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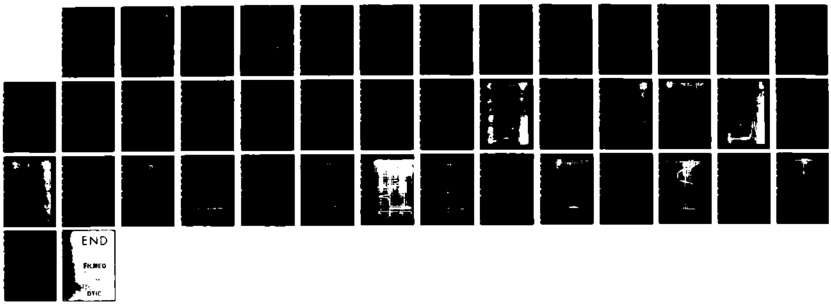

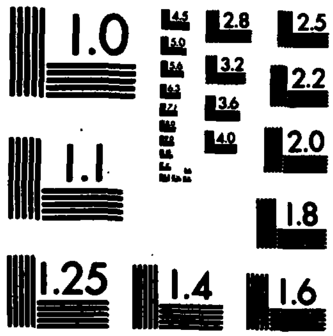

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MOTION ANALYSIS OF A SEMI-SUBMERSIBLE PLATFORM

by

YOUNG S. HONG

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SHIP PERFORMANCE DEPARTMENT

OCTOBER 1984

DTNSRDC/SPD-1122-01

NDW-DTNSRDC 5602/30 (2-80)
(supersedes 3960/46)

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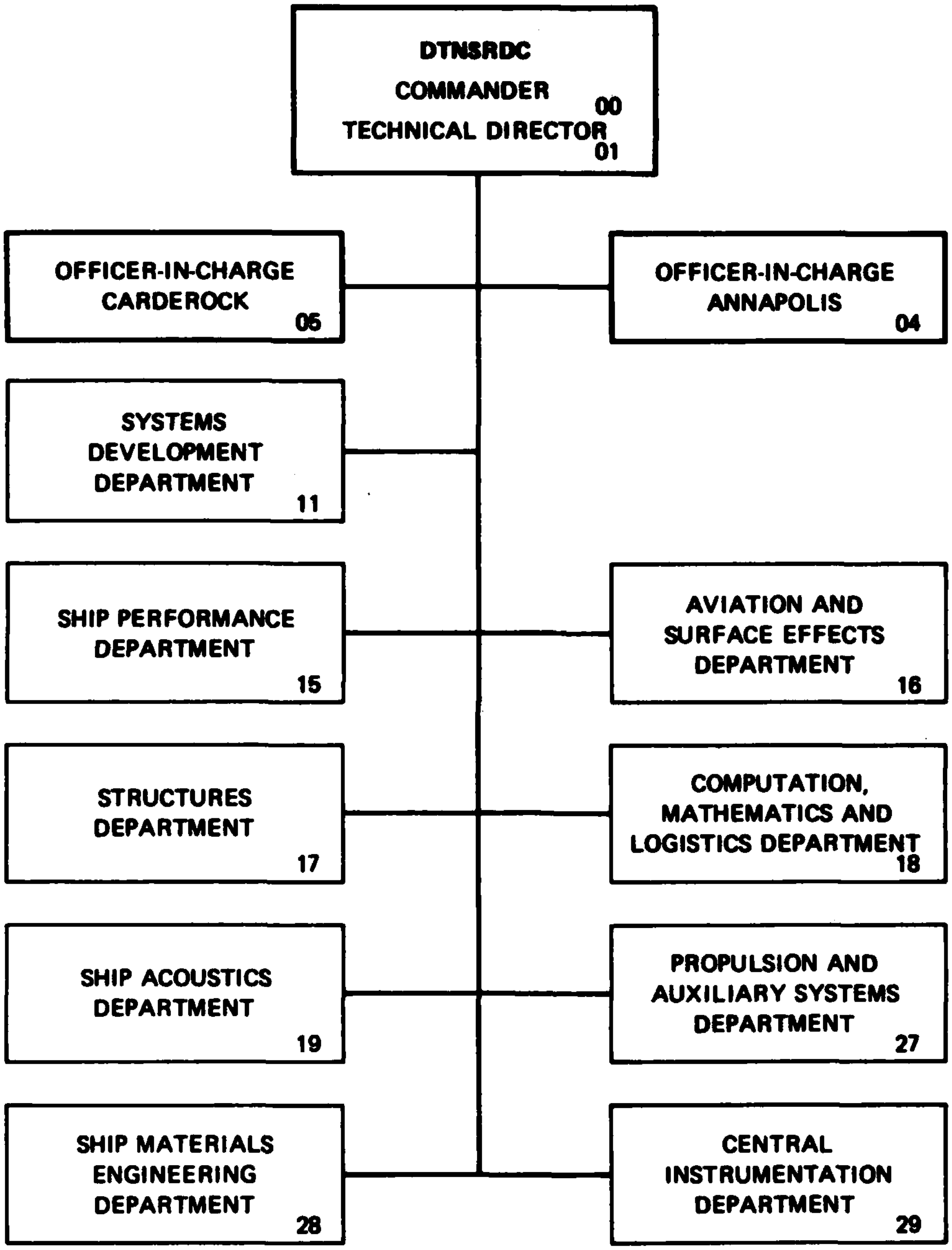

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DTNSRDC/SPD-1122-01	2. GOVT ACCESSION NO. A148030	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Motion Analysis of A Semi-Submersible Platform		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Young S. Hong		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS David Taylor Naval Ship Research and Development Center (Code 1562) Bethesda, MD 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit 1500-001
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release: Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Semi-Submersible; Motion Analysis;

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The motions of a semi-submersible platform are computed for three different headings relative to the waves. This was done as part of a study established to compare various methods of semi-submersible platform motion prediction organized by the ITTC Ocean Engineering Committee. A strip method is applied in the numerical analysis. The results of this analysis are presented alone, that is, no comparisions are made with other theoretical methods or experimental data. This can be done when the ITTC Committee publishes the results

of all participants of this study. The results of heave motion show a resonance when the wave period is about 3.335 seconds.

TABLE OF CONTENTS

NOTATION

A	Amplitude of incoming wave
A_{wp}	Waterplane area
A_{jk}	Added mass coefficients
B_{jk}	Damping coefficients
C_{jk}	Hydrostatic coefficients
f_j	Exciting force
g	Gravitational acceleration
$i = (-1)^{1/2}$	Imaginary unit
I_j	Moments of inertia (roll, pitch and yaw)
GM_L	Longitudinal metacentric height
GM_T	Transverse metacentric height
$K = \omega_o^2/g$	Wave number of incoming wave
m_{jk}	Mass matrix
M	Mass of the platform
M_{wp}	Moment of waterplane area
n_j	Components of unit vector directed into the fluid
x_c	Longitudinal location of center of flotation
x_g	Longitudinal location of center of gravity
z_g	Vertical location of center of gravity
ρ	Water density
Δ	Displacement of platform
β	Angle of incoming wave in the xy-plane positive clockwise (present computer program notation)
χ	Angle of incoming wave in the xy-plane positive counterclockwise (ITTC notation)
ω	Frequency of wave encounter
ω_o	Wave frequency

Φ	Total velocity potential
ϕ_I	Potential of incoming wave
ϕ_B	Disturbance velocity potential due to the presence of the platform
ψ_j	Velocity potential due to motion of the platform with unit amplitude in each of six degrees of freedom
ξ_j	Amplitude of motion in each of six degrees of freedom (surge, sway, heave, roll, pitch, and yaw)
ψ_7	Diffraction potential

In Figures 5 through 16, the following notation is used:

T	Wave period
ζ_A	Free-surface wave elevation
X_A	Surge amplitude of motion
Y_A	Sway amplitude of motion
Z_A	Heave amplitude of motion
ϕ_A	Roll amplitude of motion
θ_A	Pitch amplitude of motion
ψ_A	Yaw amplitude of motion
ε	Phase angle of motion ($\varepsilon=0$: maximum positive motion occurs when wave crest is amidship.)

ABSTRACT

The motions of a semi-submersible platform are computed for three different headings relative to the waves. This was done as part of a study established to compare various methods of semi-submersible platform motion prediction organized by the ITTC Ocean Engineering Committee. A strip method is applied in the numerical analysis. The results of this analysis are presented alone, that is, no comparisions are made with other theoretical methods or experimental data. This can be done when the ITTC Committee publishes the results of all participants of this study. The results of heave motion show a resonance when the wave period is about 3.35 seconds.

ADIMINSTRATIVE INFORMATION

This study was performed under the Department Overhead Function. The Work Unit number is 1500-001.

INTRODUCTION

The 17th ITTC Ocean Engineering Committee, which met in the Autumn 1982 at Tokyo, decided to sponsor a comparative study on the motions of a semi-submersible. The primary purpose of this study is to compare existing computational methods and to validate their results. An opportunity was thus provided to further validate the computer program currently used by the Special Ships and Ocean Systems Dynamics Branch at the David Taylor Naval Ship Research and Development center.

The platform configuration to be used for the study was selected by the ITTC Committee, and its description is given later in this report. The existing computer program was developed for semi-submersible platforms, with strip theory being applied as described in Reference 1.*

EQUATIONS OF MOTION

The coordinate system, oxyz, is fixed at the midship section of the semi-submersible platform (see Figure 1). The oz-axis is directed vertically upward, and the oxy-plane is in the plane of the undisturbed free surface.

The total velocity potential of the fluid in the presence of the platform is expressed as

$$\Phi(x,y,z,t) = Re[(\phi_I + \phi_B)e^{-i\omega t}] \qquad (1)$$

*References are listed on page 6.

where ϕ_I is the potential of the incoming wave and is given as

$$\phi_I = \frac{igA}{\omega_o} \exp[Kz + iKx\cos\beta - iKy\sin\beta] \qquad (2)$$

and ϕ_B is the disturbance velocity potential due to the presence of the platform. In Equation (2), A is the amplitude of the incoming wave, ω_o is its frequency, g the gravitational acceleration, β the angle of the incoming wave relative to the ox-axis (β = 0 deg is following seas and β = 180 deg is head seas), and $K = \omega_o^2/g$ is the wave number. The disturbance potential consists of the following velocity potentials

$$\phi_B = \psi_7 + \Sigma\xi_j\psi_j \qquad (3)$$

where ψ_j (j = 1, 2, ..., 6) is the velocity potential arising from unit amplitude of platform in each of the six degrees of freedom, and ξ_j (j = 1, 2, ..., 6) is the amplitude of motion in each of the six degrees of freedom. The diffraction potential is represented by ψ_7.

The potential ψ_j is determined as the solution of the Laplace equation with appropriate boundary conditions. To avoid the difficulty in solving a three-dimensional numerical problem, a strip theory or two-dimensional method is applied to obtain ψ_j. The fundamental assumptions of strip theory are discussed in Reference 2.

Using strip theory, ψ_j is solved for j = 2, 3, 4, and 7 (sway, heave, roll motion and diffraction potential) at each section, and potentials for pitch and yaw are computed by simply multiplying the longitudinal distance of each section from the origin by the heave and sway potentials respectively. The surge potential, ψ_1, is assumed to be zero.

In applying potential theory, it is assumed that the fluid is incompressible and inviscid, and that the flow is irrotational. The potential, ψ_j (j = 2, 3, 4, and 7) is determined as the solution of the following equation with the conditions specified.

1. Laplace equation in the fluid domain

$$\frac{\partial^2\psi_j}{\partial y^2} + \frac{\partial^2\psi_j}{\partial z^2} = 0, \text{ for } j = 2, 3, 4, 7 \qquad (4)$$

2. the body boundary condition

$$\frac{\partial\psi_j}{\partial n} = -i\omega n_j, \quad \text{for } j = 2, 3, 4 \qquad (5)$$

$$= -\frac{\partial\phi_I}{\partial n} \quad \text{for } j = 7$$

3. the linearized free-surface condition

$$K\psi_j - \frac{\partial \psi_j}{\partial z} = 0, \quad \text{on } z = 0 \text{ for } j=2,\ 3,\ 4,\ 7 \qquad (6)$$

The right hand side of Equation (5) is the normal velocity component at the body and the unit vector is directed into the fluid domain. All potential functions, ψ_j, must satisfy the radiation condition for outgoing progressive waves at infinity, and become zero as z becomes negative infinity.

The solution of Equation (4) with the boundary conditions, Equations (5) and (6), is given in Reference 3. The hydrodynamic forces and moments are obtained by integrating the pressure on the wetted surface of the body. The details of the derivation of these forces and moments for heave and pitch motions are given in Reference 4. The forces and moments for other motions can be easily derived using a procedure similar to that described in Reference 4.

If we let $\alpha_j = \xi_j e^{-i\omega t}$ and equate the inertia force with the hydrodynamic force, the equation of motion can be expressed as

$$\Sigma[(m_{jk} + A_{jk})\ddot{\alpha}_j + B_{jk}\dot{\alpha}_j + C_{jk}\alpha_j] = f_j \qquad (7)$$

where m_{jk} is the mass matrix, A_{jk} the added mass, B_{jk} the damping force, C_{jk} the hydrostatic coefficients and f_j the exciting force. The equations for A_{jk}, B_{jk}, and f_j are given in Reference 4. The mass matrix, m_{jk}, is expressed as

$$\begin{aligned}
&m_{jk} = M, \quad \text{for } j = k = 1,\ 2,\ 3 \\
&m_{44} = I_4 \\
&m_{55} = I_5 \\
&m_{66} = I_6 \\
&m_{24} = m_{42} = -Mz_g \\
&m_{15} = m_{51} = Mz_g \\
&\text{all other } m_{jk} = 0
\end{aligned} \qquad (8)$$

where M is the mass of the platform; I_4, I_5, and I_6 roll, pitch and yaw moments of inertia, and z_g is the vertical location of the center of the gravity with respect to free surface. The hydrostatic coefficent, C_{jk}, is given as

$$\begin{aligned}
&C_{33} = \rho g A_{wp} \\
&C_{35} = C_{53} = -\rho g(M_{wp} - x_g A_{wp}) \\
&C_{44} = \Delta GM_T \\
&C_{55} = \Delta GM_L + \rho g A_{wp}(x_g - x_c)^2 \\
&\text{all other } C_{jk} = 0
\end{aligned} \qquad (9)$$

where A_{wp} is the waterplane area, M_{wp} its moment, x_g the longitudinal center of gravity, x_c the longitudinal center of flotation, GM_T the transverse metacentric height, GM_L the longitudinal metacentric height, and Δ the displacement of the platform.

NUMERICAL METHOD AND RESULTS

The model description is given in Figures 2, 3, and 4, and its principal dimensions are given in Table 1. In the numerical analysis, only 8 vertical columns and lower hulls are included in the computation. The transverse, longitudinal and diagonal columns are small compared to the vertical columns, and therefore, are excluded from the computation.

The platform is divided into 29 sections in the longitudinal direction. At each section, the hydrodynamic forces (added mass, damping force and exciting force) are computed, and later these sectional forces are integrated along the length. There are 17 sections with lower hulls only and 12 sections with lower hulls and columns. The sections with lower hull only are treated as completely submerged sections and those with hull and column are treated as floating sections. The locations and types of sections are given in Table 2.

The computations have been carried out for three different headings: $\beta = 0$ (following), $\beta = 315$ ($\chi = 45$), and $\beta = 270$ ($\chi = 90$). The heading angle of the incoming wave in the oxy-plane is taken positive counterclockwise by the ITTC Committee, while this angle is taken positive clockwise in the existing computer program. Therefore, the relationship between χ and β is: $\chi + \beta = 360$. A step increment of wave period of 0.2 seconds was used for periods between 0.5 and 10 seconds. Wherever there is resonance in the motion, smaller time time increments were used. Furthermore, it has been assumed that the water depth is infinite even though it was given as 3 m by the ITTC Committee. This assumption is necessary because the present computer program is applicable only for the deep water. The computer program can be easily extended to treat the case of finite water depth.

The results are plotted in Figures 5 through 16. Since the experimental or numerical results produced by the other participants are not available at the present time, only the results computed by the author are shown in the figures.

ACKNOWLEDGEMENT

The author thanks Dr. W. B. Morgan, the Head of the Ship Performance Department, for his support in carrying out this project. The author also wishes to thank Mr. A. Gersten for his editorial advice.

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Table 1 : Principal Dimensions

Length of lower hull, L		1.797 m
Beam (total)		1.172 m
Beam (one hull)		0.234 m
Hull spacing between centerlines		0.938 m
Draft		0.313 m
Center of gravity	LCG	at the midship
	TCG	at the center line
	KG	0.281 m
Metacentric height	GML	0.037 m
	GMT	0.046 m
Radius of gyration	Roll	0.536 m
	Pitch	0.556 m
	Yaw	0.634 m
Displacement in fresh water		230.3 N
Water depth		infinite
Wave direction	β	360, 315, 270
	χ	0, 45, 90

Table 2 : Locations of Sections

	x (meter)	Section Type	NO. of Input Points
1 (AP)	-0.8975	0	0
2	-0.8400	Lower Hull	19
3	-0.7815	"	19
4	-0.6665	"	19
5	-0.6145	Lower Hull + Column	27
6	-0.5625	"	25
7	-0.5105	"	27
8	-0.4585	Lower Hull	19
9	-0.3650	"	19
10	-0.2715	"	19
11	-0.2285	Lower Hull + Column	27
12	-0.1875	"	27
13	-0.1465	"	27
14	-0.1035	Lower Hull	19
15	0.0	"	19
16	0.1035	"	19
17	0.1465	Lower Hull + Column	27
18	0.1875	"	27
19	0.2285	"	27
20	0.2715	Lower Hull	19
21	0.3650	"	19
22	0.4585	"	19
23	0.5105	Lower Hull + Column	27
24	0.5625	"	25
25	0.6145	"	27
26	0.6665	Lower Hull	19
27	0.7815	"	19
28	0.8400	"	19
29 (FP)	0.8985	0	0

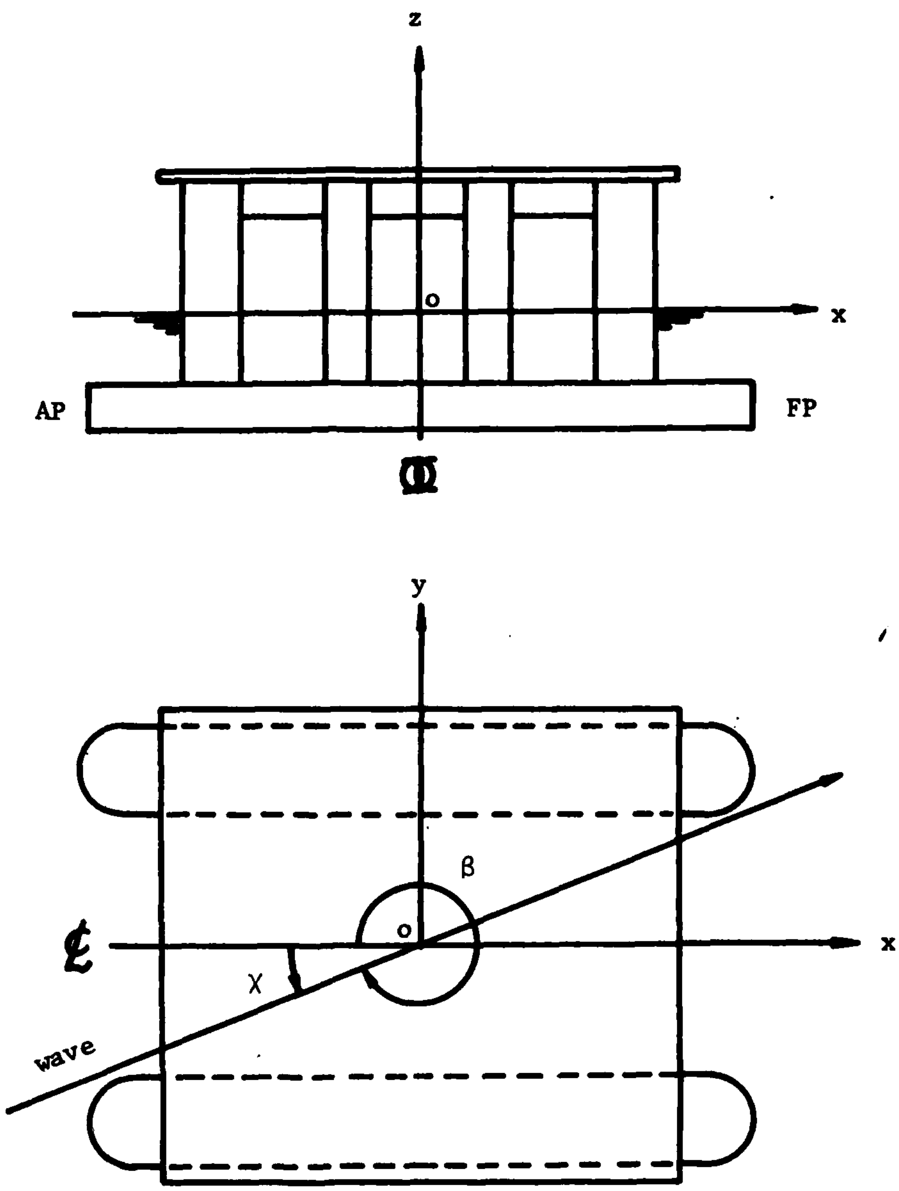


Figure 1 - Coordinate System

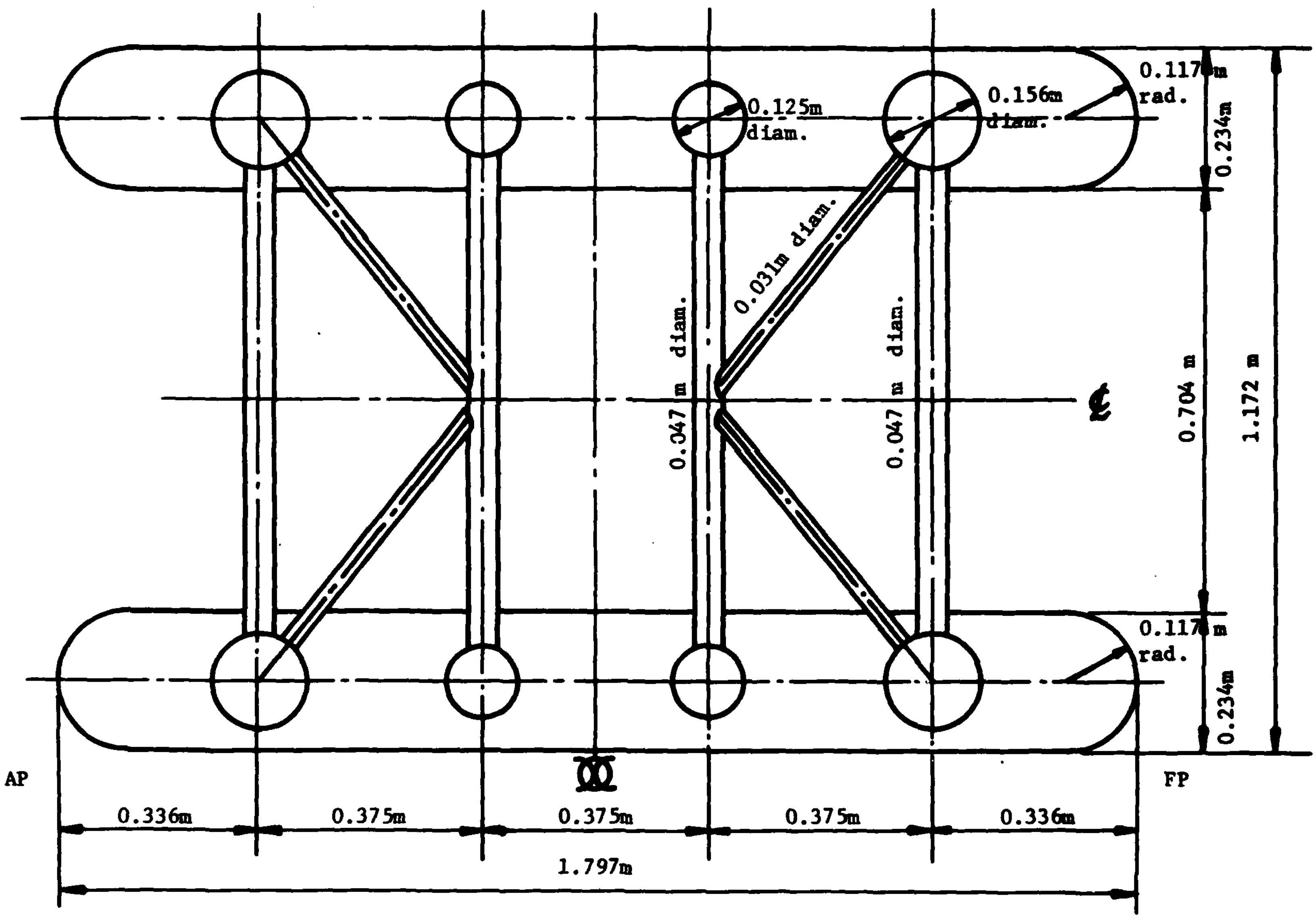


Figure 2 - Plan View of Platform

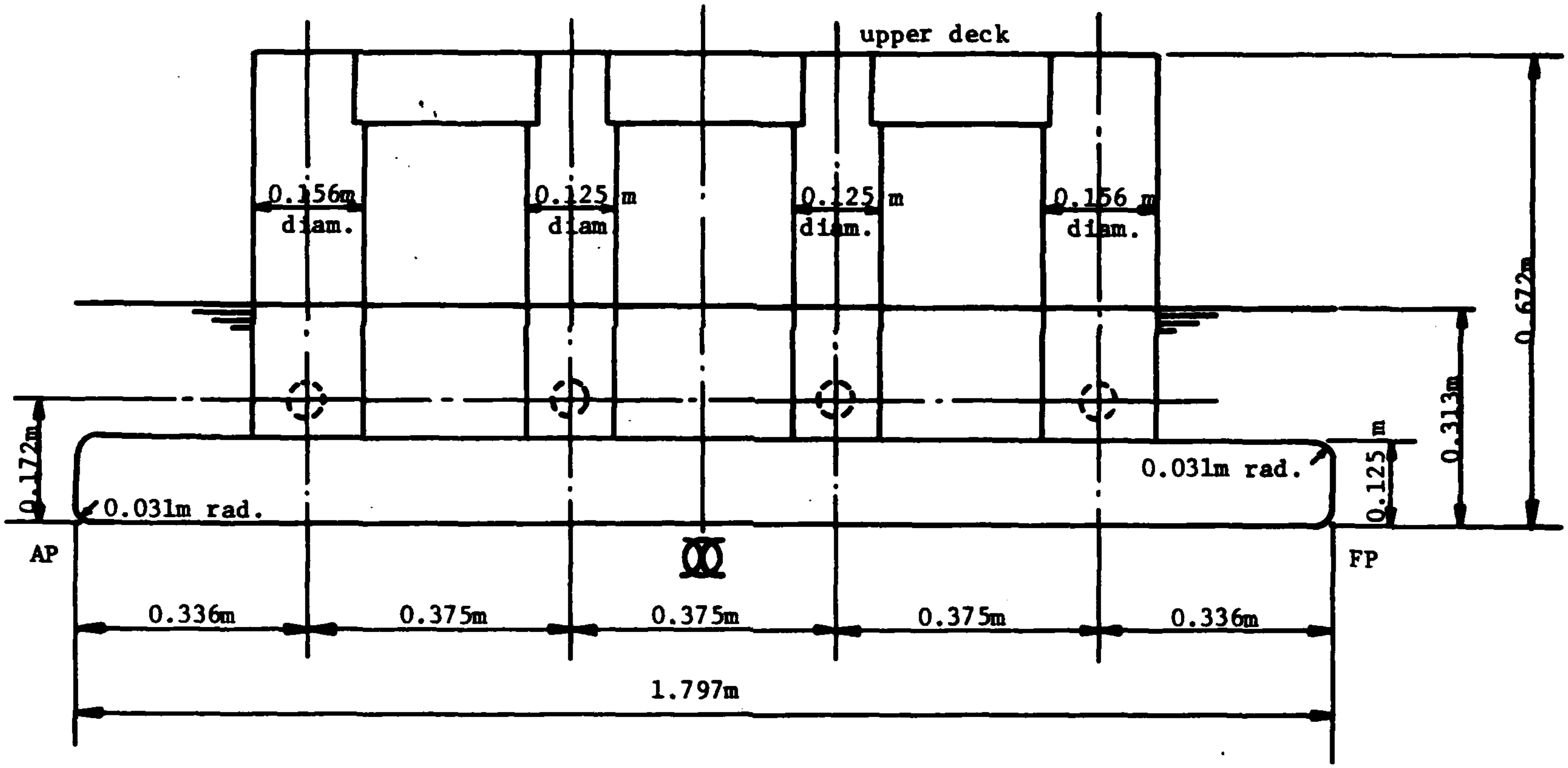


Figure 3 - Starboard View of Platform

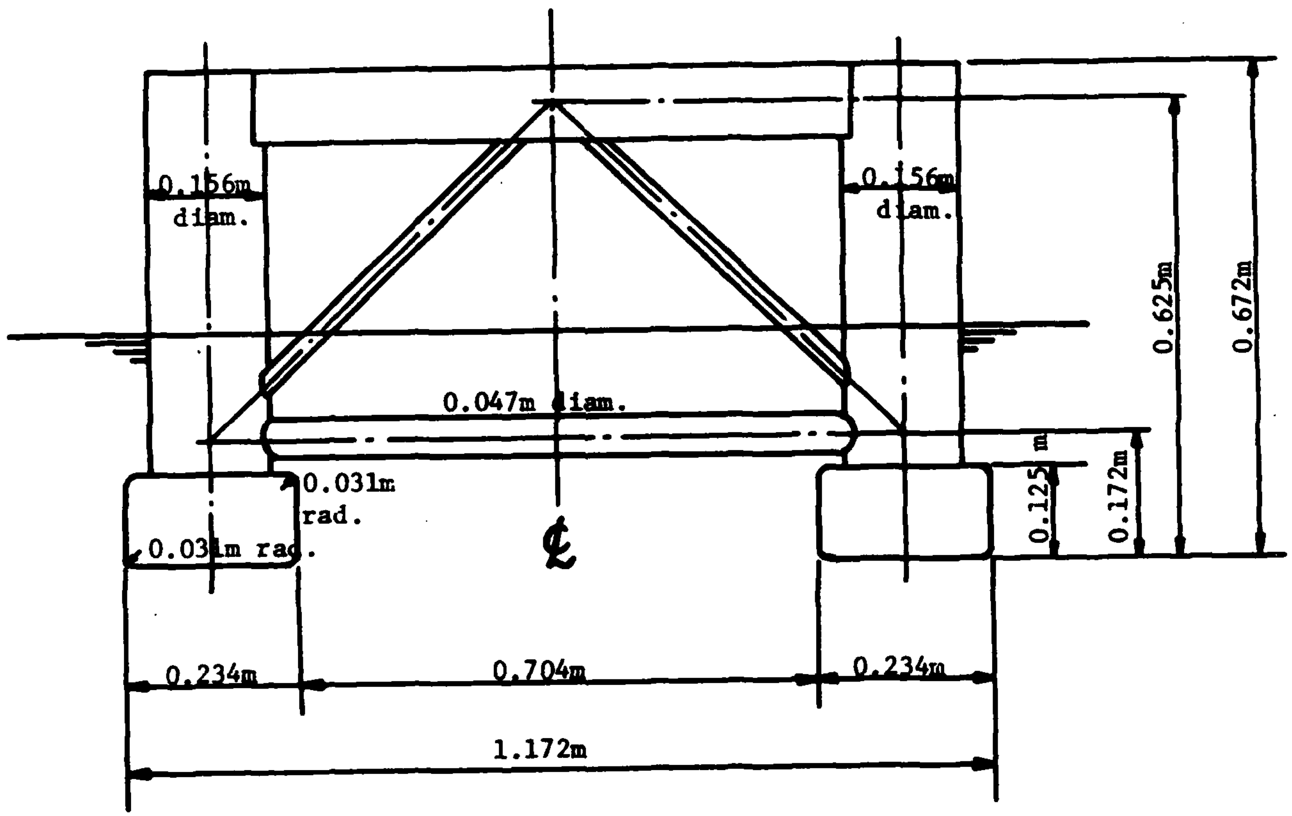


Figure 4 - Forward View of Platform

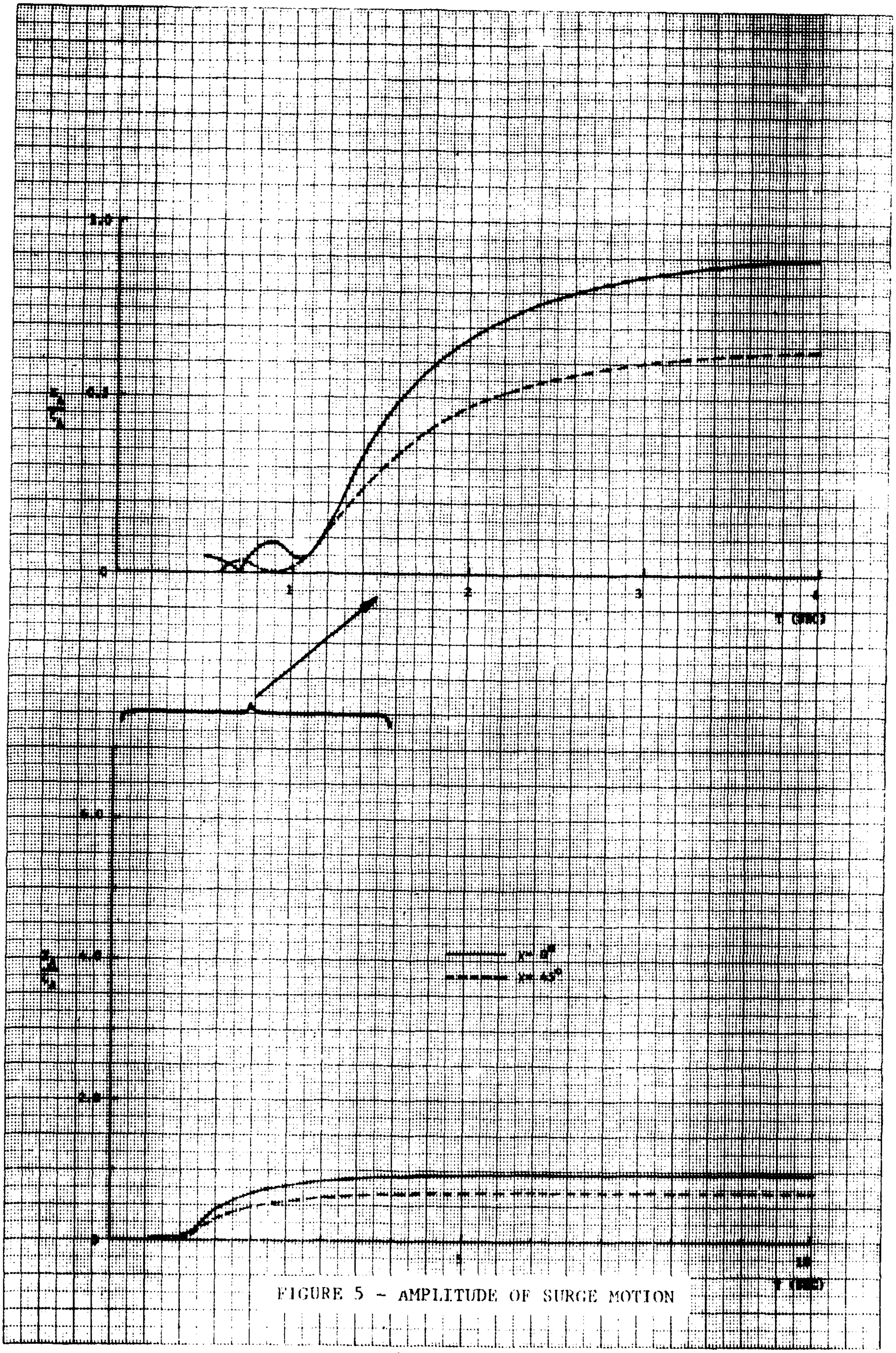


FIGURE 5 - AMPLITUDE OF SURGE MOTION

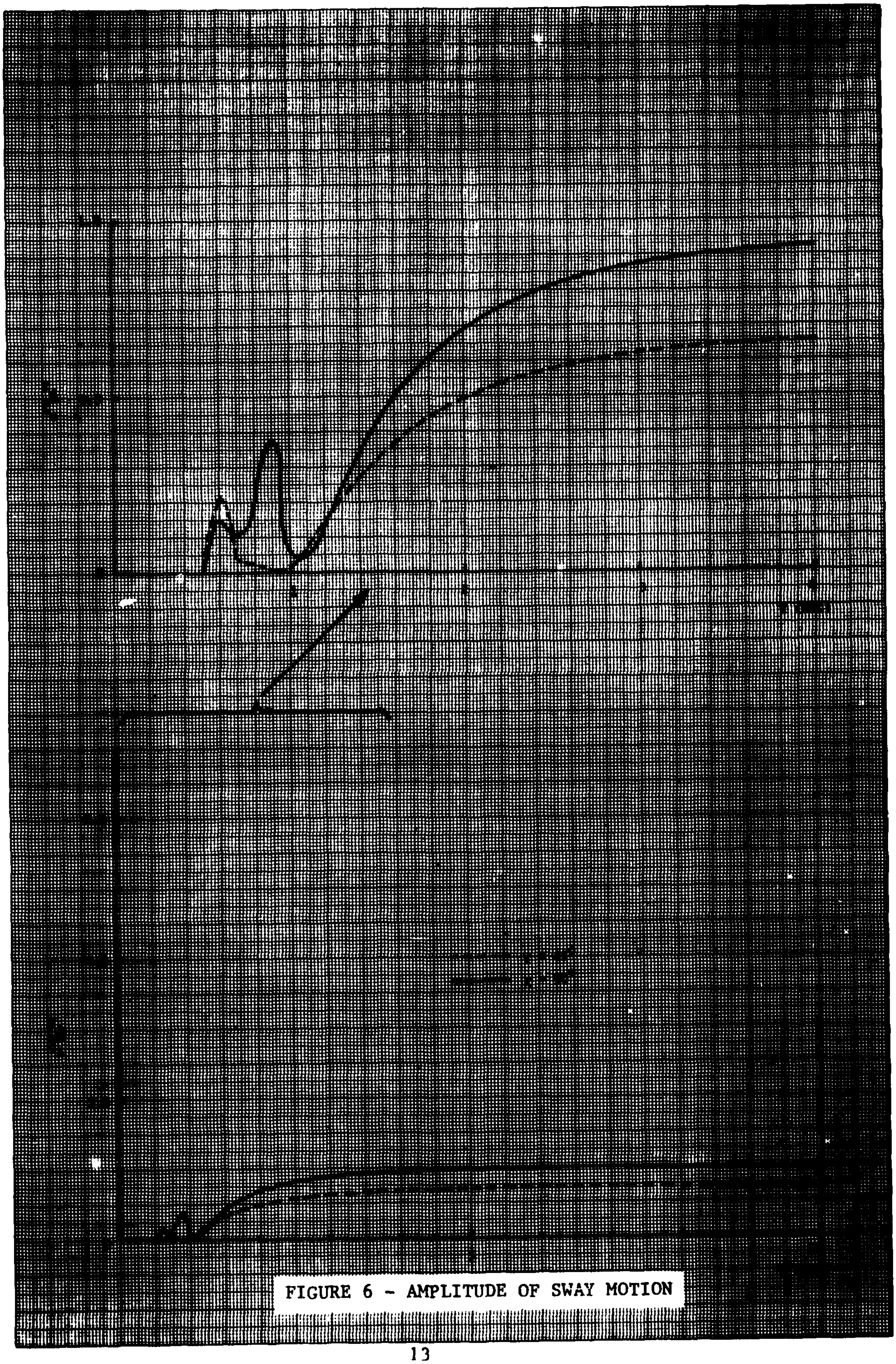


FIGURE 6 - AMPLITUDE OF SWAY MOTION

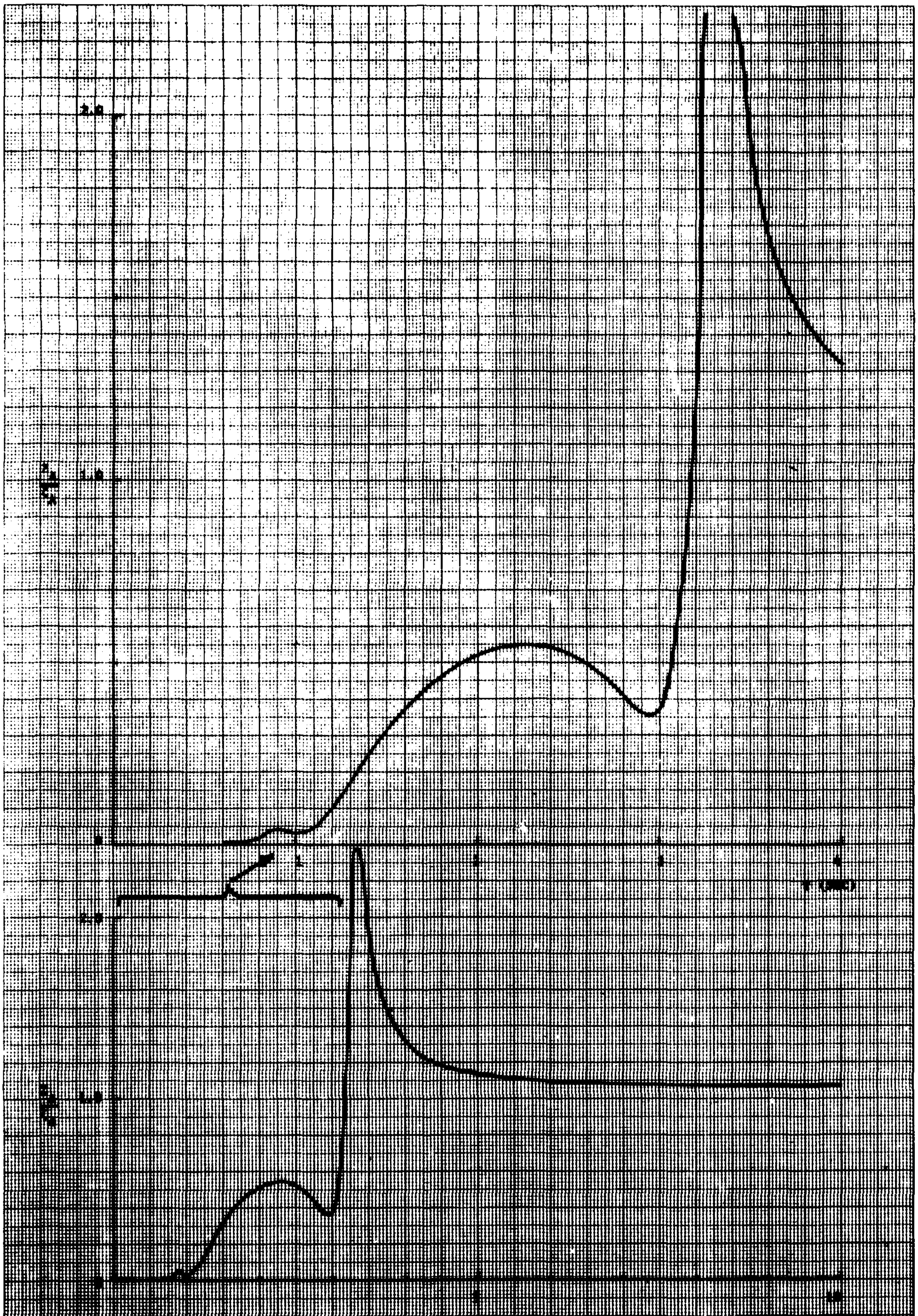


FIGURE 7a - AMPLITUDE OF HEAVE MOTION AT $\chi=0^{\circ}$

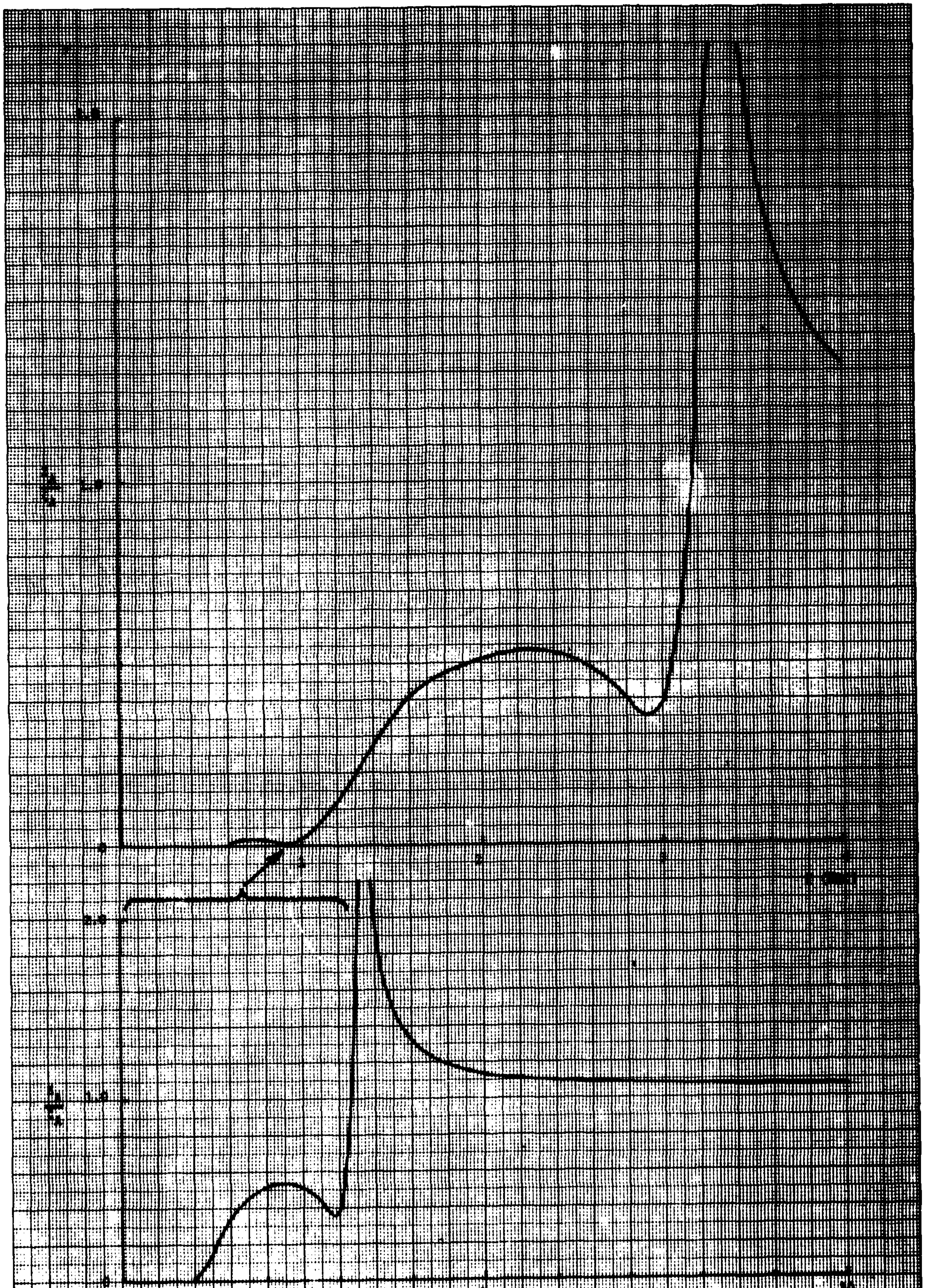


FIGURE 7b - AMPLITUDE OF HEAVE MOTION AT χ=45°

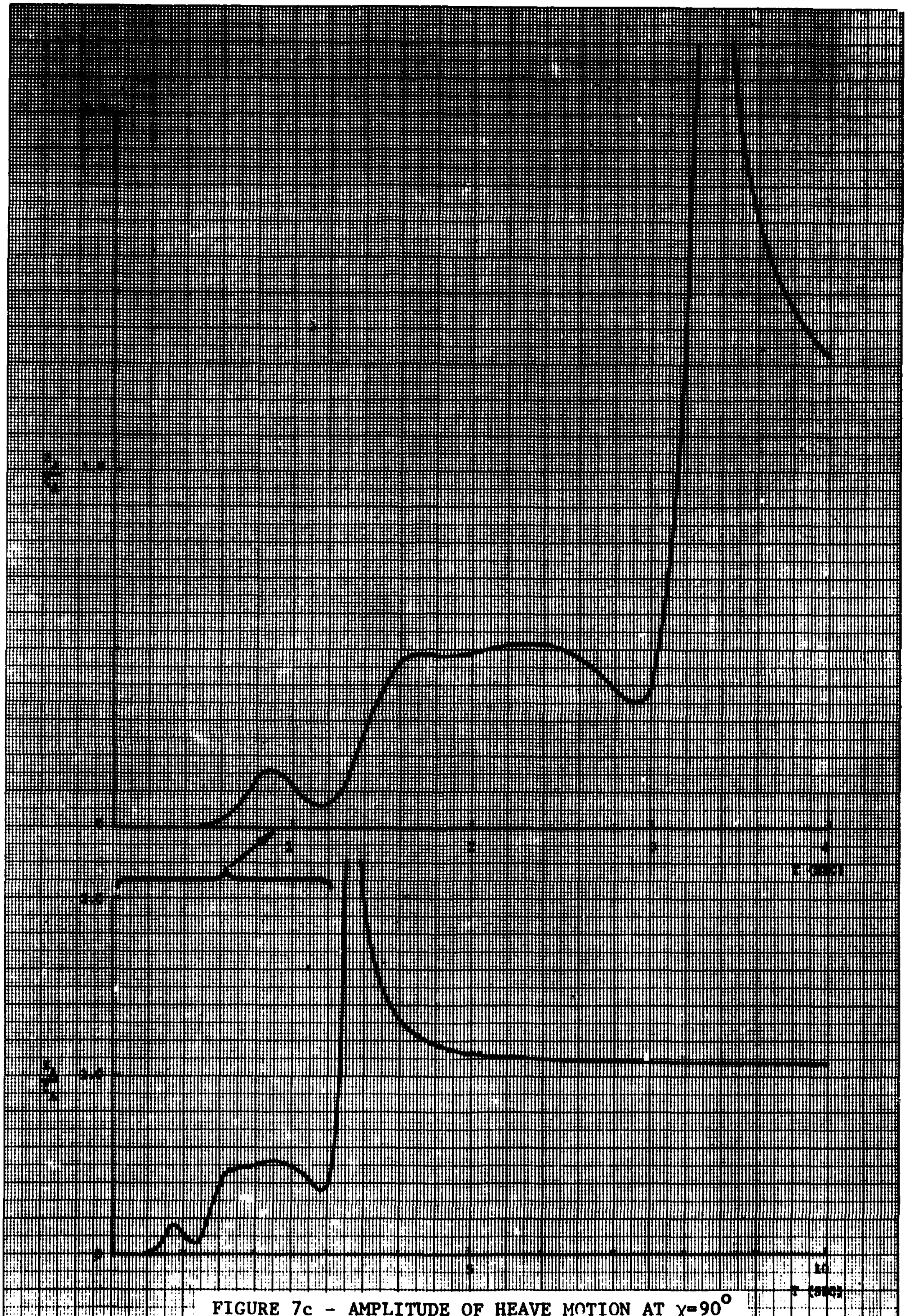


FIGURE 7c - AMPLITUDE OF HEAVE MOTION AT $\chi=90^{o}$

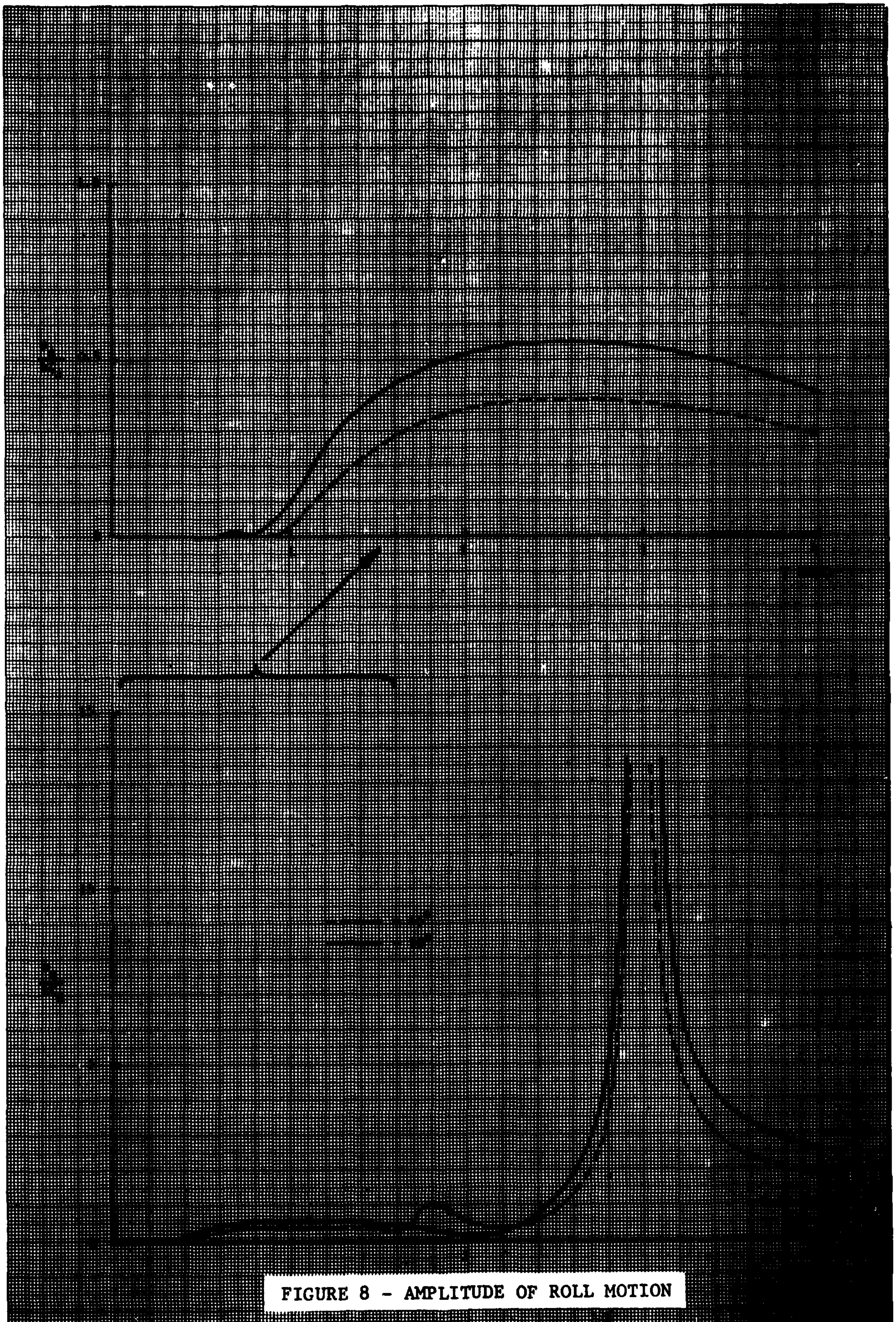


FIGURE 8 - AMPLITUDE OF ROLL MOTION

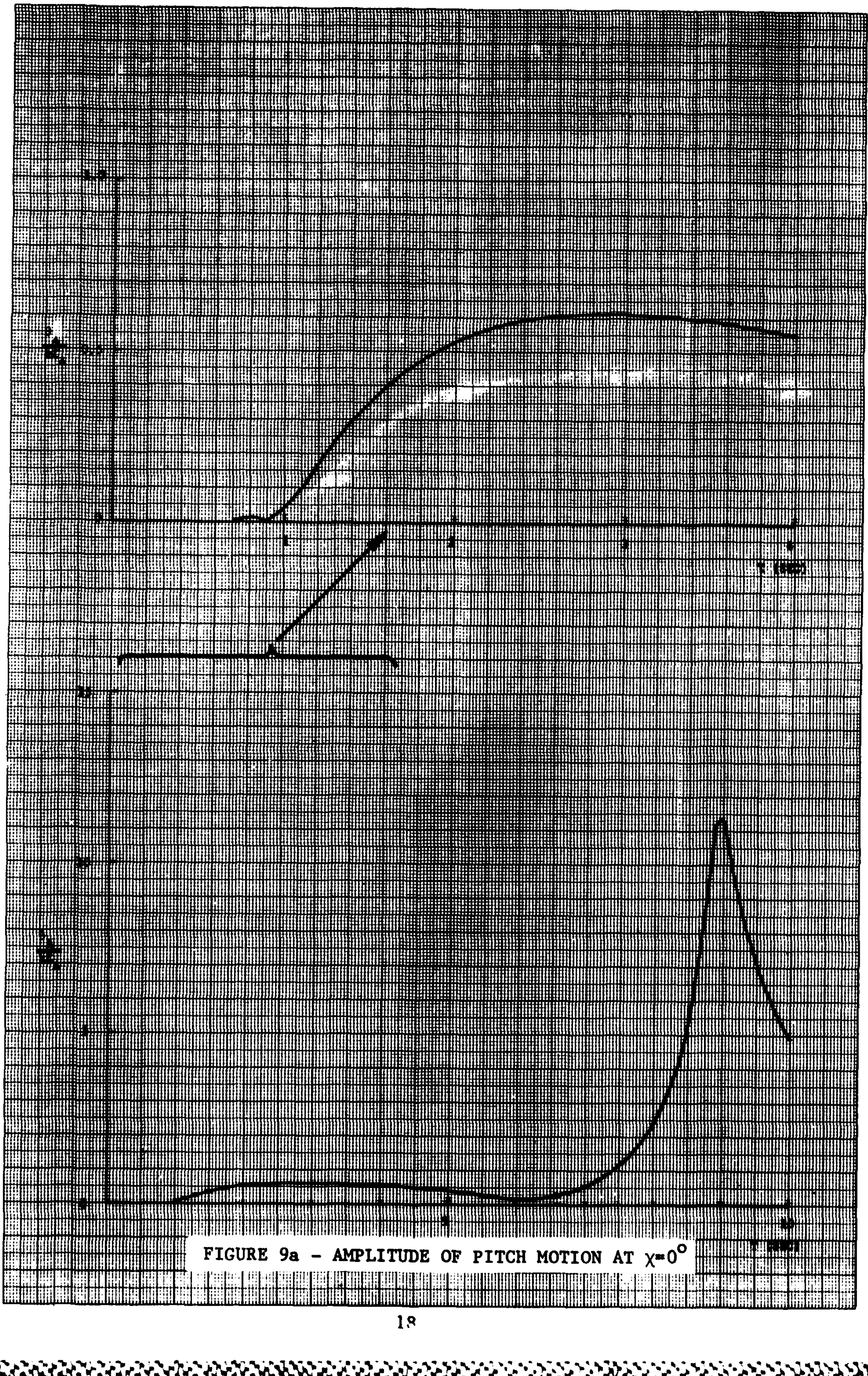


FIGURE 9a - AMPLITUDE OF PITCH MOTION AT $\chi=0^{\circ}$

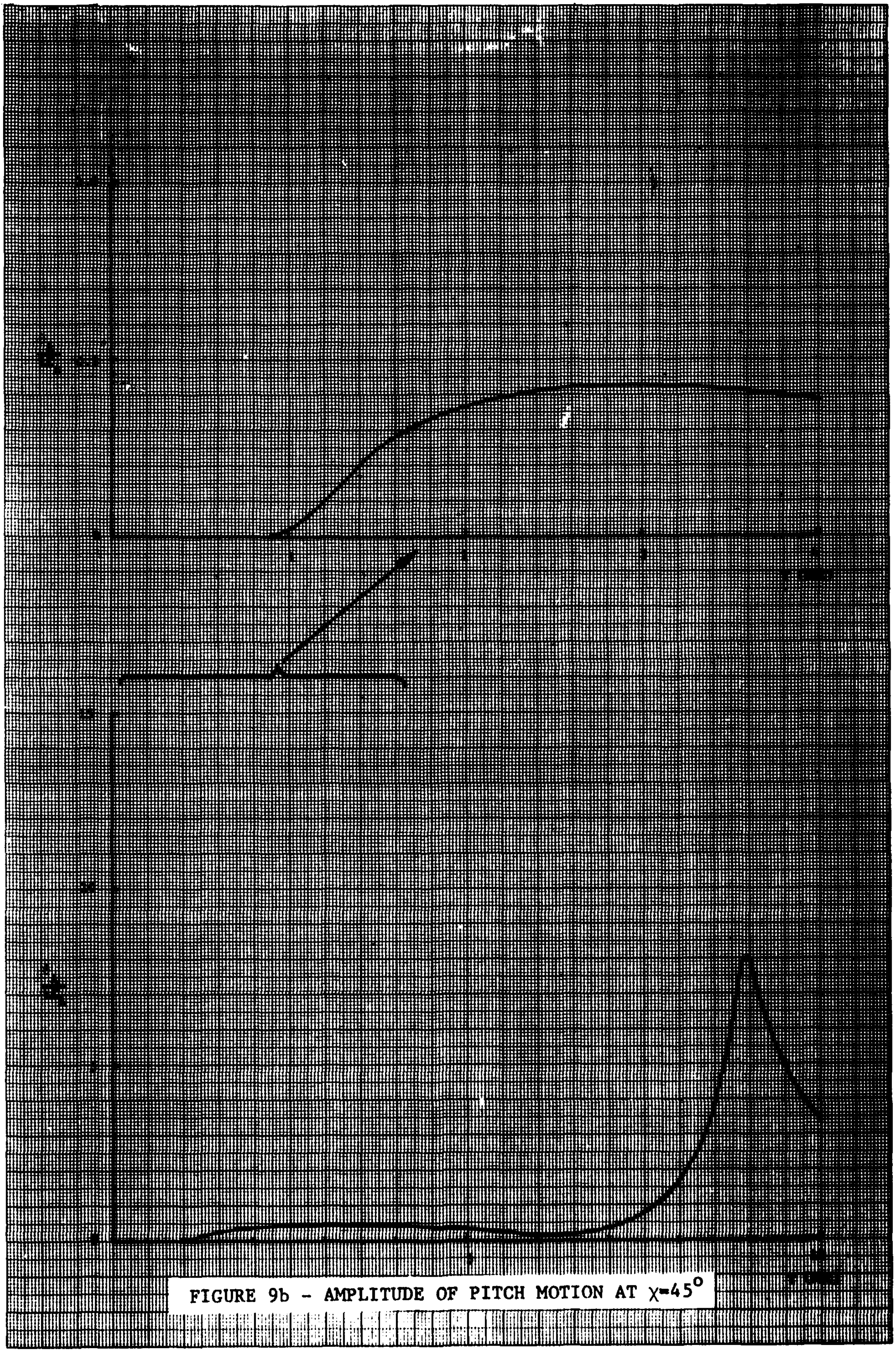


FIGURE 9b - AMPLITUDE OF PITCH MOTION AT $\chi=45^{o}$

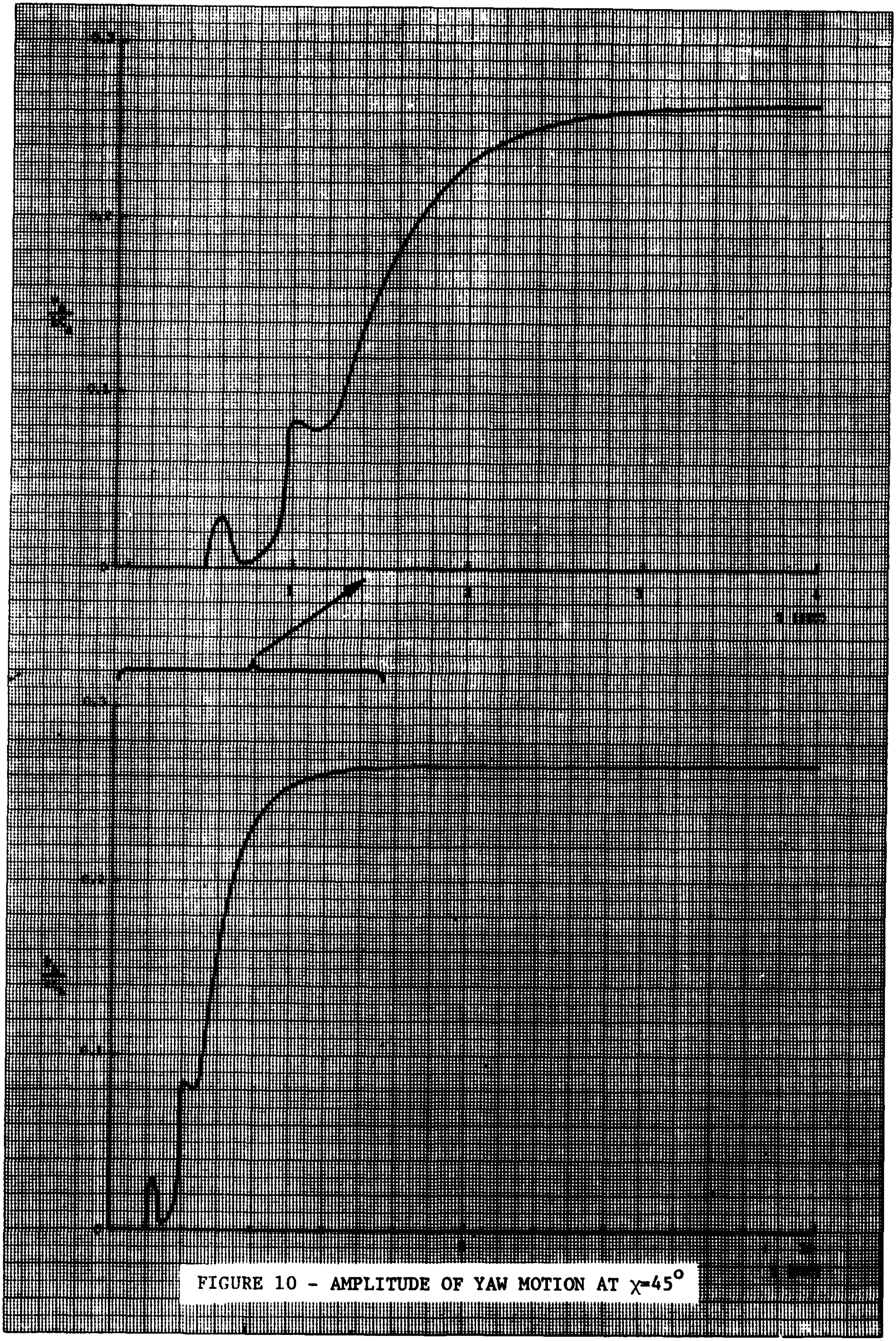


FIGURE 10 - AMPLITUDE OF YAW MOTION AT χ=45°

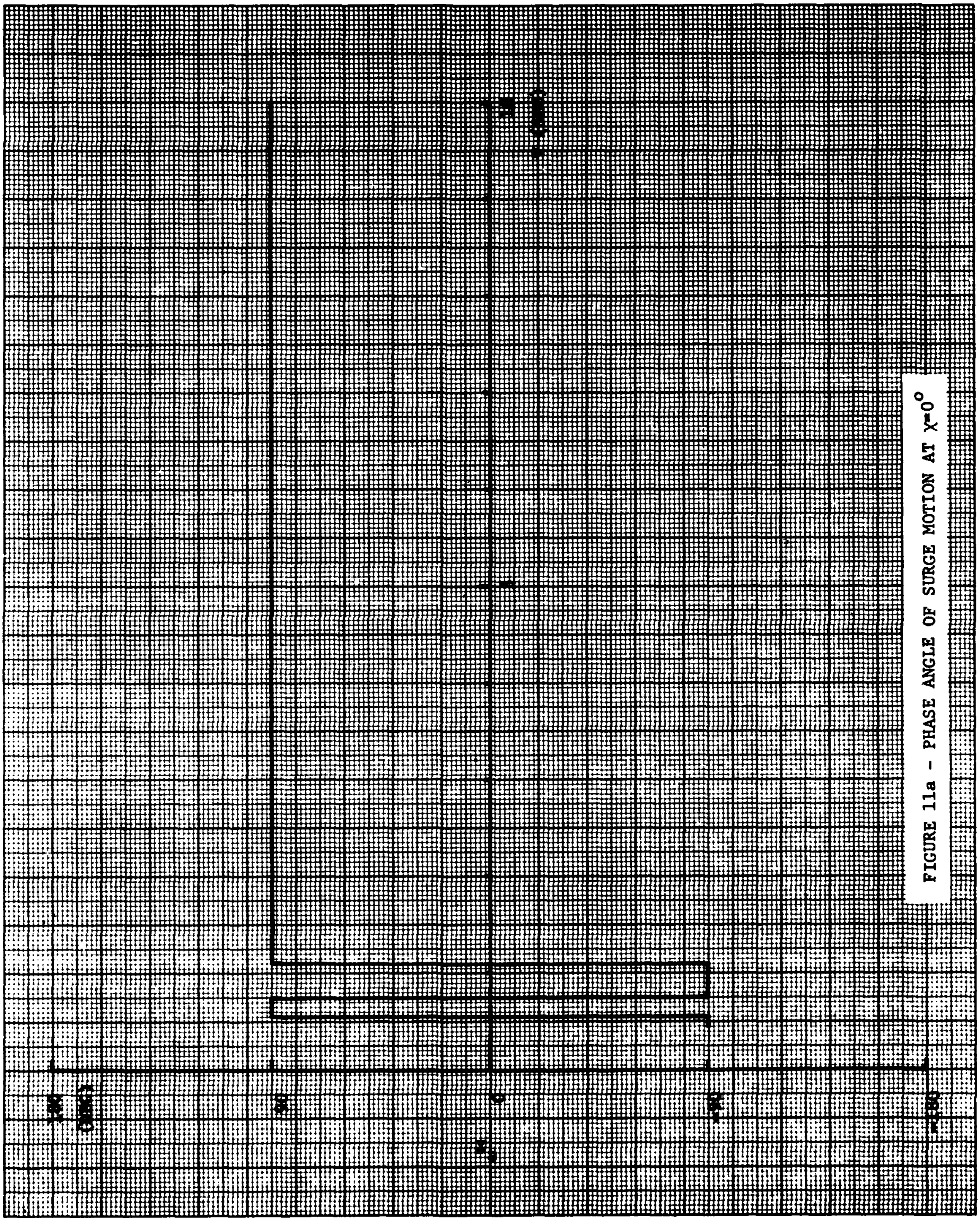


FIGURE 11a - PHASE ANGLE OF SURGE MOTION AT $\chi=0^{\circ}$

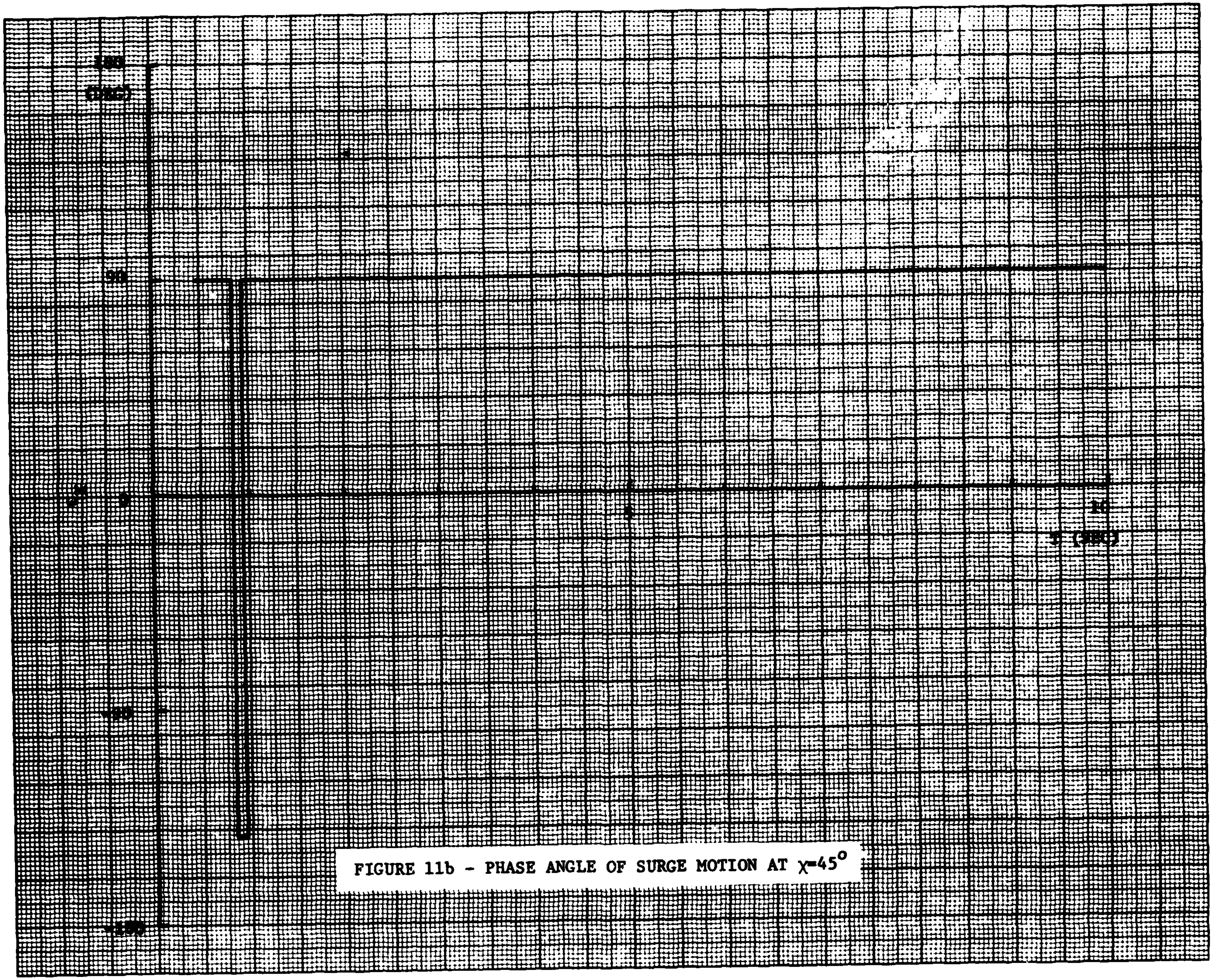


FIGURE 11b - PHASE ANGLE OF SURGE MOTION AT χ=45°

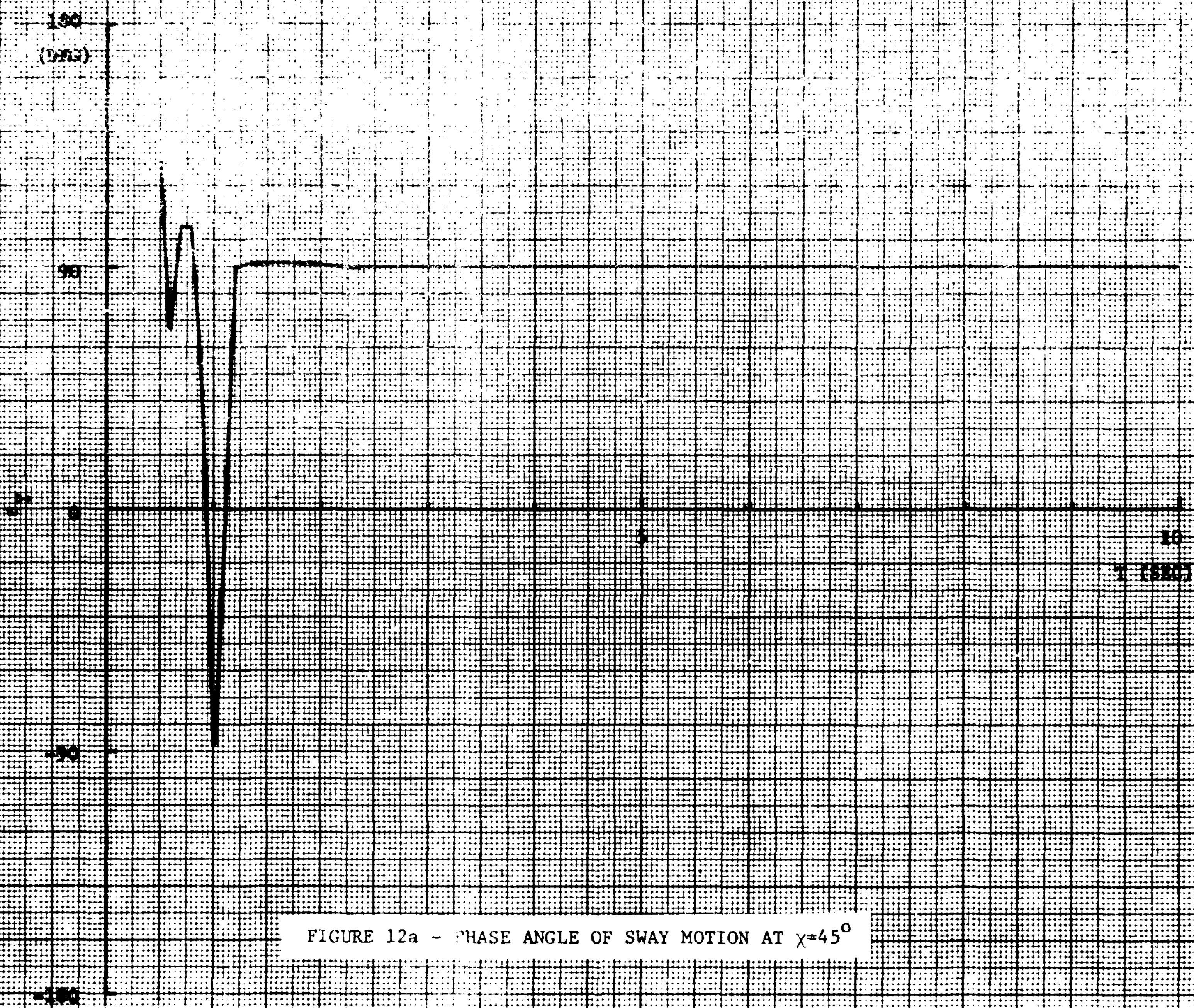


FIGURE 12a - PHASE ANGLE OF SWAY MOTION AT χ=45°

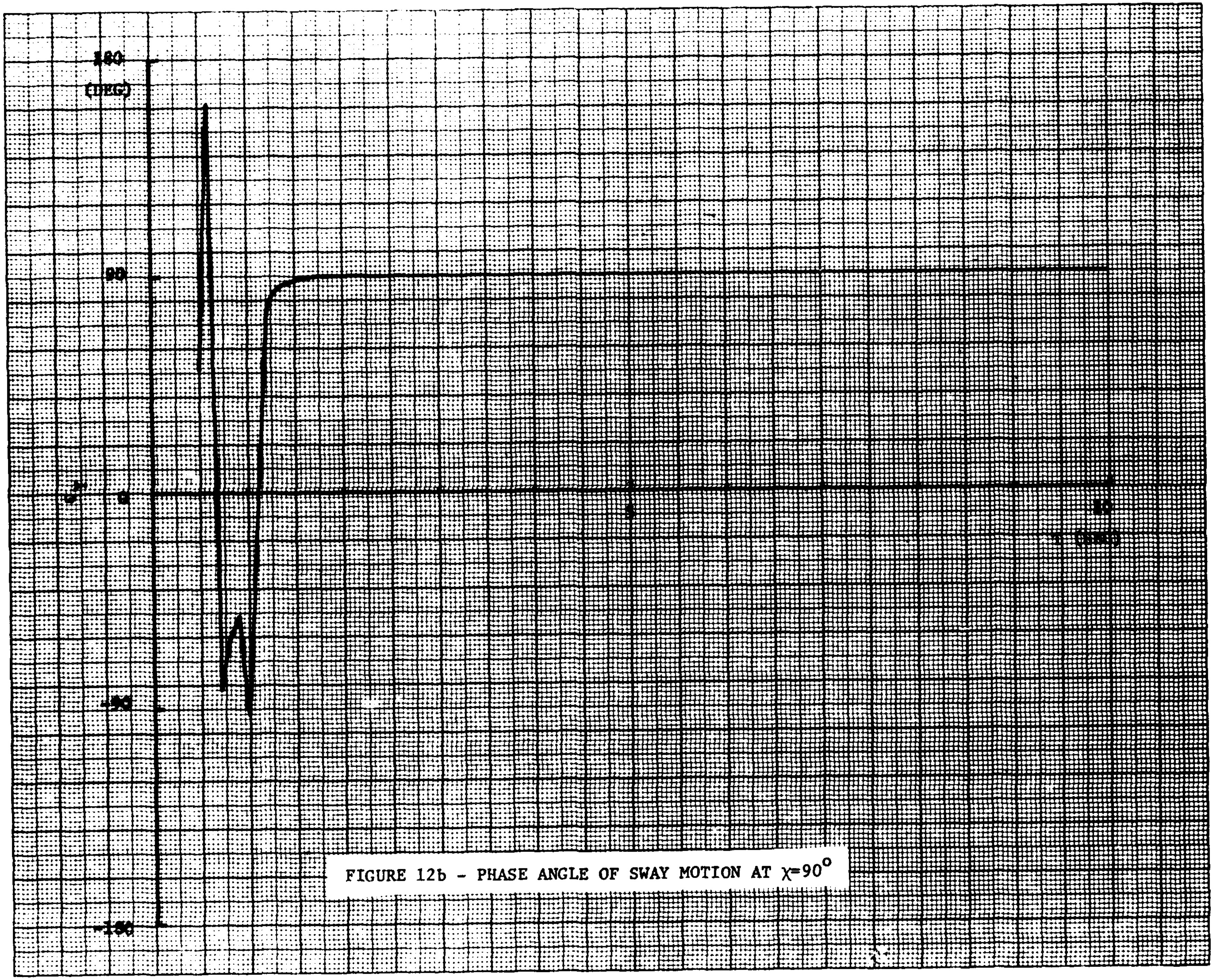


FIGURE 12b - PHASE ANGLE OF SWAY MOTION AT $\chi=90^{o}$

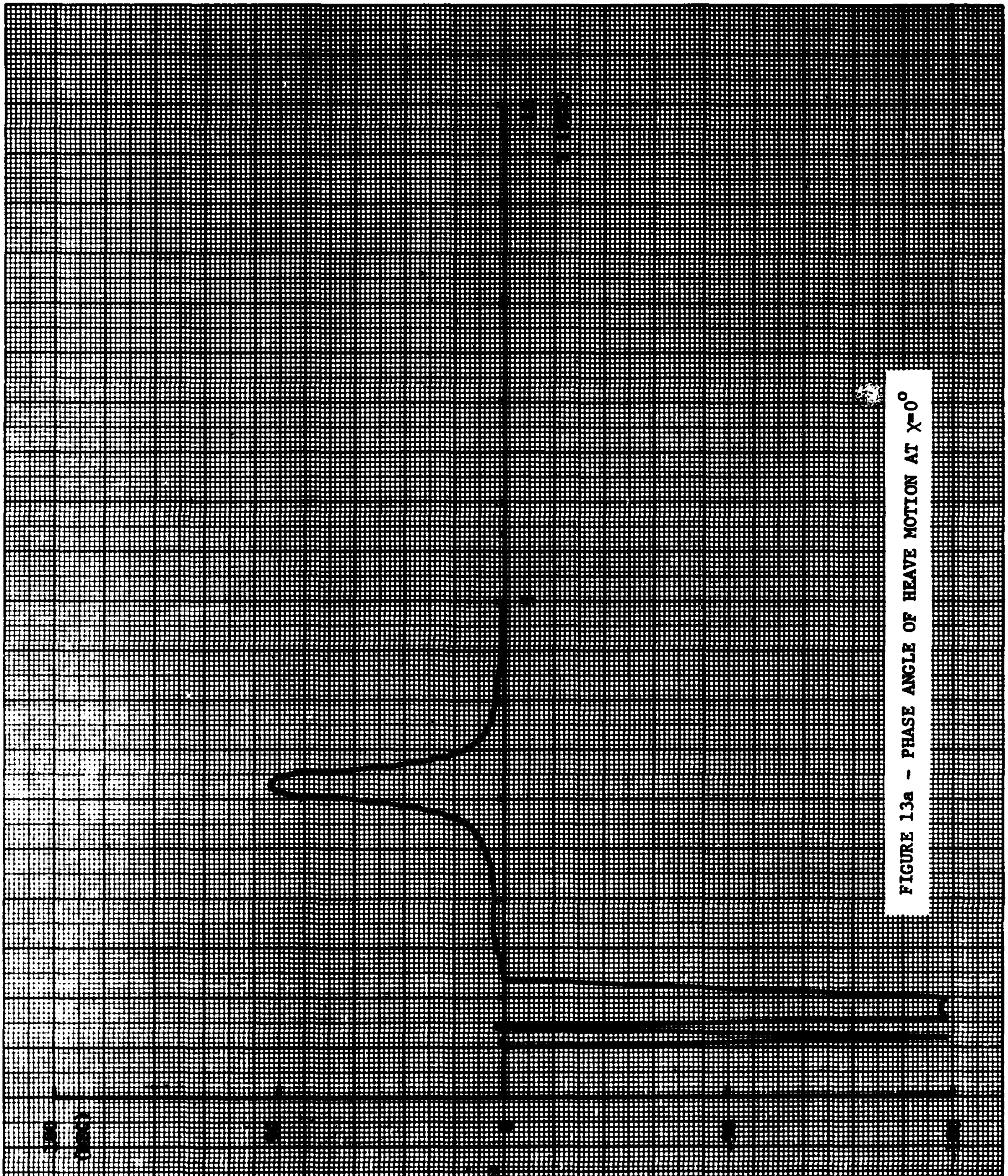


FIGURE 13a - PHASE ANGLE OF HEAVE MOTION AT $\chi=0^{o}$

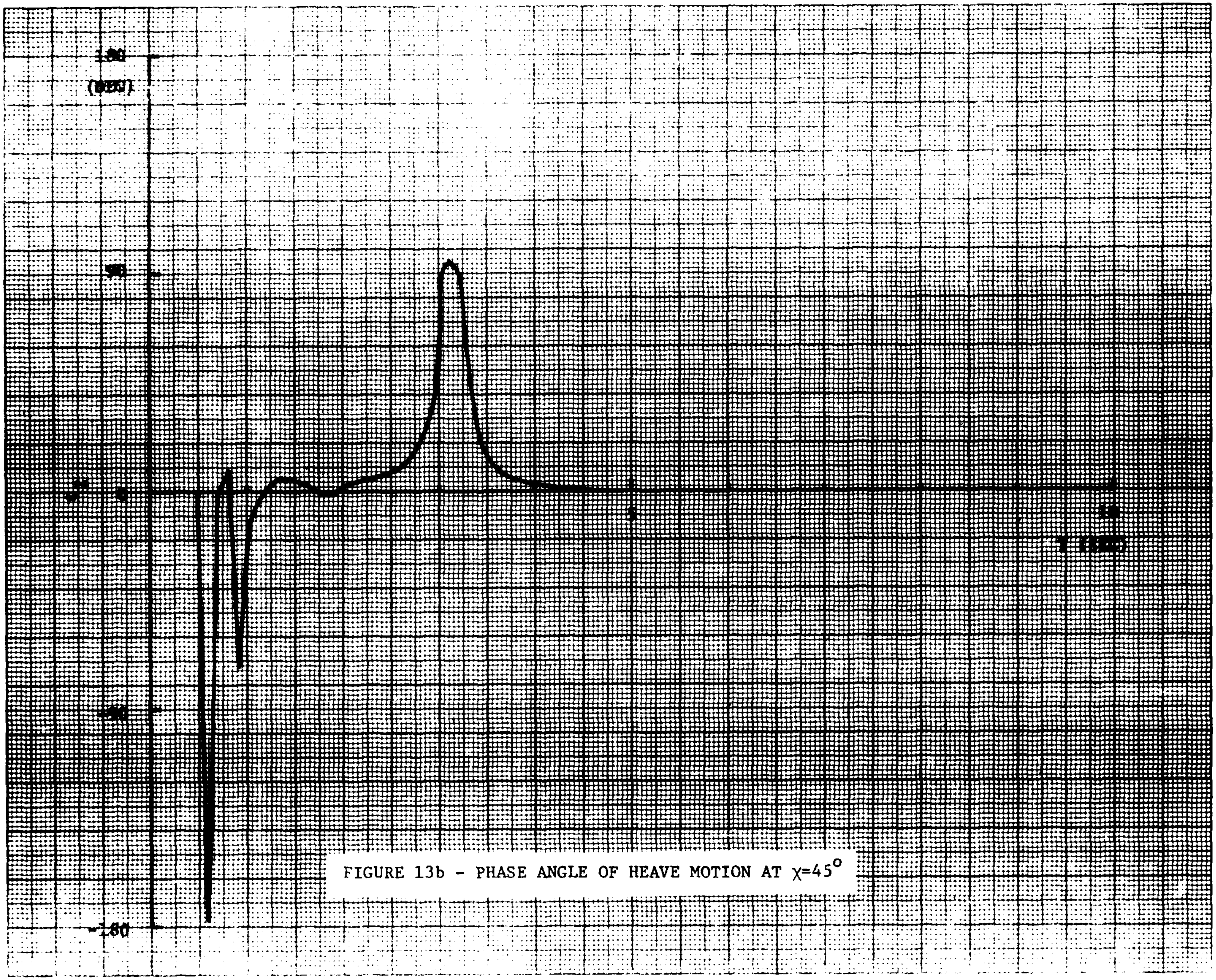
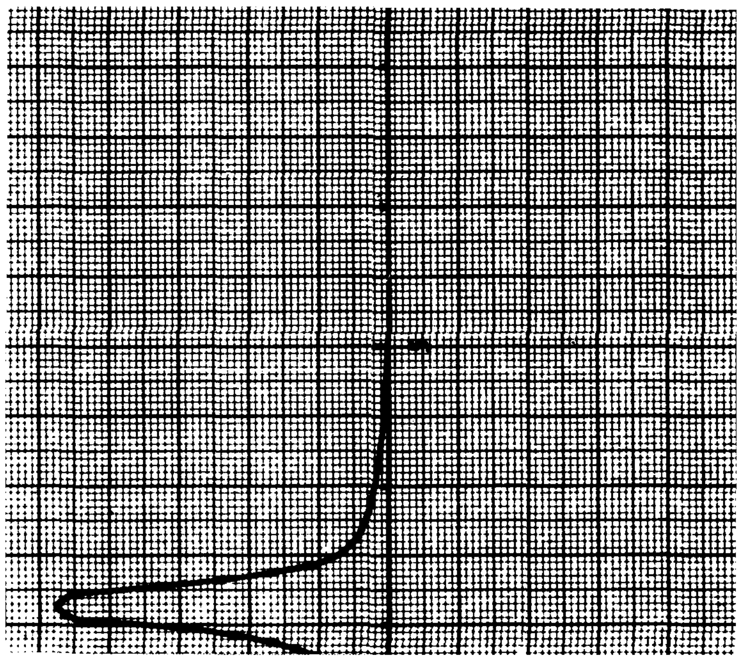


FIGURE 13b - PHASE ANGLE OF HEAVE MOTION AT $\chi=45^{\circ}$



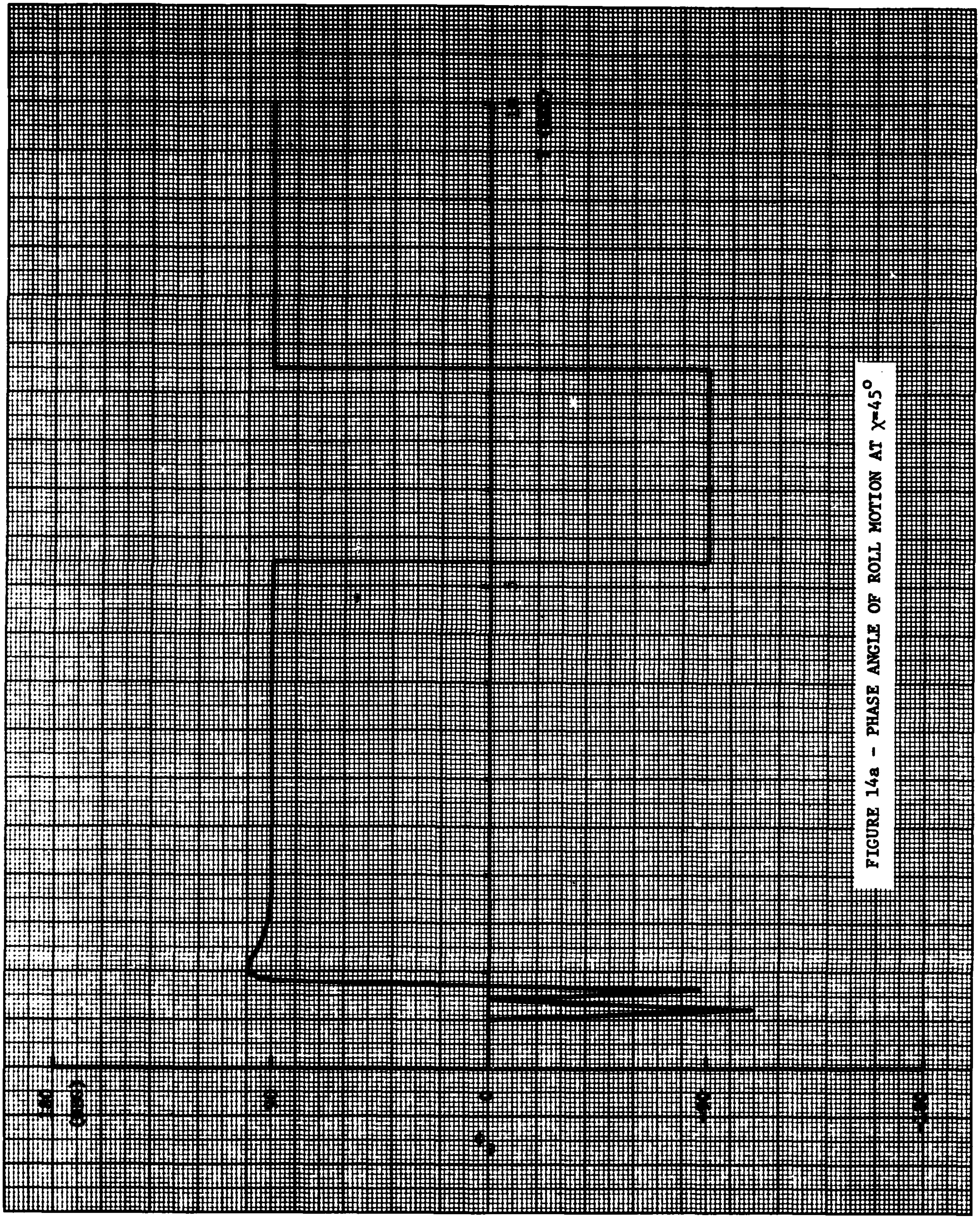


FIGURE 14a - PHASE ANGLE OF ROLL MOTION AT $\chi=45^{o}$

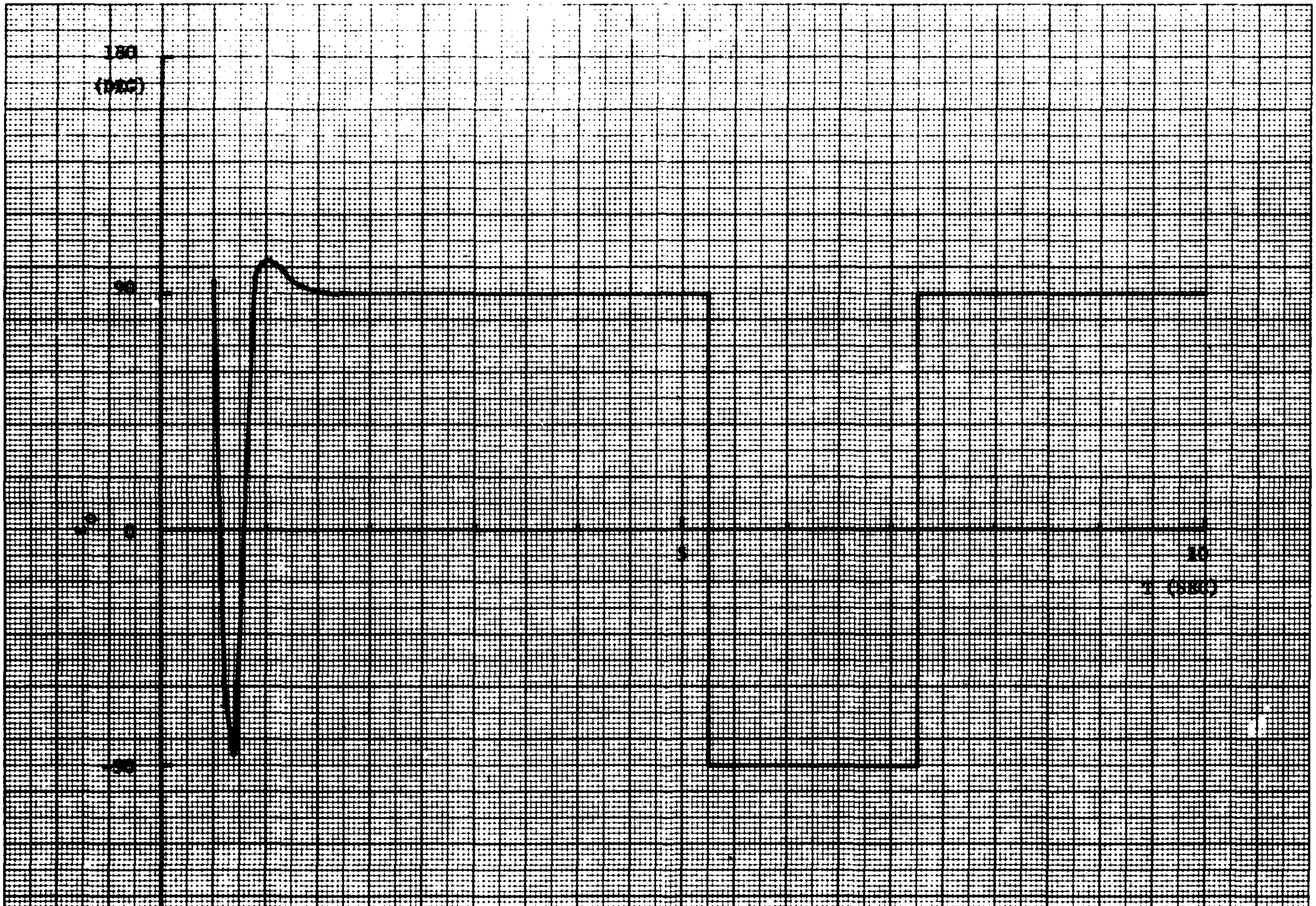


FIGURE 14b - PHASE ANGLE OF ROLL MOTION AT $\chi=90^{o}$

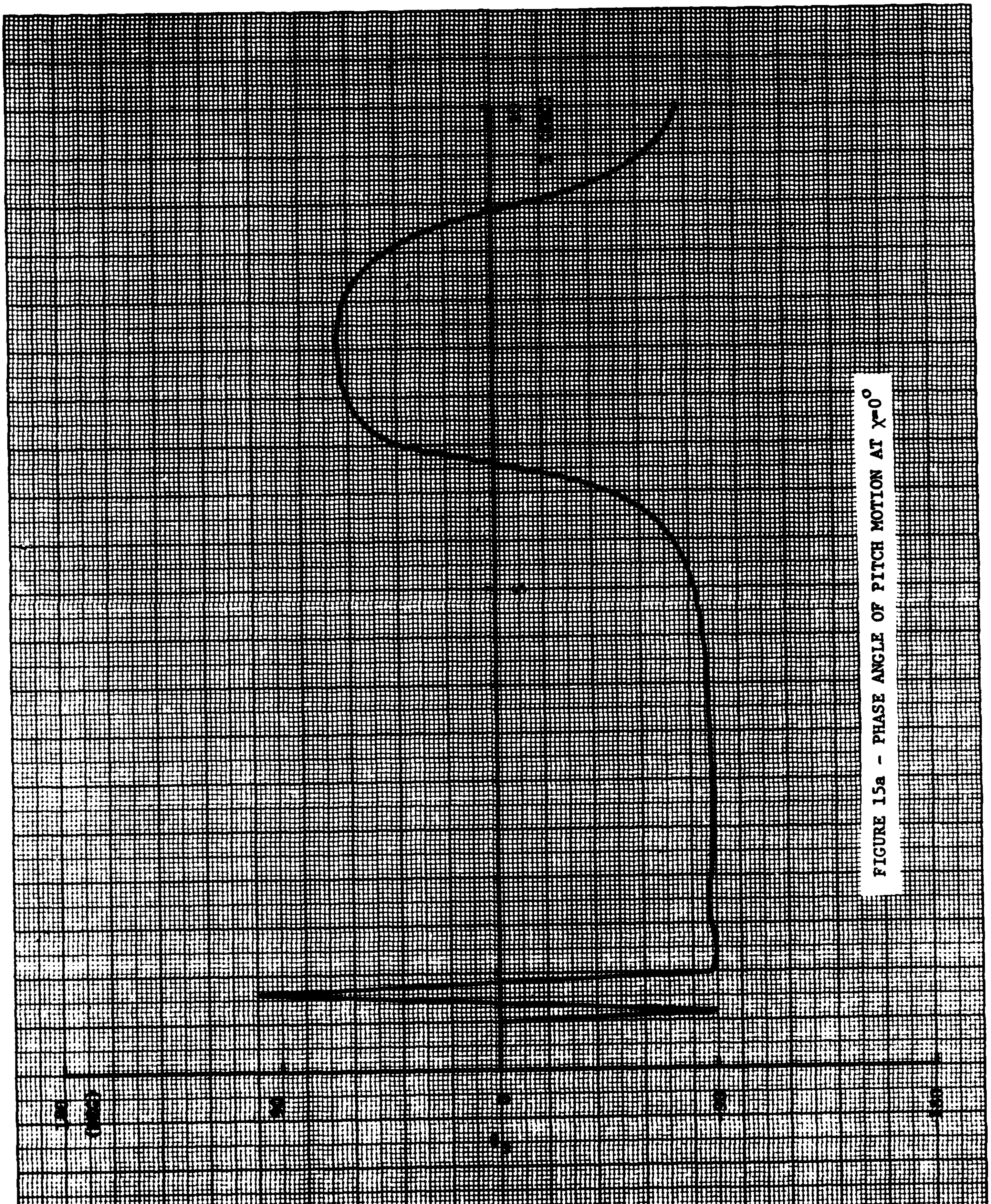


FIGURE 15a - PHASE ANGLE OF PITCH MOTION AT $\chi=0^{\circ}$

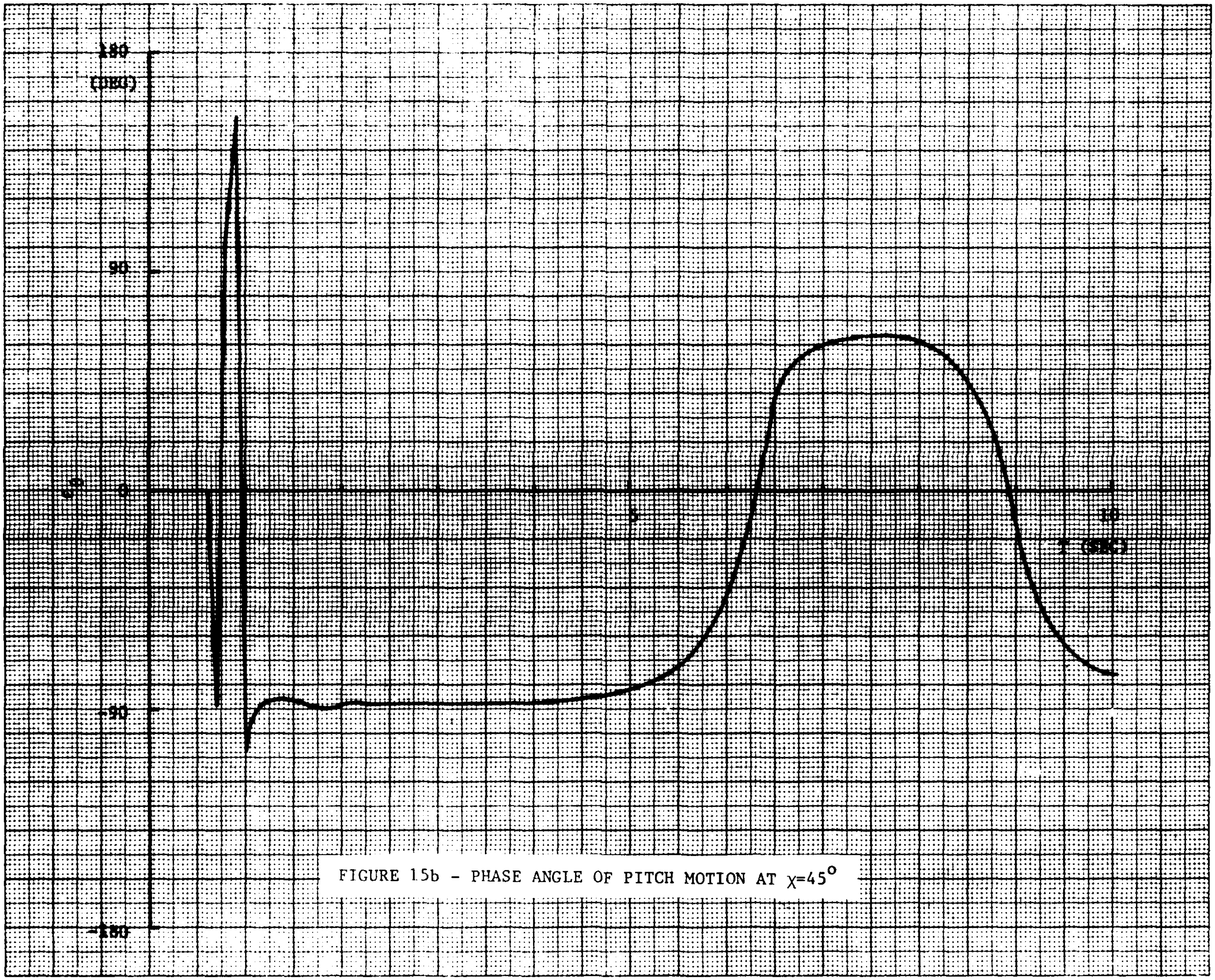


FIGURE 15b - PHASE ANGLE OF PITCH MOTION AT $\chi=45^{o}$

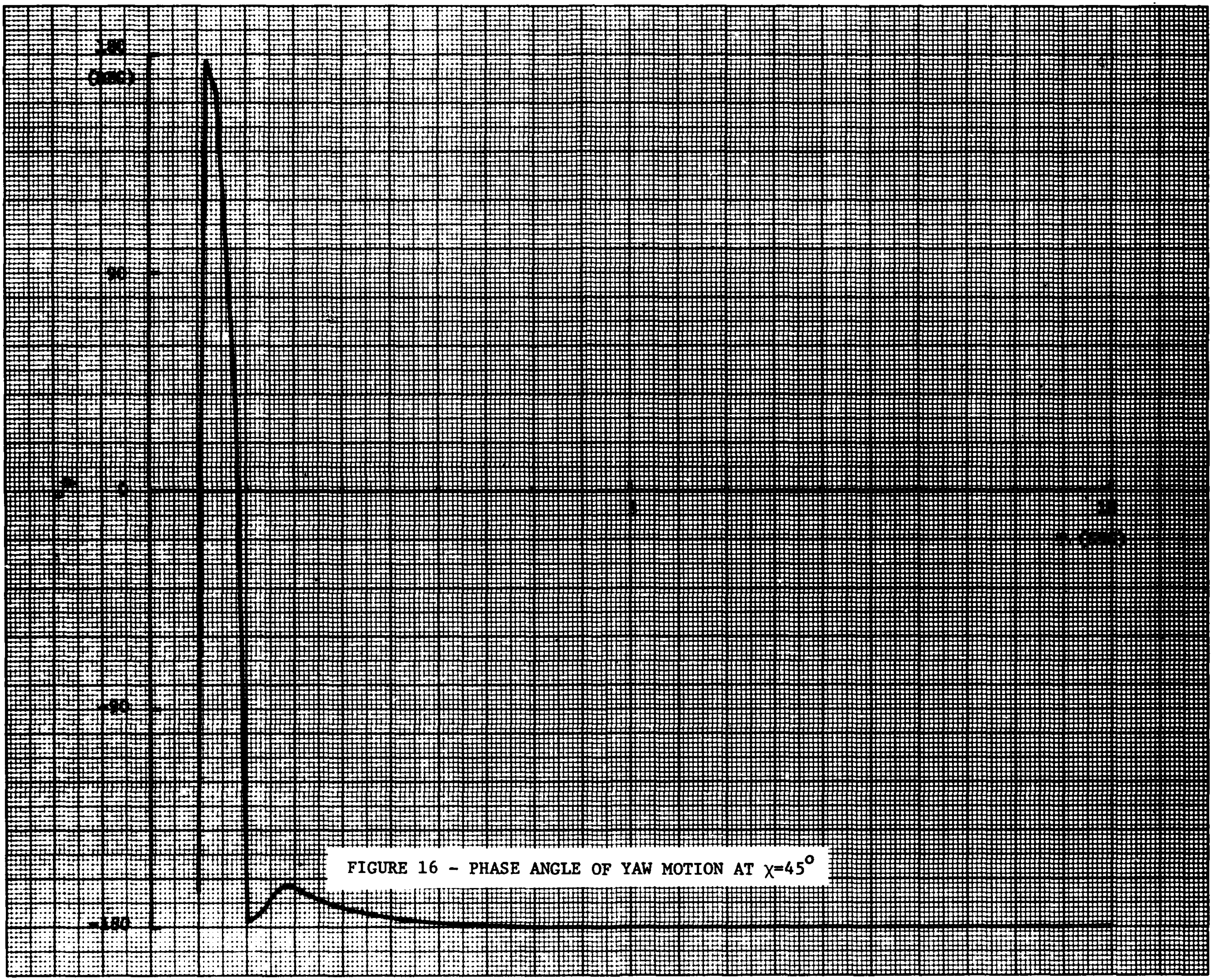


FIGURE 16 - PHASE ANGLE OF YAW MOTION AT $\chi=45^{\circ}$

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3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.

FIGURE 10 - AMPLITUDE OF YAW MOTION AT χ=45°