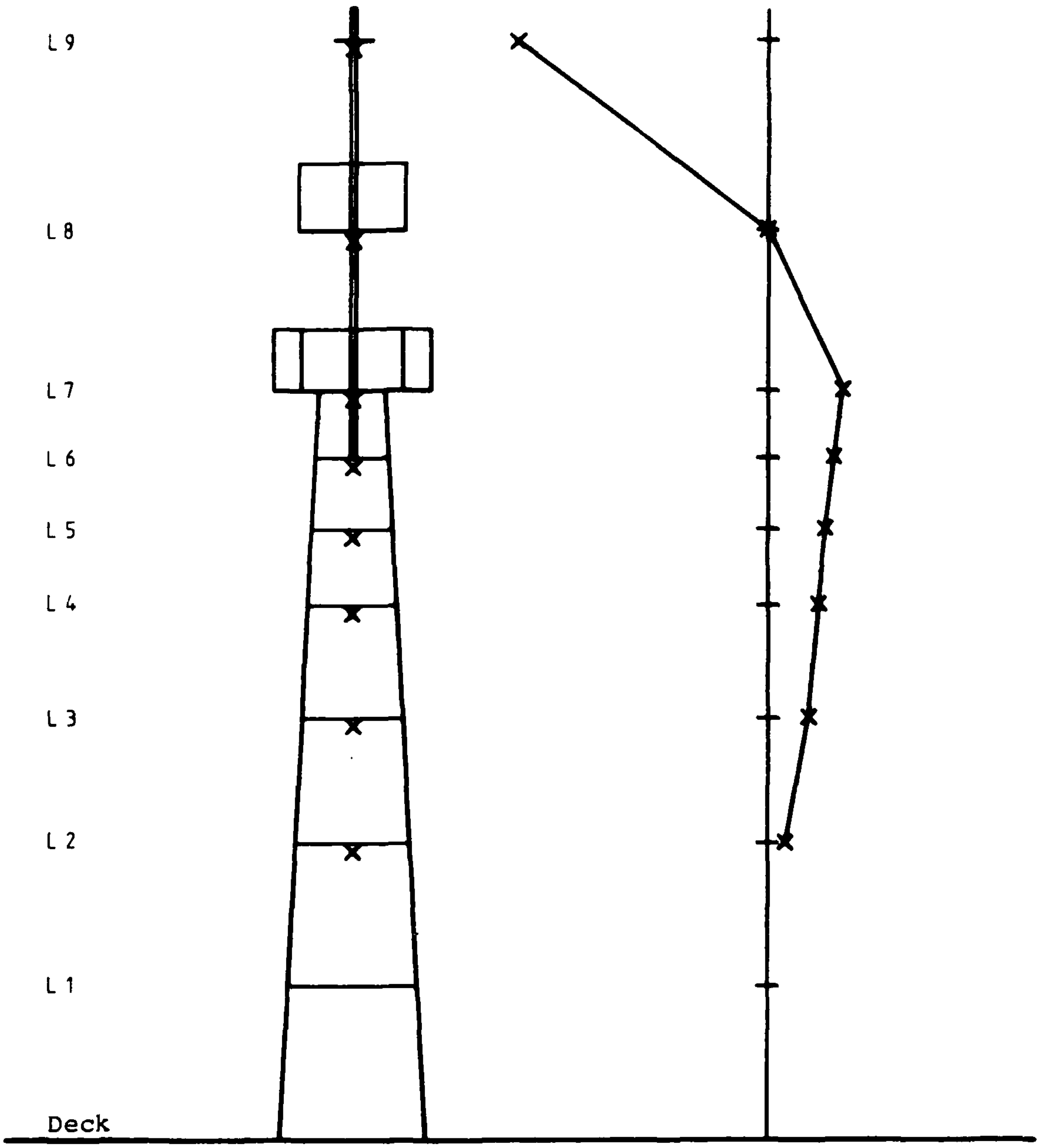


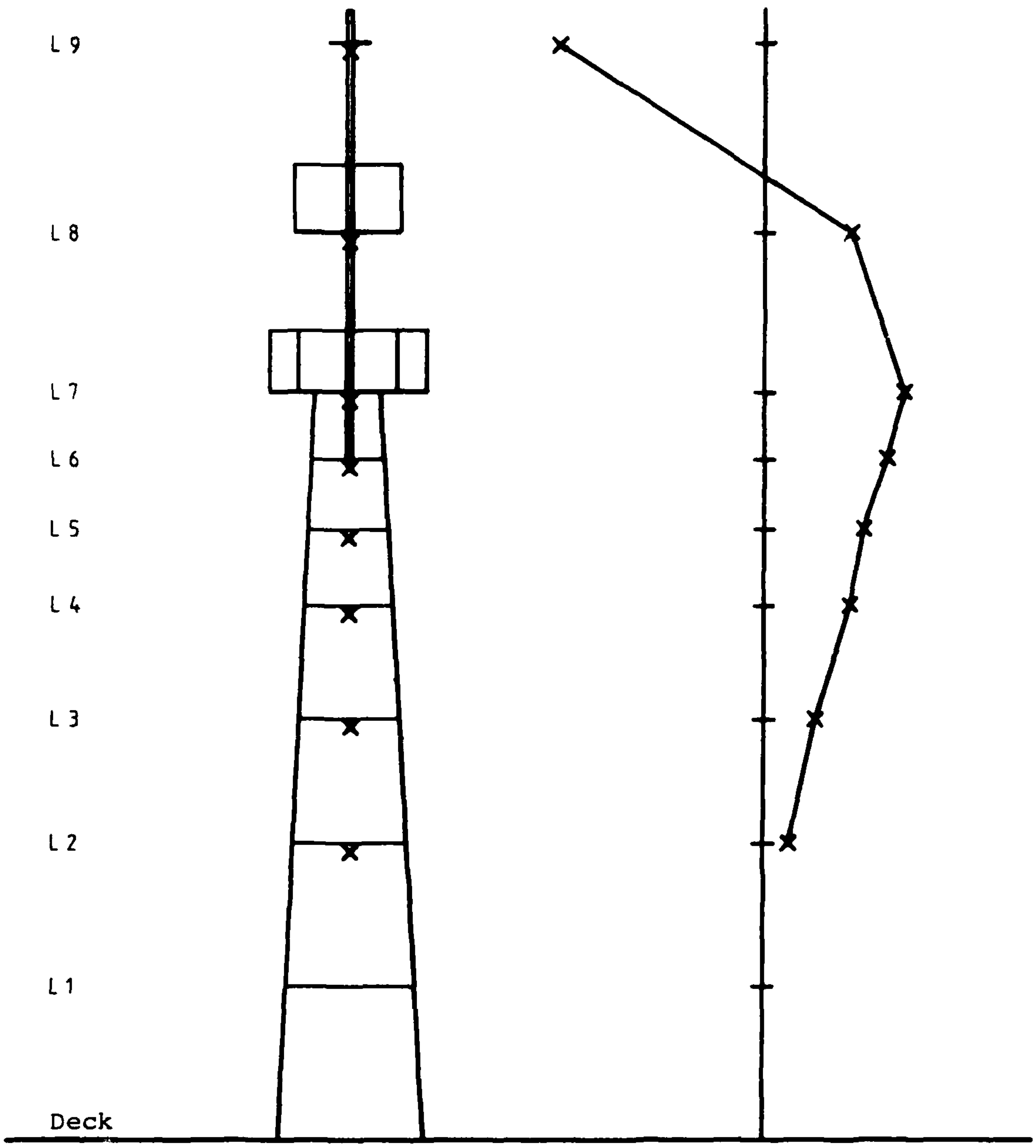
FIG. 7 MEASURED TRANSVERSE MODE AT 5.19 Hz



Direction - Fore/aft
Frequency - 5.43 Hz

× Accelerometer location

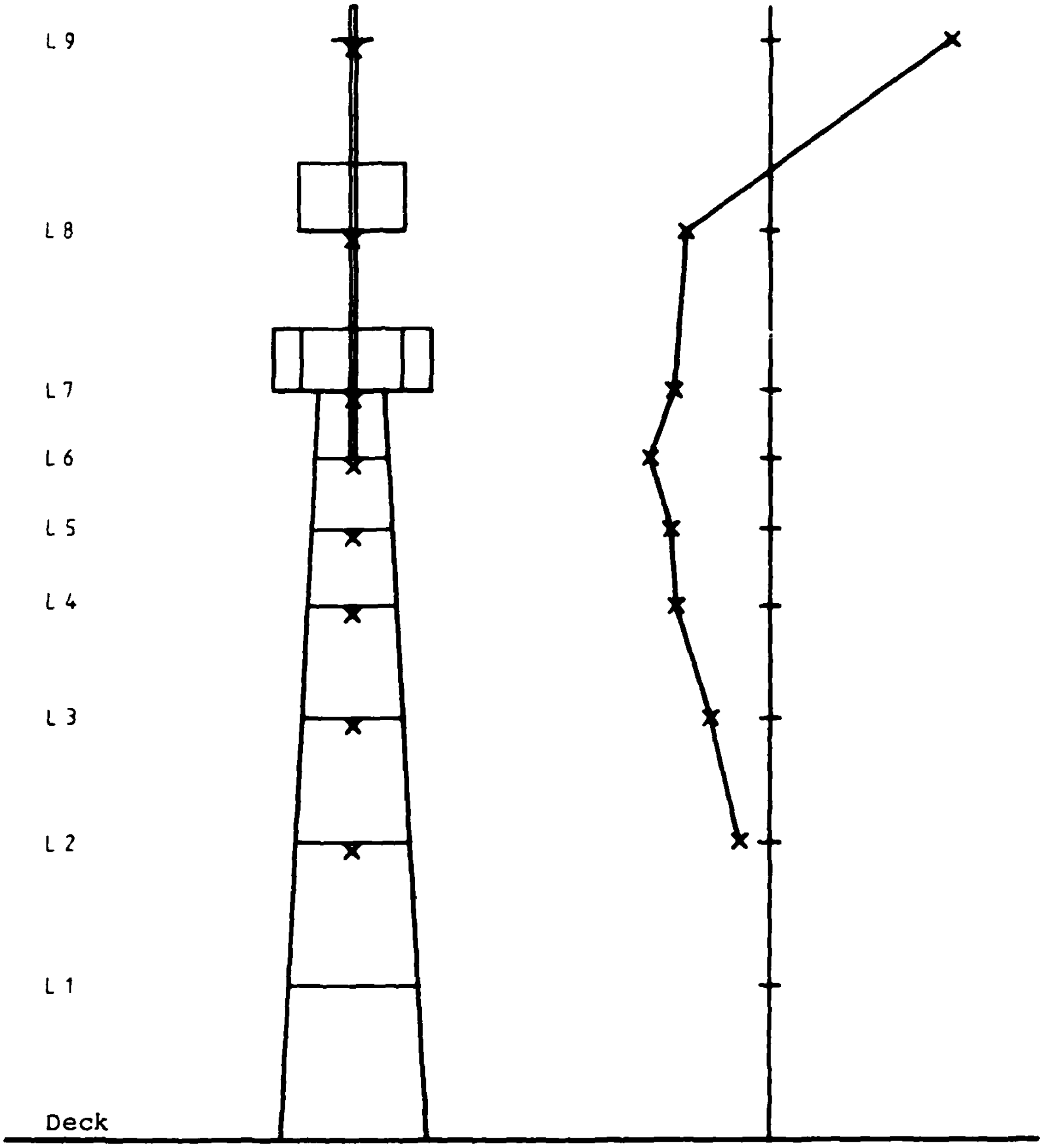
FIG. 8 MEASURED FORE/AFT MODE AT 5.43 Hz



Direction - Fore/aft
Frequency - 7.68 Hz

✕ Accelerometer location

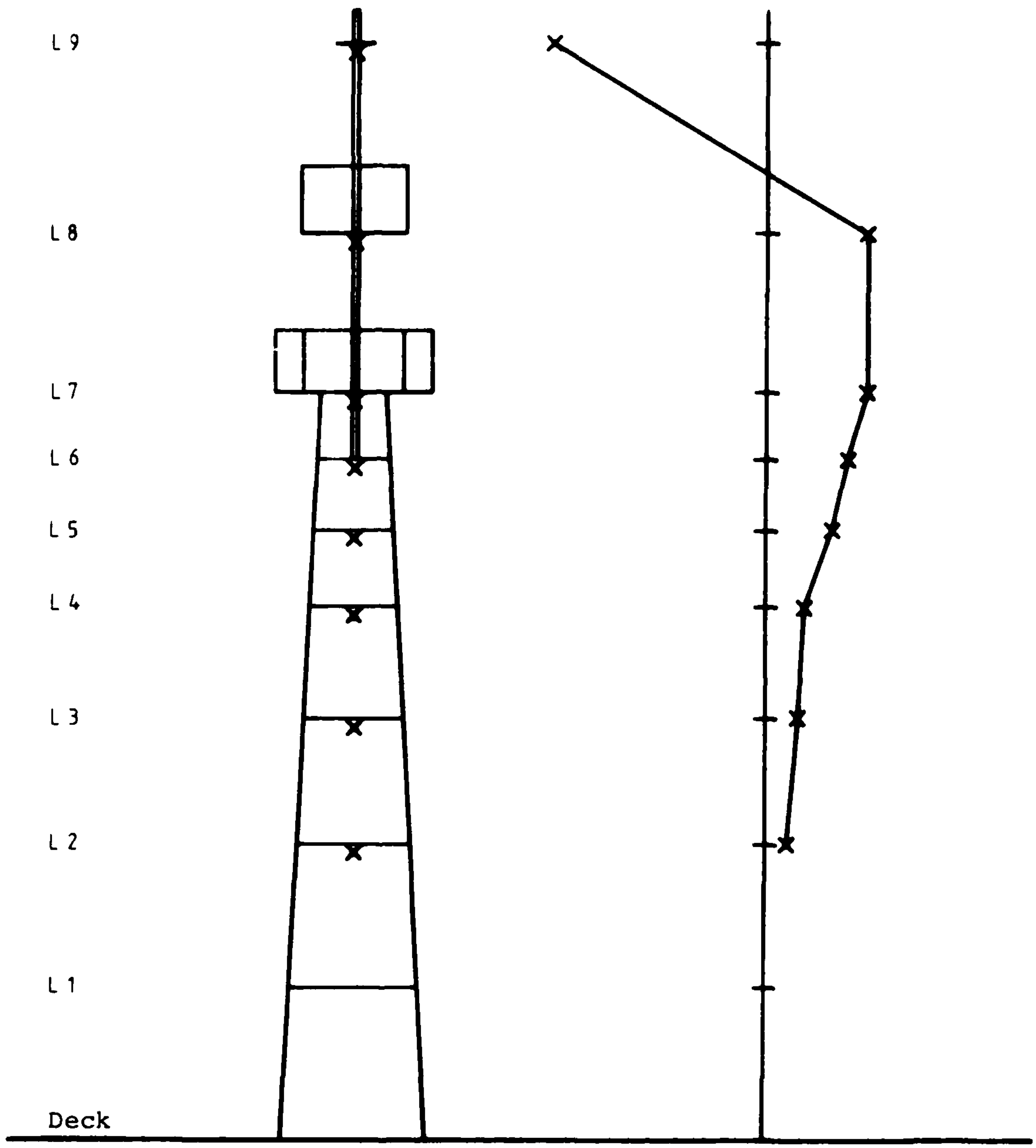
FIG. 9 MEASURED FORE/AFT MODE AT 7.68 Hz



Direction - Transverse
Frequency - 9.25 Hz

× Accelerometer location

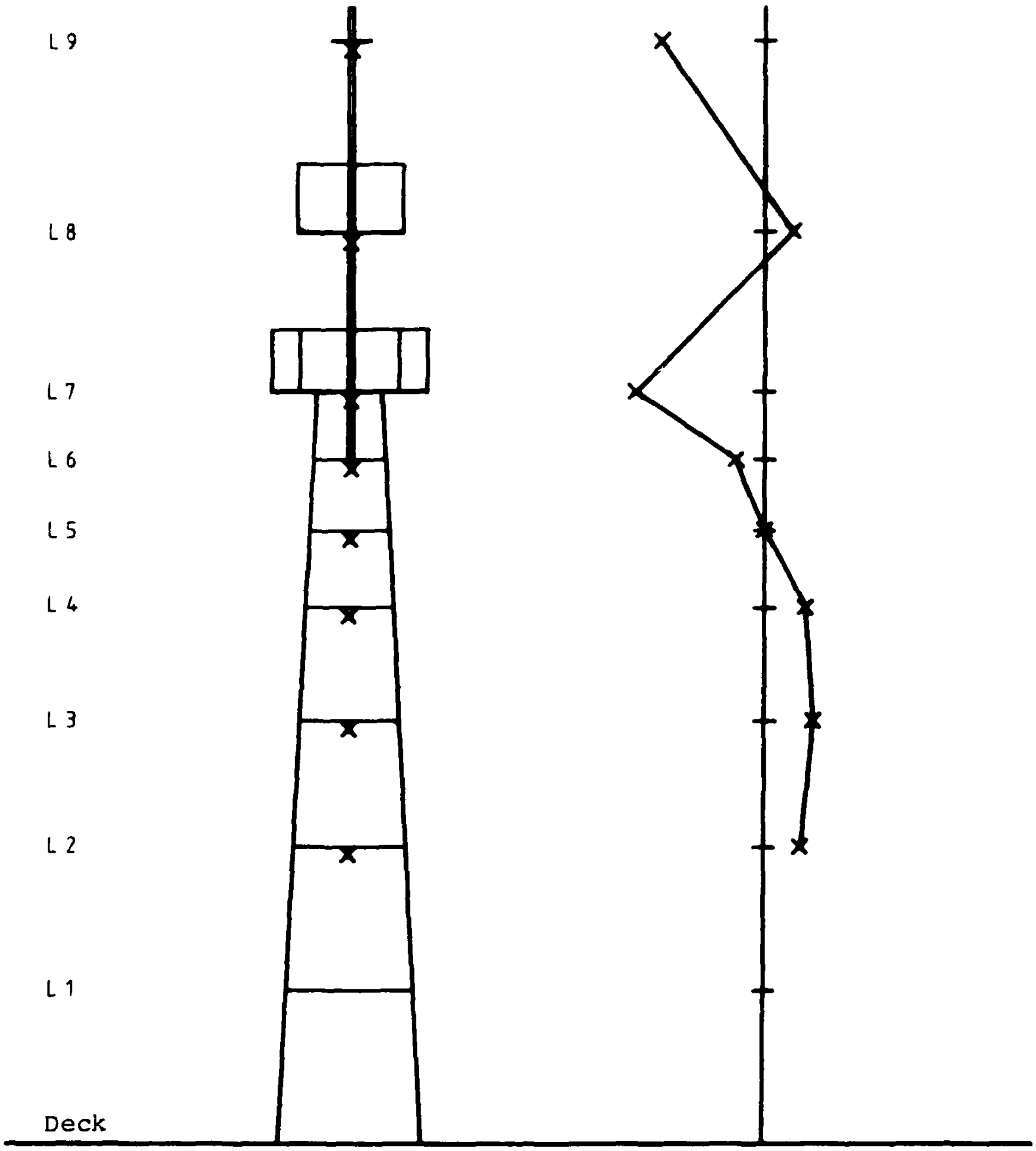
FIG. 10 MEASURED TRANSVERSE MODE AT 9.25 Hz



Direction - Fore/aft
Frequency - 10.29 Hz

× Accelerometer location

FIG. 11 MEASURED FORE/AFT MODE AT 10.29 Hz



Direction - Transverse
Frequency - 17.76 Hz

× Accelerometer location

FIG. 12 MEASURED TRANSVERSE MODE AT 17.76 Hz

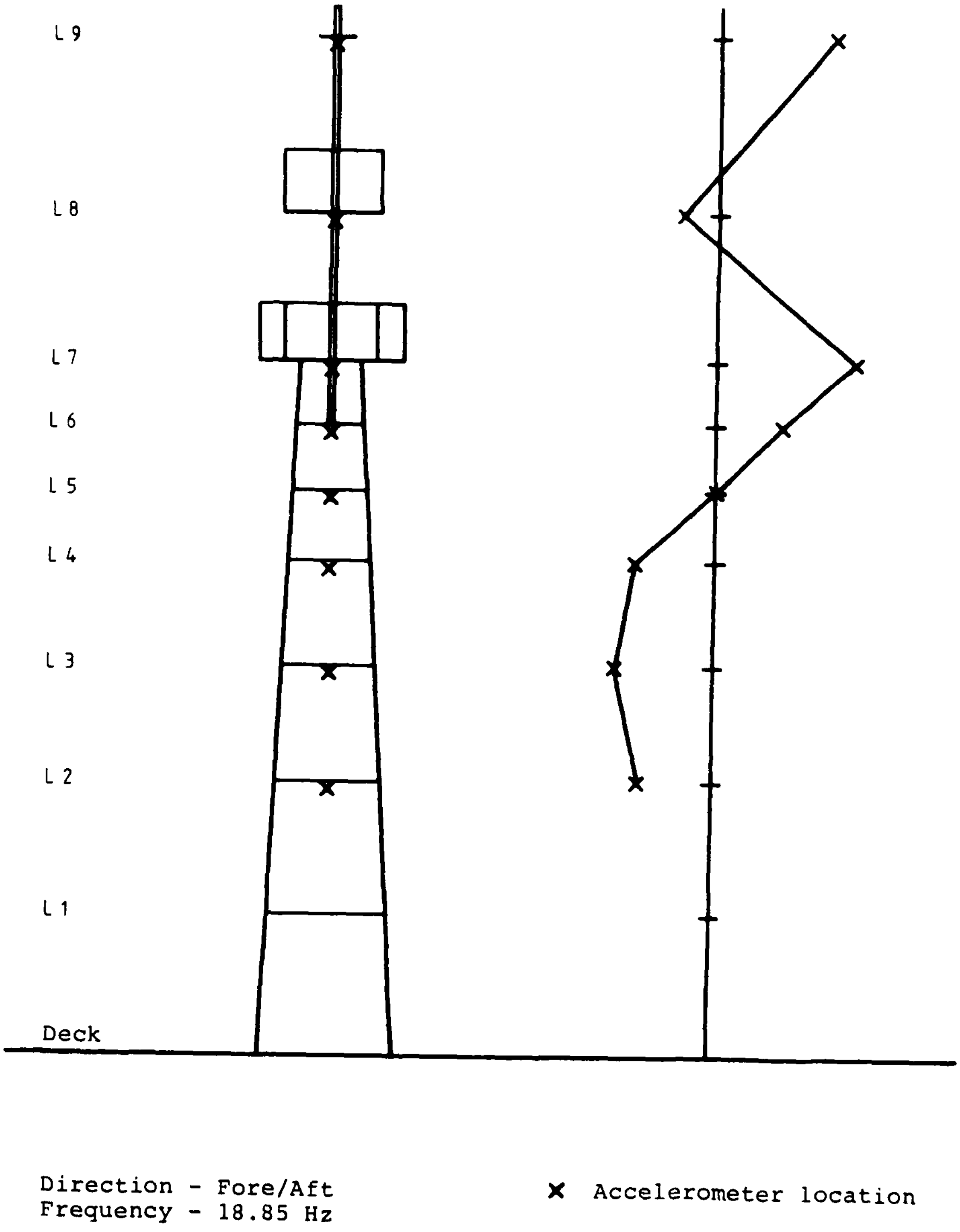


FIG. 13 MEASURED FORE/AFT MODE AT 18.85 Hz

LATTICE TRANSVERSE AT 160 RPM

0 Hz TO 25 Hz

0.16 G RMS FULL SCALE

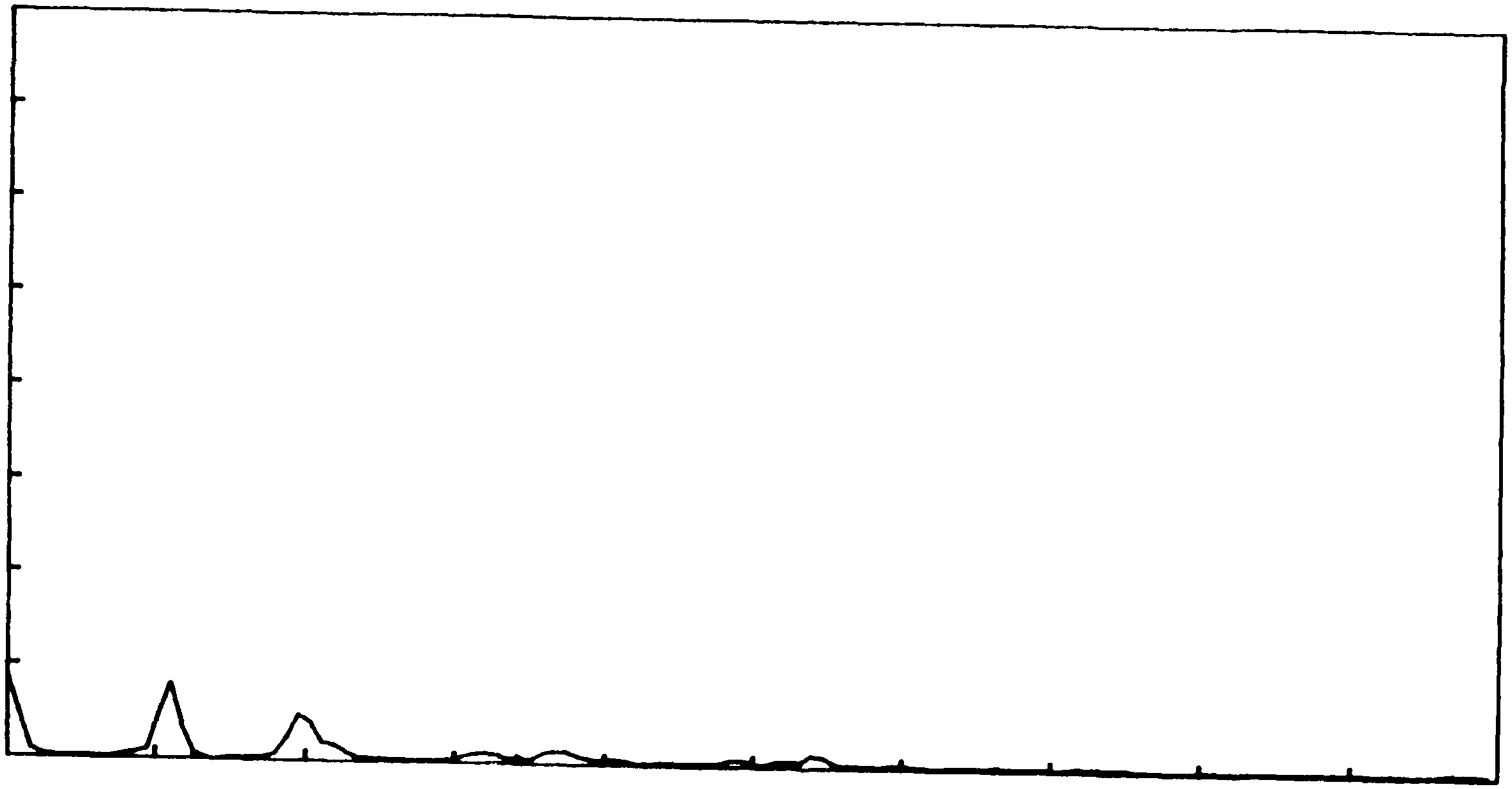


FIG. 14 ACCELERATION - FREQUENCY SPECTRUM

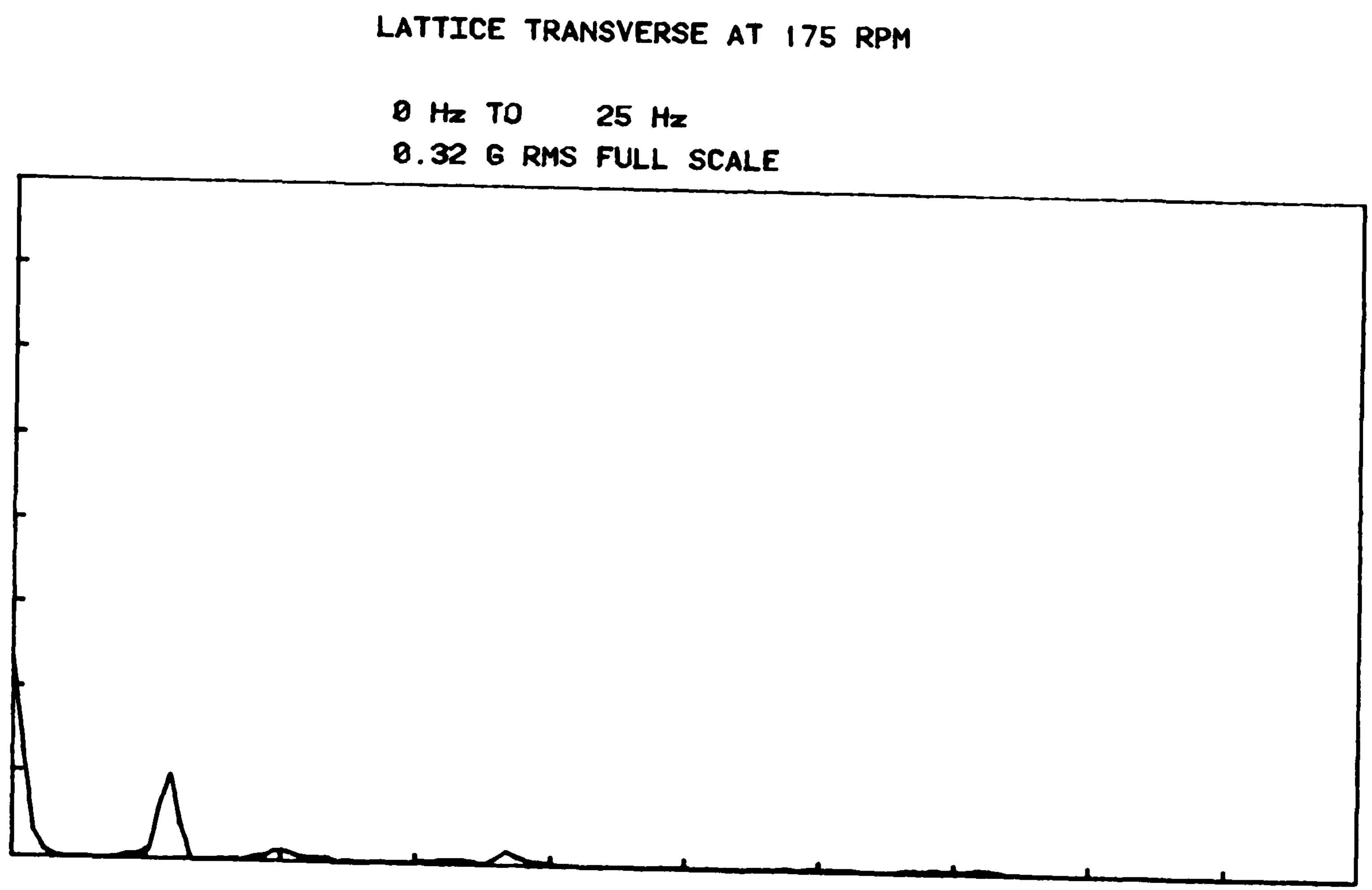


FIG. 15 ACCELERATION - FREQUENCY SPECTRUM

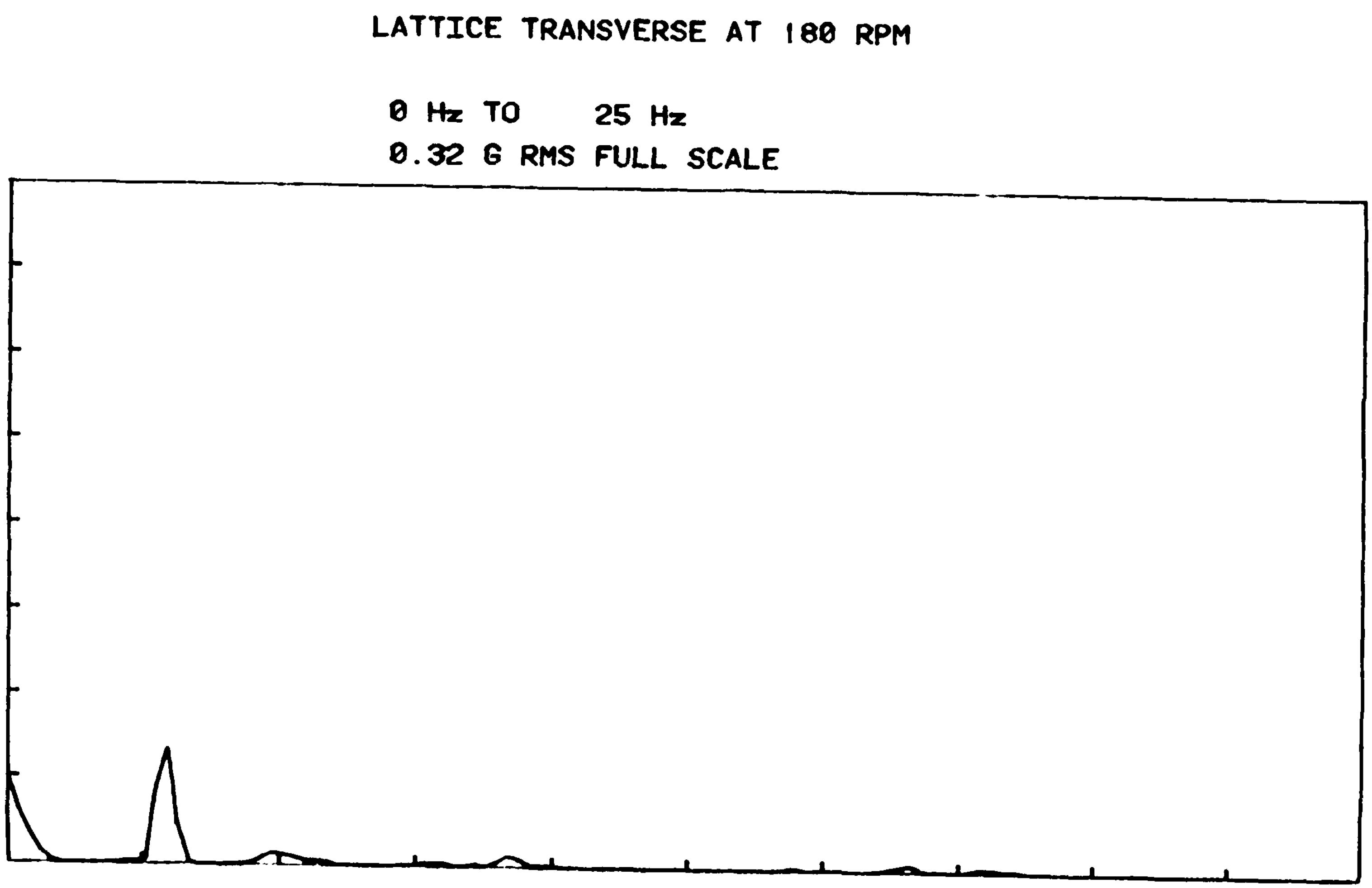


FIG. 16 ACCELERATION - FREQUENCY SPECTRUM

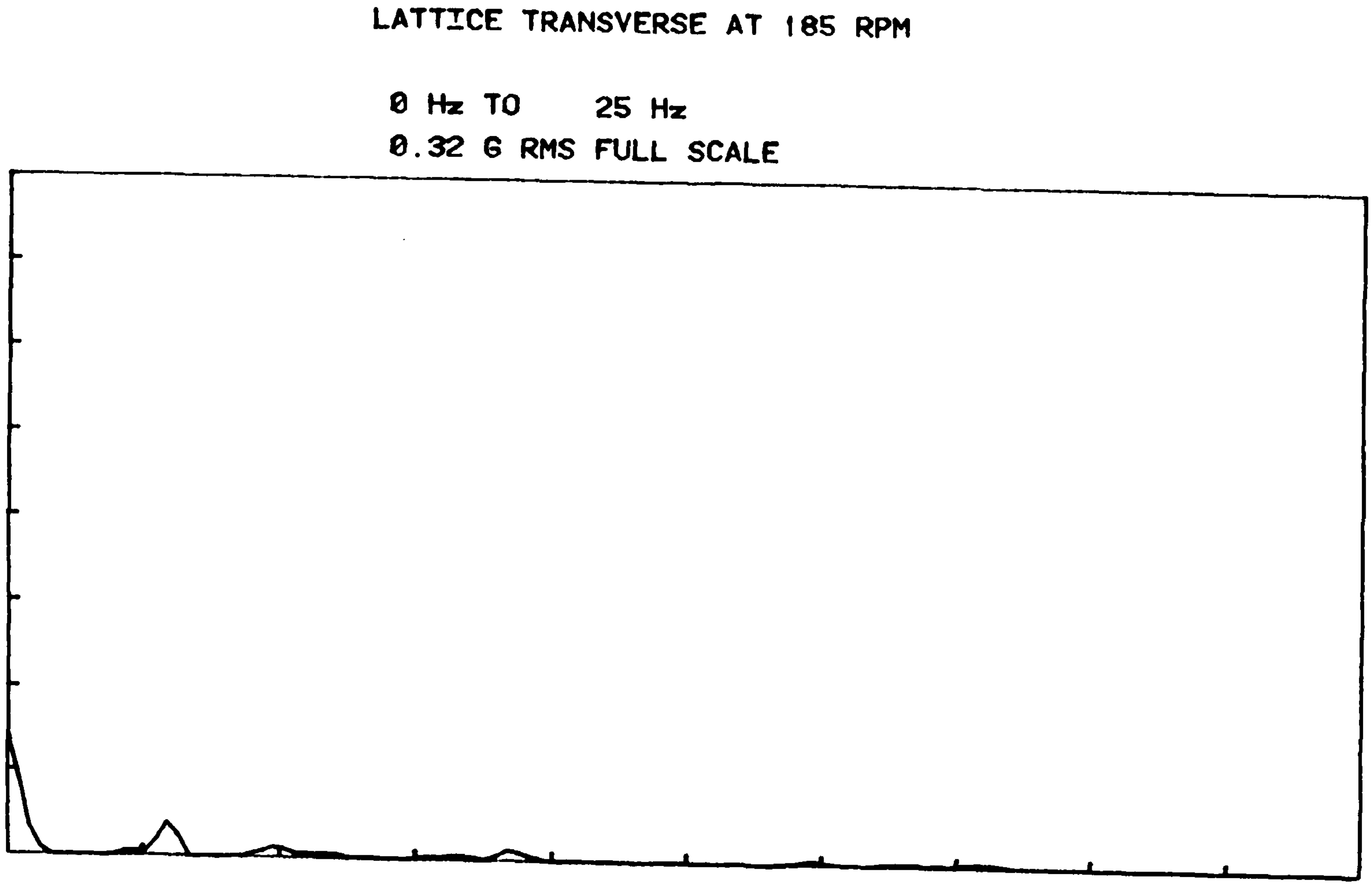


FIG. 17 ACCELERATION - FREQUENCY SPECTRUM

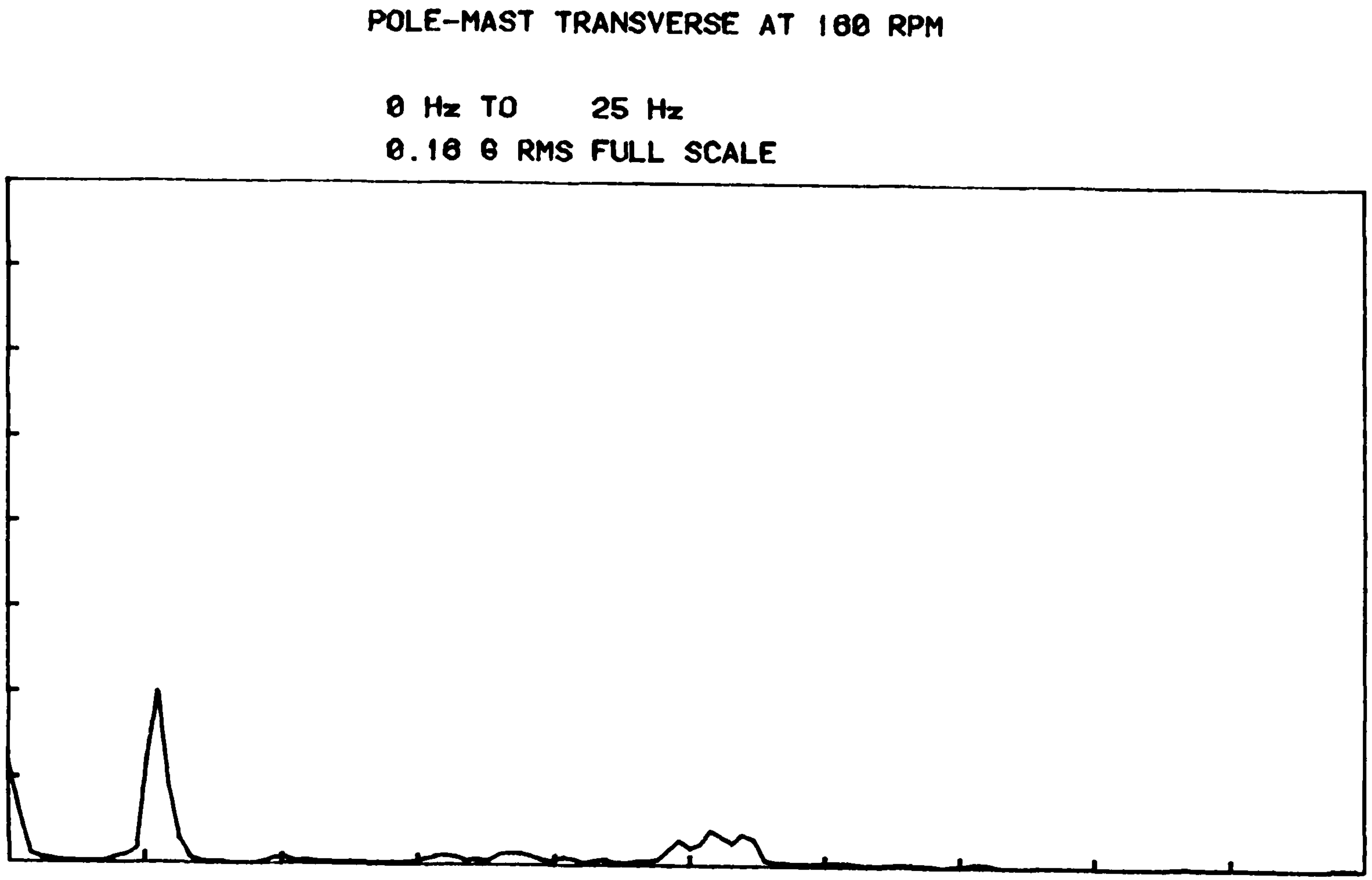


FIG. 18 ACCELERATION - FREQUENCY SPECTRUM

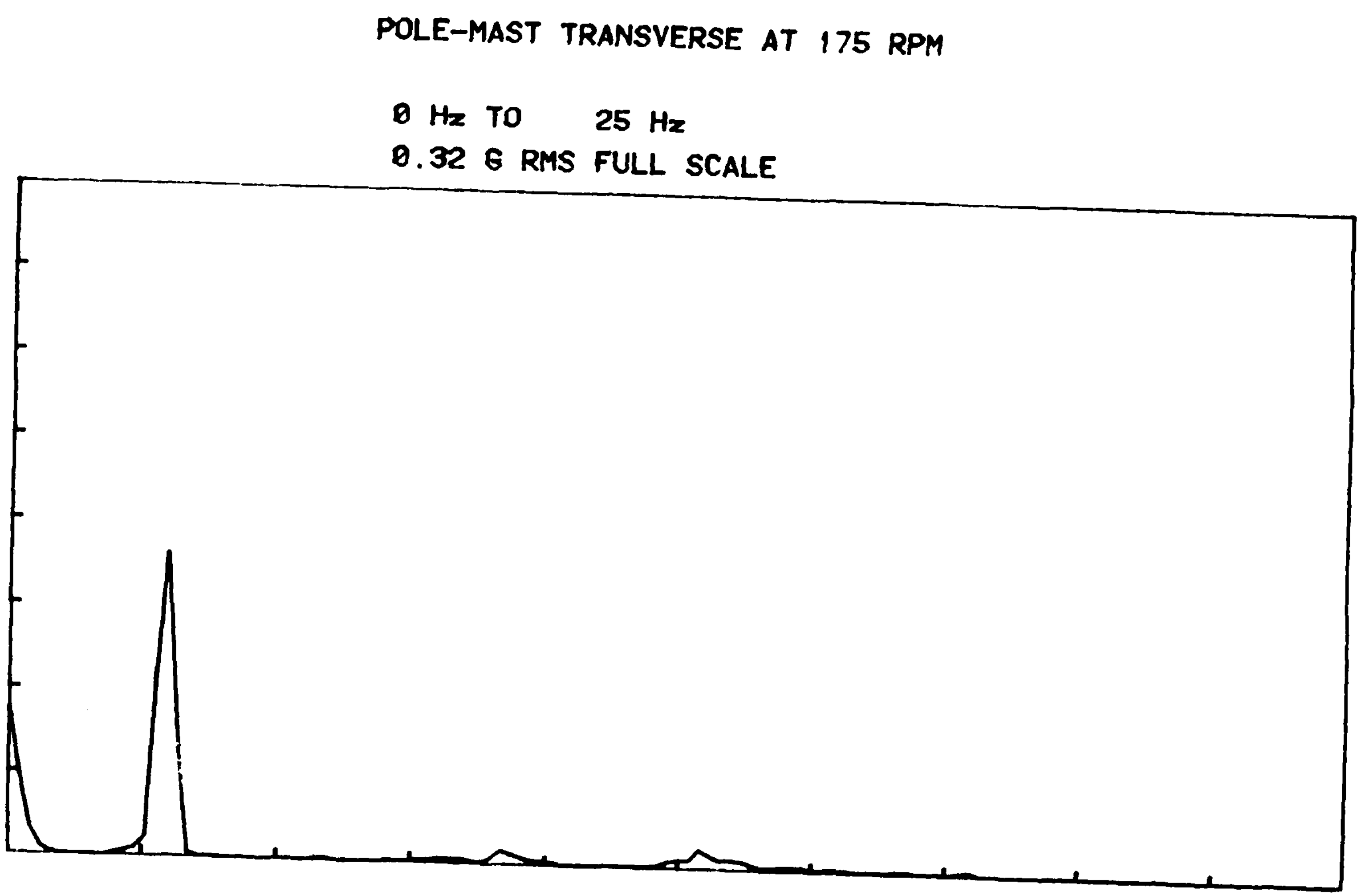


FIG. 19 ACCELERATION - FREQUENCY SPECTRUM

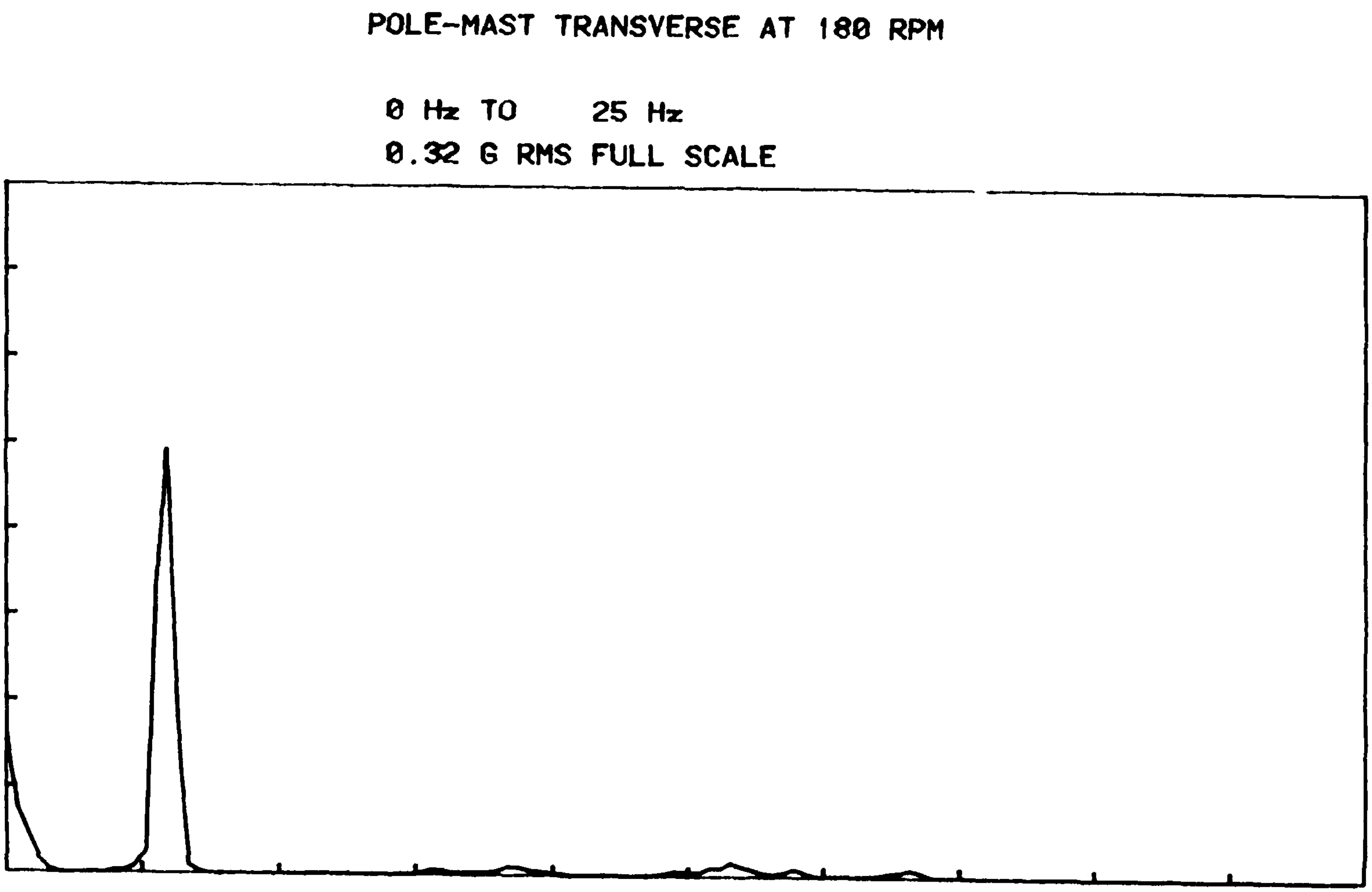


FIG. 20 ACCELERATION - FREQUENCY SPECTRUM

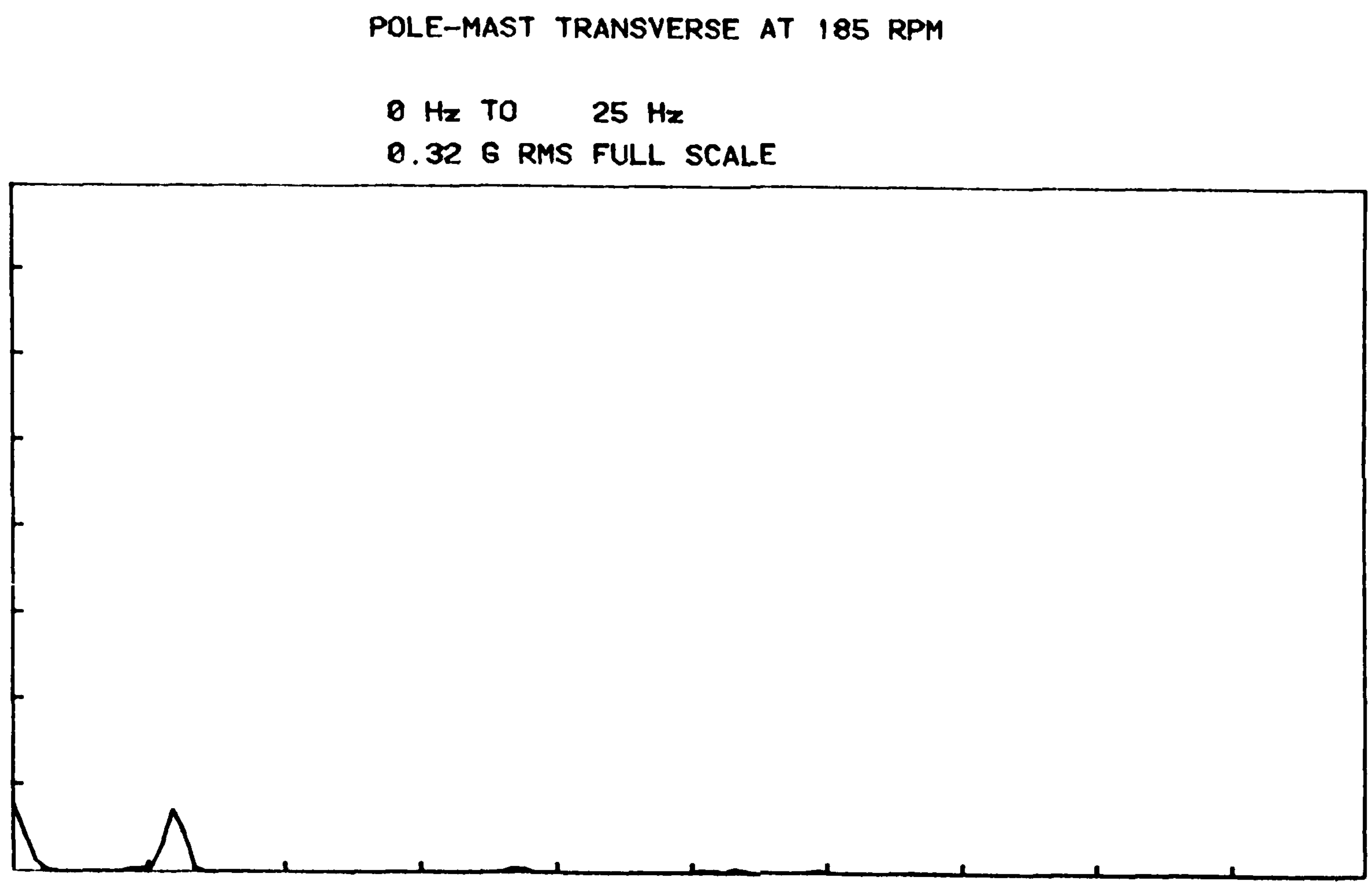


FIG. 21 ACCELERATION - FREQUENCY SPECTRUM

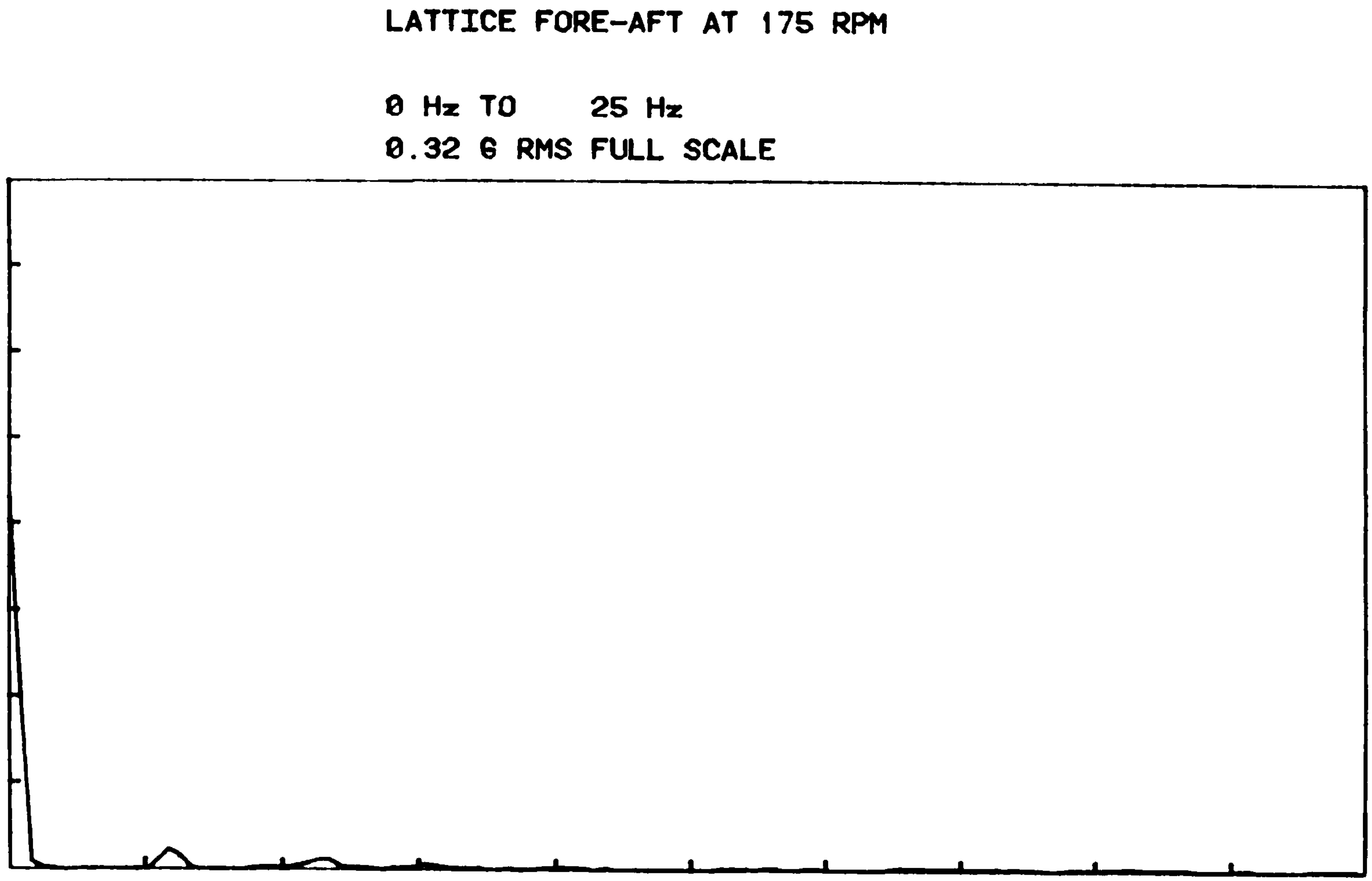


FIG. 22 ACCELERATION - FREQUENCY SPECTRUM

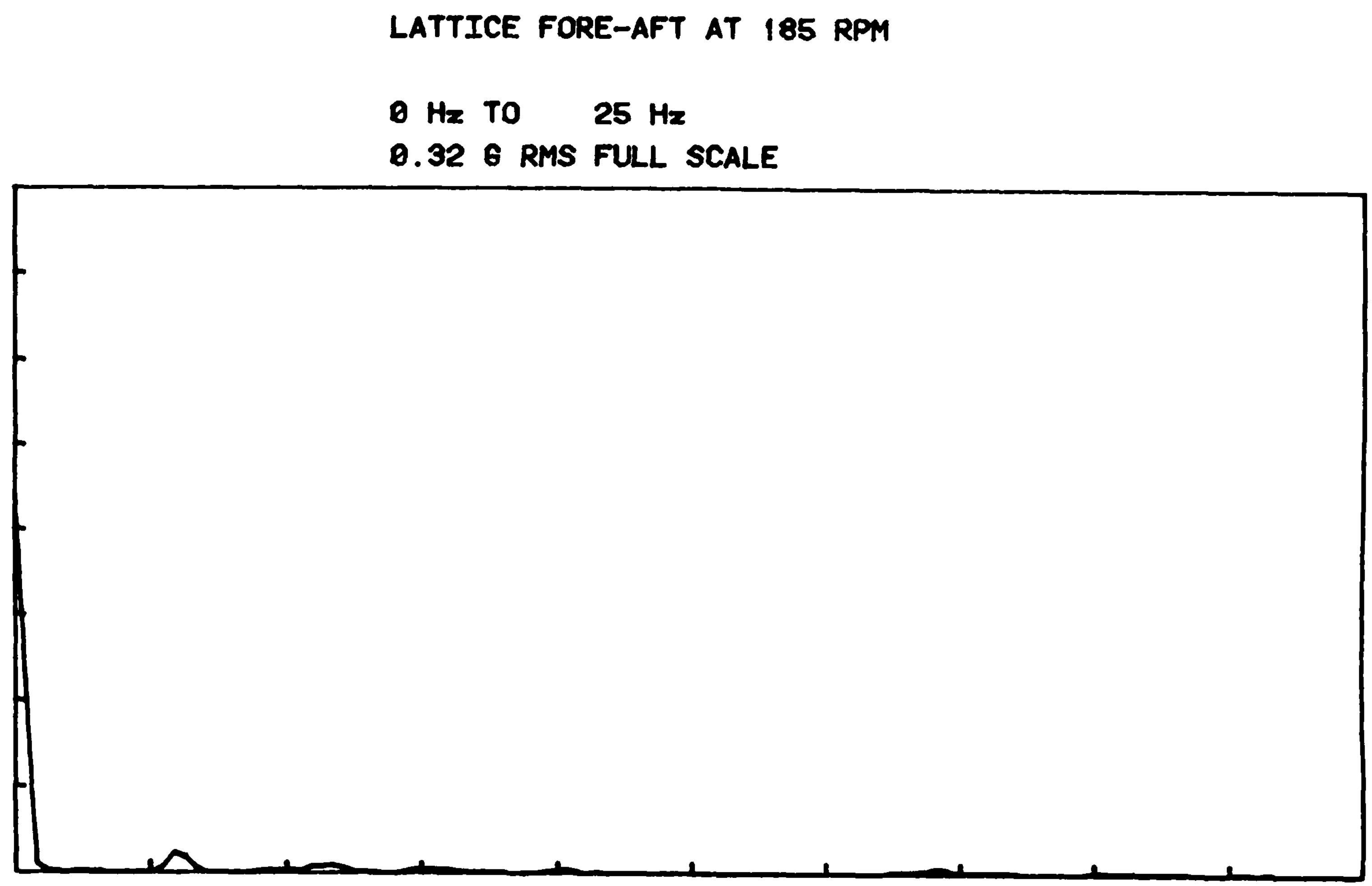


FIG. 23 ACCELERATION - FREQUENCY SPECTRUM

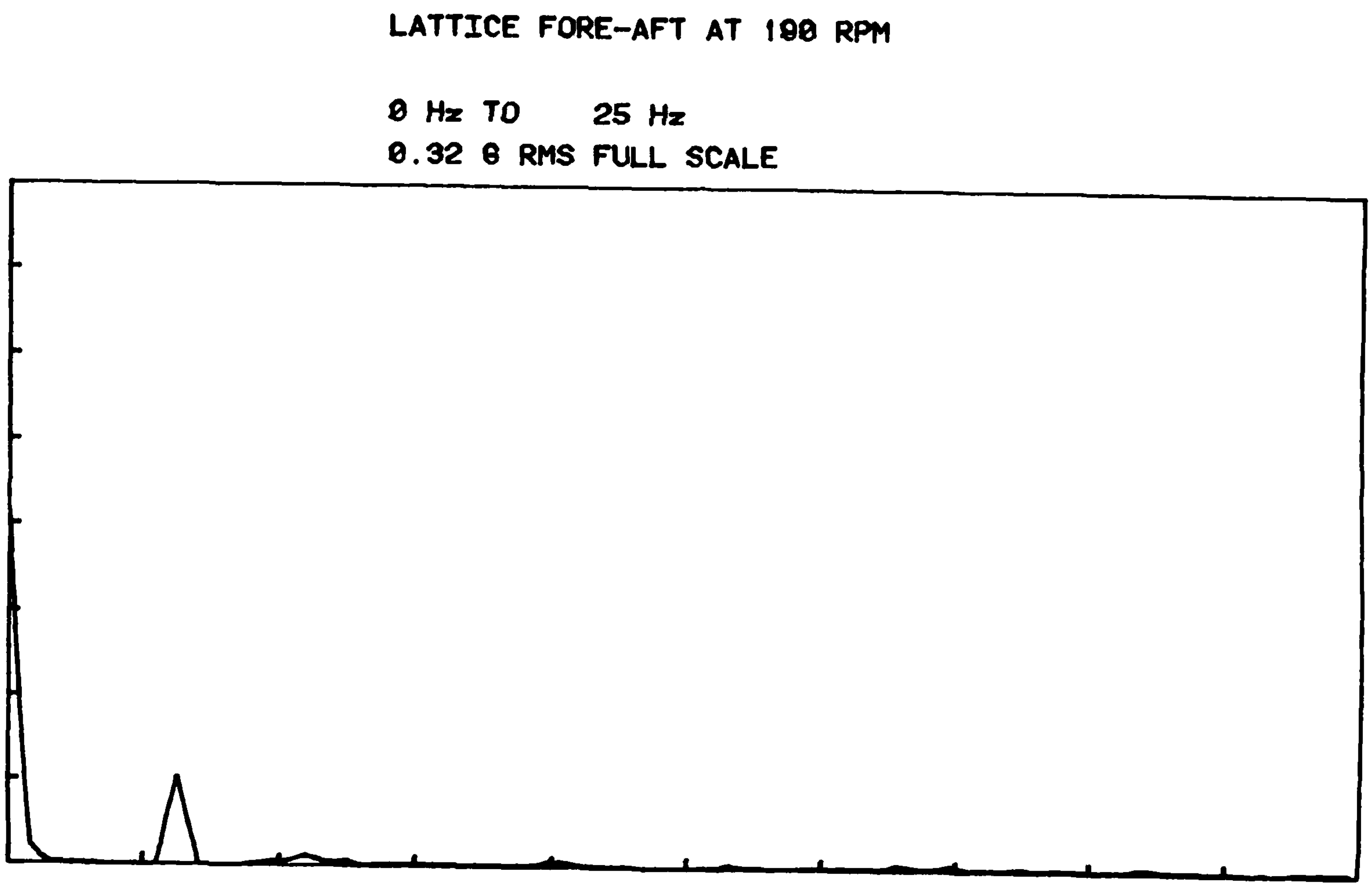


FIG. 24 ACCELERATION - FREQUENCY SPECTRUM

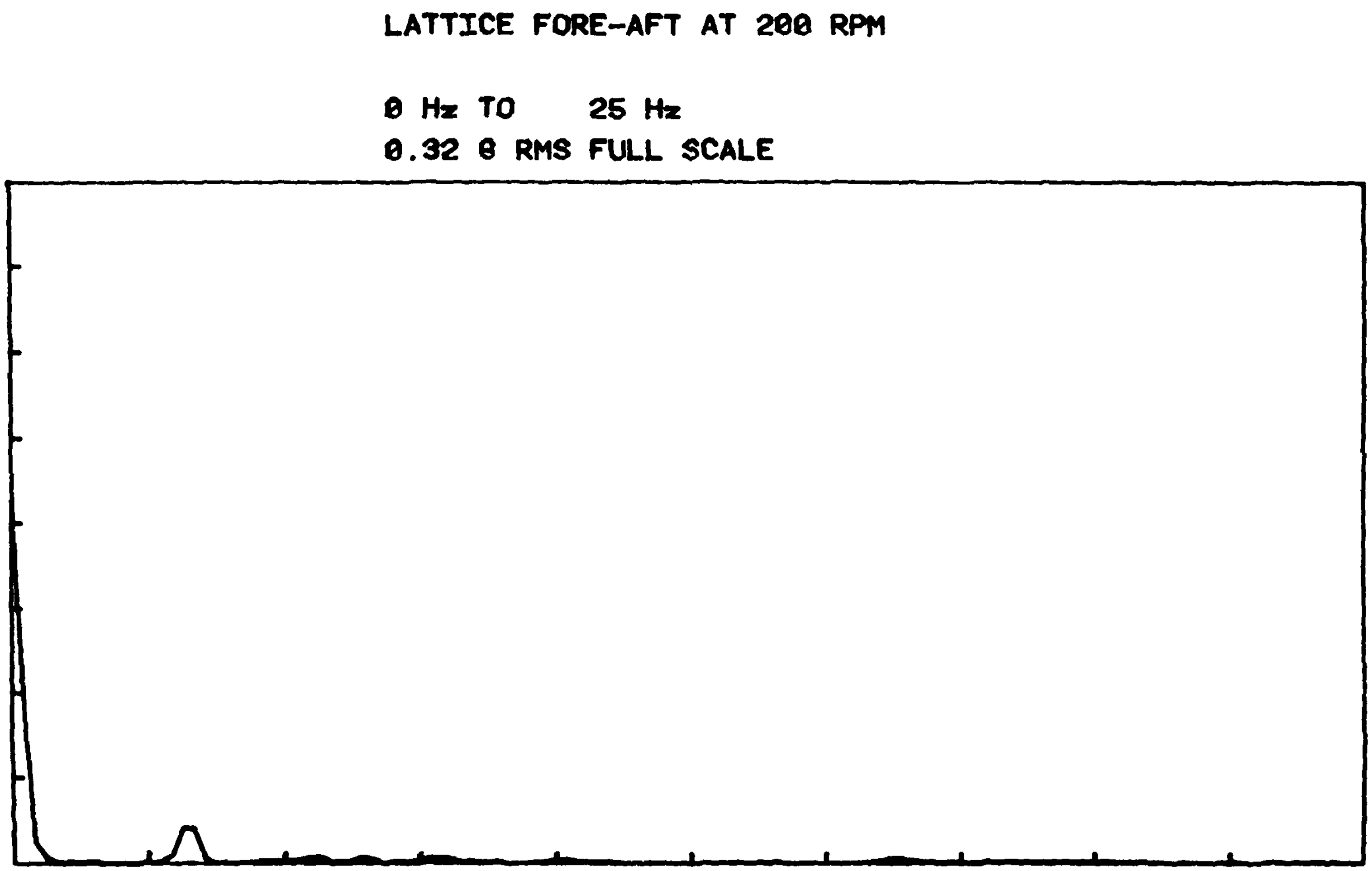


FIG. 25 ACCELERATION - FREQUENCY SPECTRUM

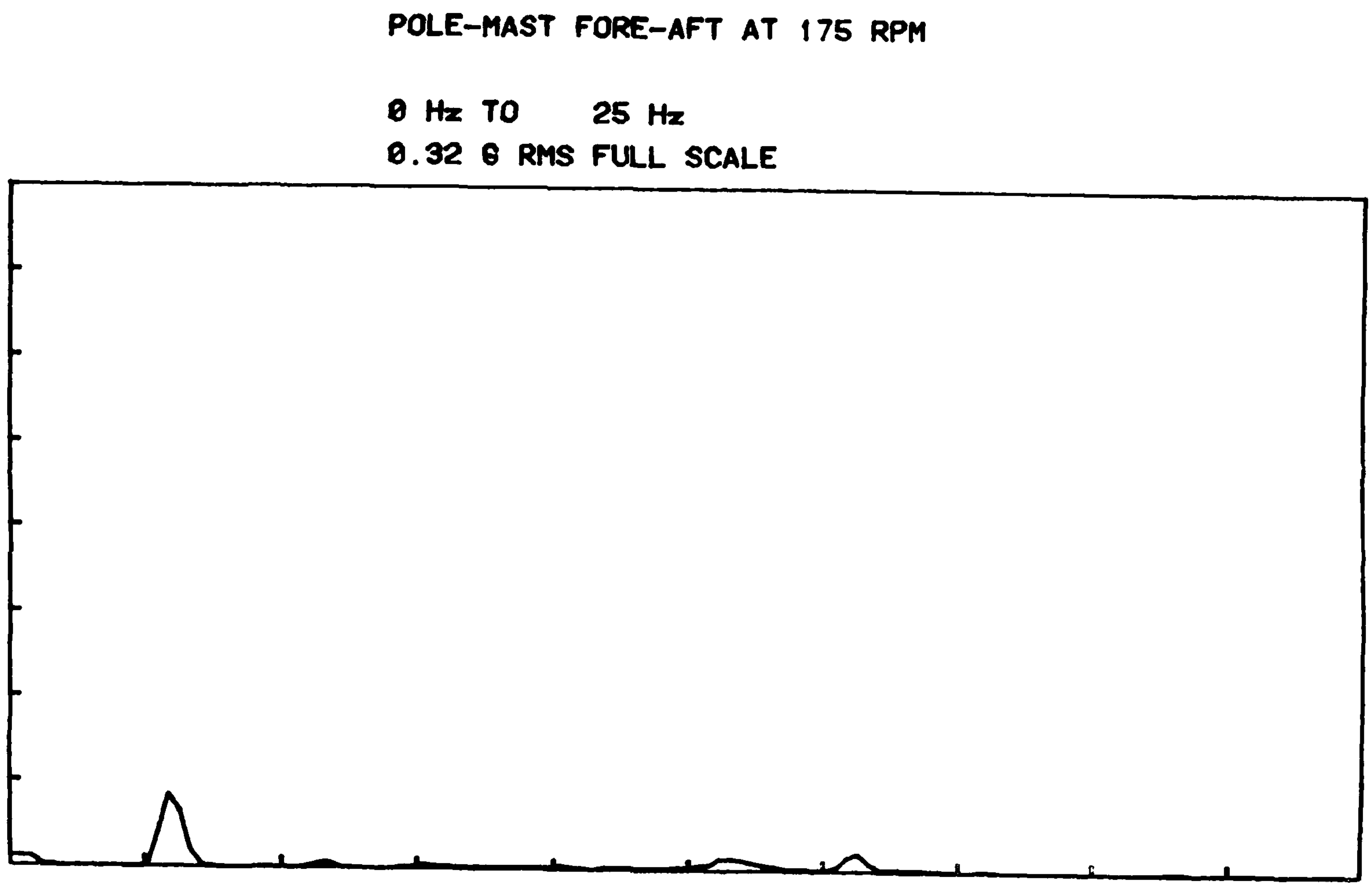


FIG. 26 ACCELERATION - FREQUENCY SPECTRUM

POLE-MAST FORE-AFT AT 185 RPM

0 Hz TO 25 Hz

0.32 G RMS FULL SCALE

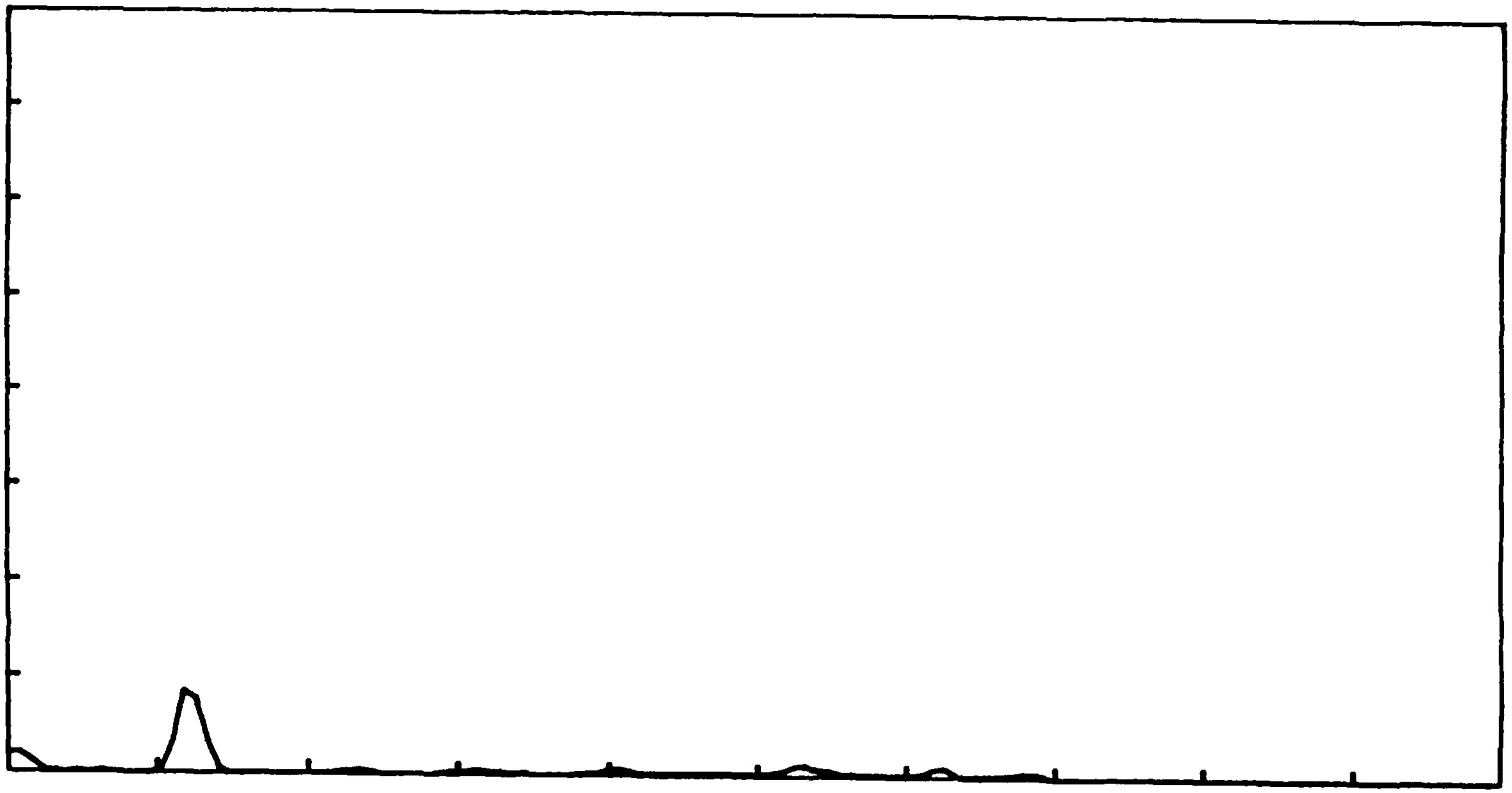


FIG. 27 ACCELERATION - FREQUENCY SPECTRUM

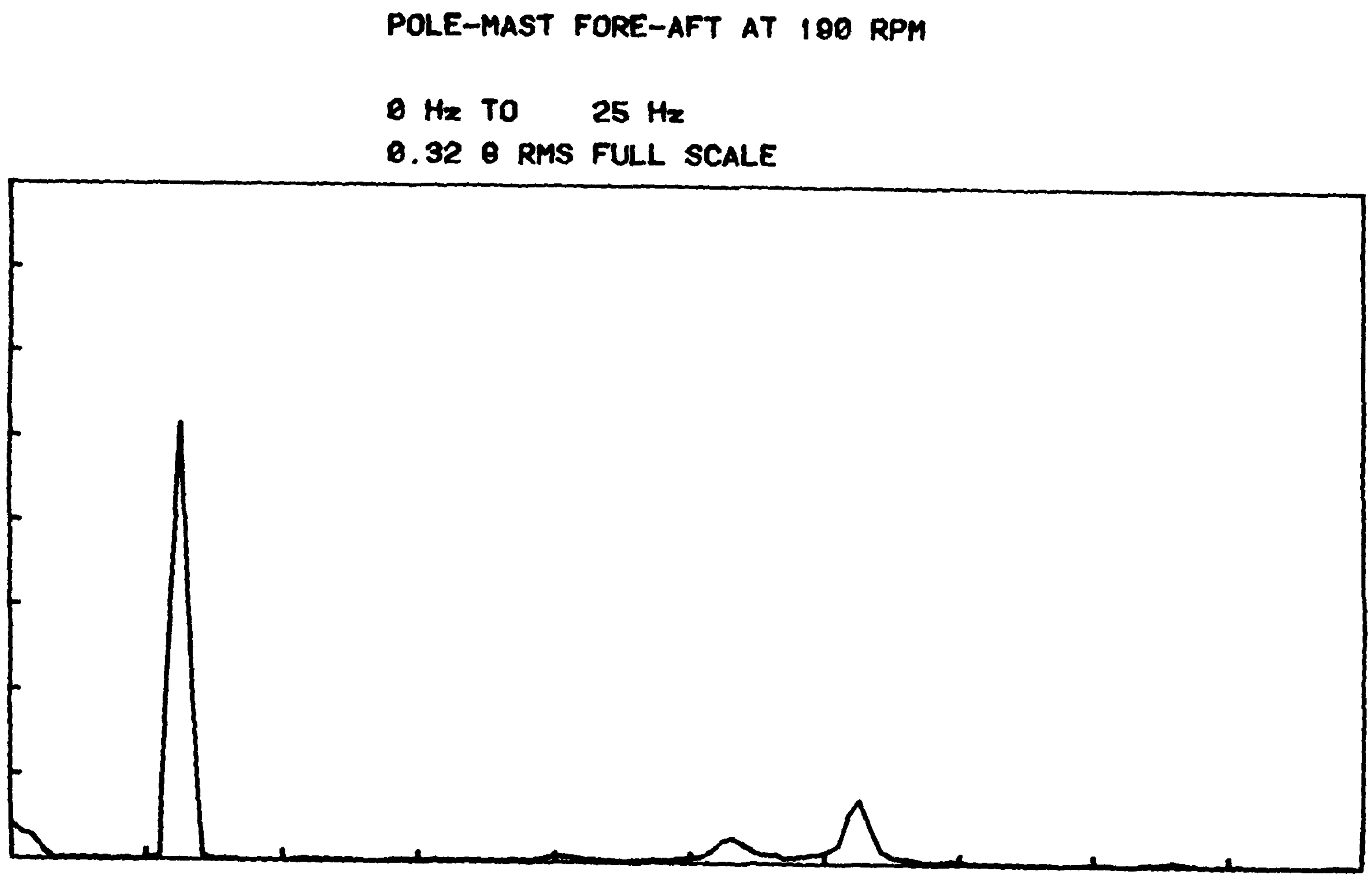


FIG. 28 ACCELERATION - FREQUENCY SPECTRUM

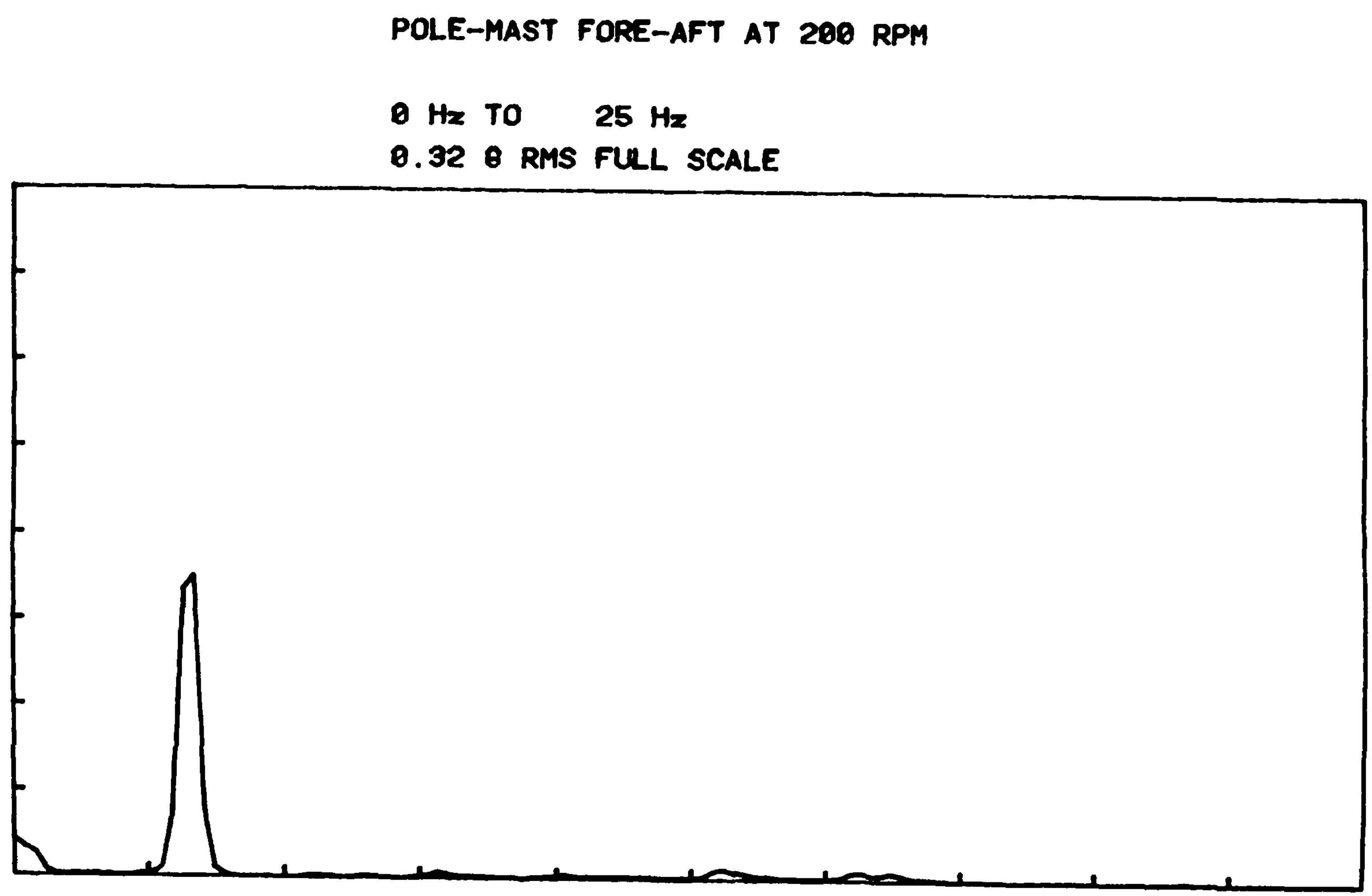


FIG. 29 ACCELERATION - FREQUENCY SPECTRUM

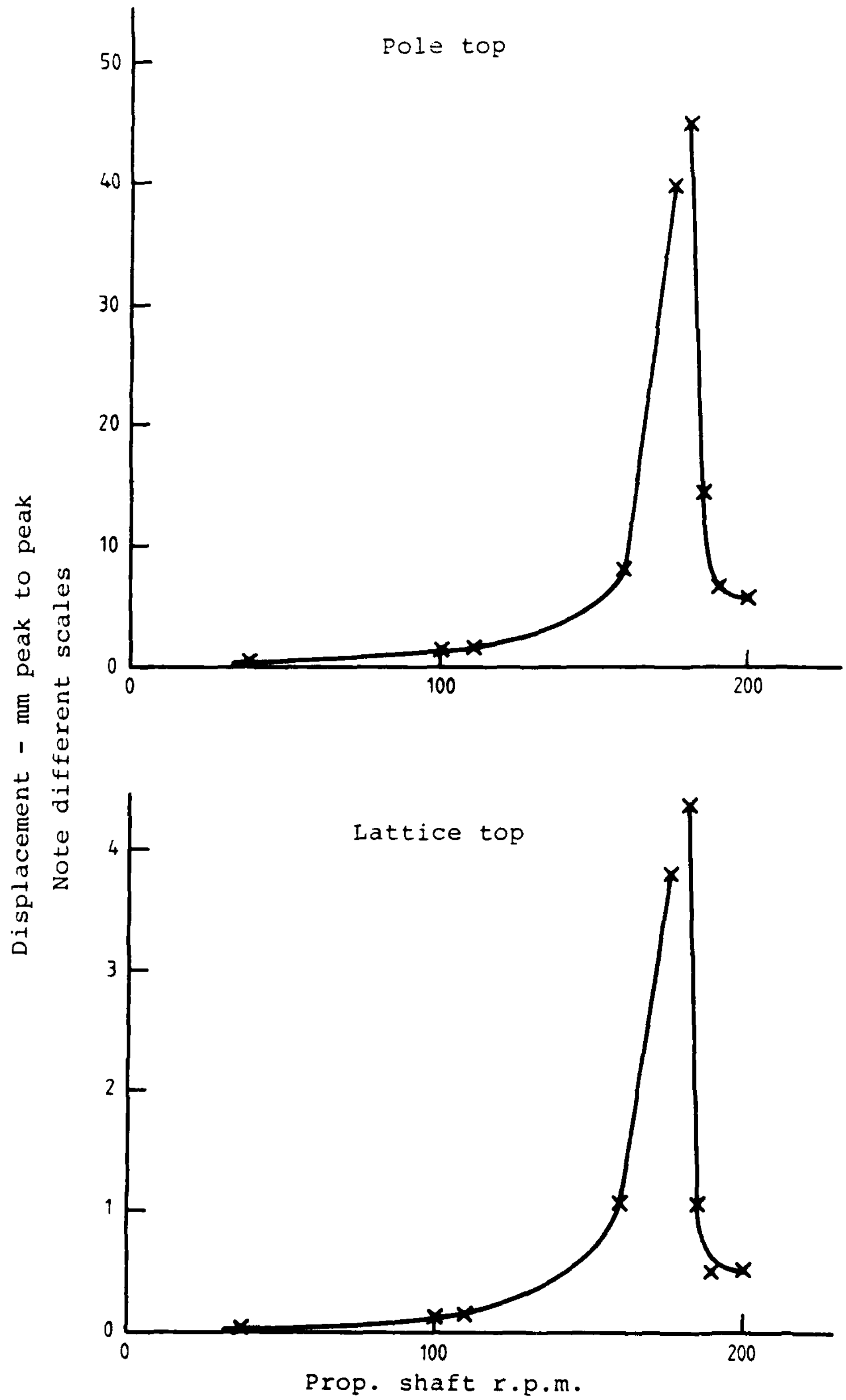


FIG. 30 AMPLITUDE OF MAST VIBRATION AT 3 Hz IN TRANSVERSE DIRECTION vs SHAFT SPEED

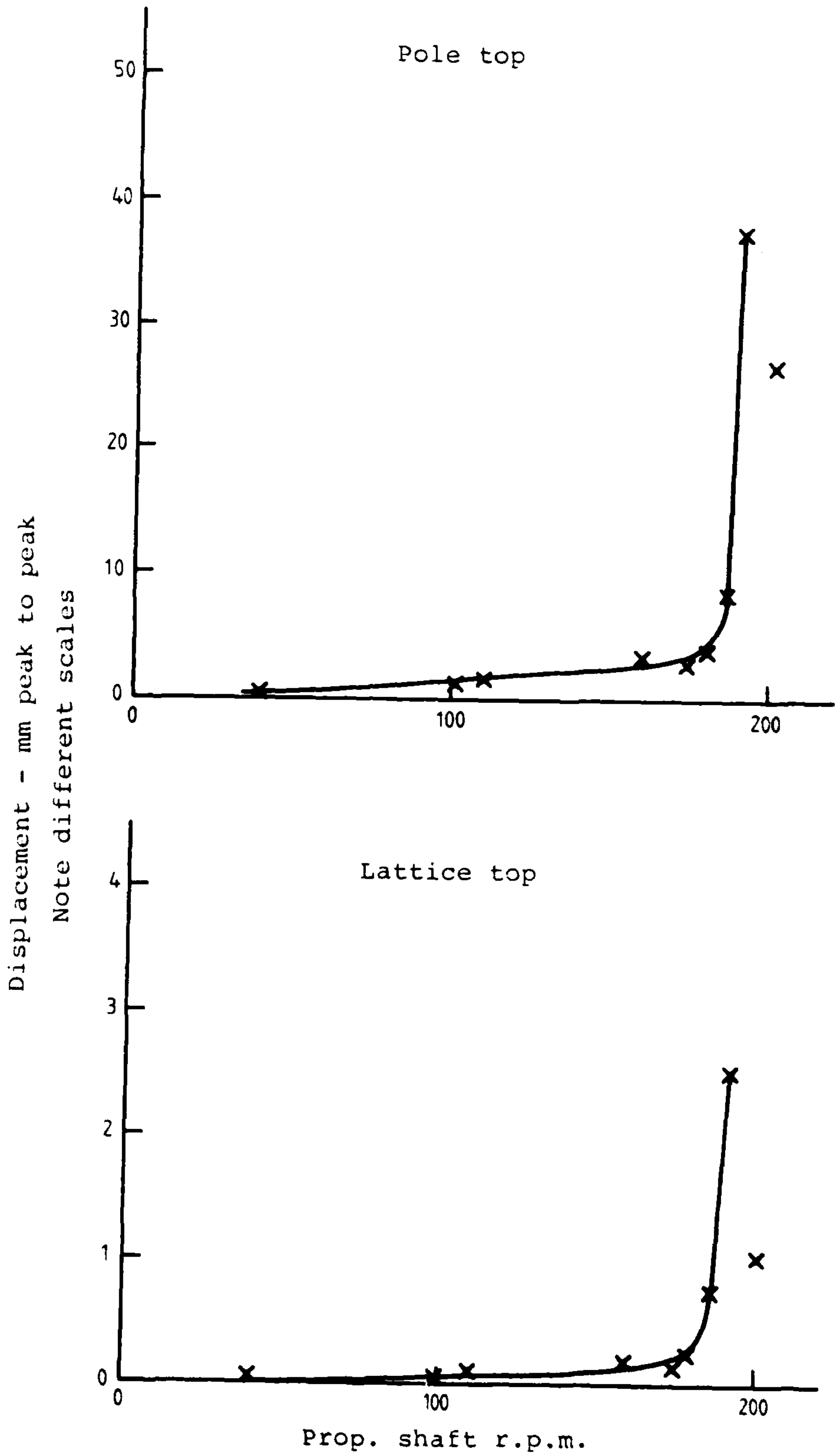
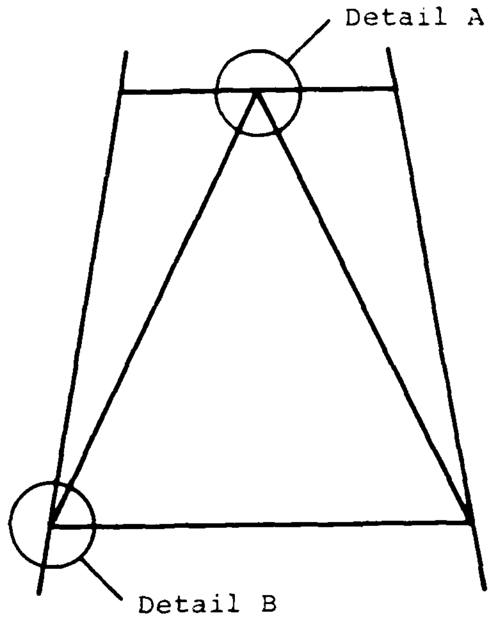
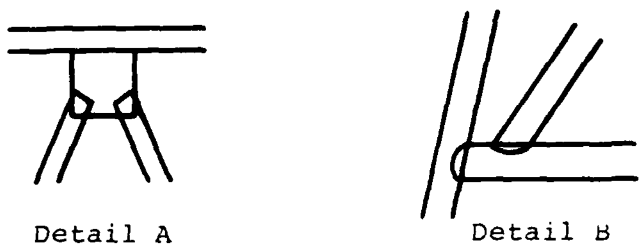


FIG. 31 AMPLITUDE OF MAST VIBRATION AT 3.3 Hz IN FORE/AFT DIRECTION vs SHAFT SPEED



Idealised construction



Actual construction

FIG. 32 DETAIL OF MAST CONSTRUCTION

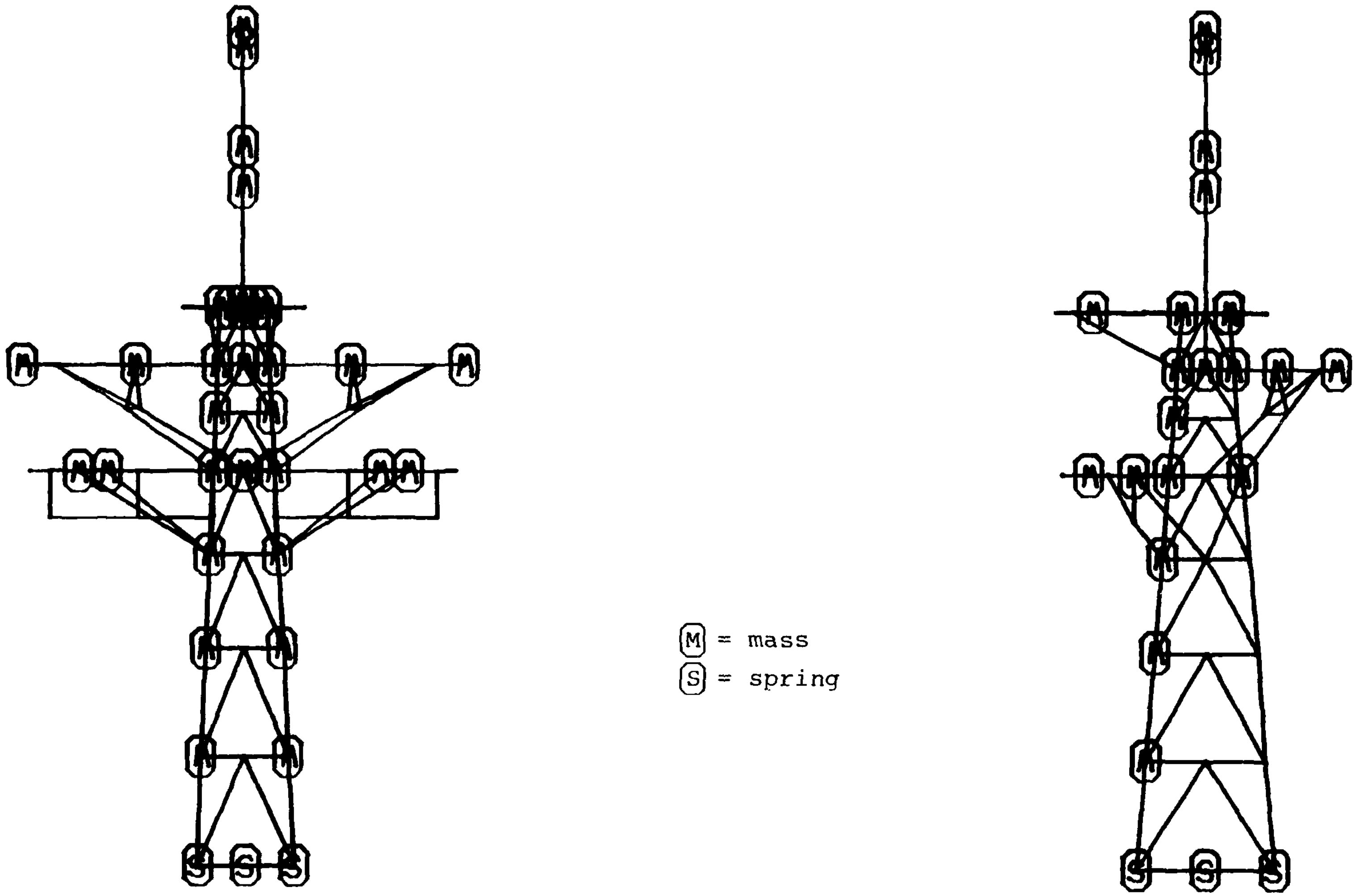


FIG. 33 DISTRIBUTION OF MASSES AND SPRINGS

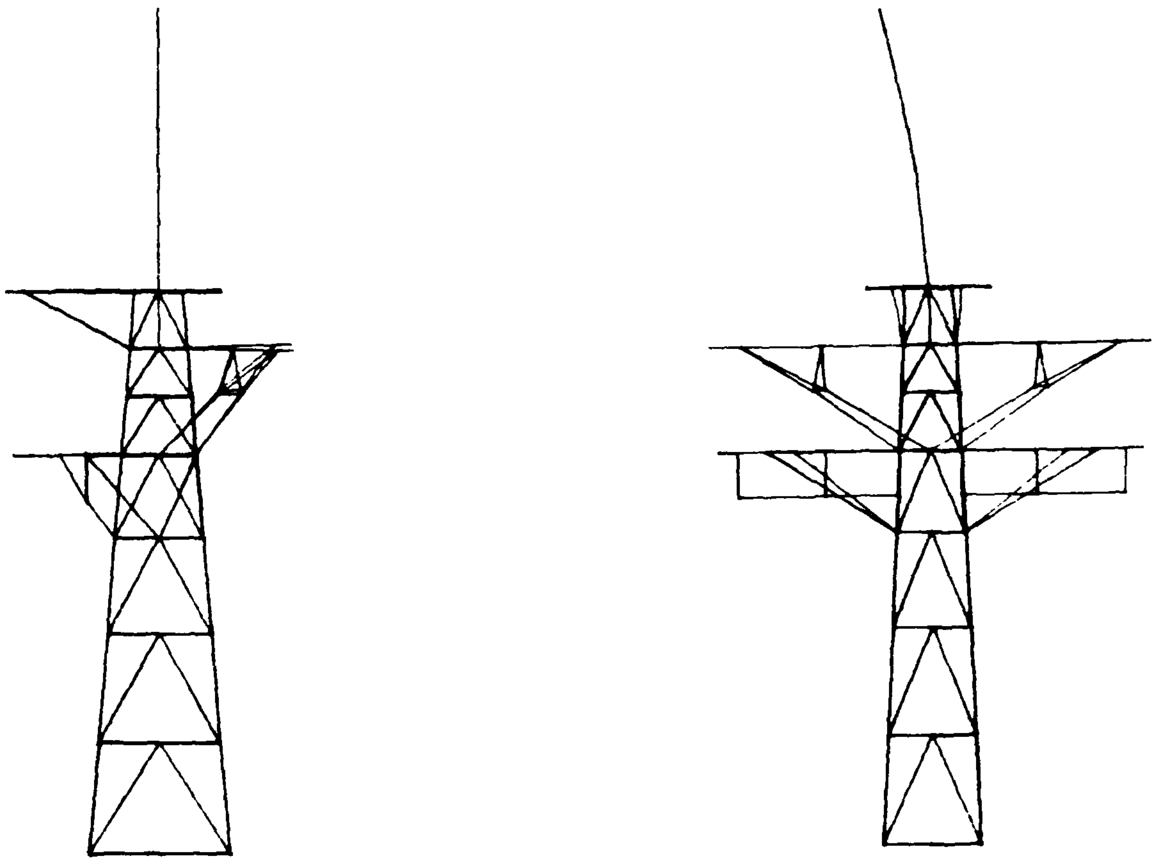


FIG. 34 CALCULATED MODE AT 3.16 Hz

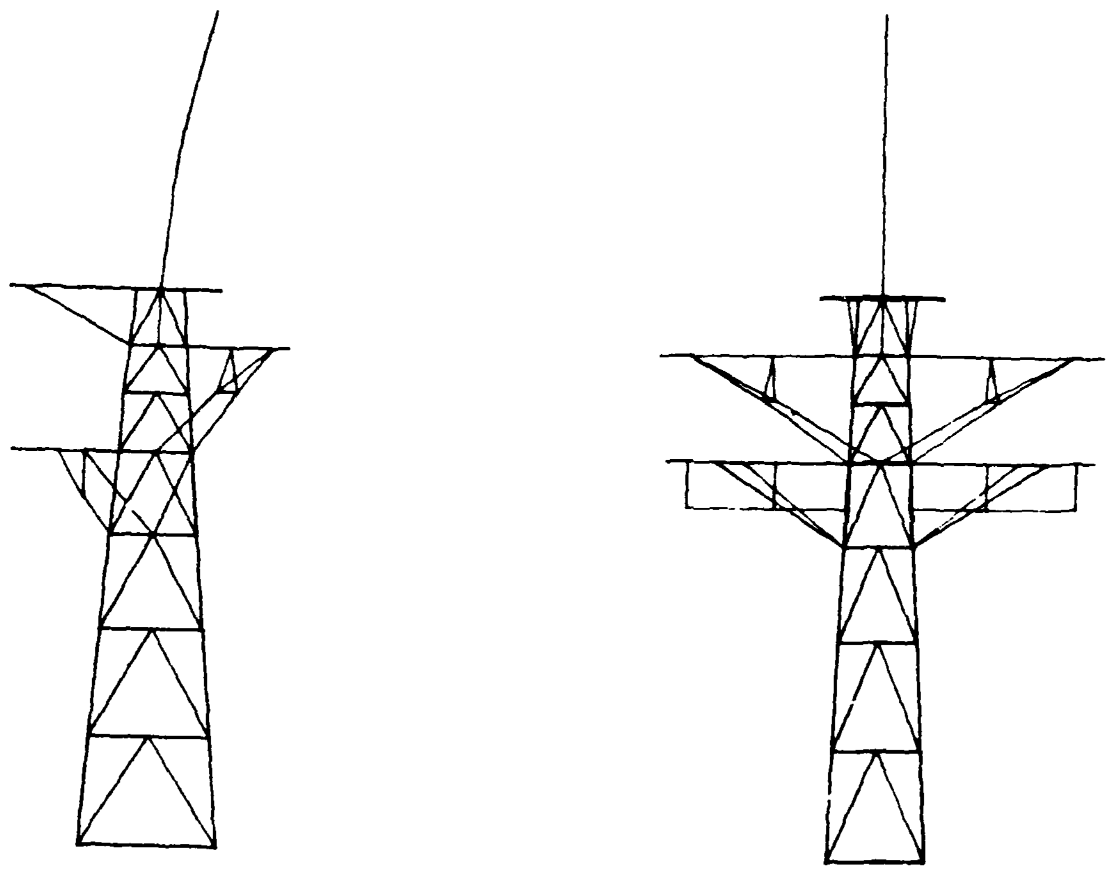


FIG. 35 CALCULATED MODE AT 3.38 Hz

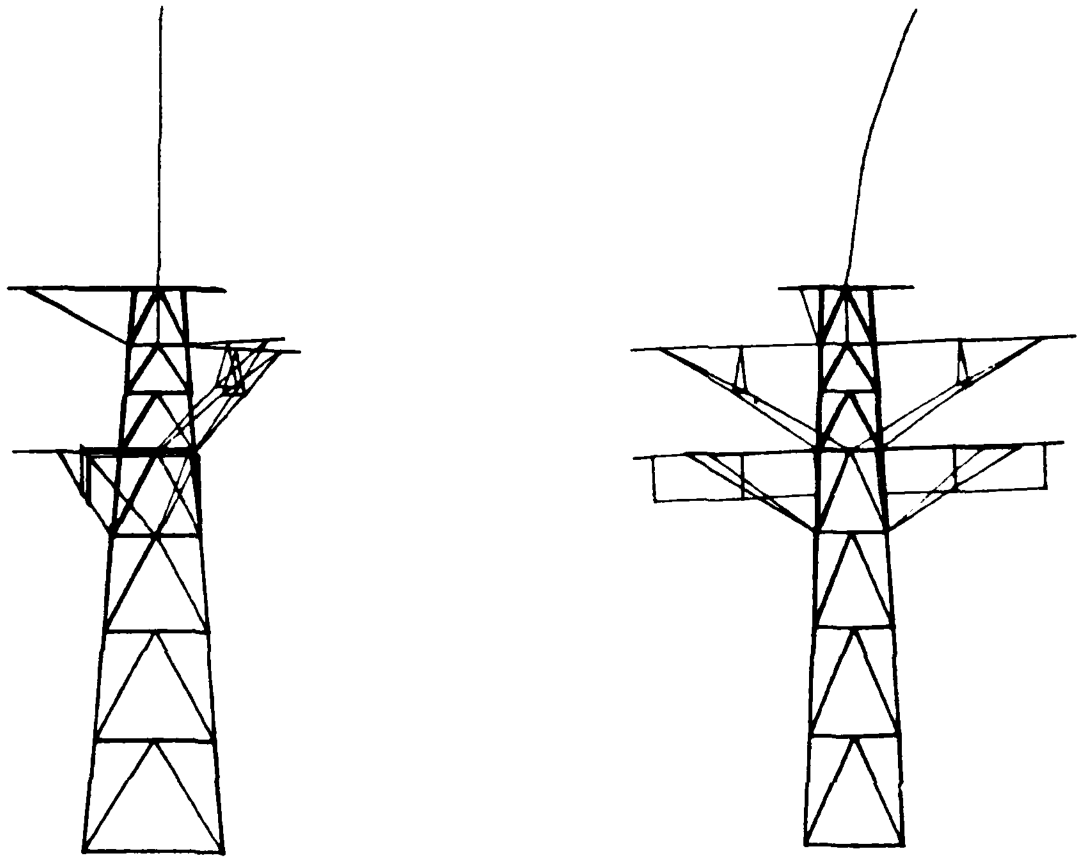


FIG. 36 CALCULATED MODE AT 4.75 Hz

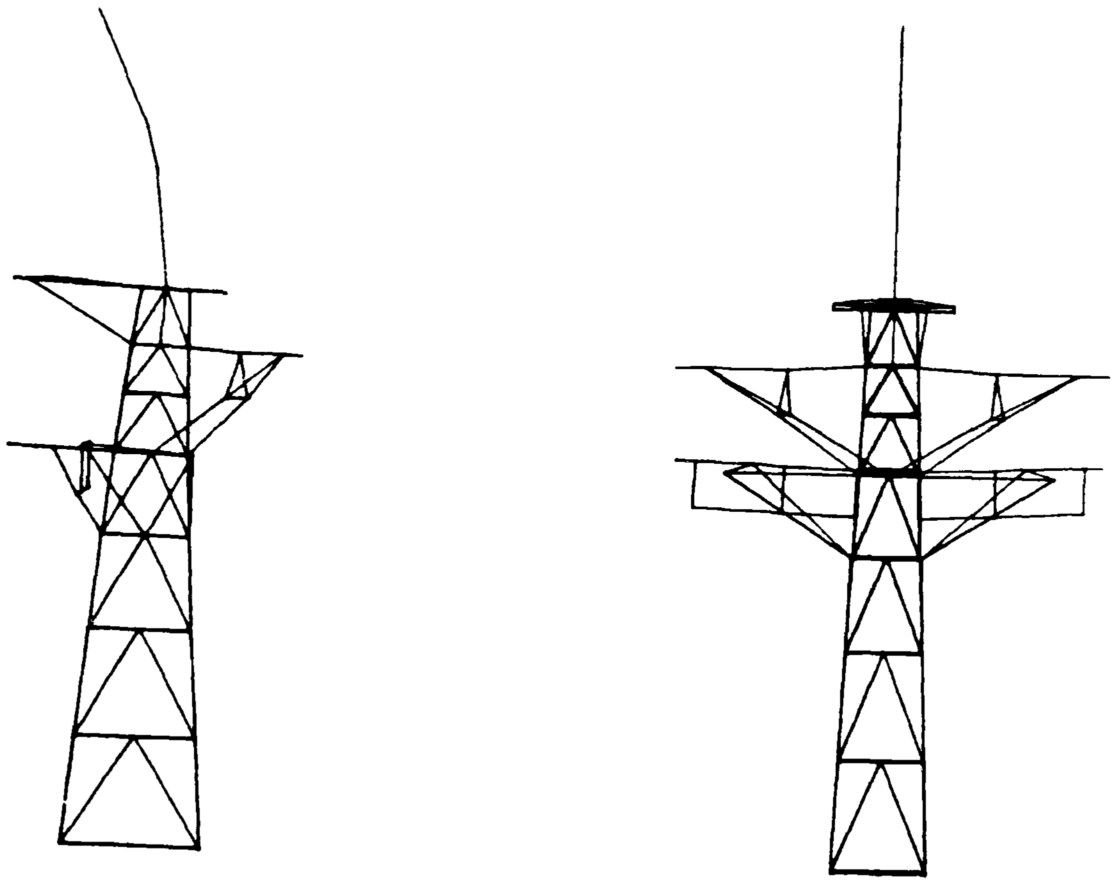


FIG. 37 CALCULATED MODE AT 5.84 Hz

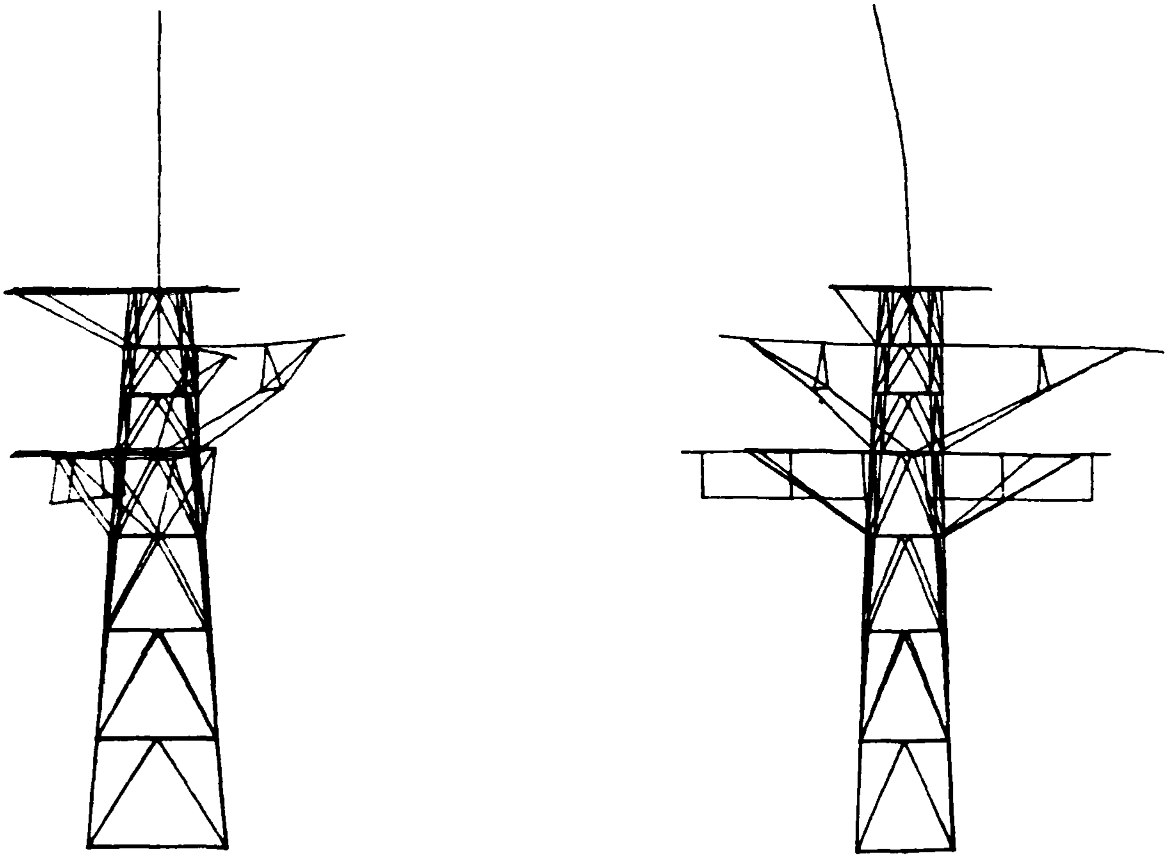


FIG. 38 CALCULATED MODE AT 6.67 Hz

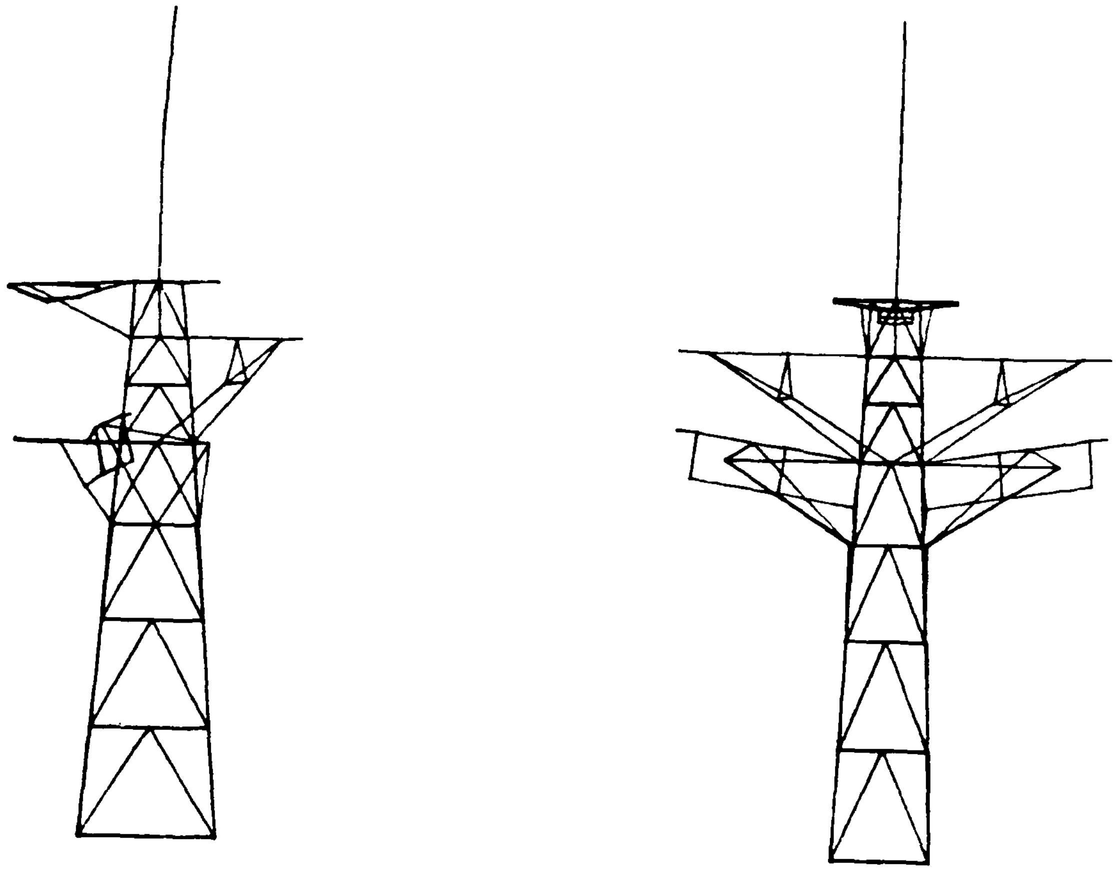


FIG. 39 CALCULATED MODE AT 8.38 Hz

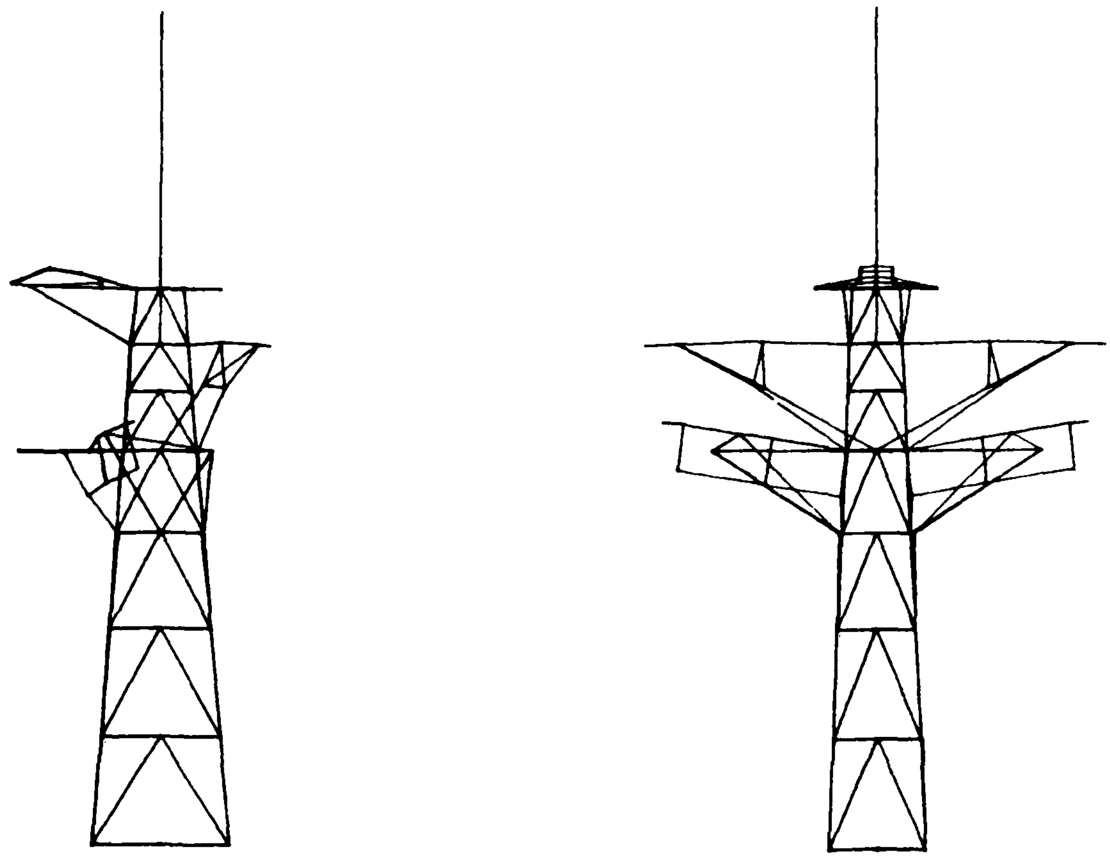


FIG. 40 CALCULATED MODE AT 8.64 Hz

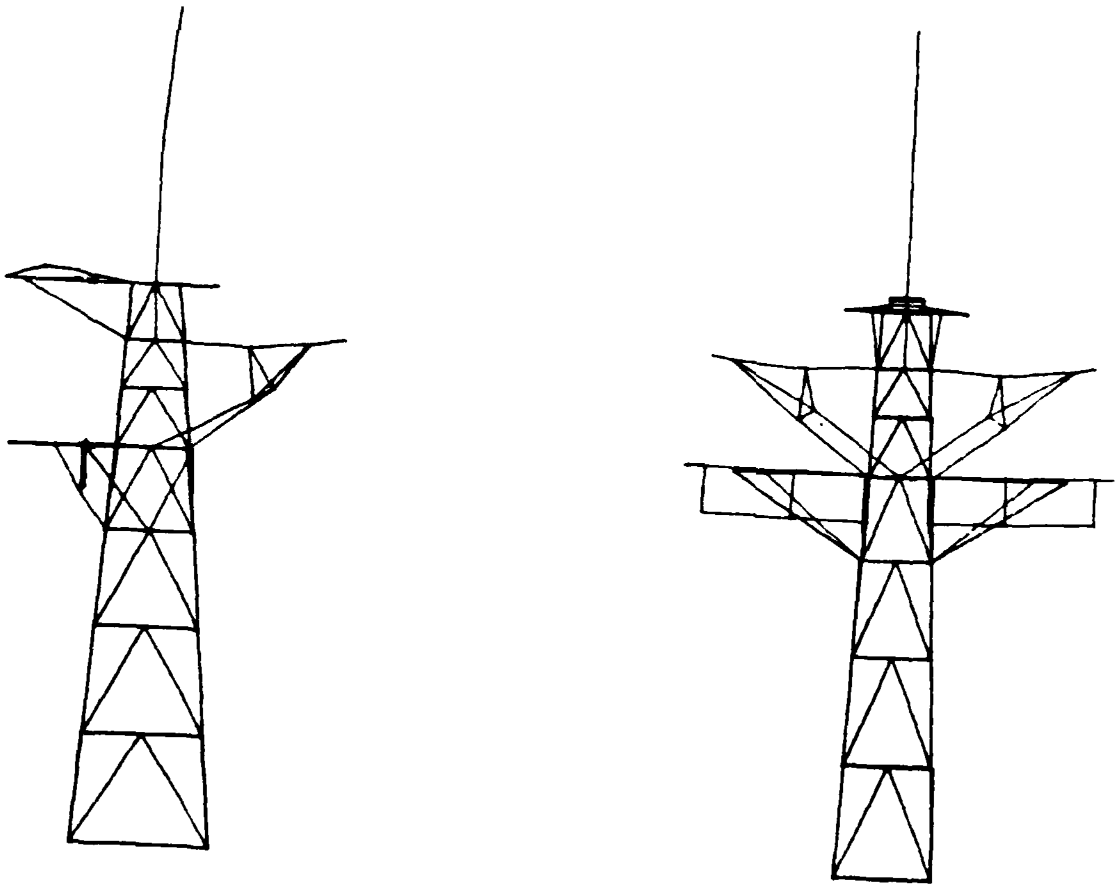


FIG. 41 CALCULATED MODE AT 9.11 Hz

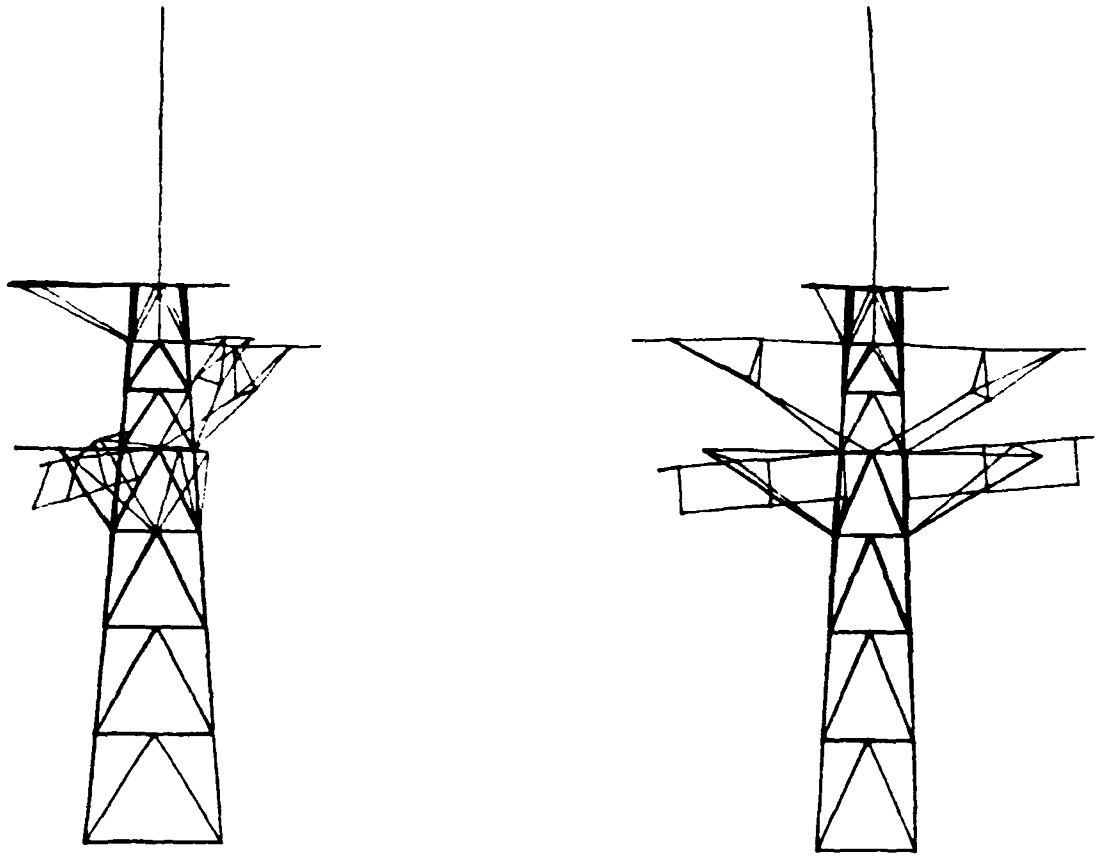


FIG. 42 CALCULATED MODE AT 9.19 Hz

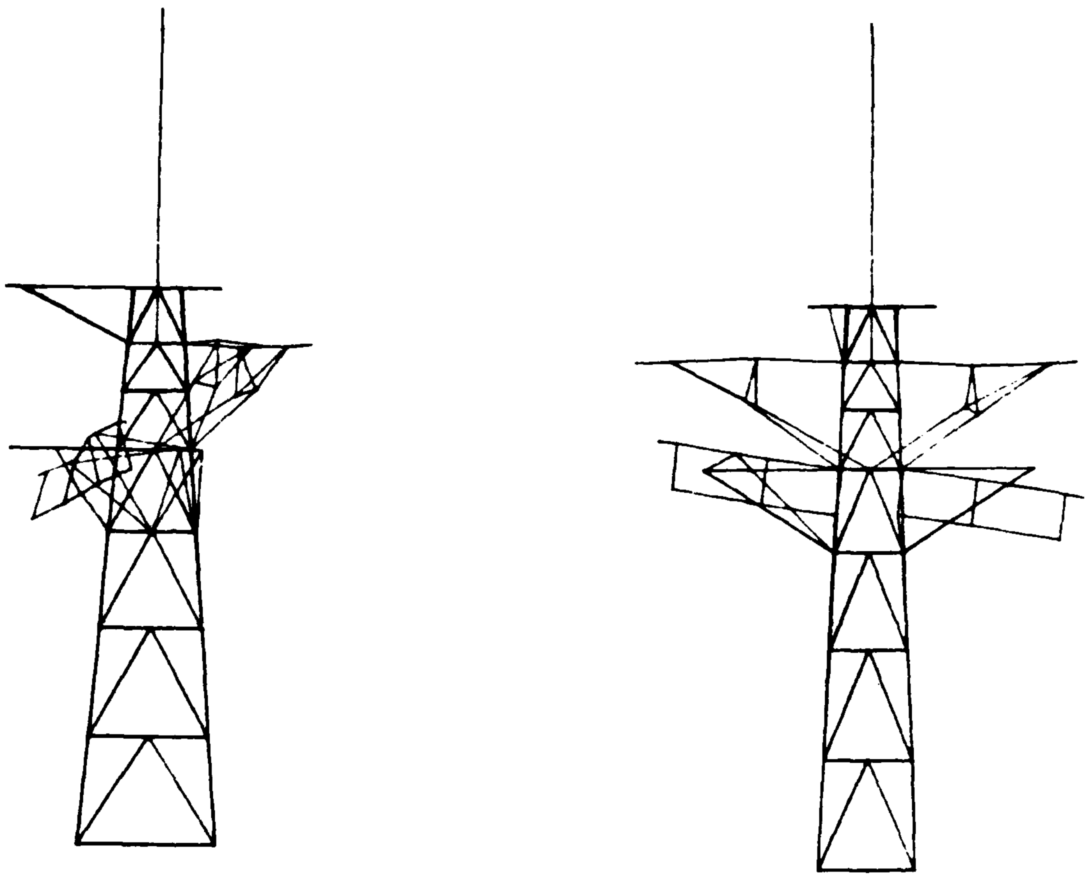


FIG. 43 CALCULATED MODE AT 9.42 Hz

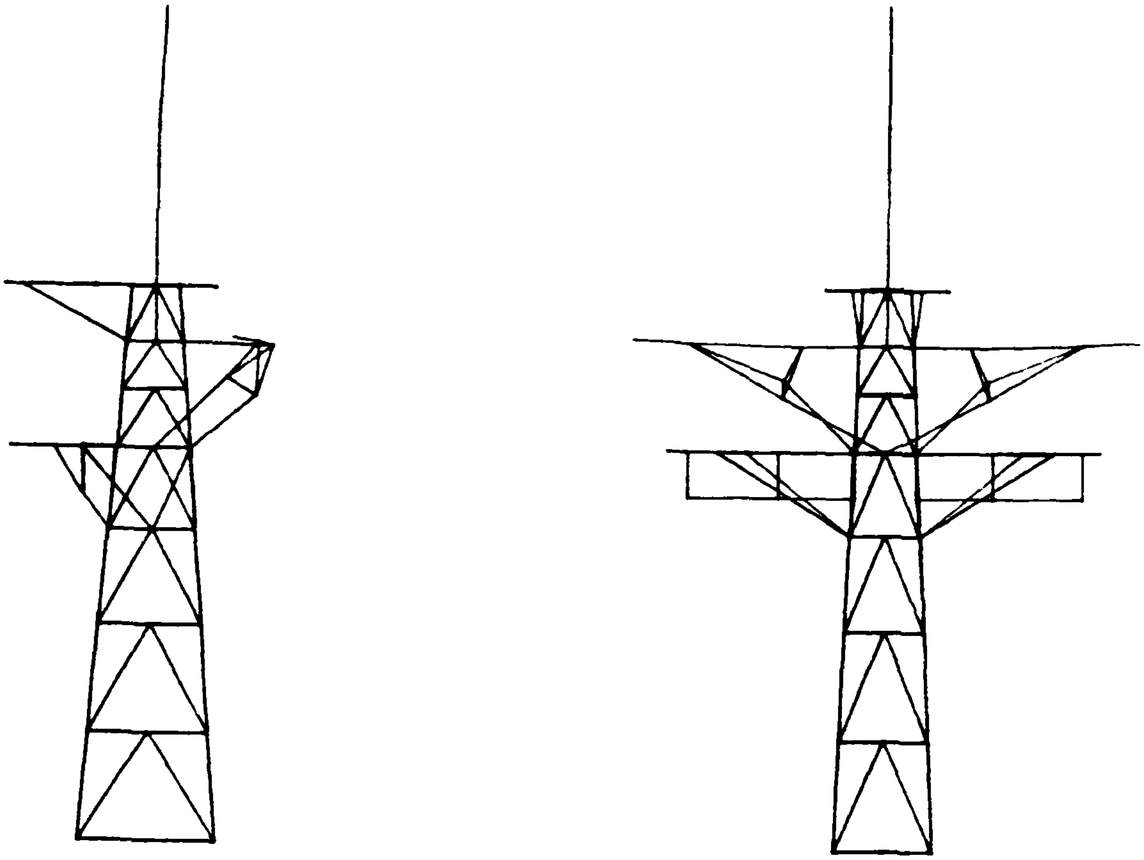


FIG. 44 CALCULATED MODE AT 10.95 Hz

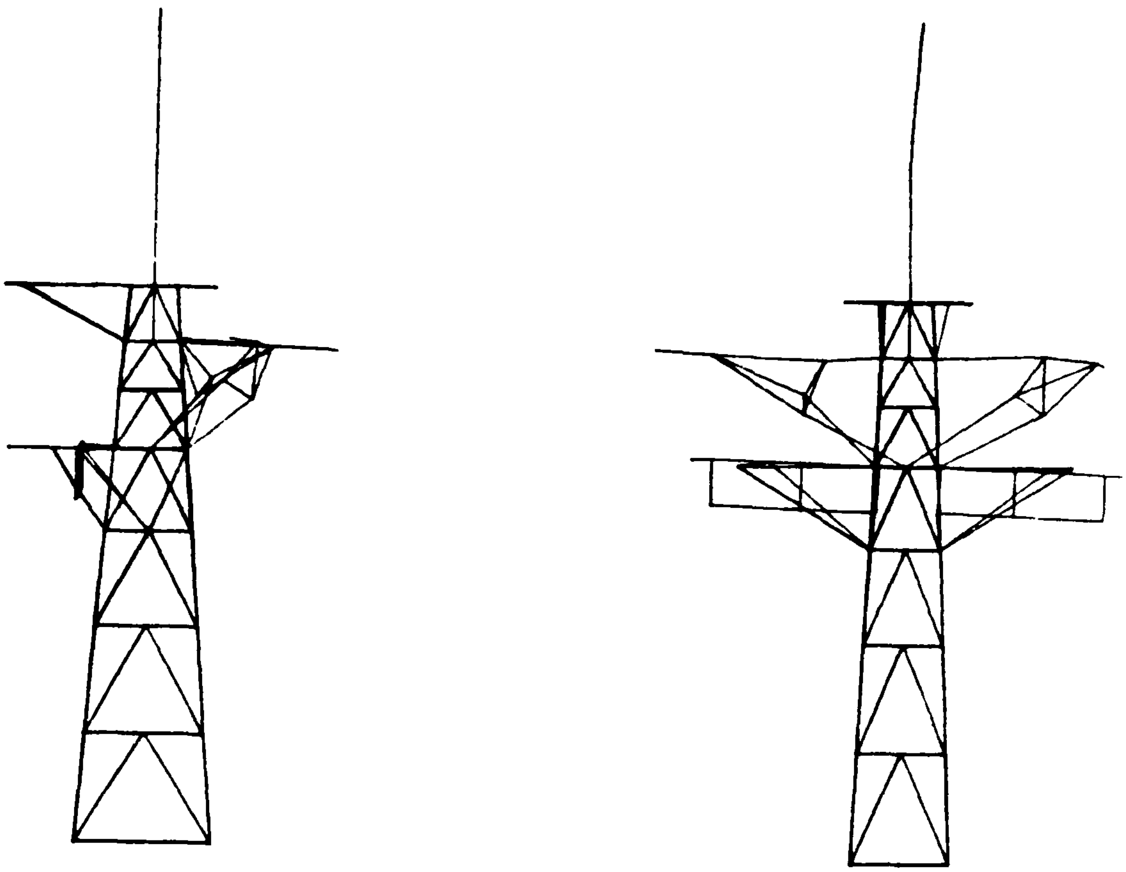


FIG. 45 CALCULATED MODE AT 11.09 Hz

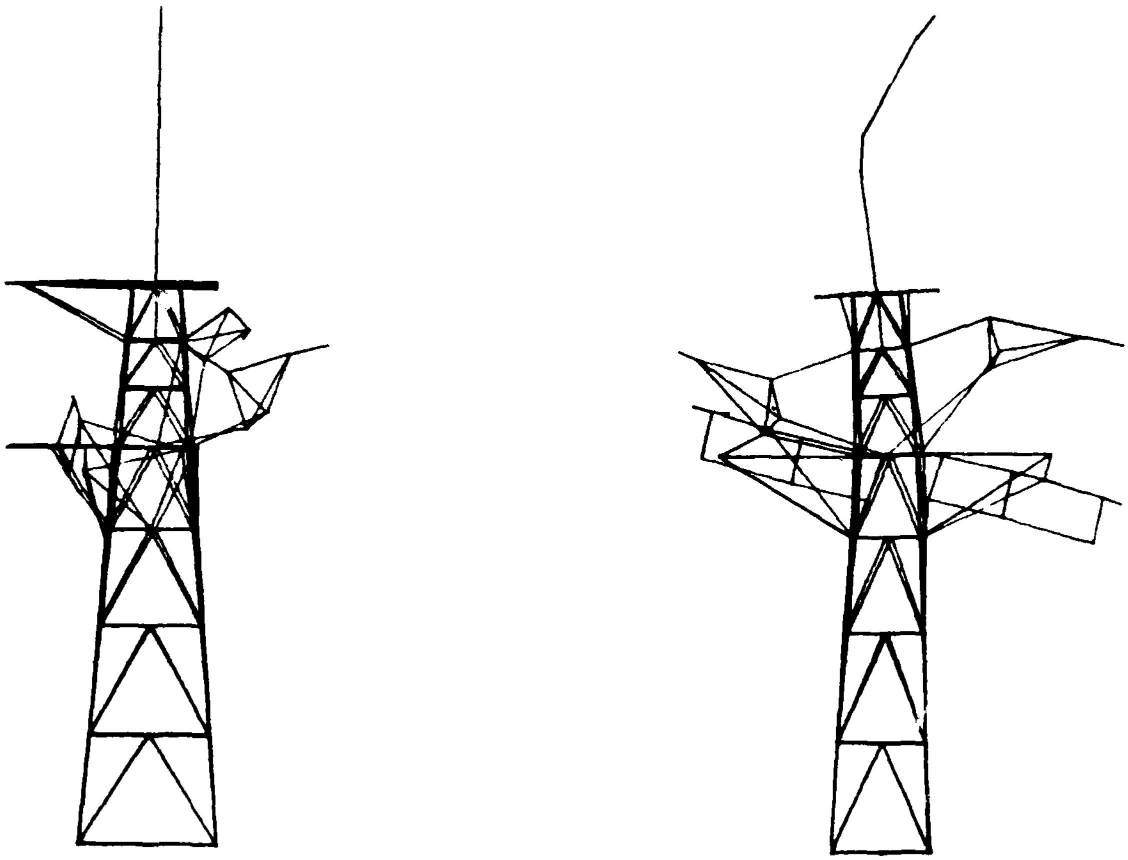


FIG. 46 CALCULATED MODE AT 11.67 Hz

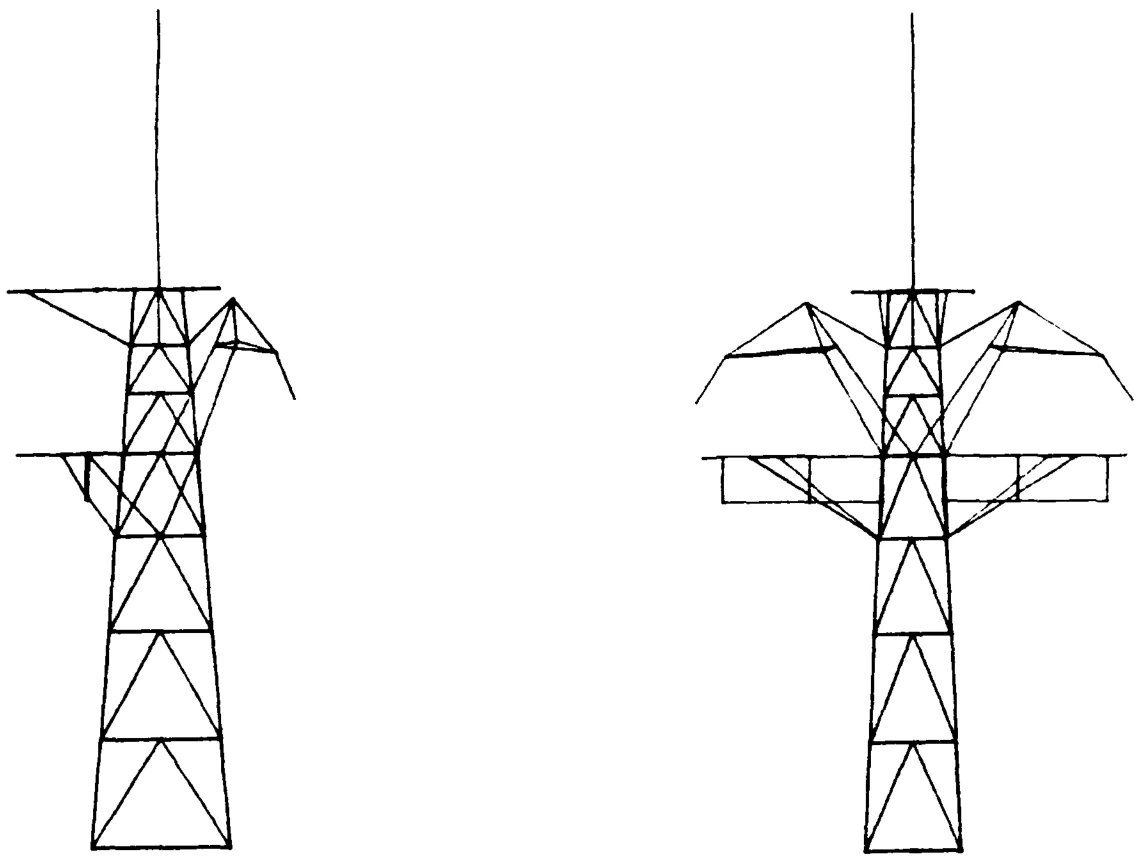


FIG. 47 CALCULATED MODE AT 12.51 Hz

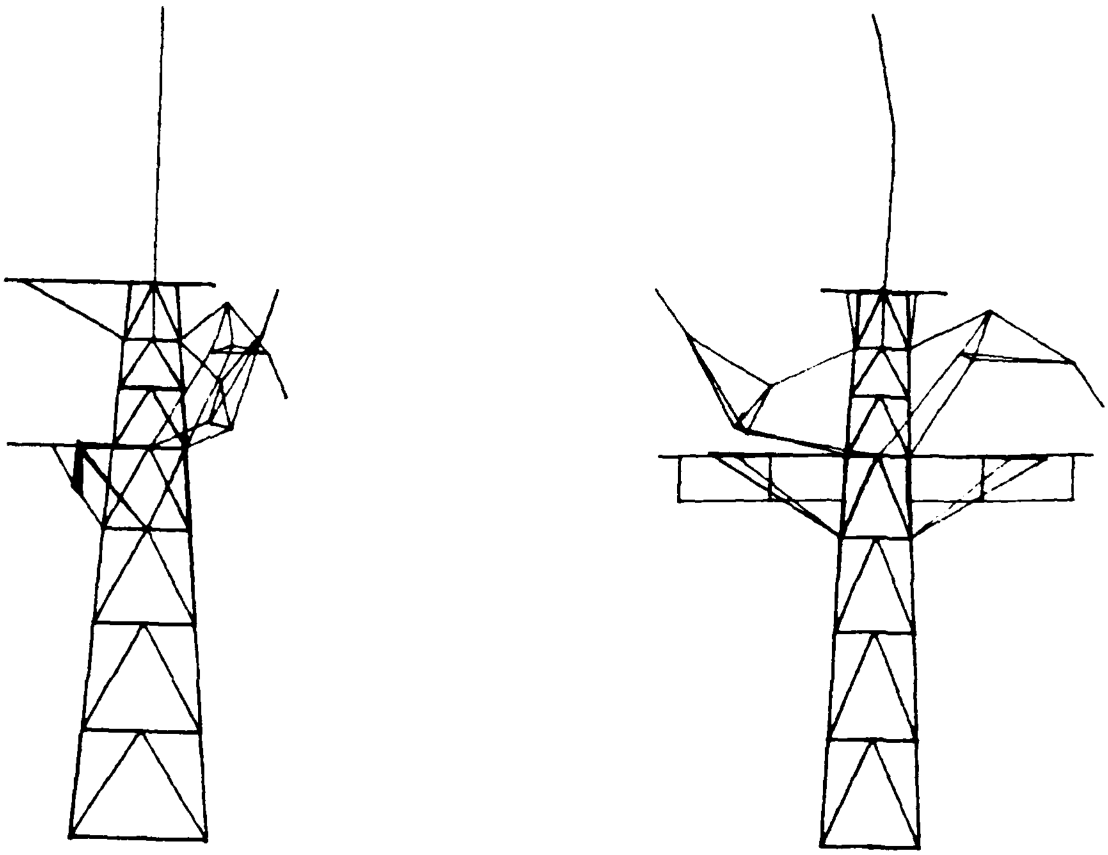


FIG. 48 CALCULATED MODE AT 12.55 Gz

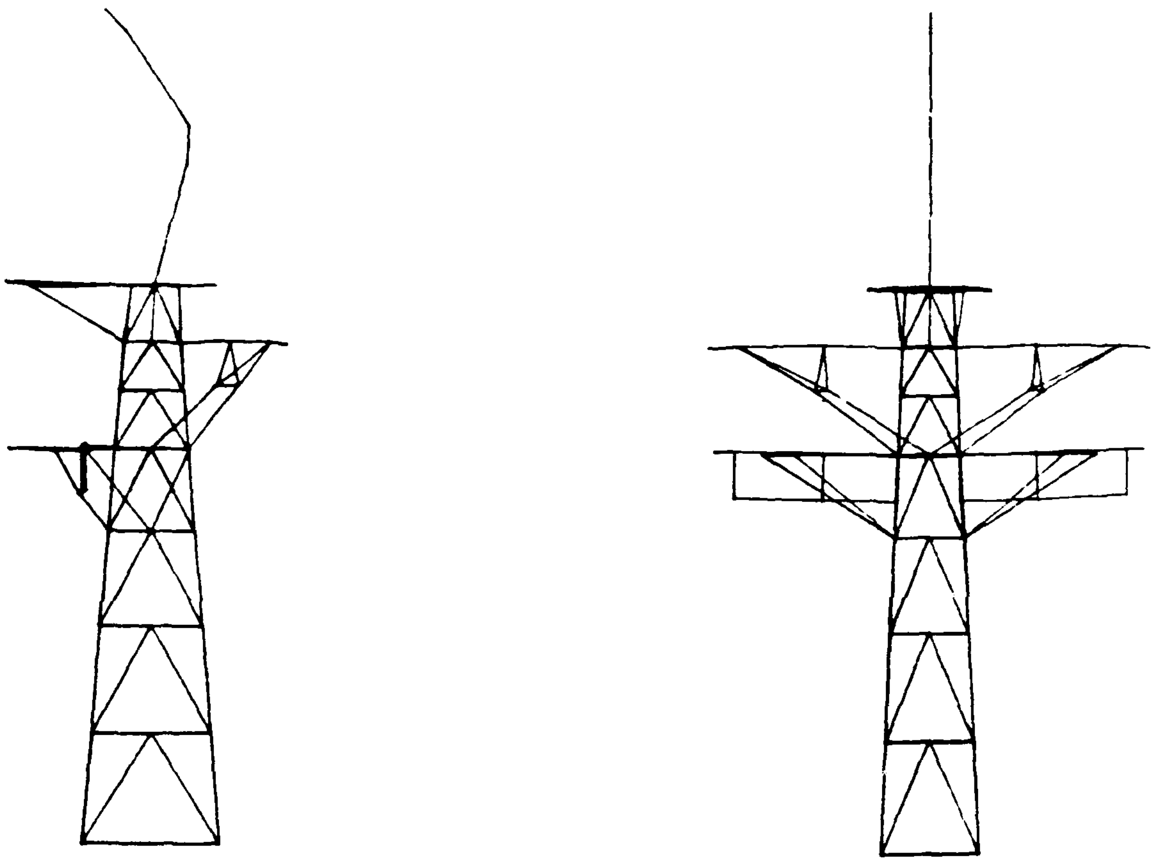


FIG. 49 CALCULATED MODE AT 13.72 Hz

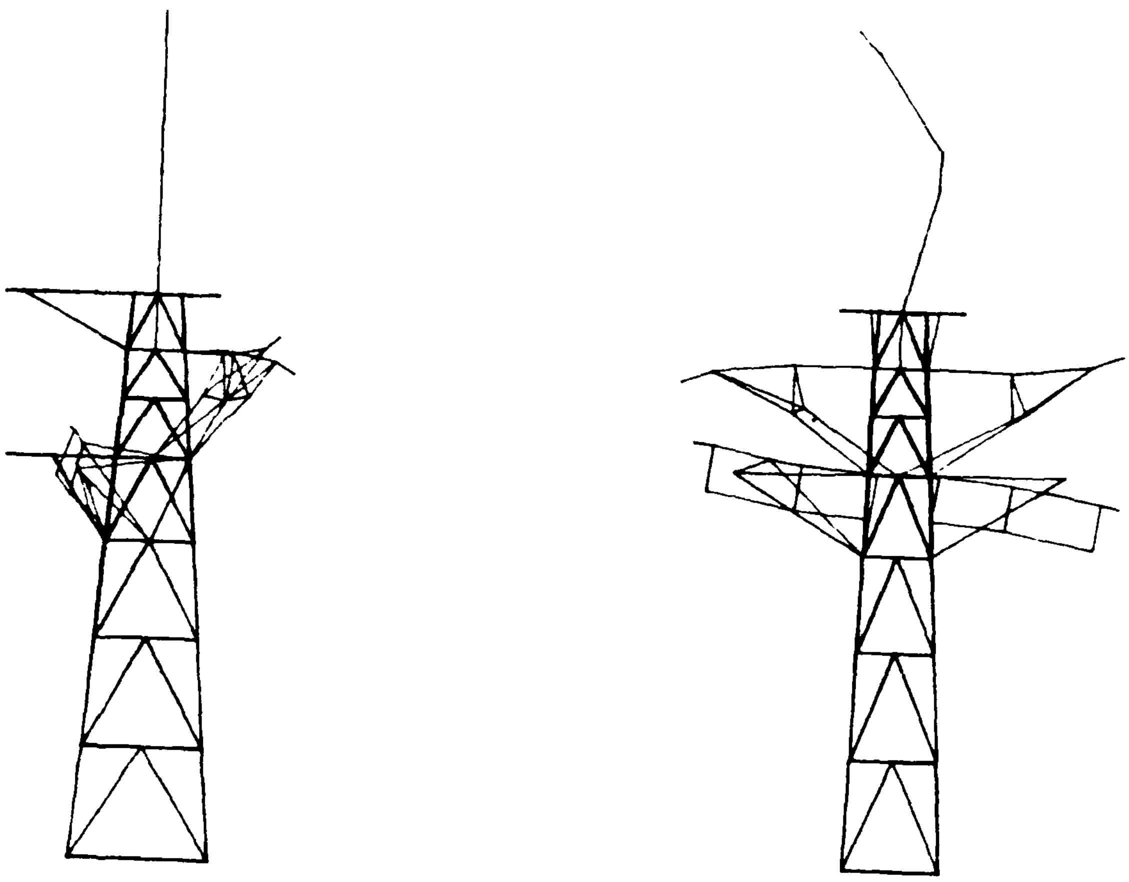


FIG. 50 CALCULATED MODE AT 13.98 Hz

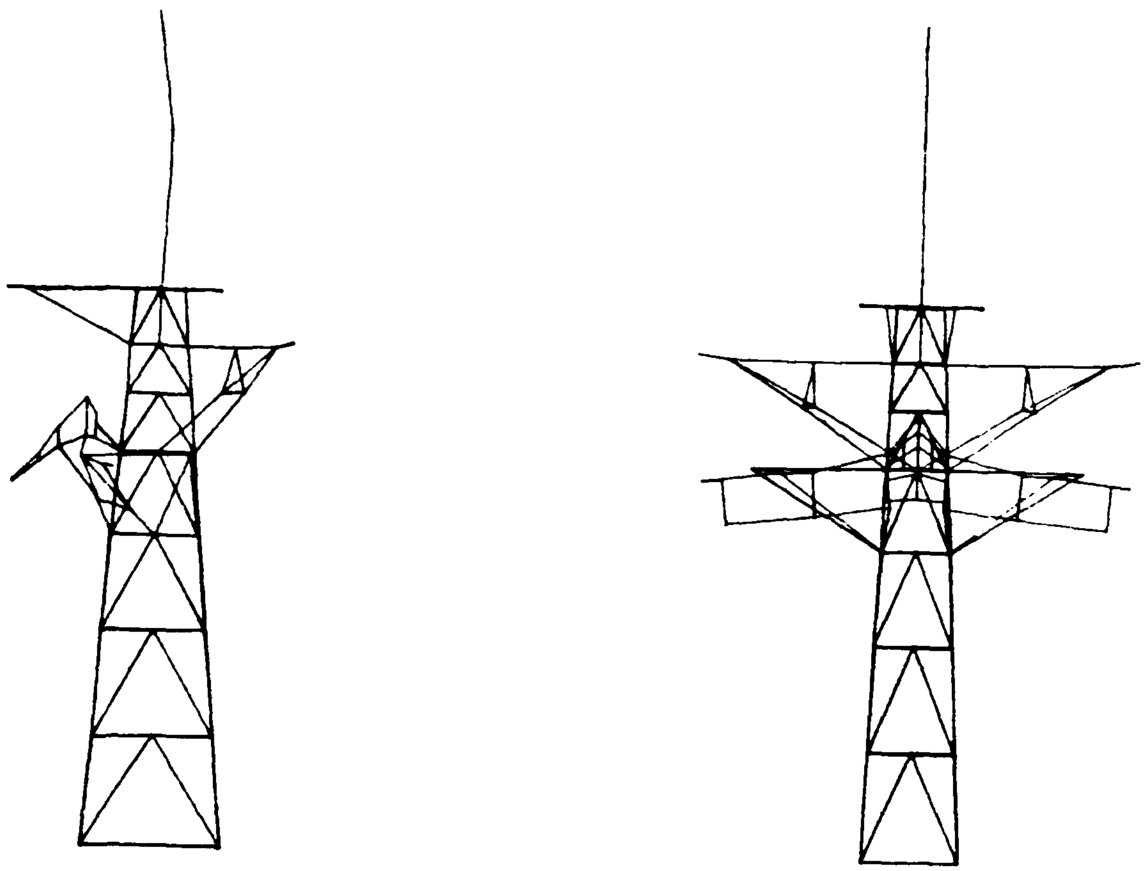


FIG. 51 CALCULATED MODE AT 14.95 Hz

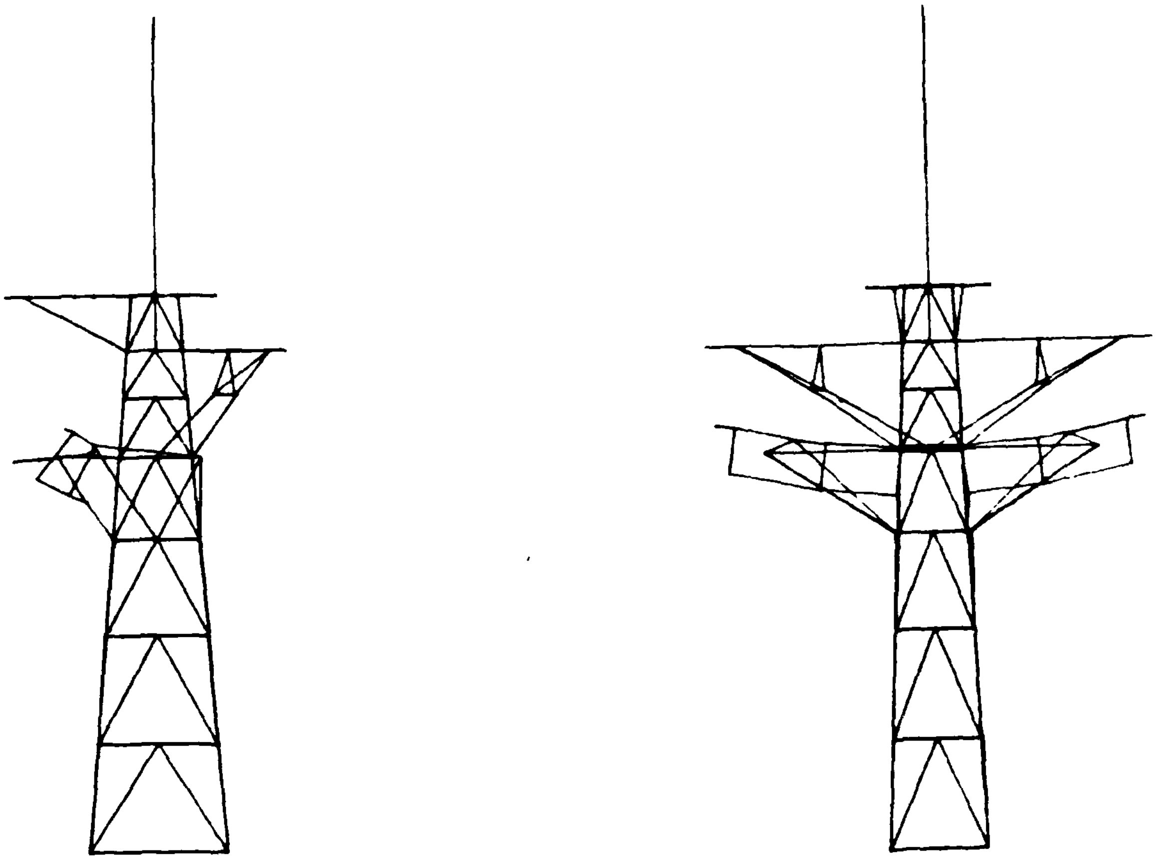


FIG. 52 CALCULATED MODE AT 15.04 Hz

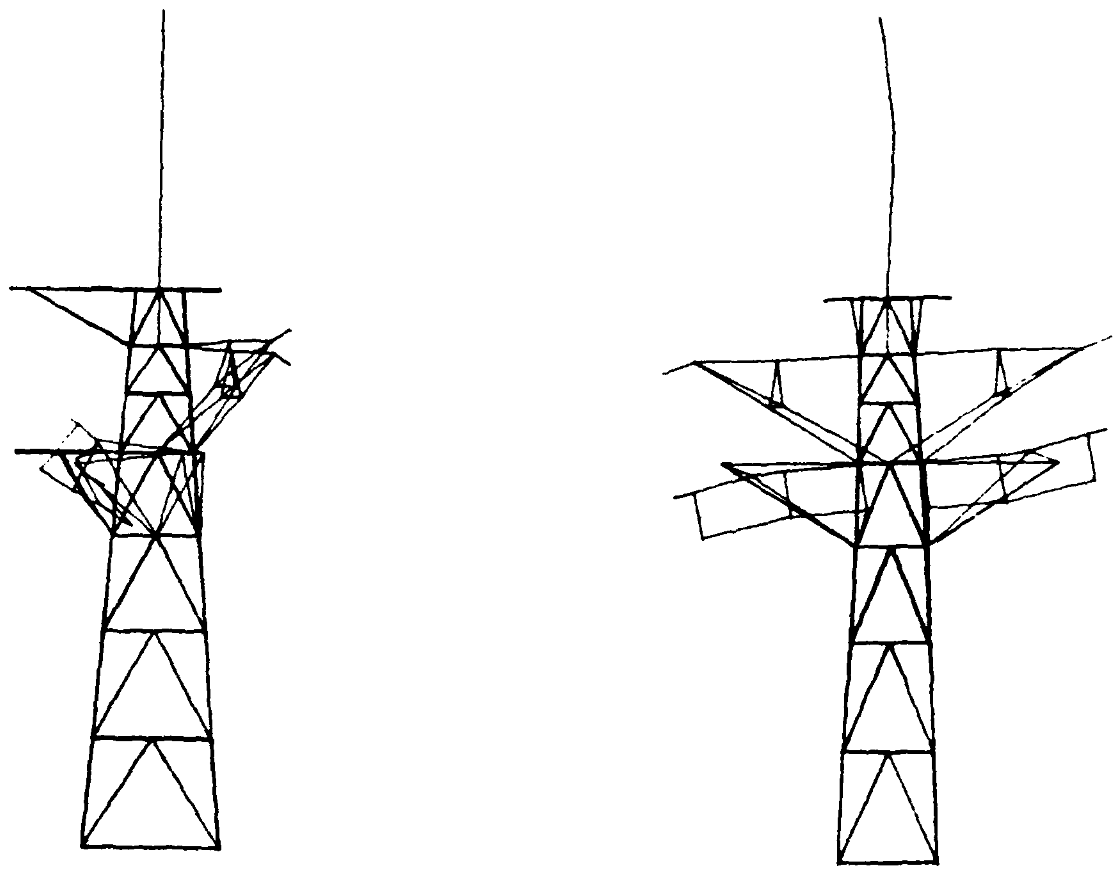


FIG. 53 CALCULATED MODE AT 15.52 Hz

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16. Abstract

Tests have been carried out to determine the shapes of the natural modes of vibration, up to 20 hertz, of the new foremast fitted to HMAS Parramatta. Subsequent sea trials were undertaken to determine the amplitudes of vibrations under various operating conditions. A mathematical model of the mast has been developed to determine the modes of vibration. Results of the tests, and comparisons with the model, are presented.

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