B E R I C H T E

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Nr. 20b

Inverse Analysis of the

Trimoored

Internal Wave Experiment (IWEX)

Part 2

by

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FIGURES:

FIGURES:

Depth (m)	Level	Leg A	Leg B	Leg C	N (cph)
603.6	1	VACM[+]		VACM	2.54
605.7	2	VACM	VACM	VACM	2.54
610.6	4	VACM[+]	VACM[+]		2.55
639.5	5	VACM[+]	VACM[+]	VACM[+]	2.60
730.6	6	VACM	VACM	VACM[+]	2.76
1014.4	8	VACM			2.07
1023.1	10	VACM	VACM[+]	VACM[+]	2.05
2050.4	14	.850	850	850	0.66

TABLE I.1 Current meter array (from Briscoe 1975). Asterices indicate instruments used for mean data set of horizontal currents. N from Knorr cruise 34 mean.

Frequency No.	Frequency cph	Period h	Average over original frequencies	Equiv. degrees of freedom	Bias for zero true coherence	C_{95} for zero true coherence
3	.0400	25.0	1	48	.20	.35
4	.0533	18.8	1	48	.20	.35
5	.0667	15.0	1	48	.20	.35
6	.0800	12.5	1	48	.20	.35
7	.0933	10.7	1	48	.20	.35
8	.1067	9.4	1	48	.20	.35
9	.1200	8.3	1	48	.20	.35
10	.1333	7.5	1	48	.20	.35
11	.1466	6.8	2	64	.18	.30
12	.1733	5.8	2	64	.18	.30
13	.2000	5.0	2	64	.18	.30
14	.2266	4.4	2	64	.18	.30
15	.2600	3.8	3	94	.15	.27
16	.3000	3.3	3	84	.15	.27
17	.3400	2.9	3	84	.15	.27
18	.3866	2.6	4	105	.14	.24
19	.4400	2.3	4	105	.14	.24
20	.5000	2.0	5	126	.13	.22
21	.5733	1.74	6	148	.12	.20
22	.6600	1.52	7	170	.11	.19
23	.7600	1.32	8	193	.10	.18
24	.8667	1.15	8	193	.10	.18
25	.9866	1.01	10	237	.09	.16
26	1.133	.88	12	281	.08	.15
27	1.300	.77	13	303	.08	.14
28	1.487	.67	15	347	.08	.13
29	1.700	.59	17	392	.07	.12
30	1.947	.51	20	458	.07	.12

TABLE I.2: Mean data set: frequencies, edofs, 95% conf. limit and bias for zero true coherence.

frequency interval	3 - 21	22 - 29	30
total number of spectra	1444	1225	729
number of autospectra	38	35	27
number of cross-spectra	1406	1190	702
Number of cross-spectra with vertical separation	1218	1008	562
Number of cross-spectra with purely horizontal separation	134	128	98
Number of cross-spectra with no separation	54	54	42

TABLE I.3: Number of spectra used in the analysis

	slant separation	horizontal separation	vertical separation	no separation $M_m = M_{-m}^*$
Symmetry	$e^{-i\gamma} M_{-1}^{ij} - e^{i\gamma} M_1^{ij} = 0$ $e^{-2i\gamma} M_{-2}^{ij} - e^{2i\gamma} M_2^{ij} = 0$	$M_t^{ij} = 0$ $M_{-t}^{ij} = 0$	$Im\{M_0^{ij}\} = 0$ $M_1^{ij} + [M_{-1}^{ij}]^* = 0$ $M_2^{ij} - [M_{-2}^{ij}]^* = 0$	$M_1 = 0$
Isotropy	$Im\{M_0^{ij}\} = 0$ $M_1^{ij} - [M_{-1}^{ij}]^* = 0$ $Im\{e^{-i\gamma} M_1^{ij}\} = 0$ $M_2^{ij} - [M_{-2}^{ij}]^* = 0$ $Im\{e^{-2i\gamma} M_{-2}^{ij}\} = 0$	$Im\{M_0^{ij}\} = 0$ $M_1^{ij} + [M_{-1}^{ij}]^* = 0$ $Re\{e^{-i\gamma} M_1^{ij}\} = 0$ $M_2^{ij} - [M_{-2}^{ij}]^* = 0$ $Im\{e^{-2i\gamma} M_{-2}^{ij}\} = 0$	$M_1^{ij} = 0$ $M_{-1}^{ij} = 0$ $M_2^{ij} = 0$ $M_{-2}^{ij} = 0$	$M_1 = 0$ $M_2 = 0$
Symmetry and isotropy		$Im\{M_0^{ij}\} = 0$ $M_1^{ij} = 0$ $M_{-1}^{ij} = 0$ $M_2^{ij} - [M_{-2}^{ij}]^* = 0$ $Im\{e^{-2i\gamma} M_{-2}^{ij}\} = 0$	$Im\{M_0^{ij}\} = 0$ $M_1^{ij} = 0$ $M_{-1}^{ij} = 0$ $M_2^{ij} = 0$ $M_{-2}^{ij} = 0$	$M_1 = 0$ $M_2 = 0$
Non-vanishing moments in case of symmetry and isotropy	$Re\{M_0^{ij}\}$ $Re\{e^{-i\gamma} M_1^{ij}\}$ $Re\{e^{-2i\gamma} M_2^{ij}\}$	$Re\{M_0^{ij}\}$ $Re\{e^{-2i\gamma} M_{-2}^{ij}\}$	$Re\{M_0^{ij}\}$	$Re\{M_0\}$

$$Re\{M_0^{ij}\} = \int d\alpha\, E(\omega,\alpha)\, J_0(\alpha \tau_{ij})\,\cos\Theta_{ij}$$

$$Re\{e^{-i\gamma} M_1^{ij}\} = -\int d\alpha\, E(\omega,\alpha)\, J_1(\alpha \tau_{ij})\,\sin\Theta_{ij}$$

$$Re\{e^{-2i\gamma} M_2^{ij}\} = -\int d\alpha\, E(\omega,\alpha)\, J_2(\alpha \tau_{ij})\,\cos\Theta_{ij}$$

TABLE II.1   Symmetry and isotropy relations for propagating waves.

	slant separation	horizontal separation	vertical separation	no separation
different cross spectral components	18	18	18	9
independent consistency relations	8	8	8	4
independent wave moments	10	10	10	5
independent relations satisfied by a symmetric wave field	0	4	5	2
independent relations satisfied by an isotropic wave field	4	7	8	4
independent relations satisfied by a symmetric and isotropic wave field	7	8	9	4
non-vanishing moments in case of symmetry and isotropy	3	-2	1	1

TABLE II.2. Number of independent moments and relations for propagating waves.

	slant separation	horizontal separation	vertical separation	no separation $A_{\nu\mu} = A_{\mu\nu}^*$
Consistency relations	$(\omega+f)^2 A_{++}^{ij} - (\omega-f)^2 A_{--}^{ij} = 0$	$(\omega+f)^2 A_{++}^{ij} - (\omega-f)^2 A_{--}^{ij} = 0$ $(\omega-f) A_{-0}^{ij} + (\omega+f) A_{0+}^{ij} = 0$ $(\omega+f) A_{+0}^{ij} + (\omega-f) A_{0-}^{ij} = 0$	$(\omega+f)^2 A_{++}^{ij} - (\omega-f)^2 A_{--}^{ij} = 0$ $(\omega-f)[A_{-0}^{ij}]^* + (\omega+f) A_{+0}^{ij} = 0$ $(\omega+f)[A_{+0}^{ij}]^* + (\omega-f) A_{-0}^{ij} = 0$ $\Im\{A_{00}^{ij}\} = 0$ $\Im\{A_{--}^{ij}\} = 0$ $A_{-+}^{ij} - [A_{+-}^{ij}] = 0$	$(\omega+f)^2 P_{++} - (\omega-f)^2 P_{--} = 0$ $(\omega+f) A_{+0} + (\omega+f) A_{-0}^* = 0$
Independent moments	M_0^{00} M_0^{++} M_1^{+0} M_{-1}^{+0} M_1^{++} M_{-1}^{0+} M_2^{++} M_{-2}^{++}	M_0^{00} M_0^{++} M_1^{+0} M_{-1}^{+0} M_2^{++} M_{-2}^{++}	$\Re\{M_0^{00}\}$ $\Re\{M_0^{++}\}$ M_1^{+0} M_1^{0+} M_2^{++}	$\Re\{M_0^{00}\}$ $\Re\{M_0^{++}\}$ M_1^{+0} M_2^{++}
Isotropy relations	$\Im\{M_0^{00}\} = 0$ $\Im\{M_0^{++}\} = 0$ $M_1^{+0} + [M_{-1}^{0+}]^* = 0$ $M_1^{0+} + [M_{-1}^{+0}]^* = 0$ $M_2^{++} - [M_{-2}^{++}]^* = 0$ $\Re\{e^{-i\psi} M_1^{+0}\} = 0$ $\Re\{e^{-i\psi} M_1^{0+}\} = 0$ $\Im\{e^{-2i\psi} M_{-2}^{++}\} = 0$	$\Im\{M_0^{00}\} = 0$ $\Im\{M_0^{++}\} = 0$ $M_1^{+0} + [M_{-1}^{0+}]^* = 0$ $M_2^{++} - [M_{-2}^{++}]^* = 0$ $\Re\{e^{-i\psi} M_{-1}^{+0}\} = 0$ $\Im\{e^{-2i\psi} M_{-2}^{++}\} = 0$	$M_1^{+0} = 0$ $M_1^{0+} = 0$ $M_2^{++} = 0$	$M_1^{+0} = 0$ $M_2^{++} = 0$
Non-vanishing moments in case of isotropy	$\Re\{M_0^{00}\}$ $\Re\{M_0^{++}\}$ $\Im\{e^{-i\psi} M_{-1}^{00}\}$ $\Im\{e^{-i\psi} M_1^{0+}\}$ $\Re\{e^{-2i\psi} M_{-2}^{++}\}$	$\Re\{M_0^{00}\}$ $\Re\{M_0^{++}\}$ $\Im\{e^{-i\psi} M_{-1}^{00}\}$ $\Re\{e^{-2i\psi} M_{-2}^{++}\}$	$\Re\{M_0^{00}\}$ $\Re\{M_0^{++}\}$	$\Re\{M_0^{00}\}$ $\Re\{M_0^{++}\}$

$$\Re\{M_0^{00}\} = \int d\alpha\, \tilde{E}(\omega,\alpha)\, \tilde{\eta}_0(x_3^i)\, \tilde{\eta}_0(x_3^j)\, J_0(\alpha r_{ij})$$
$$\Re\{M_0^{++}\} = \int d\alpha\, \tilde{E}(\omega,\alpha)\, \tilde{\eta}_+(x_3^i)\, \tilde{\eta}_+(x_3^j)\, J_0(\alpha r_{ij})$$
$$\Im\{e^{-i\psi} M_{-1}^{+0}\} = -\int d\alpha\, \tilde{E}(\omega,\alpha)\, \tilde{\eta}_+(x_3^i)\, \tilde{\eta}_0(x_3^j)\, J_1(\alpha r_{ij})$$
$$\Im\{e^{-i\psi} M_{-1}^{0+}\} = -\int d\alpha\, \tilde{E}(\omega,\alpha)\, \tilde{\eta}_0(x_3^i)\, \tilde{\eta}_+(x_3^j)\, J_1(\alpha r_{ij})$$
$$\Re\{e^{-2i\psi} M_{-2}^{++}\} = -\int d\alpha\, \tilde{E}(\omega,\alpha)\, \tilde{\eta}_+(x_3^i)\, \tilde{\eta}_+(x_3^j)\, J_2(\alpha r_{ij})$$

TABLE II.3 Consistency and isotropy relations for standing modes.

	slant separation	horizontal separation	vertical separation	no separation
different cross spectral components	18	18	18	9
independent consistency relations	2	6	10	3
independent wave moments	16	12	8	6
independent isotropy relations	11	8	6	4
non-vanishing moments in case of isotropy	5	4	2	2

TABLE II.4 Number of independent moments and relations for standing modes.

Name	Transformation class	fundamental invariants	cross-spectral matrix	invariance relations
3-dimensional isotropy	arbitrary rotations and reflections or arbitrary rotations	$a_m b_m$	$P_{mn} = P\,\delta_{mn}$	$P_{11} + P_{22} - 2P_{33} = 0$ $Q_{12} = 0$ $P_{11} - P_{22} = P_{12} = 0$ $P_{13} = Q_{13} = P_{23} = Q_{23} = 0$
horizontal isotropy and symmetry	rotations about $\lambda = (0,0,1)$ and reflections at λ	$a_m b_m,\ a_m \lambda_m,\ b_m \lambda_m$	$P_{mn} = P\delta_{mn} + B\lambda_m \lambda_n$	$Q_{12} = 0$ $P_{11} - P_{22} = P_{12} = 0$ $P_{13} = Q_{13} = P_{23} = Q_{23} = 0$
horizontal isotropy	rotation about $\lambda = (0,0,1)$ without reflections	$a_m b_m,\ a_m \lambda_m,\ b_m \lambda_m,$ $\varepsilon_{mno}\, a_m b_n \lambda_o$	$P_{mn} = P\delta_{mn} + B\lambda_m \lambda_n$ $+ C\,\varepsilon_{mno}\,\lambda_o$	$P_{11} - P_{22} = P_{12} = 0$ $P_{13} = Q_{13} = P_{23} = Q_{23} = 0$
vertical symmetry	reflection at the plane $\nu = (0,1,0),$ $\mu = (1,0,0)$	$a_m b_m,\ a_m \nu_m,\ b_m \nu_m,$ $a_m \mu_m,\ b_m \mu_m$	$P_{mn} = P\delta_{mn} + B\nu_m \nu_n$ $+ C\nu_m \mu_n + D\mu_m \nu_n$ $+ E\mu_m \mu_n$	$P_{13} = Q_{13} = P_{23} = Q_{23} = 0$

TABLE II.5 Fundamental invariants, structure of cross spectral matrix and invariance relations for various transformation classes. Here a and b represent arbitrary unit vectors and A,B,C,D and E arbitrary constants.

METRIC	$\langle \epsilon^2 \rangle$	VAR$[\epsilon^2]$	L_{eff}
$W_{\ell\ell'} = S_{\ell\ell'}^{-1}$	L	$2L$	L
$W_{\ell\ell'}^{(a)} = \delta_{\ell\ell'} \dfrac{1}{S_{\ell\ell}}$	L	$2\sum_{\ell,\ell'} C_{\ell\ell'}$	$\dfrac{L^2}{\sum_{\ell,\ell'} C_{\ell\ell'}}$
$W_{\ell\ell'}^{(b)} = \delta_{\ell\ell'} \dfrac{1}{S_{\ell\ell}} \sum_k C_{\ell k}^{-1}$	$\sum_{\ell,\ell'} C_{\ell\ell'}^{-1}$	$2\sum_{\ell,\ell'} C_{\ell\ell'}^{-1}$	$\sum_{\ell,\ell'} C_{\ell\ell'}^{-1}$
$W_{\ell\ell'}^{IWEX} = \delta_{\ell\ell'} \dfrac{k_\ell}{S_{\ell\ell'}}$	$\sum_\ell k_\ell$	$2\sum_{\ell,\ell'} C_{\ell\ell'} k_\ell k_{\ell'}$	$\dfrac{\sum_{\ell,\ell'} k_\ell k_{\ell'}}{\sum_{\ell,\ell'} C_{\ell\ell'} k_\ell k_{\ell'}}$

$$C_{\ell\ell'} = \frac{S_{\ell\ell'}}{\sqrt{S_{\ell\ell} S_{\ell'\ell'}}} \quad , \quad k_\ell = \left(\sum_{\ell'} C_{\ell\ell'}\right)^{-1}$$

S = covariance matrix

L = number of data

TABLE III.1 Properties of various metrics.

	Fig.	FREQUENCY INTERVAL 3 - 21	22 - 29	30
Number of different cross spectral components		1444	1225	729
Zero model	IV.1	1444	1225	729
White noise	IV.1	1406	1190	702
Finestructure	IV.1	1218	1008	562
Basic assumptions of the Garrett and Munk model	IV.2	854	797	492
Homogeneity and WKB-scaling UVζ	IV.3	83	80	60
UV	IV.4	32	32	24
ζ	IV.4	19	16	12
Propagating waves, vert. symmetric, hor. isotropic	IV.5	771	717	432
Hor. isotropy	IV.6	54	54	42
Vert. symmetry	IV.7	36	36	28
Propagating waves	IV.9	324	324	196
Standing modes Discriminating tests	IV.13	38	38	30
All tests	IV.14	119	119	79
Standing modes hor. isotropic	IV.15	690	636	323
Combination of standing and prop. waves	IV.16	81	81	49
D_3^{ij}, D_4^{ij} = 0	IV.17	162	162	98
D_1^{ij} = 0 total	IV.18	81	81	49
no sep.	IV.18	9	9	7
slant sep.	IV.19	62	62	33
hor. sep.	IV.19	10	10	9
Prop. waves contaminated by white noise	IV.20	306	306	182
Prop. waves contaminated by finestructure	IV.21	286	286	166
Prop. waves contaminated by coherent noise	IV.22	243	243	147
IWEX model class	IV.23	224	224	132

TABLE IV.1 Number of different cross spectral components and number of different consistency relations.

	Fig.	Low frequency band		Medium frequency band	High frequency band
		inertial fr. f	tidal fr. M_2		
Basic assumption of the Garrett and Munk model	IV.2	?	strongly violated	slightly violated	strongly violated
Homogeneity and WKB-scaling	IV.3	satisfied	satisfied	satisfied	strongly violated (partly due to proximity of turning point)
Prop. waves, hor. isotropic, vert. symmetric	IV.5	?	strongly violated	slightly violated	strongly violated
Hor. isotropy	IV.6	strongly violated	strongly violated	satisfied	slightly violated
Vert. symmetry	IV.7	strongly violated	strongly violated	satisfied	slightly violated
Prop. waves	IV.9	?	strongly violated	slightly violated	strongly violated
Standing modes	IV.14	?	strongly violated	satisfied	satisfied
Comb. of standing and prop. waves	IV.16	?	strongly violated	satisfied	satisfied
D_3^{ij}, $D_4^{ij} = 0$	IV.17	satisfied	satisfied	satisfied	slightly violated (partly due to proximity of turning point)
$D_1^{ij} = 0$	IV.18	strongly violated	strongly violated	slightly violated	strongly violated
Prop. waves contaminated by finestructure	IV.21	?	strongly violated	slightly violated	strongly violated
Prop. waves contaminated by coherent noise	IV.22	?	slightly violated	satisfied	slightly violated (partly due to proximity of turning point)
IWEX model class	IV.23	satisfied	slightly violated	satisfied	slightly violated (partly due to proximity of turning point)

TABLE IV.2   Results of consistency tests.

	GM 72	GM 75	CW
j_*	20	6	3
j_e	20	11	10
t	∞	5/2	2
s	∞	1	2
d	0	0	0
I(t,s)	1	3/2	2/π
J(t,s)	1	1.8	π

TABLE V.1: Models of internal wave spectrum

J(t,s)

s \ t	1.300	1.500	1.700	2.000	2.200	2.500	3.000	3.500	4.000
1.00	17.778	8.000	4.898	3.000	2.361	1.778	1.250	0.960	0.778
1.10	16.968	7.800	4.861	3.043	2.424	1.854	1.332	1.041	0.856
1.20	16.320	7.632	4.824	3.074	2.473	1.917	1.402	1.112	0.926
1.30	15.792	7.488	4.789	3.096	2.512	1.968	1.461	1.173	0.986
1.50	14.985	7.255	4.723	3.123	2.567	2.045	1.555	1.272	1.088
1.70	14.402	7.076	4.666	3.136	2.602	2.100	1.624	1.349	1.167
2.00	13.784	6.875	4.594	3.142	2.633	2.153	1.698	1.432	1.257
2.50	13.137	6.658	4.503	3.134	2.655	2.202	1.772	1.521	1.355
3.00	12.743	6.504	4.438	3.121	2.660	2.226	1.814	1.574	1.415
4.00	12.302	6.330	4.353	3.095	2.656	2.243	1.854	1.629	1.481
5.00	12.070	6.234	4.302	3.075	2.647	2.247	1.870	1.654	1.513
7.00	11.844	6.136	4.247	3.049	2.633	2.244	1.881	1.674	1.540
10.00	11.708	6.074	4.210	3.029	2.620	2.238	1.882	1.681	1.552

I(t,s)

s \ t	1.300	1.500	1.700	2.000	2.200	2.500	3.000	3.500	4.000
1.00	0.300	0.500	0.700	1.000	1.200	1.500	2.000	2.500	3.000
1.10	0.289	0.473	0.652	0.914	1.085	1.337	1.748	2.149	2.543
1.20	0.281	0.453	0.616	0.850	1.000	1.218	1.565	1.899	2.222
1.30	0.274	0.437	0.588	0.801	0.935	1.127	1.429	1.714	1.986
1.50	0.265	0.413	0.548	0.730	0.843	1.000	1.240	1.461	1.667
1.70	0.258	0.397	0.520	0.683	0.781	0.916	1.118	1.299	1.464
2.00	0.251	0.381	0.493	0.637	0.721	0.835	1.000	1.144	1.275
2.50	0.245	0.366	0.466	0.592	0.663	0.757	0.889	1.000	1.097
3.00	0.241	0.357	0.451	0.566	0.630	0.713	0.827	0.920	1.000
4.00	0.237	0.347	0.435	0.539	0.596	0.668	0.763	0.838	0.900
5.00	0.235	0.342	0.427	0.526	0.579	0.645	0.731	0.798	0.851
7.00	0.233	0.338	0.420	0.514	0.564	0.625	0.702	0.760	0.806
10.00	0.232	0.336	0.416	0.507	0.555	0.613	0.685	0.738	0.779

TABLE V.2 Normalization factor I(t,s) and conversion factor J(t,s) for various values of t and s.
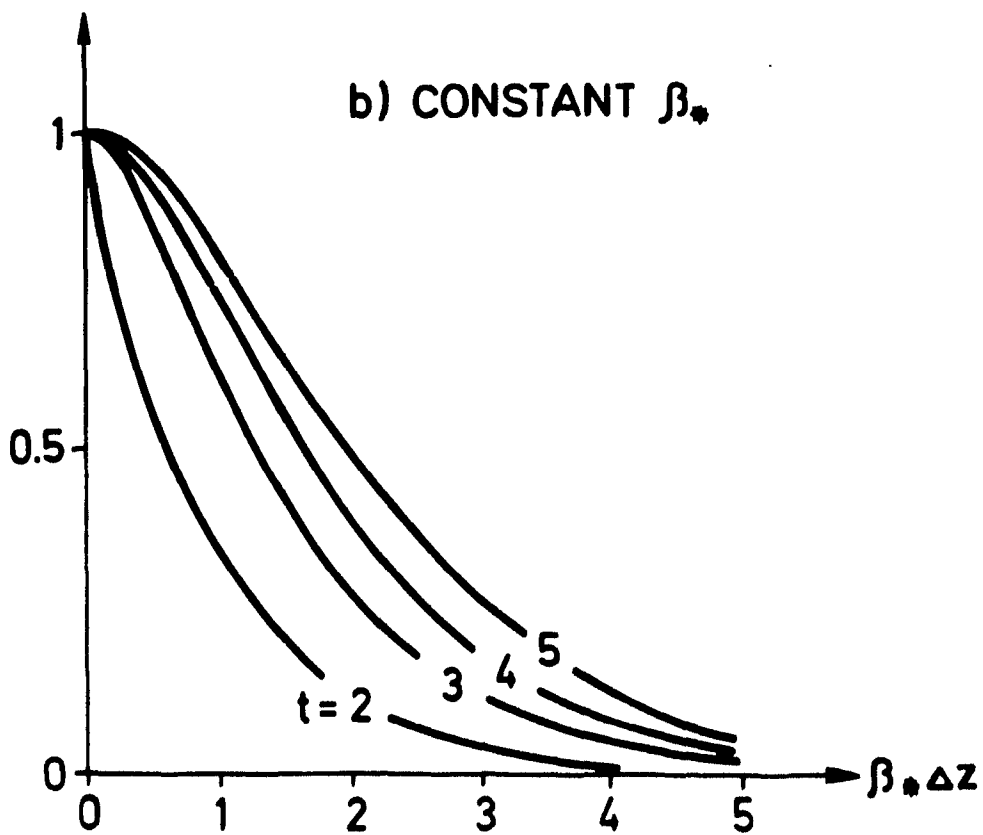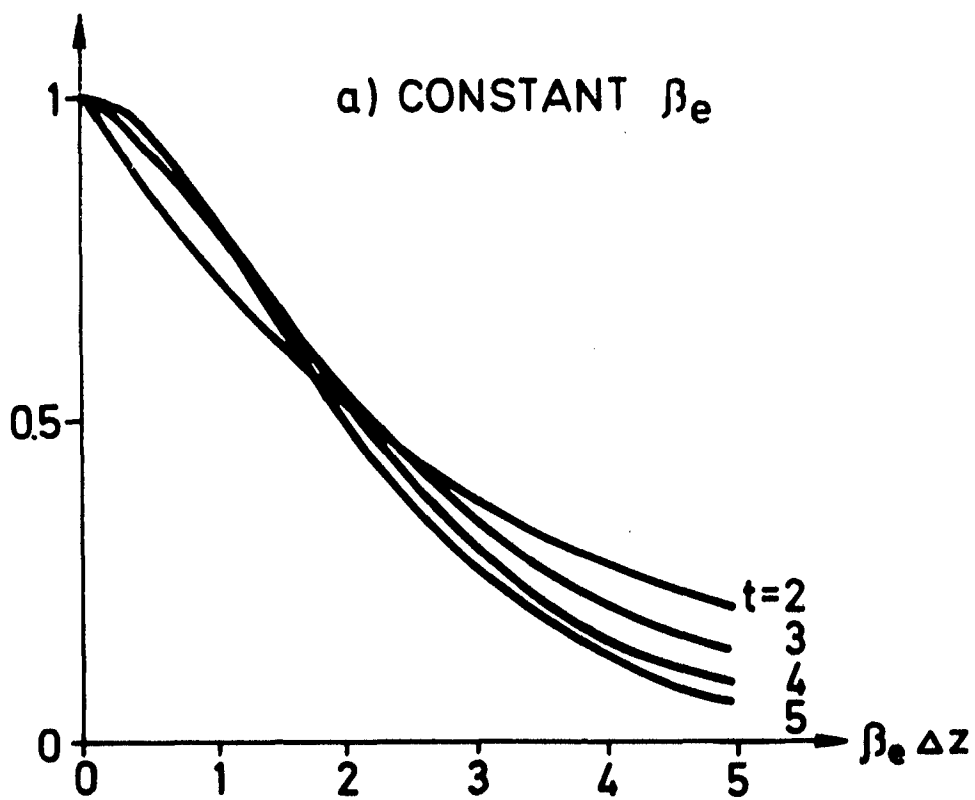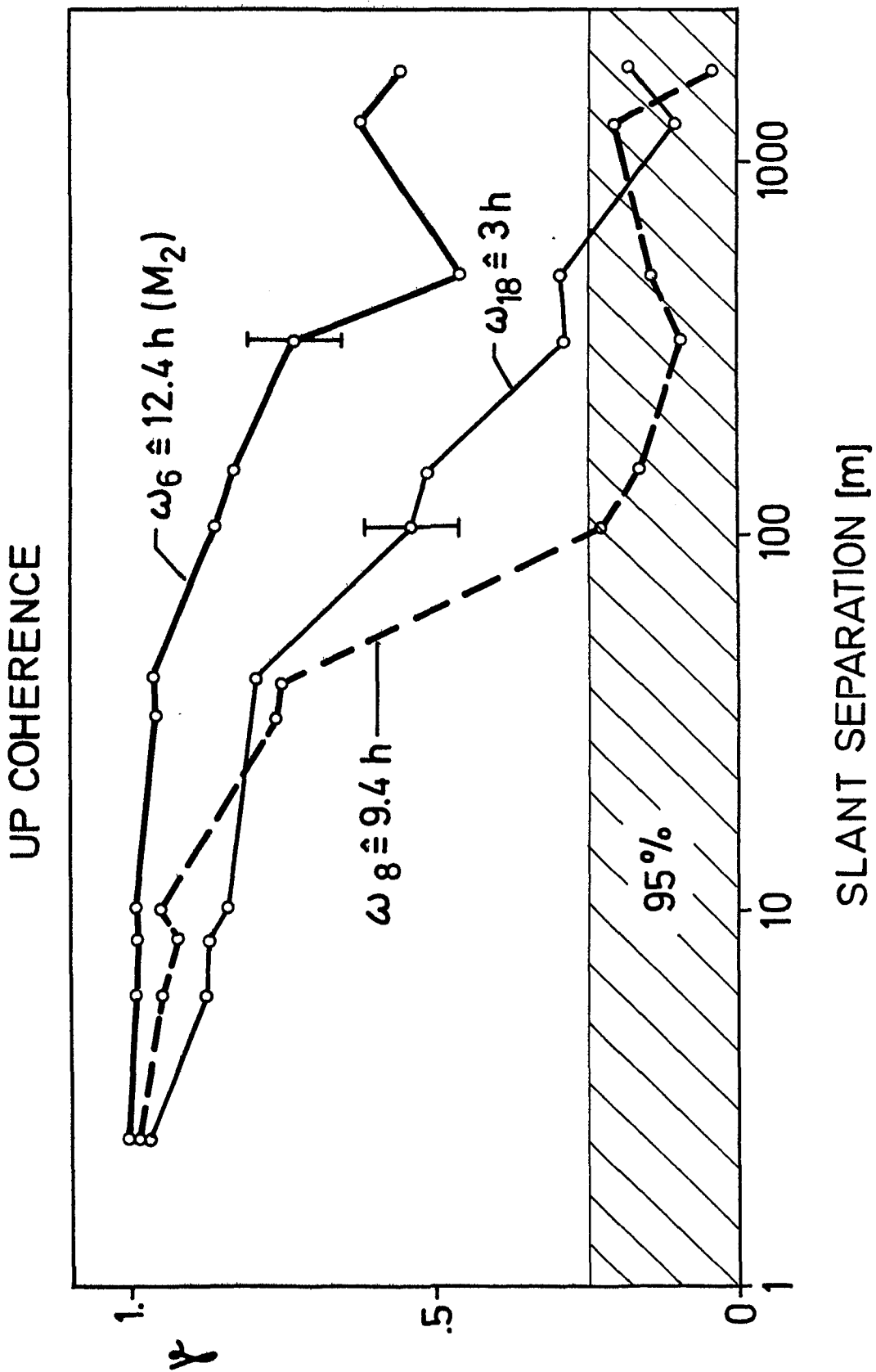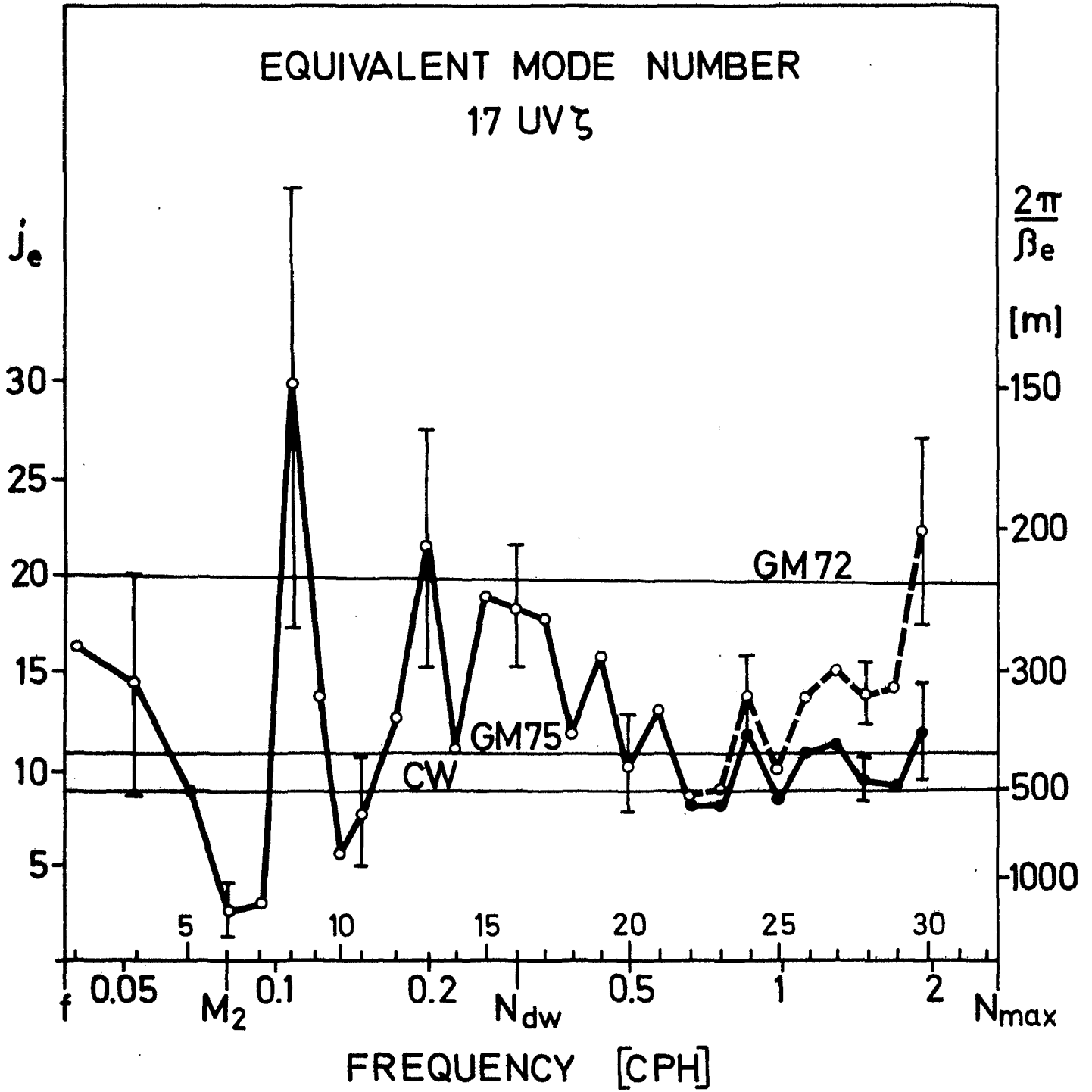
Fig. I.1
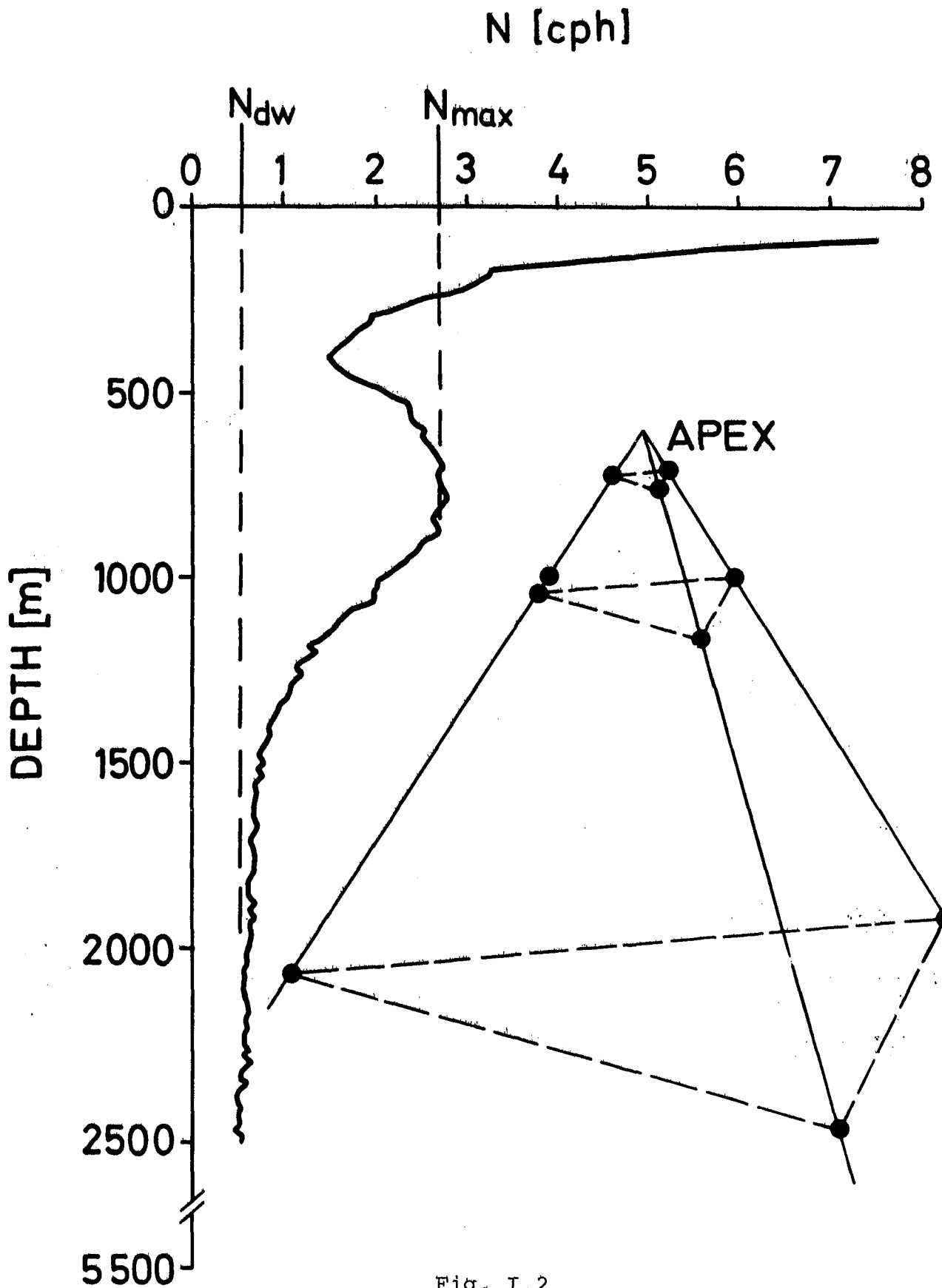
Fig. I.2

LOW PASSED TEMPERATURE
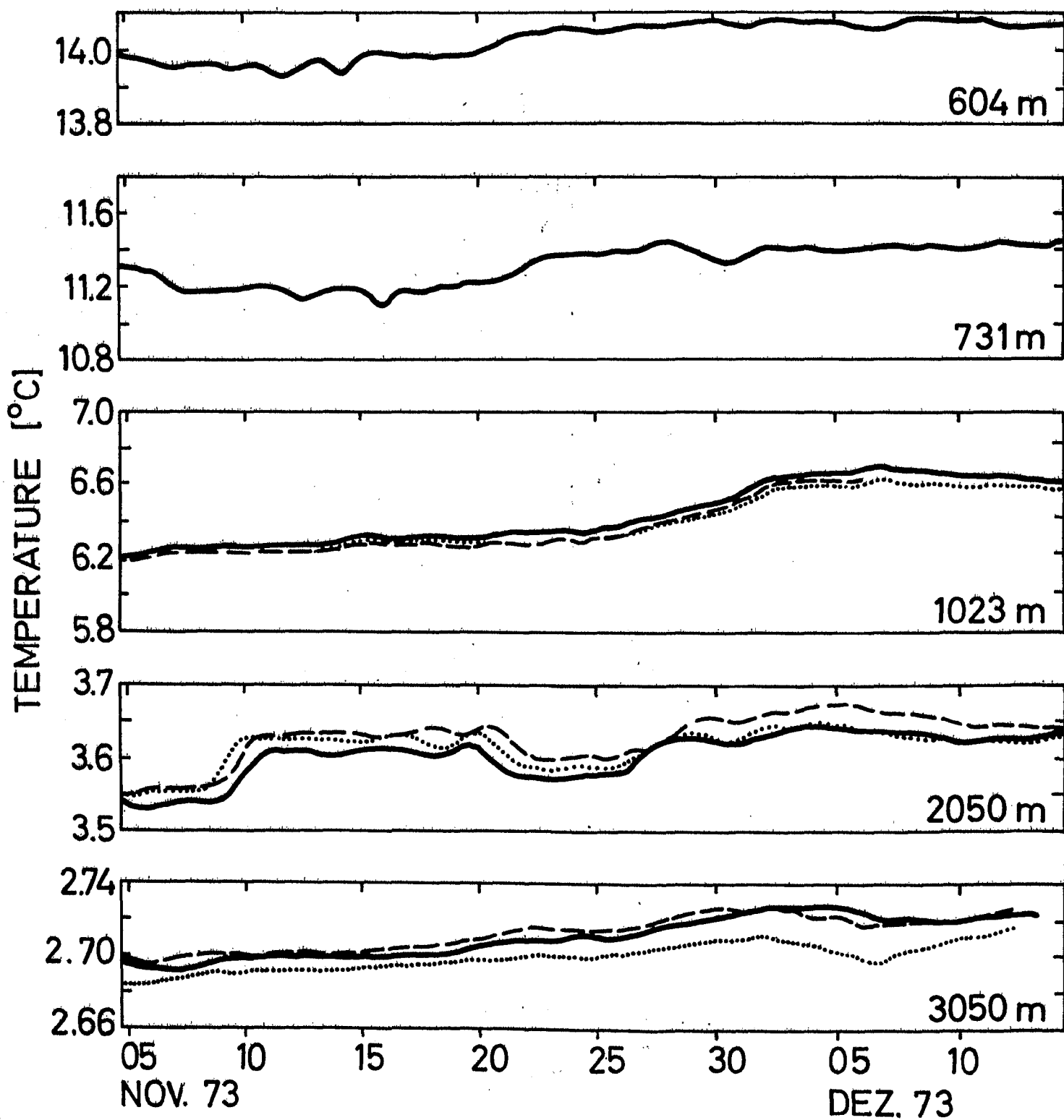
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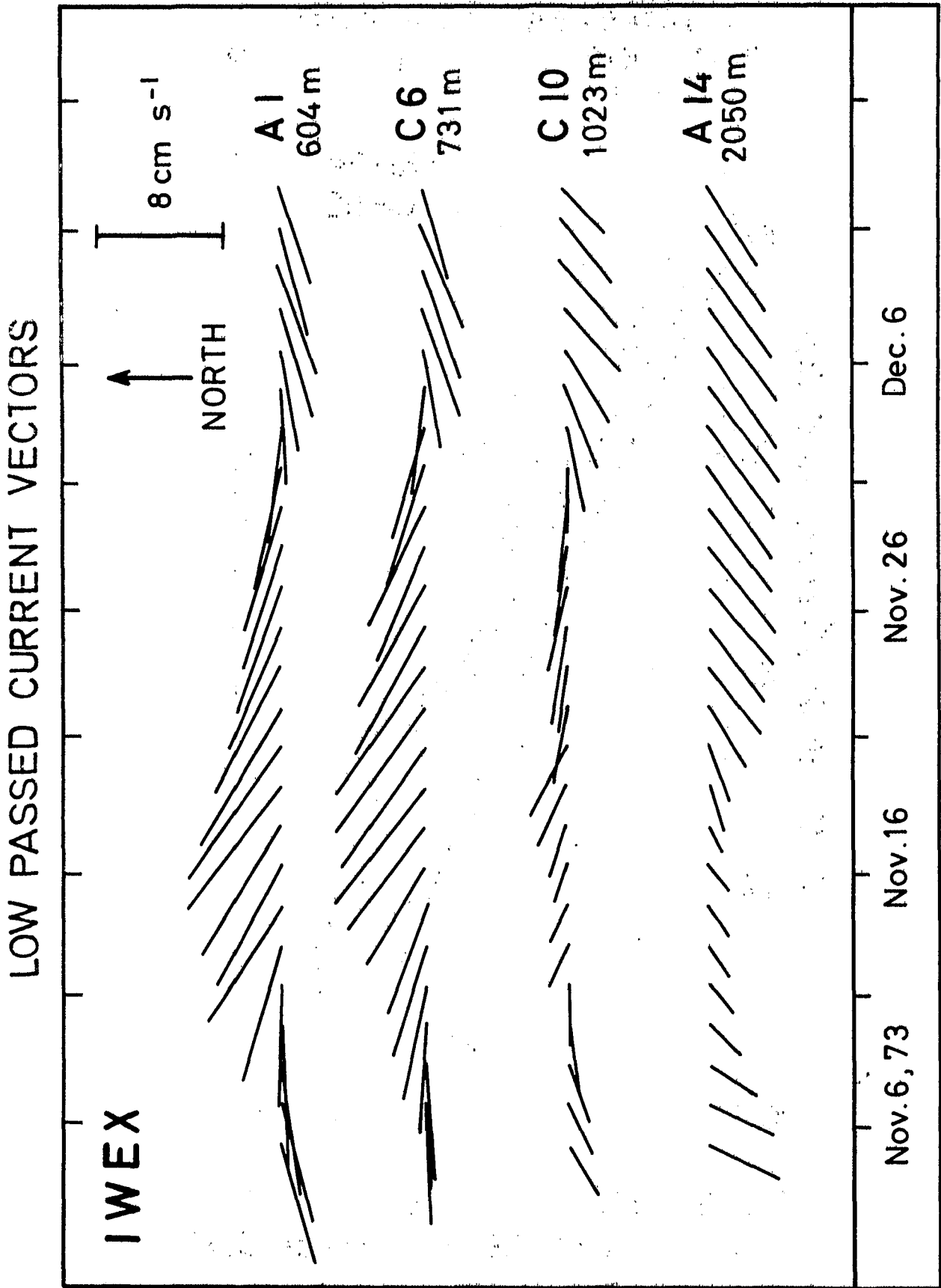
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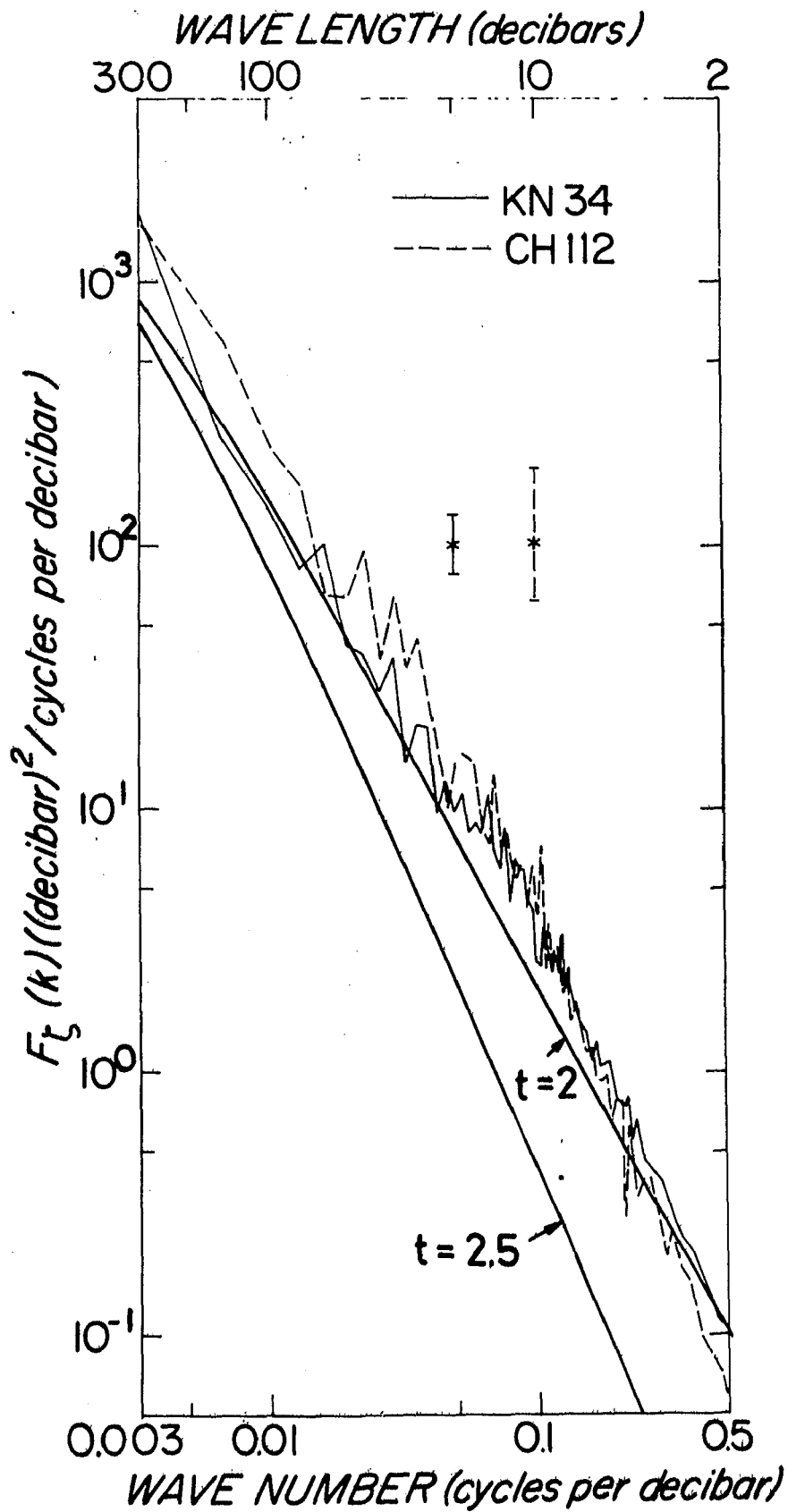
Fig. I.4

Fig. I.5

Fig. I.6

Fig. I.7

Fig. I.8

A1-EAST   A4-EAST

A1-EAST   A5-EAST

C5-EAST   C6-EAST
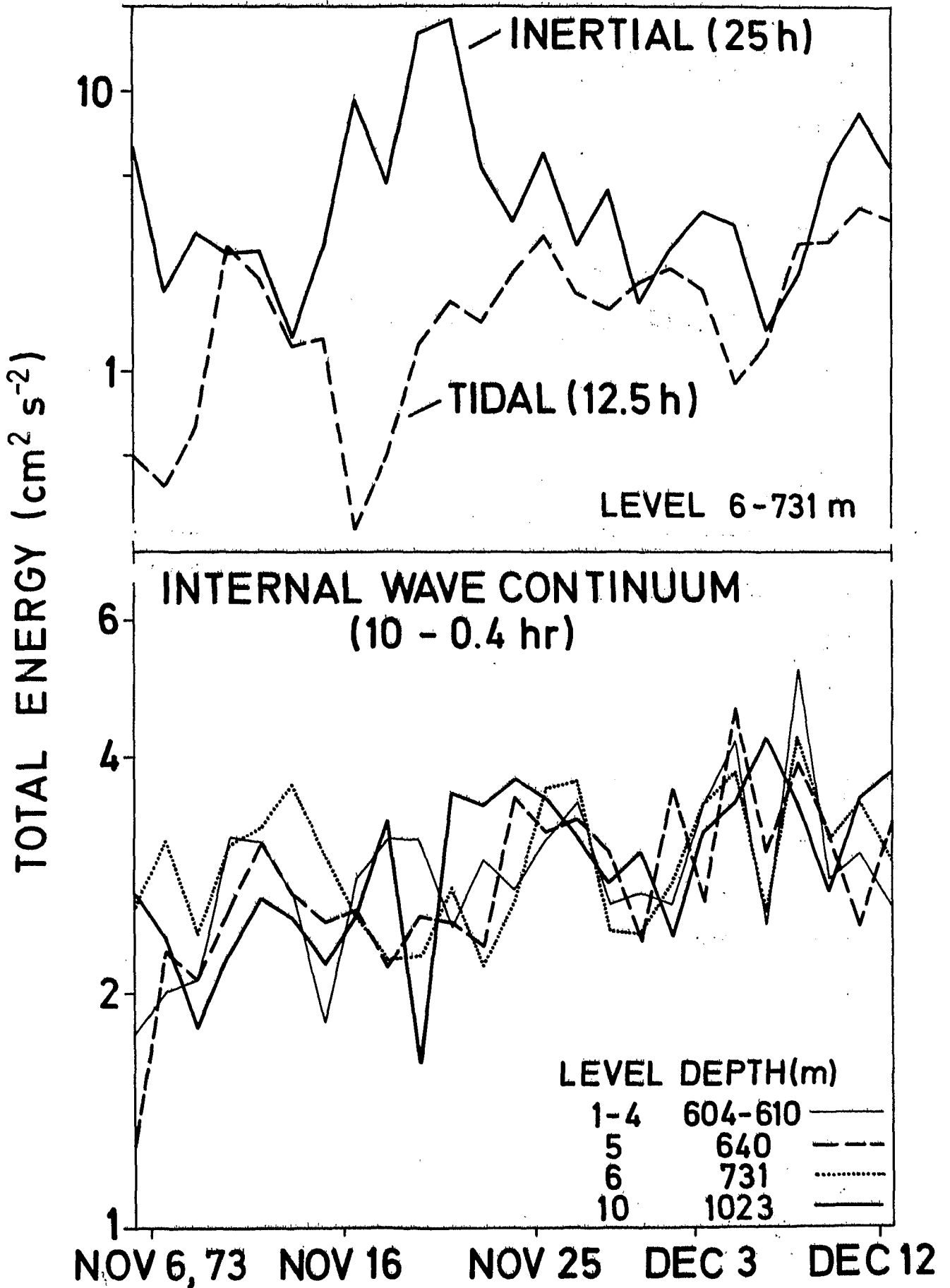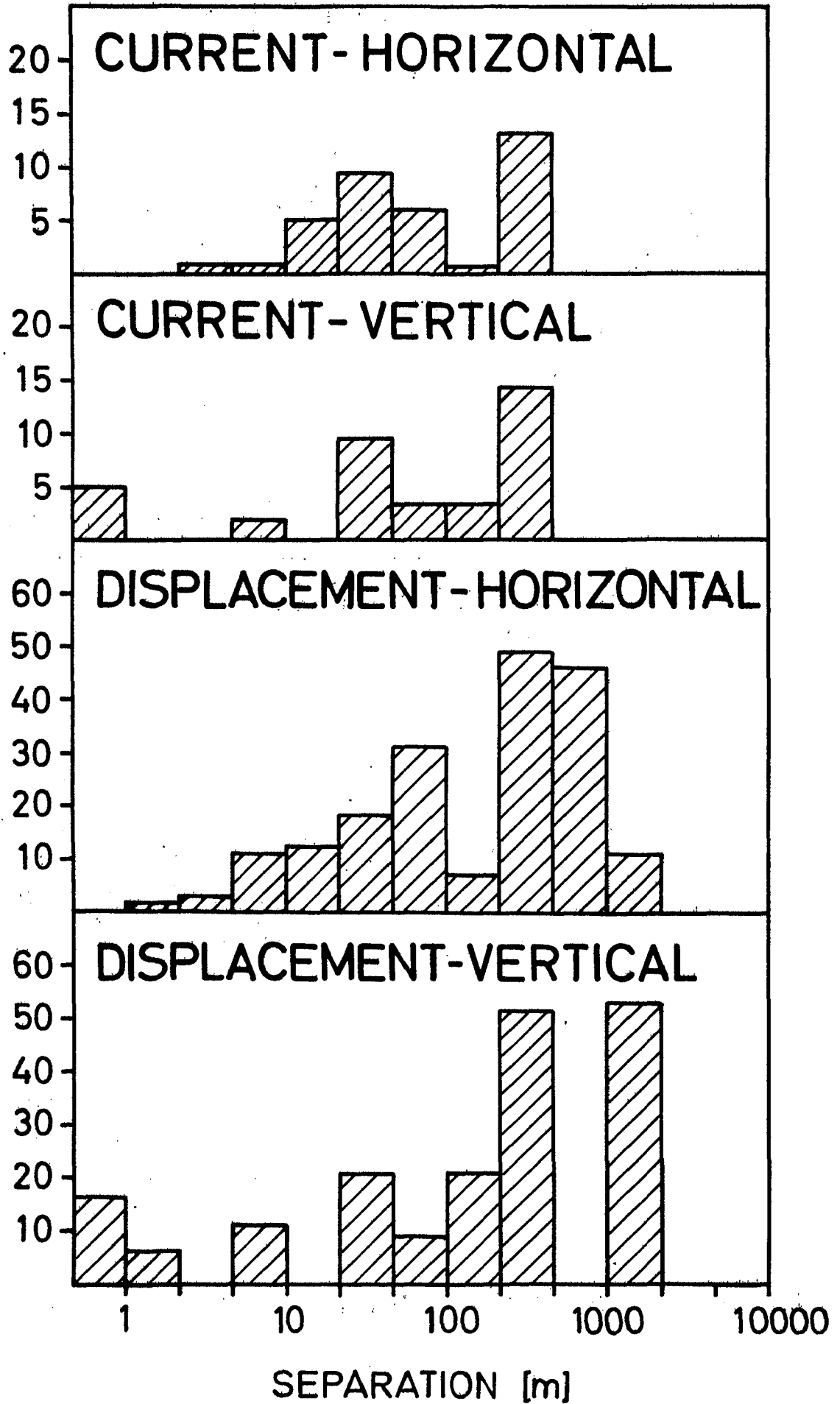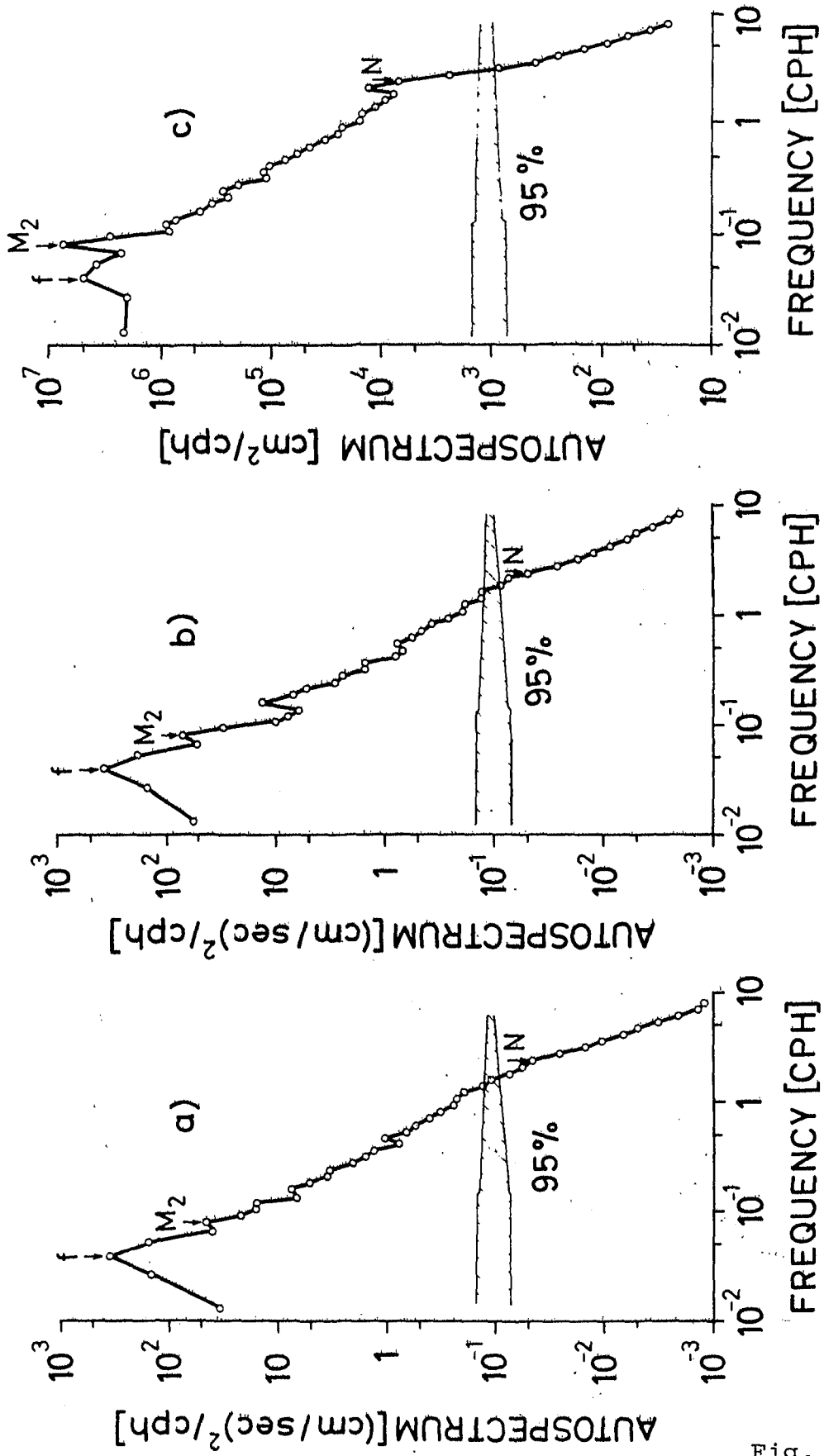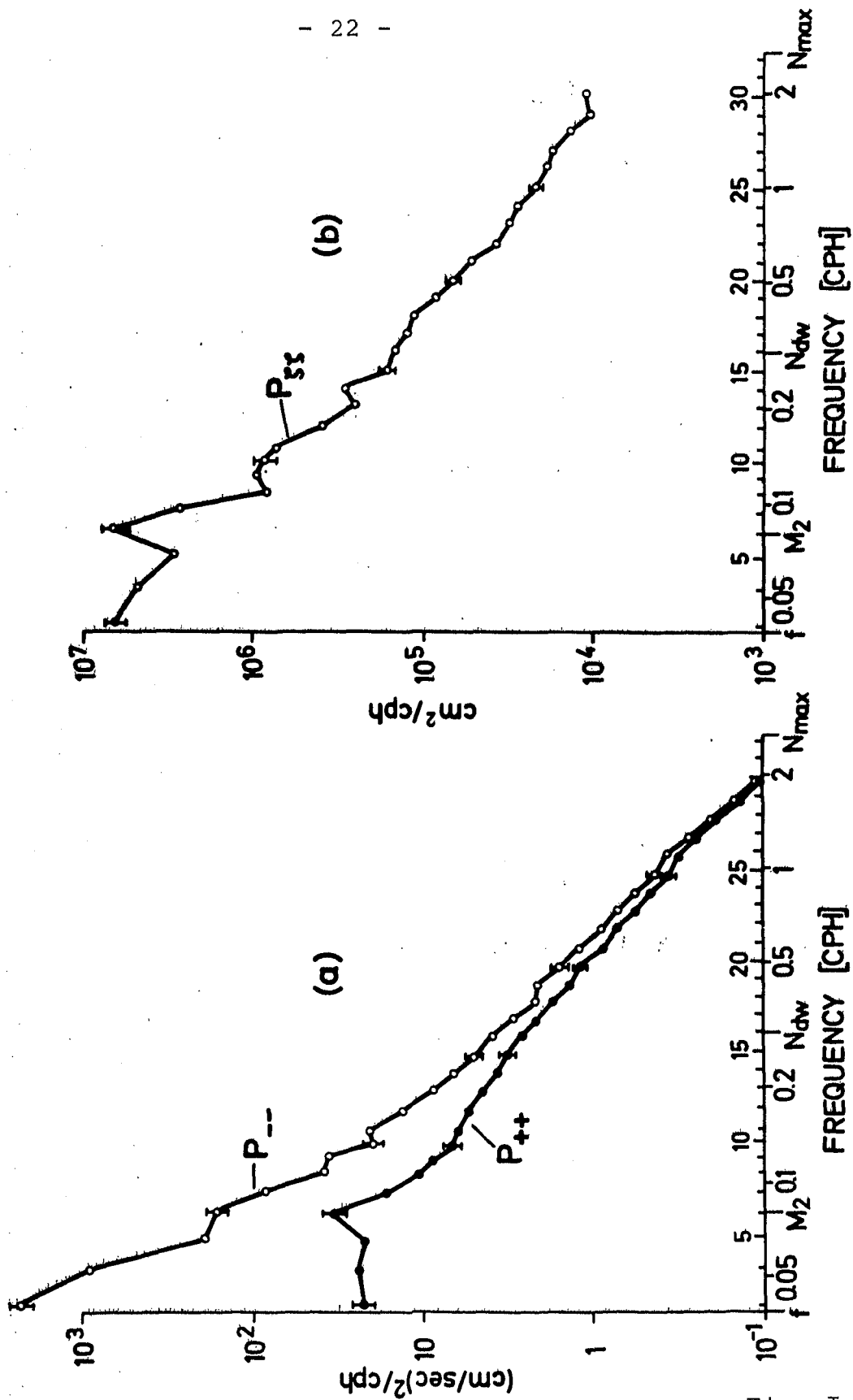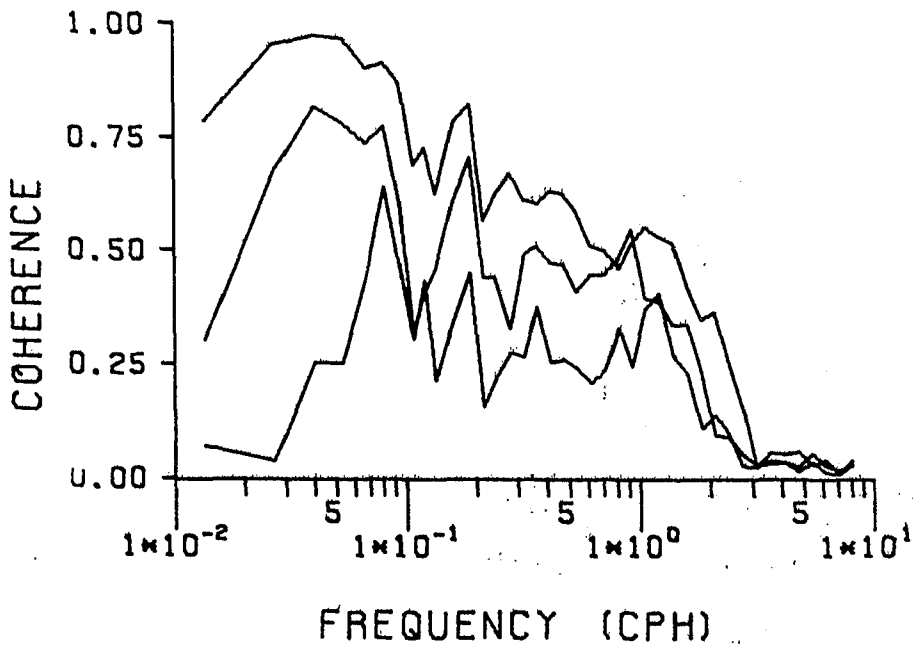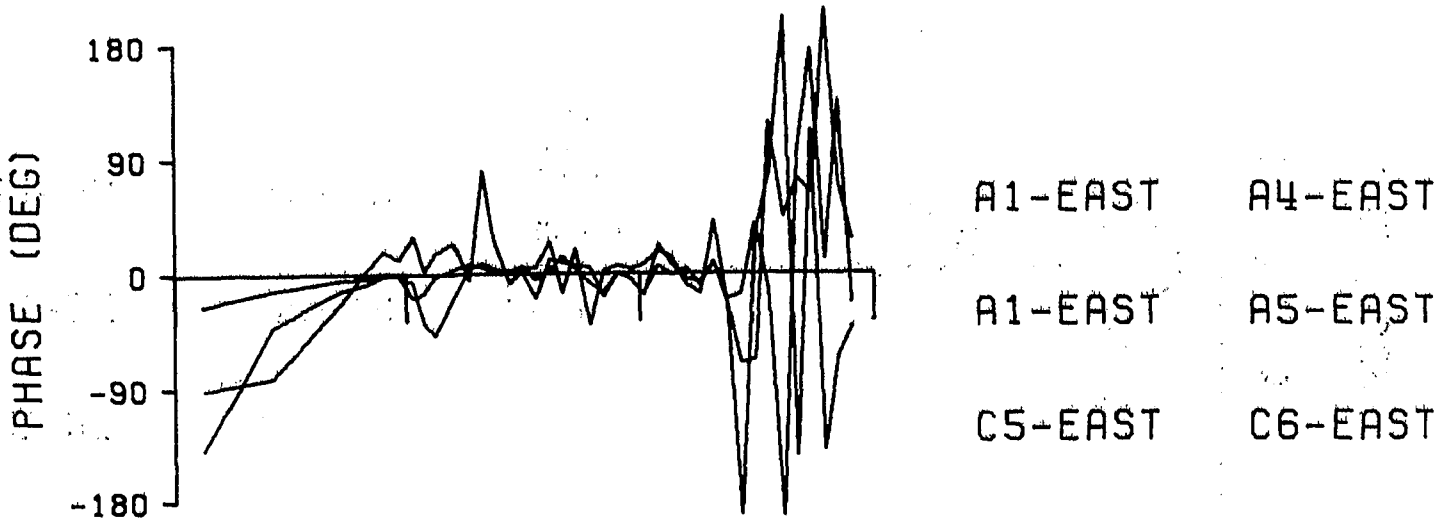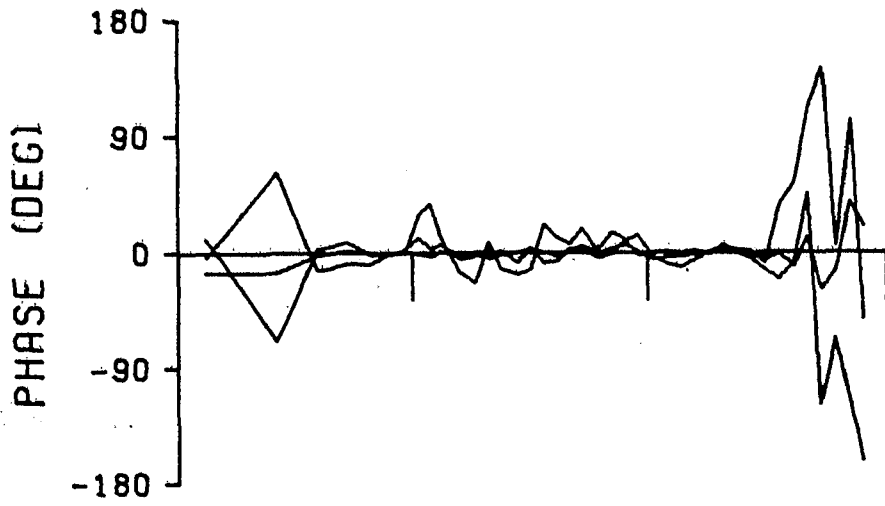
Fig. I.9a

A1-UP   A4-UP

A1-UP   A5-UP

C5-UP   C6-UP
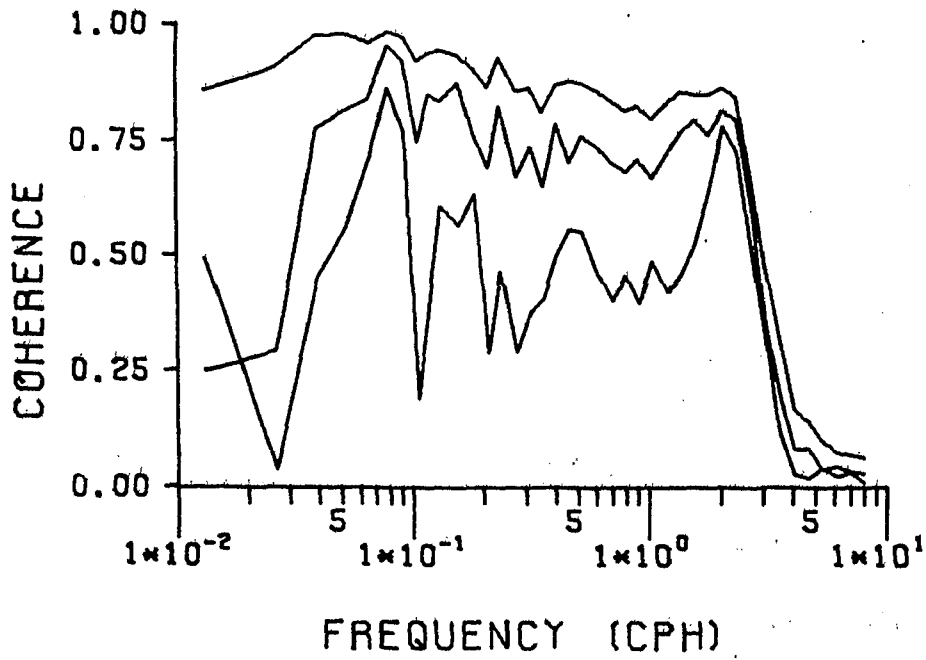
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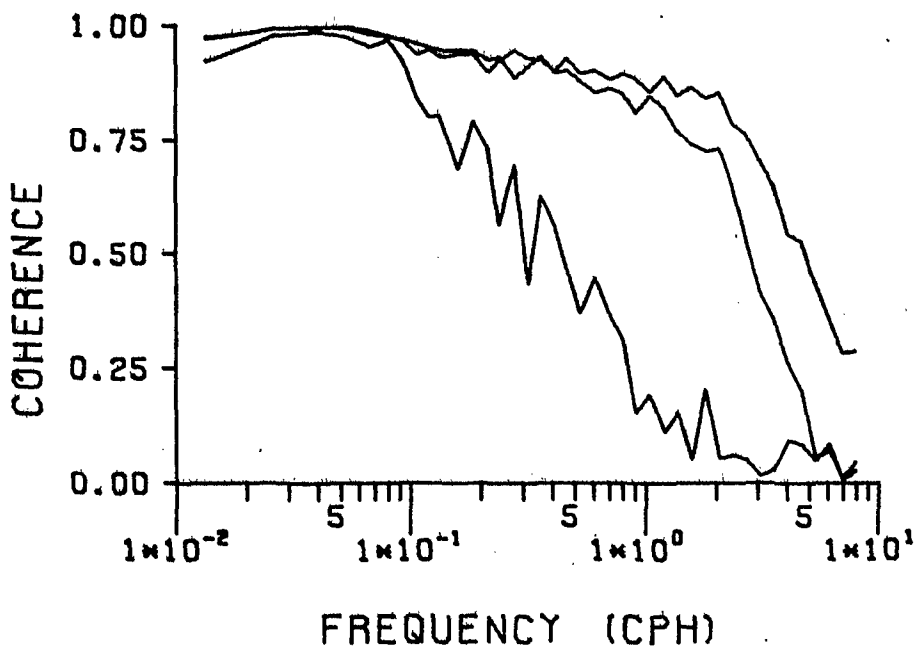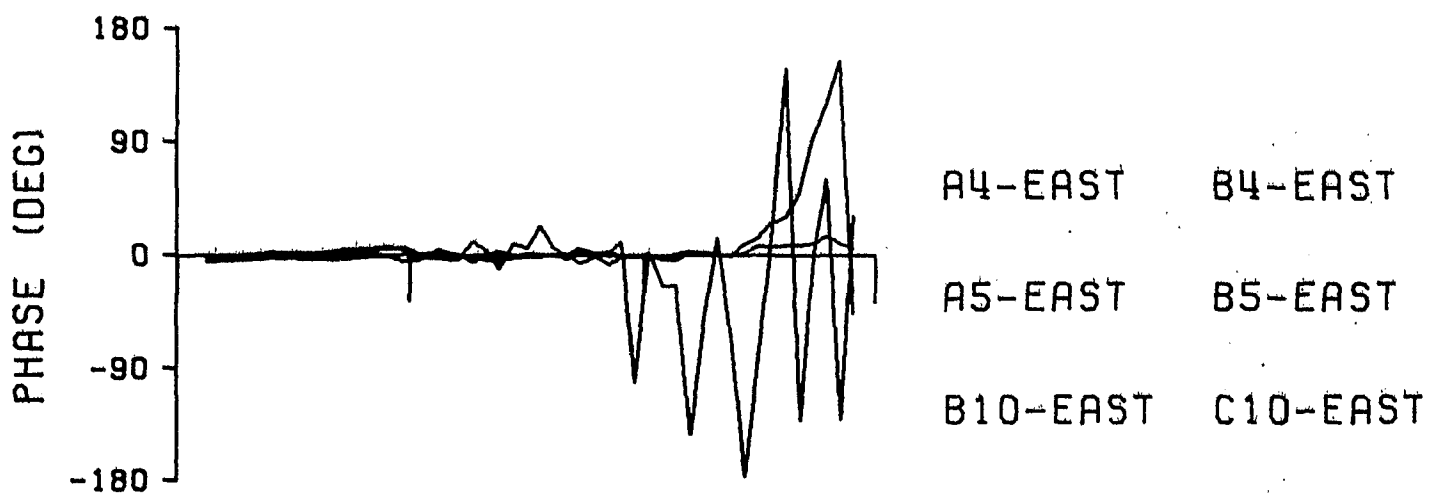
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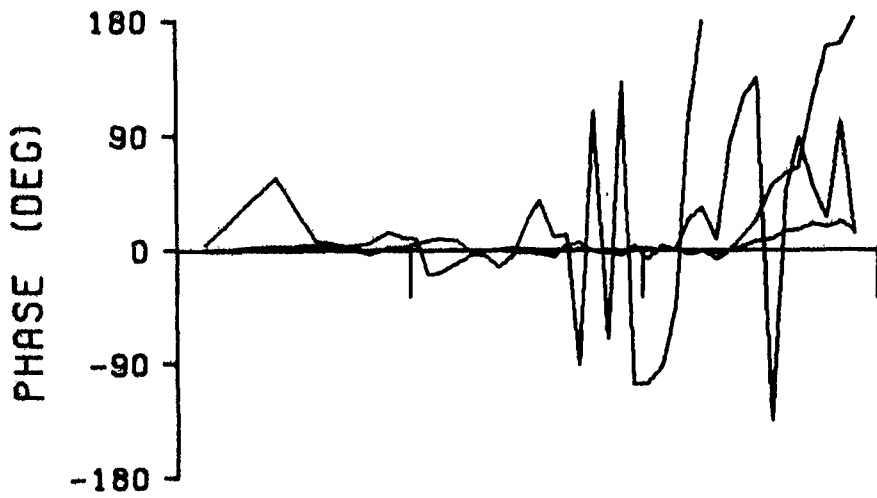
A4-UP   B4-UP

A5-UP   B5-UP

A10-UP   B10-UP

A14-UP   B14-UP
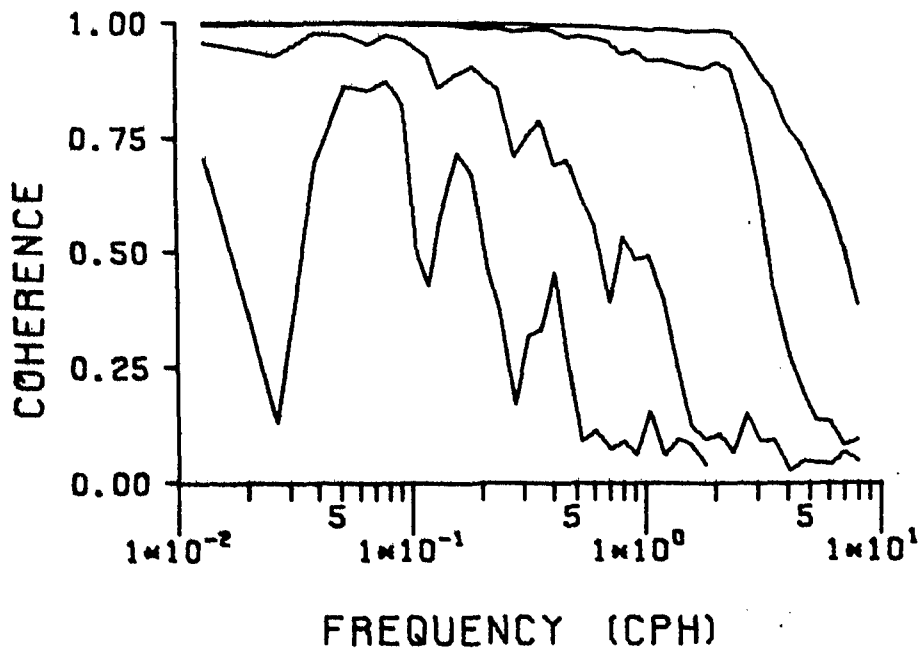
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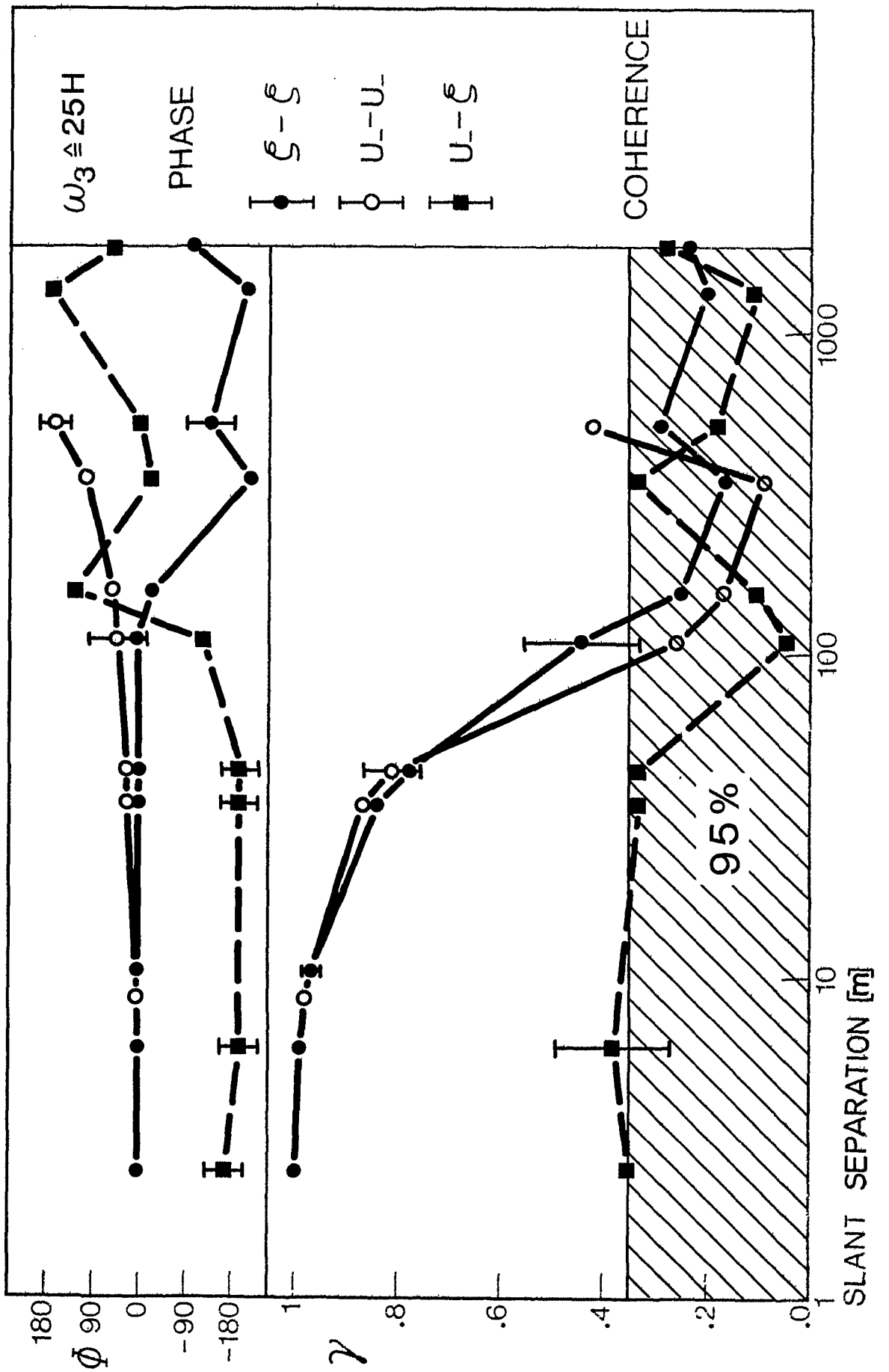
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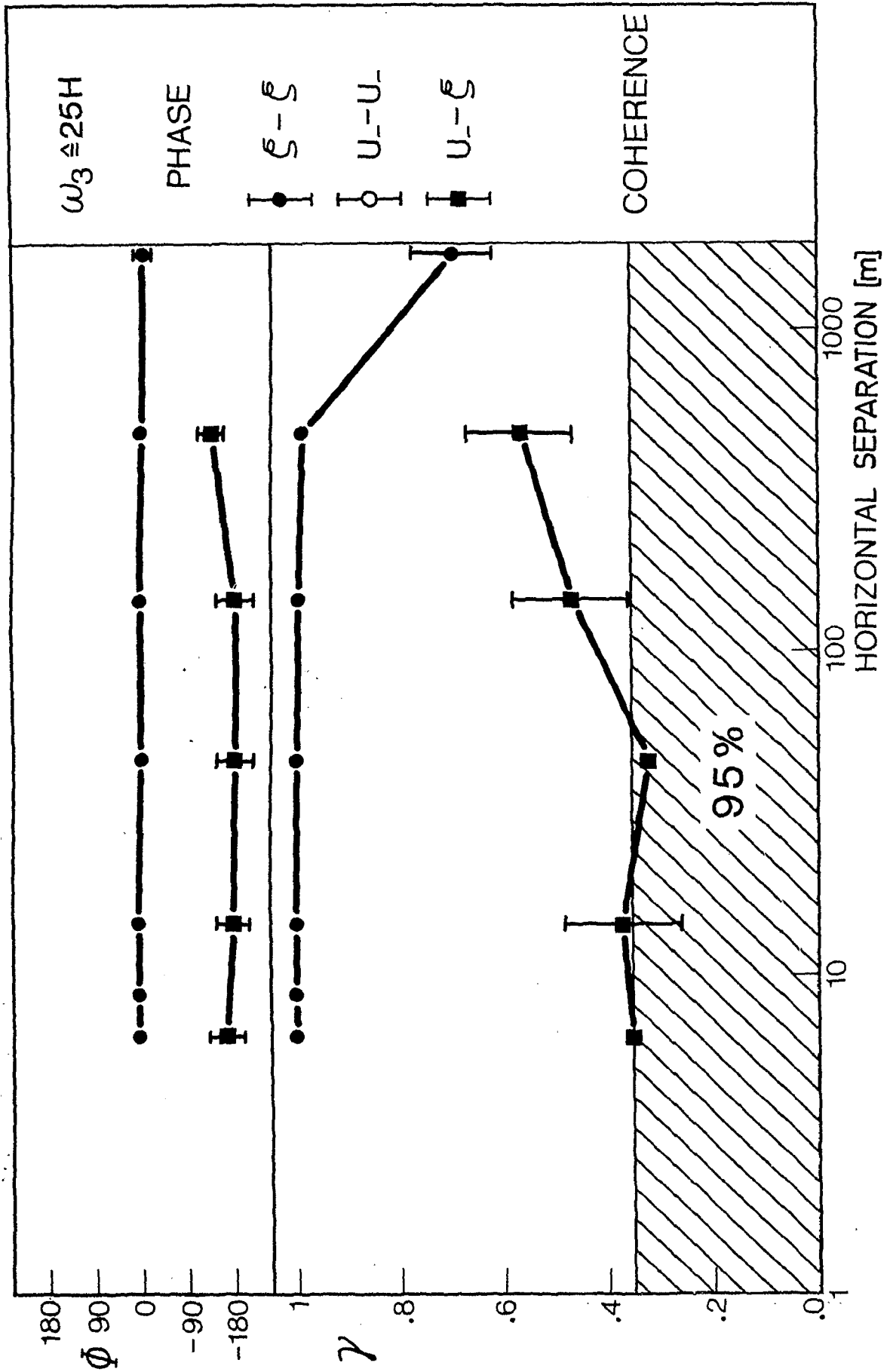
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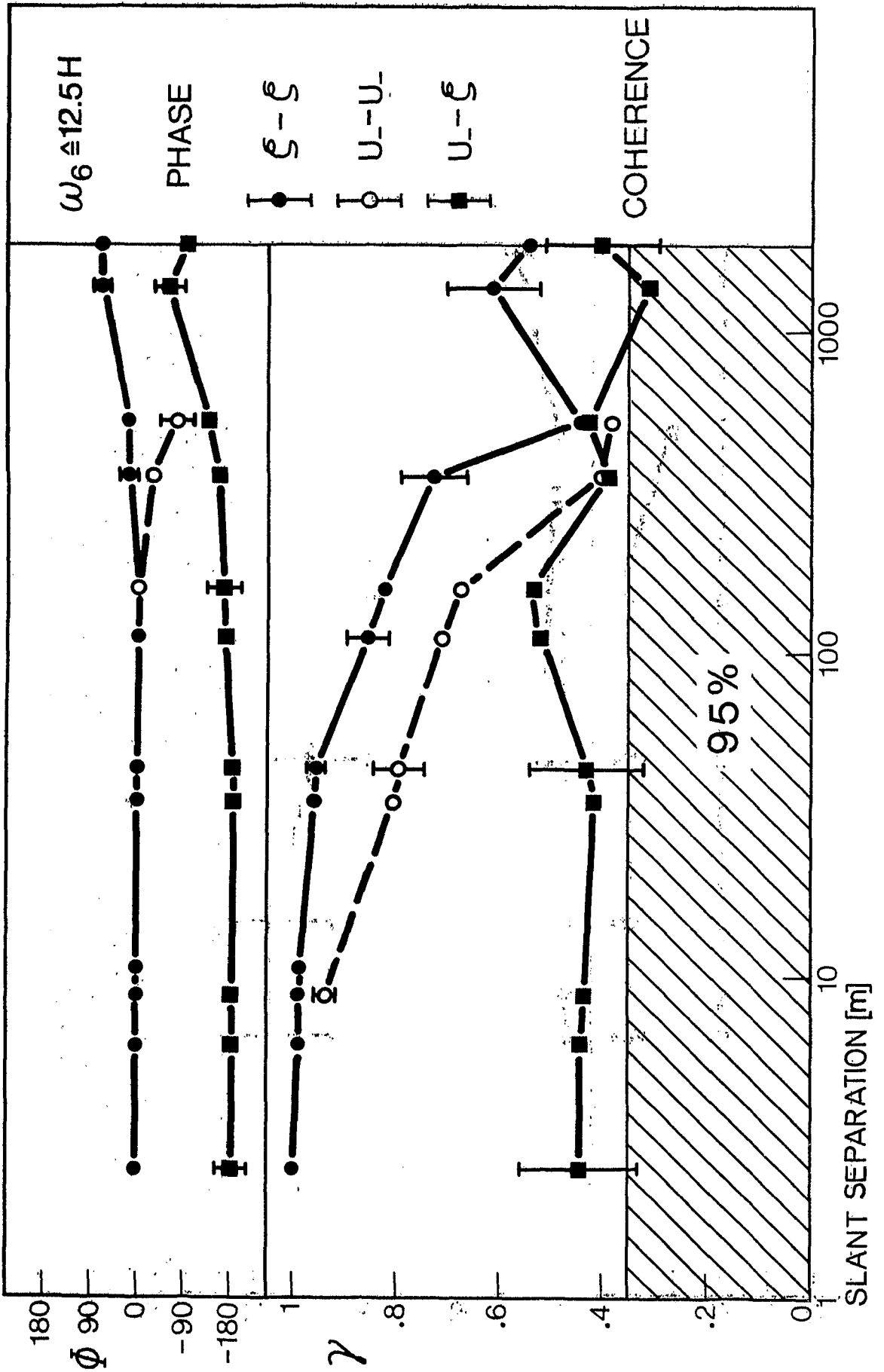
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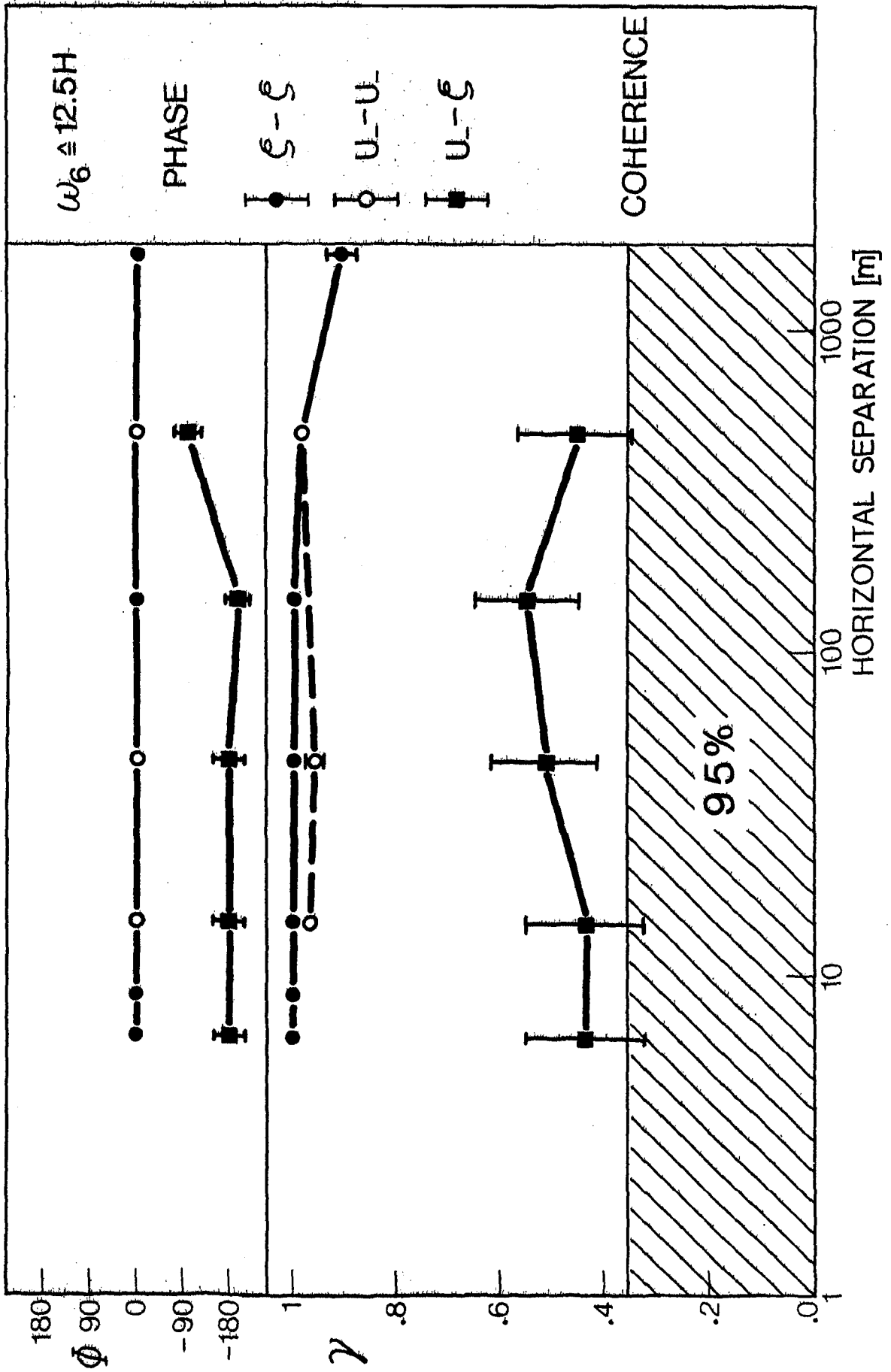
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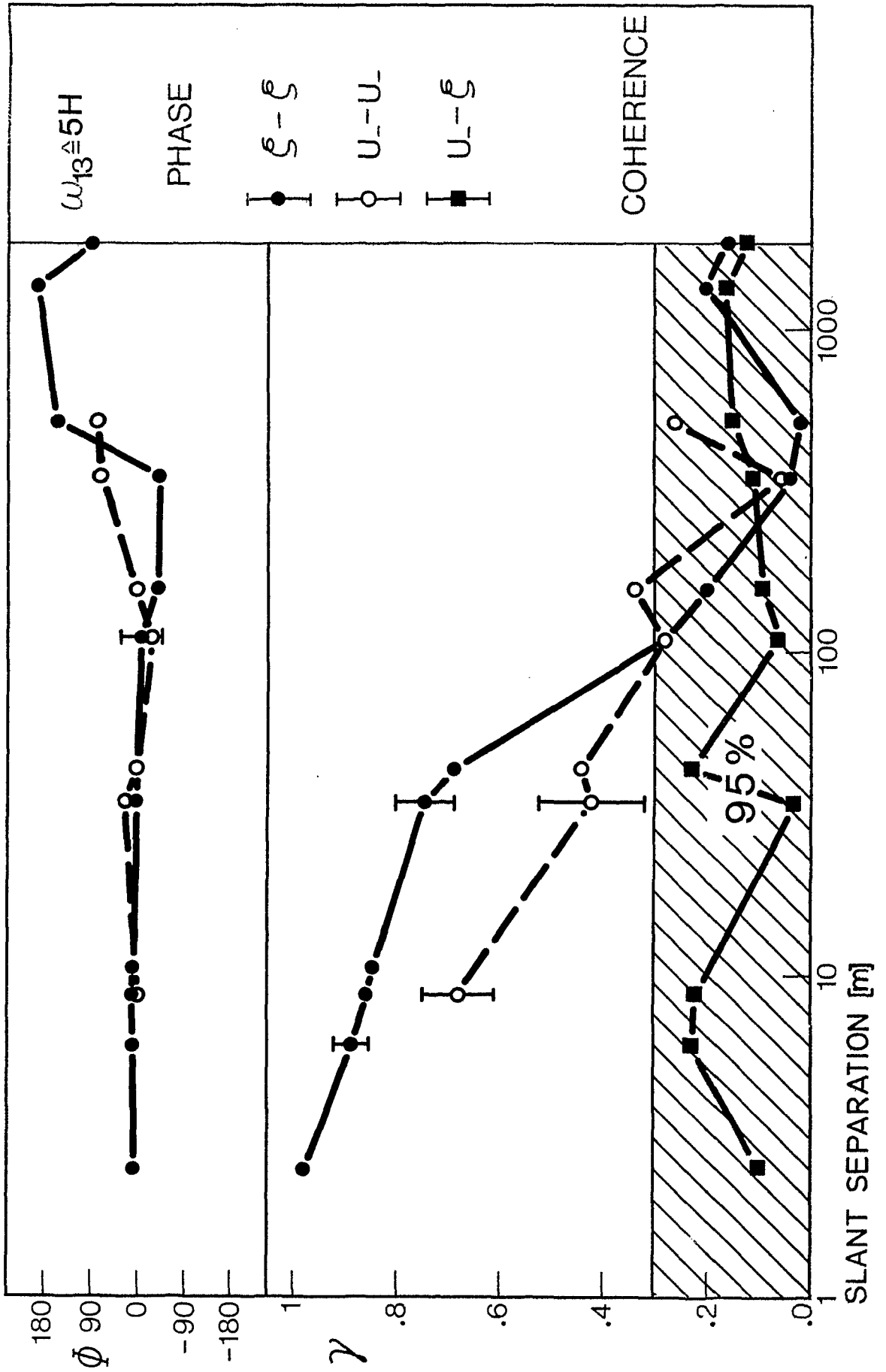
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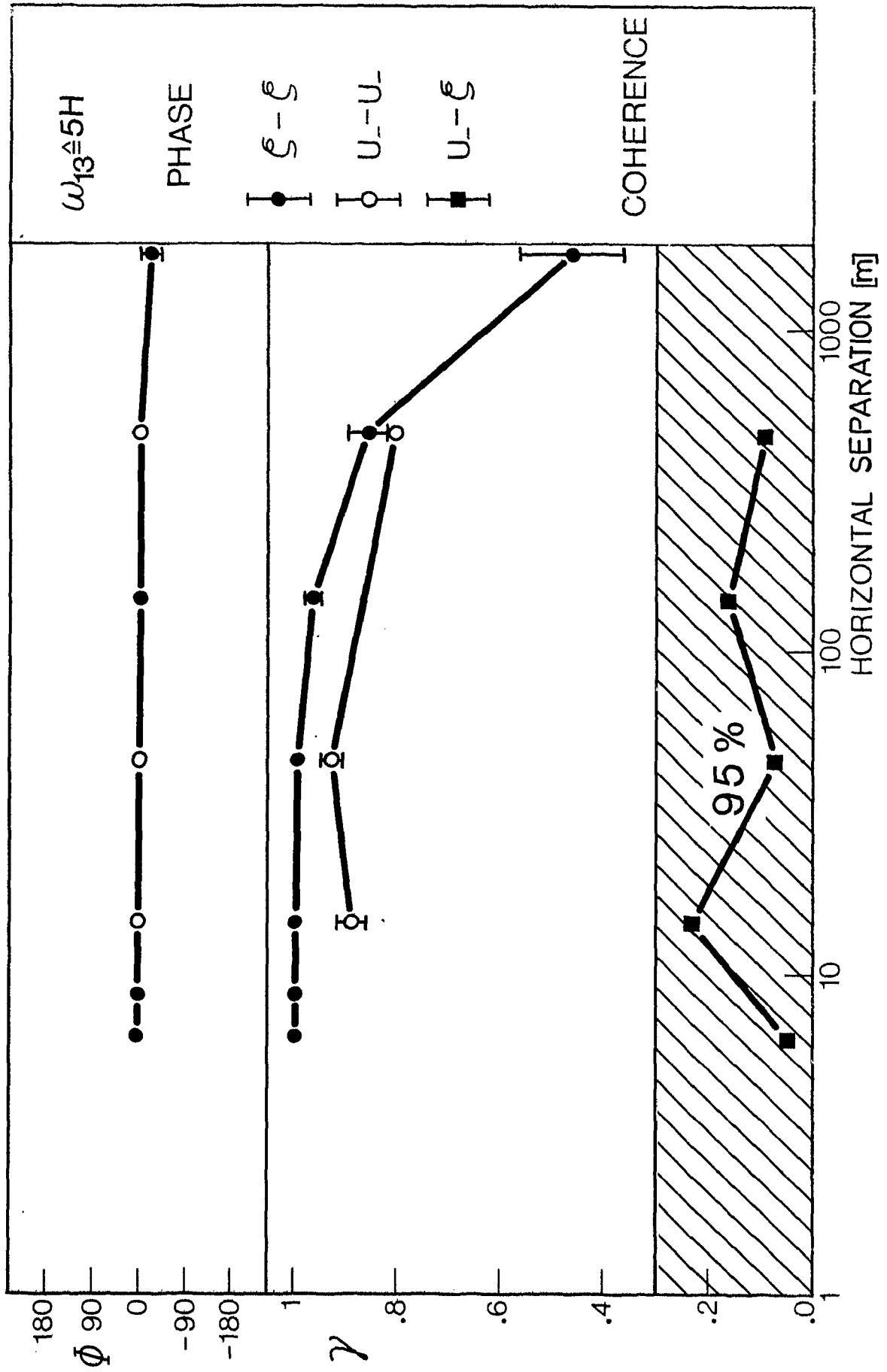
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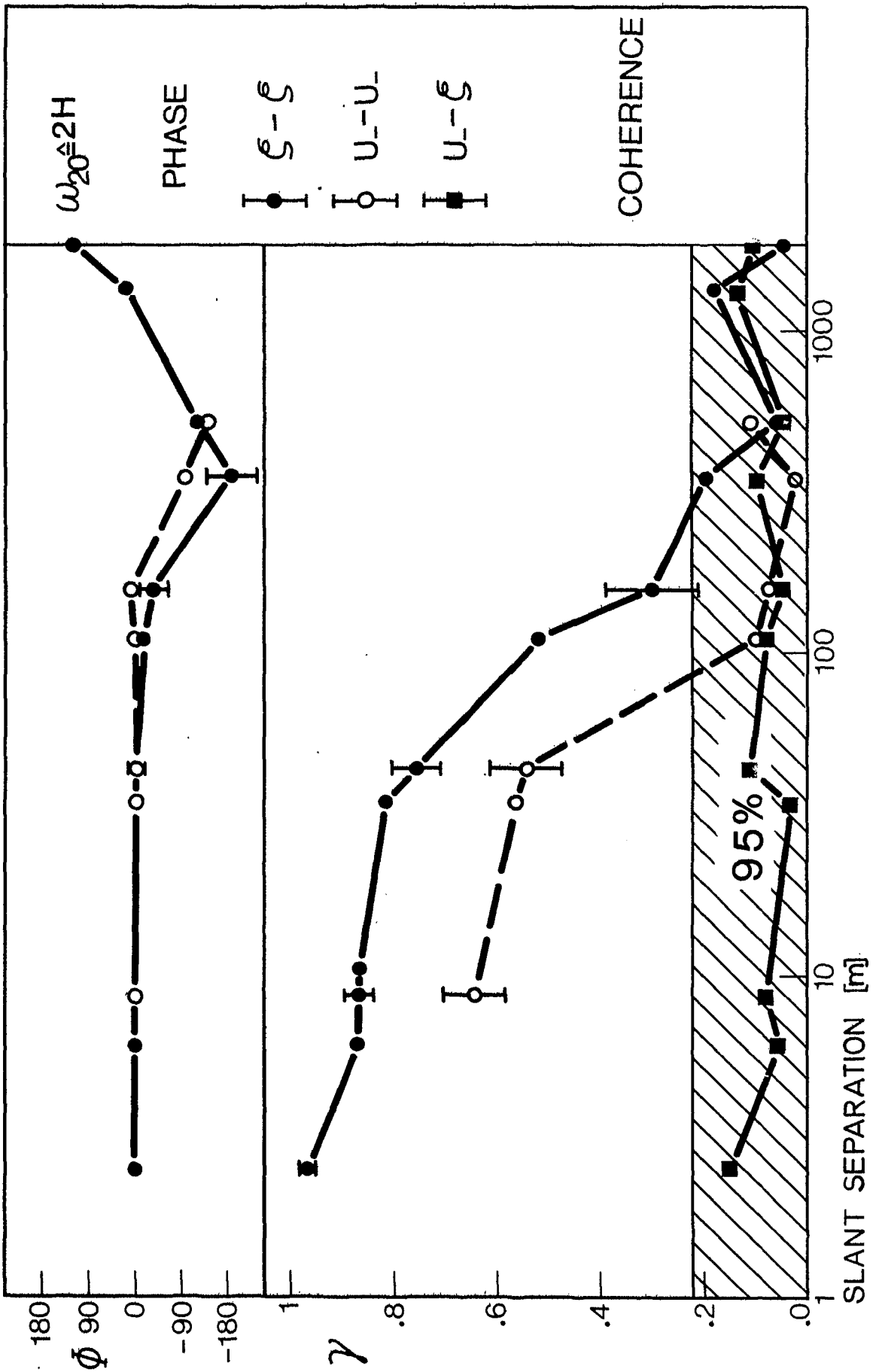
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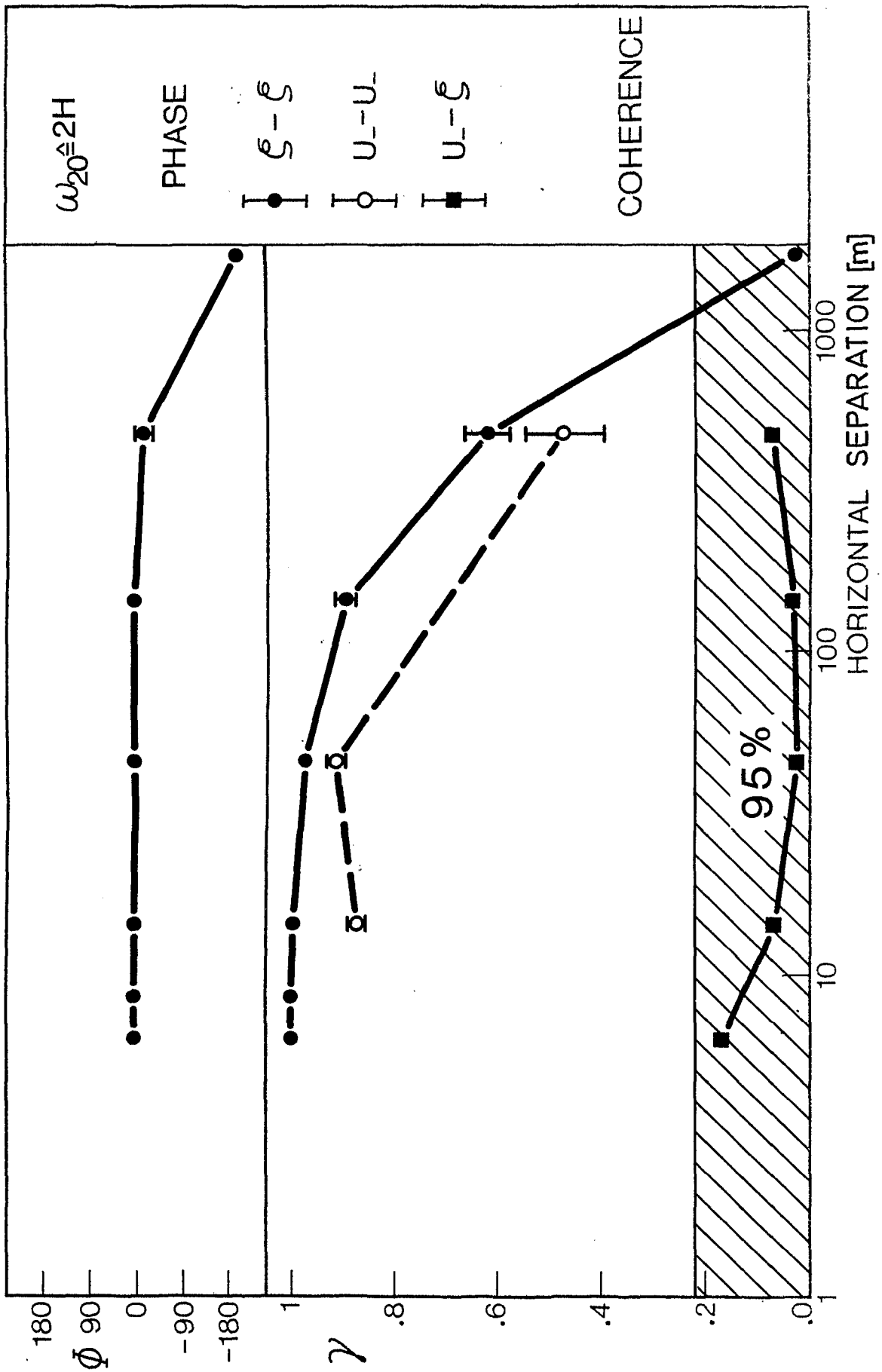
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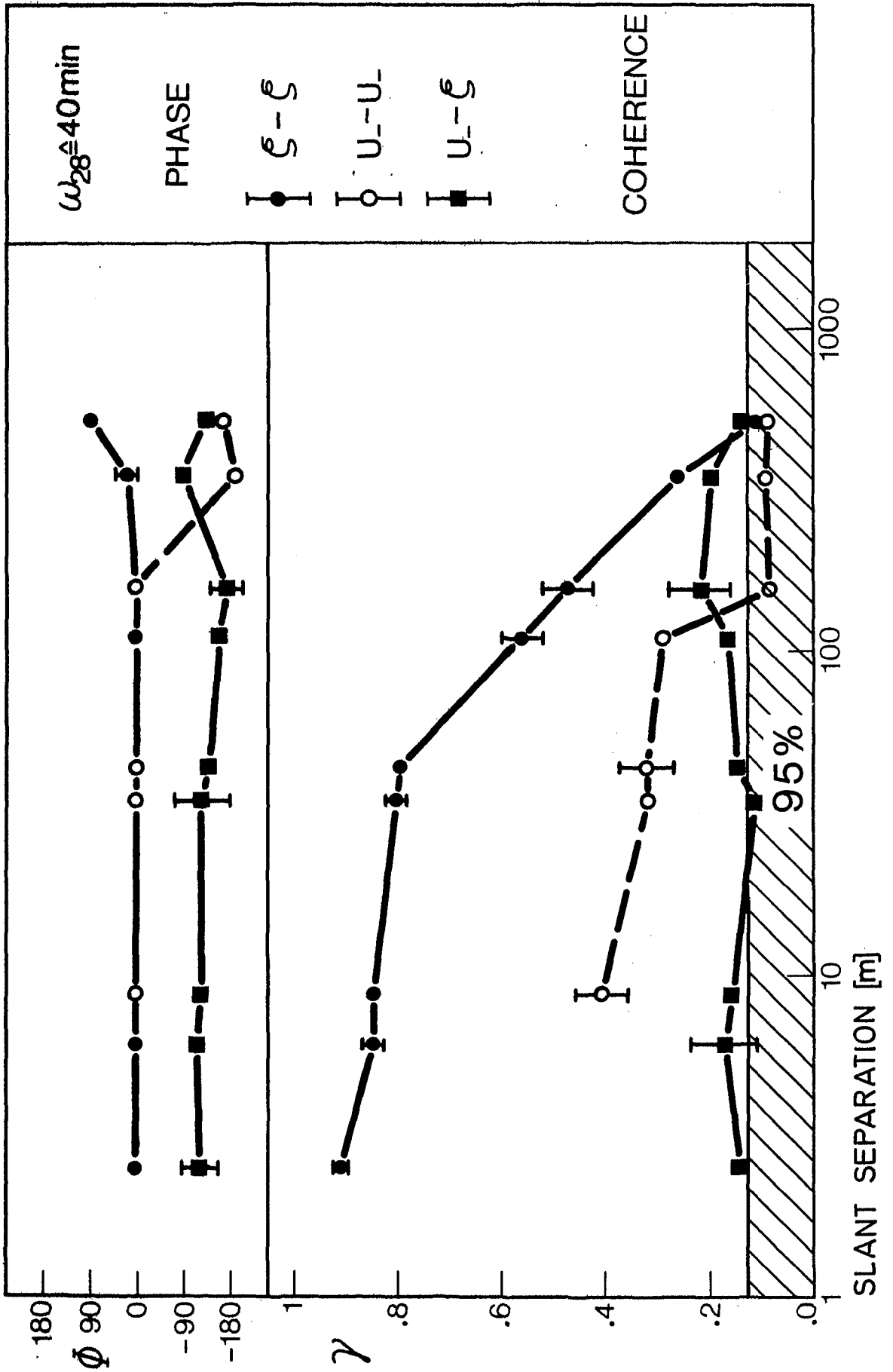
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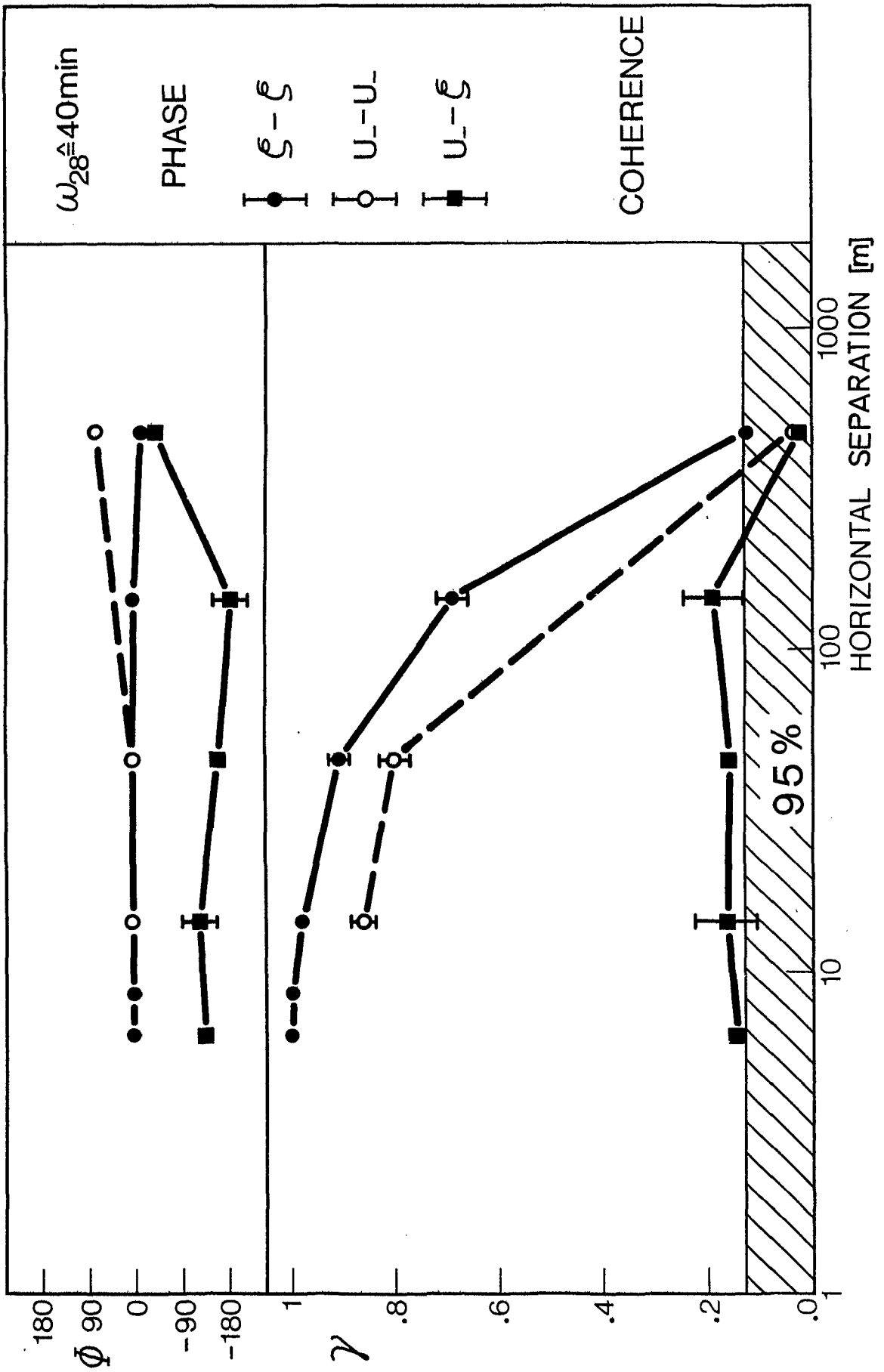
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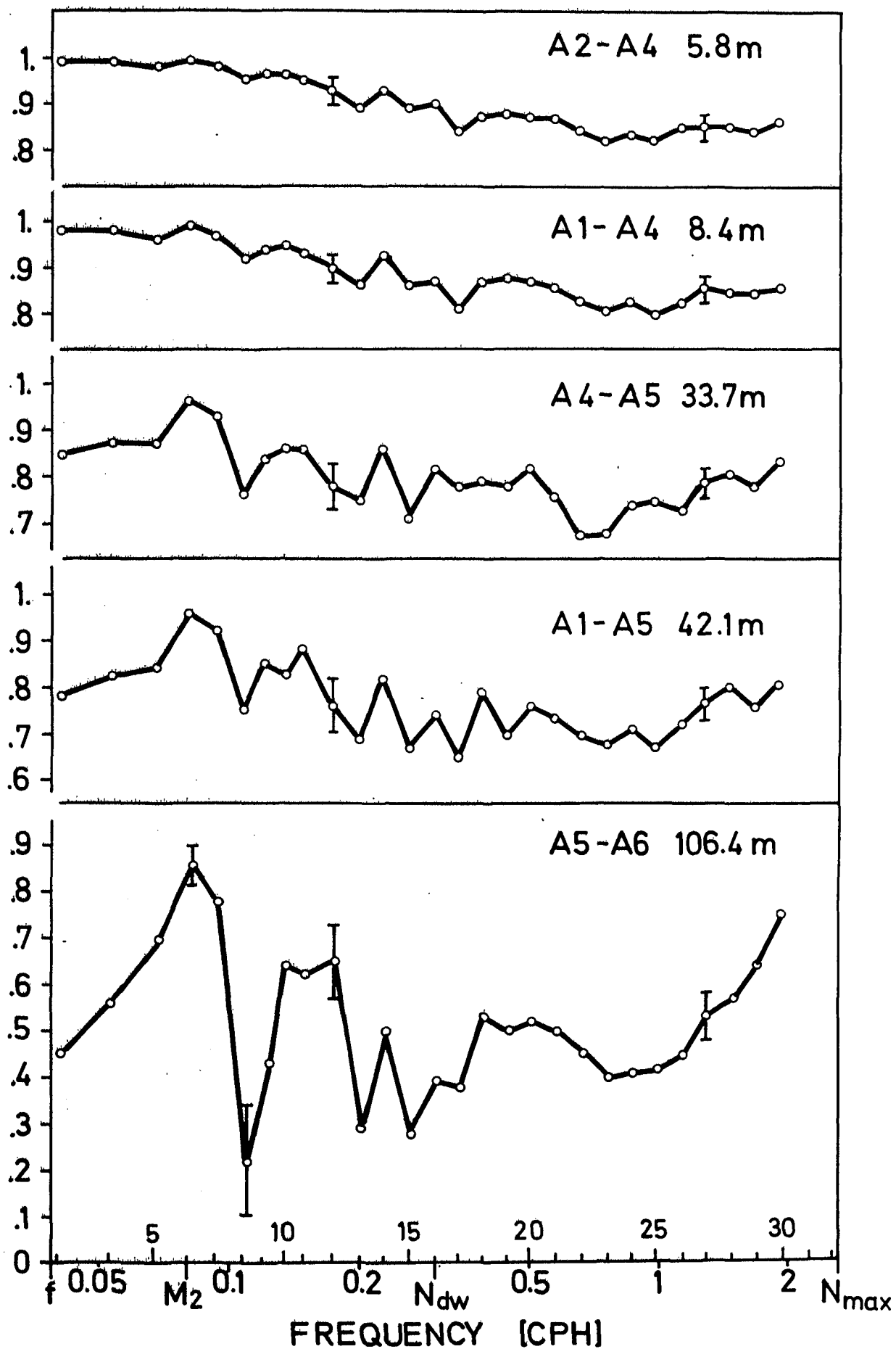
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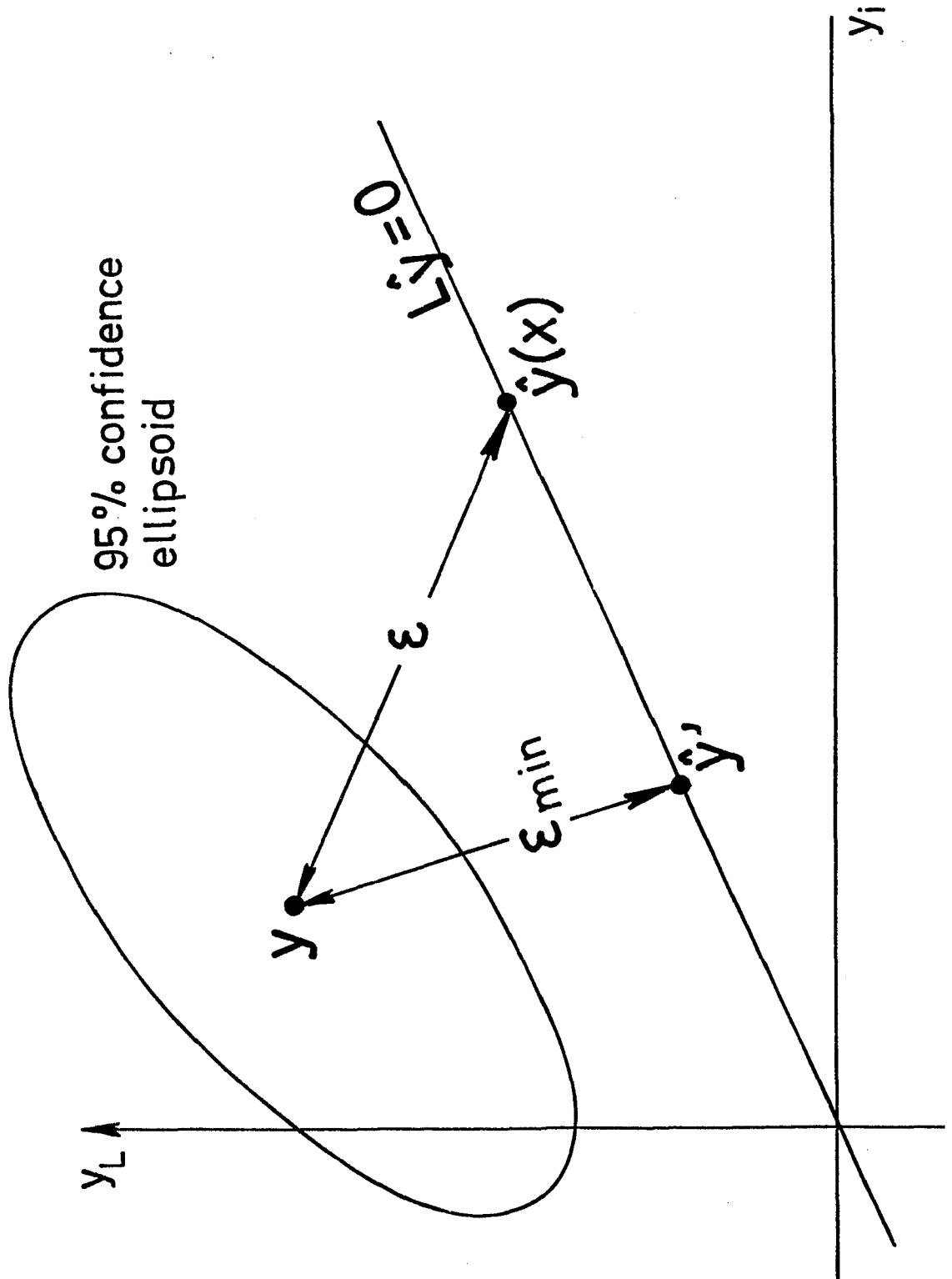
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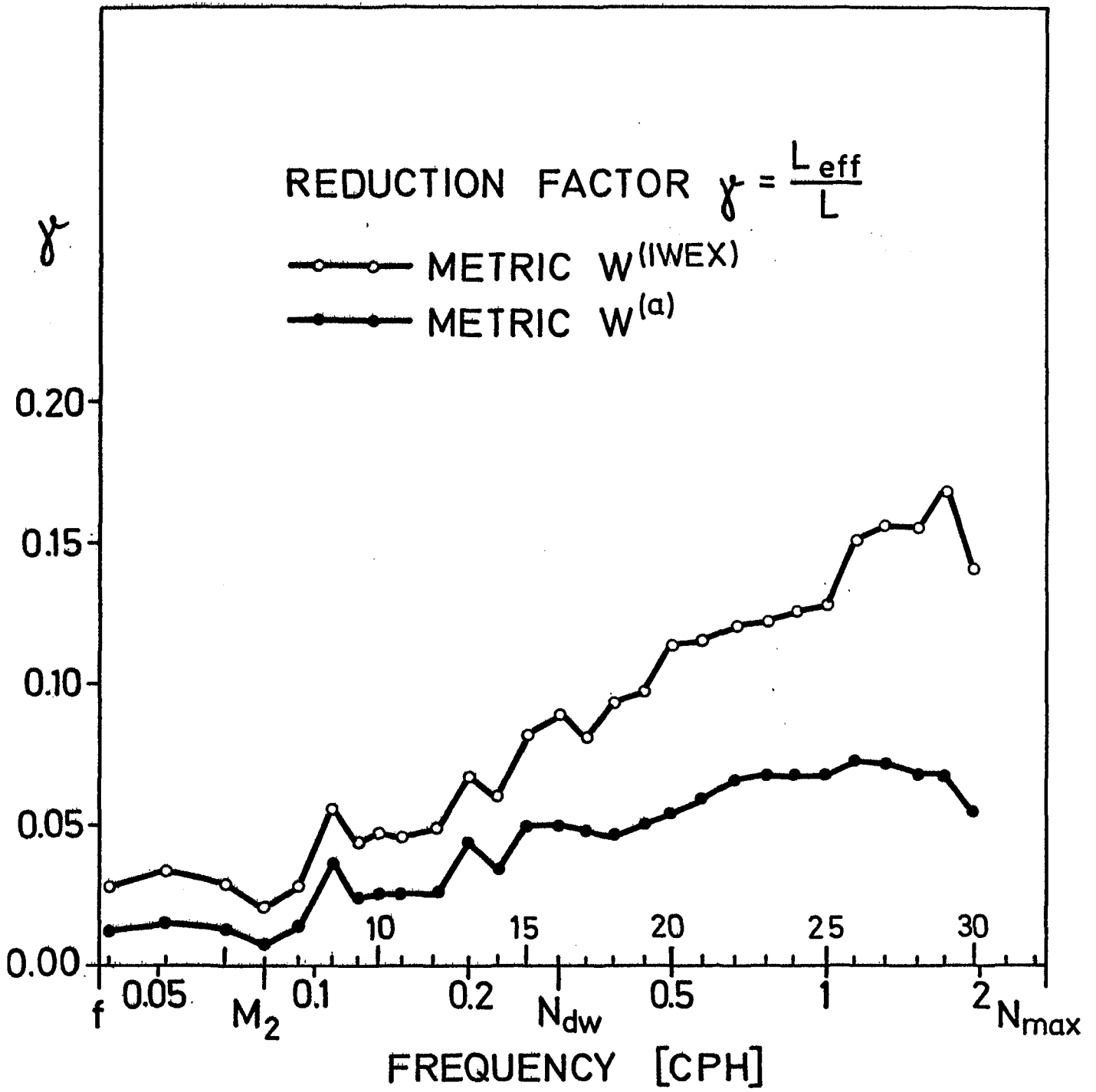
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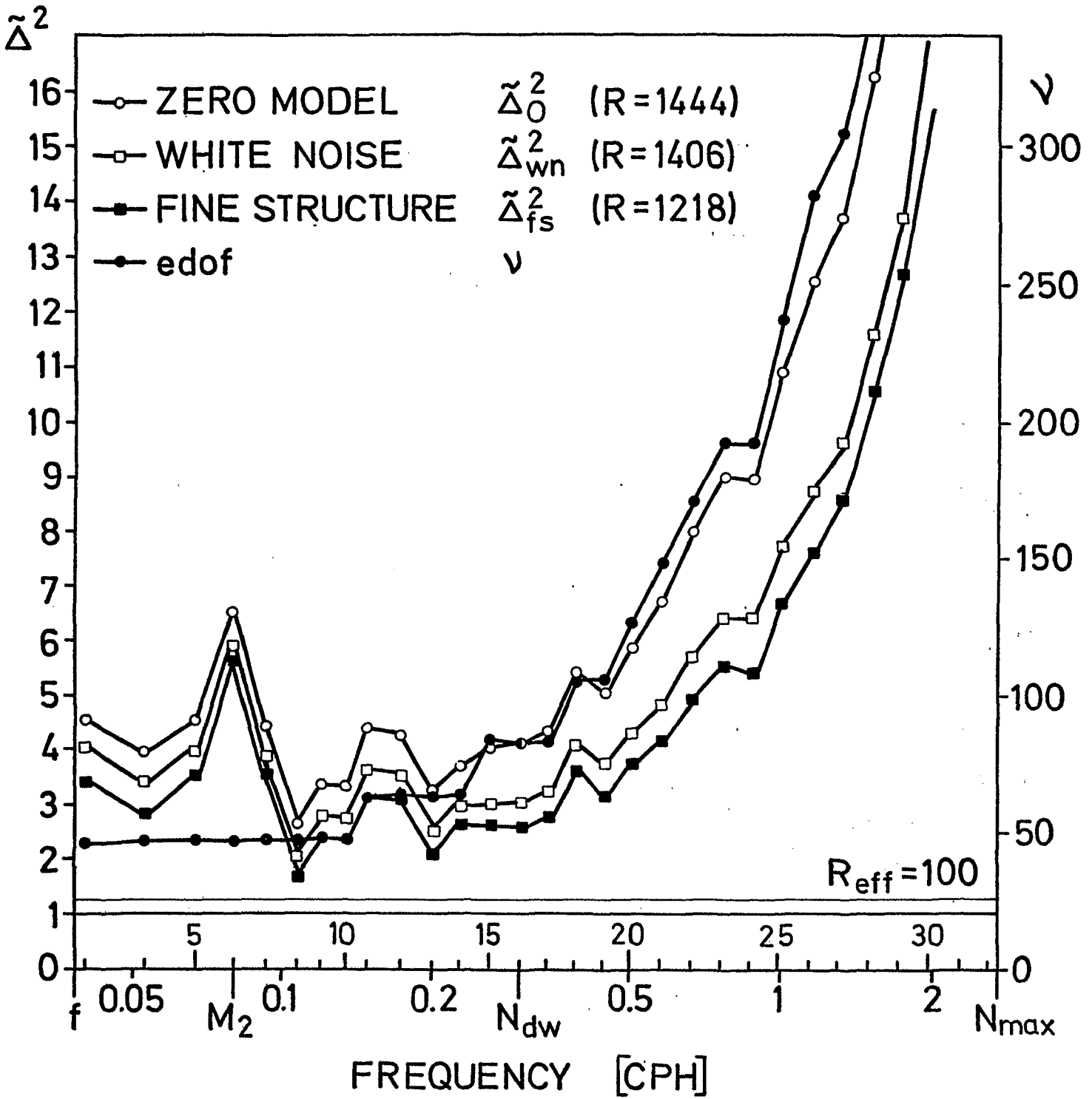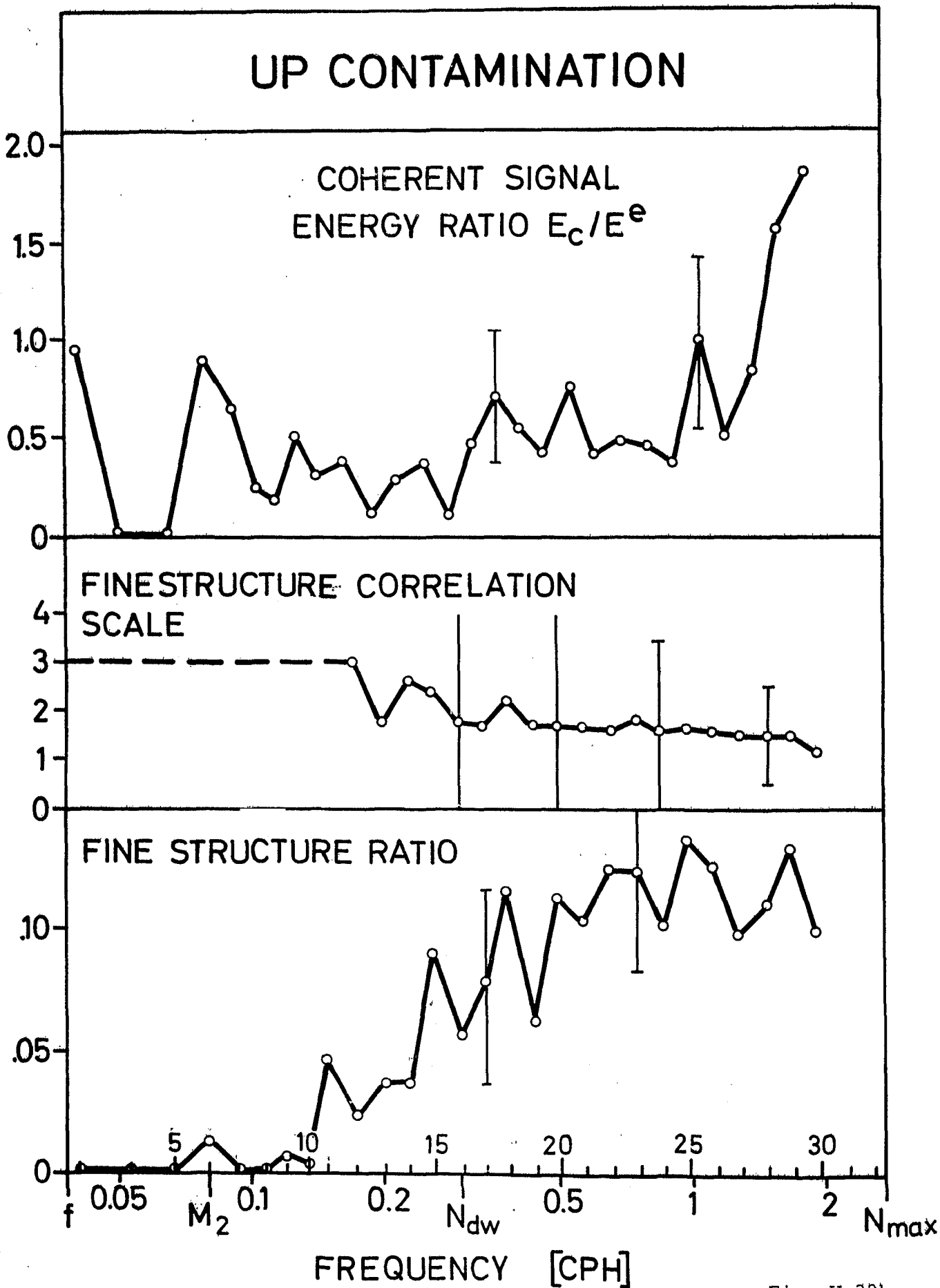
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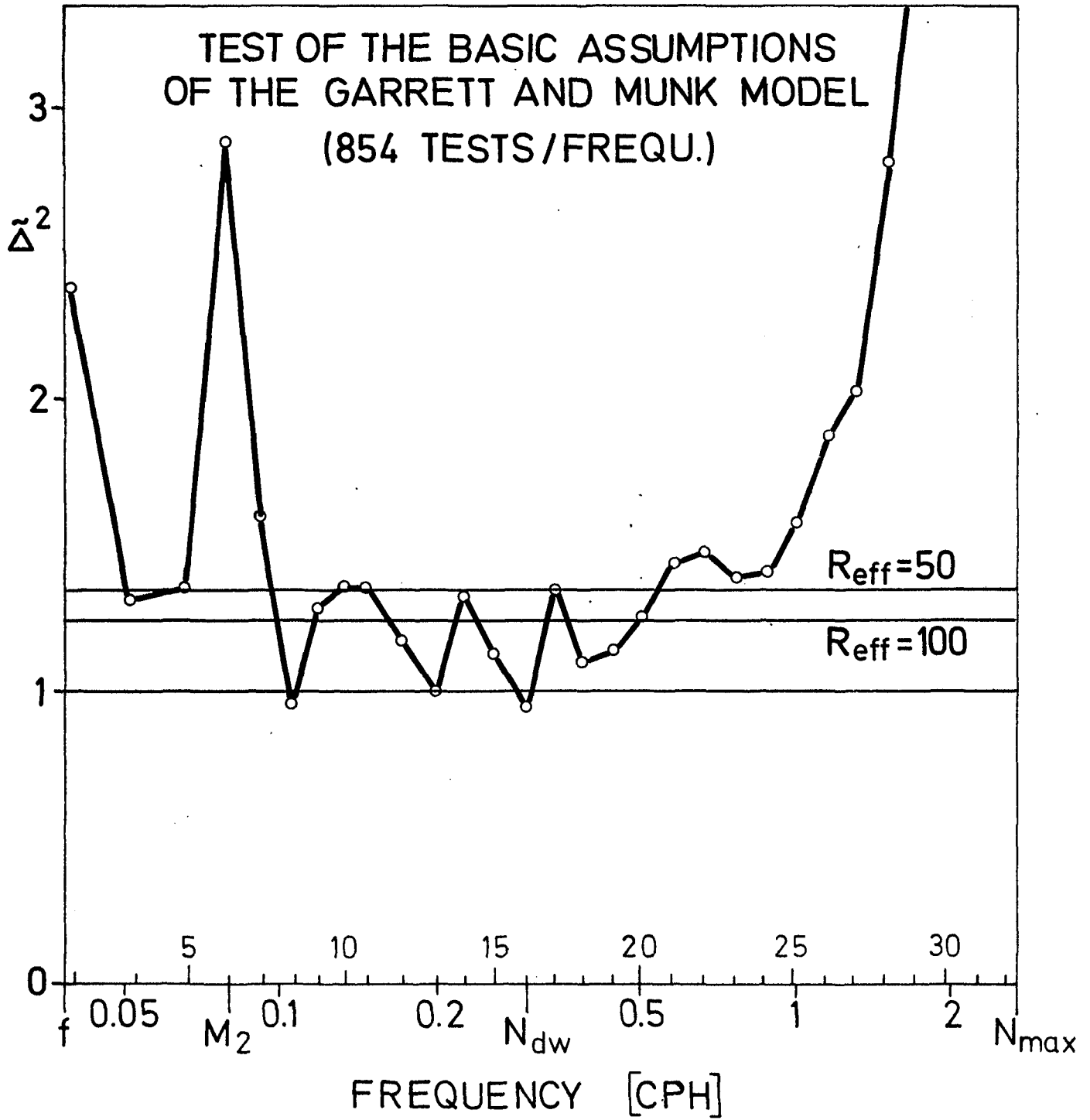
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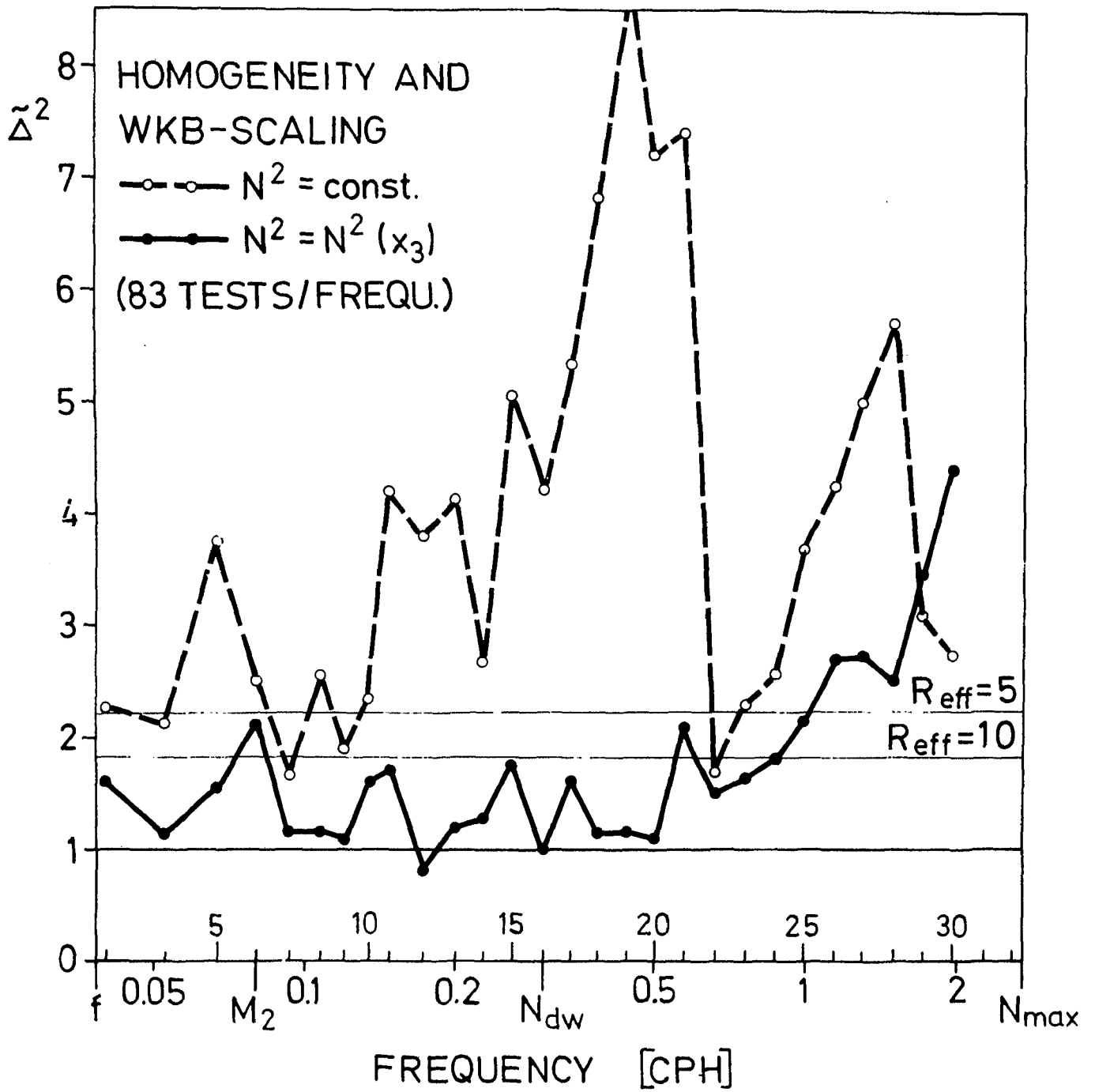
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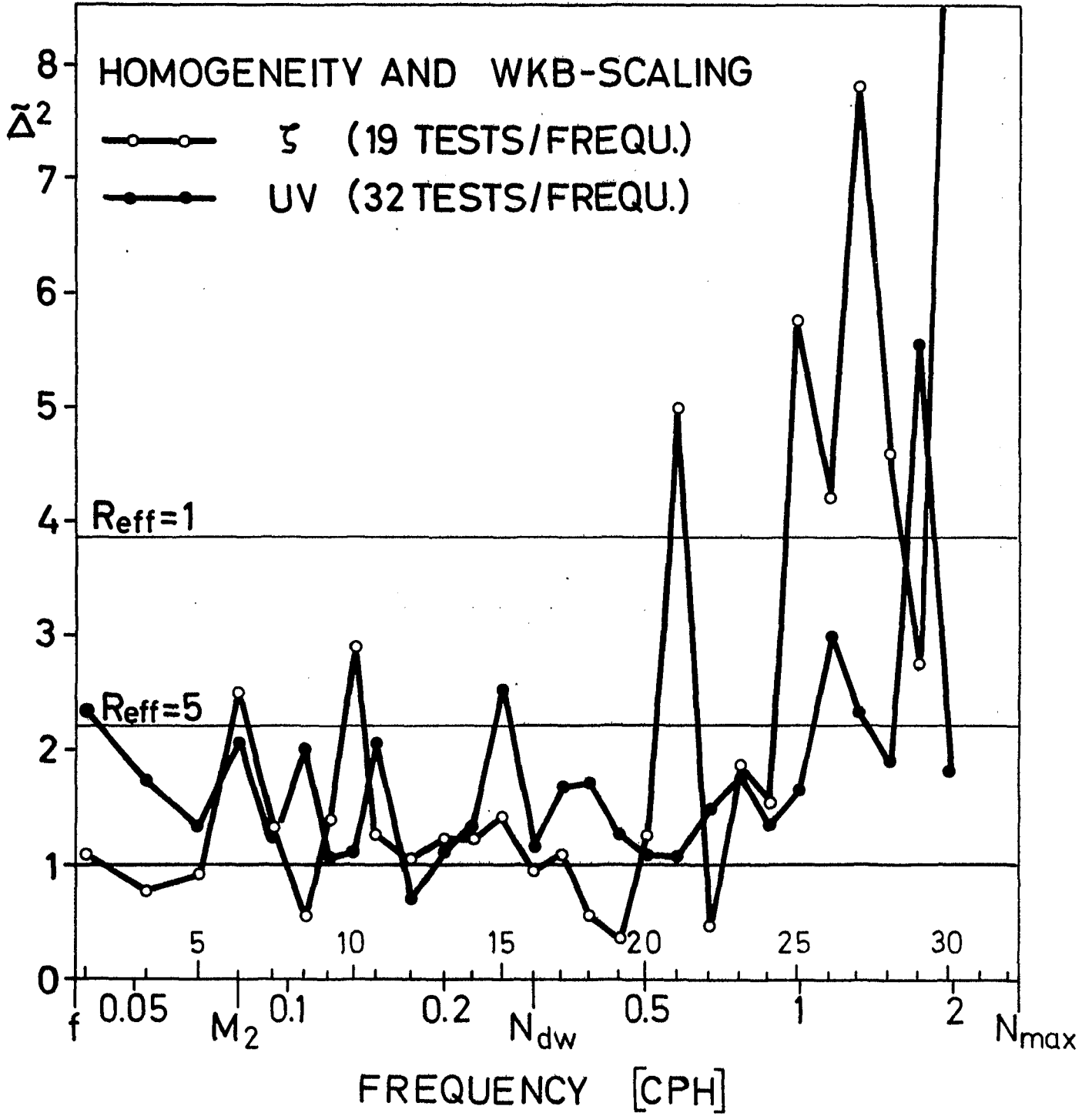
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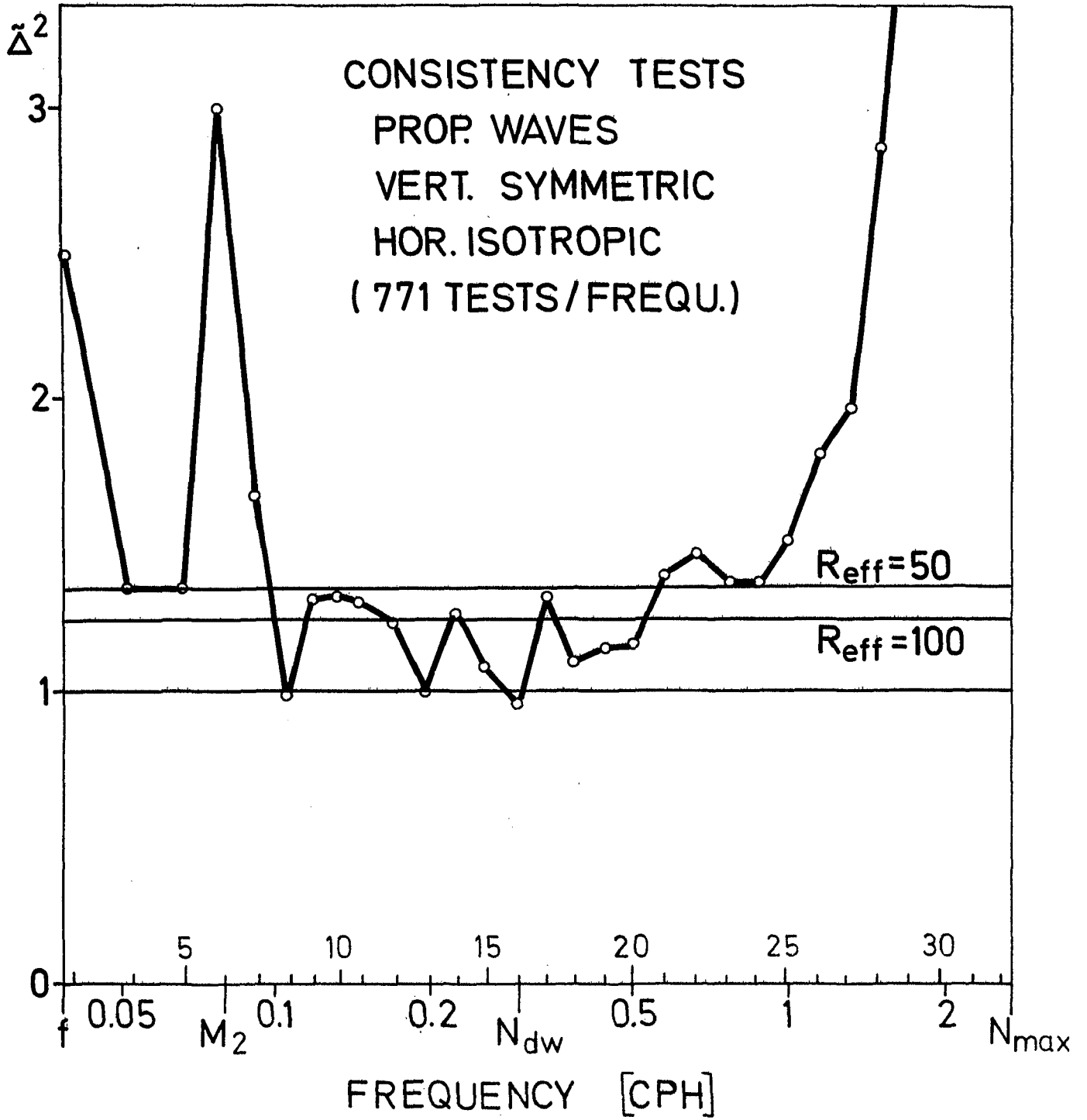
Fig. IV.5

Fig. IV.6

Fig. IV.7

Fig. IV.8

CONSISTENCY TESTS
PROP. WAVES
(324 TESTS / FREQU.)
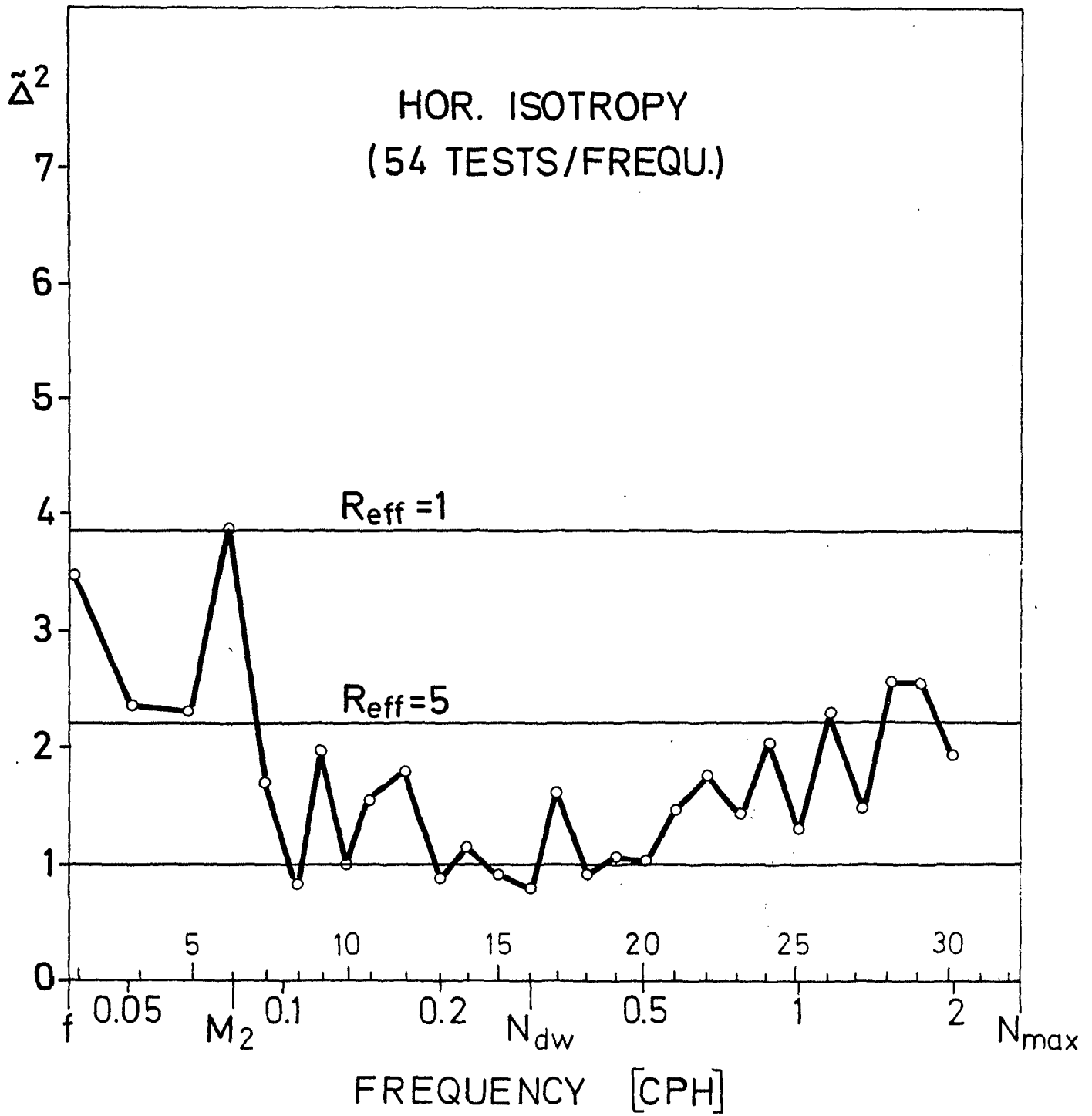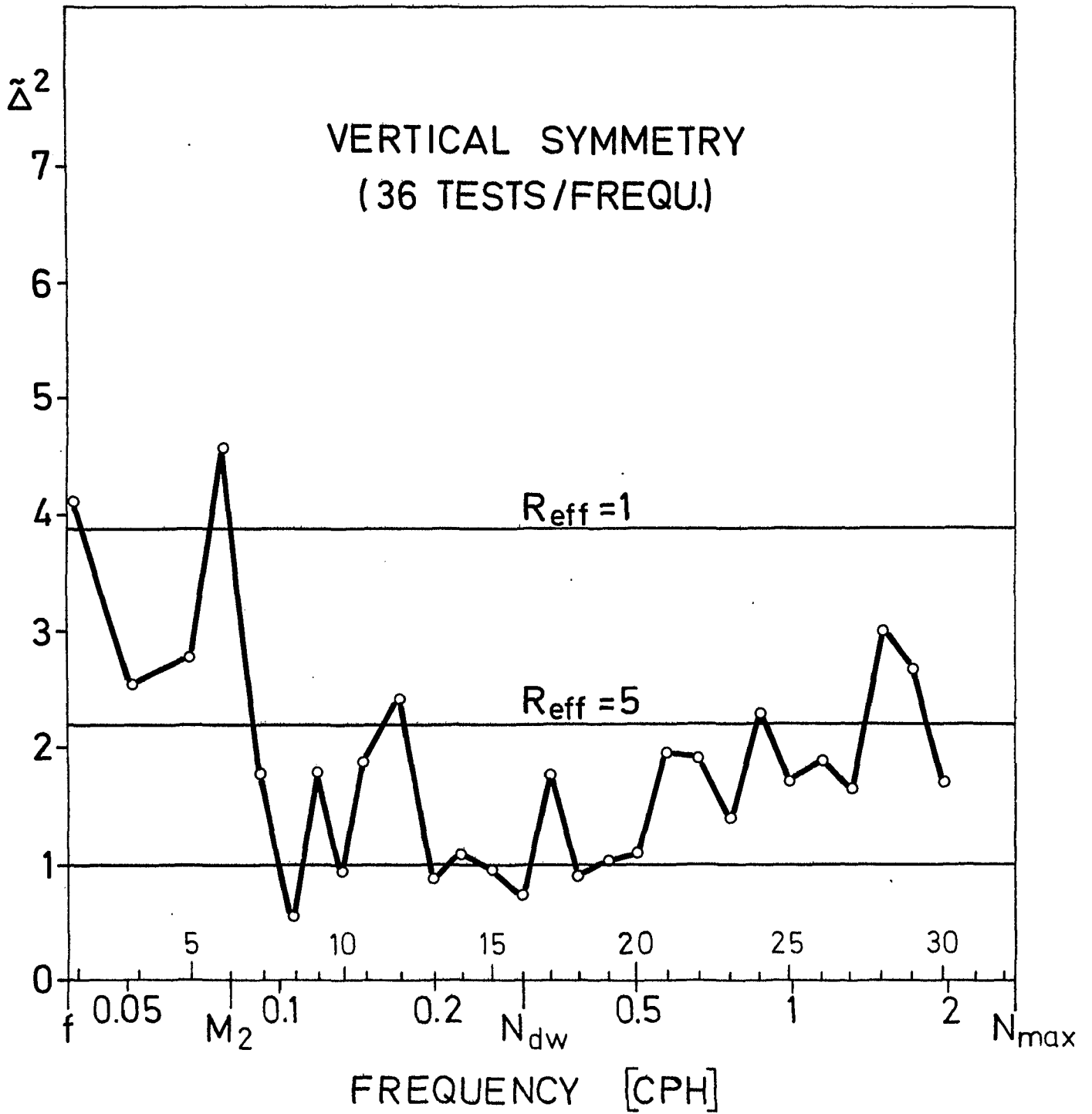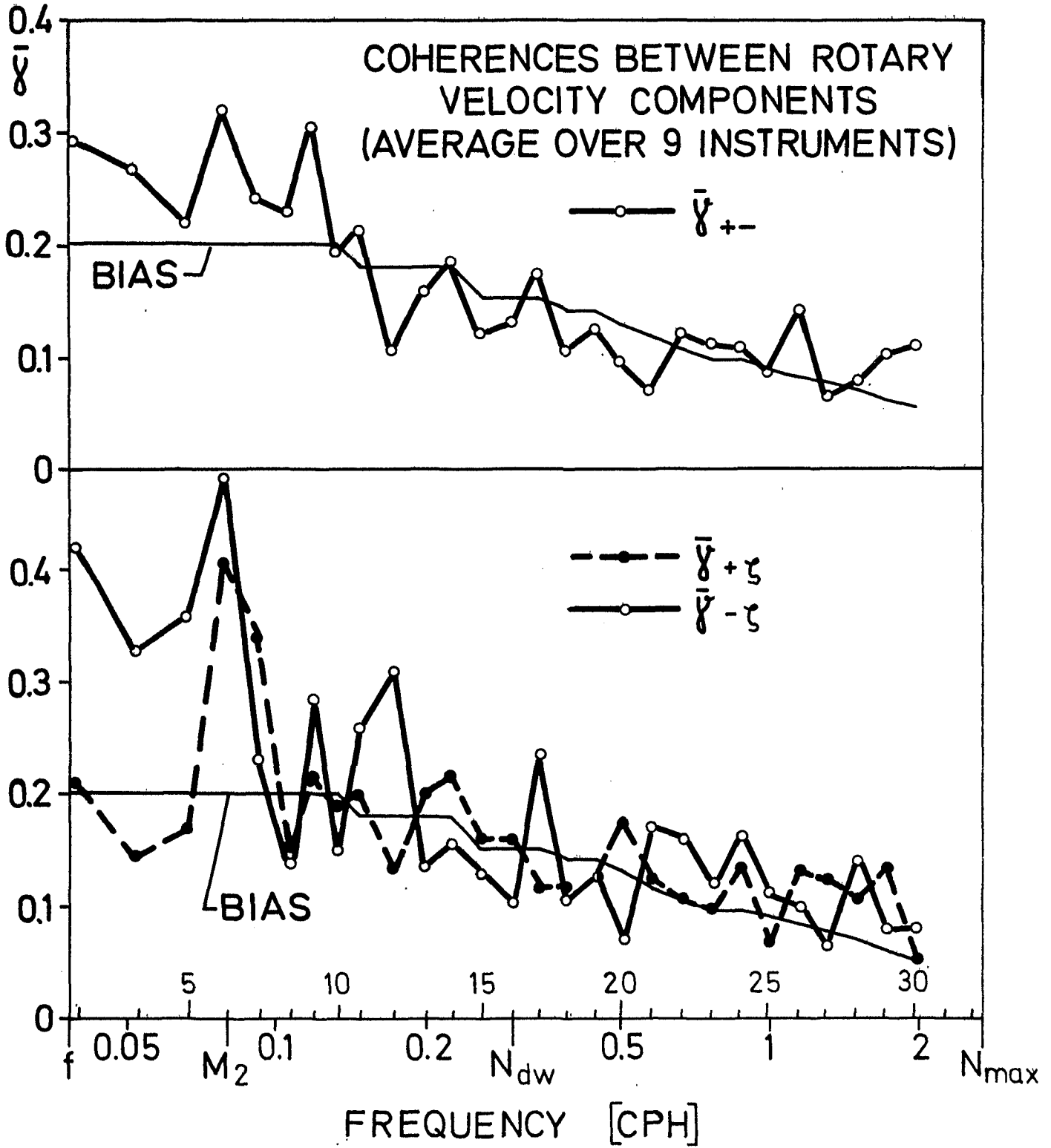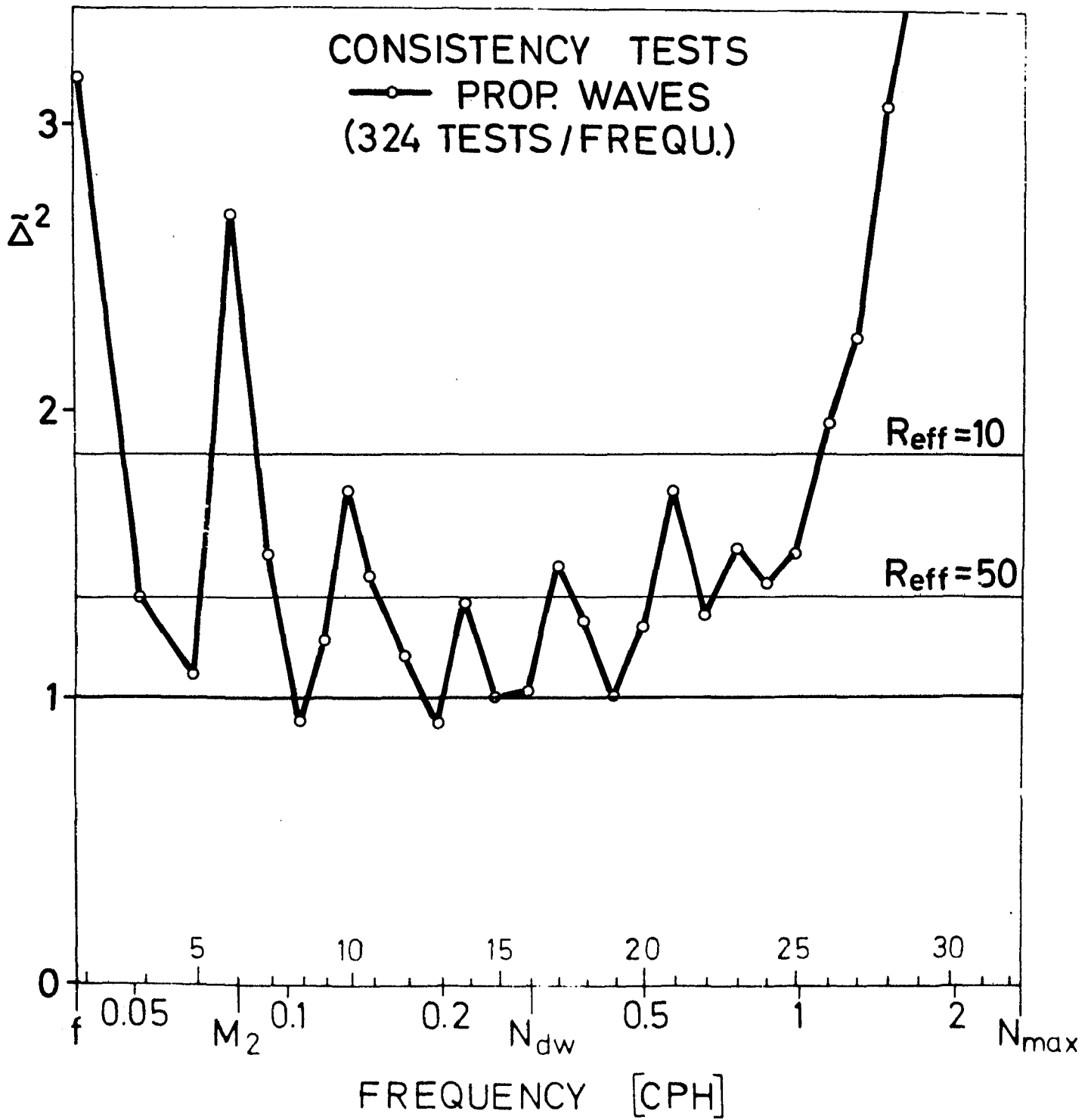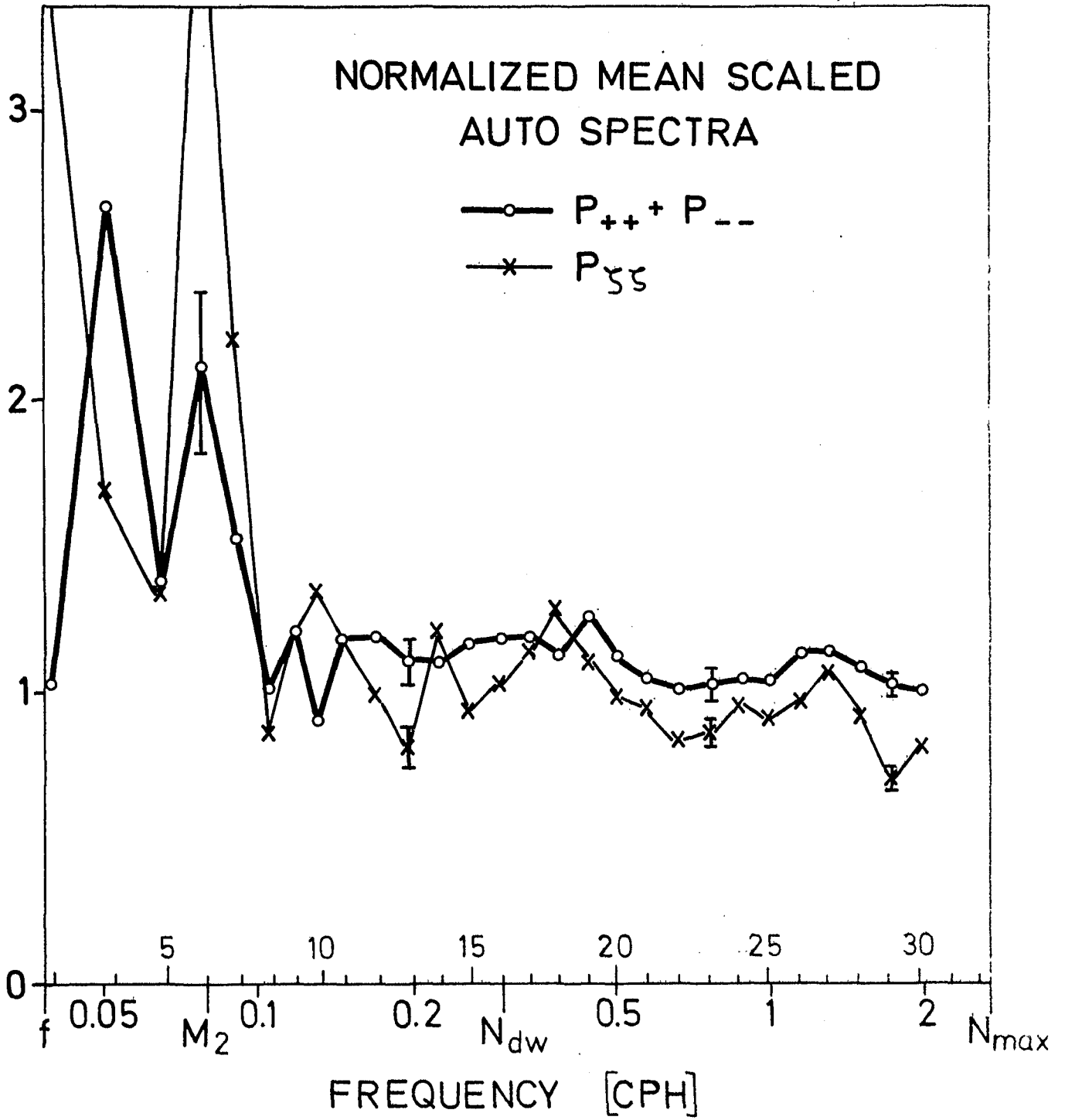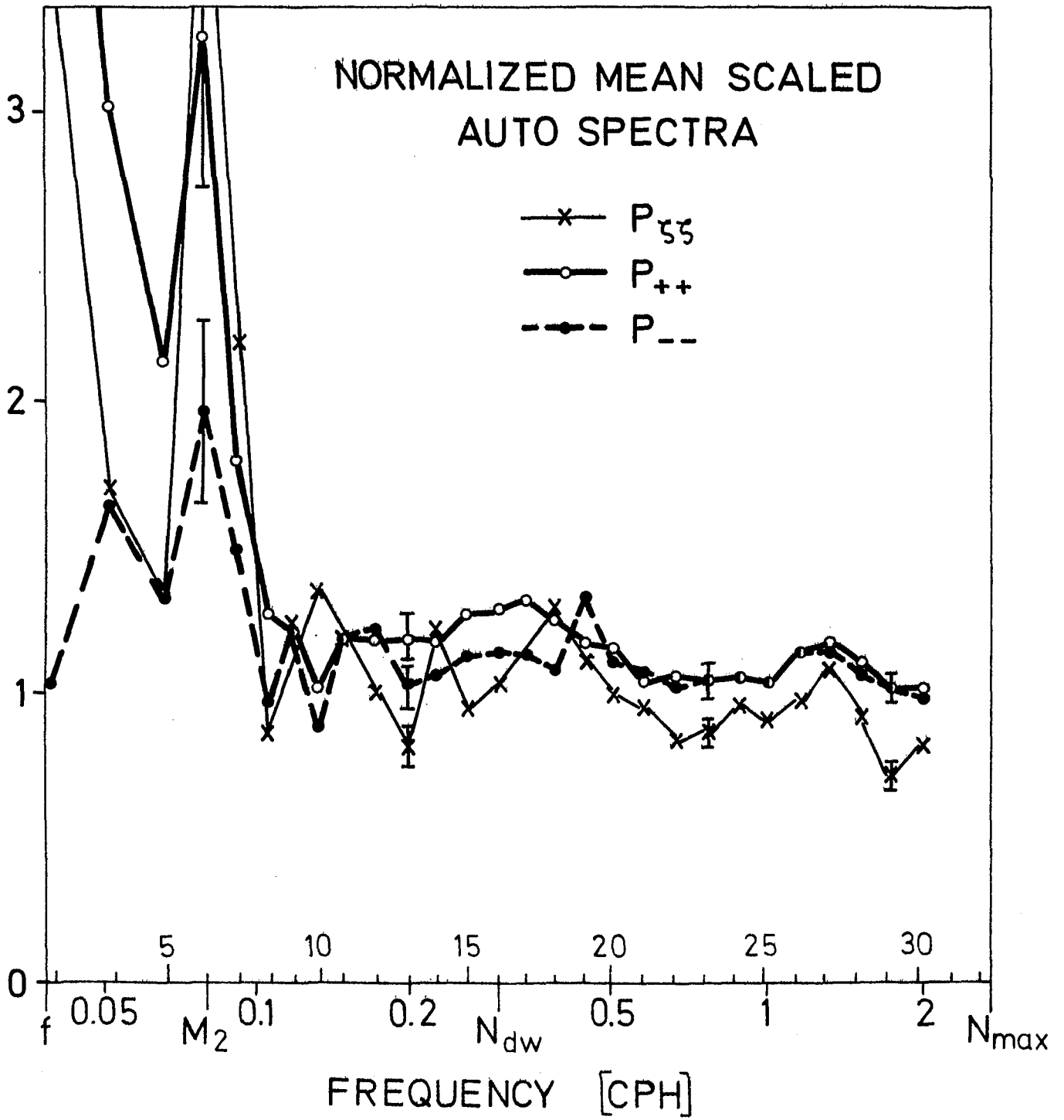
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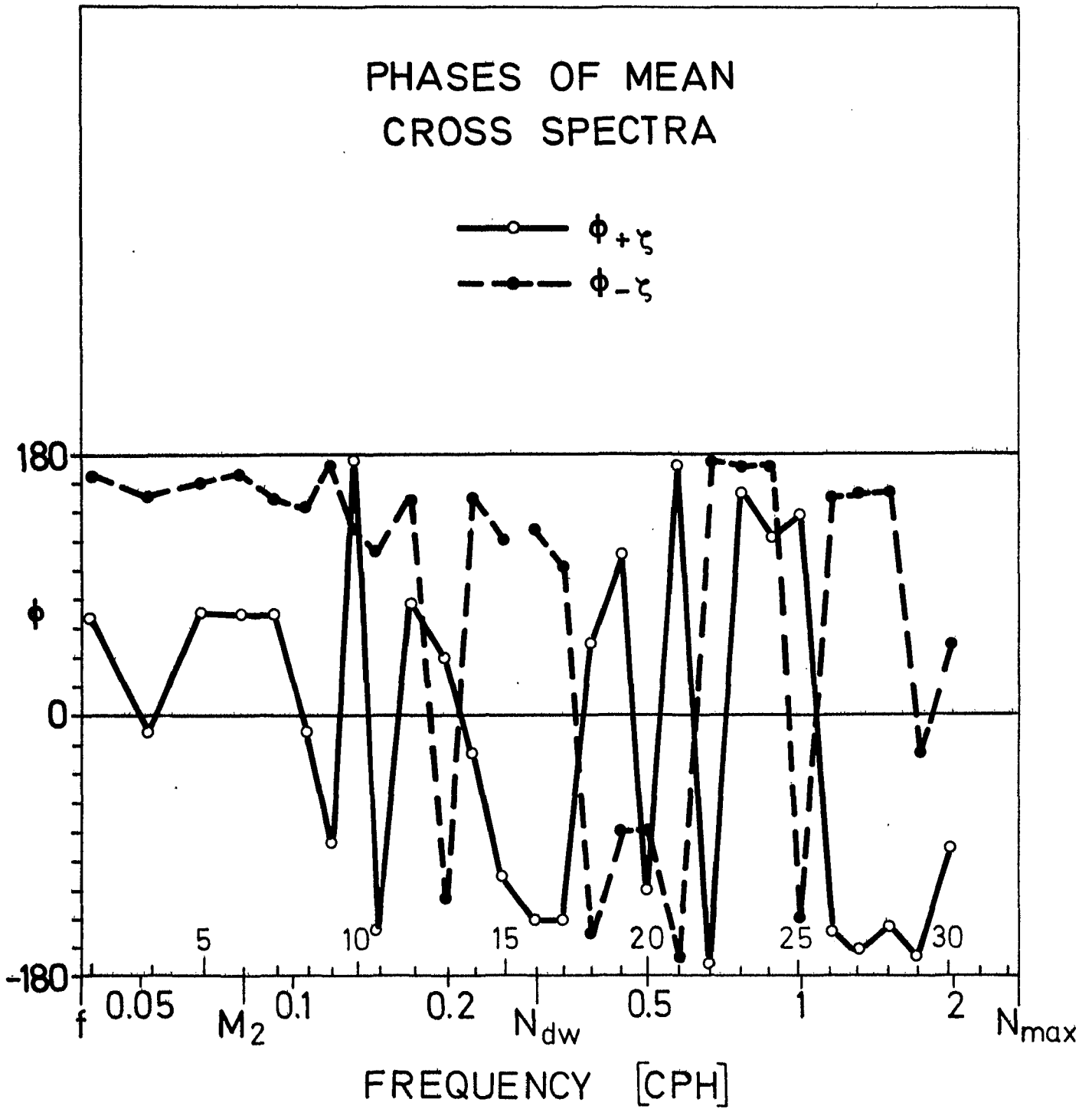
Fig. IV.10

Fig. IV.11

Fig. IV.12
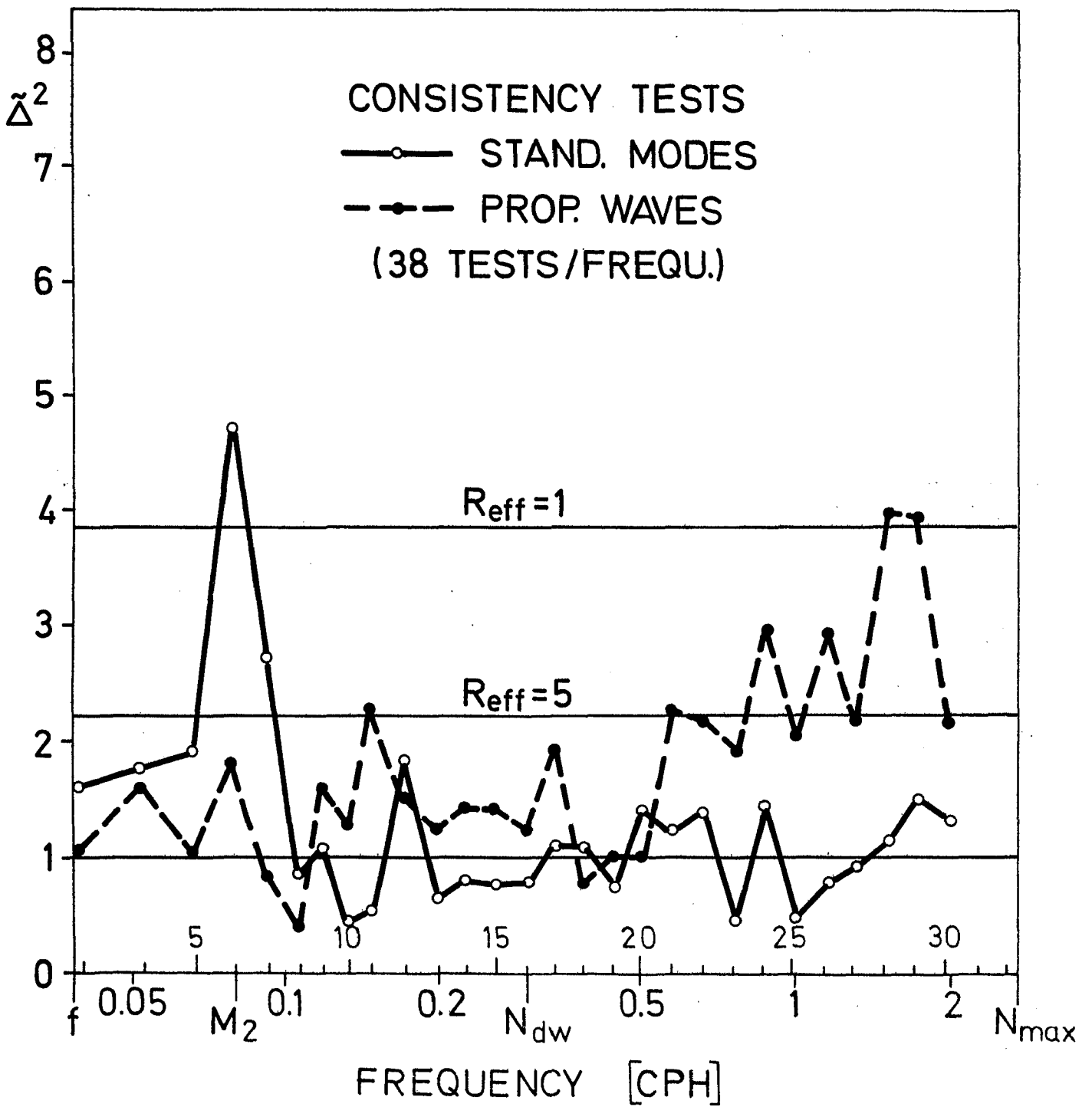
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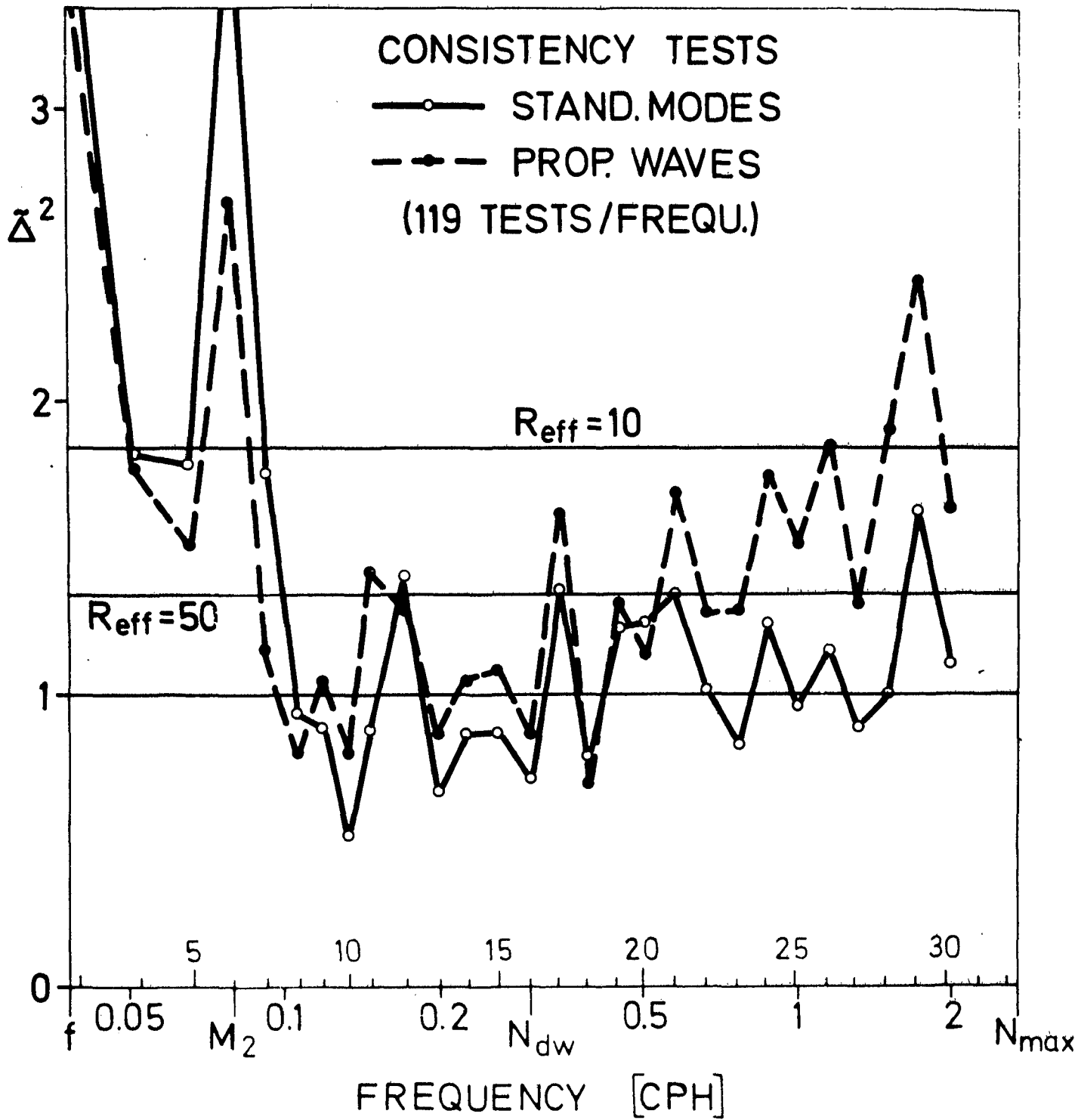
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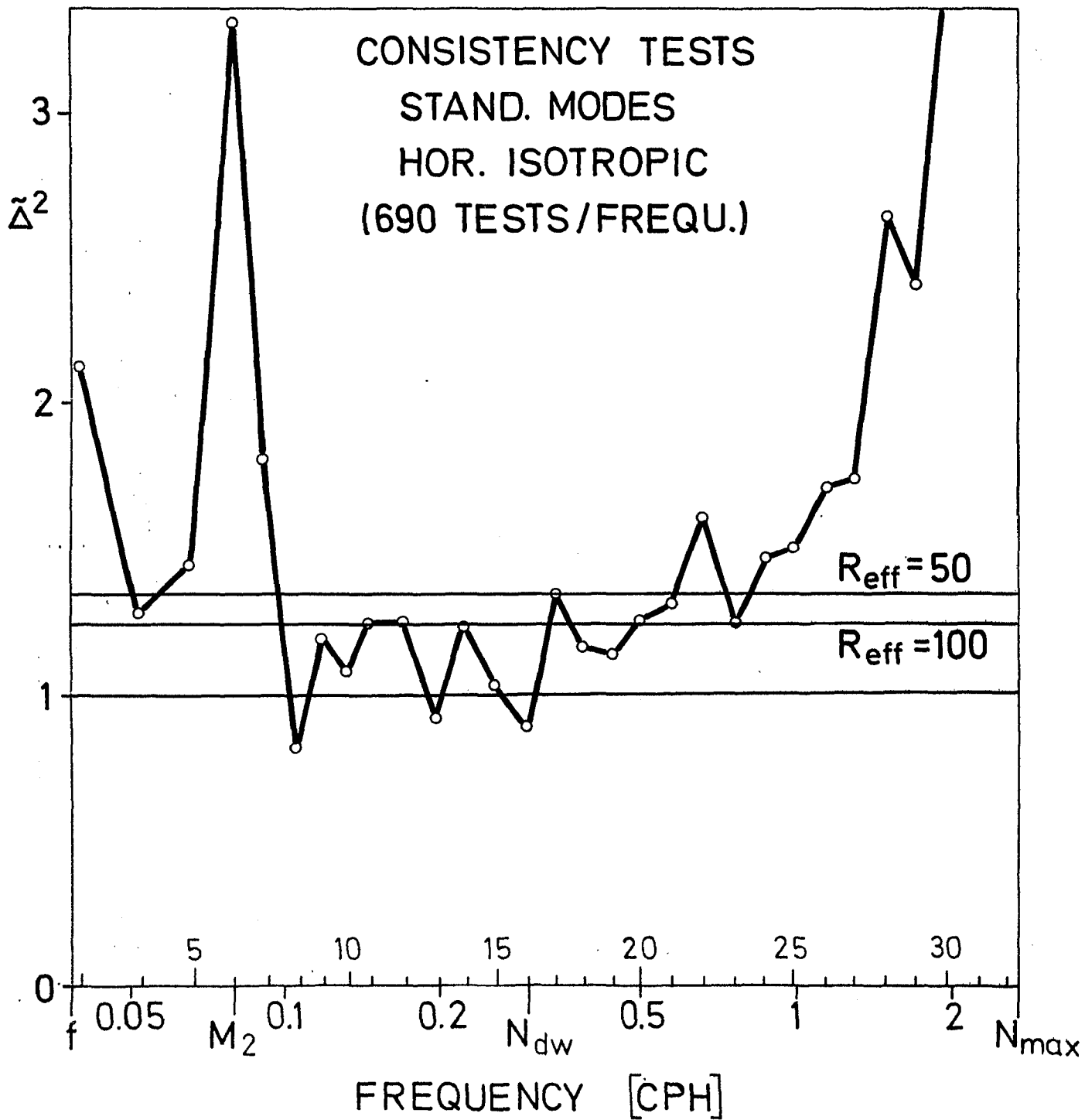
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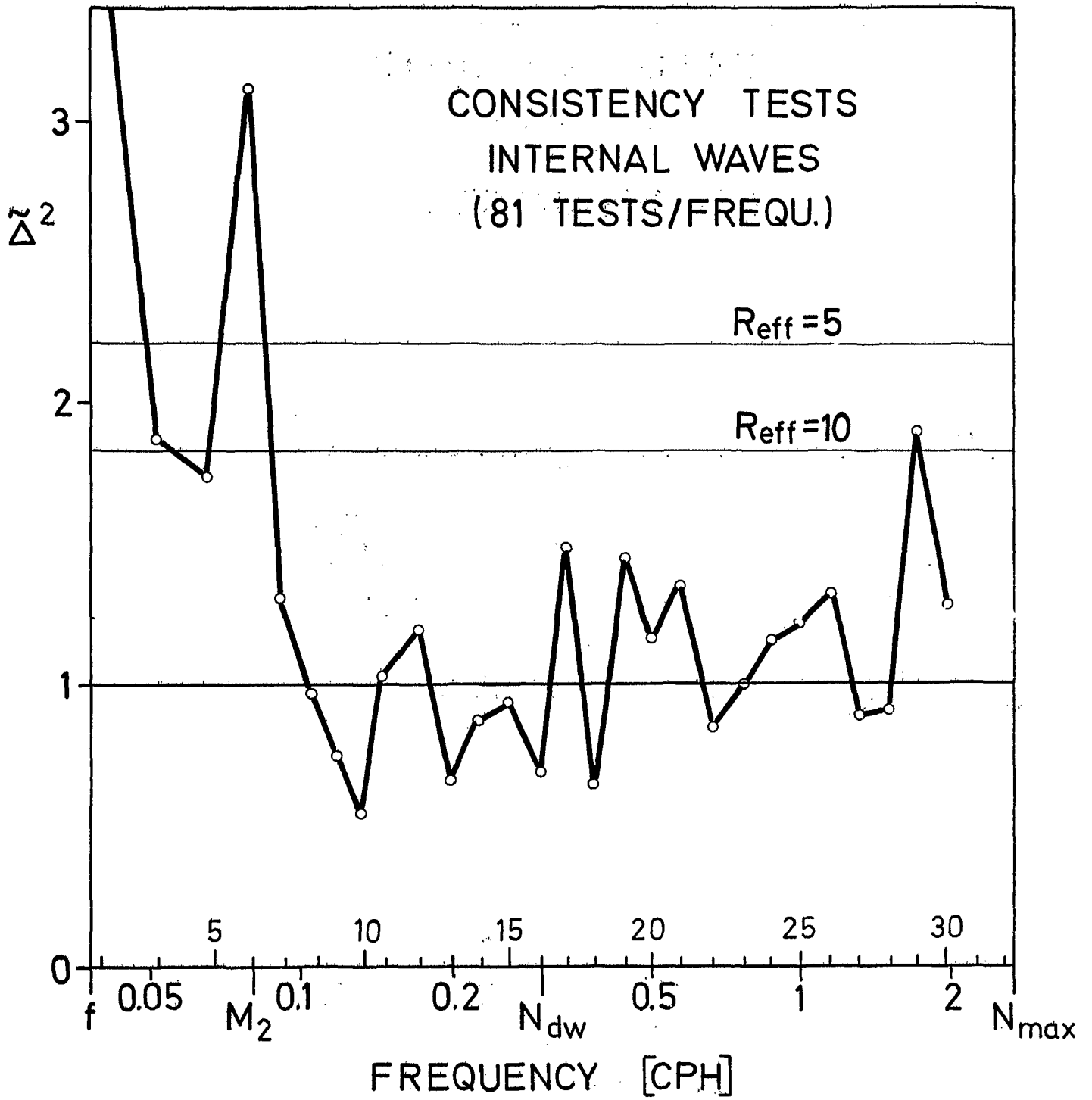
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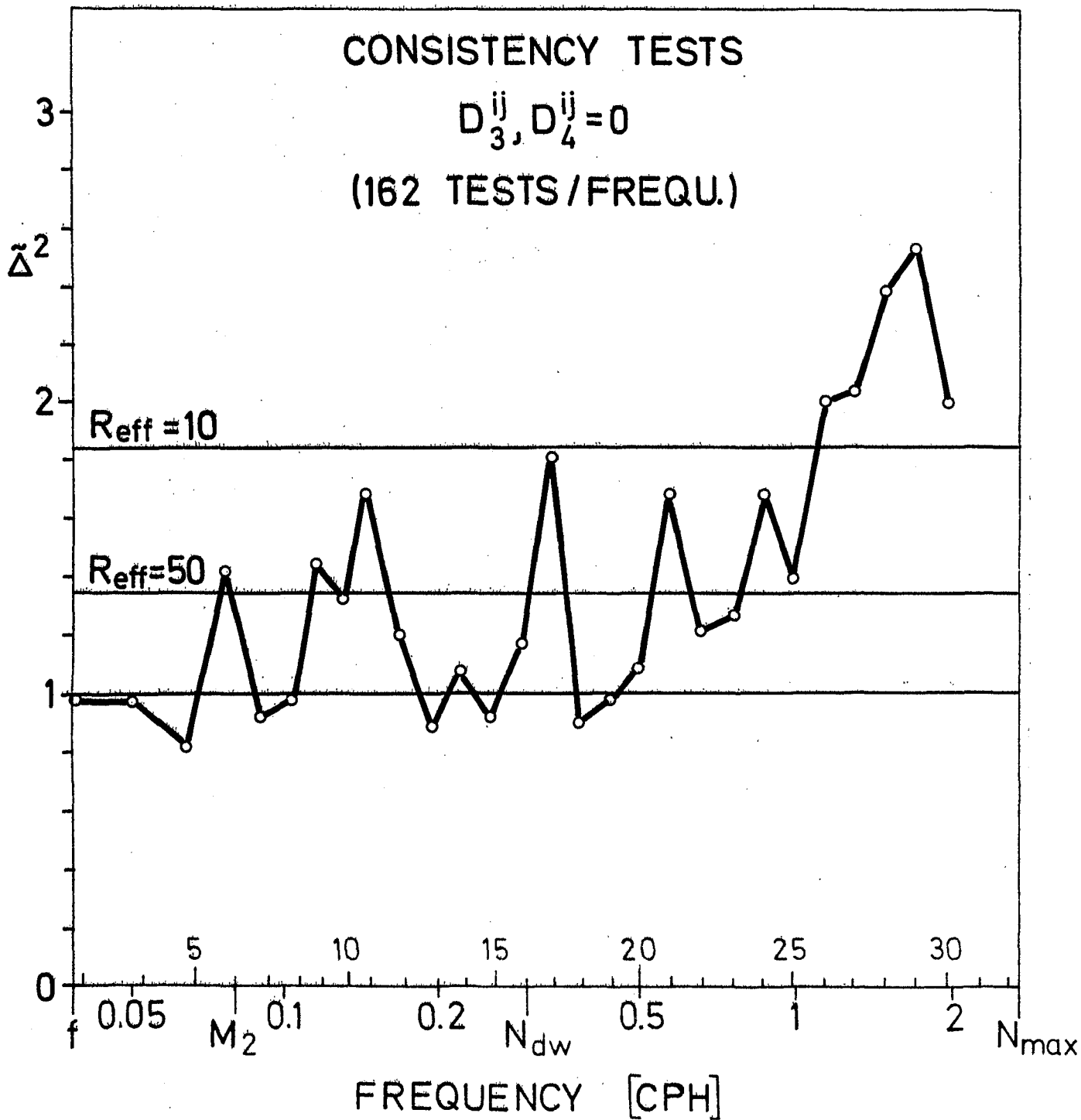
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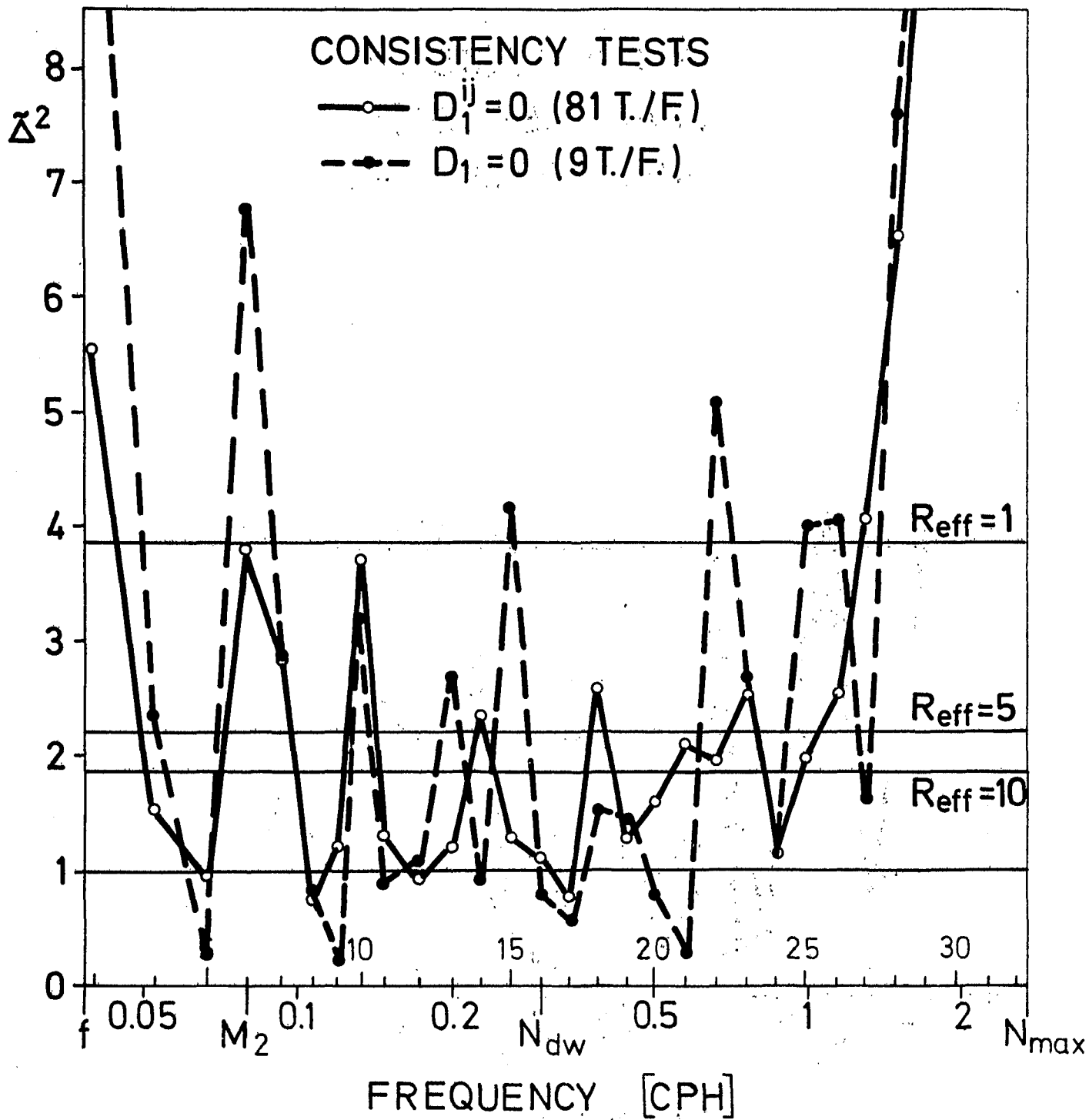
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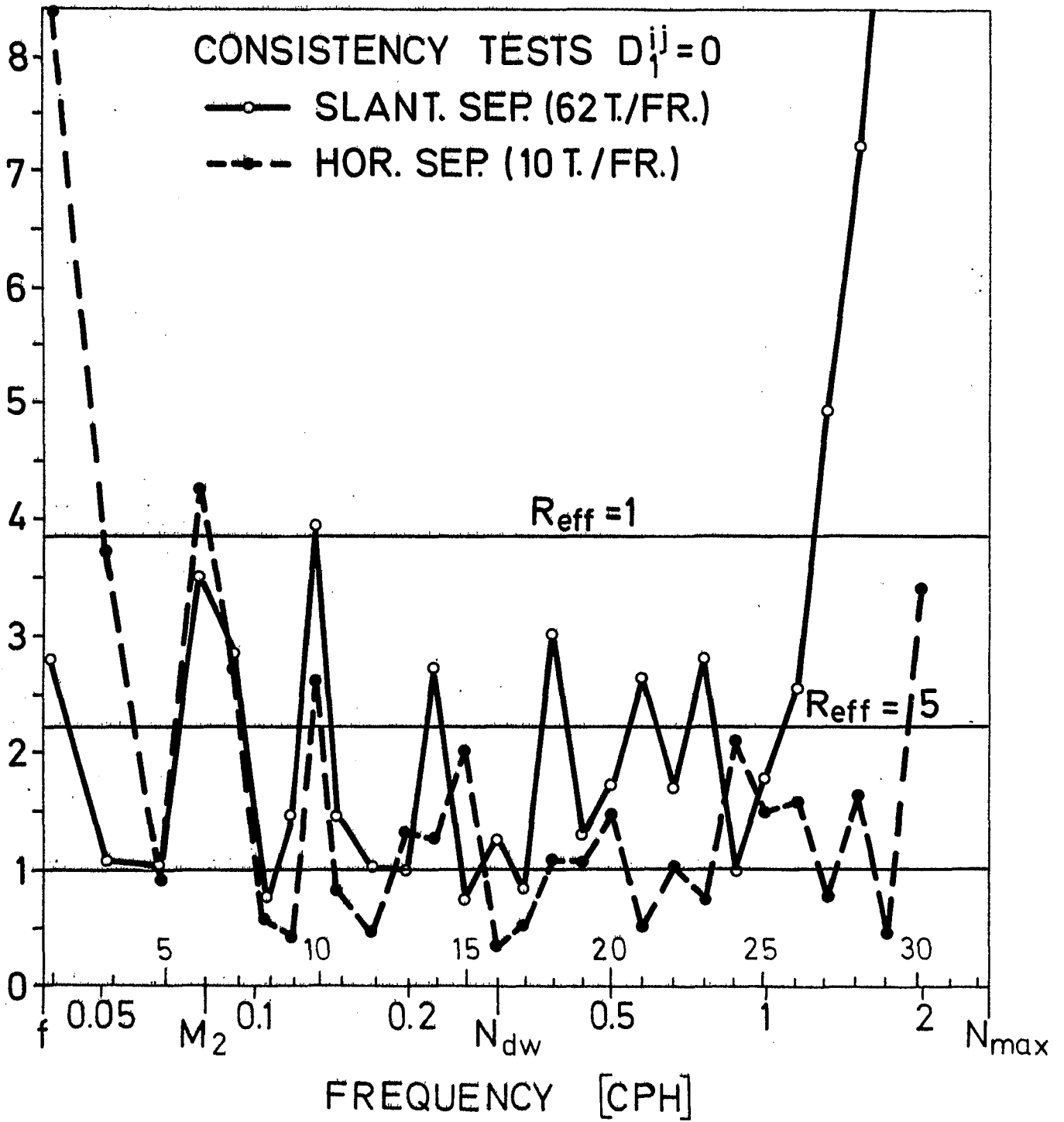
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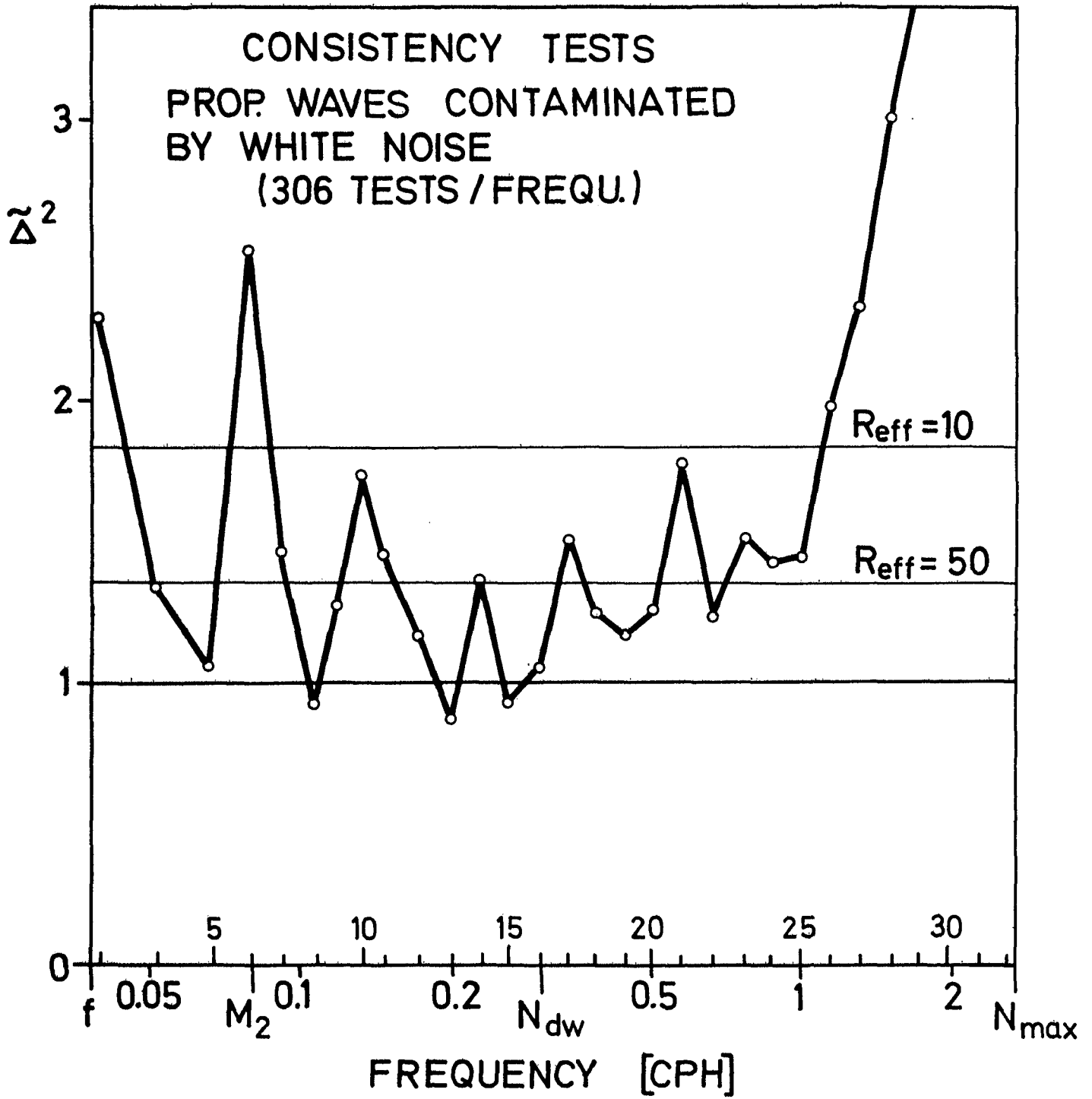
Fig. IV.20

Fig. IV.21

Fig. IV.22

CONSISTENCY TESTS
IWEX MODEL CLASS

(224 TESTS/FREQU.)

$R_{eff} = 10$

$R_{eff} = 50$

FREQUENCY [CPH]

Fig. IV.23

Fig. V.1

Fig. V.2

$$A(\lambda) = \frac{I(t,s)}{(1 + \lambda^s)^{t/s}}$$

for s = 1

t = 10

t = 3

t = 2.5

t = 2

Fig. V.3a

$$A(\lambda) = \frac{I(t,s)}{(1+\lambda^s)^{t/s}}$$

for $t = 2$

s = 10

s = 5

s = 2

s = 1
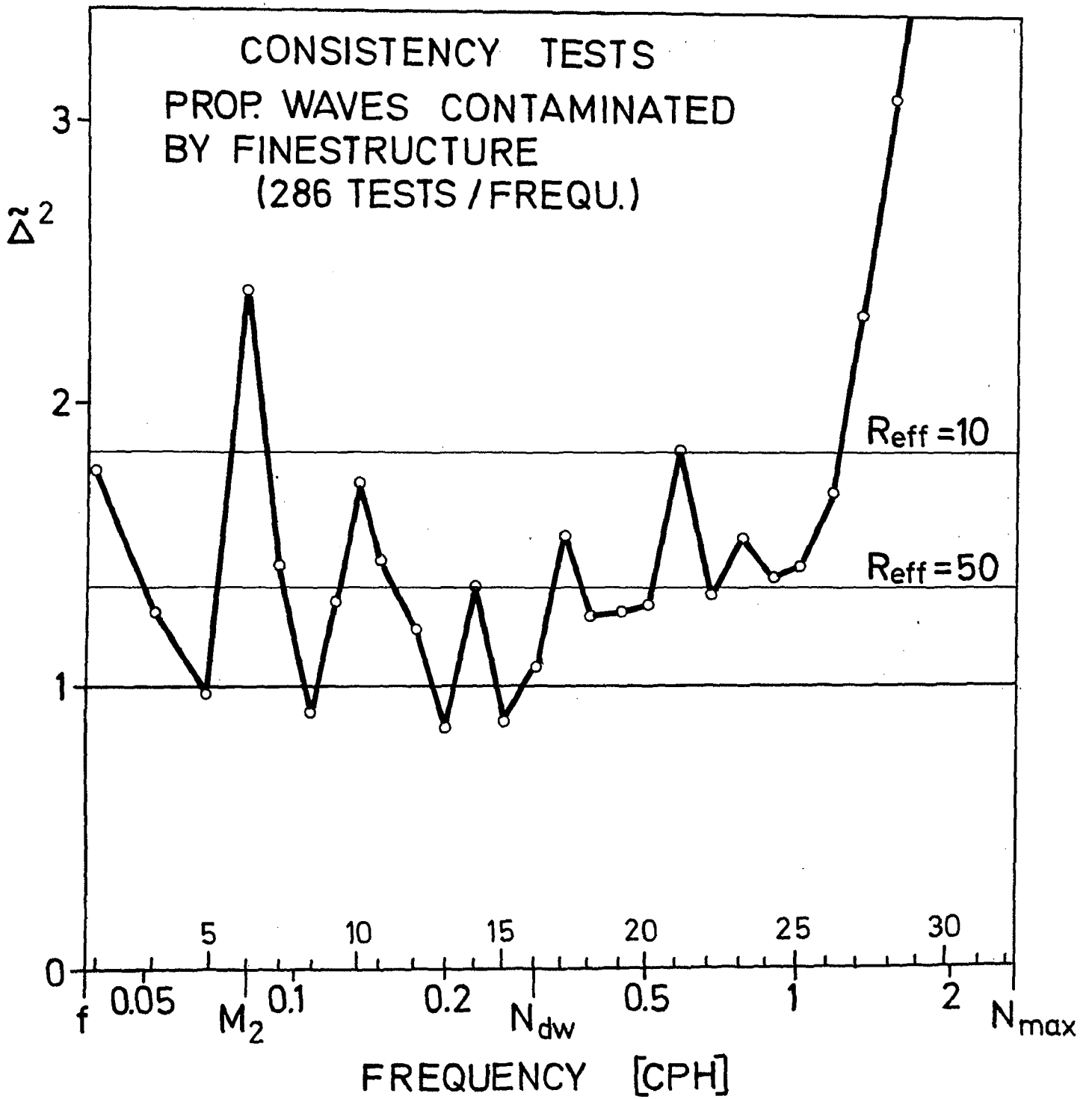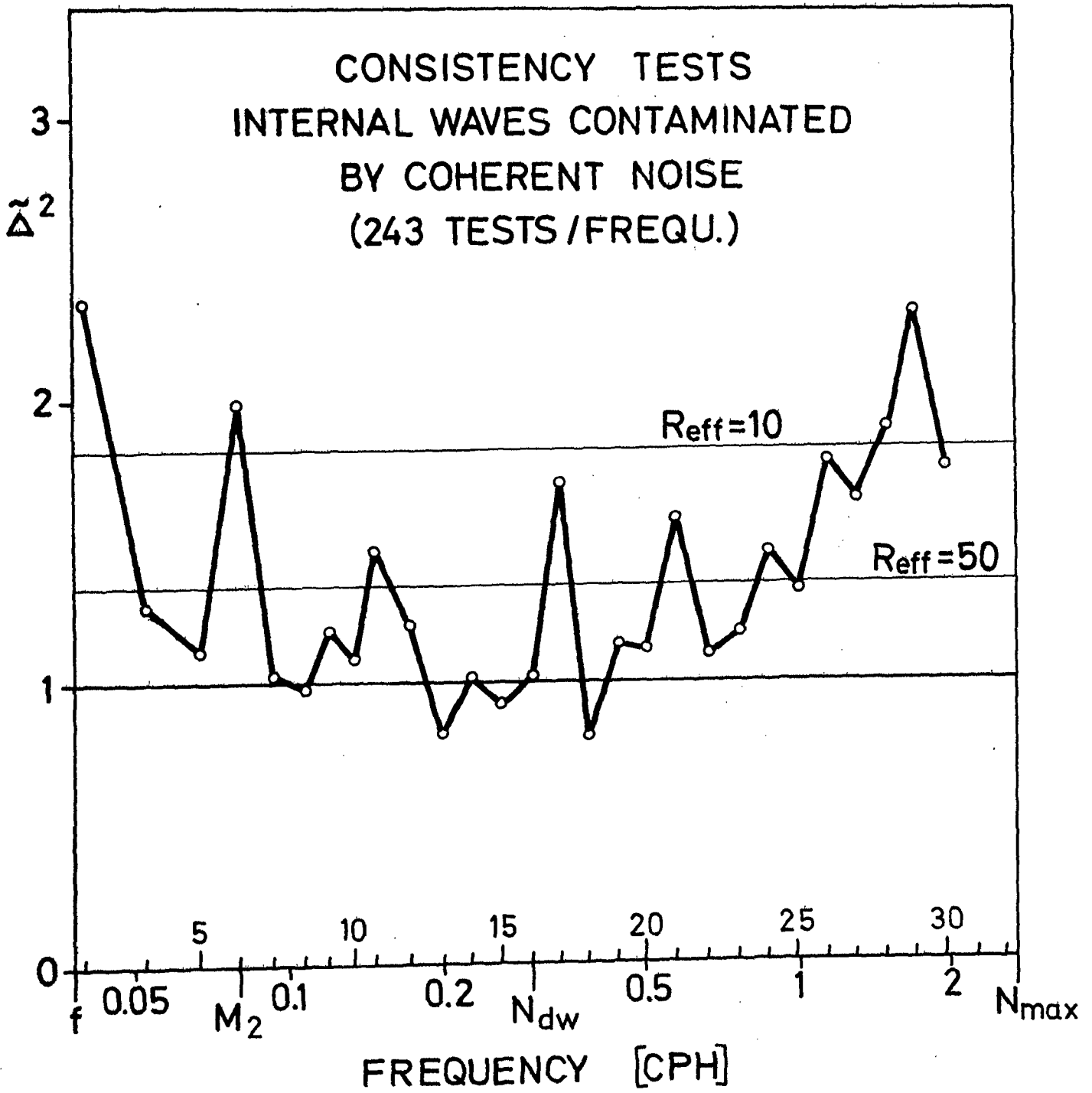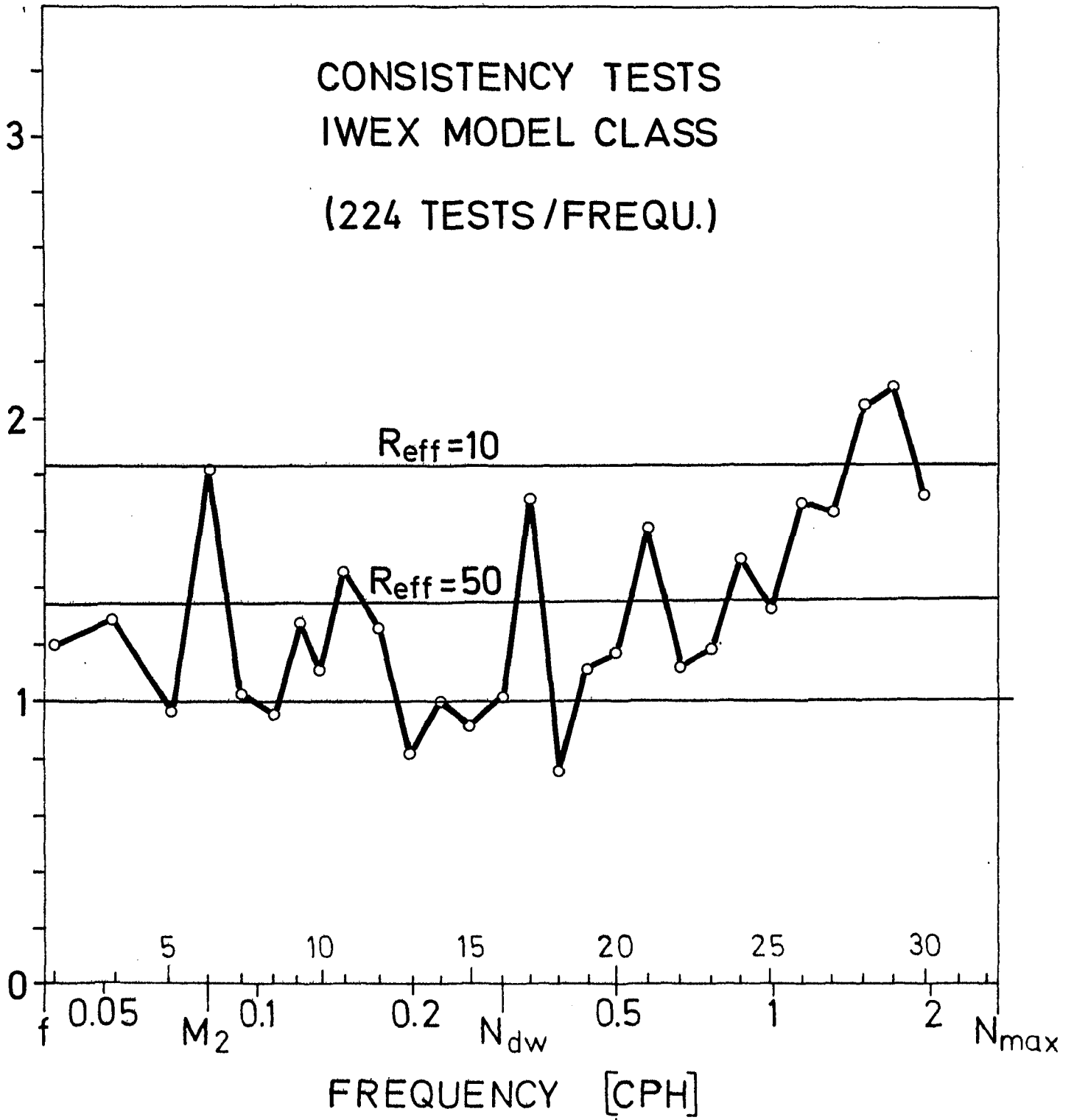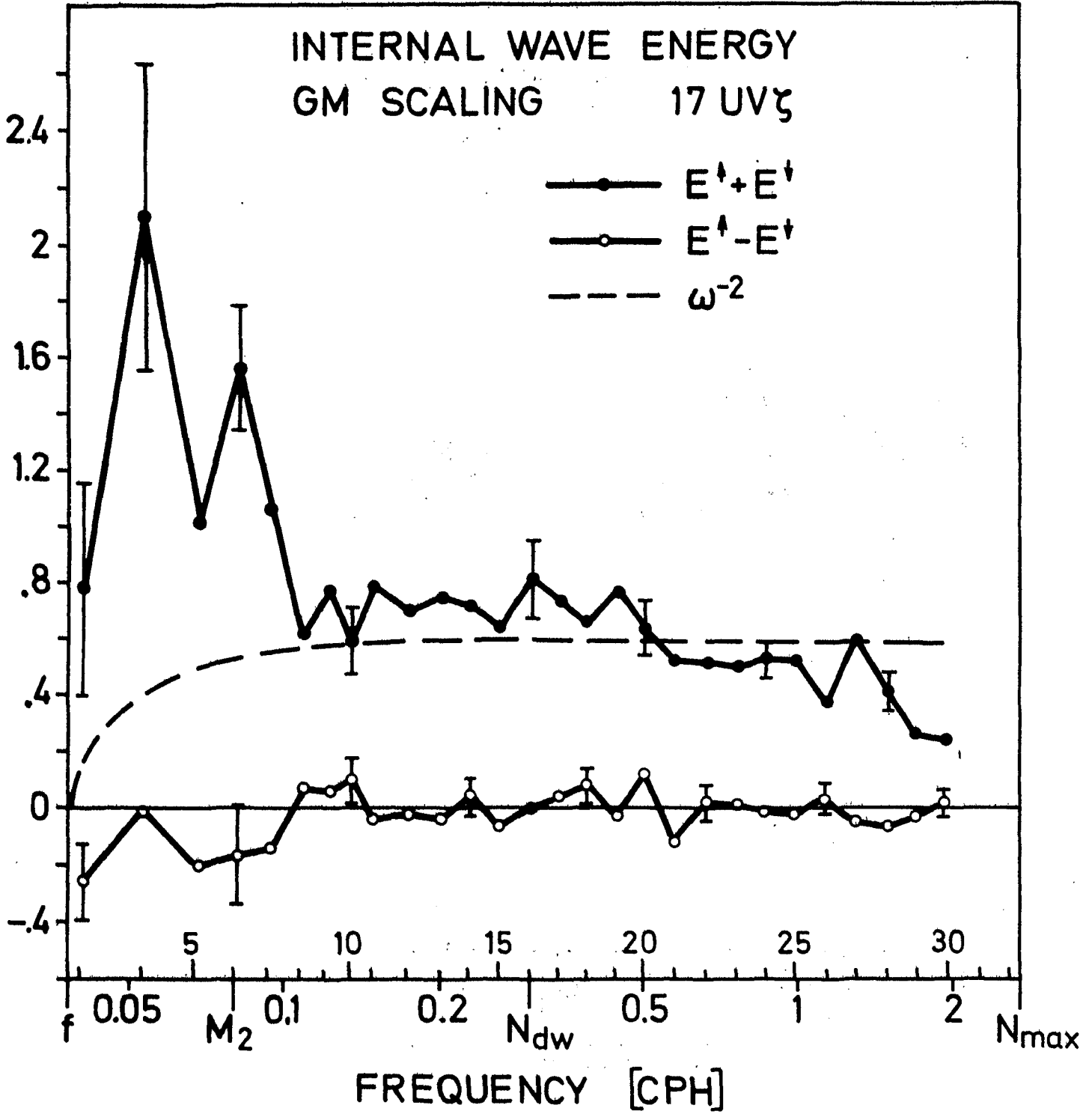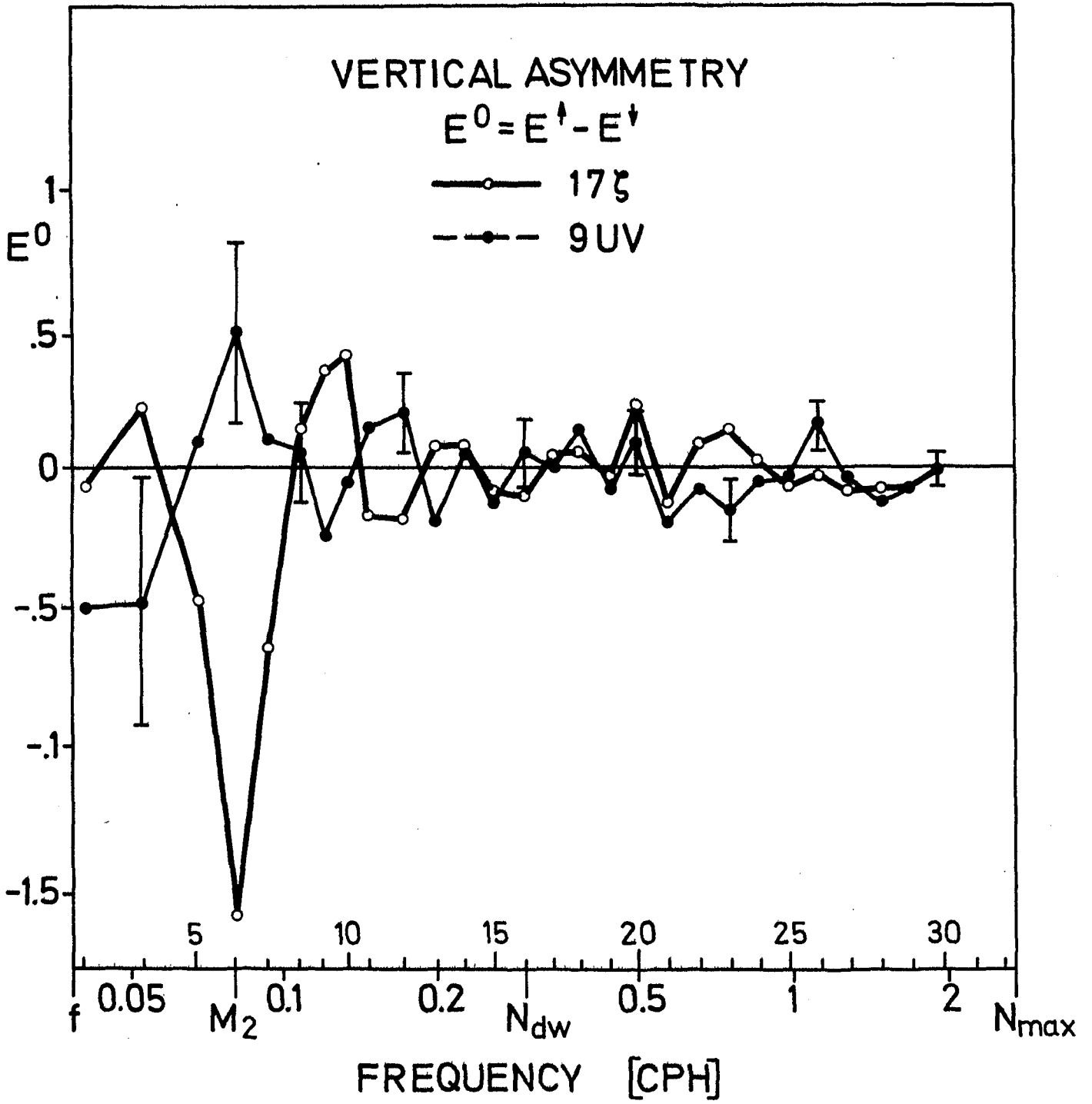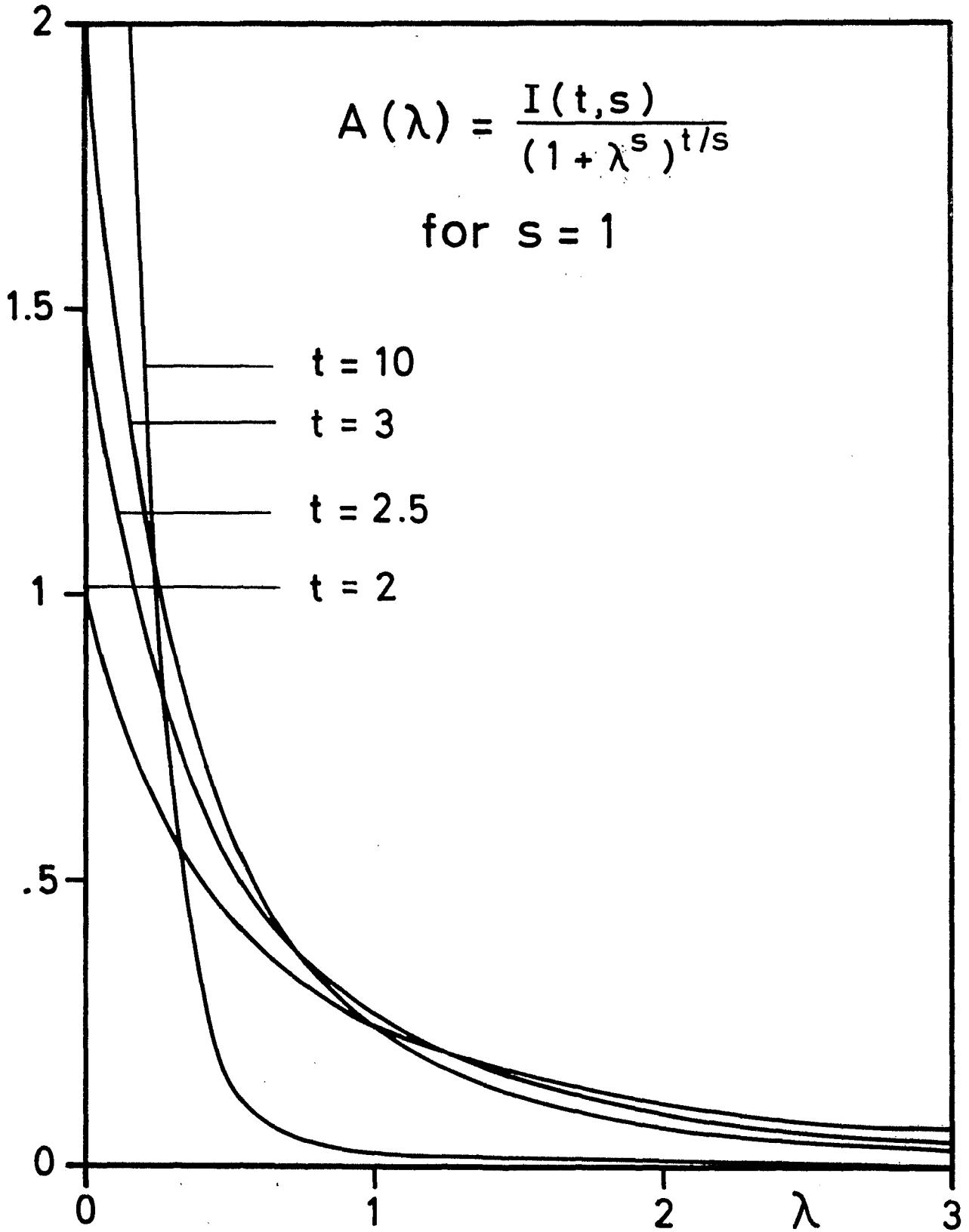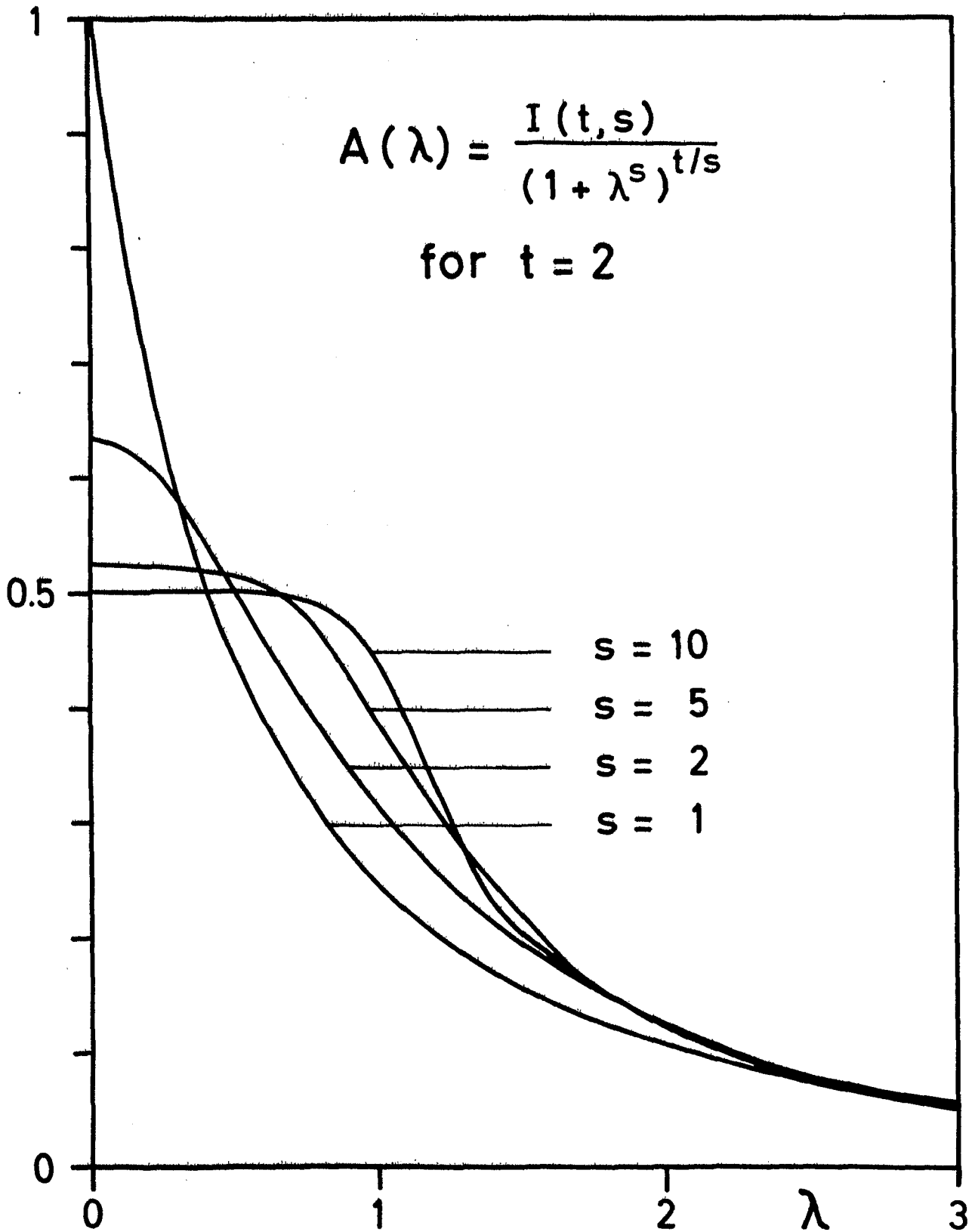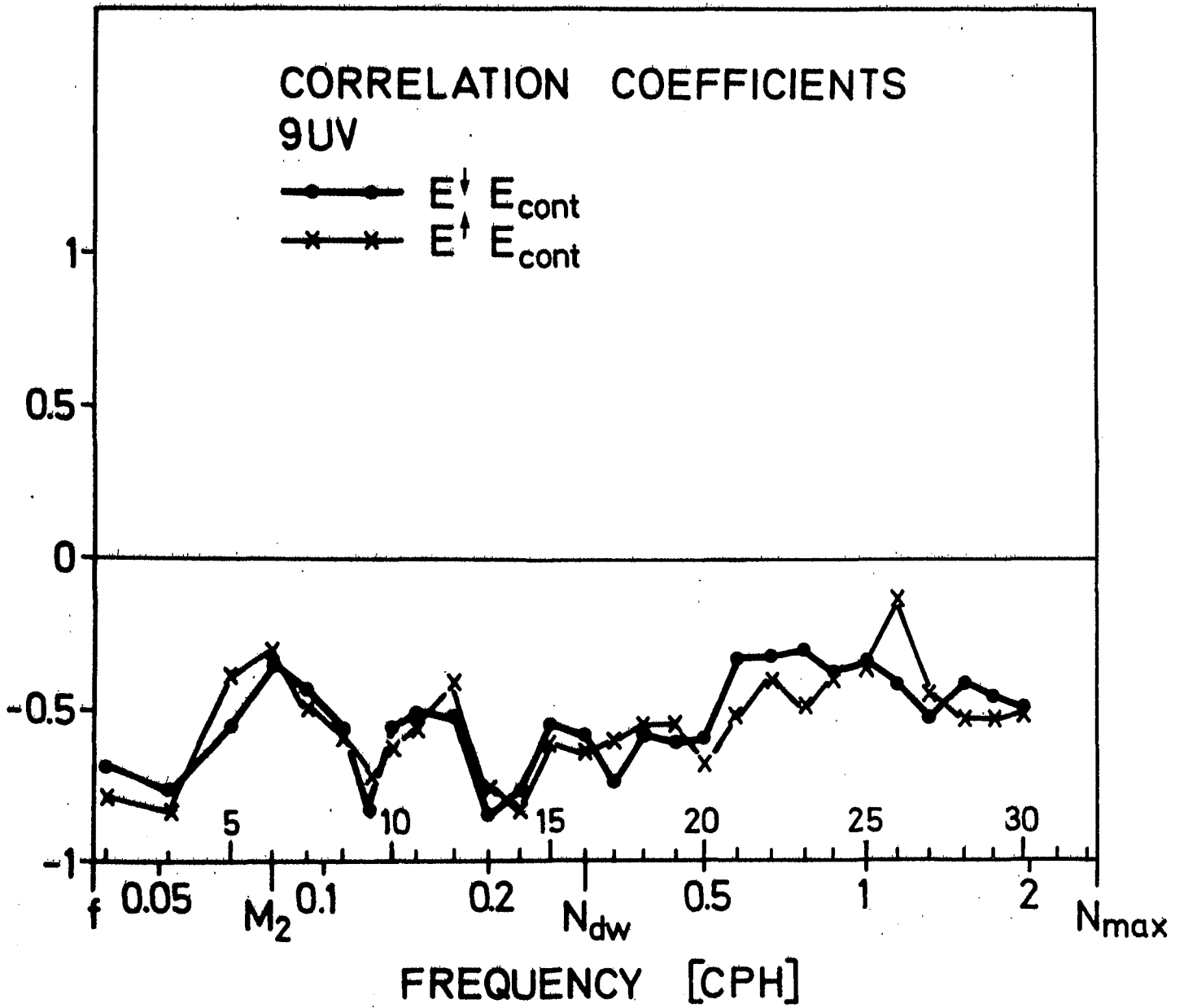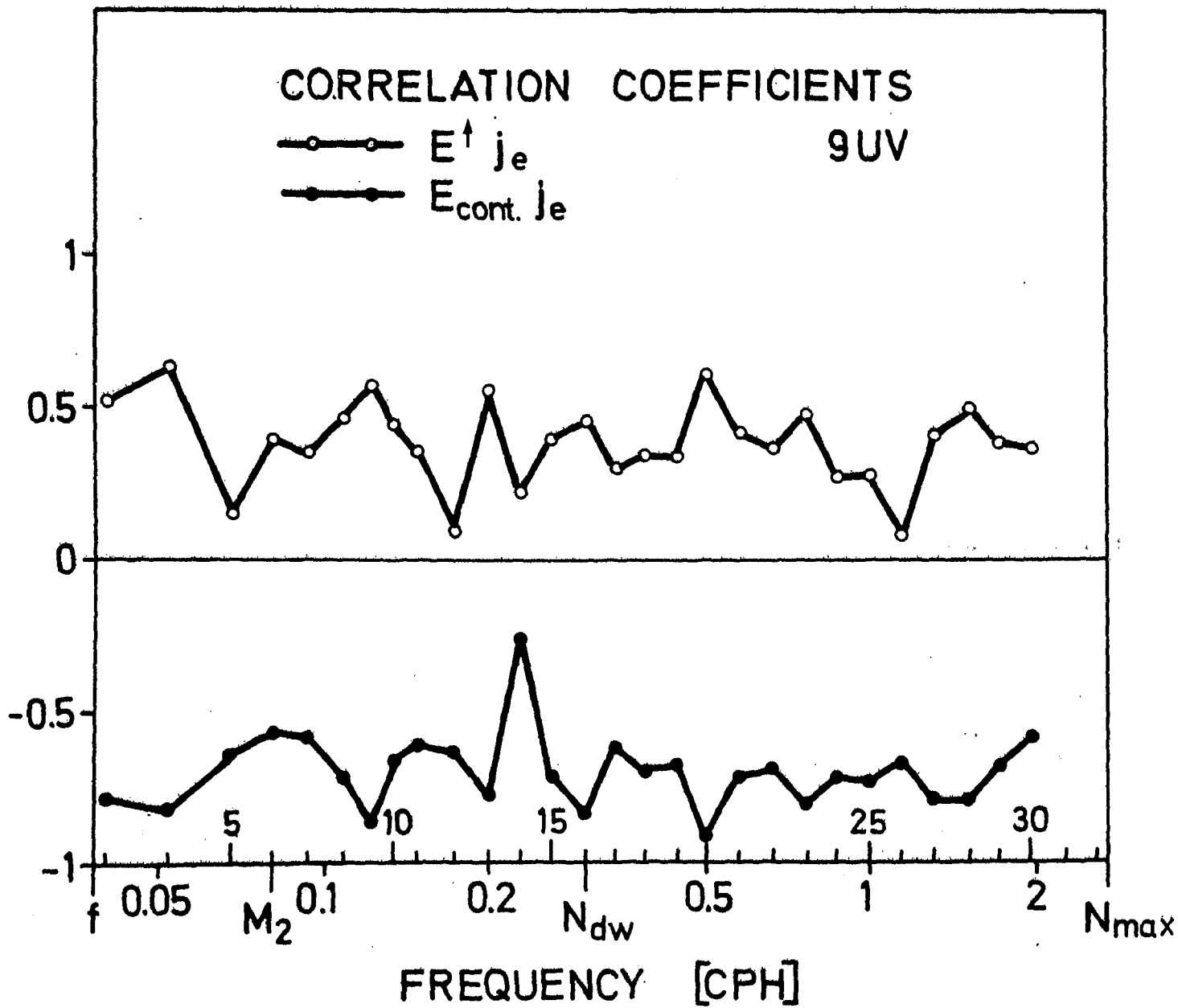
Fig. V.3b

Fig. V.4

Fig. V.5

Fig. V.6

IWEX DISPERSION RELATION

IWEX DISPERSION RELATION
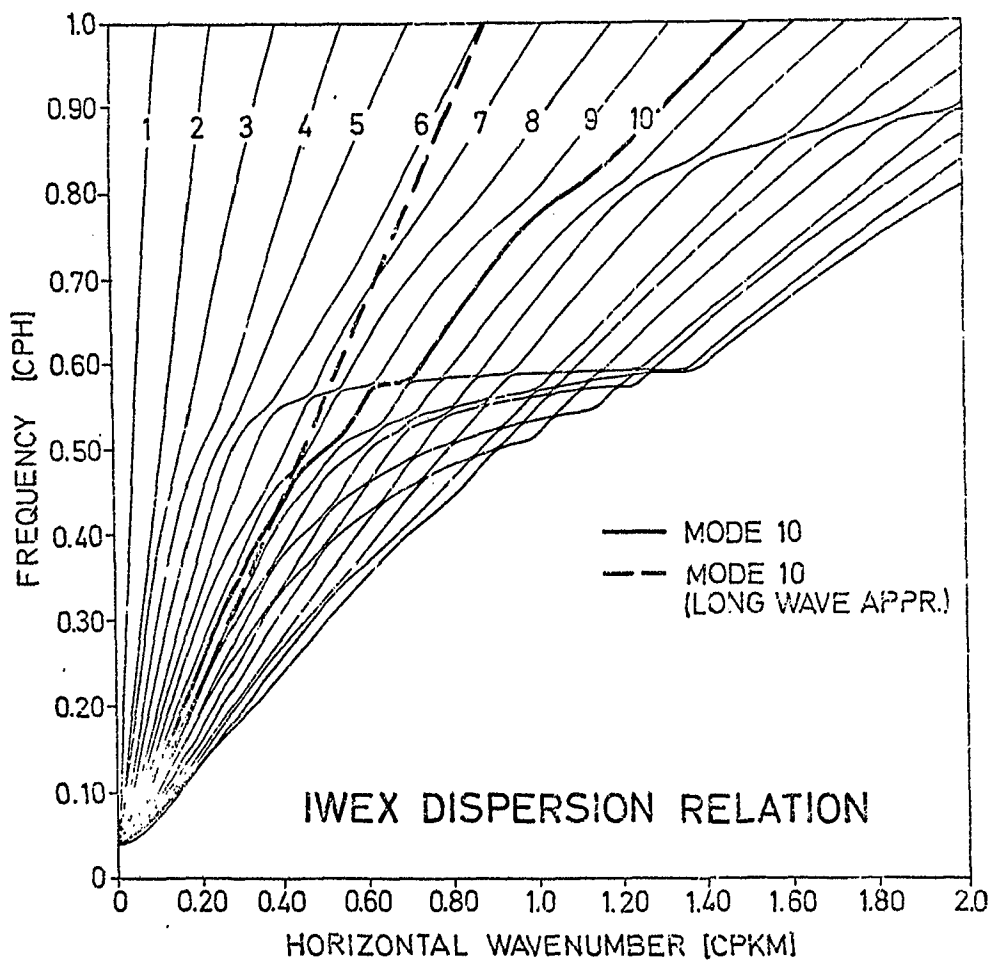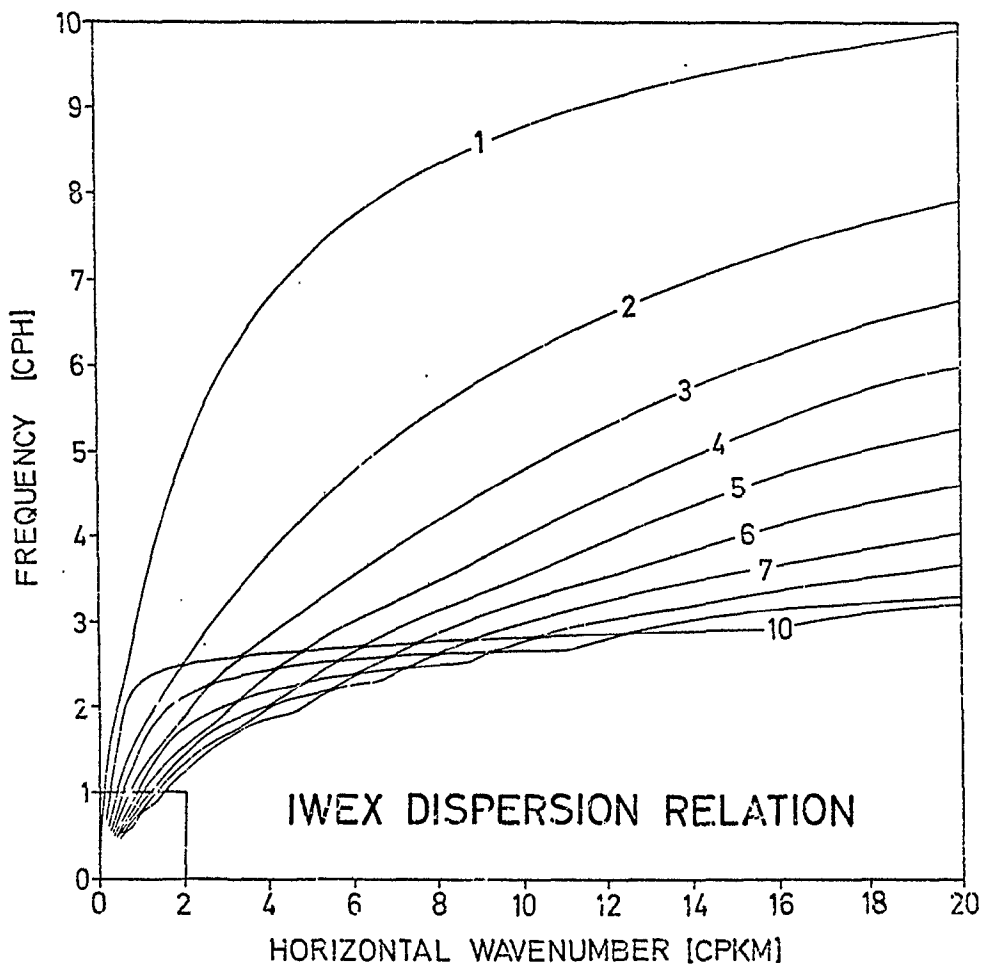
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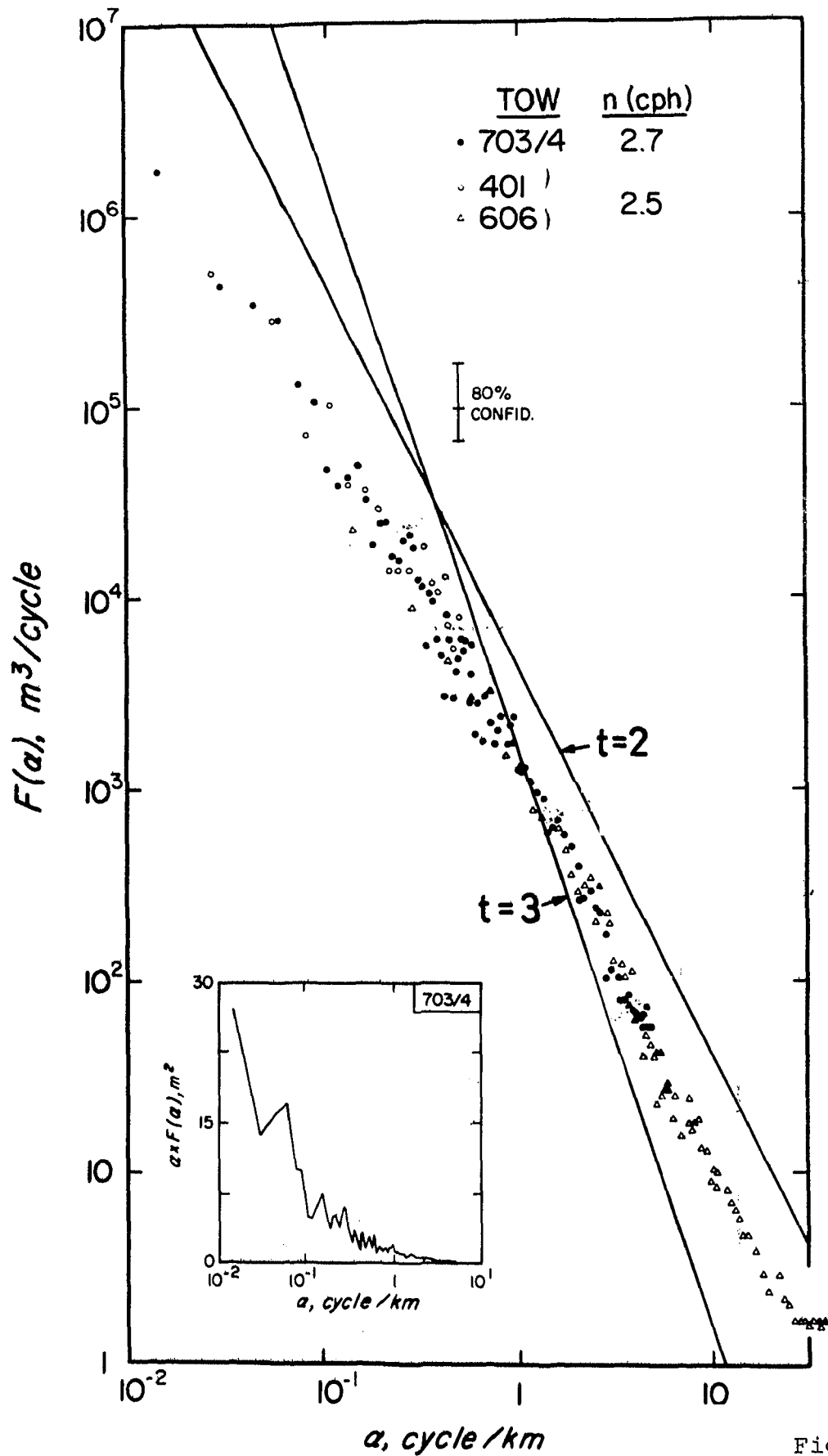
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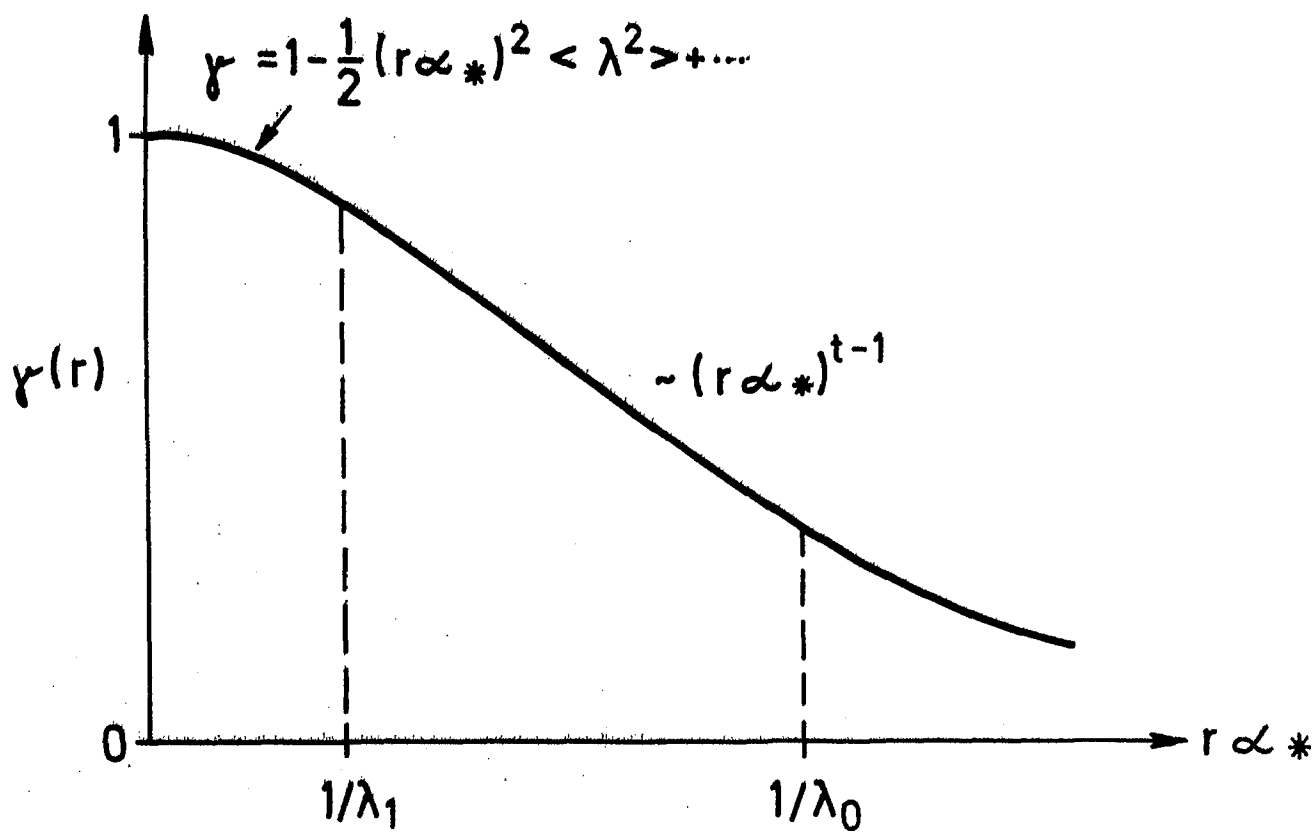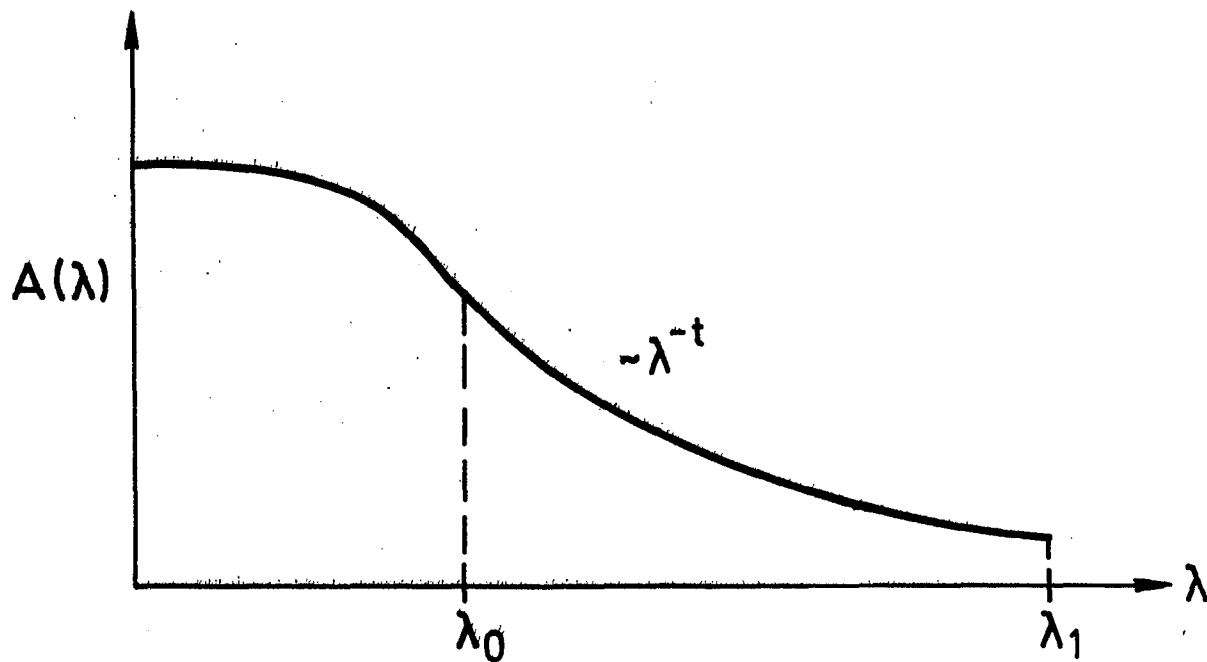
Fig. V.9

Fig. V.10

Fig. V.11

HIGH-WAVENUMBER
SLOPE t
17 ζ   (Δz < 200 m)
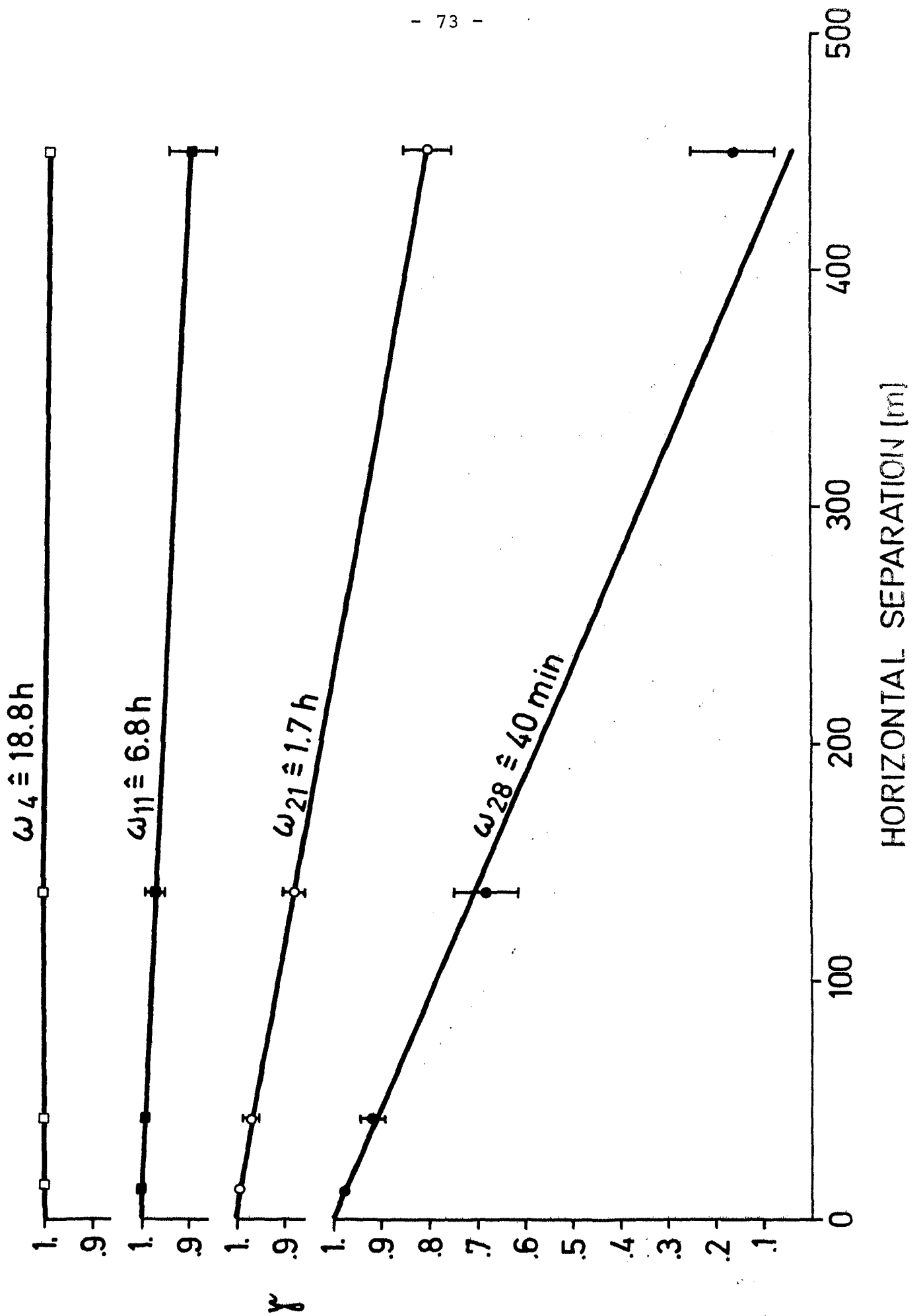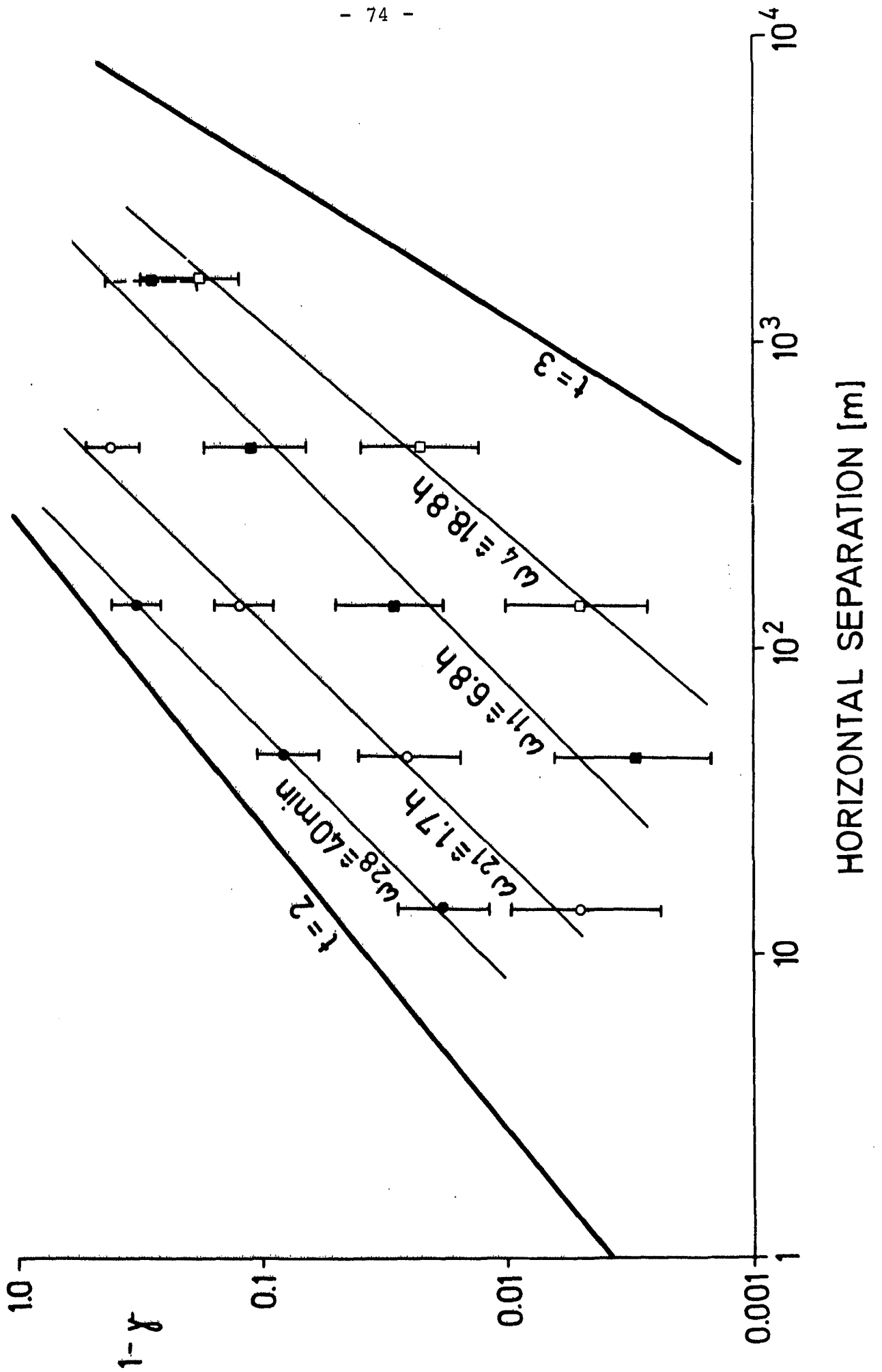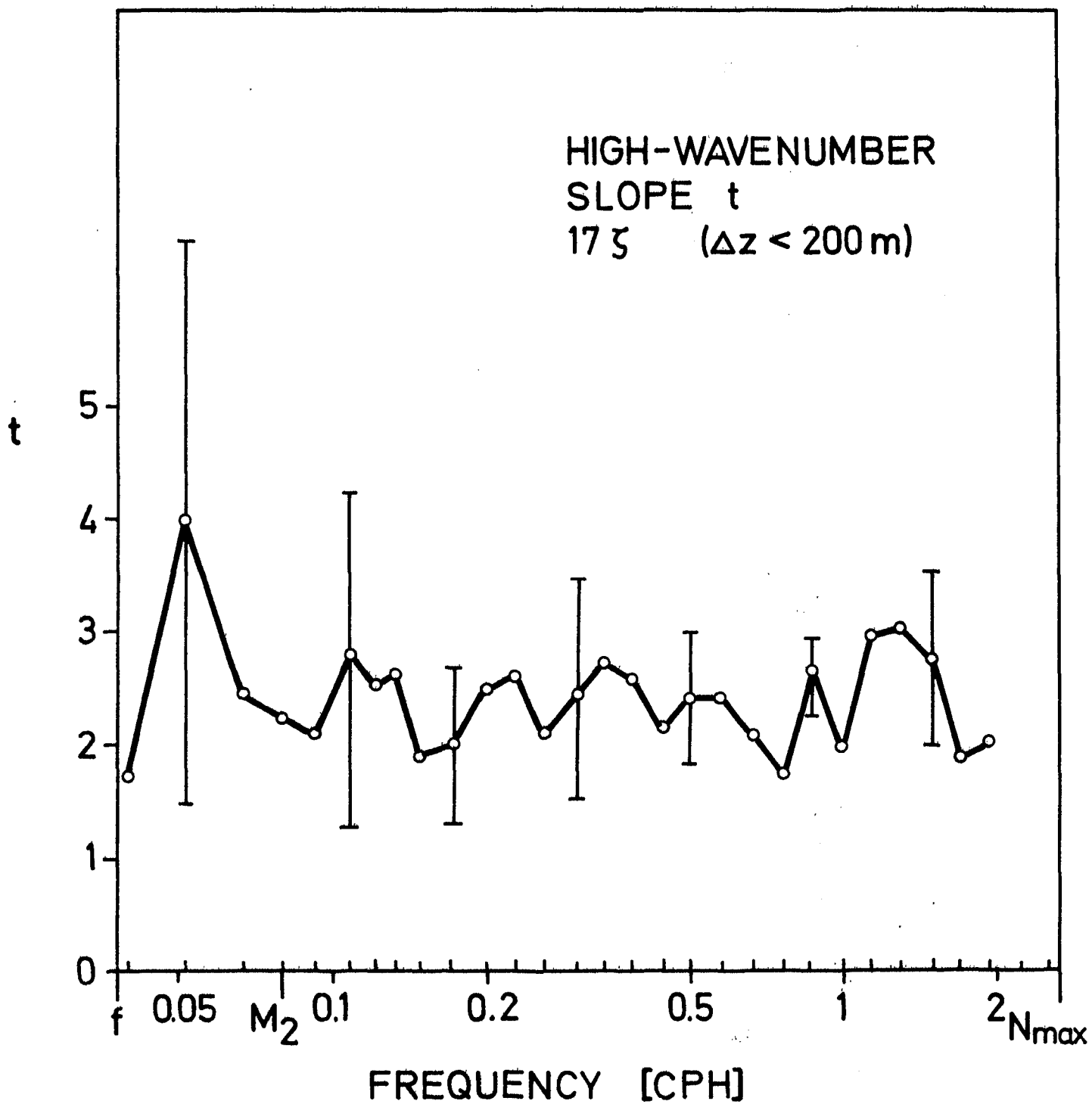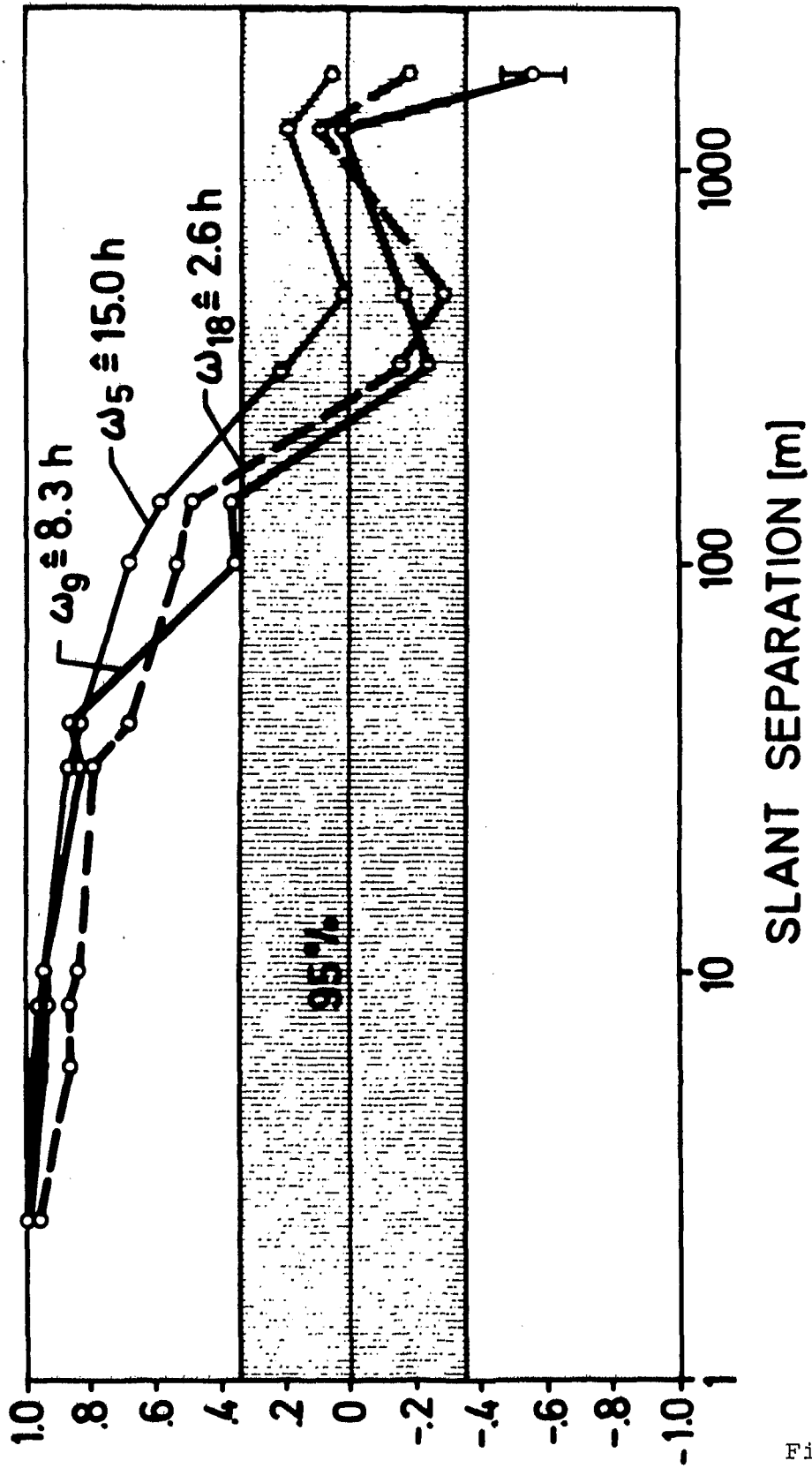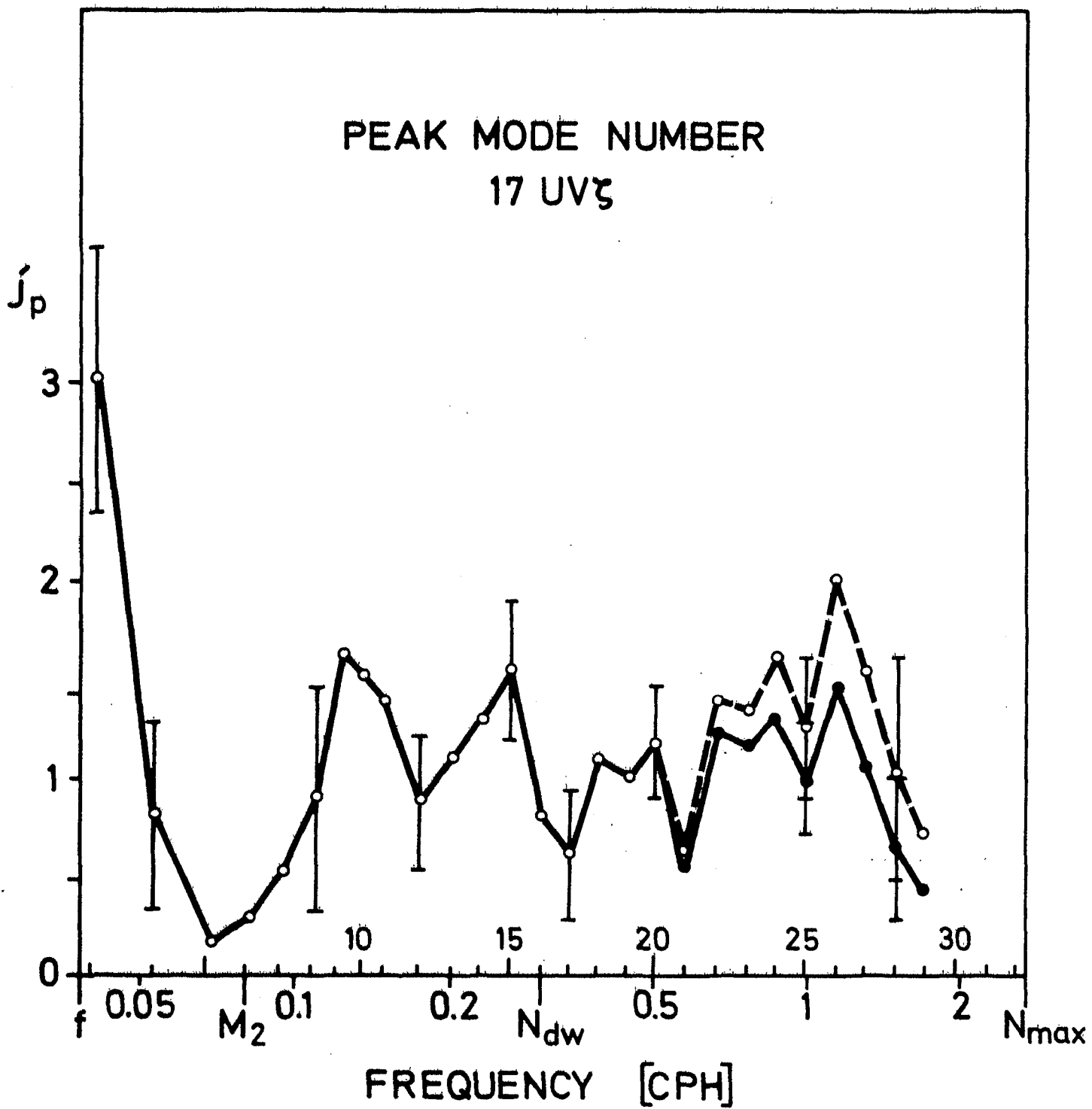
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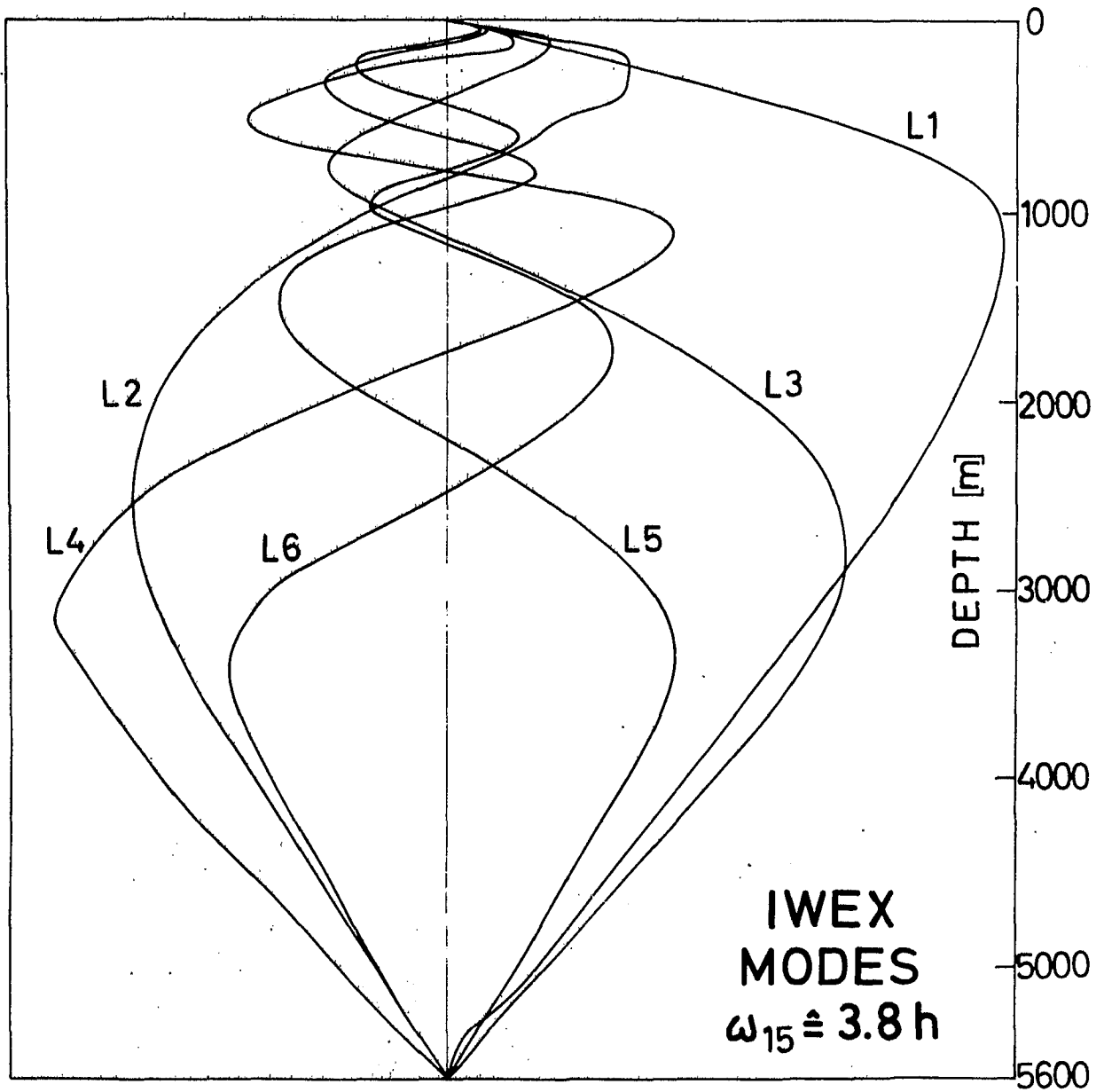
Fig. V.13

Fig. V.14

Fig. V.15
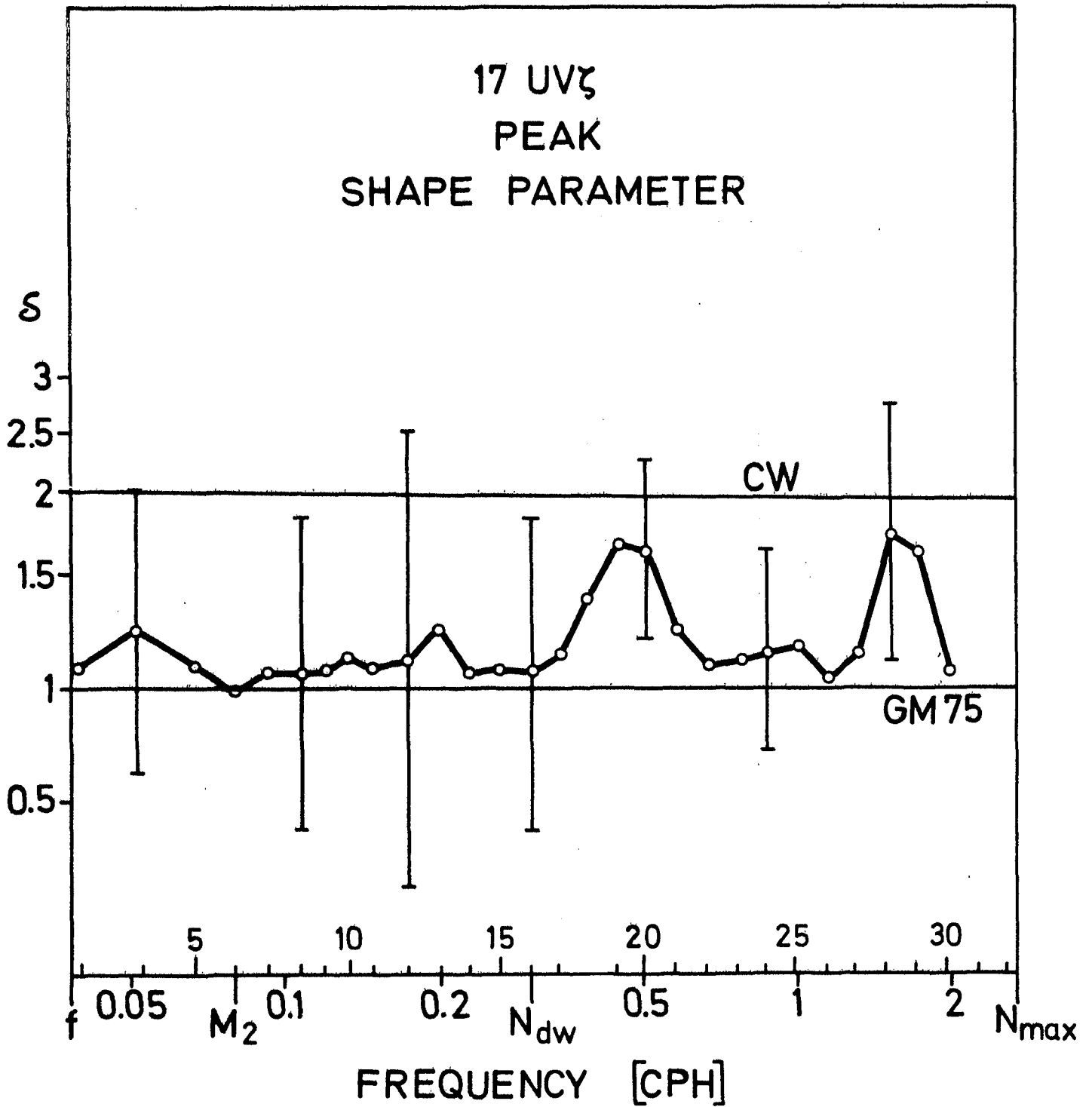
Fig. V.16

COS**2P-LAW
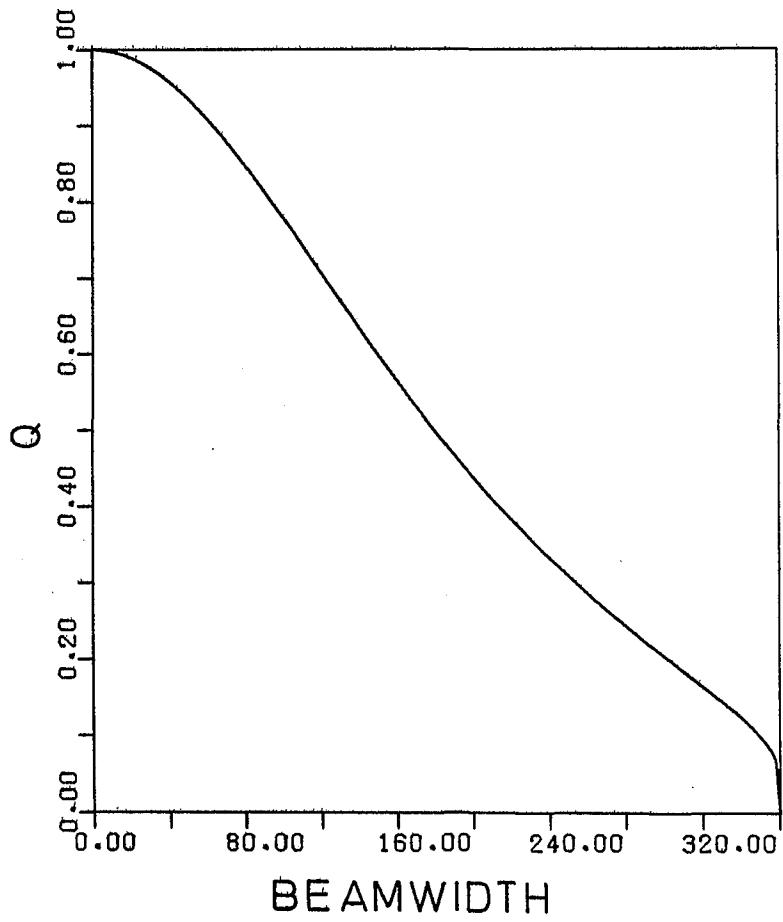
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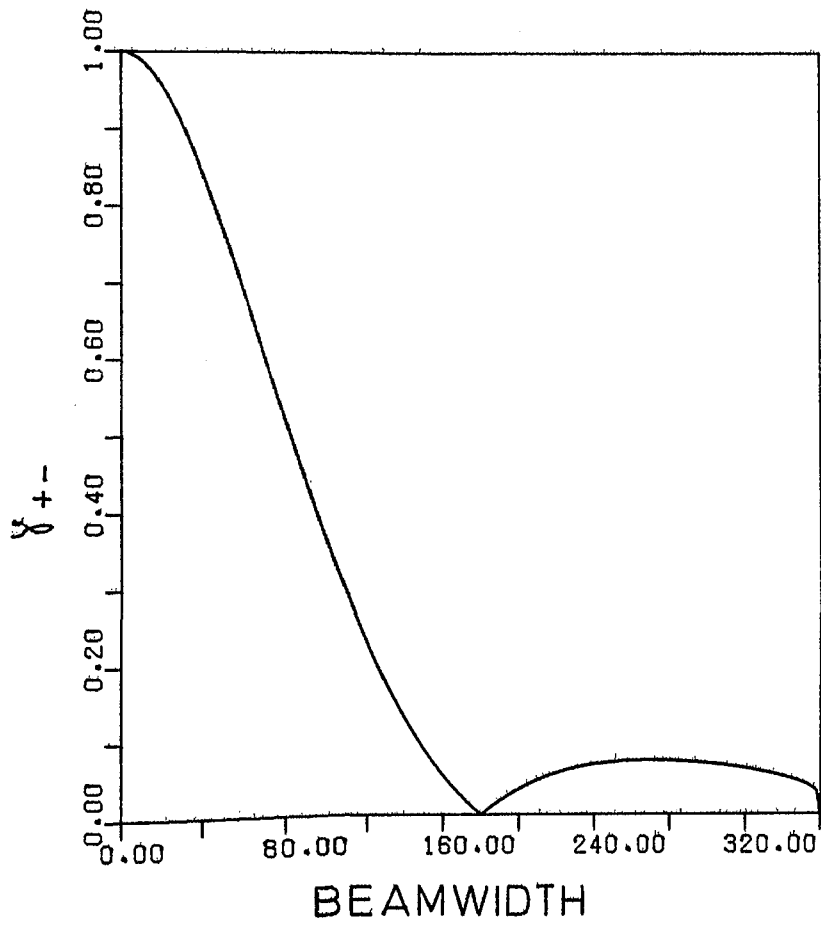
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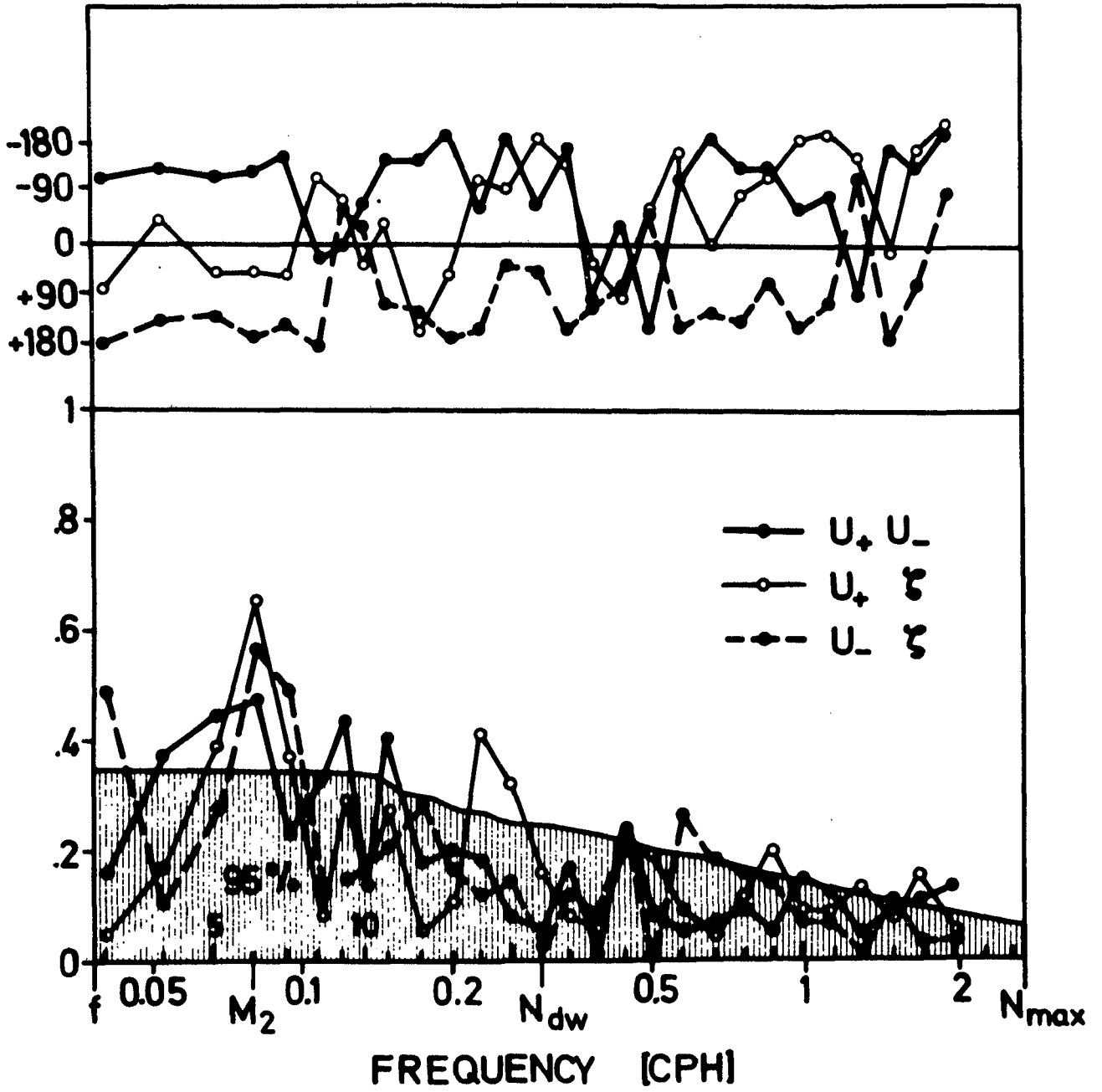
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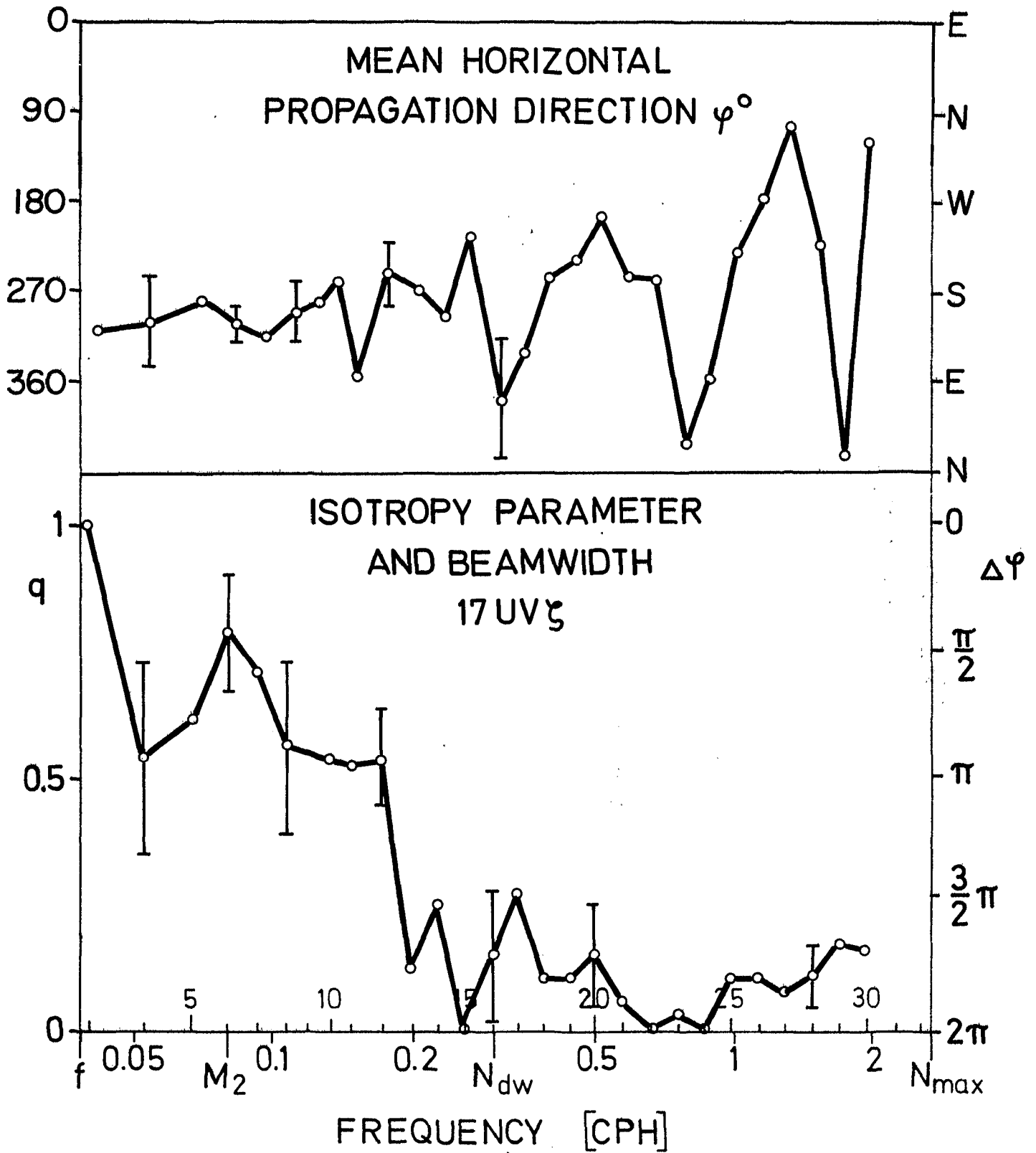
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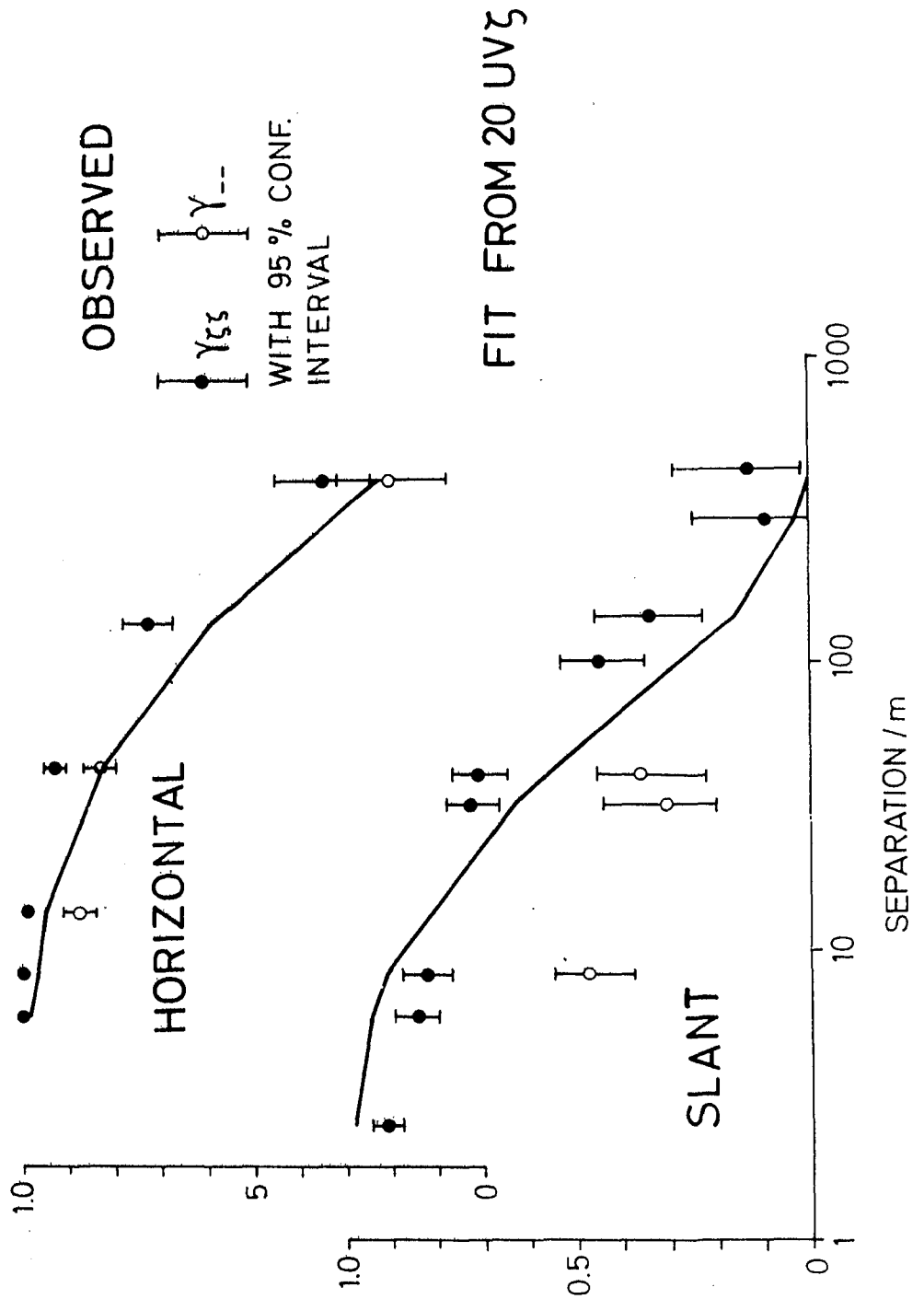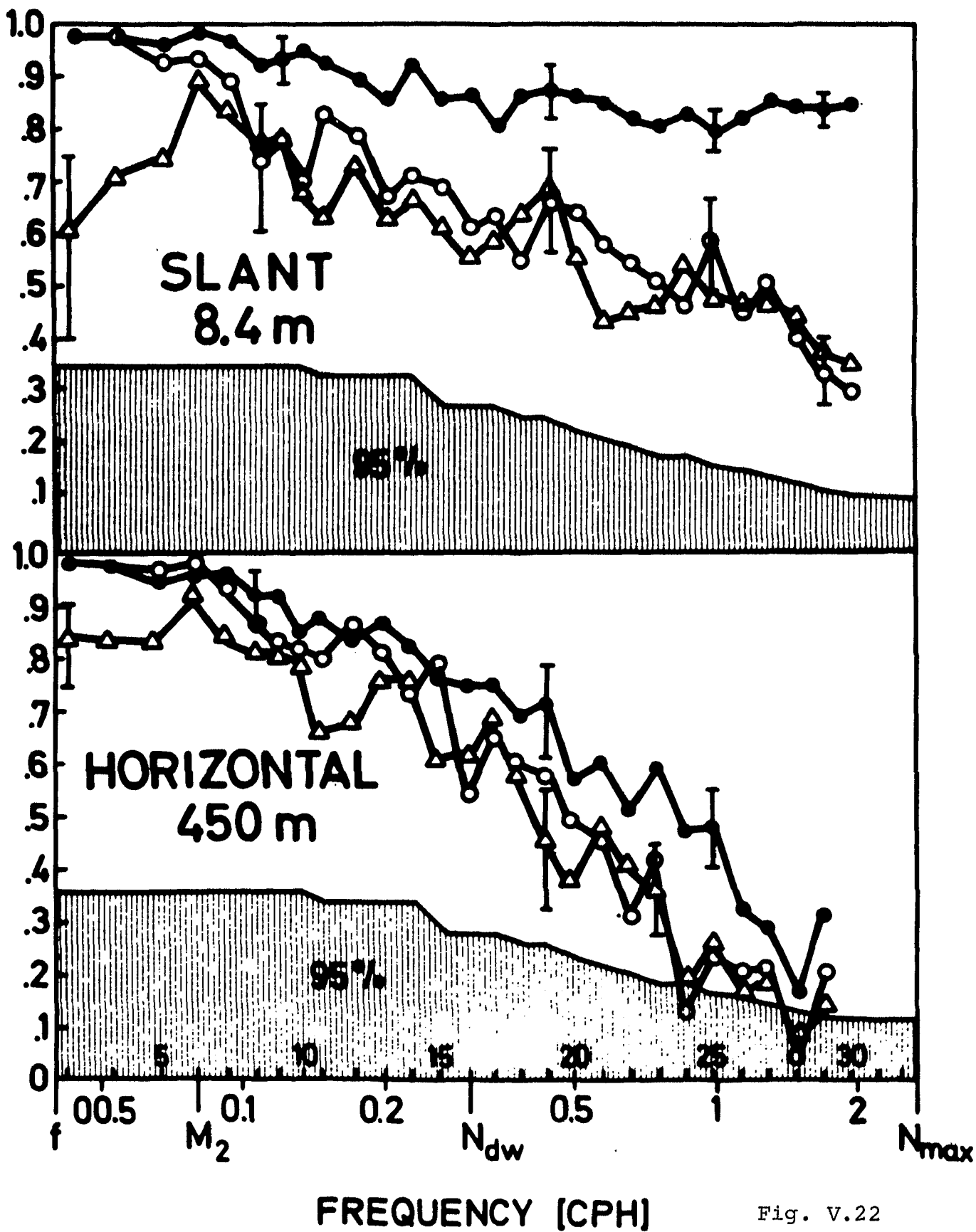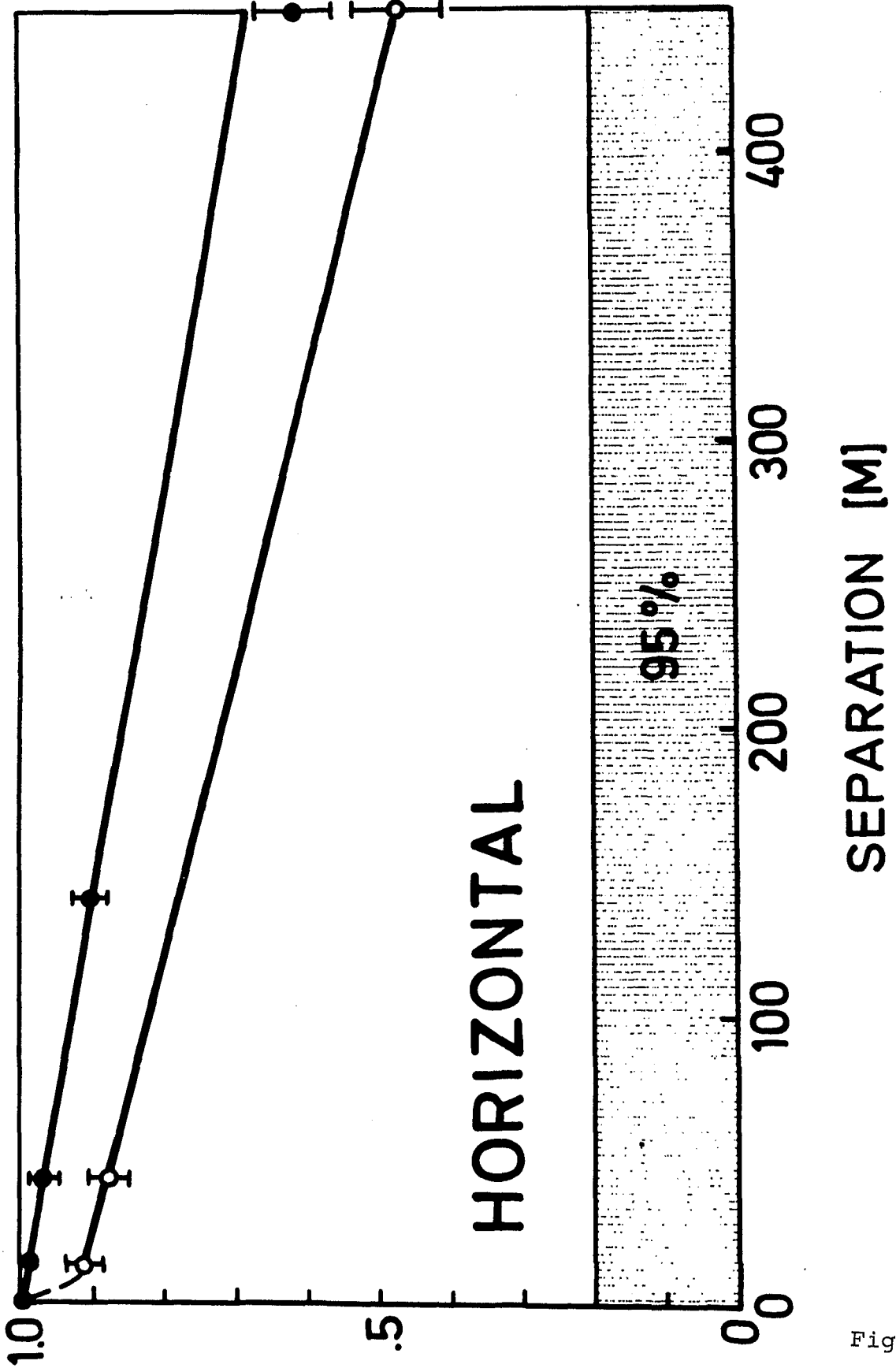
Fig. V.21

Fig. V.22

Fig. V.23
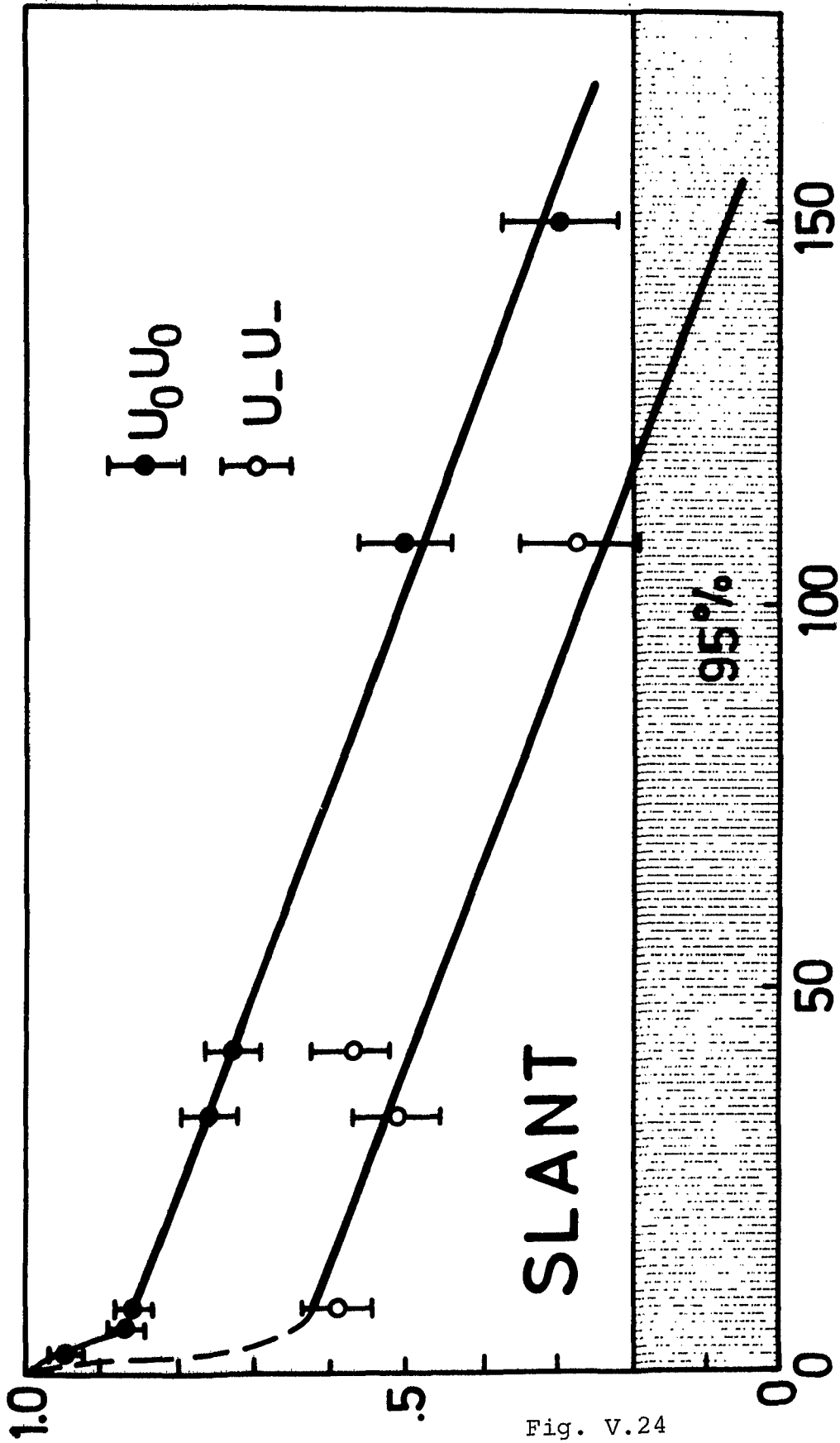
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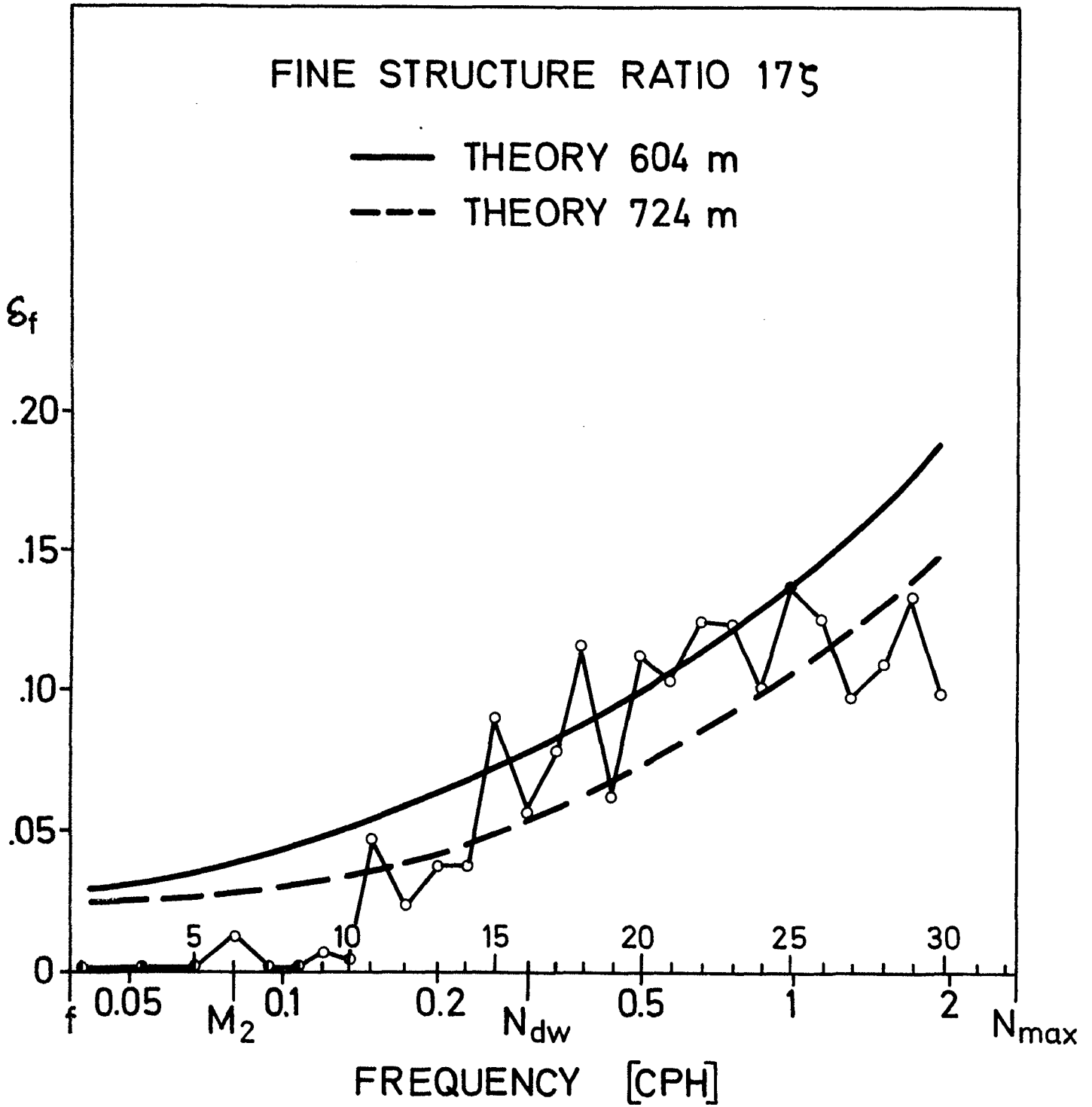
Fig. V.25

Fig. V.26

Fig. V.27

CURRENT CONTAMINATION
HOR. COHERENCE DROP
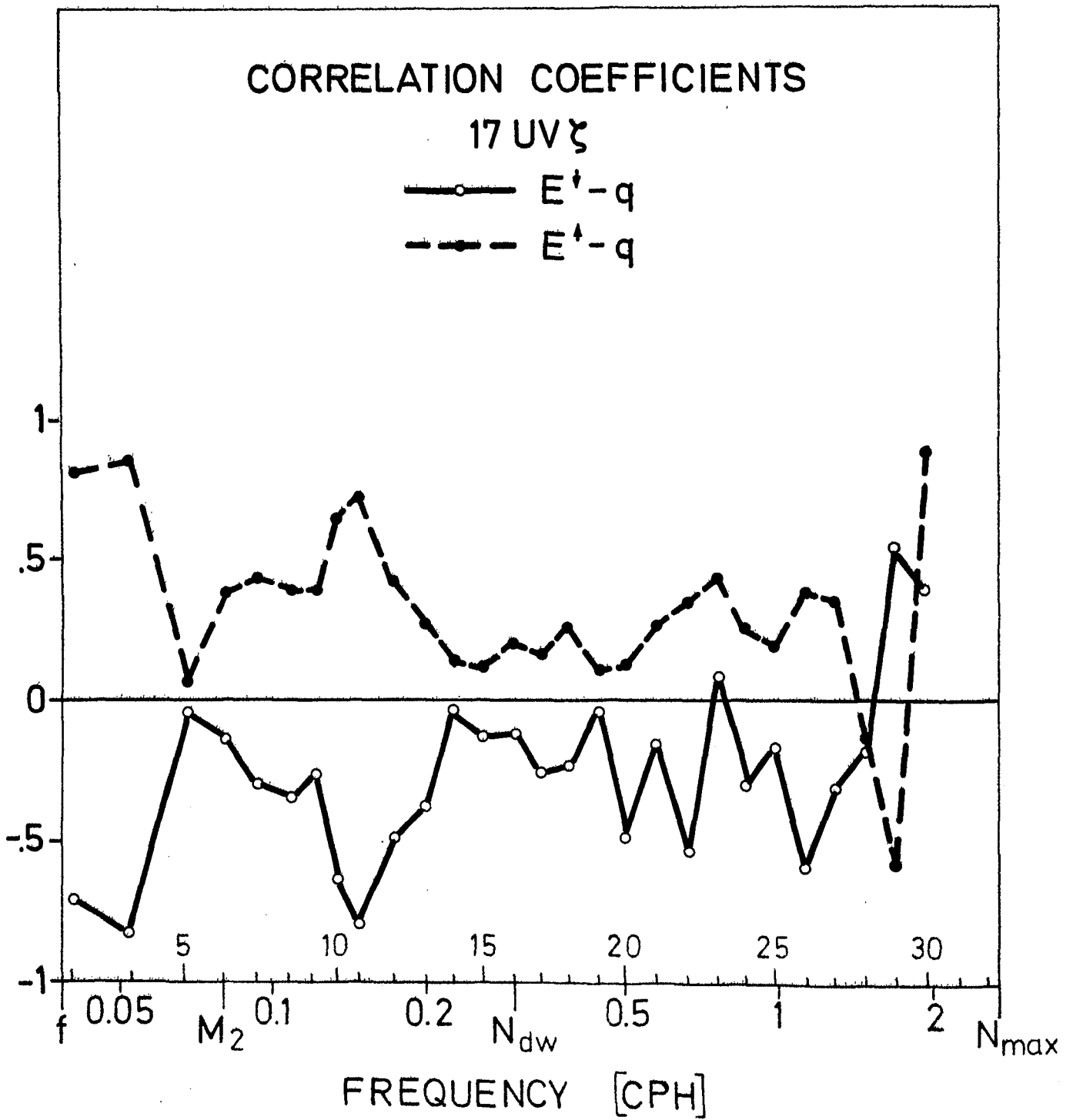9UV
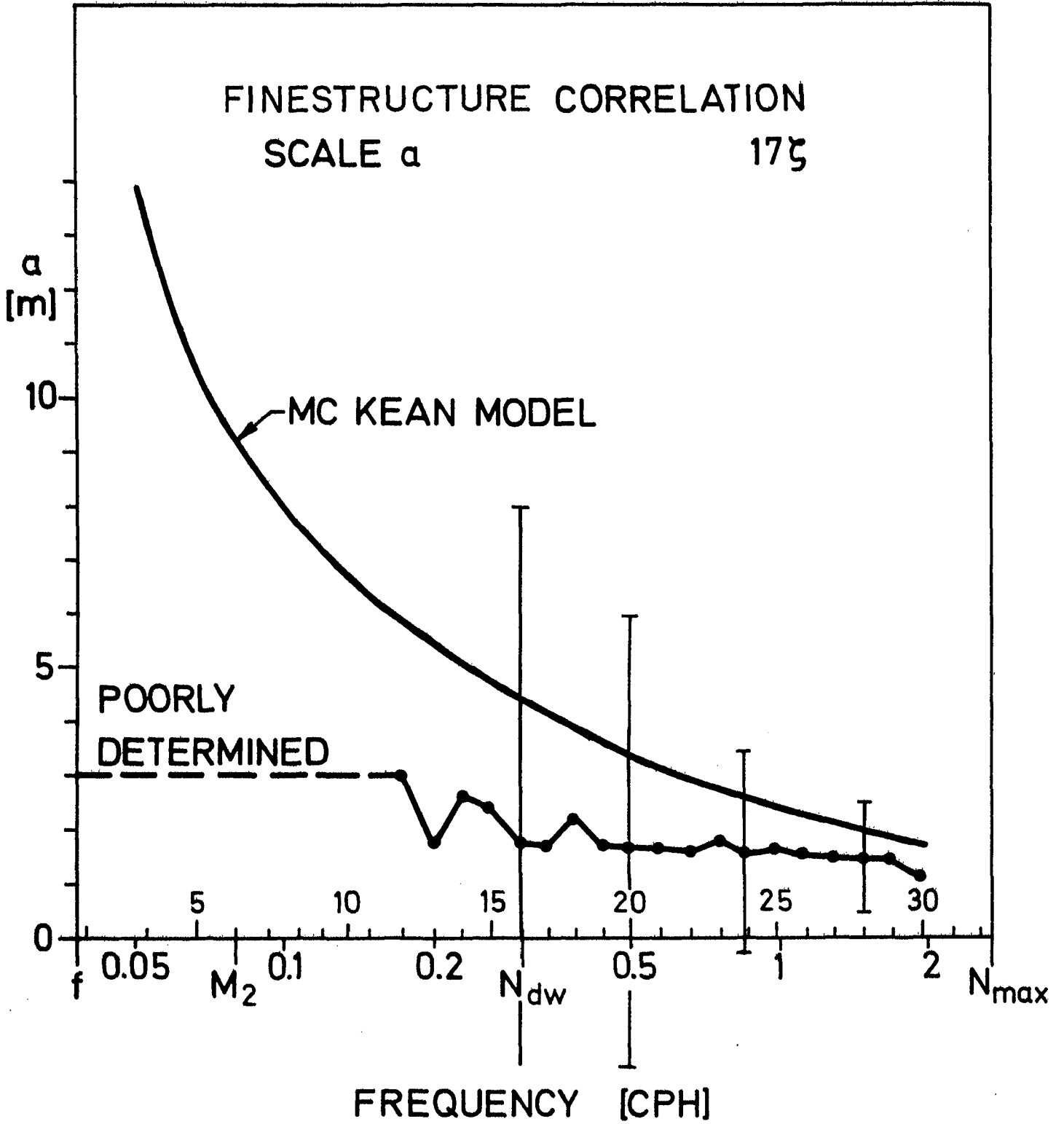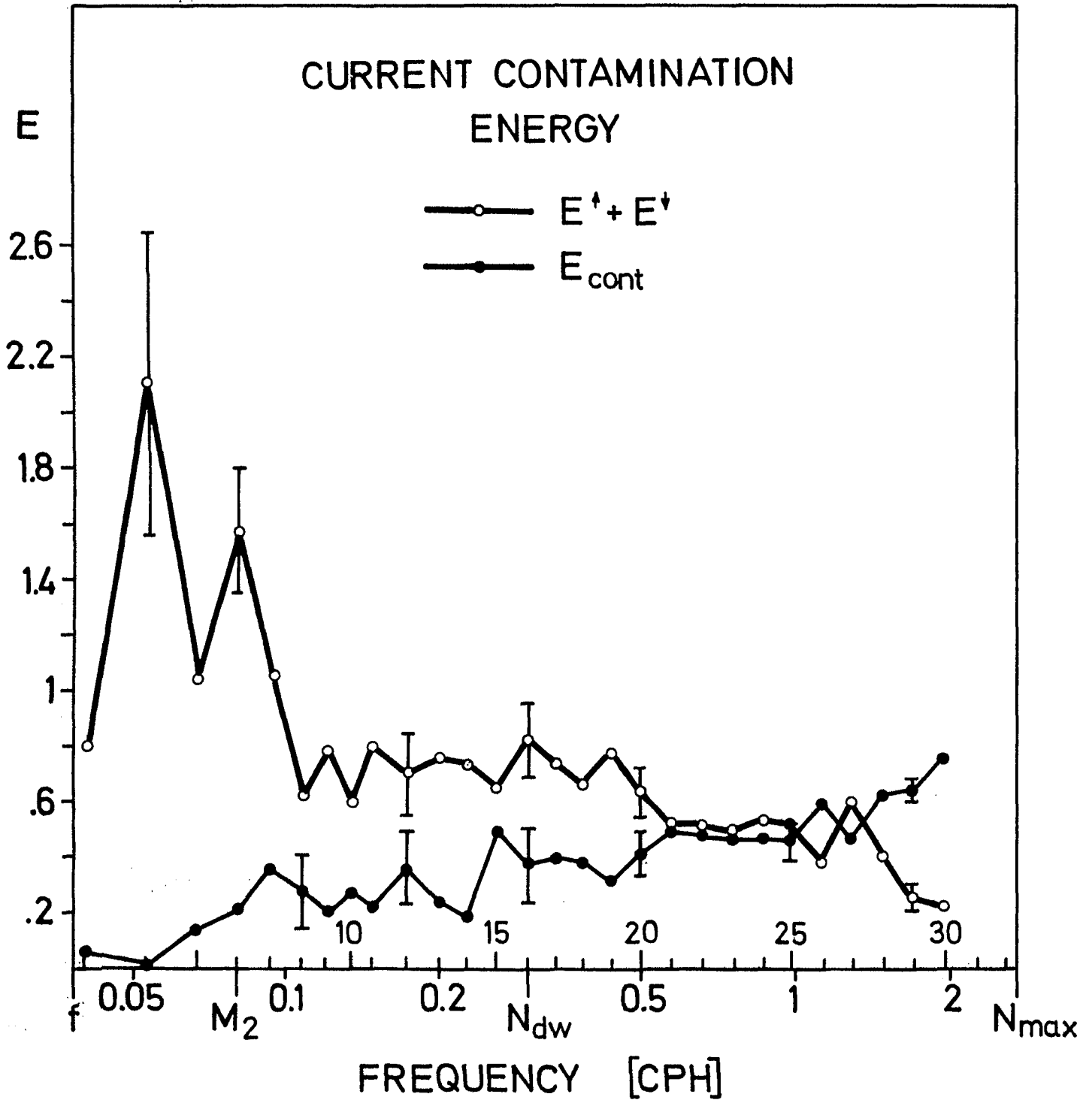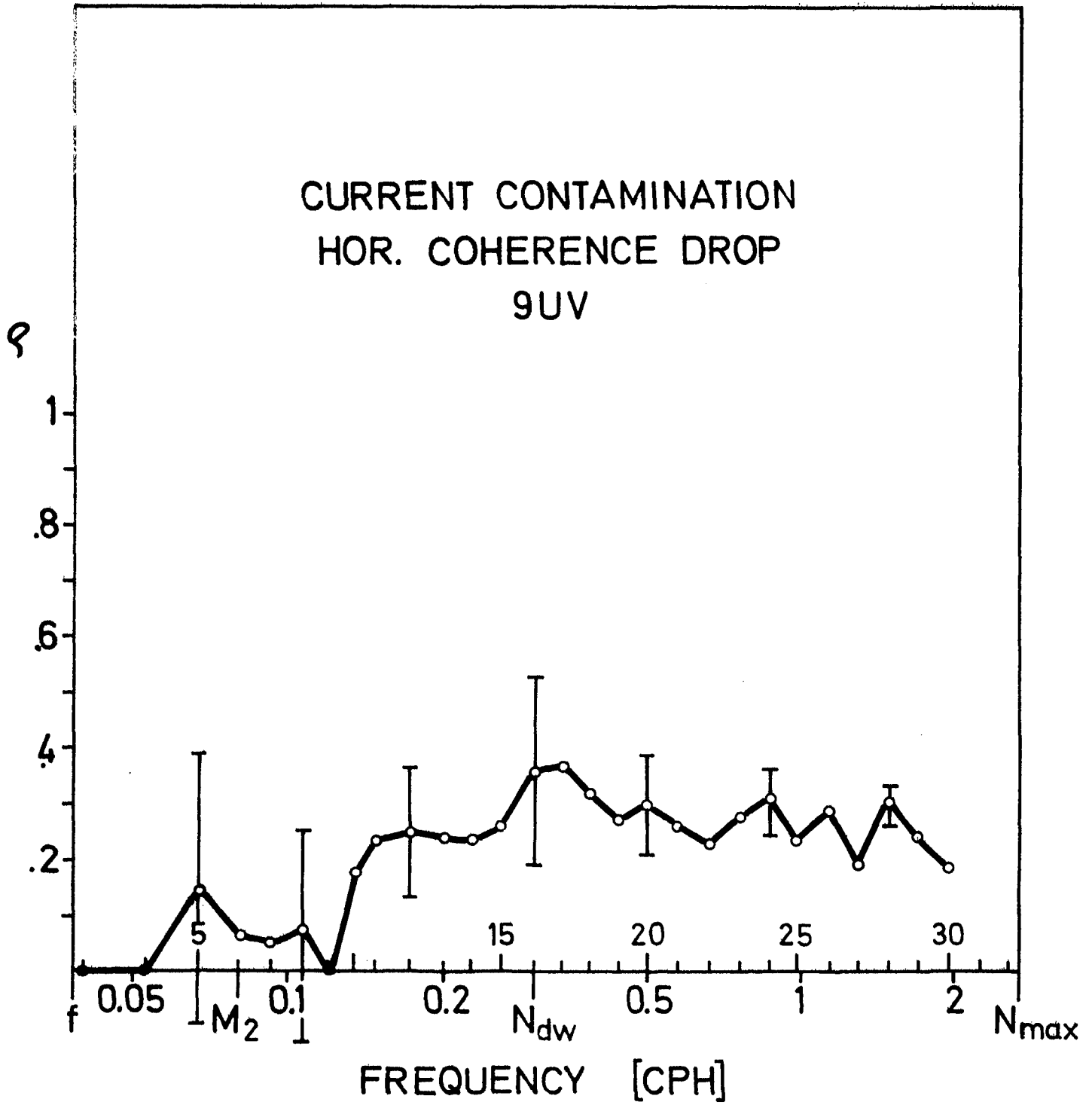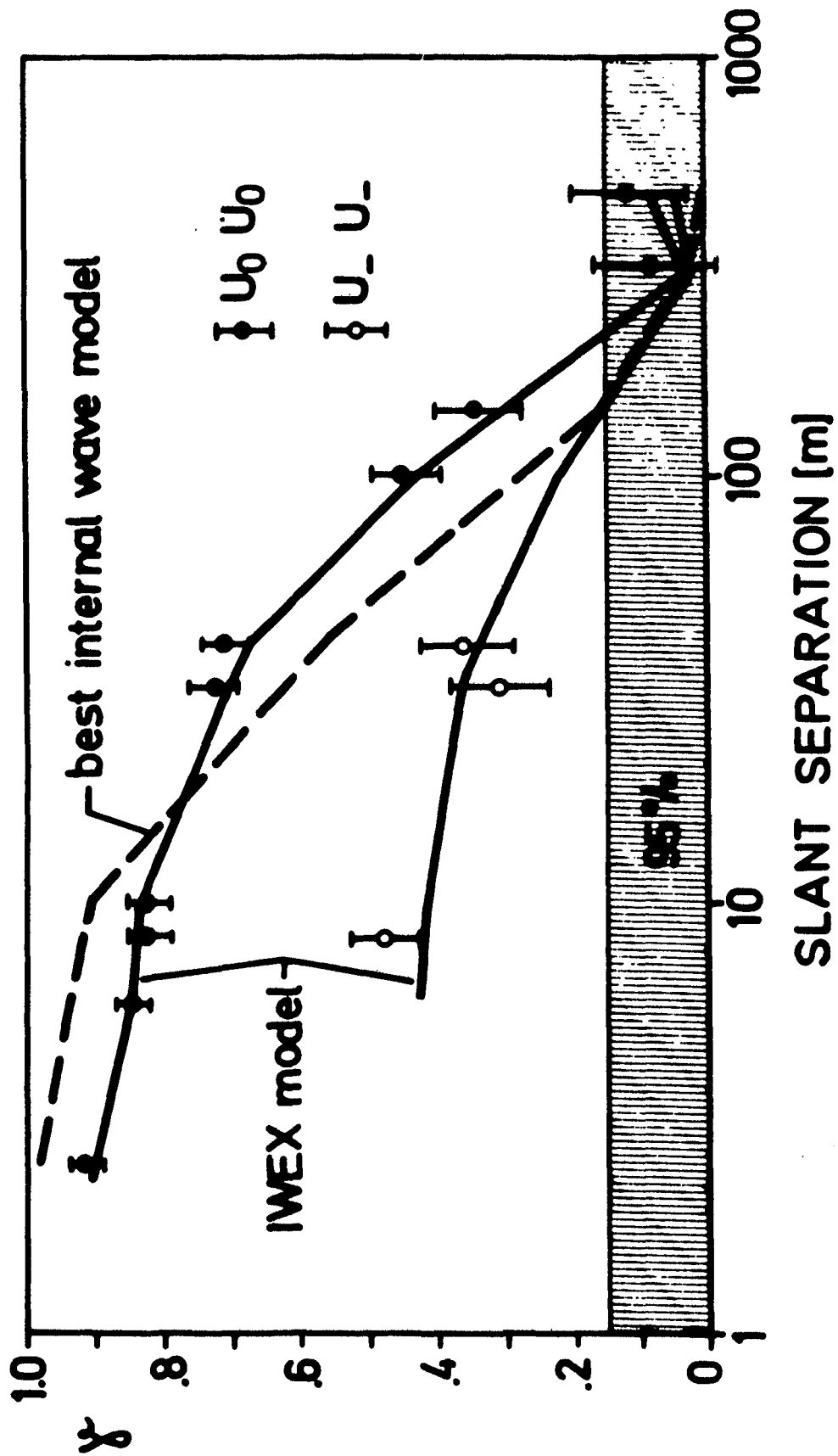
Fig. V.28

Fig. V.29
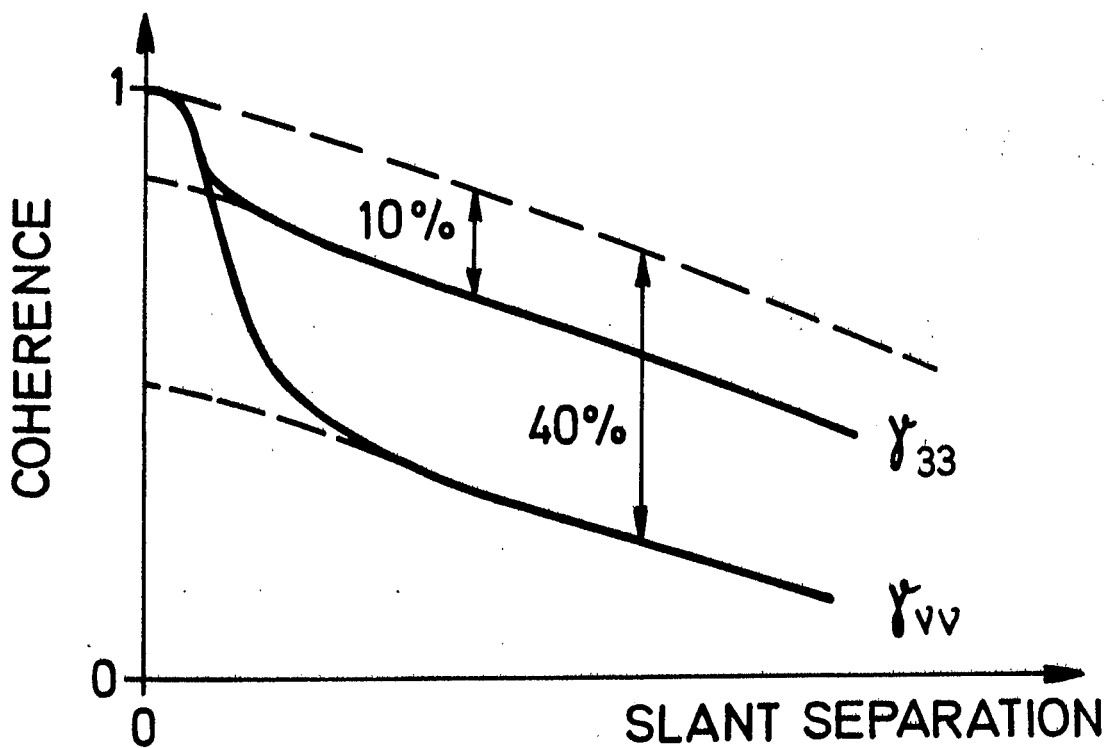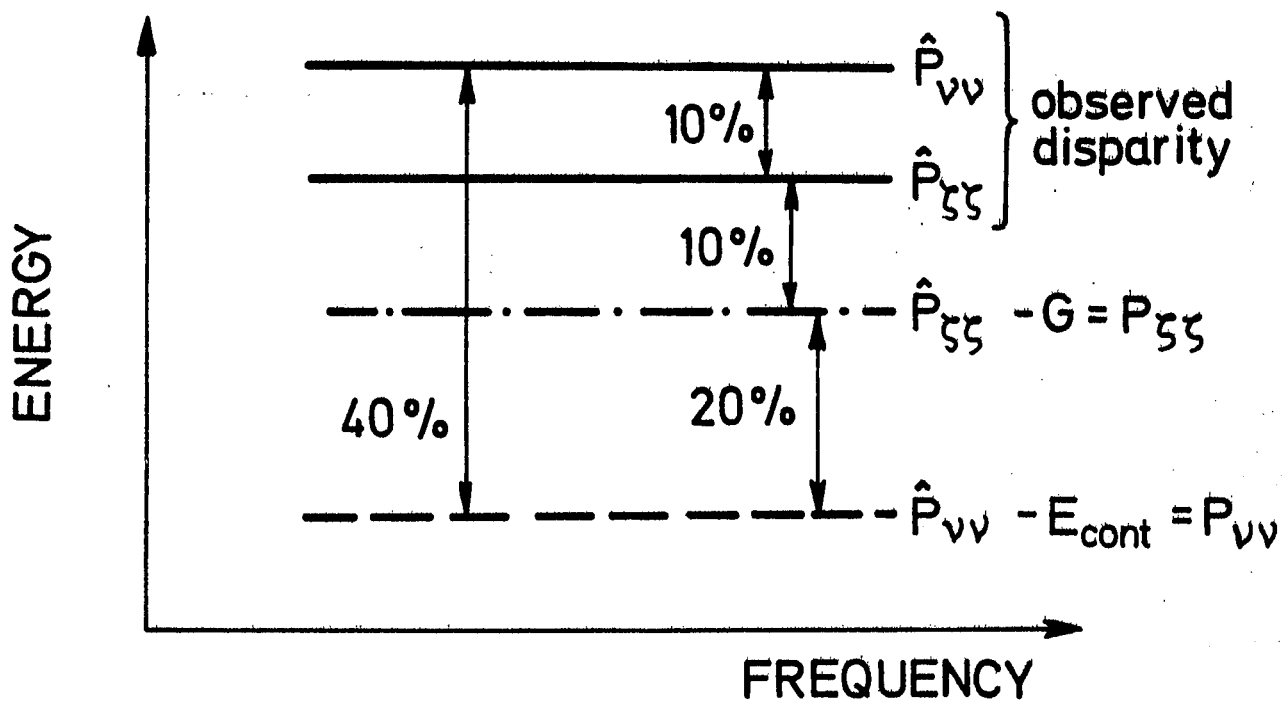
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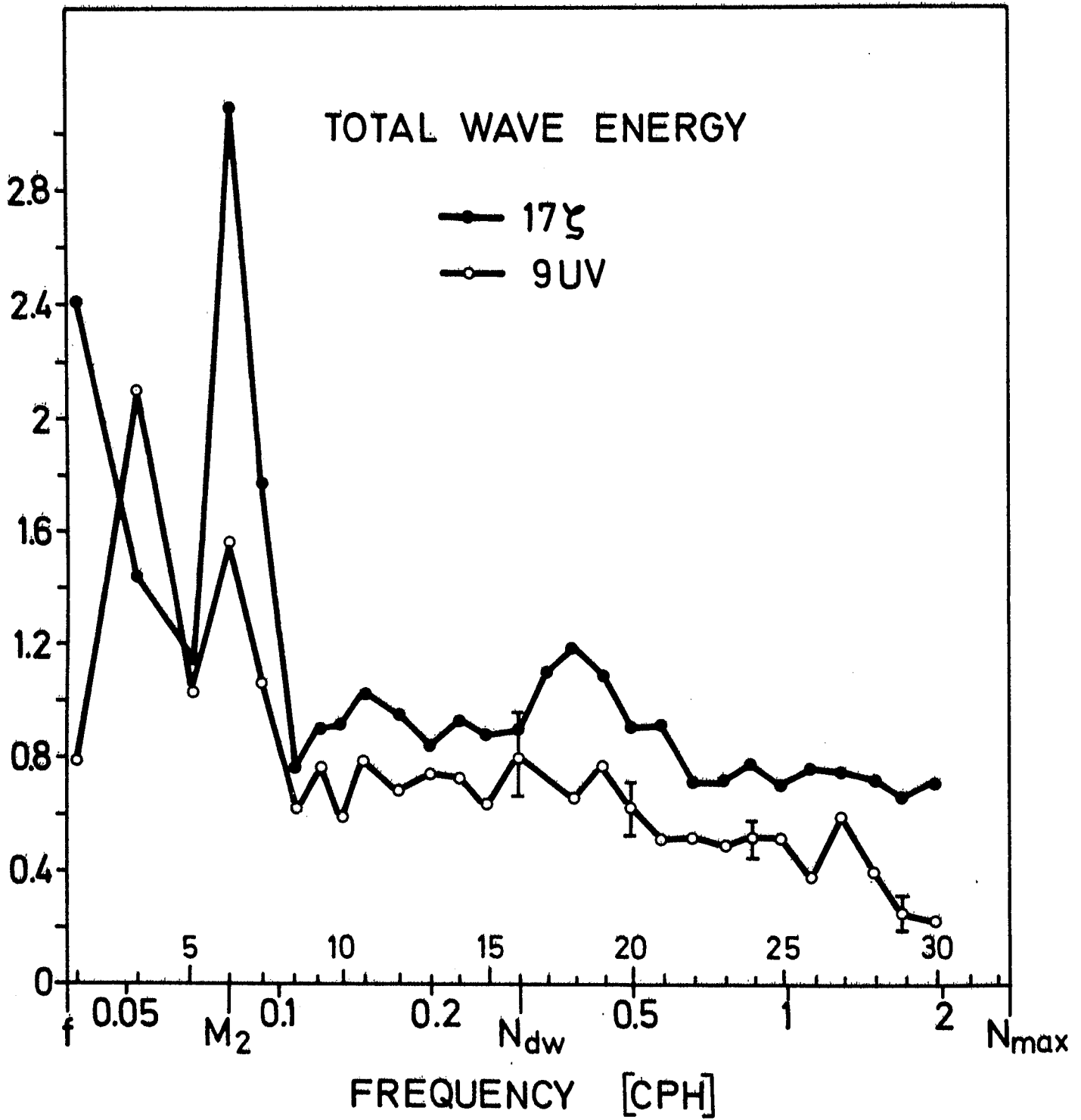
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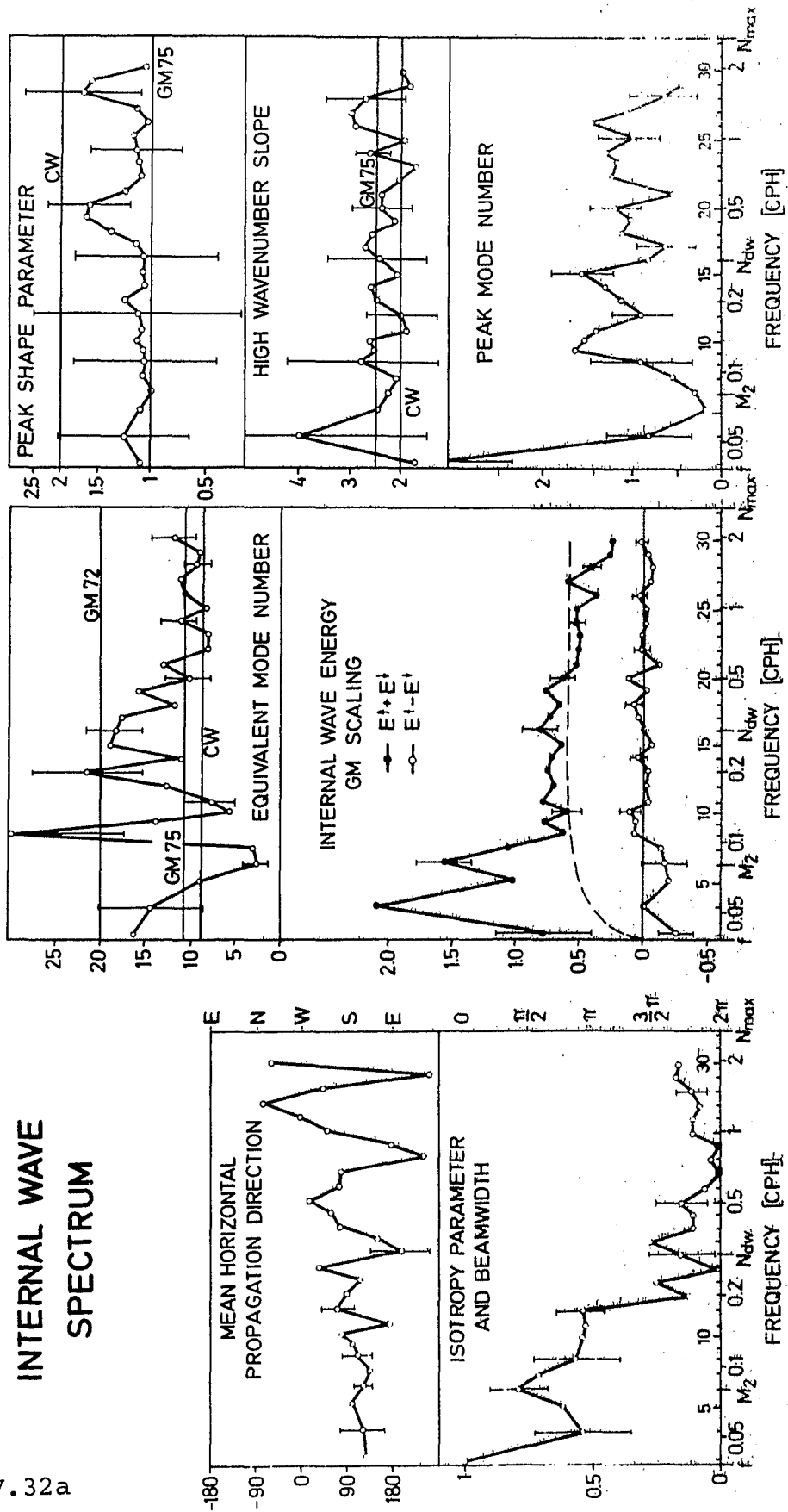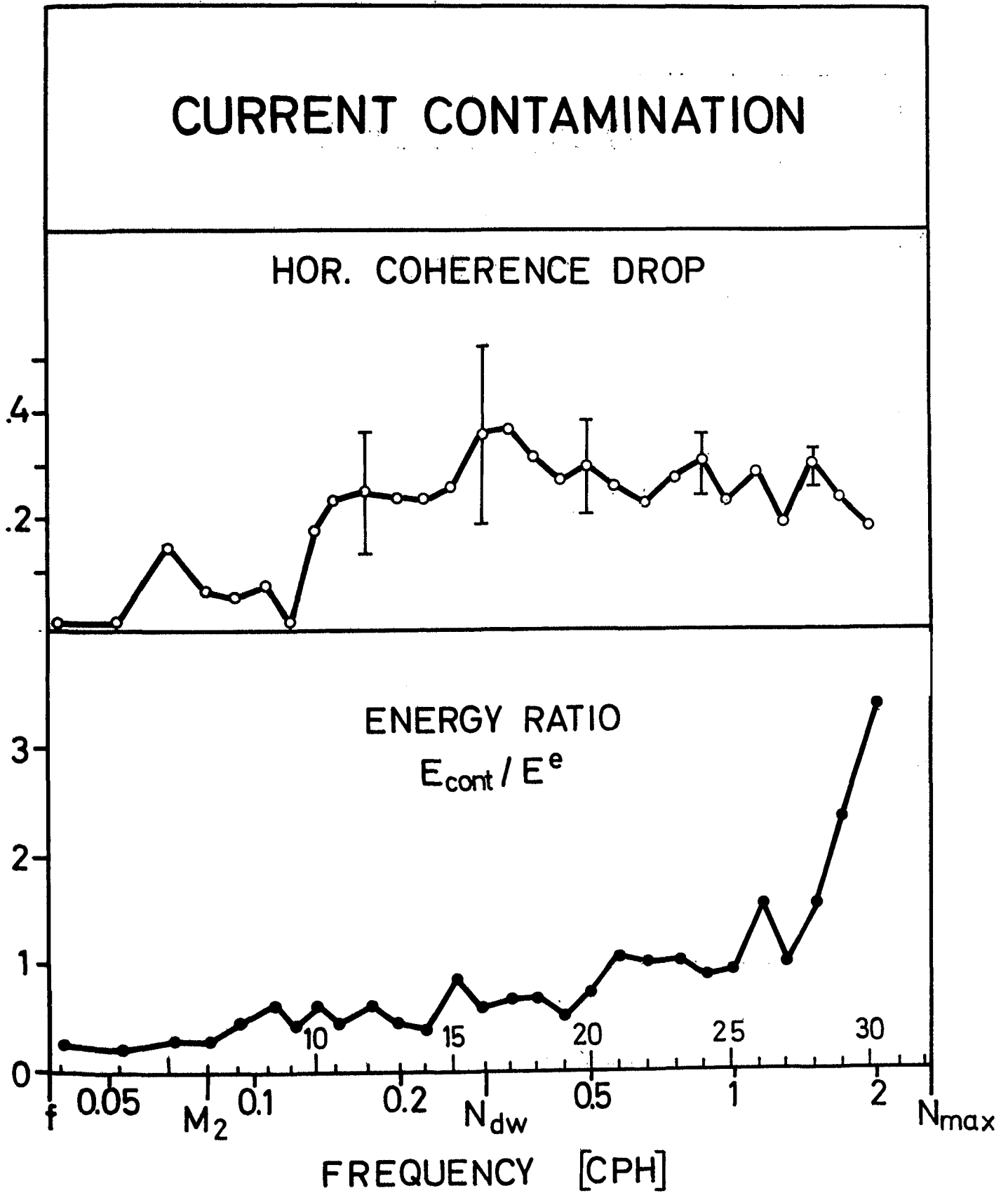
Fig. V.32a

Fig. V.32b
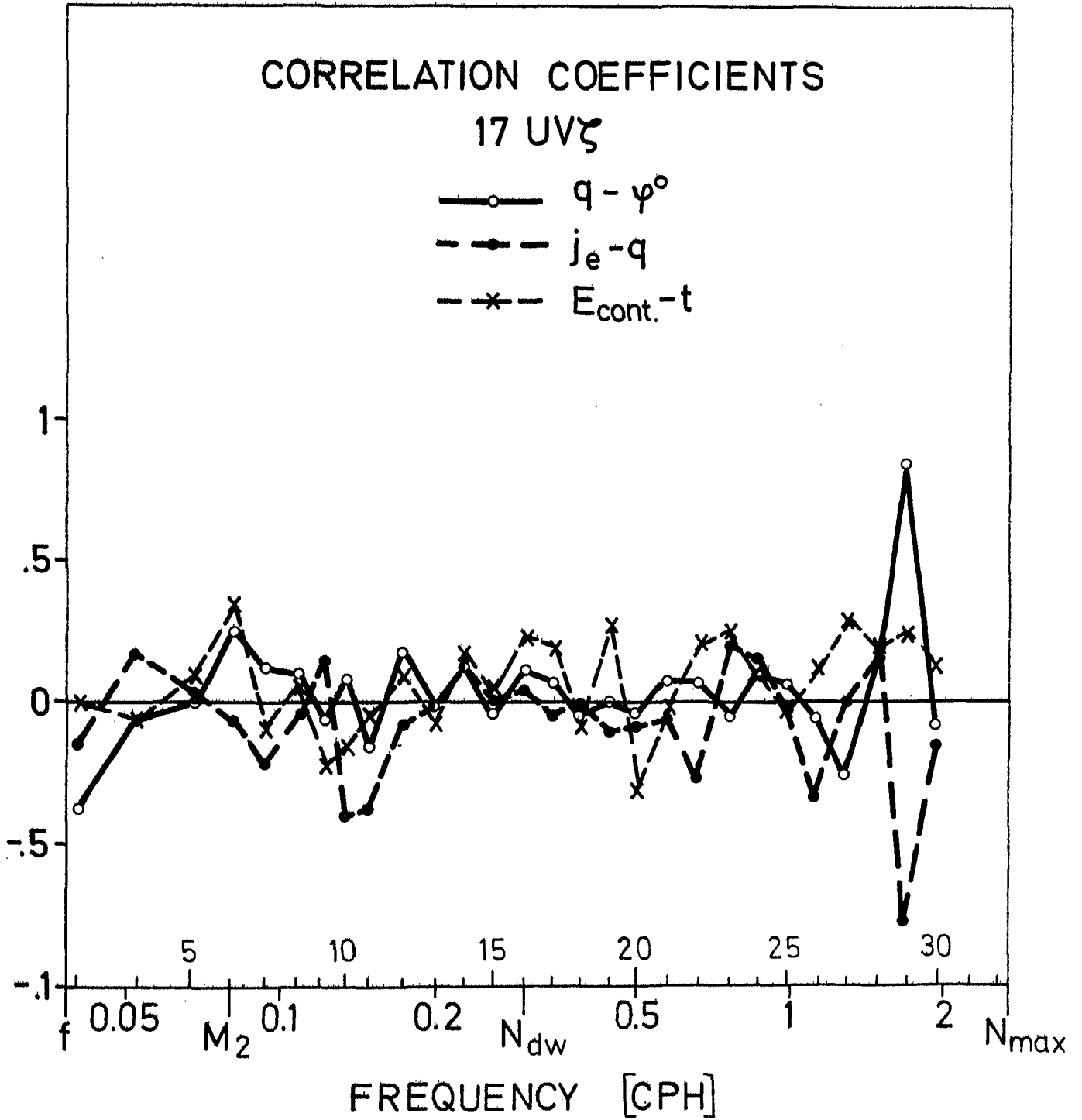
Fig. V.32c
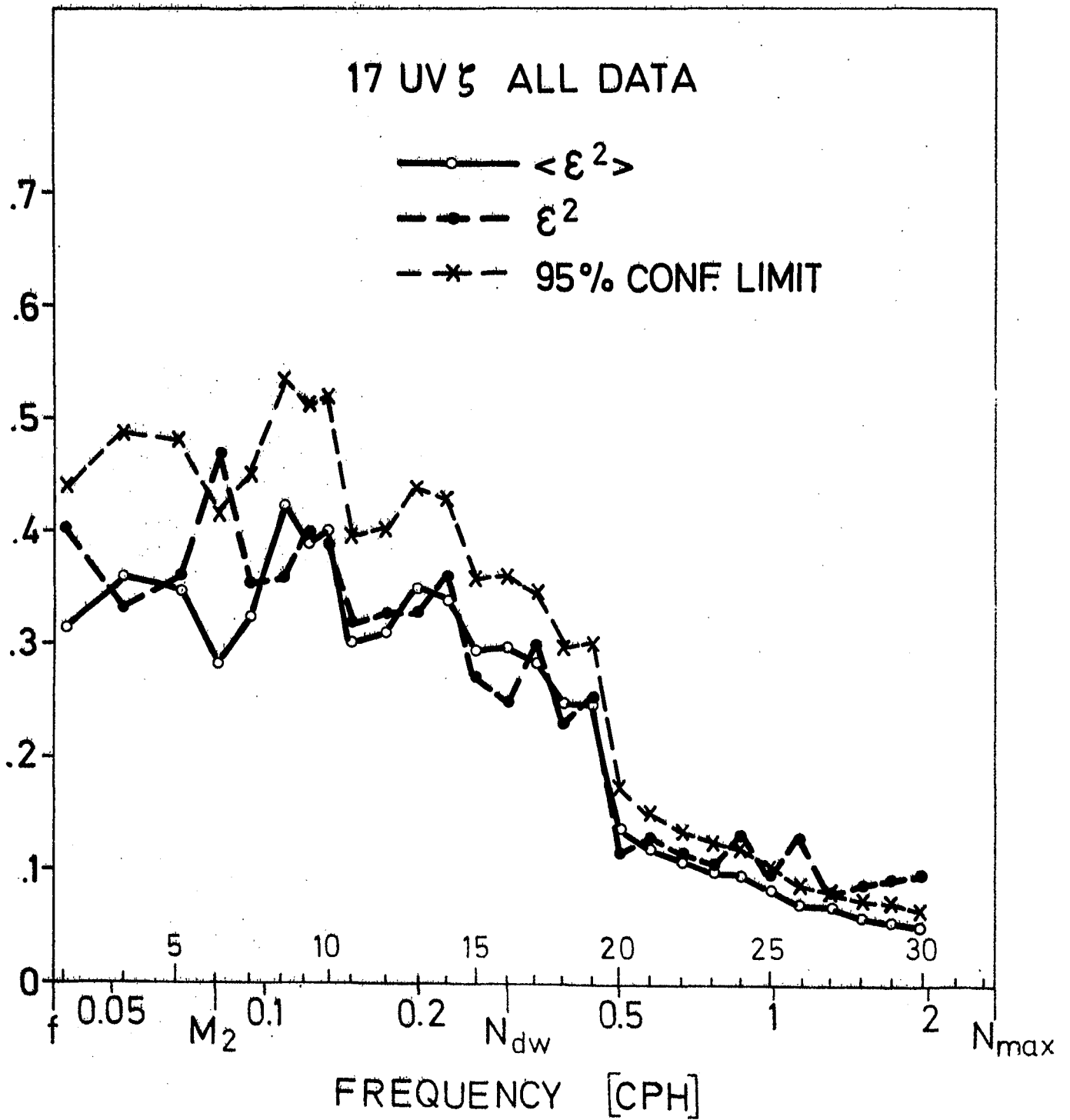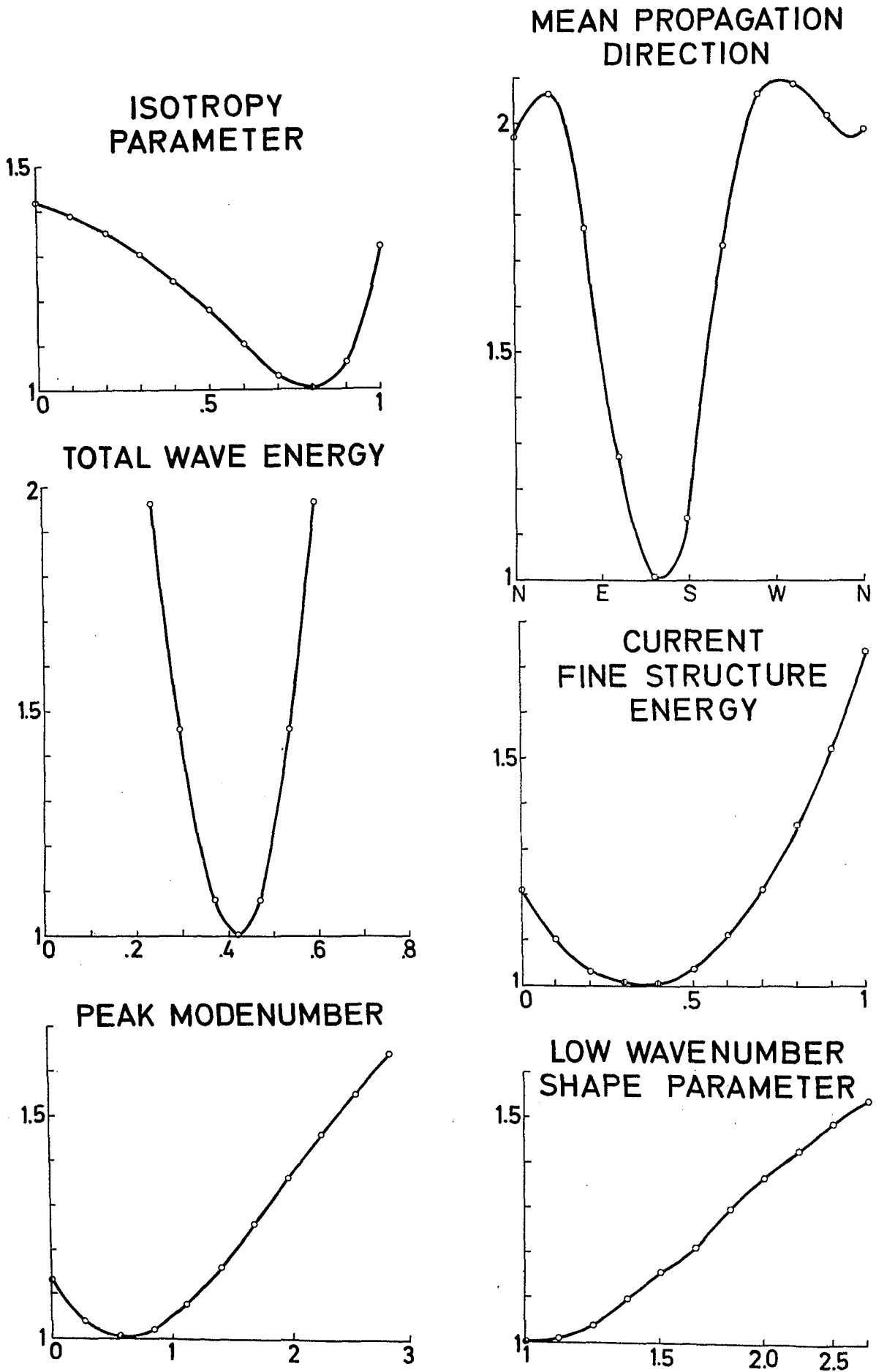
Fig. V.33
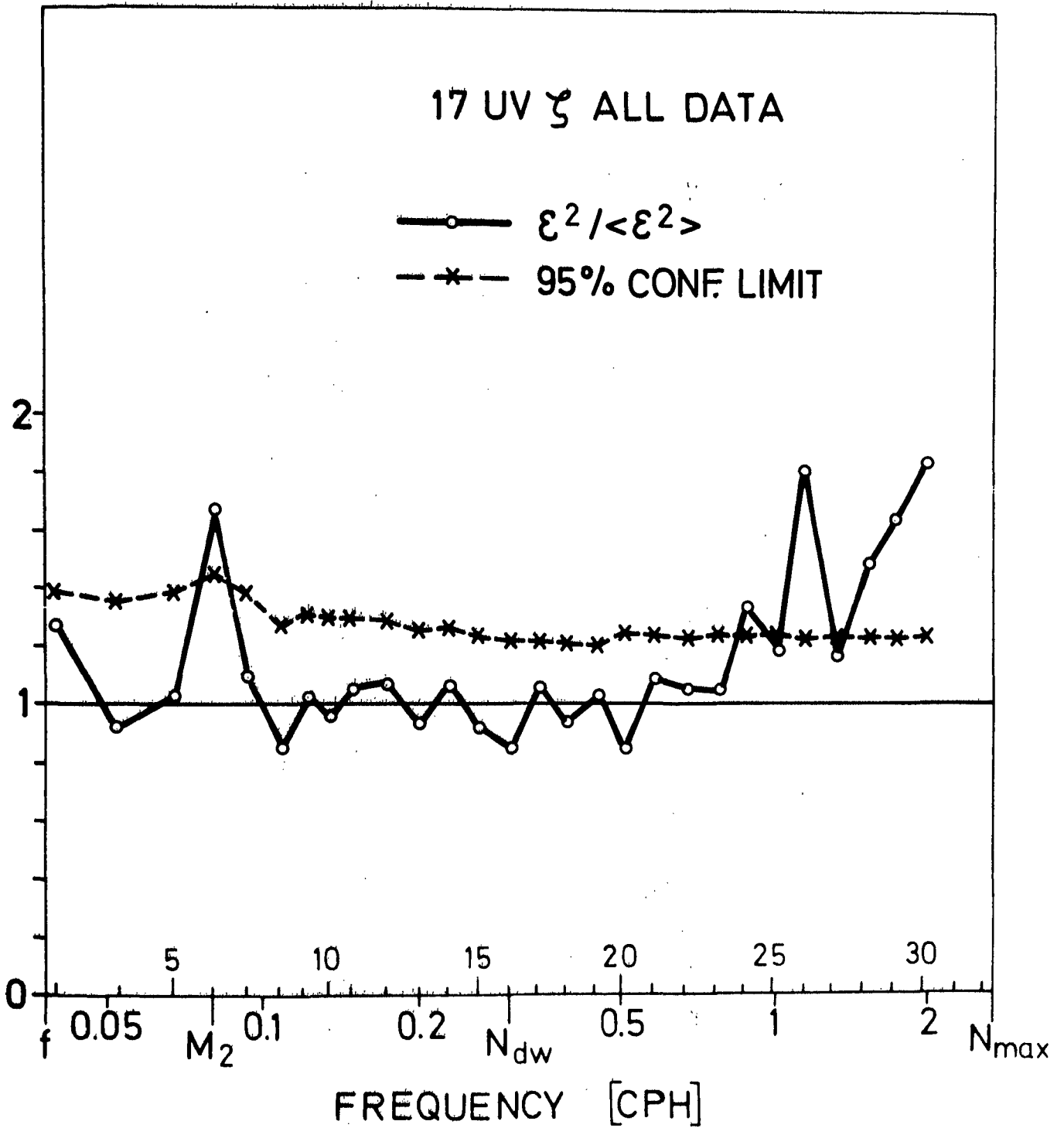
Fig. V.34
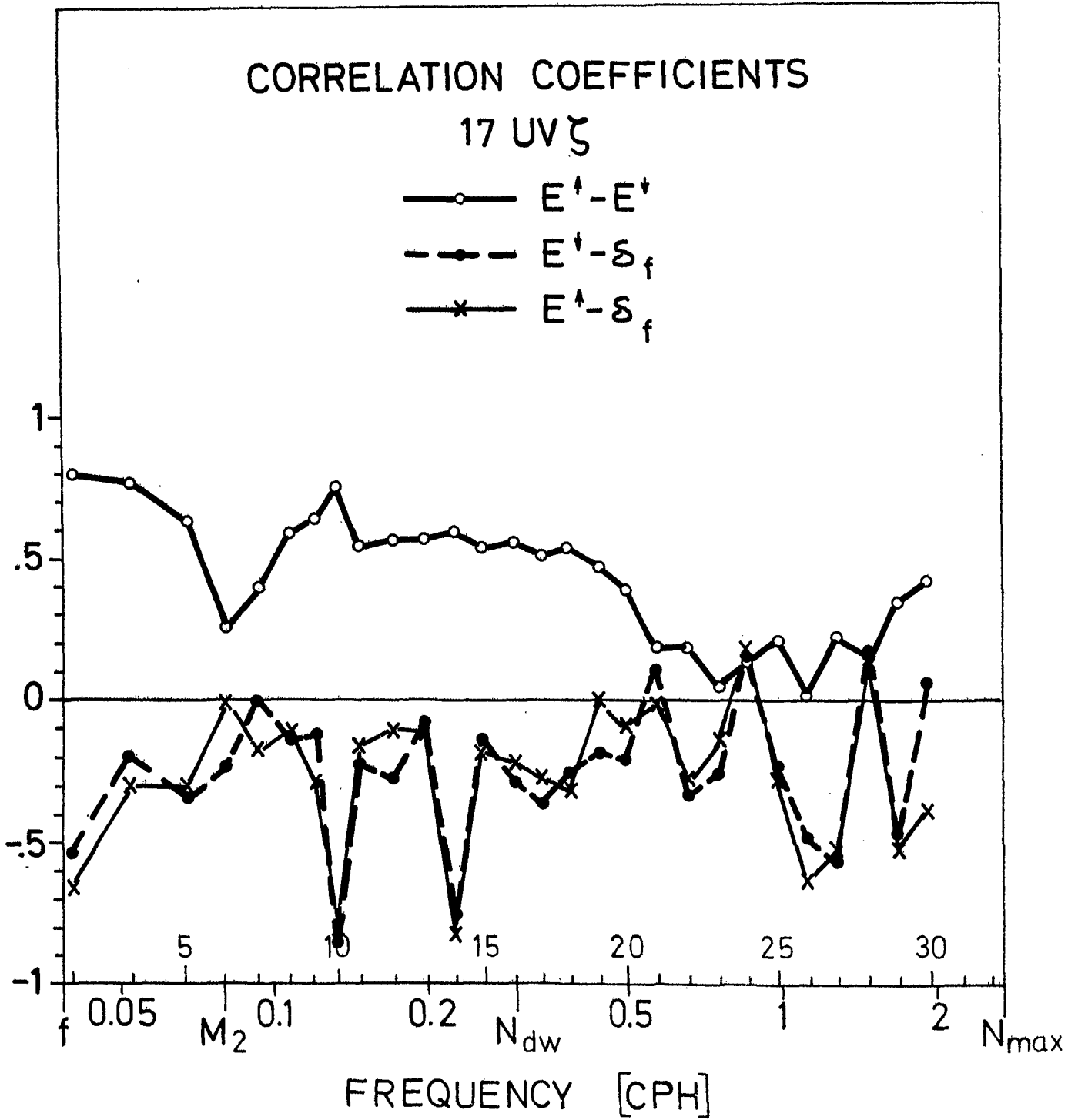
Fig. V.35a

Fig. V.35b

Fig. V.35c
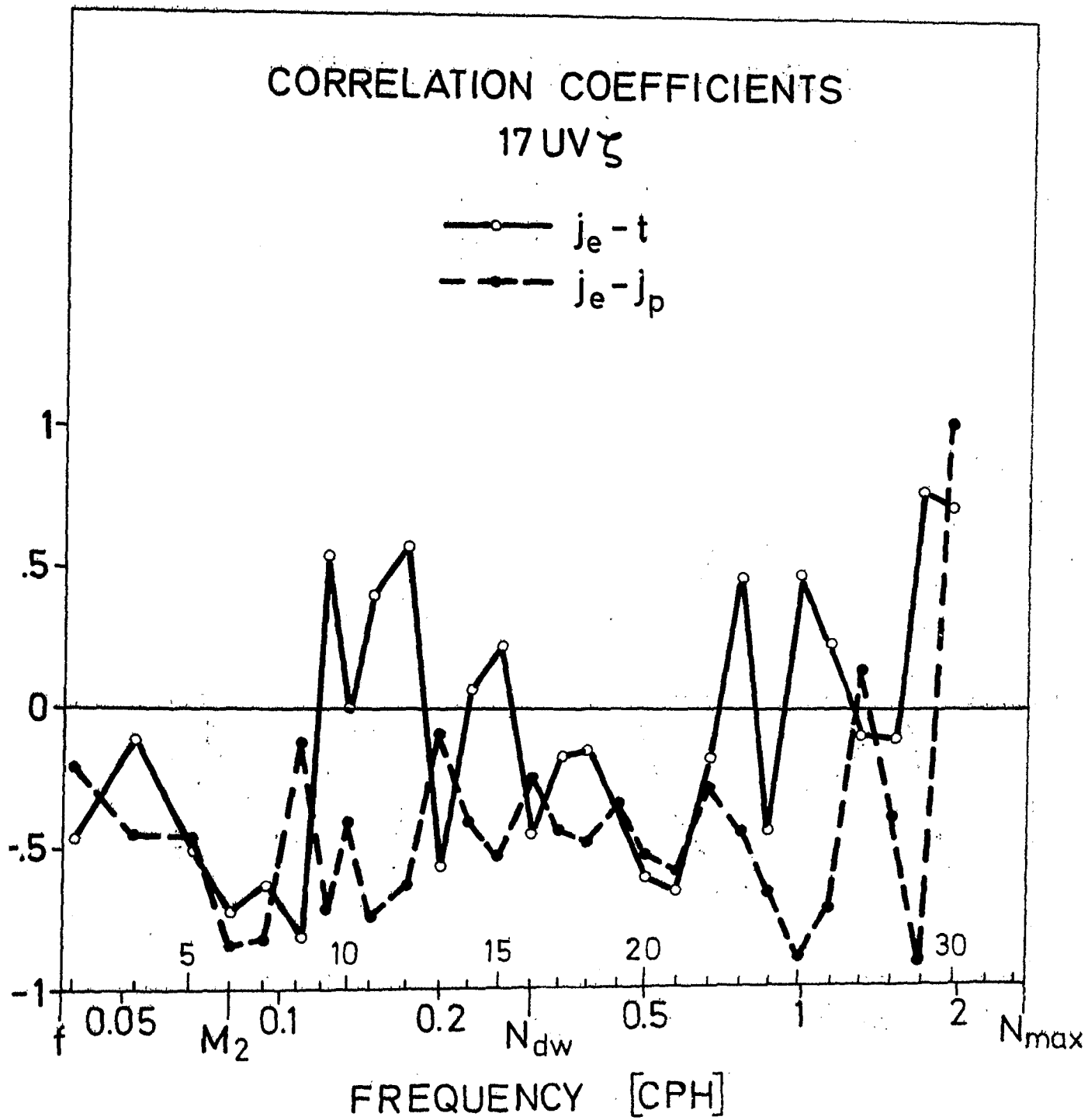
Fig. V.35d
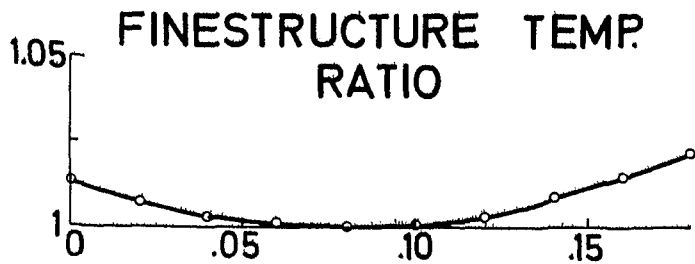
Fig. V.35e

Fig. V.35f

ISOTROPY PARAMETER

MEAN PROPAGATION DIRECTION

TOTAL WAVE ENERGY

CURRENT FINE STRUCTURE ENERGY

PEAK MODENUMBER

LOW WAVENUMBER SHAPE PARAMETER

Fig. V.36

Fig. V.36