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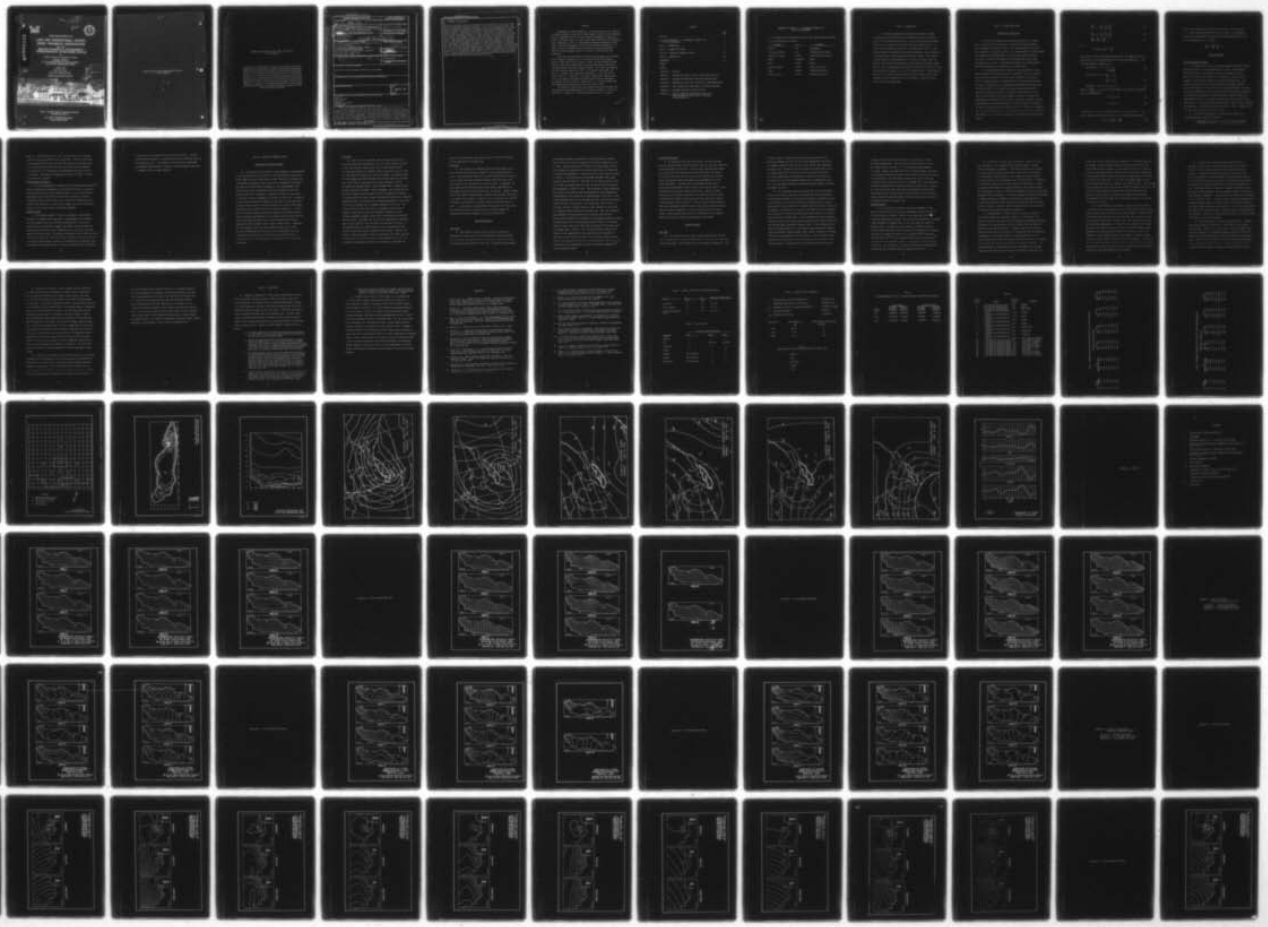

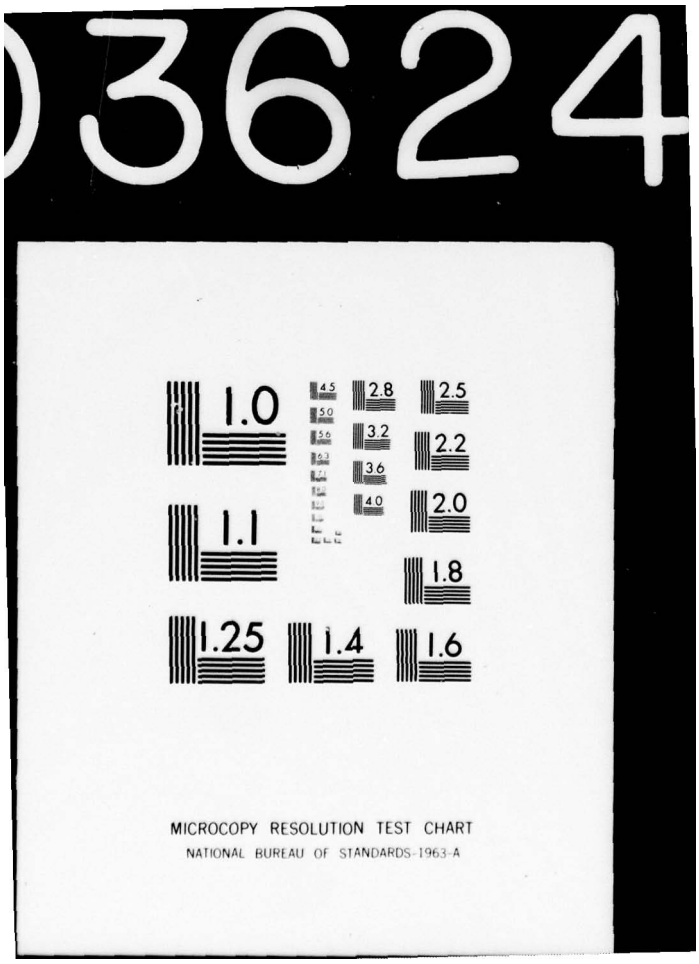
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LAKE ERIE INTERNATIONAL JETPORT MODEL FEASIBILITY INVESTIGATION

Report 17-8

RESULTS OF NUMERICAL TIME-DEPENDENT THREE-DIMENSIONAL, STORM SURGE ANALYSIS

by

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U. S. Army Engineer Waterways Experiment Station
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October 1976

Report 8 of a Series

(Main Text and Appendixes A-F)

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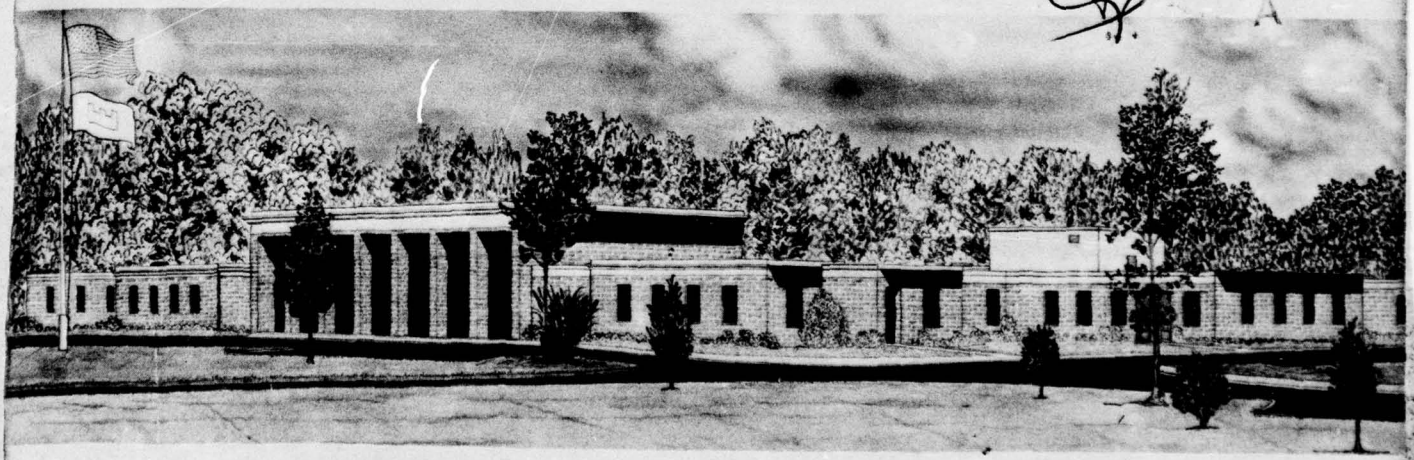

Prepared for Lake Erie Regional Transportation Authority
Cleveland, Ohio 44113

Under Task 17 of LERTA Second-Phase
Airport Feasibility Study

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The storm surge in Lake Erie in particular along the shoreline from Lorain, Ohio to Fairport, Ohio has been studied for existing conditions and as modified by a proposed jetport island located approximately four miles offshore near Cleveland, Ohio. This report includes data from numerical simulations of storm surge and three-dimensional, time-dependent horizontal velocity regimes associated with interpreted wind fields for storms of 8-9 April 1973, 25-27 November 1950 and 7-10 November 1913. In the study, the lake is assumed to be

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20. ABSTRACT (Continued).

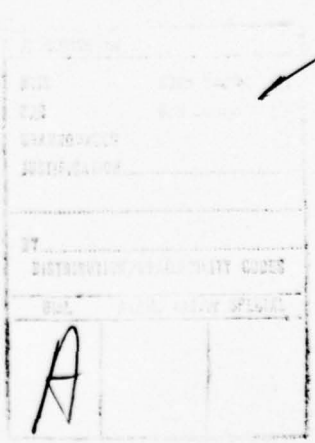
isothermal (constant density) and solutions are obtained for the entire lake and for a nearshore area near Cleveland. The report primarily presents the results of numerical simulation of storm surges, briefly summarizes the hydrodynamic model used and succinctly presents interpreted wind fields of the selected storms. Included in the data are vector plots of interpreted wind velocity over the lake, contours of surge elevations for entire lake and nearshore region, time history plots of surge elevations at selected points and vector plots of horizontal velocity at various depth levels in the nearshore region. Difference in surge elevations and horizontal velocity in the nearshore region with and without the jetport island are presented. Results of the study based on numerical simulation of storm surge in Lake Erie indicate that the effect of the jetport island on storm surge is locally confined around the jetport island and along approximately 10 miles of shoreline in the immediate vicinity of the jetport. These jetport effects are minimal with surge increases of 5 to 30 percent around jetport and 1 to 5 percent along the shoreline. Maximum increase of 0.12 feet in surge elevations was associated with surges of the severe storm of 7-10 November 1913.

PREFACE

The numerical, three-dimensional, storm surge study of the effect of a proposed offshore airport on the storm surge in Lake Erie near Cleveland, Ohio, was sponsored by the Lake Erie Regional Transportation Authority (LERTA), Cleveland, Ohio, as a part of the model feasibility investigation being conducted at the U. S. Army Engineer Waterways Experiment Station (WES). The WES investigation, Task 17 of the LERTA investigation, is a portion of the second-phase airport feasibility study undertaken by LERTA to evaluate airport sites, one of which is in Lake Erie near Cleveland.

This report and the numerical analyses were prepared and conducted by Dr. Donald L. Durham and Mr. H. Lee Butler of the Wave Dynamics Division (WDD), WES, and Dr. Donald C. Raney, who was working with WDD while on loan from AME Department, University of Alabama through the Intergovernmental Personnel Exchange Program. This study was conducted under the general supervision of Dr. R. W. Whalin, Chief, WDD, and Mr. H. B. Simmons, Chief, Hydraulics Laboratory. Assisting in this study was Mr. C. W. Coe, WDD. The authors express their appreciation to Dr. Mike Webb of Meteorological Applications Branch, Atmospheric Environment Services, Ontario, Canada and Dr. D. T. Resio of WDD, WES, for supplying the wind data for each of the three storms.

The Director of WES during the conduct of this investigation and the preparation and publication of this report was COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.



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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
inches per second	2.54	centimetres per second
$inches^2$ per second	6.4516	$centimetres^2$ per second
pounds	4.448×10^5	dynes
feet	0.3048	metres
feet per second	0.3048	metres per second
miles	1.6093	kilometres per hour
miles per hour	1.6093	kilometres per hour

PART I: INTRODUCTION

1. The Lake Erie Regional Transportational Authority (LERTA) is conducting a feasibility and site selection study for a major hub airport in the Cleveland Service area. One of the possible sites being evaluated is an offshore site in Lake Erie near Cleveland, Ohio. As a part of the feasibility analysis of an offshore site, the U. S. Army Engineer Waterways Experiment Station (WES) conducted a model feasibility investigation and is performing numerical model studies. The results of these efforts are being published in a series of reports under the general title "Lake Erie International Jetport Model Feasibility Investigation." This miscellaneous paper presents results of the numerical storm surge simulation analyses for a lake of constant density. These data are the results of a storm surge simulation study for storms of April 1973, November 1950 and November 1913 with and without a jetport island in Lake Erie near Cleveland, Ohio.

PART II: HYDRODYNAMIC MODEL

Mathematical Formulation

2. As part of a numerical model feasibility study[1], the scheme which is used in this investigation was selected from several models for calculating storm surge in lakes. The selected model has been initially applied[2] in testing the effects of a proposed jetport island offshore of Cleveland on the hydrodynamics of the nearshore region containing the island. Details of the numerical storm surge model can be found in References 1,2, and 3. An abbreviated statement of the hydrodynamic model and assumptions are presented here in summary form.

3. The mathematical model as applied by Hag and Sheng[3] is based upon the shallow lake theory developed by Welander.[4] Since the primary application of the model is for storm surge simulation on Lake Erie, several assumptions result in simplification of the governing equations: the lake is considered to be homogeneous (approximately valid from about the middle of fall to the beginning of summer), non-linear inertial forces are assumed to be small by comparison with the Coriolis force, effects of horizontal friction are ignored, pressure is assumed to be hydrostatic, the turbulence in the lake is modeled by a constant vertical eddy diffusivity, and the displacement of the lake surface is assumed to be small by comparison with the depth of the lake. Under these assumptions and with the introduction of a new coordinate system (vertically stretched coordinates x, y, σ), the basic equations can be written in dimensionless form as:

$$\frac{\partial u}{\partial t} - v = -\frac{\partial \eta}{\partial x} + \frac{E_v}{h^2}\frac{\partial^2 u}{\partial \sigma^2} \tag{1}$$

$$\frac{\partial v}{\partial t} + u = -\frac{\partial \eta}{\partial y} + \frac{E_v}{h^2}\frac{\partial^2 v}{\partial \sigma^2} \tag{2}$$

$$\frac{\partial hu}{\partial x} + \frac{\partial hv}{\partial y} + h\frac{\partial \omega}{\partial \sigma} = 0 \tag{3}$$

where

$$\sigma = \bar{z}/\bar{h}(x,y) \text{ and } \omega = \frac{d\sigma}{dt}$$

The barred ($\bar{}$) terms are dimensional quantities; all symbols and unusual abbreviations are listed and defined in the Notation (Appendix A). The associated boundary conditions are:

$$\text{Lake Bottom } (\sigma = -1): \quad u = v = 0, \quad w = \frac{1}{\beta h}\frac{\partial \eta}{\partial t} \tag{4}$$

$$\text{Free Surface } (\sigma = 0): \quad \frac{\partial u}{\partial \sigma} = h\,\tau_x^w, \quad \frac{\partial v}{\partial \sigma} = h\,\tau_y^w \tag{5}$$

$$\text{Coastline:} \quad (U + iV) \cdot (n_x + in_y) = 0 \tag{6}$$

where $\beta = \frac{gH}{L^2 f^2}$, $n_x + in_y$ is the unit normal vector along the shoreline, and U, V are defined as

$$U = h \int_{-1}^{0} u \, d\sigma \tag{7}$$

$$V = h \int_{-1}^{0} v \, d\sigma \tag{8}$$

The quantity ω is the velocity perpendicular to the constant σ plane and is related to the vertical velocity w by the following equation:

$$w = \omega h + \frac{z}{h}\left(u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y}\right) \tag{9}$$

If one is not interested in the vertical velocities, the calculation of ω can be eliminated completely from the system. By integrating equation (3) and applying the lake bottom boundary conditions (4), one obtains an equation for η, namely,

$$\frac{\partial \eta}{\partial t} + \beta\left(\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y}\right) = 0$$

Numerical Scheme

Finite Difference Procedure

4. To numerically solve the governing equations an explicit finite difference analog on a space-staggered grid is used. The associated stability criteria is the familiar Courant-Lewy condition, namely, that a time step be less than the time required for a gravity wave to propagate across one grid spacing in the horizontal direction. From numerical experiments[3] it was determined that the maximum allowable time step was about 1/5 that allowed by the Courant condition. In order to conserve computer time, three grids were used in the surge calculations. An 8-mile grid was applied to the Eastern Basin of Lake Erie where the maximum depth occurs. A 4-mile grid was applied to the rest of the lake (see Plate 1). For the Cleveland nearshore region, where a finer resolution was required, a 1-mile grid was used (see Plate 2). Table 1 summarizes the grid data and time steps used in this study.

5. The numerical procedure for carrying out the storm surge calculations can be described as follows:

a. Assume that the values of η, u, v at time t_n are known (initially at time $t = t_1 = 0$, set $\eta = u = v = 0$).

b. Use finite difference analogs to equations (1) and (2) to calculate u^{n+1} and v^{n+1} at the next time step for each σ level (u^{n+1} and v^{n+1}).

c. Evaluate U^{n+1} and V^{n+1} by numerically integrating equations (7) and (8) using a modified Simpson's rule.

d. Compute η^{n+1} from a simple difference analog of equation (10).

This completes the calculations of the three-dimensional flow field at time $t^{n+1} = (n+1)\,\Delta t$ and the computation for the next time step can now be started with step (a) in the procedure. Note that all variables, η,u & v , in the nearshore grid are advanced for 4 time steps while those in the rest of the lake are advanced for one step only. The three grids are properly coupled in space and time.

Lake Bathymetry

6. Various quantities such as the bottom topography, wind stress, and other characteristic parameters are specified as input to the numerical codes for simulating storm surge on Lake Erie. Discrete values of the bottom topography of Lake Erie were obtained for each grid point of the three grids in Plates 1&2. For the entire lake, discrete values of depths were obtained from a 2 mile grid used in a previous study[6] of the steady-state, wind driven circulation for well-mixed conditions in Lake Erie. The original depth values were taken from Lake Survey Center Charts as published by the U. S. Army Corps of Engineers. An outline of the procedure with which these values were read from charts, interpolated and smoothed is given in Reference 5. Contours of the resultant, discretized bottom topography for the full lake are depicted in Plate 3. For the finer nearshore grid, descrete values for depth were obtained from a 1/4-mile grid used in the previous study.[6] Contours of these discrete depths for the nearshore grid are depicted in Plate 4.

Wind Fields

7. The study consisted of running storm surge simulations for three storms: a severe storm occurring in April 1973 for which prototype data was available to verify the surge model for existing conditions and two additional storms for which extreme wind conditions occurred. The first of the very severe storms occurred in November 1913 with peak winds crossing Lake Erie along its minor axis from north to south. The second storm occurred in November 1950 with strong winds crossing the lake along its major axis from east to west during a portion of the storm. In order to estimate the surge levels during these storms, reliable wind input is required to produce realistic results. For the 1973 and 1950 storms, data recorded at six land stations around Lake Erie were available. For the 1913 storm, data from four U. S. stations were available. Table 2 lists the wind stations from which wind data were used for each storm. Plate 1 depicts the locations of the various stations which reported the wind data used in this study. In order to apply the wind data recorded at land stations, they must be transformed to provide reliable, unbiased estimates of winds over water. The procedure for transforming the winds is given in Reference 7. For the determination of lake surge levels, a knowledge of the wind shear stress at the lake surface is required. Having transformed the land recorded wind data to values at 10 m above the lake surface, the wind shear stress, $\vec{\tau}$, is determined by the following formulas developed by Wilson.[8]

$$\vec{\tau} = 0.00273\ \rho_a |\vec{W}_a| \vec{W}_a$$

where ρ_a is the density of air, $\vec{W}_a$ the wind velocity in m/sec and 0.00273 is the drag coefficient for strong winds. Since the wind field is not uniform over the lake, and the wind velocities are measured only at a few stations around the lake, the wind stress over the remainder of the lake has to be determined by interpolating from known values at a few points. The method of interpolation used in this study is similar to that used by Platzman.[9]

Characteristic Parameters

8. In the non-dimensional formulation of the governing equations[1,2,3] various characteristic parameters are defined and are used in scaling the non-dimensional results of the numerical study. A list of the pertinent parameters and the values used in this study is presented in Table 3. In addition, Table 3 gives values used in each storm simulation for the vertical eddy viscosity, E_v, and the base height, D_b, of the lake surface relative to the survey datum of the bottom topography.

Numerical Codes

9. The numerical model,[2,3] which was developed at Case Western University to compute three-dimensional, time-dependent flow (currents) and storm surge for the full lake and nearshore region of Lake Erie, consisted of a Fortran code to compute the surface elevations above the still lake level and the velocity components (u,v, & w) at any selected depth in the water column. The Waterways Experiment Station (WES) converted this code to operate on a CDC 7600 Computer, enhanced the output procedures to include various graphics routines, and developed and incorporated codes to translate wind data observed at selected overland stations on perimeter

of Lake Erie to wind fields over the entire lake surface. The full numerical storm simulation is performed in two main jobstreams and two postprocessing codes. A description of each activity, input/output requirements and definitions, flowcharts, and deck setup are provided in Appendix G which is bound separably.

PART III: RESULTS OF NUMERICAL STUDY

Wind Fields of Selected Storms

10. The results of the numerical, three-dimensional, time-dependent storm surge analysis of the effects of a proposed jetport island on the storm surge in Lake Erie particularly in the vicinity of Cleveland, Ohio (from Lorain to Fairport, Ohio) are presented in Appendices B through F. For each of the three storms (Paragraph 7), the time-dependent wind field over the lake as interpreted from data available at land wind stations (Table II) is depicted in Appendix B by velocity vector plots at four hour intervals throughout the duration of the storm. In addition to these wind velocity plots (Appendix B) for each of the three storms, synoptic weather charts of surface conditions for selected times during the 1950 and 1973 storms are present in Plates 5 through 10. The movement of the storm front associated with high and low pressure patterns and the direction and magnitude of the surface wind field over Lake Erie can be inferred from surface wind stations and geostrophic winds as depicted by isobar patterns in the synoptic weather charts. Comparison of these synoptic charts with the interpreted wind velocity plots for the corresponding times during each storm demonstrates that the interpreted wind fields over the lake are quite realistic and are representative of the time-dependent wind field over Lake Erie during each storm.

1913 Storm

11. The storm of 7-10 November 1913 was chosen because (a) it is considered by many investigators to be one of the severest storms[10] to move into the Great Lakes region, (b) it's peak winds crossed the lake from northwest to southeast (lake's minor axis), and (c) southwest winds persisted during last 12 hours of storm. At Cleveland, Ohio the storm began about 0430 9 November 1913 with precipitation and light snow. Winds from the northwest were initially moderate, steadily increased, and reached 40 mph at 1350 9 November 1913. During the next 16 hours from 1400 9 November - 0600 10 November, the wind velocity was relatively uniform with an average velocity of 50 mph and the highest or maximum velocity of about 60 mph occurring about 1600 hrs on 9 November. During this time, the wind direction varied from northwest to west until 2000 hrs on 9 November when it changed permanently to the west. The wind came from the west until 0830 on 10 November at which time it changed to southwest and continued throughout remainder of storm. Northern Hemisphere synoptic weather maps are available on microfilm[11] for this storm. These maps are available for climatological conditions once a day at 1300 GMT. The resolution of these maps is too poor to distinguish details of surface conditions over and around Lake Erie. For this reason they are not reproduced in this report. However, the general trend of geostrophic winds as indicated by the surface pressure patterns agrees with the interpreted winds (Appendix B) over Lake Erie. In addition, the general characteristics (direction, magnitudes and

peaks) of the interpreted winds match very well the above description of wind conditions at Cleveland, Ohio.

1950 Storm

12. The storm of 25-27 November 1950 was chosen because it was another of the most destructive storms[12] in the northeastern United States. The low pressure center of the storm stalled south of Lake Erie causing strong winds from southeast-northeast along the lake's major axis to persist over the lake for at least 24 hours. In addition, its peak winds of 30-40 mph from NW-NE occurred during 1300-1900 EST on 25 November 1950 and crossed the minor axis of the lake. Synoptic weather charts[13] for surface climatological conditions (particularly wind field) are available every 6 hours. Portions of two of these maps for 1930 EST 25 November and 1030 EST 20 November 1950 are presented in Plates 5 and 6. In these plates, the geostrophic wind patterns and surface wind data from land stations favorably agree and strongly support the interpreted wind fields (Appendix B) for the storm of 1950.

Model Verification

1973 Storm

13. The storm of 8-9 April 1973 was chosen to verify the application to Lake Erie of the three-dimensional storm surge model. For this storm, wind data from six land stations (Table 2) were used to interpret the wind field over the lake. In general, good agreement

exists between surface and geostrophic winds from synoptic weather charts (Plates 7-10) and the interpreted wind fields (Appendix C) over the lake. Surge elevation data[14] from five lake level gages (Table 4) were available for comparison of prototype observations of storm surge with numerical computations. The results of this verification are shown in Plate 11. Time histories of the prototype and model storm surge elevations for 0100 April 8 - 0000 April 10, 1973 agree within 0.5 foot at all lake level gages except for those at the west end of Lake Erie where agreement is within 1.0 feet. The difference in surge comparisons for the west end of the lake may be associated with the topographical representation of the islands in the Western Basin of Lake Erie. There is good agreement ($\leq$0.5 ft) of prototype and model surges for the Central and Eastern Basins of Lake Erie. The storm surge in the vicinity of Cleveland (Lorain to Fairport Harbor) is most important in this study of a proposed jetport island off Cleveland, Ohio. Thus, the relatively good agreement of surge comparisons at Cleveland, Ohio and Erie, Pennsylvania increases one's confidence in the numerical model and assures reasonably good results in determining relative effects of a proposed jetport island on the storm surge along the shoreline from Lorain, Ohio to Fairport, Ohio. However, a full calibration and/or complete verification of the application of this numerical storm surge model to Lake Erie was not within the scope of this feasibility study and such efforts would require specific types of prototype data,[1] which at present do not exist, and a comprehensive series of parametric experiments[20] with the numerical model.

Previous Verification

14. In addition to the above verification, the same numerical model was applied by Haq, Lick and Sheng[3] to Lake Erie for wind conditions during Storm Agnes in June 1972. In that study, good agreement between model results and observations were obtained for surface elevations. It should be noted that for this study and the study by Haq, Lick and Sheng, the numerical model verification was performed only on storm surge (elevations). No comparisons (verification) of horizontal velocities were performed in Haq's study or this study because of a lack of prototype velocity data during severe storms. Since the surface elevations are relatively insensitive to the detailed velocity regime, verification on surface elevation alone does not necessarily insure a correct detailed velocity regime.[19] This fact should be kept firmly in mind when considering absolute velocity values from the numerical model. However, relative comparisons of velocity regimes with and without a jetport island should provide qualitative indications of the jetport's effect on horizontal velocity regimes during severe storms.

Surge Elevations

Full Lake

15. For each of the three storms, surge elevations over the full lake are numerically computed and contoured at 4 hour intervals throughout the storm duration. These contour plots are presented in Appendix C. For

all three storms, a comparison between the surge contours and the wind field (Appendix B) over the lake vividly demonstrates the spatial and temporal coupling between the wind stress and the storm surge over the entire lake. During most of the duration of the April 1973 storm, the maximum surge setup is located in the western end of Lake Erie while east northeasterly winds dominate. During the last 8 hours of the storm, the wind field changed dramatically to southwesterly winds with the surge rapidly migrating eastwardly along the southern shoreline to Buffalo, New York.

16. For the November 1950 storm simulation, the surge initially set up on the southern shoreline of Lake Erie near Erie, Pennsylvania; slowly migrated westward as the wind field changed its predominate direction from NNW to N to ENE; and increased with maximum surge occurring approximately 26 hours (1800 EST 25 November 1950) after initial wind field was applied. During the last 12 hours of the storm, the wind is predominantly from the E to ESE with maximum surge setup located in the western end of the lake at Toledo, Ohio. For the November 1913 storm simulation, the initial setup of the storm surge occurred along the southern shoreline with maximum surge located near Sandusky, Ohio. As the predominate wind direction changed from NW to W, the maximum setup slowly moved eastward along the shoreline reaching Buffalo about 28 hours (0300 EST 10 November 1913) after the beginning of storm simulation. West to southwest winds dominated the wind field over the lake during the last 24 hours of the storm simulation. Although these wind directions persisted during the

remainder of the storm, the wind velocity over the lake as a whole decreased significantly. These SW winds along the major axis of the lake sustain relatively large ($\geq$5 ft) surge setup between Buffalo and Toledo. However, the peak setup of 10 ft between Buffalo and Toledo occurred around 0700 EST 10 November 1913 or about 32 hours after starting storm simulation. This peak setup occurred about 12 hours after the occurrence of peak winds at 1950 EST on 9 November 1913. The predominate direction associated with the peak wind field was from the NW. Crossing the minor axis of the lake, these peak winds produced a smaller surge setup than the later SW winds which crossed the major axis of Lake Erie. However these peak winds did create a relatively large surge setup of 6.5 ft between Cleveland and Toledo, Ohio.

Nearshore Region

17. The contours of simulated storm surge in Appendix C show general characteristics of storm surge throughout the lake for each of the three storms of interest. However, such surge plots do not [redacted] sufficient resolution to indicate the relatively local effects of a jetport island offshore of Cleveland, Ohio on the storm surge from Lorain to Fairport, Ohio. To define such local effects, a nearshore region of 15 miles along shore and 15 miles offshore of Cleveland, Ohio is selected such that it includes the tentative site selection zone[15] and the preliminary lake site[1,6,16] for a proposed jetport island configuration.[17] The location of the nearshore region is indicated on the full lake grid in Plate #1. The location of the jetport island and the Cuyahoga River mouth within this nearshore region is depicted in Plate #2.

18. For each of the three storms of interest, contours of storm surge elevations in the nearshore region with and without a jetport island are presented in Appendix D. The surge elevations are contoured at 4 hour intervals through the duration of each storm. Each contour in the nearshore region correlates with a contour of surge elevations in the full lake at the corresponding time of storm duration. In addition to contours of surge in the nearshore region with and without a jetport, a contour of the difference in surge elevations in the nearshore region with and without a jetport is presented in Appendix D at each 4 hour interval throughout the storm duration. It should be pointed out that the differences in surge elevations are computed by subtracting at each grid point in the nearshore region the storm surge with a jetport from the storm surge without a jetport. Therefore, positive jetport effects (increased surge elevations) are indicated by negative differences.

19. Maximum effects of the jetport on the surge elevations in the nearshore region are tabulated in Table 5. In this table, the jetport's effects on the storm surge are presented as minimum and maximum differences in surge elevations near the jetport island and along the shoreline in the nearshore region. Keeping in mind that increases in surge elevations due to the jetport are indicated by negative differences in Appendix D, the maximum increase in surge elevations due to the jetport occurred for surge setup during the 1913 storm and was an increase of 0.12 feet ($\sim$6%) both near the jetport and along the shoreline. The maximum decrease in surge elevation due to the jetport also occurred during the 1913 storm and was a decrease of 0.06 feet ($\sim$15%) near the

jetport and 0.04 feet (~25%) along the shoreline. The maximum effects of the jetport on surge elevations along the shoreline for the other two storms (1950 & 1973) of interest are less than one half of the jetport's effects on surge elevations for the 1913 storm. The percent changes for maximum jetport effects along the shoreline are approximately 1% for 1973 storm and 3% for 1950 storm. In all cases the maximum change in surge elevations associated with the jetport is less than 0.15 feet. This maximum change occurred for one of the severest storms[10] recorded on Lake Erie. The severity of this storm may be qualified by the fact that this storm produced in the vicinity of Cleveland, Ohio significant and maximum wave heights[18] which are larger than wave heights expected to occur once in 50 years to 75 years.

20. A careful analysis of Appendix D indicates that the effects of the jetport on surge elevations are very local with the largest effects normally being within two to three miles of the jetport. Maximum effects occasionally reach the shoreline near Cleveland, Ohio as in the case of the 1913 storm on 0000 EST 10 November 1913. For all practical purposes and engineering applications, all effects of the jetport on storm surge elevations are contained within the 15 mile by 15 mile nearshore region. Differences in surge elevations diminish to 0.01 feet or less as the boundaries of the nearshore region are approached. Therefore, outside this area, jetport effects on storm surge can be neglected. From results of this study, storm surge along Lake Erie shoreline SW of Cleveland from Rocky River to Lorain and NE of Cleveland from Euclid Creek to Fairport, Ohio can be considered unaffected by the jetport.

21. In addition to the surge elevation contour plots in Appendices C and D, time histories of surge elevation at selected locations in the nearshore region and full lake are presented in Appendix E. During the numerical simulation of each storm, time histories (functions of storm duration) of surge elevations relative to mean lake level were stored on magnetic tape and later were printed and plotted for 40 specific grid points or locations throughout the lake. From these 40 points, twenty were selected for which the time histories of surge elevations with and without a jetport for each storm are presented in Appendix E. The location of all 40 points are indicated by dots in Plates 1 and 2. The twenty points selected for Appendix E are indicated by numbered dots in Plates 1 and 2 and are listed in Table 6 with their grids, grid indices and locations. Ten of these twenty points are located in the nearshore region around the jetport island and along the shoreline. Locations of the remaining ten points are scattered along the shoreline in the full lake grid.

22. Of the ten points in the full lake grid, points 7 through 11 are of major interest to the study of local effects of the jetport on storm surge. Points 7 and 8 are located at Lorain and Rocky River which are southwest of the nearshore region, and Points 9 and 10 are located at Willowick and Fairport which are northeast of the nearshore region. Point #11 in the middle of the lake is located approximately 20 miles NNW of the jetport island. For these five points, careful examination of the surge time histories with and without a jetport

reveals no jetport effects in the surge elevations at these locations. Such comparisons indicate the jetport's effects are quite local and are confined within the nearshore region. These results are consistent with the results of previous analyses (Paragraph 19) of storm surge contour plots (Appendix D) in the nearshore region.

23. Since the jetport's effects on the storm surge elevations have been shown to be very small in absolute value from analyses of data in Appendix D, time histories of surge elevations around the jetport and along the shoreline should be relatively unchanged with and without the presence of the jetport island. Comparisons of time history plots of surge elevations with and without the jetport at the ten points selected in the nearshore region show the jetport effects are difficult to detect, if detectable at all, except for the extreme case of 1913 storm.

Nearshore Horizontal Velocity Field

24. For the nearshore region, plots of horizontal velocity vectors with and without a jetport island and vector plots of velocity differences associated with the jetport's effects are presented in Appendix F. Horizontal velocity vectors at 0,10,15,20,30, and 40 ft depths in the water column are plotted at 4 hour intervals throughout the duration of each storm. These plots indicate the spatial extent (horizontal and vertical) of the jetport's effect on the time-dependent, horizontal velocity field in the nearshore region. Major effects of the jetport

on the horizontal velocity for the 1913 storm are confined within 1 to 2 miles of the jetport. Smaller velocity variations extend to the shoreline in extreme storm conditions during the 25th hour of this storm. In Table 7 are presented magnitudes and directions of horizontal velocity for the 25^{th} hour of the 1913 storm at seven points in the nearshore region with and without the jetport and changes in these quantities due to the jetport. Points #12,#15,#16, and #19 (Plate #2 and Table 6) are located around the jetport within 2½ miles. For these points the percent change due to the jetport are larger than the three points #13,#17 and #20 which are located along the shoreline. For those points along the shoreline, Point #17 has the largest percent change in magnitude. Considering Points #16 and #17, the jetport definitely increases the horizontal velocity between the jetport and shoreline when the storm surge produces velocities (mass transports) parallel to the shoreline. During peak wind conditions of the severe 1913 storm, the horizontal velocities at all depth levels between jetport and shoreline have maximum increases in magnitude of approximately 25% near the jetport and 10% along the shoreline with 18^{o} and 4^{o} maximum changes in direction, respectively. These maximum changes occur for Point #17 along the shoreline and Point #12 near the jetport. For other locations around the jetport, the percent change can vary from 5-25% with areas of relatively strong upwelling and downwelling existing along the perimeter of the jetport. Along the shoreline, percent changes in magnitude vary from 0.5-10%. Around the jetport and along the shoreline, maximum velocity changes occur nominally at mid-depths of the water column.

25. Effects of the jetport on the horizontal velocity regime for the 1950 and 1973 storms are presented in Tables 8 and 9, respectively. Maximum velocity differences occur around 3 hours for the 1950 storm with 27% and 16° changes near the jetport and 22% and 33° changes along the shoreline. One change in magnitude of 108% is calculated for Point #17 at 15 ft depth in water column; however, this percent change is associated with an 0.5 ft/sec increase in velocity. For the 1950 storm, velocity differences are greatest at mid-depths of the water column. Maximum velocity differences occur around 44 hours for the 1973 storm with 160% and 46° changes near the jetport and 47% and 23° changes along the shoreline. These large percent changes in velocity magnitudes for this storm are associated with relatively small absolute changes of 0.14 ft/sec and 0.12 ft/sec, respectively, near the lake bottom. Disregarding velocity changes near the lake bottom where absolute velocity values are quite small for this storm, all changes in velocity magnitudes and directions are less than 35 percent and 30 degrees, respectively. For this storm, the jetport effects on velocity magnitudes increase with depth in water column.

26. Effects of the jetport on the horizontal velocity are evidenced throughout the water column for all three storms and can be detected to some degree at all depth levels with maximum percent changes occurring nominally at mid-depths. Since the jetport affects basically the net mass transport in the nearshore region, the jetport effects at each depth level is dependent upon the magnitude and direction of the current in

each level and the spatial location relative to the jetport structure. Since the horizontal mass transport is primarily generated by the wind stress (more specifically the curl of the wind stress) associated with the wind field of the storm over the lake, the horizontal velocity regime and perturbations in this regime due to the jetport can vary immensely from storm to storm as well as during the duration of any one storm. From results of numerical storm surge studies for three specific storms, major effects of the jetport on the horizontal velocity regime are confined within 1 to 2 miles of the jetport island with smaller effects extending to the shoreline in the vicinity of Cleveland, Ohio.

PART IV: CONCLUSIONS

27. Numerical simulations of storm surges and horizontal velocity fields associated with three specific storms of 8-9 April 1973, 25-27 November 1950 and 7-10 November 1913 were performed during WES investigation of the effects of a jetport island located approximately four miles offshore of Cleveland, Ohio, on the storm surge in Lake Erie particularly along the shoreline between Lorain and Fairport, Ohio. The above three storms were chosen because of the variation in their severity and wind fields, their movement across Lake Erie, and the availability of prototype data for surge and wind. Results of these numerical simulations are as follow:

a. All jetport effects of an engineering and practical interest on storm surge in Lake Erie are local and are confined within a 15 mile by 15 mile nearshore region.

b. Changes in surge elevations due to the presence of a jetport island are approximately 5 to 15 percent around the jetport island and 1 to 5 percent along the shoreline from Rocky Creek, southwest of Cleveland, to Euclid Creek, northeast of Cleveland, with storm surge along the shoreline outside of these reaches unaffected by a jetport island located four miles offshore.

c. The maximum change, which can be associated with the jetport, in storm surge elevations around the jetport island and along the shoreline was +0.12 feet and was estimated for one of the severest storms, storm of 7-10 November 1913, to occur in the Great Lakes area. For storms of less severity, such as November 1950 and certainly April 1973 storms, the jetport's effect on storm surge elevations are less than one half of those for 1913 storm with maximum changes of 1 to 3 percent along the shoreline.

d. Jetport effects in horizontal velocities associated with storm surges are also confined to a local region in the vicinity of the jetport with major changes of 25 to 30 percent occurring around the jetport island and smaller changes of 10 to 20 percent extending to the shoreline near Cleveland, Ohio.

e. Horizontal velocities between the jetport and shoreline may increase slightly (10-15%) with evidence of maximum percent changes occurring at mid-depths of the water column.

28. Based on above results of this study, it is concluded that a 2 mile by 3 mile jetport island located (Plate 2) in Lake Erie at least four miles offshore of Cleveland, Ohio will have minimal effects on storm surge in Lake Erie. All local effects of engineering interest will occur within 2 miles of the jetport island with smaller effects extending shoreward and occurring along approximately 10 miles of shoreline in the immediate vicinity of Cleveland, Ohio. For the severe storm of 7-10 November 1913, the maximum increase in storm surge elevations along the shoreline is estimated to be less than 0.15 feet. Estimates of jetport effects on the horizontal velocity regime are more subject to error than storm surge estimates; however, relative comparisons of numerical results indicate major changes in horizontal velocity are confined within 2 miles of jetport island with some changes extending to the shoreline. Maximum changes in horizontal velocity occur at mid-depths of the water column, and horizontal velocities between jetport and island may increase slightly.

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Table 1. Summary of Lake Erie and Characteristics

Region	Δx (mile)	Δt (sec)	Dimension (Horizontal)
Nearshore	1	20	16 x 16
Eastern Basin	8	80	11 x 6
Central and Western Basins	4	80	40 x 20

Table 2. Wind Stations

	Wind Data Used for Storms		
Location	1913	1950	1973
Buffalo	x	x	x
Erie	x	Not used	Not used
Cleveland	x	x	x
Toledo	x	x	x
Windsor	Not available	x	x
London	Not available	x	x
Long Point	Not available	x	x

Table 3. Characteristic Parameters

L	Characteristic horizontal length scale	10^7cm(62.1 mi)
H	Reference length scale in z-direction	10^3cm(32.8 ft)
U_{Ref}	Reference velocity in horizontal direction	10 cm/sec(.22 mph)
f	Coriolis parameter	10^{-4}sec^{-1}
τ_{Ref}	Reference wind stress	1 dyne/cm^2

Storm Year	Base Depth, D_b (cm)	Vertical Eddy Viscosity, E_v (cm^2/sec)
1973	148.44	27
1913	53.34	40
1950	47.24	30

Table 4
Gage Locations for Storm Surge Data of 8-10 April 1973

Buffalo

Erie

Cleveland

Toledo

Fermi

Table 5

Maximum Differences (ft) in Surge Elevations Associated with Jetport

Storm	Near Jetport		Along Shoreline	
	Maximum Decrease	Maximum Increase	Maximum Decrease	Maximum Increase
1973	0.009(3%)	0.010(3%)	0.005(1%)	0.005(1%)
1950	0.036(4%)	0.044(5%)	0.02(3%)	0.03(3%)
1913	0.06(15%)	0.12(6%)	0.04(25%)	0.12(6%)

Table 6

Special Pt	Grid	Indices (I,3)	Location
1	8 mi grid of Eastern Basin	11,3	Buffalo
2	8 mi grid of Eastern Basin	2,2	Erie
3	8 mi grid of Eastern Basin	4,5	Long Point
4	4 mi grid of Central/Western Basin	7,20	Windsor
5	4 mi grid of Central/Western Basin	5,19	Fermi
6	4 mi grid of Central/Western Basin	2,18	Toledo
7	4 mi grid of Central/Western Basin	14,6	Lorain
8	4 mi grid of Central/Western Basin	16,4	Rocky River
9	4 mi grid of Central/Western Basin	22,4	Willowick
10	4 mi grid of Central/Western Basin	24,4	Fairport
11	4 mi grid of Central/Western Basin	20,10	30 mi NNW of Cleveland
12	1 mi grid of Nearshore Region	5,7	2½ mi WSW of island
13	1 mi grid of Nearshore Region	5,3	4 mi WSW of Cleveland
14	1 mi grid of Nearshore Region	7,5	1½ mi S of island
15	1 mi grid of Nearshore Region	9,11	2½ mi NNW of island
16	1 mi grid of Nearshore Region	9,5	1½ mi SSW of island
17	1 mi grid of Nearshore Region	9,3	Cleveland
18	1 mi grid of Nearshore Region	11,5	1½ mi SE of island
19	1 mi grid of Nearshore Region	13,7	2½ mi ENE of island
20	1 mi grid of Nearshore Region	13,3	4 mi ENE of Cleveland

Table 7. Difference in Horizontal Velocity for 25th Hour of 1913 Storm Simulation

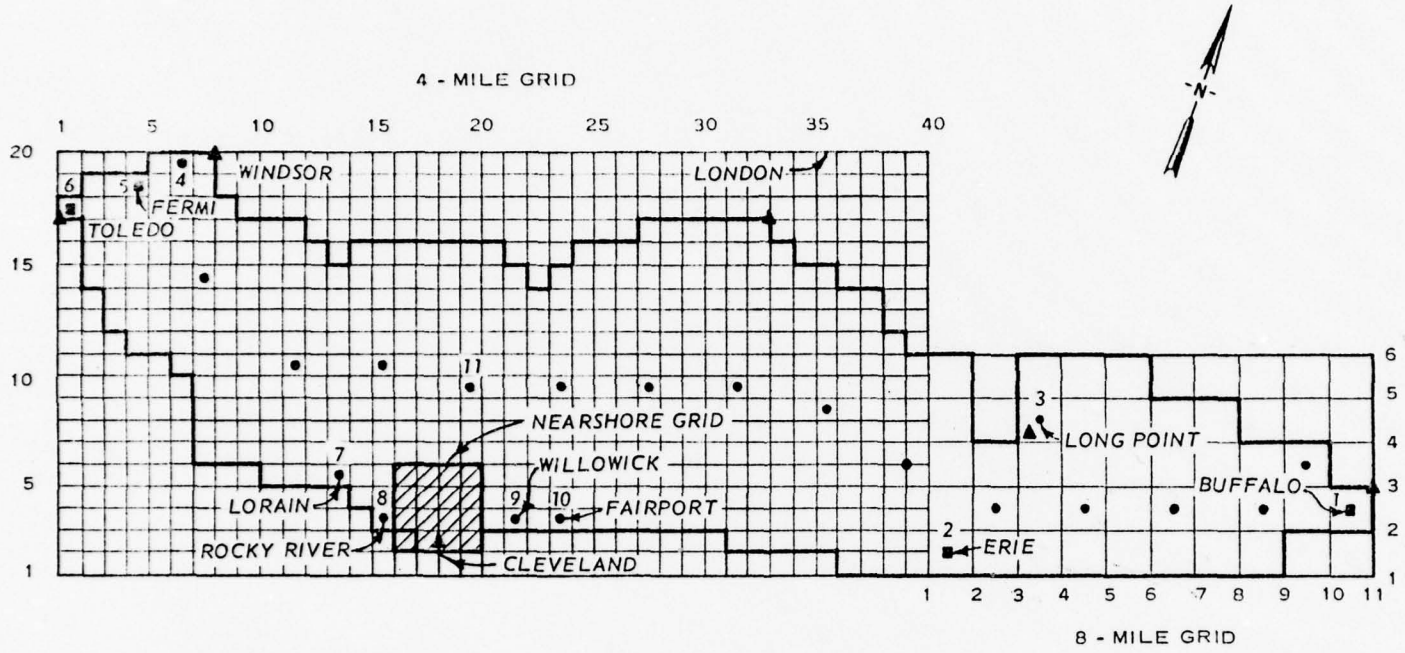
Points		Depth Levels in Water Column									
		0 ft.		10 ft.		15 ft.		20 ft.		30 ft.	
No.	Indices	Mag (%)	Dir (deg)	Mag	Dir	Mag	Dir	Mag	Dir	Mag	Dir
12	5,7	7.40	1.03	14.6	1.06	26.13	-8.59	5.58	-17.8	-2.90	-12.28
13	5,3	-0.60	0.02	-0.94	0.02	-1.51	0.03	-2.09	0.17	-2.98	0.60
15	9,11	-4.00	-1.23	-9.08	-1.84	-15.82	3.11	-6.69	6.14	-2.74	5.07
16	9,5	-7.30	-2.21	-12.85	-2.33	-23.85	1.28	-19.37	8.71	-9.79	9.86
17	9,3	-4.58	-0.84	-7.08	-0.67	-8.86	0.40	-10.10	2.32	-8.72	3.72
19	13,7	3.74	0.85	7.39	0.46	9.48	-2.98	5.39	-4.90	3.07	-4.46
20	13,3	-1.25	-0.47	-2.30	-0.97	-3.55	-0.45	-3.46	0.59	-2.81	1.19

Table 8. Differences in Horizontal Velocity for 30th Hour of 1950 Storm Simulation

Points		Depth Levels in Water Column									
		0 ft.		10 ft.		15 ft.		20 ft.		30 ft.	
No.	Indices	Mag (%)	Dir (deg)	Mag	Dir	Mag	Dir	Mag	Dir	Mag	Dir
12	5,7	-4.48	-11.69	18.06	-16.12	23.47	-3.76	19.45	-0.01	17.82	1.08
13	5,3	0.25	-32.80	0.21	-0.29	2.97	-0.23	0.05	-0.61	0.14	-10.72
15	9,11	-3.89	4.31	-11.2	2.55	-10.45	-0.76	-8.54	-1.84	-7.99	-1.97
16	9,5	-6.62	10.15	-26.3	7.97	-27.08	-0.74	-20.83	-3.70	-18.34	-4.70
17	9,3	1.92	6.84	-2.5	17.51	-108.00	-5.34	-22.24	-13.29	-12.92	-10.37
19	13,7	0.11	-4.8	7.43	-5.35	9.91	-1.81	9.05	0.17	8.64	1.12
20	13,3	-2.35	2.35	-12.22	3.88	-6.88	-6.41	-1.18	-4.53	0.49	-3.72

Table 9. Differences in Horizontal Velocity for 44th Hour of 1973 Storm Simulation

Points		Depth Levels in Water Column									
		0 ft.		10 ft.		15 ft.		20 ft.		30 ft.	
No.	Indices	Mag (%)	Dir (deg)	Mag	Dir	Mag	Dir	Mag	Dir	Mag	Dir
12	5,7	6.84	-.66	13.24	.90	22.00	6.79	25.33	27.81	-45.45	45.43
13	5,3	-2.33	1.29	-6.06	1.62	-10.05	-1.83	-4.96	-4.44	-.30	-4.02
15	9,11	-4.23	.24	-7.53	-.28	-13.65	-1.20	-28.15	-1.88	-50.32	9.82
16	9,5	-8.17	.57	-16.14	-.09	-31.80	-1.69	-75.16	-1.65	-159.89	46.35
17	9,3	-6.75	.67	-12.34	.59	-19.70	-.13	-29.25	-.98	-46.77	-.92
19	13,7	3.99	-.04	7.53	.34	13.03	.72	24.30	-3.04	19.11	-17.03
20	13,3	-1.06	-.63	-2.02	-1.41	-4.01	-3.26	-14.43	-8.85	-21.62	22.74



LEGEND

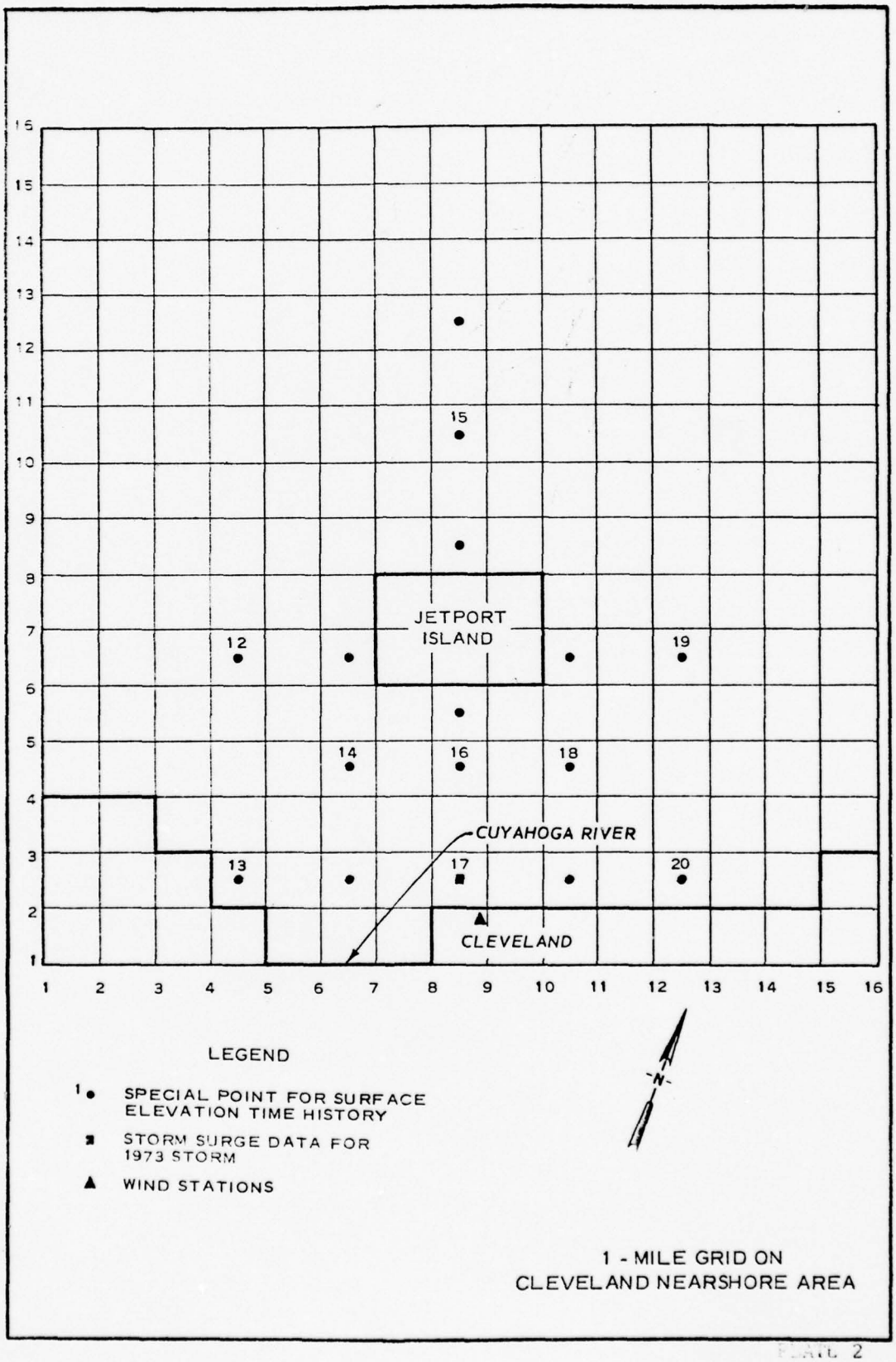
1 ● SPECIAL POINT FOR SURFACE ELEVATION TIME HISTORY

■ STORM SURGE DATA FOR 1973 STORM

▲ WIND STATIONS

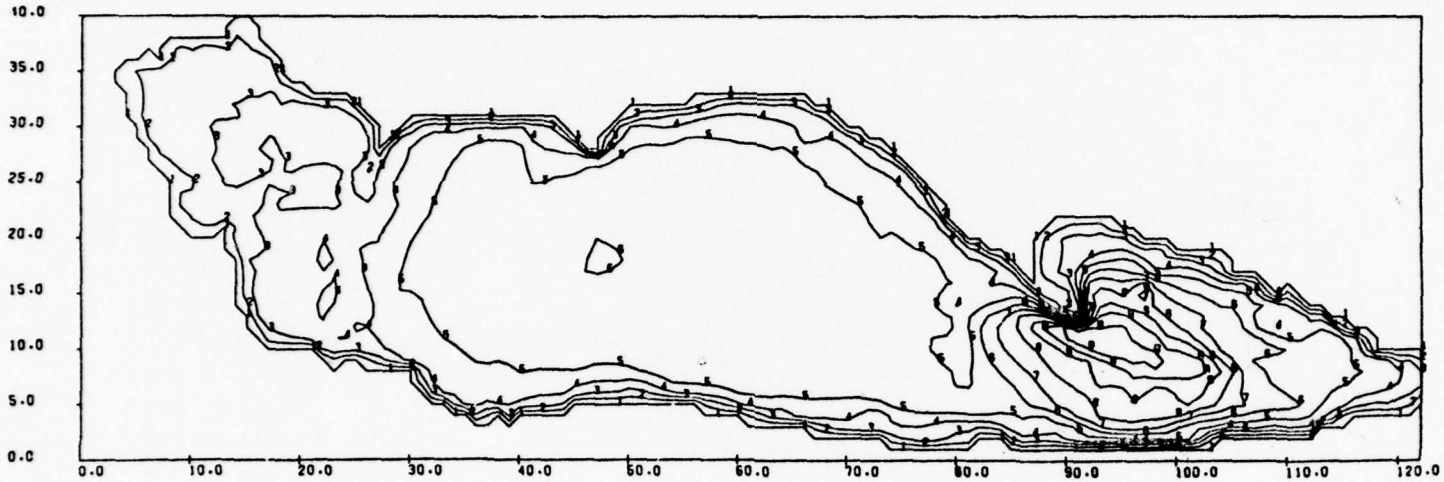
DISCRETIZATION OF LAKE ERIE INTO A 4- AND 8-MILE GRID

PLATE 1



1 - MILE GRID ON
CLEVELAND NEARSHORE AREA

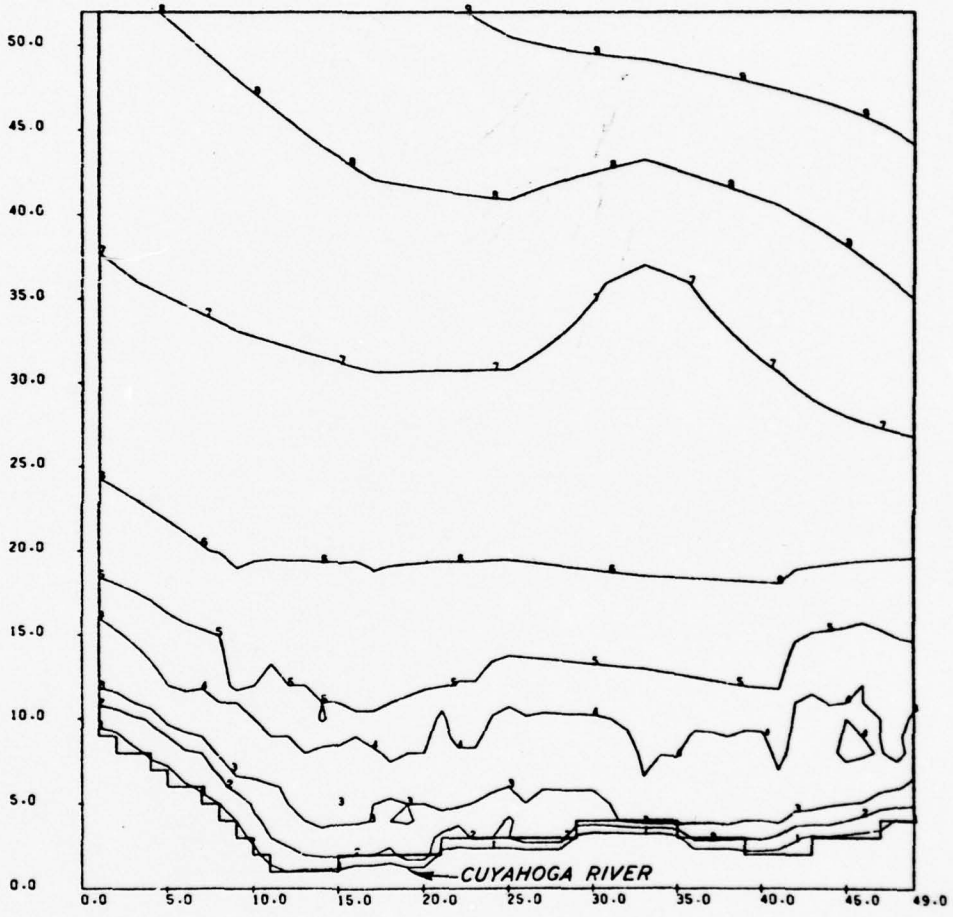
Part 2



SYMBOLS	CONTOURS, FT
1	0.100
2	15.000
3	30.000
4	45.000
5	60.000
6	80.000
7	100.000
8	120.000
9	140.000
A	160.000
B	180.000

BOTTOM TOPOGRAPHY FOR
LAKE ERIE 4-MILE GRID

PLATE 3



SYMBOLS	CONTOURS, FT
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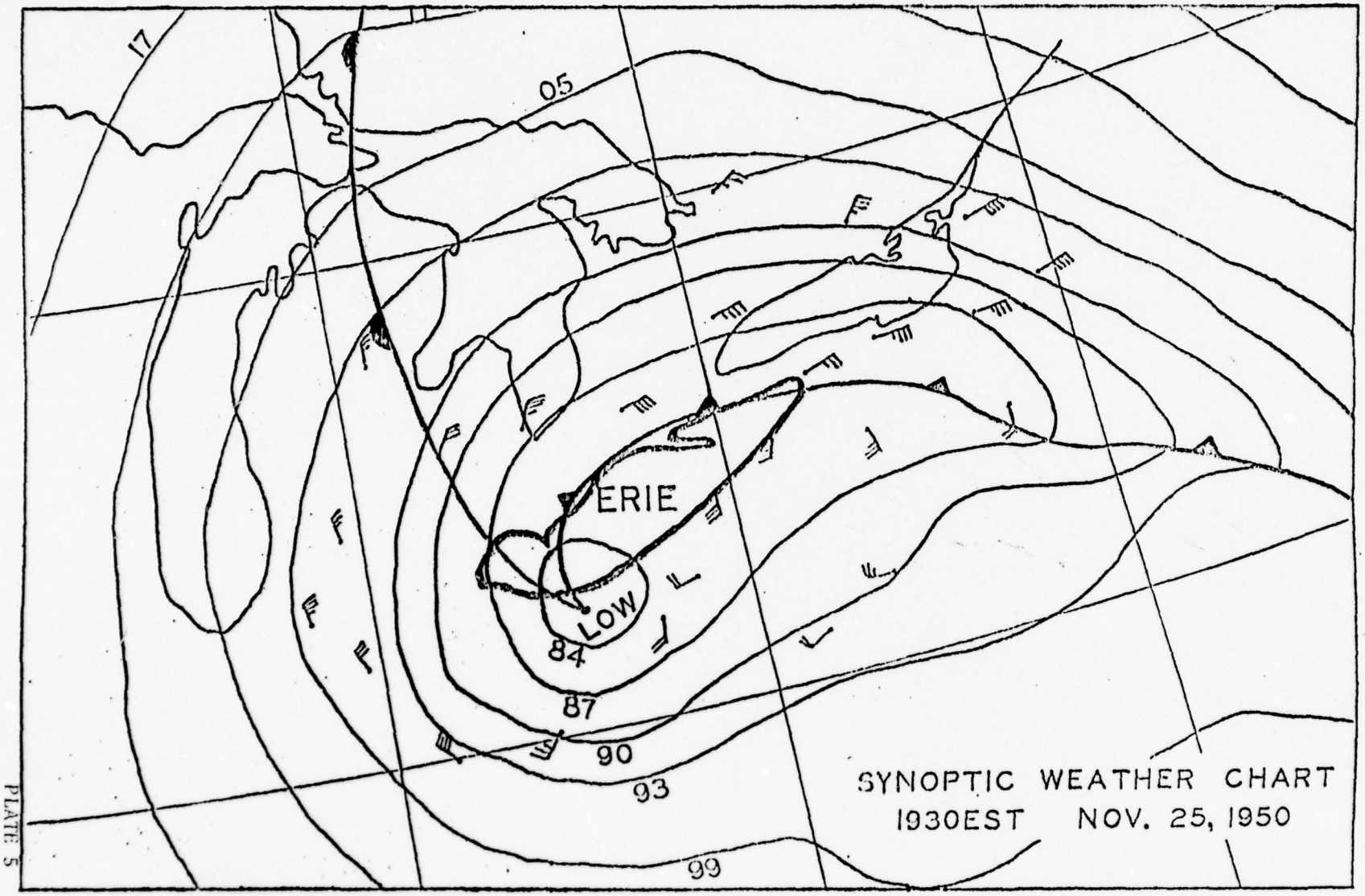
2	20.000
3	30.000
4	40.000
5	45.000
6	50.000
7	55.000
8	60.000
9	65.000

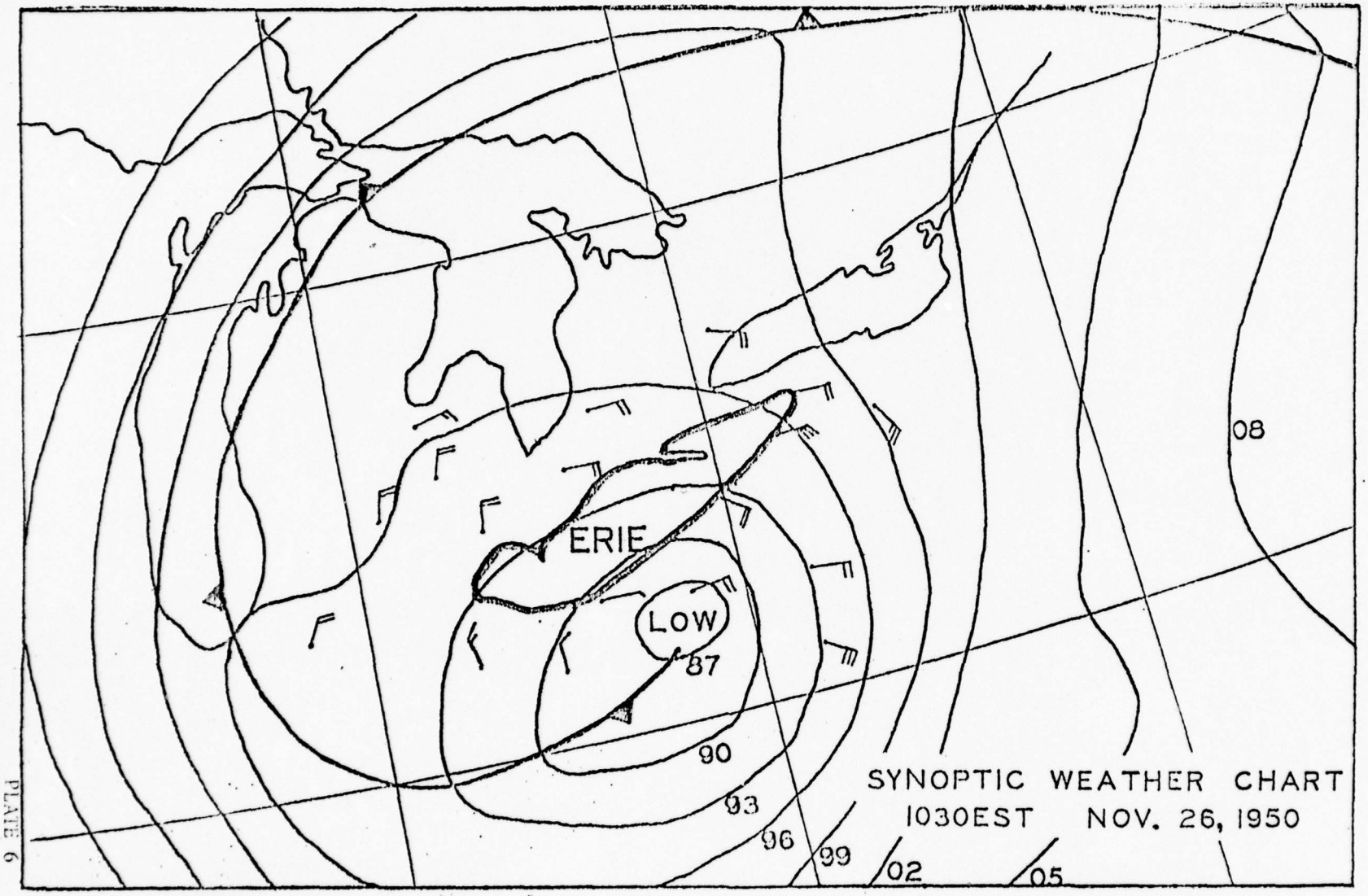
BOTTOM TOPOGRAPHY FOR
CLEVELAND NEARSHORE AREA

PLATE 4



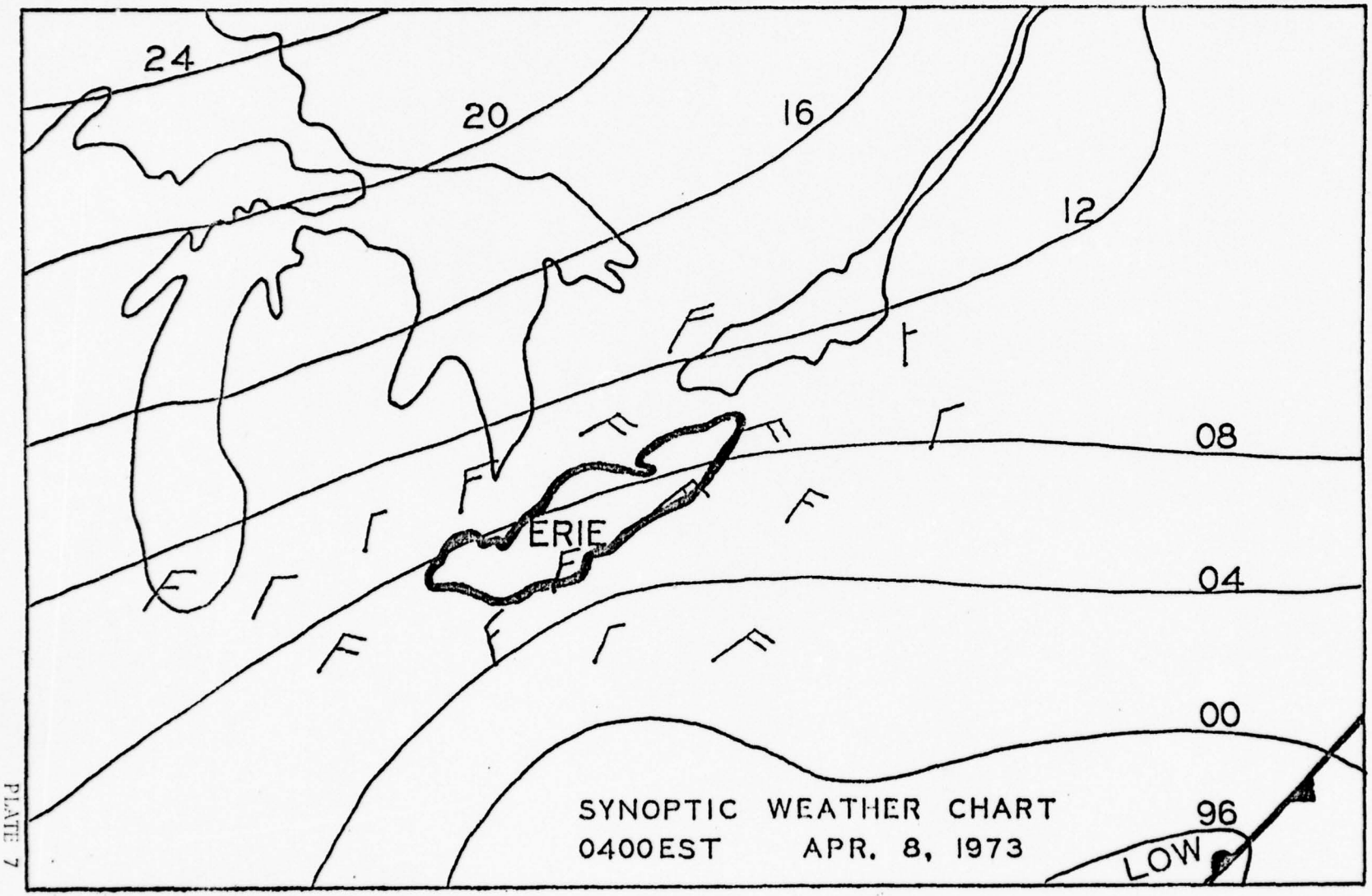
SYNOPTIC WEATHER CHART
1930EST NOV. 25, 1950

PLATE 5



SYNOPTIC WEATHER CHART
1030EST NOV. 26, 1950

PLATE 9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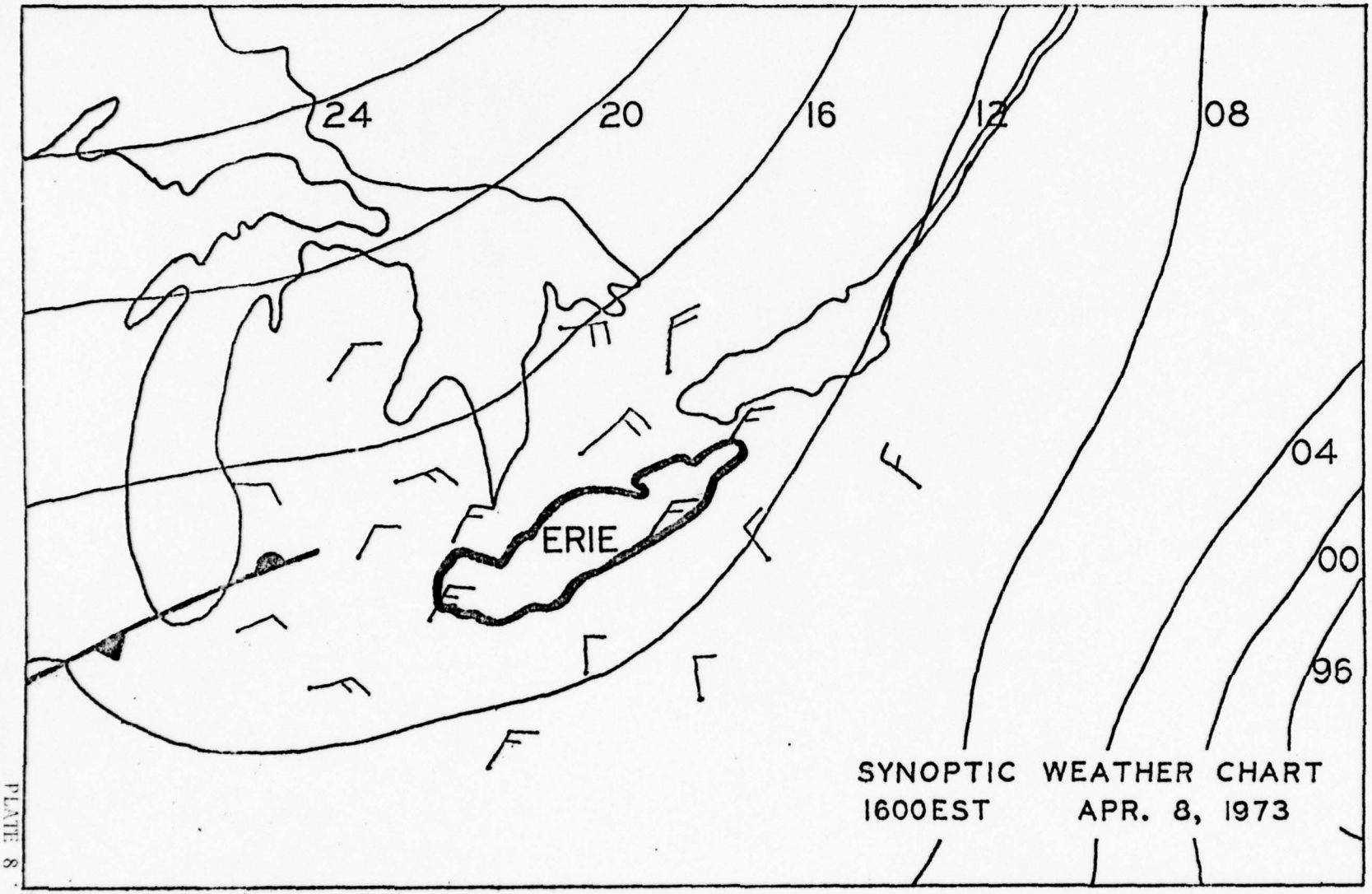
ERIE
LOW
SYNOPTIC WEATHER CHART
0400EST APR. 8, 1973

PLATE 7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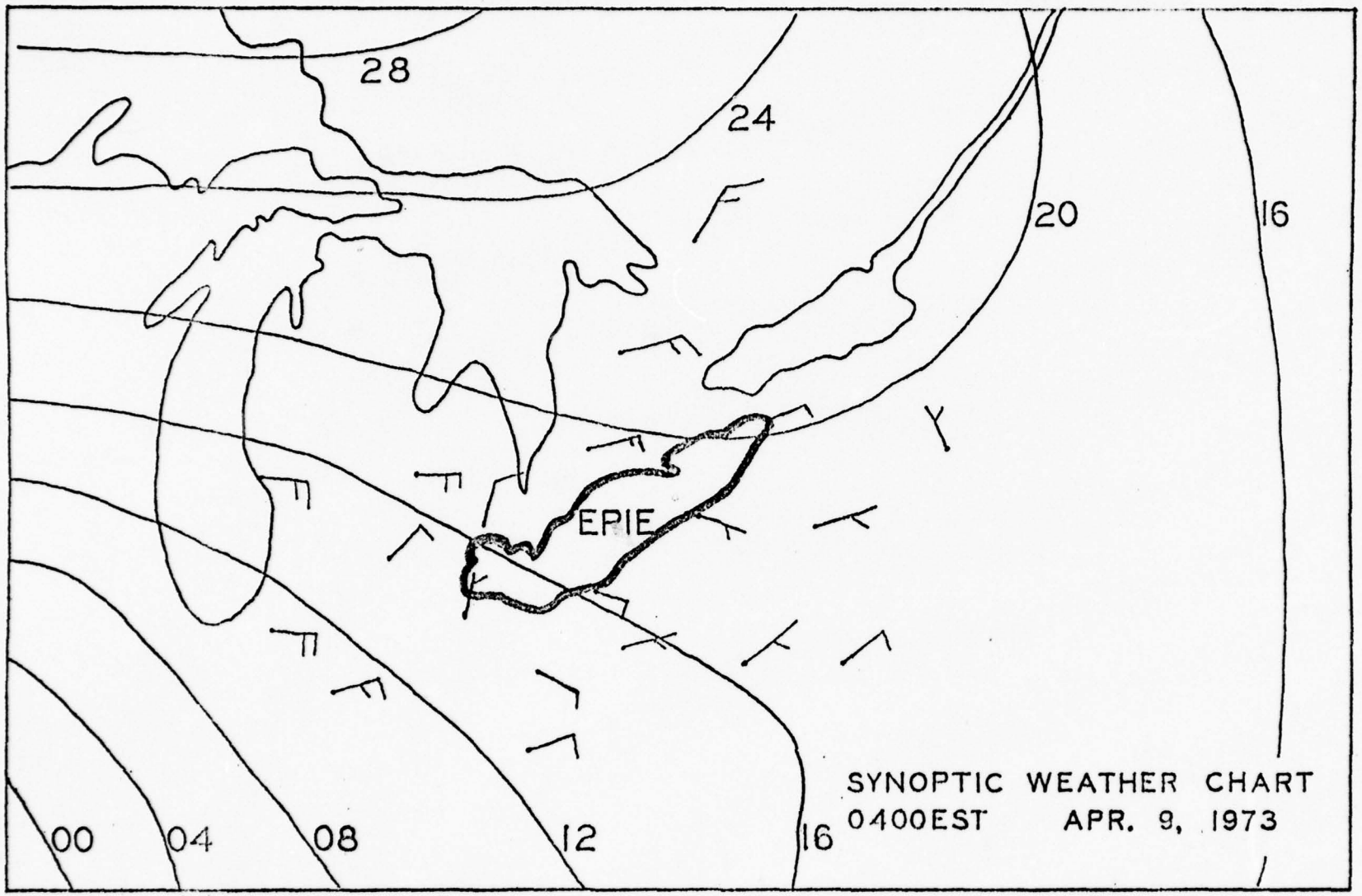
SYNOPTIC WEATHER CHART
1600EST APR. 8, 1973

PLATE 8


28
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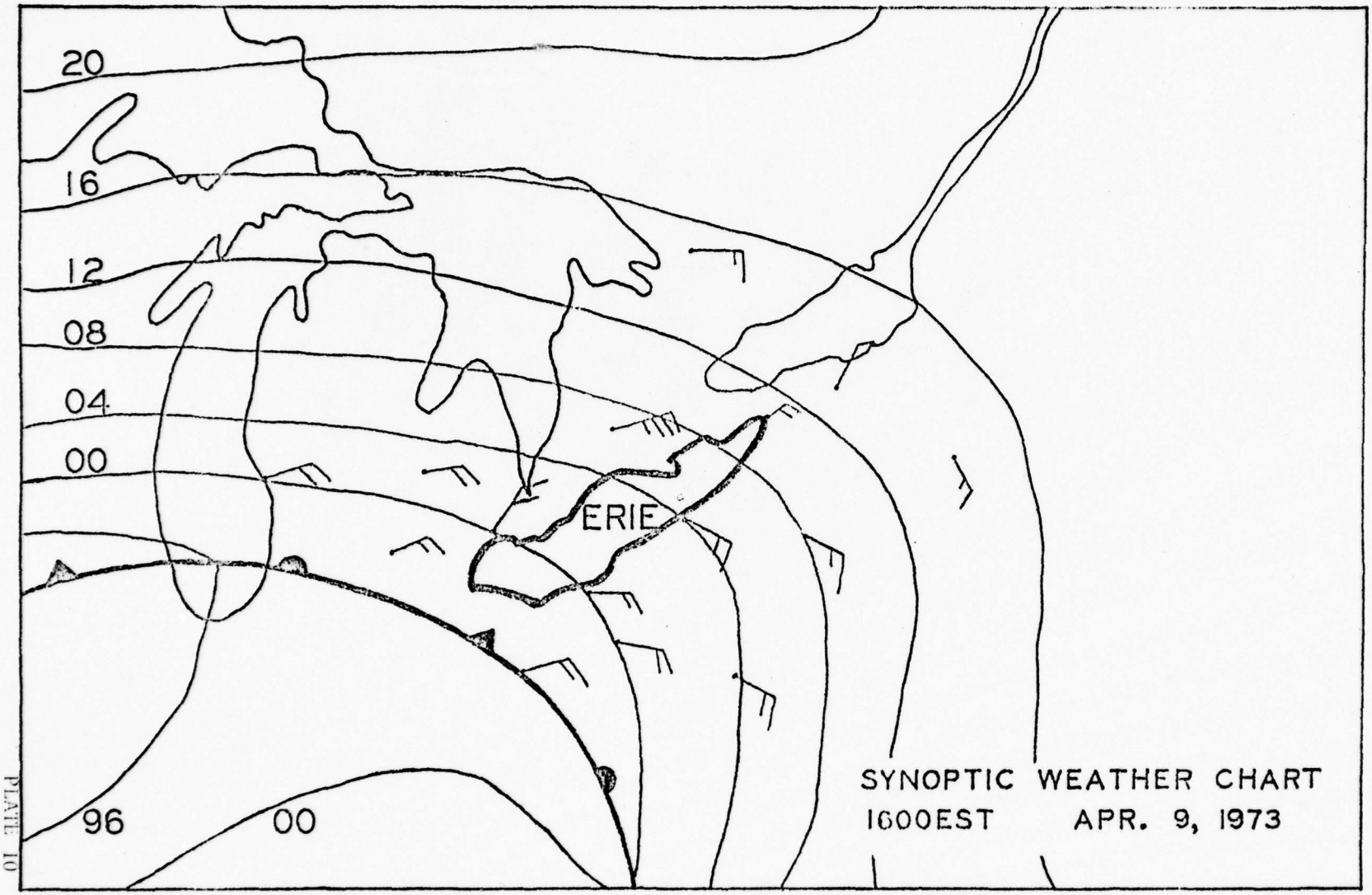
SYNOPTIC WEATHER CHART
0400EST APR. 9, 1973

PLATE 9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16
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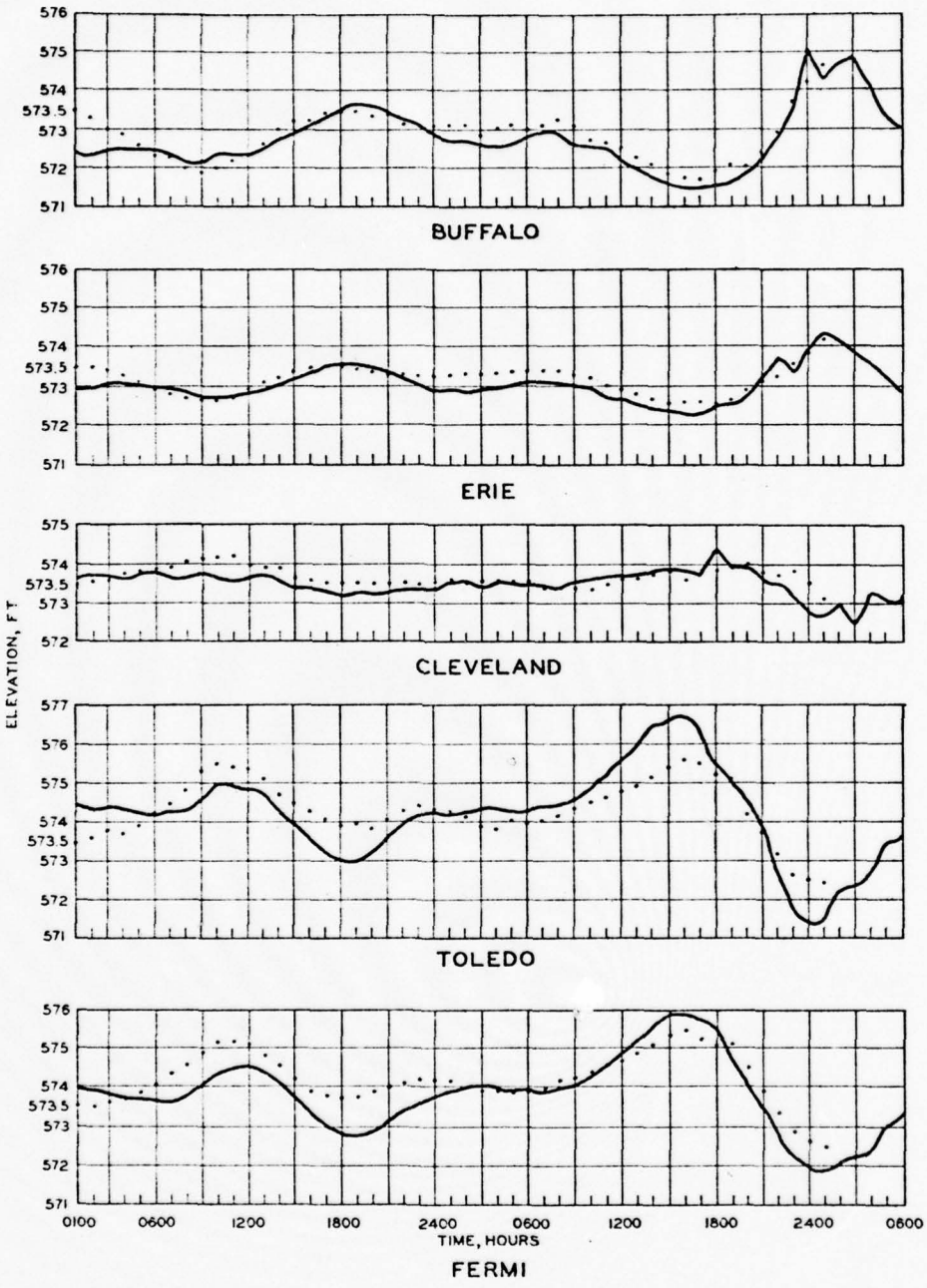
SYNOPTIC WEATHER CHART
1600EST APR. 9, 1973

PLATE 10



COMPARISON OF STORM SURGE ELEVATIONS

PLATE 11

APPENDIX A: Notation

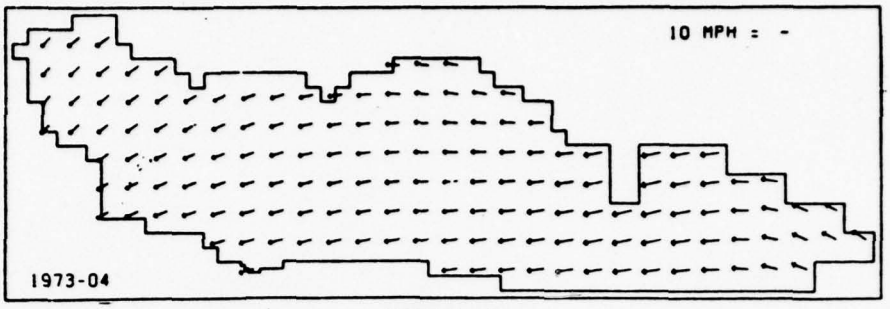
NOTATION

E_v	Vertical eddy viscosity coefficient
h	Lake depth
u	Horizontal velocity in x direction at given depth
U	Vertically integrated velocity component in the direction of the x axis
v	Horizontal velocity in y direction at given depth
V	Vertically integrated velocity component in the direction of the y axis
w	Vertical component of velocity
W_a	Wind velocity
x,y	Horizontal coordinates
η	Displacement of water surface from still lake level
σ	Vertically stretched coordinate
ω	Vertical velocity along stretched coordinate
ρ_a	Density of air
τ	Wind stress

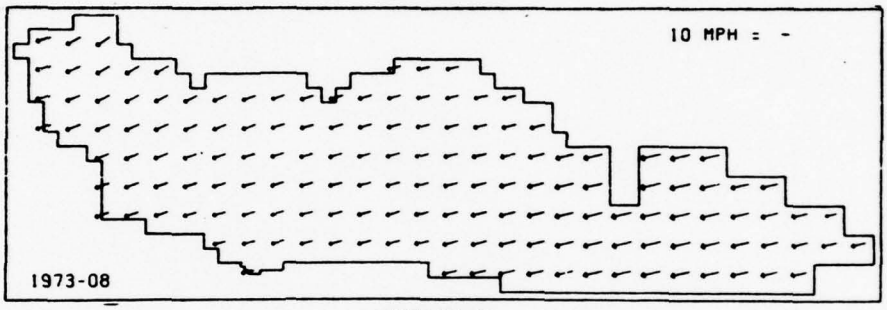
APPENDIX B: Interpreted Velocity (MPH) of Wind Field Over Lake

Inclosure 1: 8-9 April 1973 Storm
Inclosure 2: 25-27 November 1950 Storm
Inclosure 3: 7-10 November 1913 Storm

Inclosure 1: 8-9 April 1973 Storm



HOUR 4



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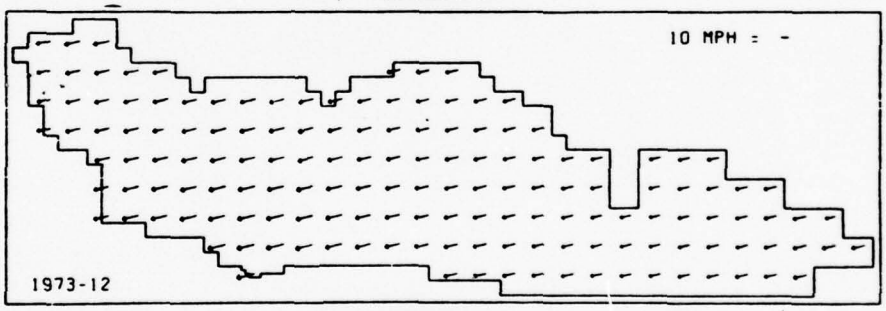

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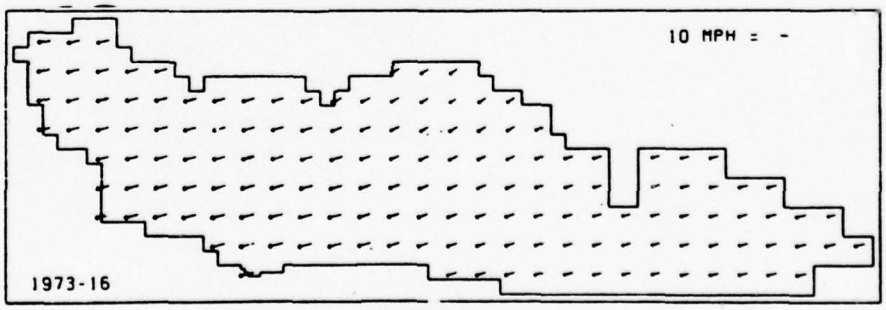
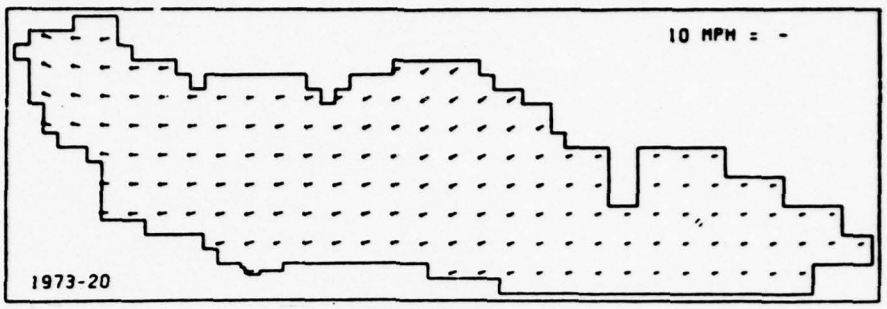


HOUR 16

INTERPRETED VELOCITY (MPH) OF WIND FIELD OVER LAKE

4, 8, 12, AND 16 HOURS INTO STORM OF 0100 APR 8 - 2400 APR 9, 1973



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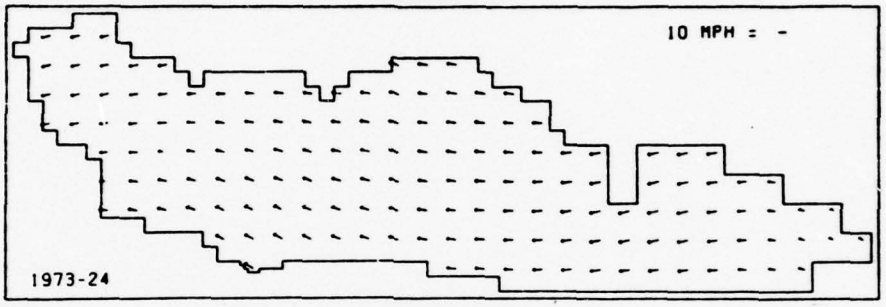

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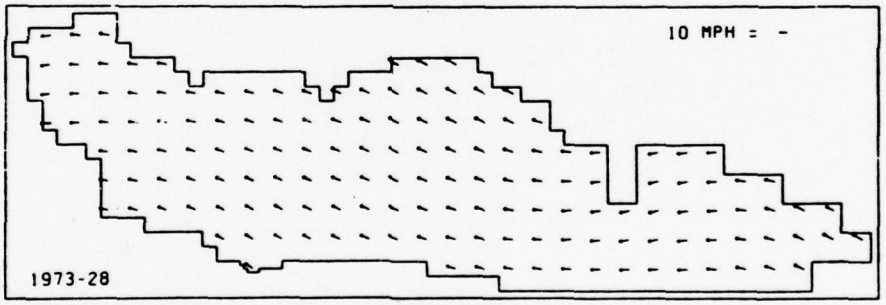

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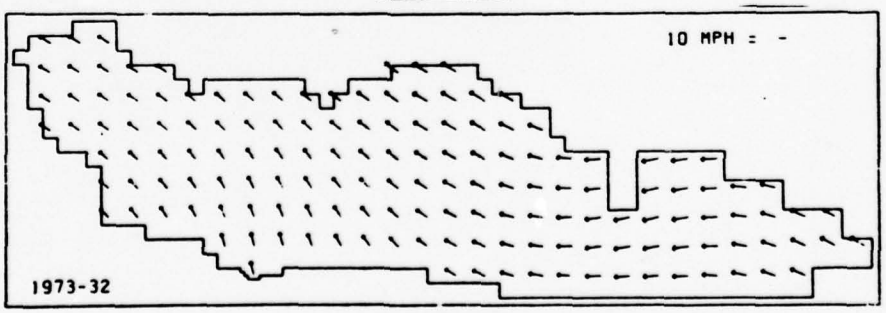
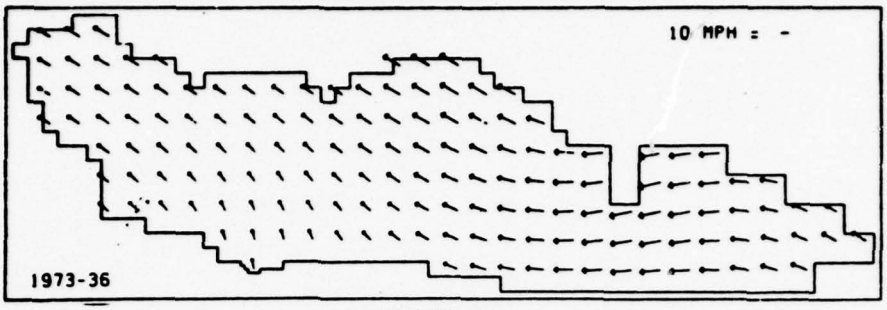


HOUR 32

INTERPRETED VELOCITY (MPH)
OF WIND FIELD OVER LAKE
20, 24, 28, AND 32 HOURS INTO STORM OF
0100 APR 8 - 2400 APR 9, 1973



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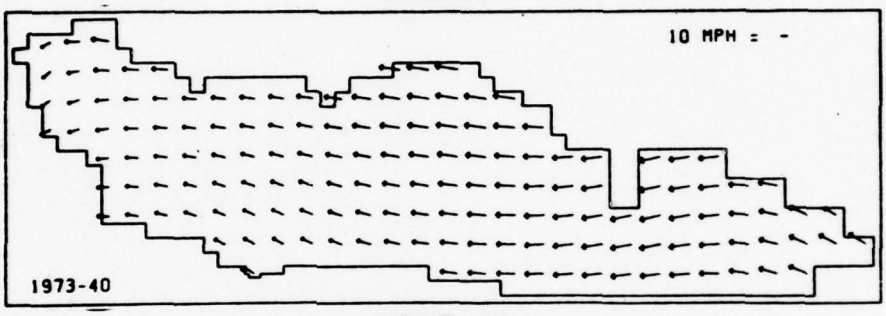

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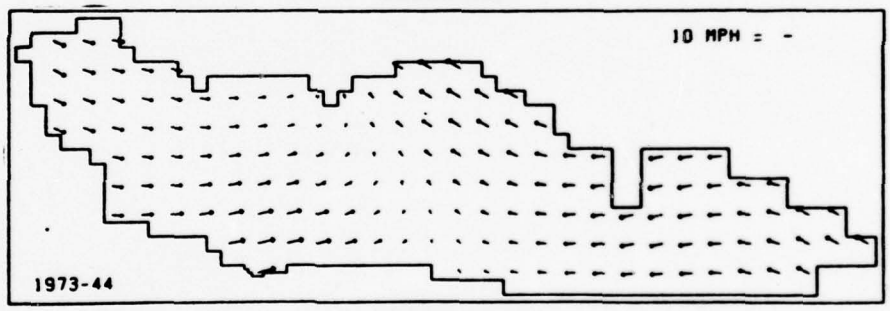

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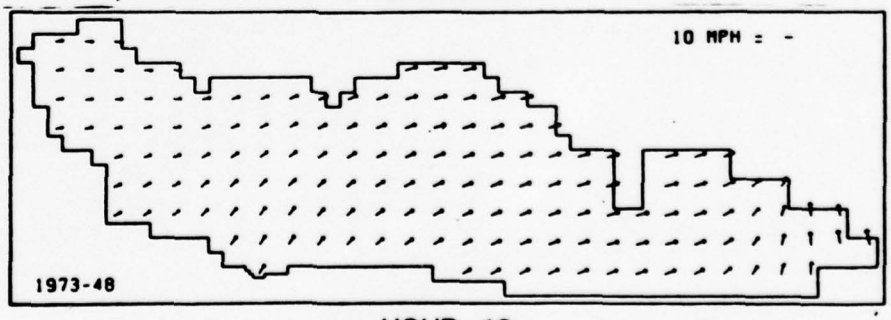
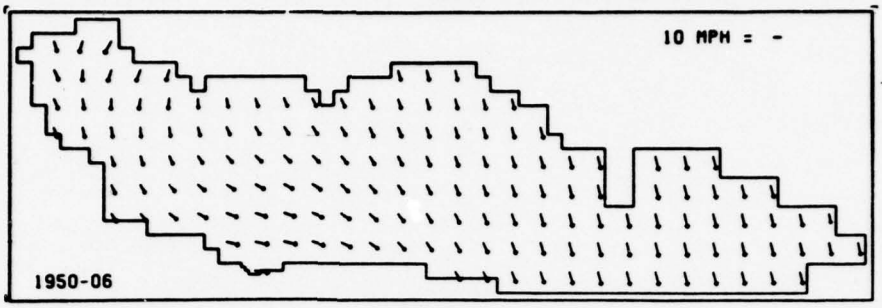


HOUR 48

INTERPRETED VELOCITY (MPH)
OF WIND FIELD OVER LAKE
36, 40, 44, AND 48 HOURS INTO STORM OF
0100 APR 8 - 2400 APR 9, 1973

Inclosure 2: 25-27 November 1950 Storm



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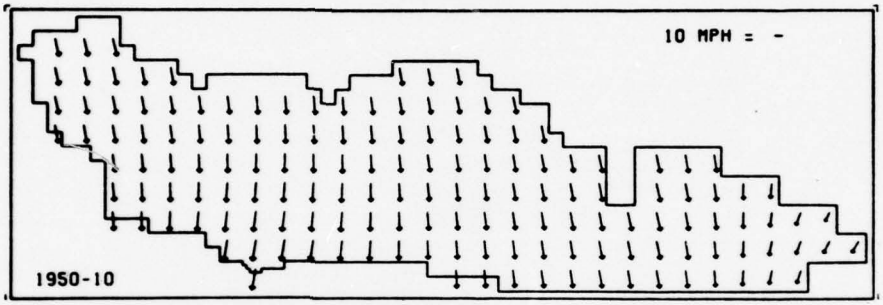

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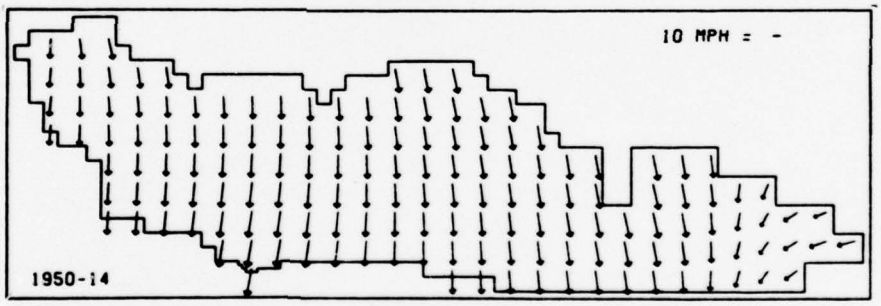

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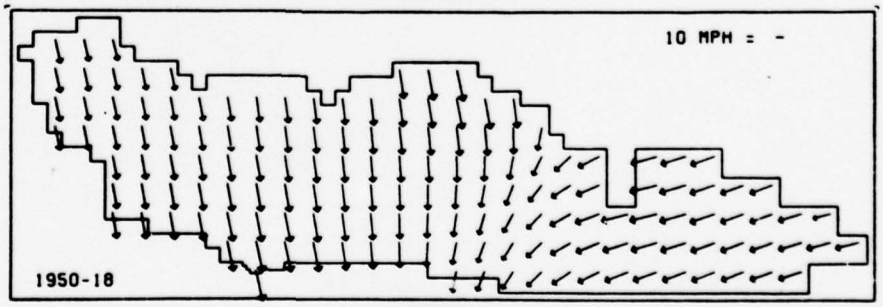
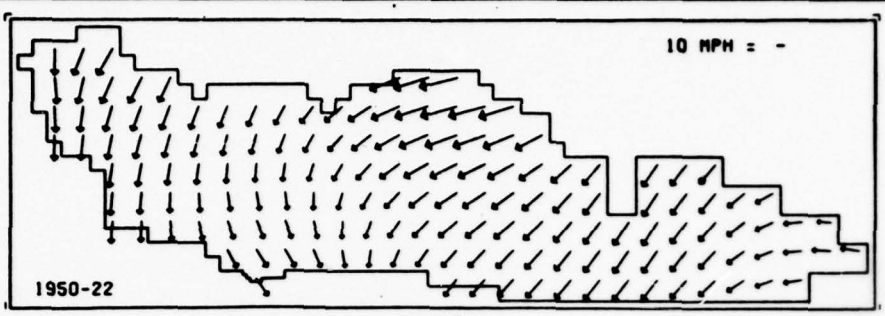


HOUR 18

INTERPRETED VELOCITY (MPH)
OF WIND FIELD OVER LAKE
6, 10, 14, AND 18 HOURS INTO STORM OF
1700 NOV 24 - 1000 NOV 26, 1950



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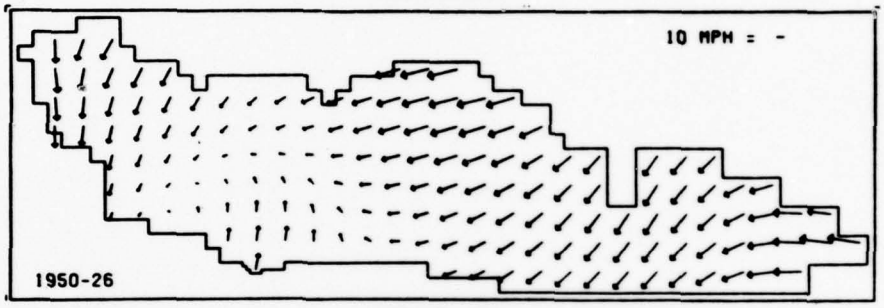

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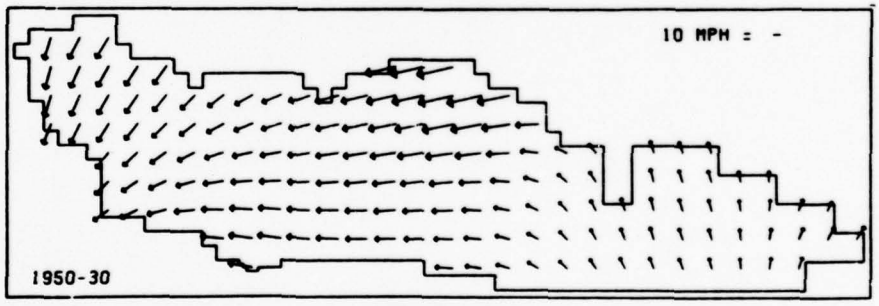

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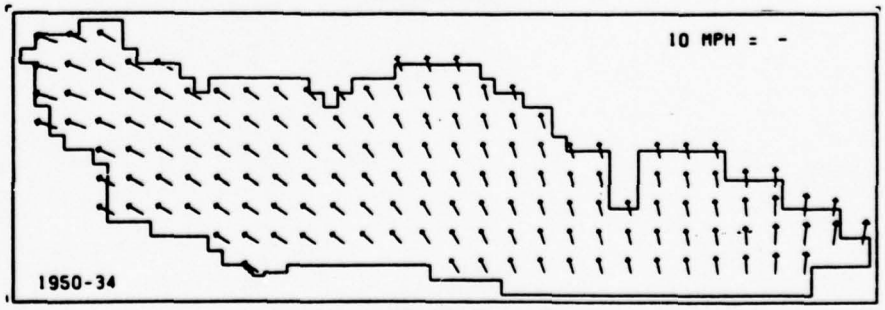
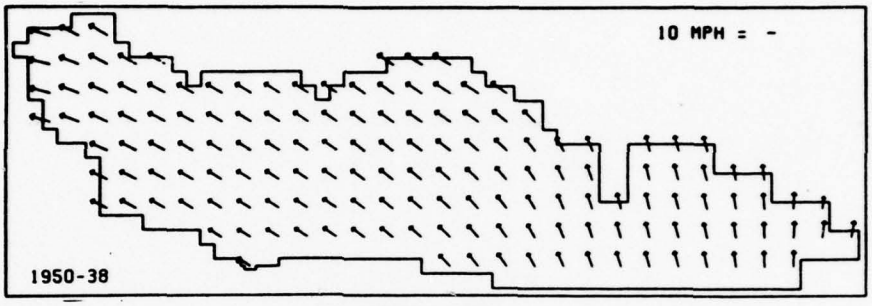


HOUR 34

INTERPRETED VELOCITY (MPH)
OF WIND FIELD OVER LAKE
22, 26, 30, AND 34 HOURS INTO STORM OF
1700 NOV 24 - 1000 NOV 26, 1950



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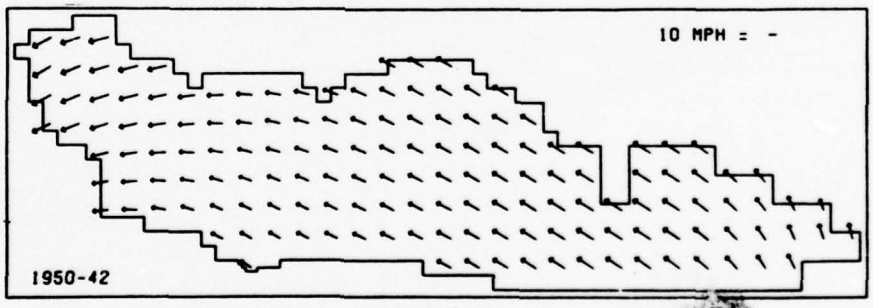
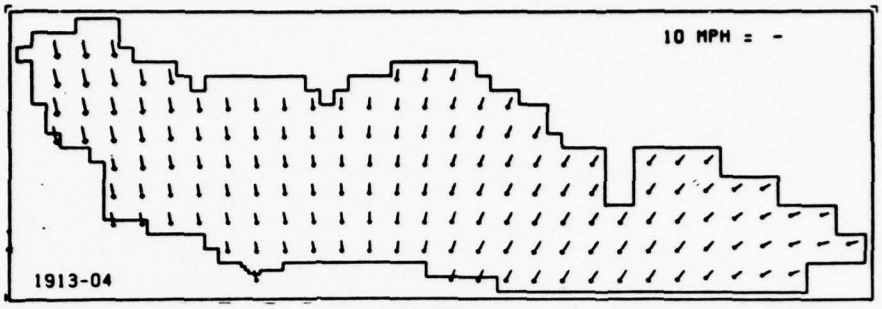


HOUR 42

INTERPRETED VELOCITY (MPH)
OF WIND FIELD OVER LAKE
38, AND 42 HOURS I[illegible] STORM OF
1700 NOV 24 - 100[illegible] OV 26, 1950

Inclosure 3: 7-10 November 1913 Storm



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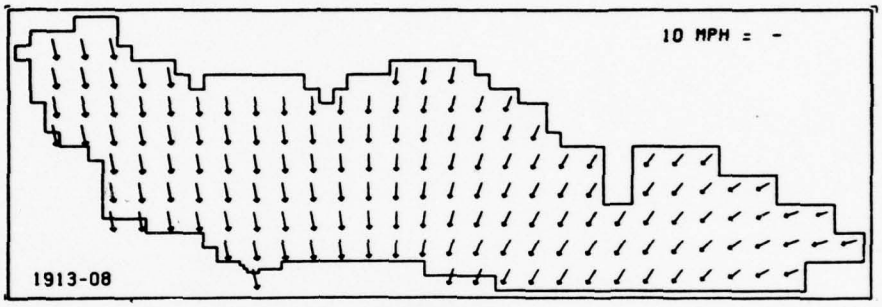

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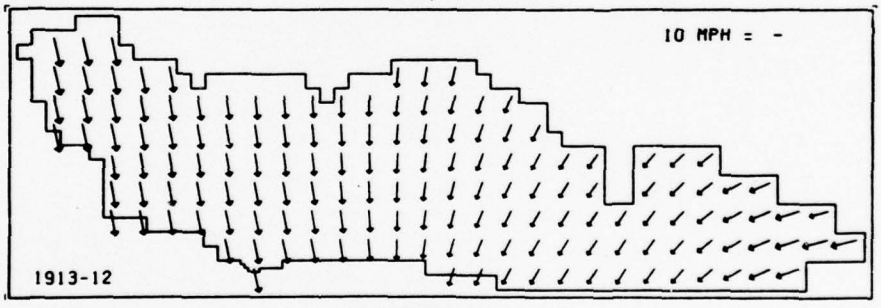

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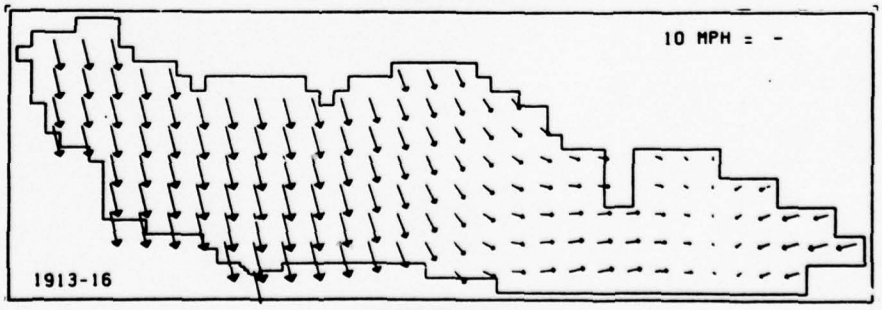
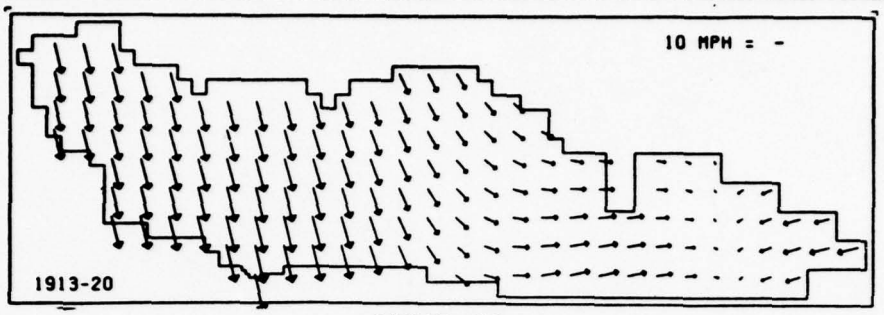


HOUR 16

INTERPRETED VELOCITY (MPH)
OF WIND FIELD OVER LAKE
4, 8, 12, AND 16 HOURS INTO STORM OF
0000 NOV 9 - 2300 NOV 10, 1913



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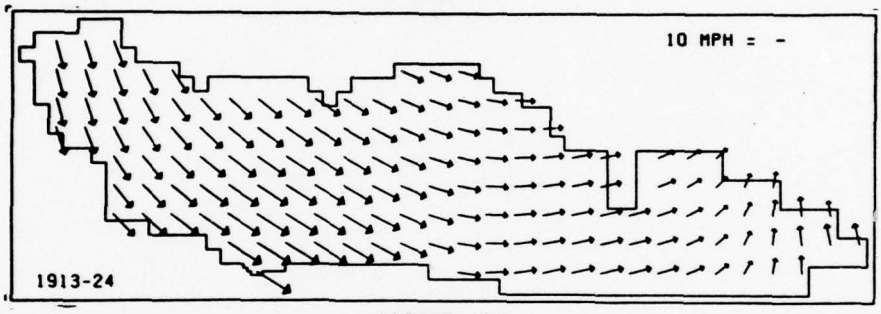

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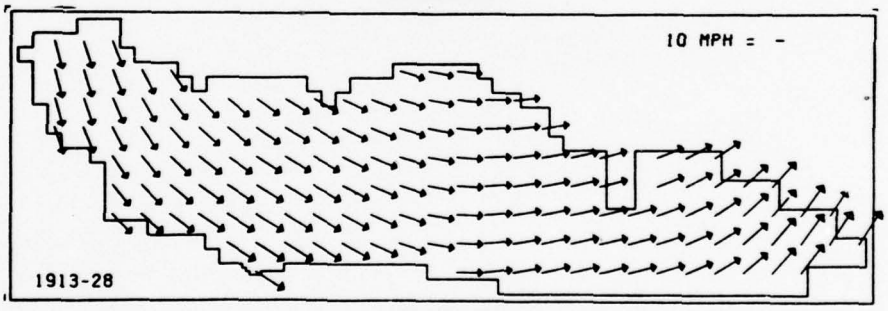

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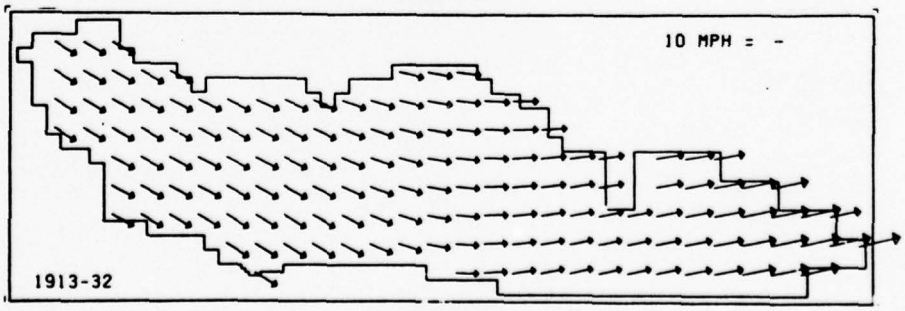
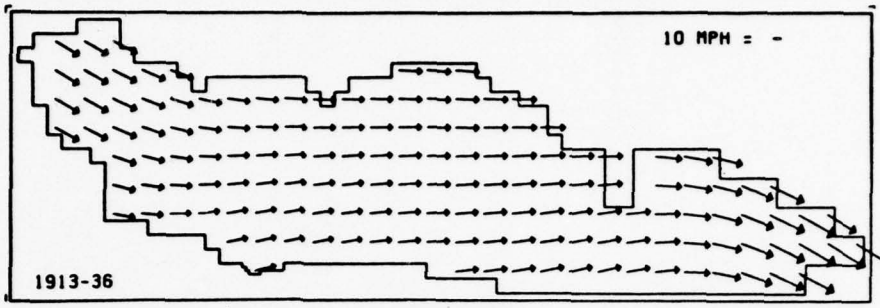


HOUR 32

INTERPRETED VELOCITY (MPH)
OF WIND FIELD OVER LAKE
20, 24, 28, AND 32 HOURS INTO STORM OF
0000 NOV 9 - 2300 NOV 10, 1913



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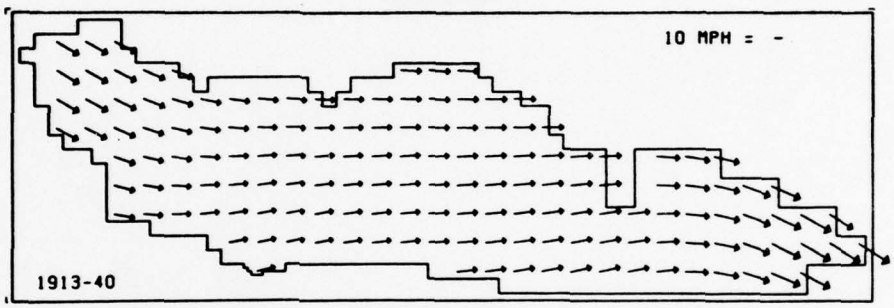

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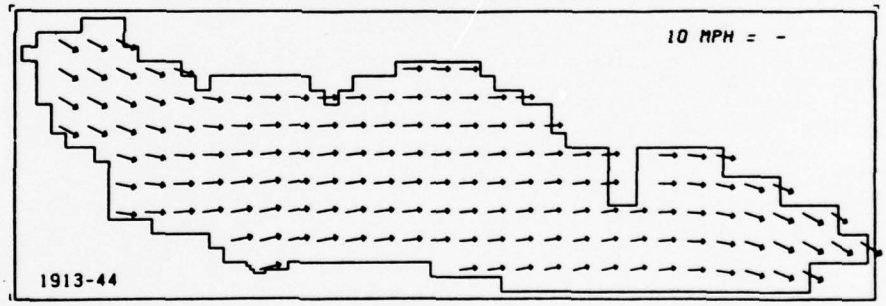
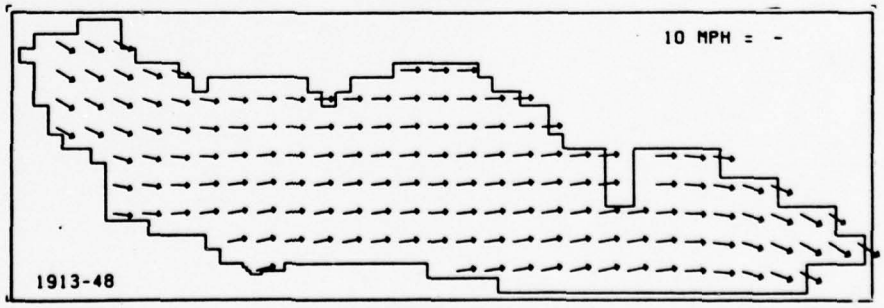


HOUR 44



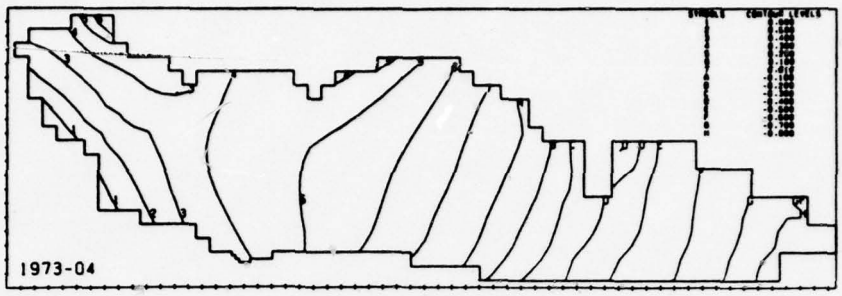
HOUR 48

INTERPRETED VELOCITY (MPH)
OF WIND FIELD OVER LAKE
36, 40, 44, AND 48 HOURS INTO STORM OF
0000 NOV 9 - 2300 NOV 10, 1913

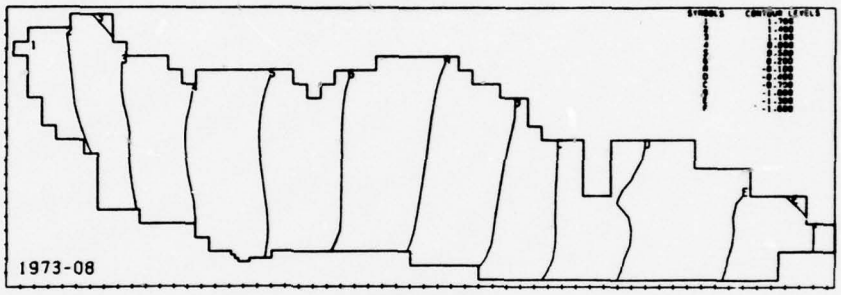
APPENDIX C: Contours of Storm
Surge Elevations for Full Lake

Inclosure 1: 8-9 April 1973 Storm
Inclosure 2: 25-27 November 1950 Storm
Inclosure 3: 7-10 November 1913 Storm

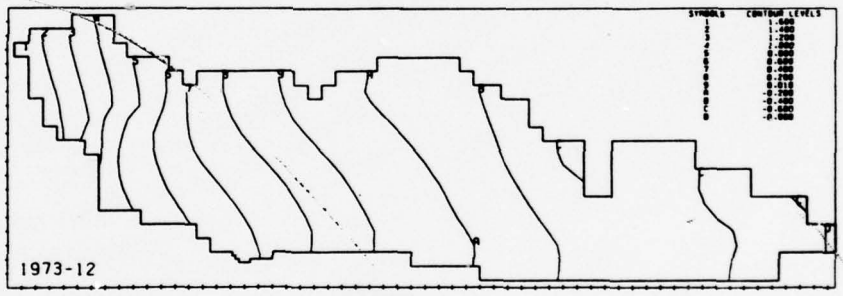
Inclosure 1: 8-9 April 1973 Storm



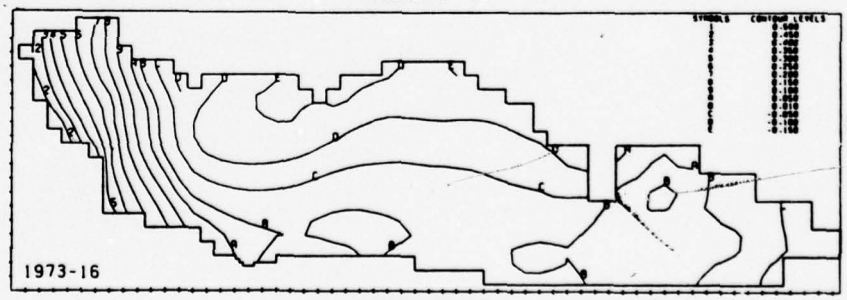
HOUR 4



HOUR 8



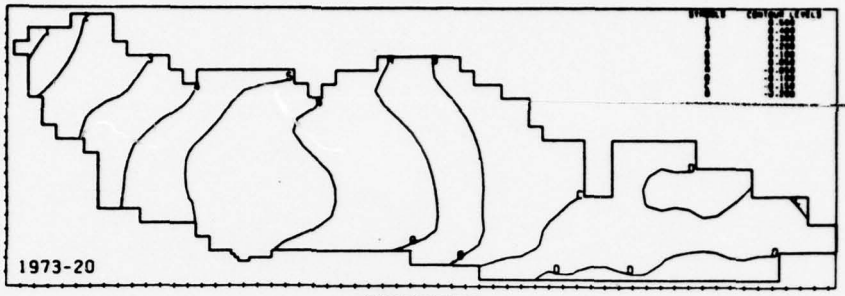
HOUR 12



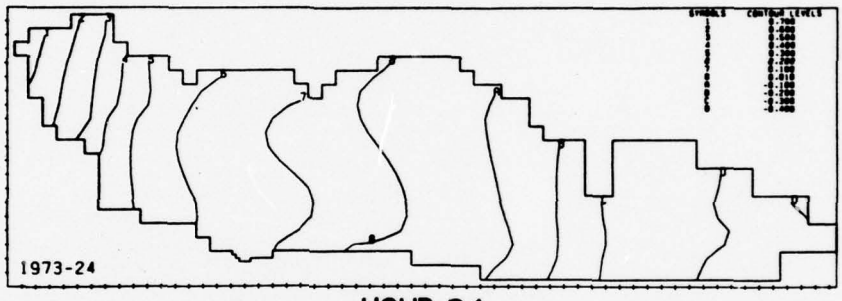
HOUR 16

CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

4, 8, 12, AND 16 HOURS INTO STORM OF 0100 APR 8 – 2400 APR 9, 1973



HOUR 20



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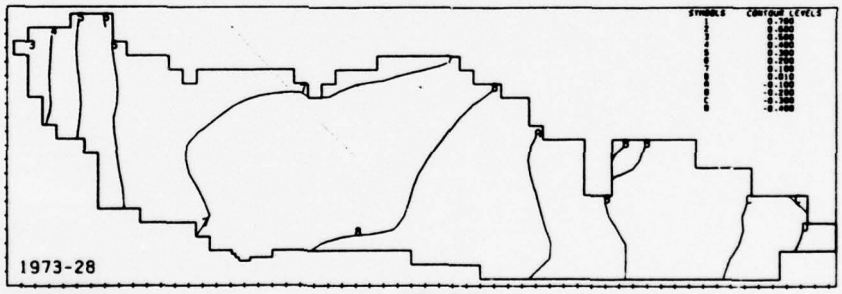
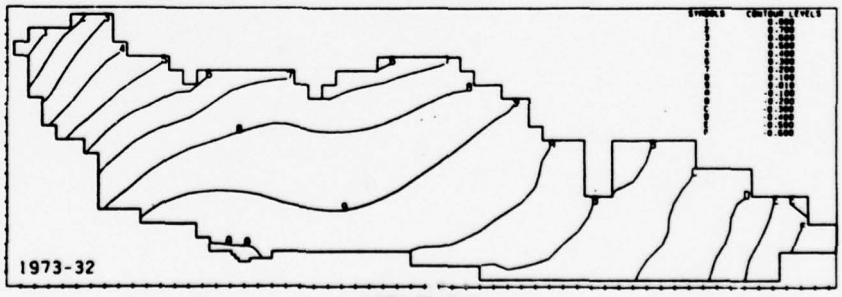


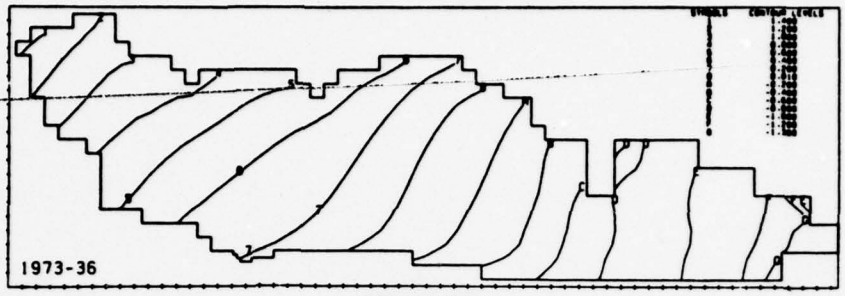
HOUR 28



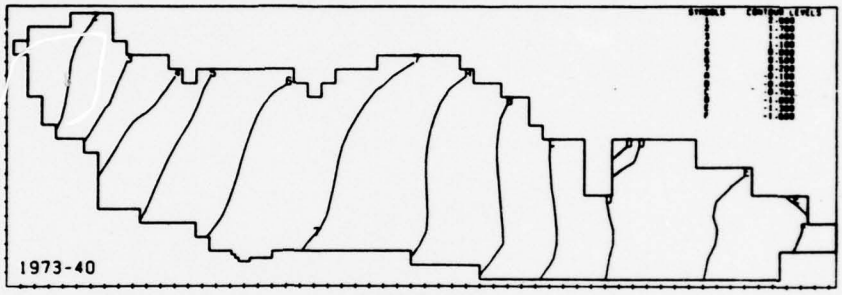
HOUR 32

CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

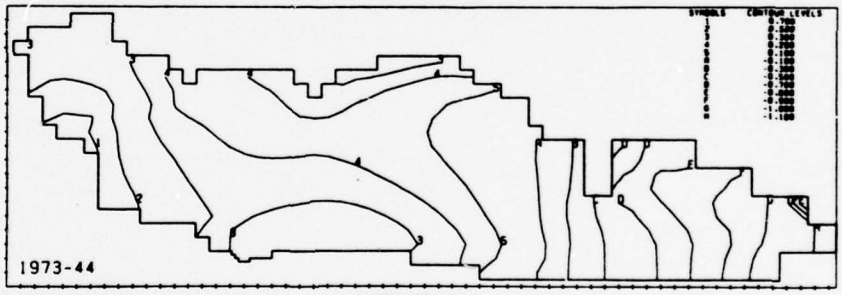
20, 24, 28, AND 32 HOURS INTO STORM OF 0100 APR 8 – 2400 APR 9, 1973



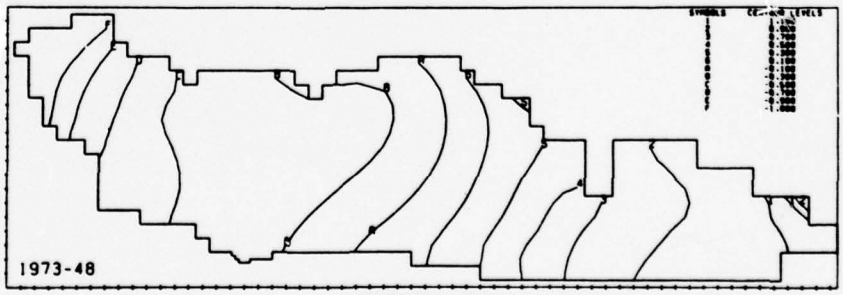
HOUR 36



HOUR 40



HOUR 44

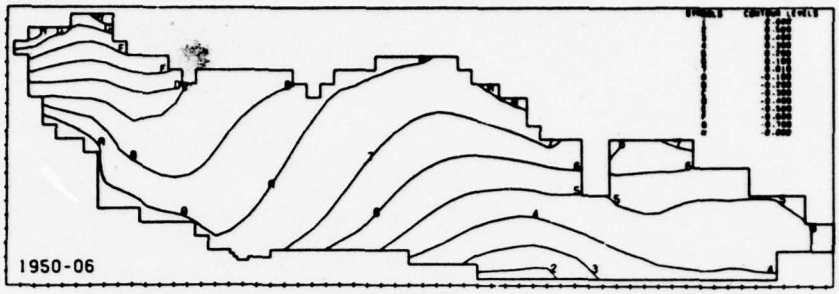


HOUR 48

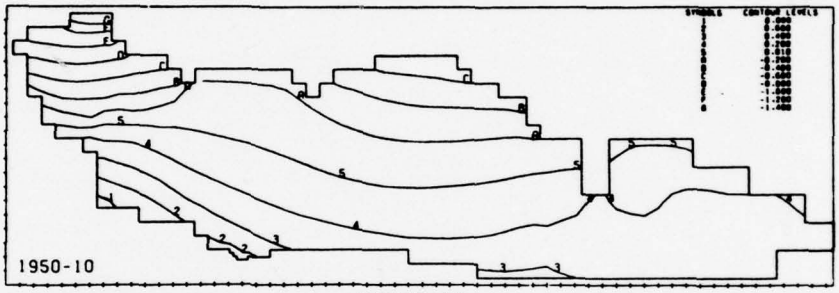
CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

36, 40, 44, AND 48 HOURS INTO STORM OF 0100 APR 8 – 2400 APR 9, 1973

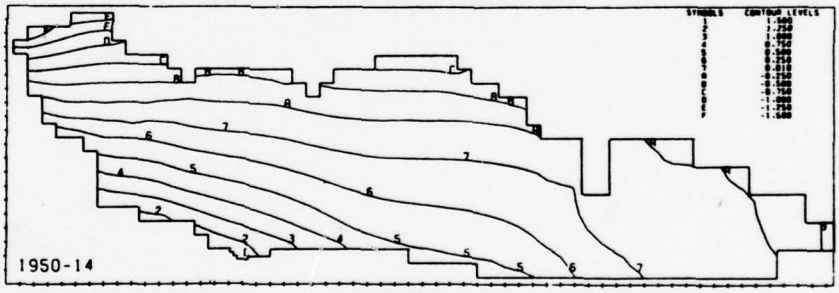
Inclosure 2: 25-27 November 1950 Storm



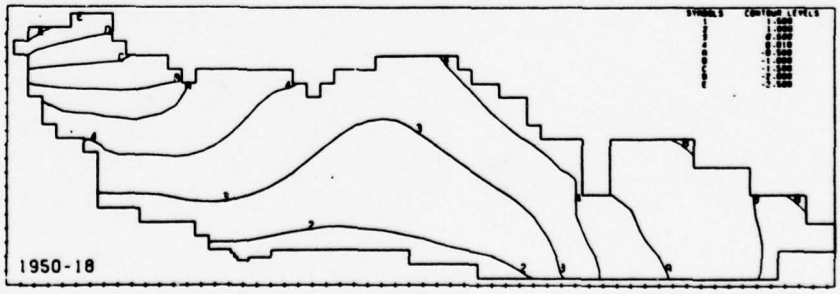
HOUR 6



HOUR 10



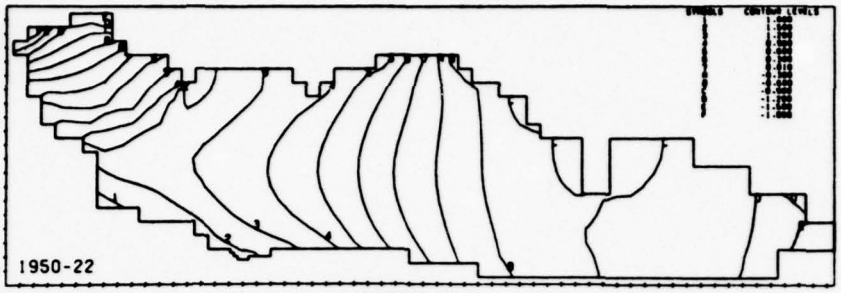
HOUR 14



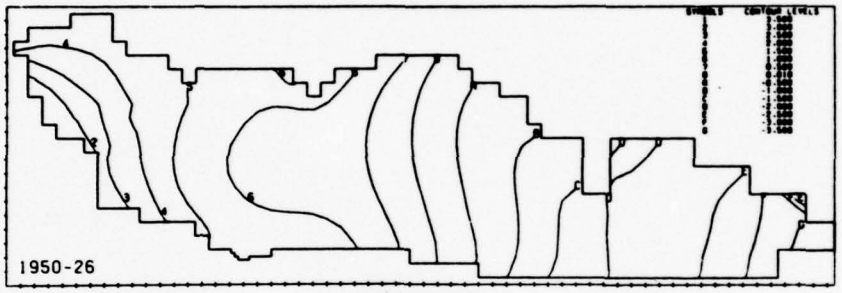
HOUR 18

CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

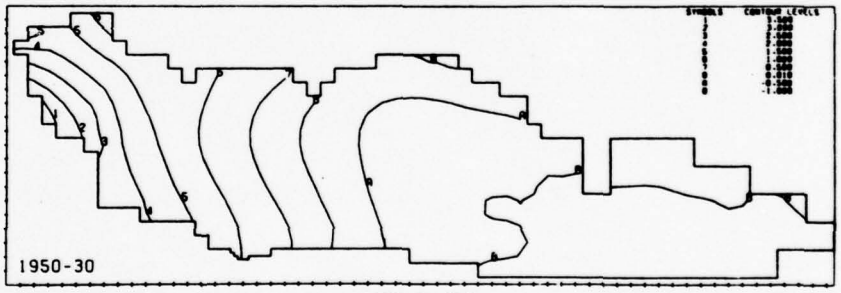
6, 10, 14, AND 18 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950



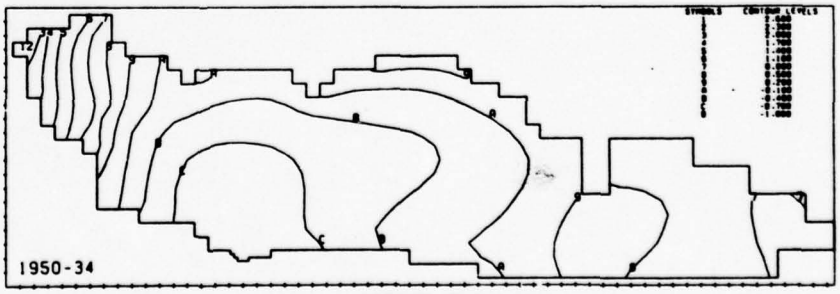
HOUR 22



HOUR 26



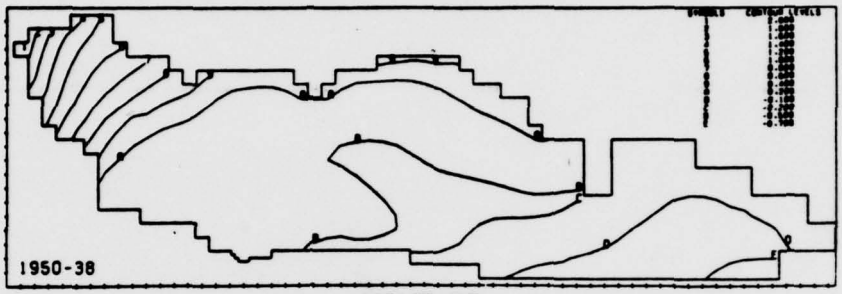
HOUR 30



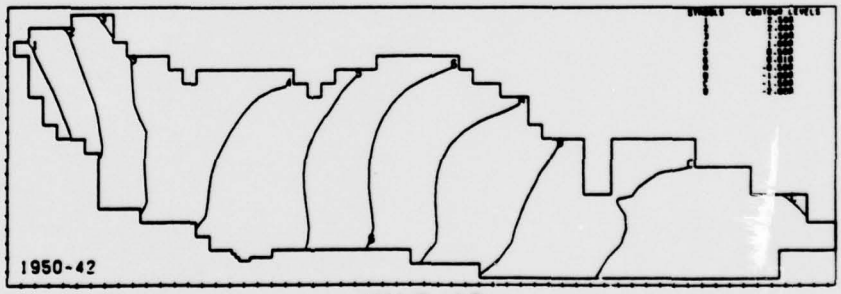
HOUR 34

CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

22, 26, 30, AND 34 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950



HOUR 38

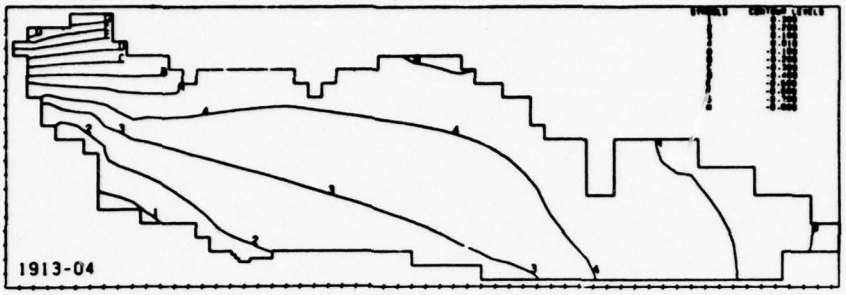


HOUR 42

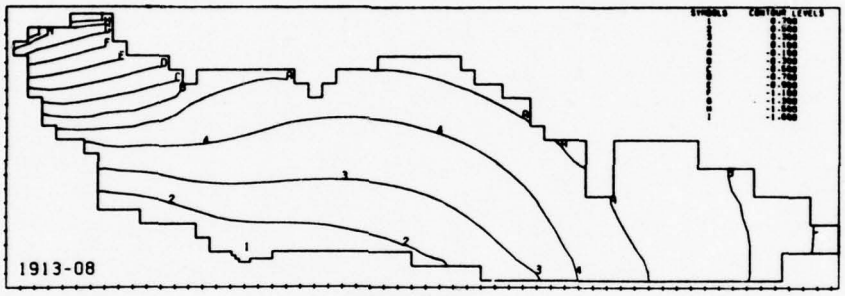
CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

38 AND 42 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950

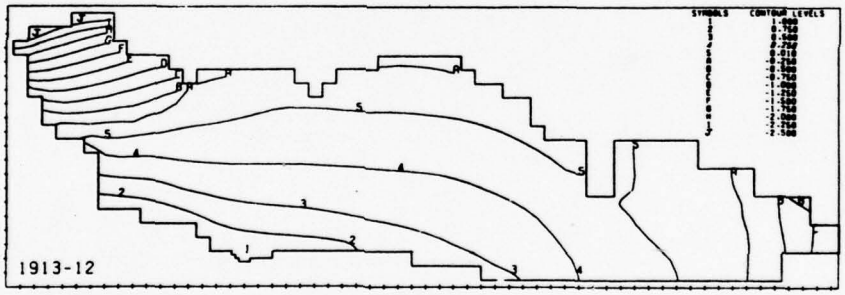
Inclosure 3: 7-10 November 1913 Storm



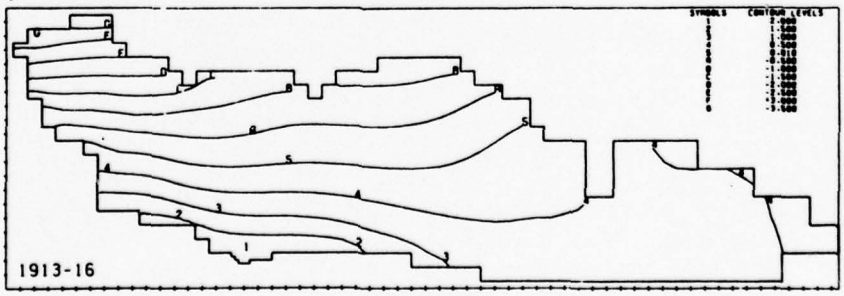
HOUR 4



HOUR 8



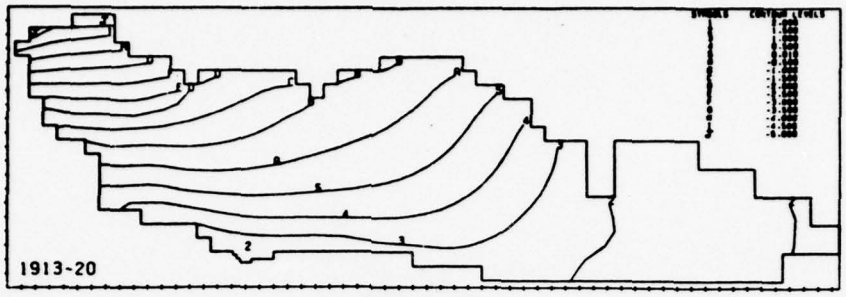
HOUR 12



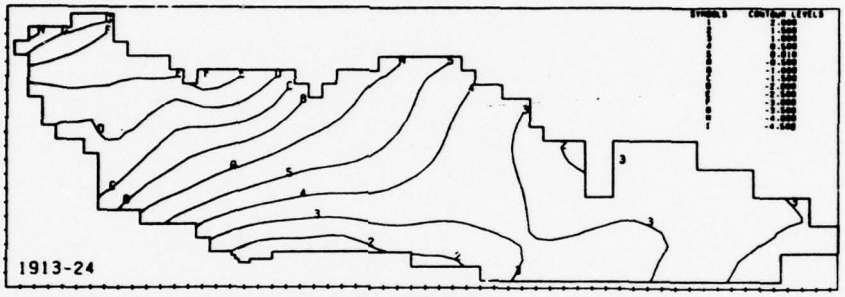
HOUR 16

CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

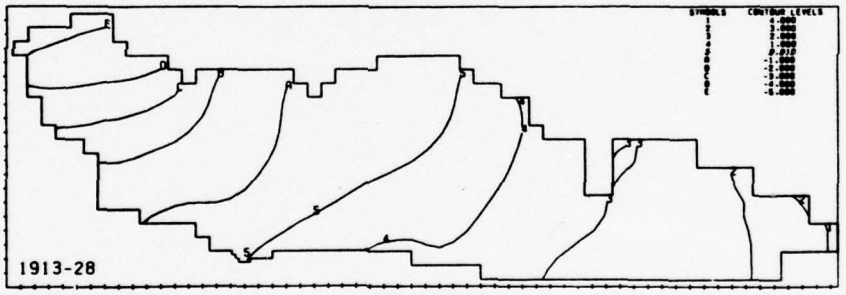
4, 8, 12, AND 16 HOURS INTO STORM OF 0000 NOV 9 - 2300 NOV 10, 1913



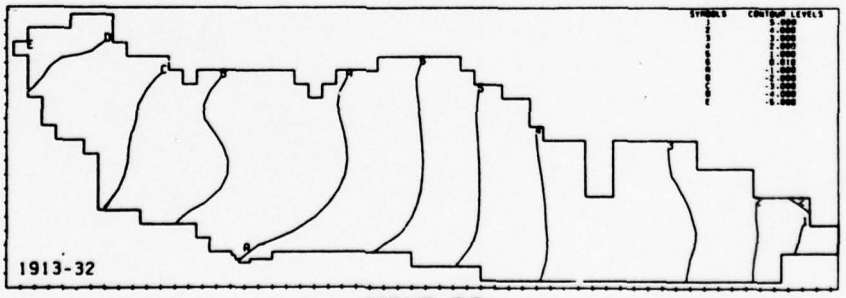
HOUR 20



HOUR 24



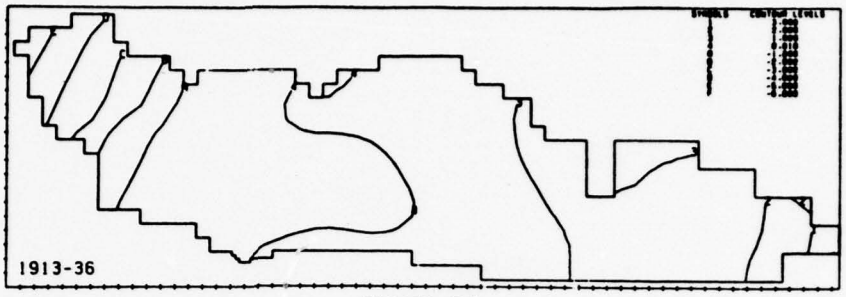
HOUR 28



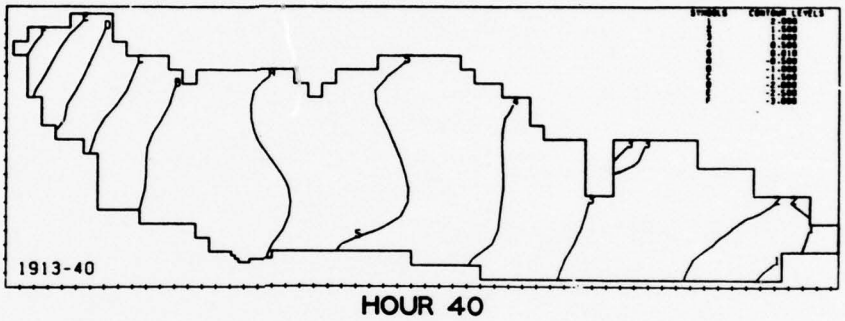
HOUR 32

CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

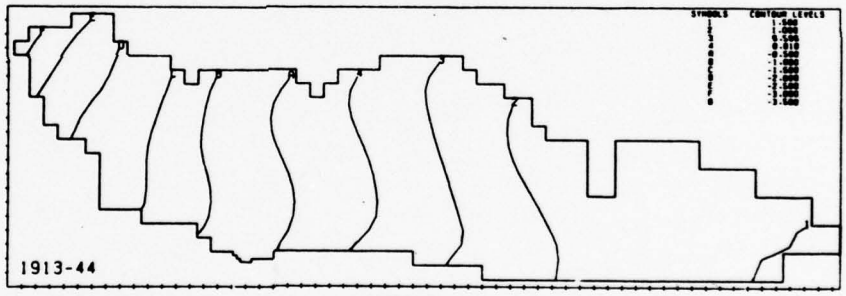
20, 24, 28, AND 32 HOURS INTO STORM OF 0000 NOV 9 - 2300 NOV 10, 1913



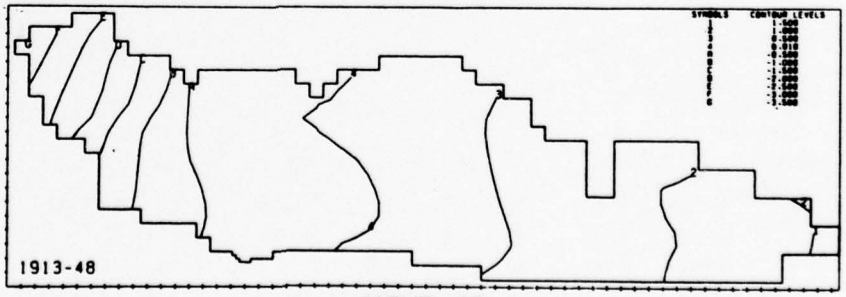
HOUR 36



HOUR 40



HOUR 44



HOUR 48

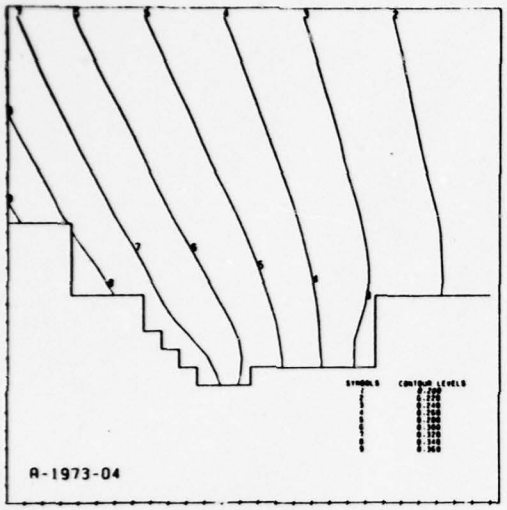
CONTOURS OF STORM SURGE ELEVATIONS (FT) FOR FULL LAKE

36, 40, 44, AND 48 HOURS INTO STORM OF 0000 NOV 9 – 2300 NOV 10, 1913

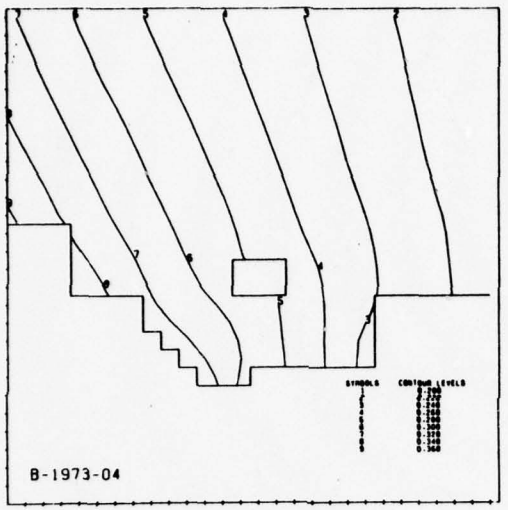
APPENDIX D: Contours of Storm Surge Elevation in Nearshore Region

Inclosure 1: 8-9 April 1973 Storm
Inclosure 2: 25-27 November 1950 Storm
Inclosure 3: 7-10 November 1913 Storm

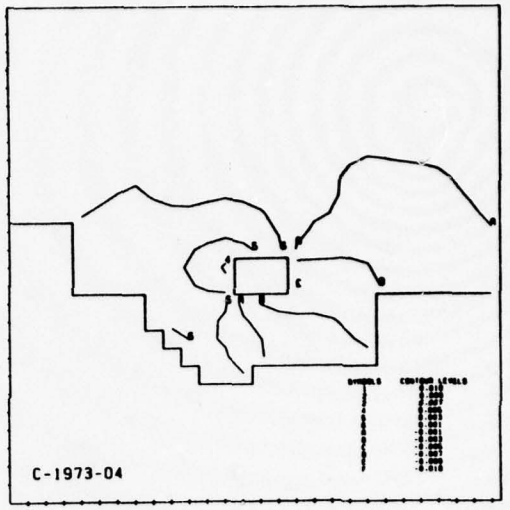
Inclosure 1: 8-9 April 1973 Storm



WITHOUT JETPORT



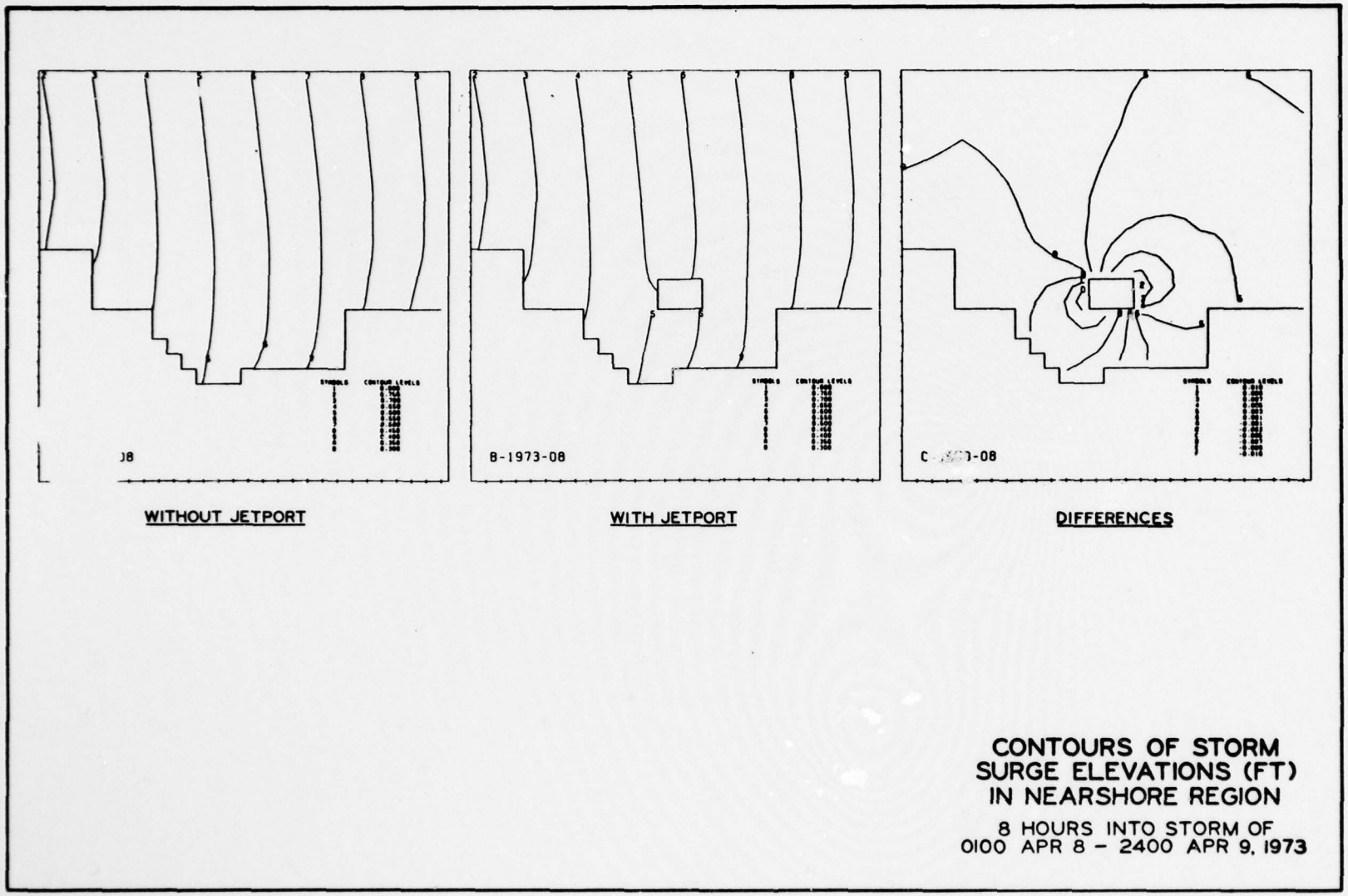
WITH JETPORT



DIFFERENCES

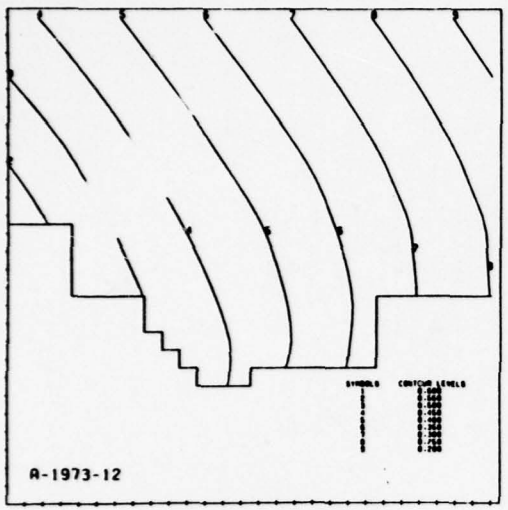
CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

4 HOURS INTO STORM OF 0100 APR 8 – 2400 APR 9, 1973

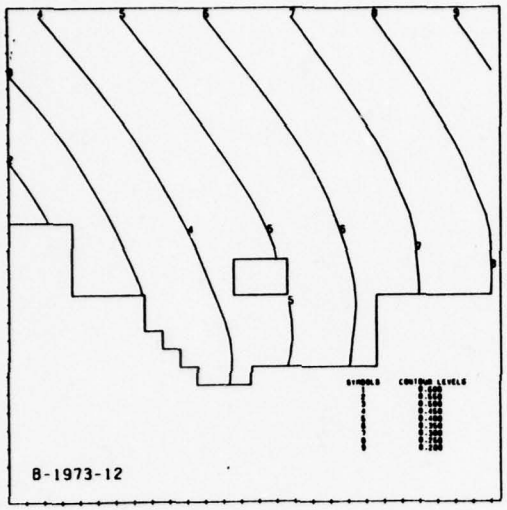


CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

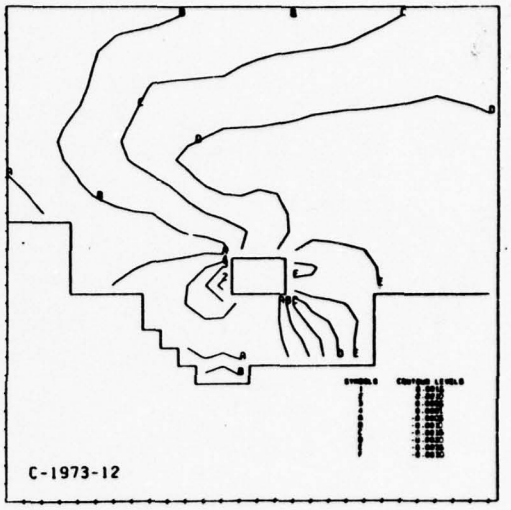
8 HOURS INTO STORM OF
0100 APR 8 – 2400 APR 9, 1973



WITHOUT JETPORT



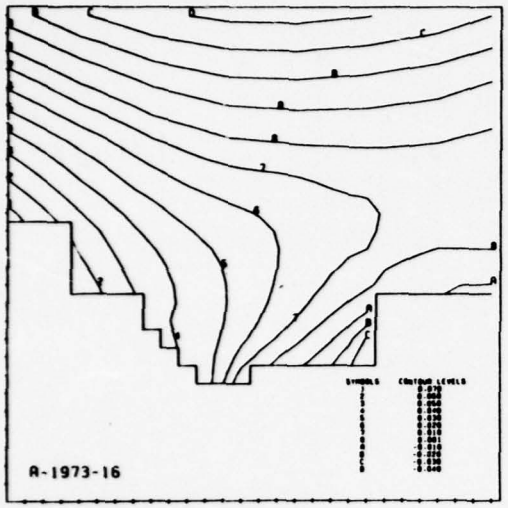
WITH JETPORT



DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

12 HOURS INTO STORM OF
0100 APR 8 – 2400 APR 9, 1973



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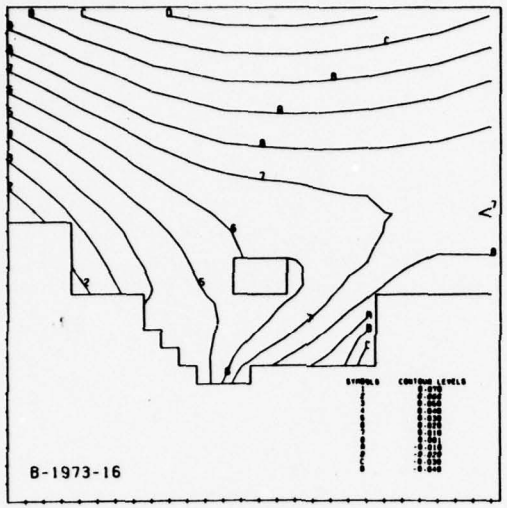

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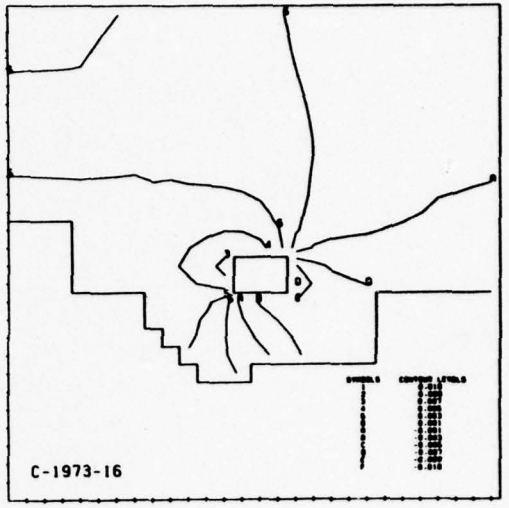
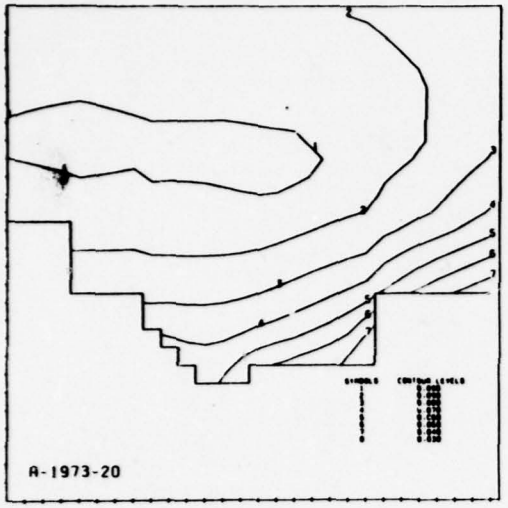


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

16 HOURS INTO STORM OF
0100 APR 8 – 2400 APR 9, 1973



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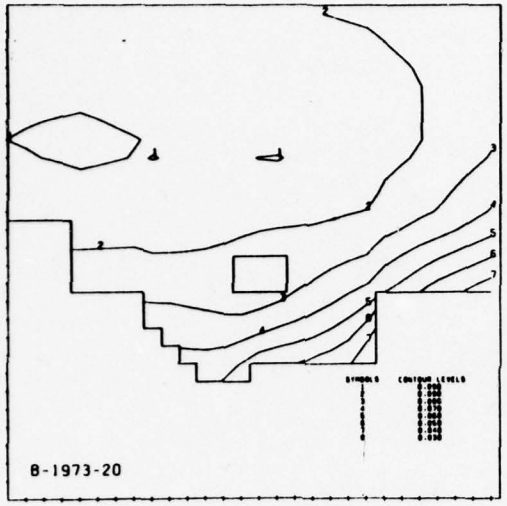
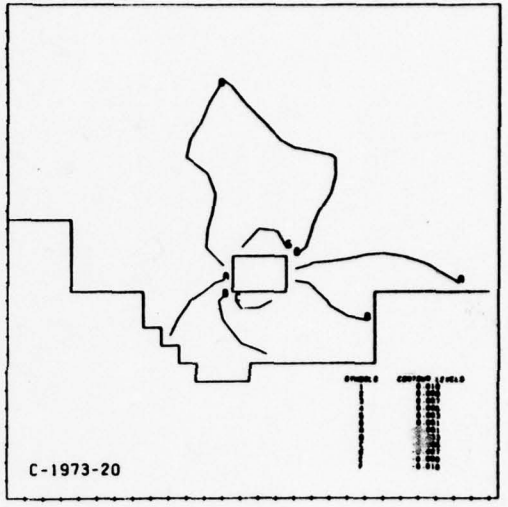


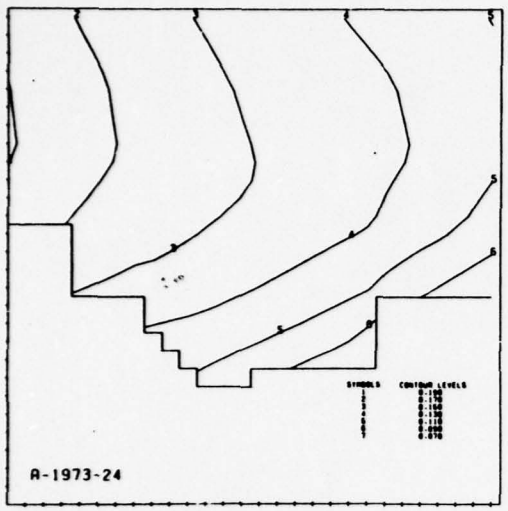
WITH JETPORT



DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

20 HOURS INTO STORM OF
0100 APR 8 - 2400 APR 9, 1973



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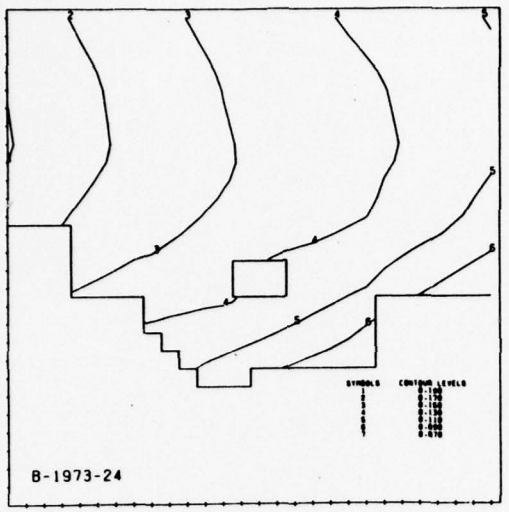

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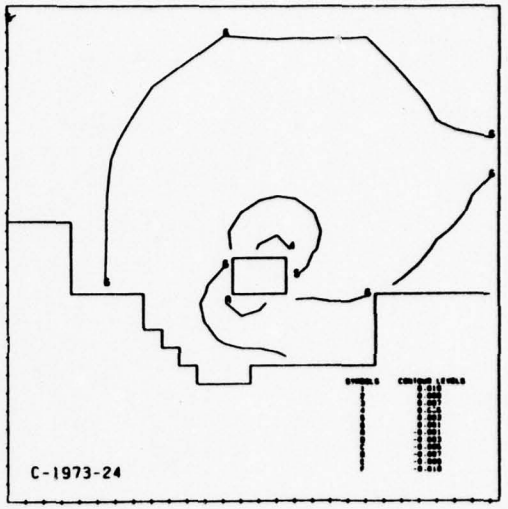
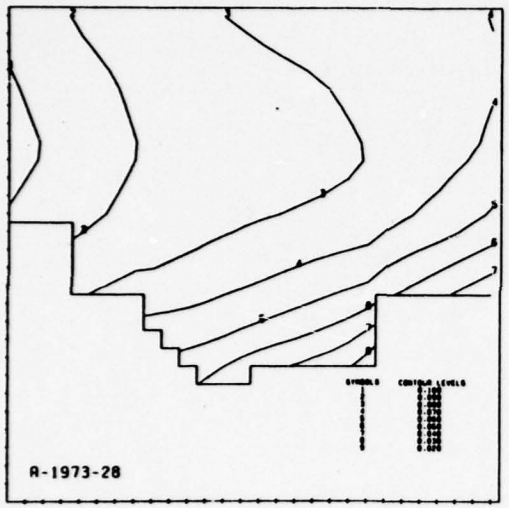


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

24 HOURS INTO STORM OF
0100 APR 8 - 2400 APR 9, 1973



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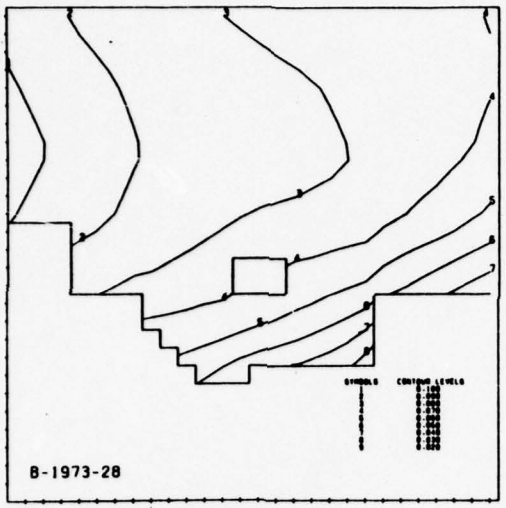

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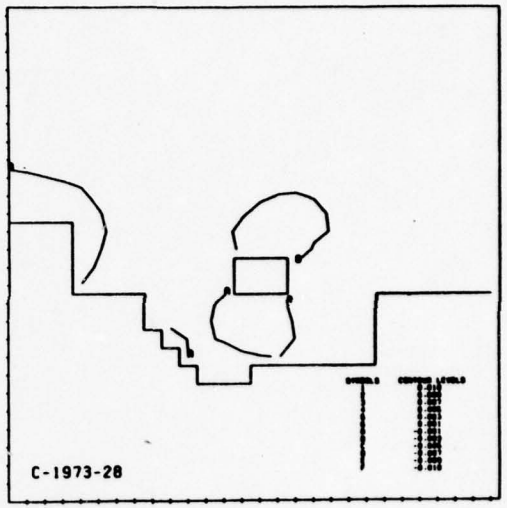
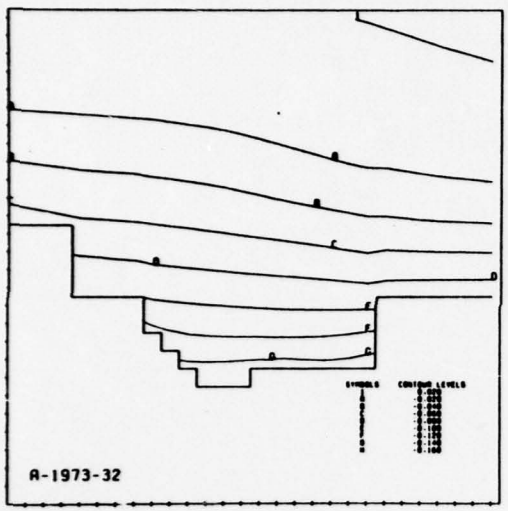


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

28 HOURS INTO STORM OF
0100 APR 8 – 2400 APR 9, 1973



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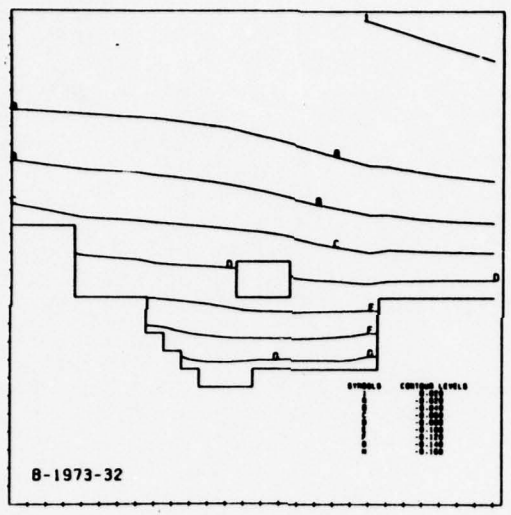

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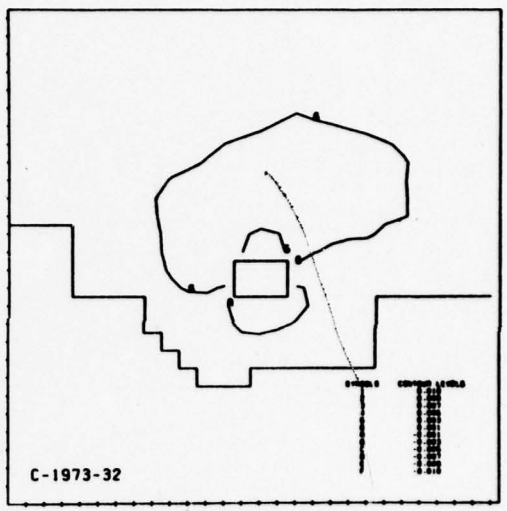
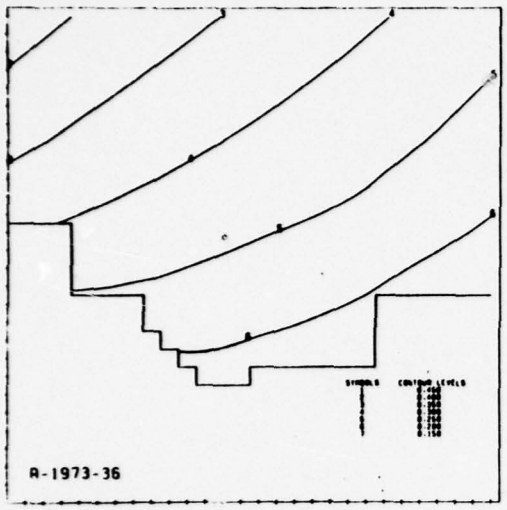


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

32 HOURS INTO STORM OF 0100 APR 8 - 2400 APR 9, 1973



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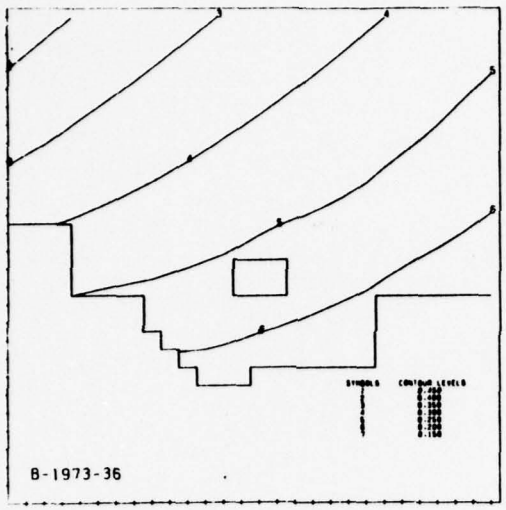

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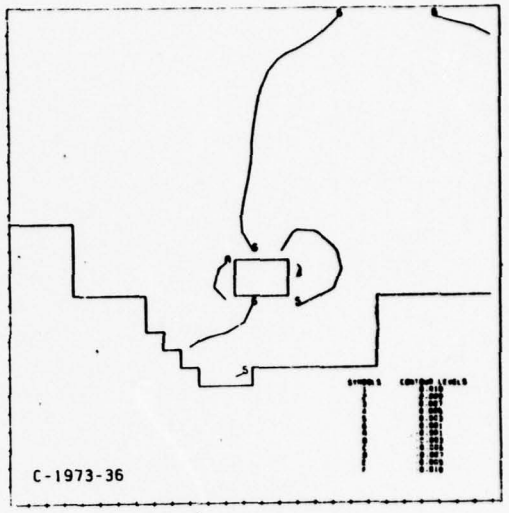
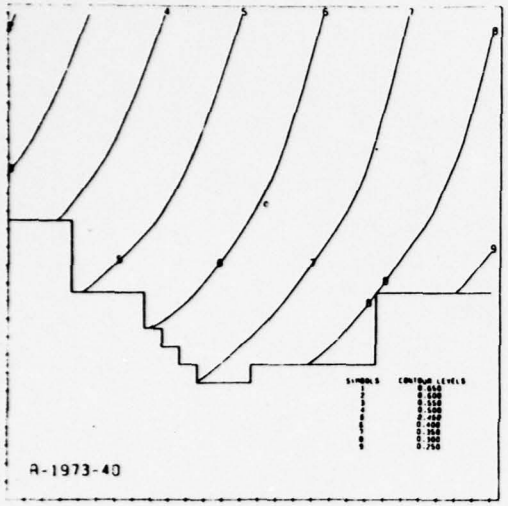


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

36 HOURS INTO STORM OF
0100 APR 8 – 2400 APR 9, 1973



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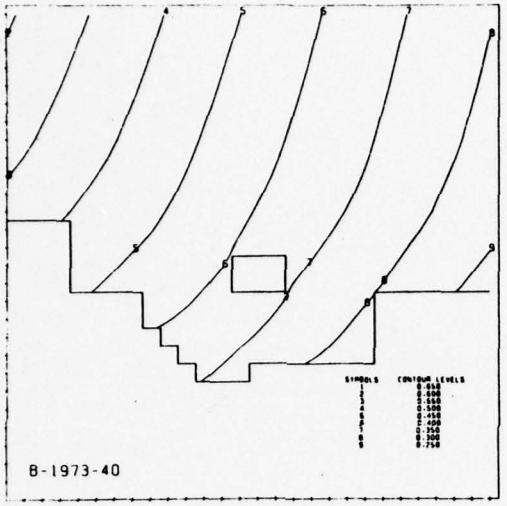
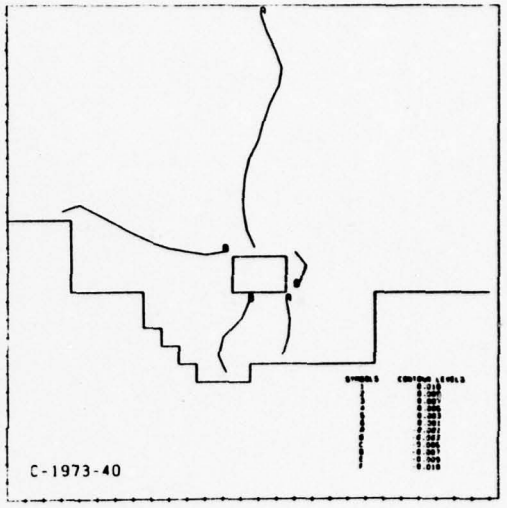


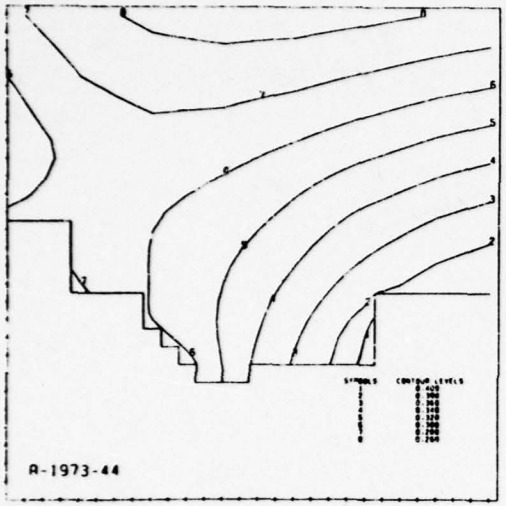
WITH JETPORT



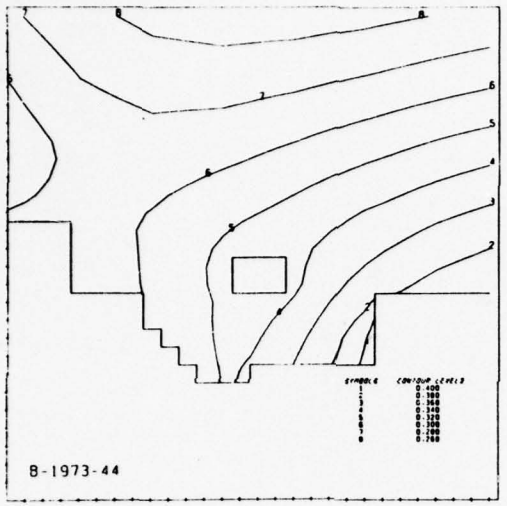
DIFFERENCES

CONTOURS OF STORM
SURGE ELEVATIONS (FT)
[illegible] REGION

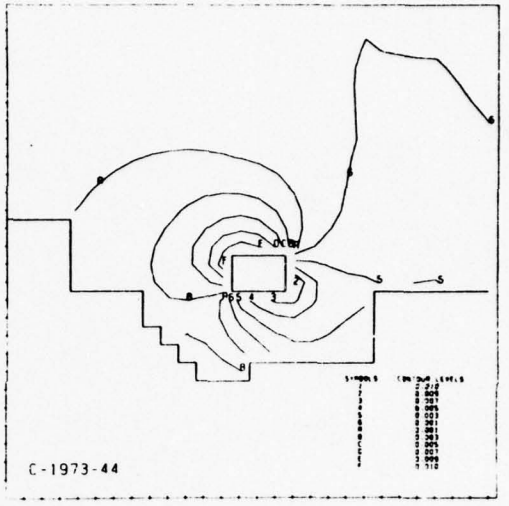
70 HOURS INTO STORM OF
0100 APR 8 - 2400 APR 9, 1973



WITHOUT JETPORT



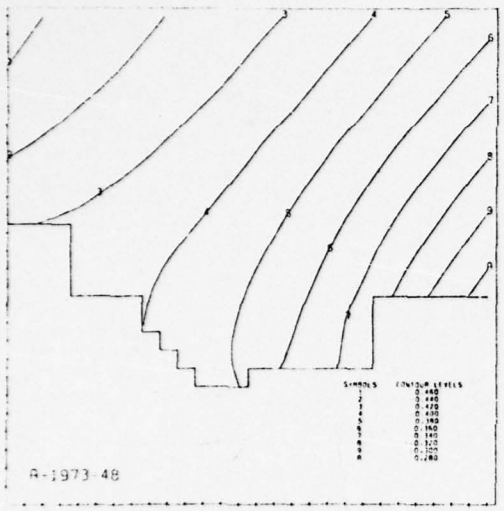
WITH JETPORT



DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

44 HOURS INTO STORM OF 0100 APR 8 – 2400 APR 9, 1973



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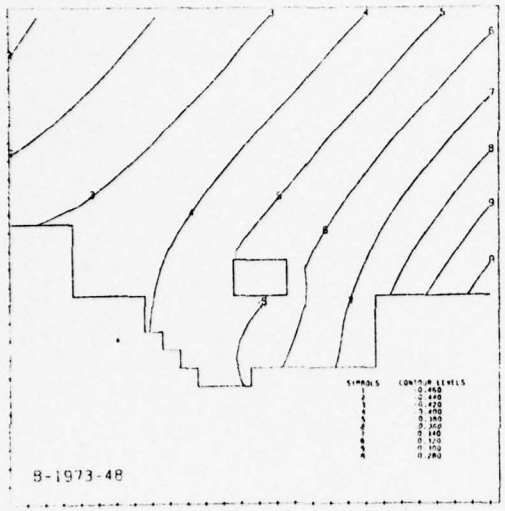
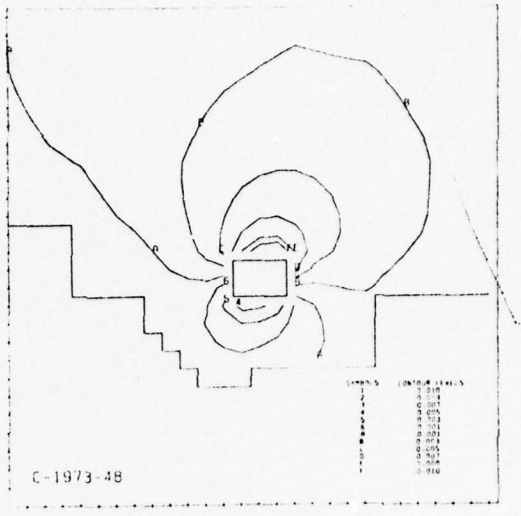


WITH JETPORT

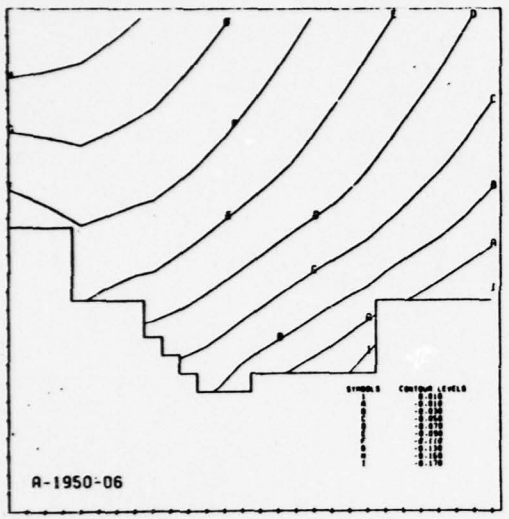


DIFFERENCES

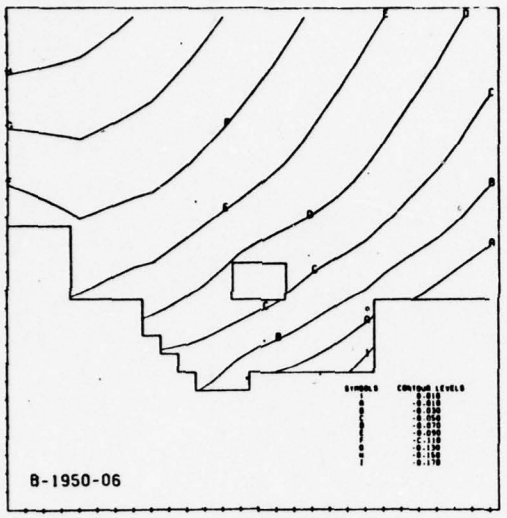
CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

48 HOURS INTO STORM OF
0100 APR 8 – 2400 APR 9, 1973

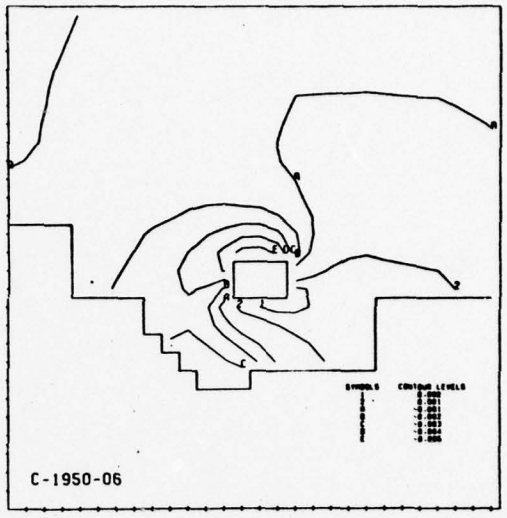
Inclosure 2: 25-27 November 1950 Storm



WITHOUT JETPORT



WITH JETPORT



DIFFERENCES

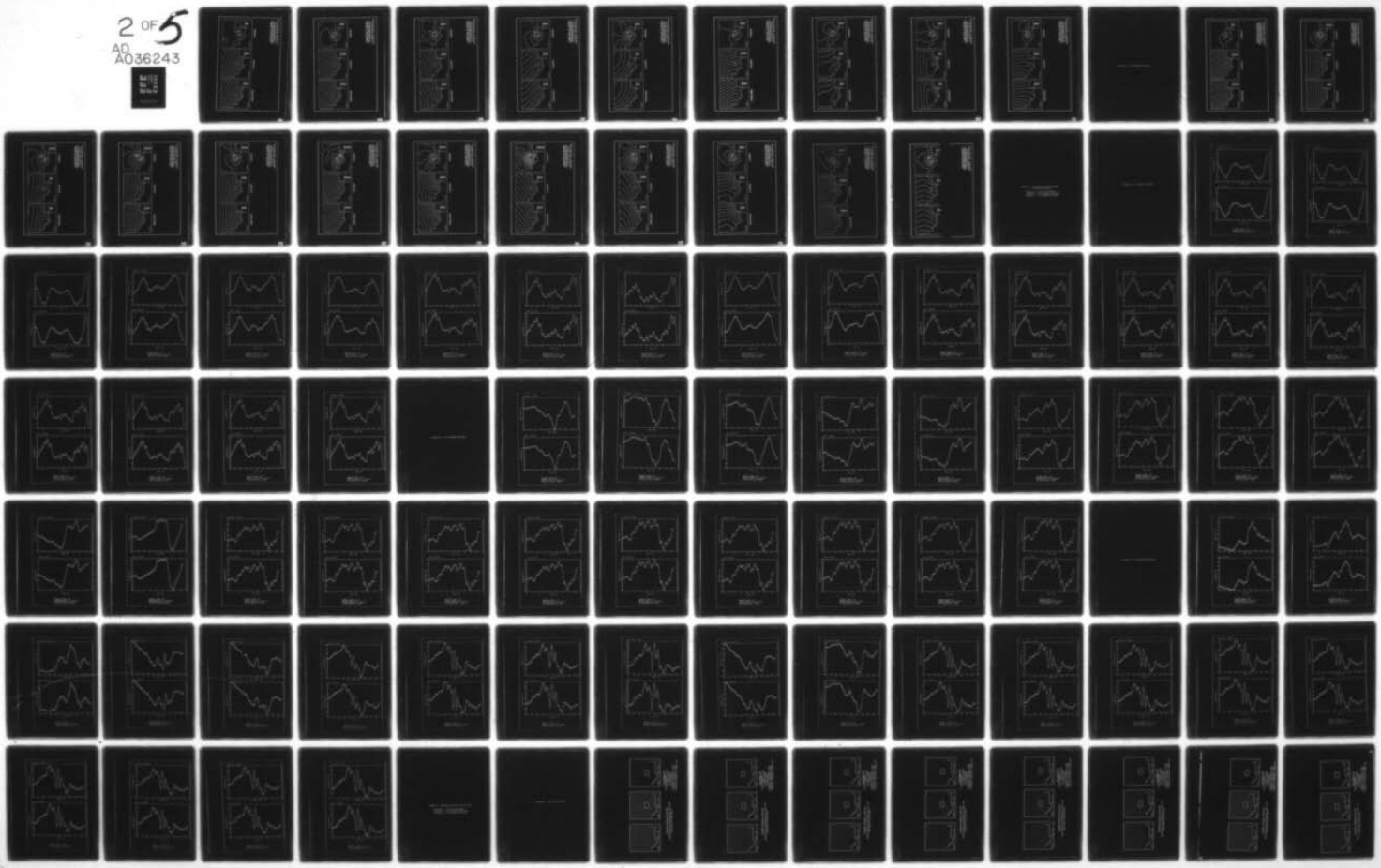
CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

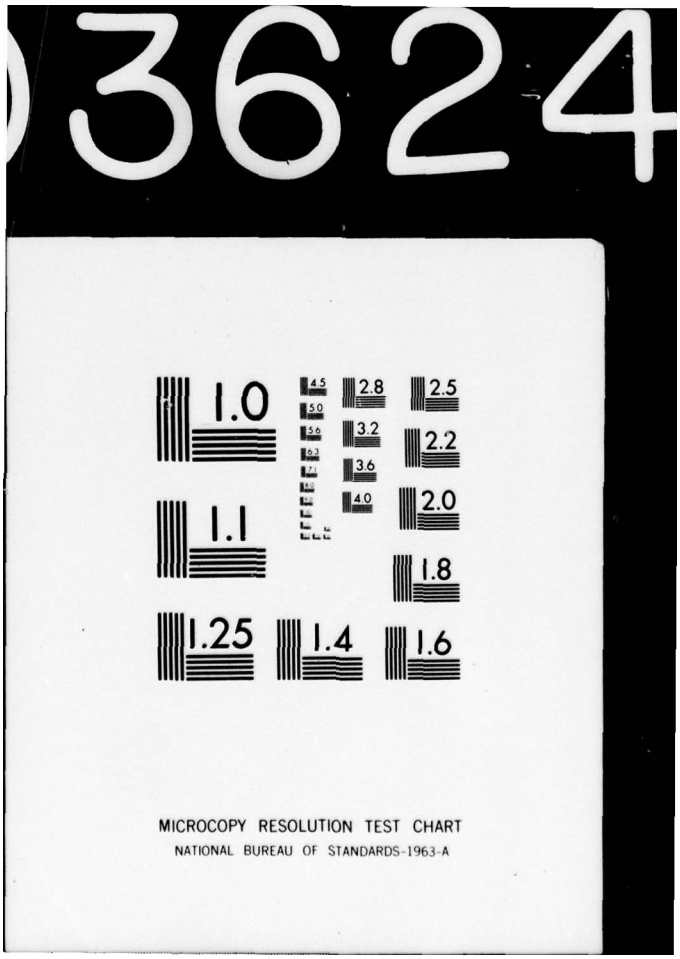
6 HOURS INTO STORM OF
1700 NOV 24 - 1000 NOV 26, 1950

AD-A036 243 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 1/5
LAKE ERIE INTERNATIONAL JETPORT MODEL FEASIBILITY INVESTIGATION--ETC(U)
OCT 76 D L DURHAM, H L BUTLER, D C RANEY

UNCLASSIFIED WES-MP-H-76-3-8 NL

2 OF 5
AD A036243




03624
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
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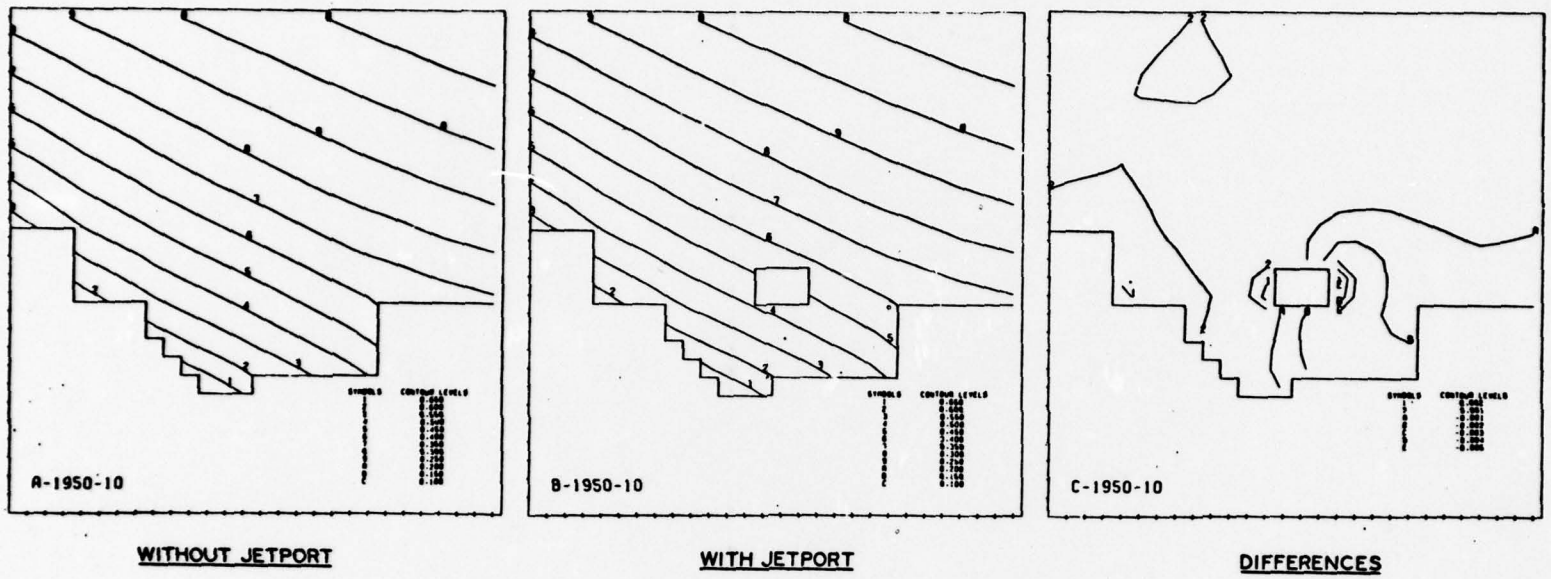
5.6
6.3
7.1
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



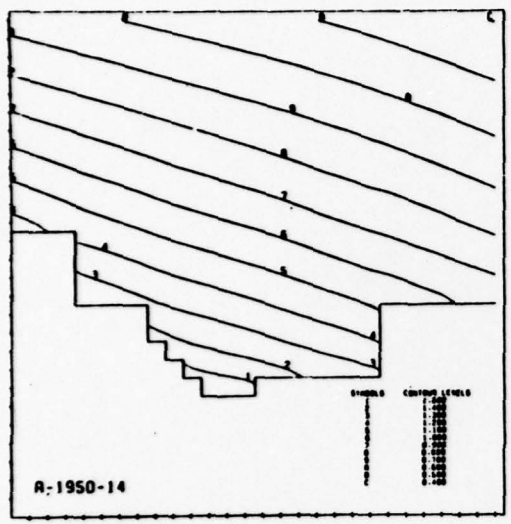
WITHOUT JETPORT

WITH JETPORT

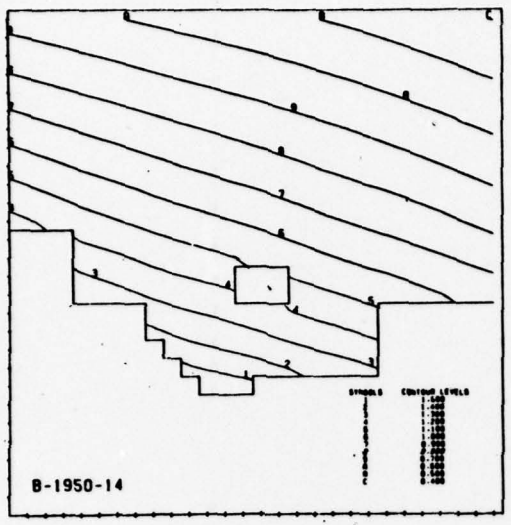
DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

10 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950



WITHOUT JETPORT



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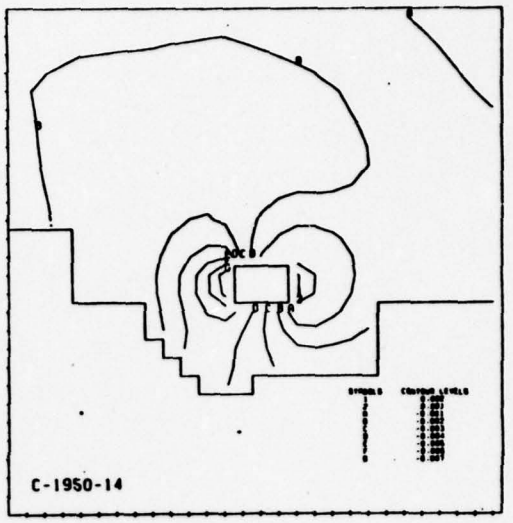
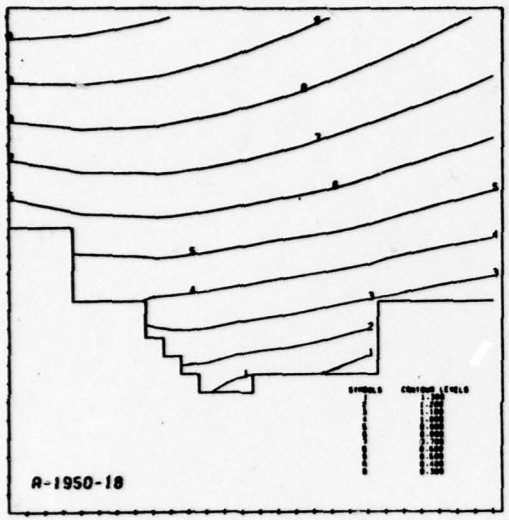


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

14 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950



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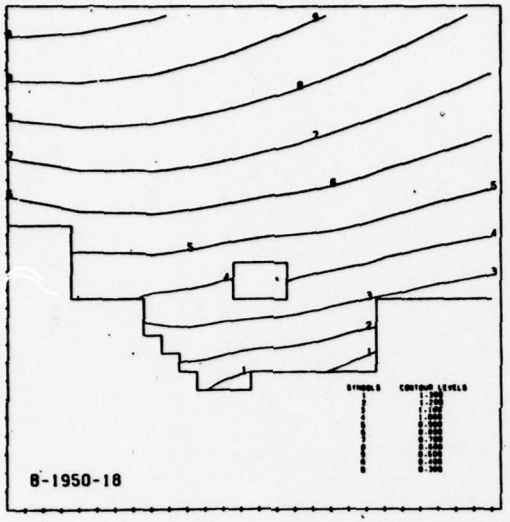

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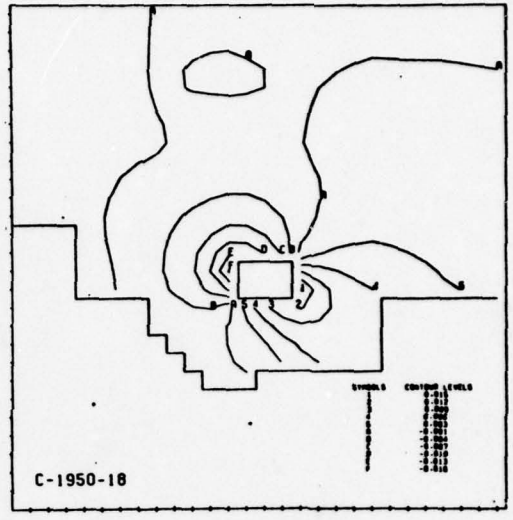
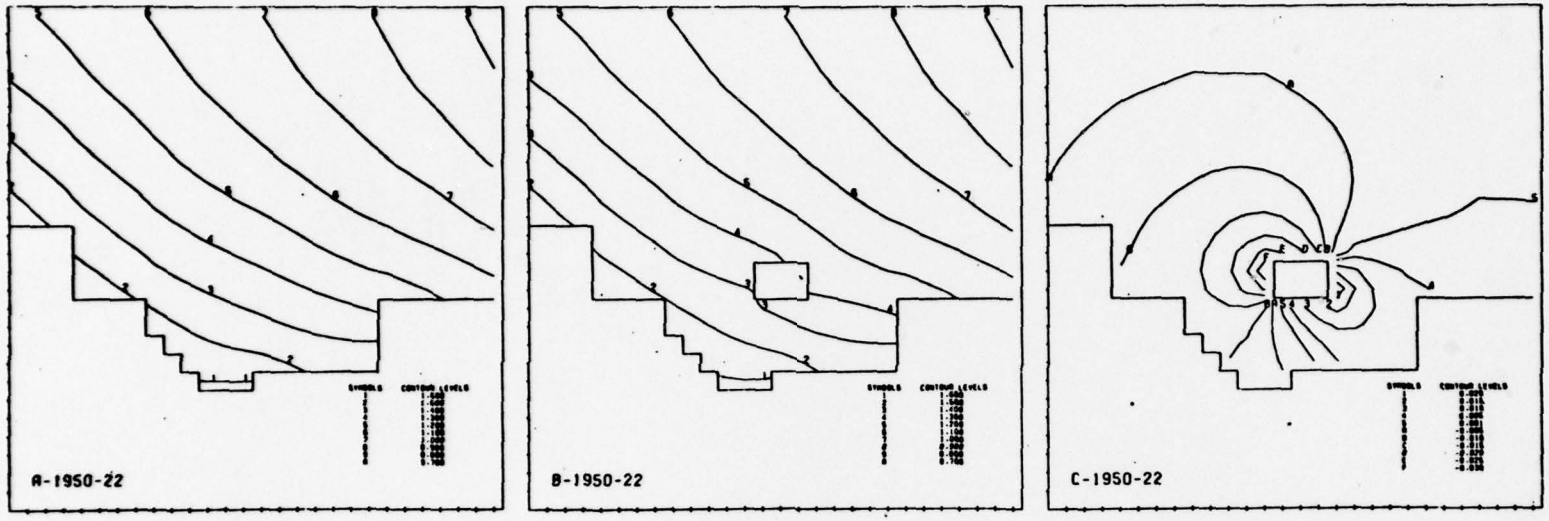


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

18 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950



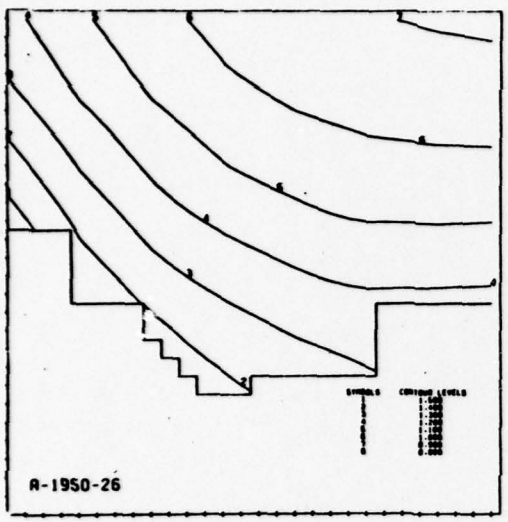
WITHOUT JETPORT

WITH JETPORT

DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

22 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950



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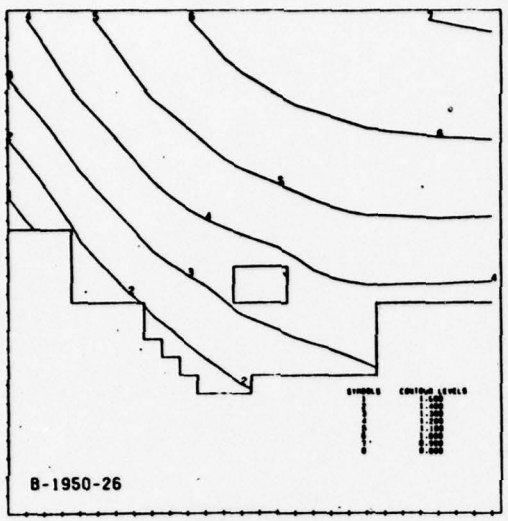

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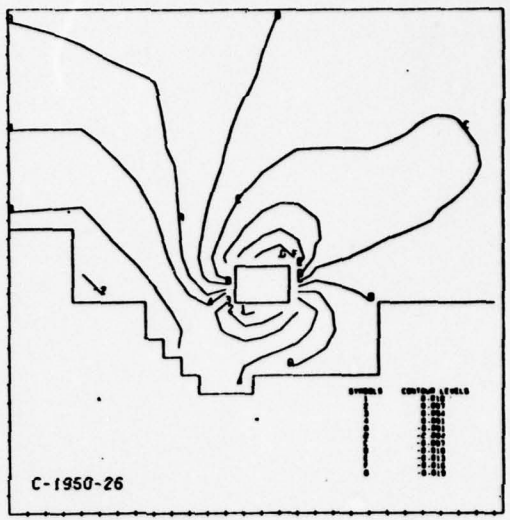
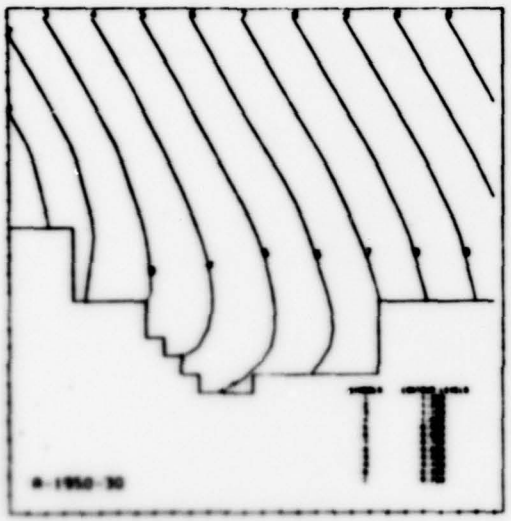


DIFFERENCES

CONTOURS OF STORM
SURGE ELEVATIONS (FT)
IN NEARSHORE REGION

26 HOURS INTO STORM OF
1700 NOV 24 - 1000 NOV 26, 1950



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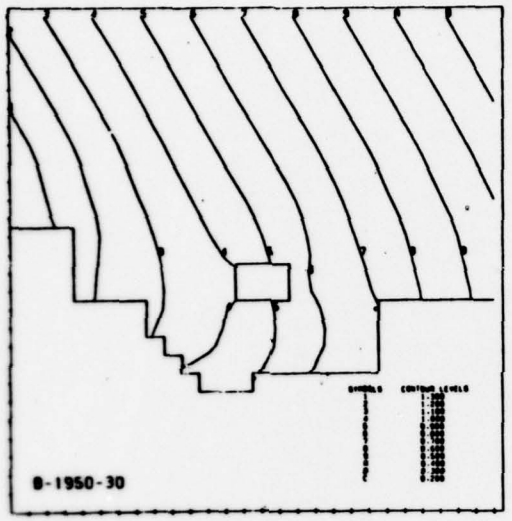

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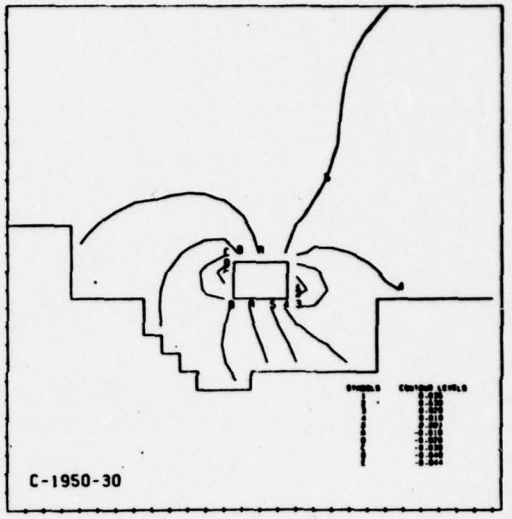
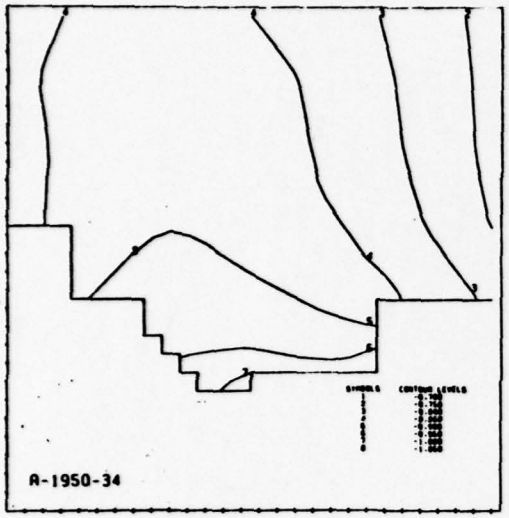


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

30 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950



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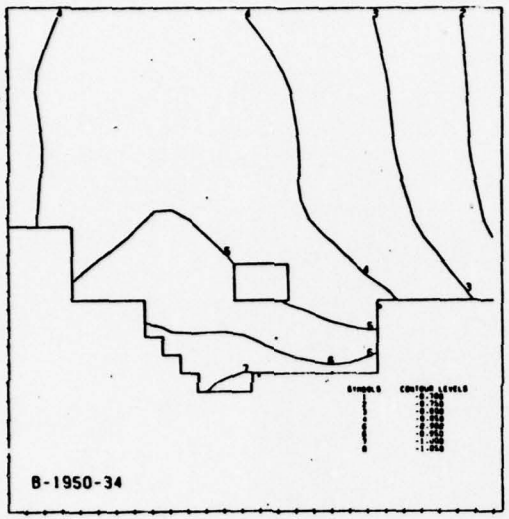
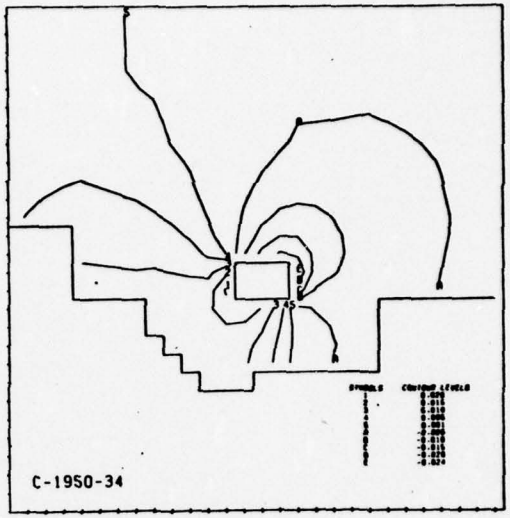


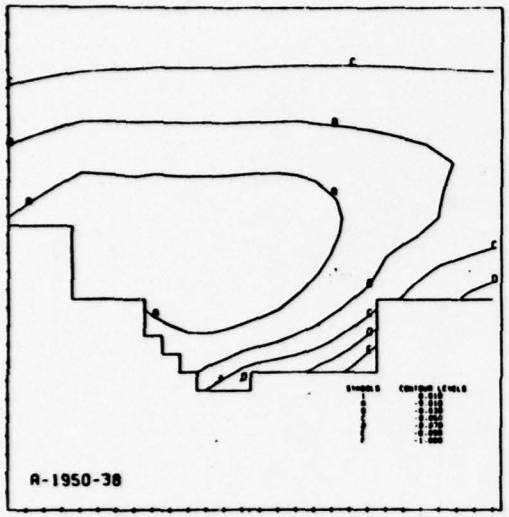
WITH JETPORT



DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

34 HOURS INTO STORM OF 1700 NOV 24 - 1000 NOV 26, 1950



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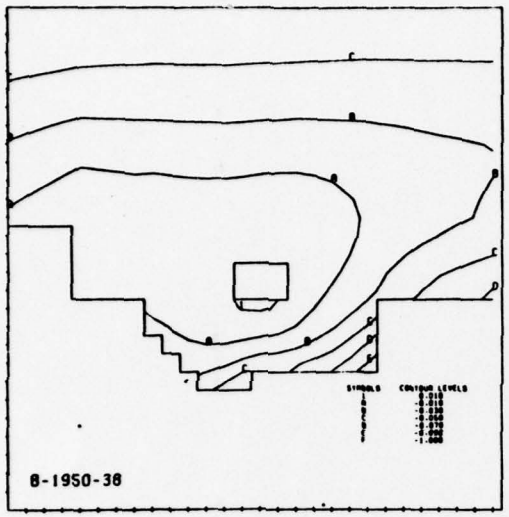

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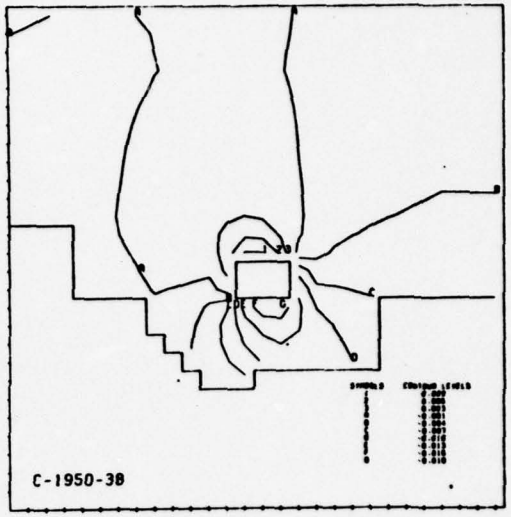
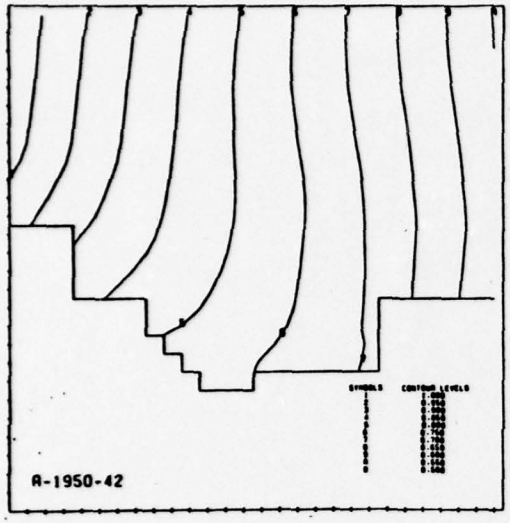


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

38 HOURS INTO STORM OF
1700 NOV 24 - 1000 NOV 26, 1950



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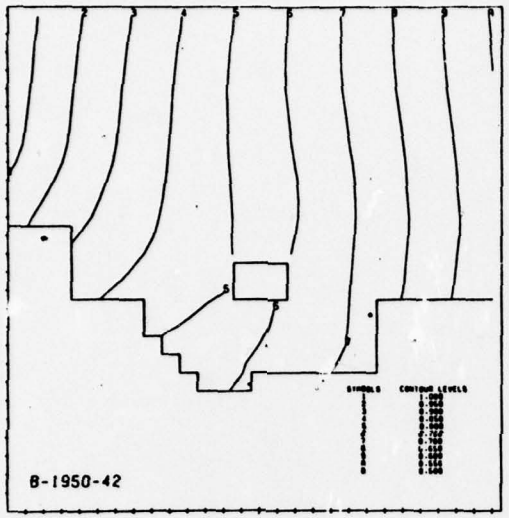

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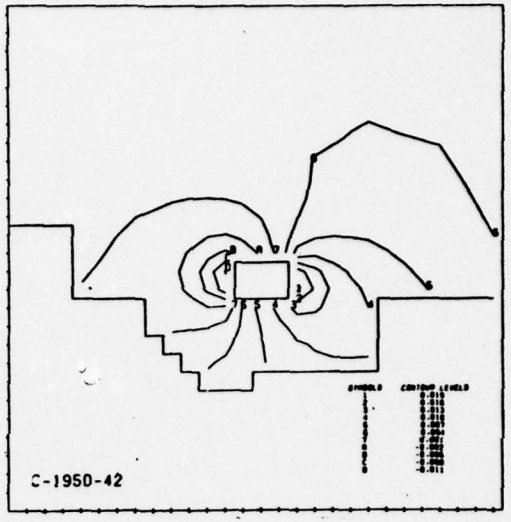
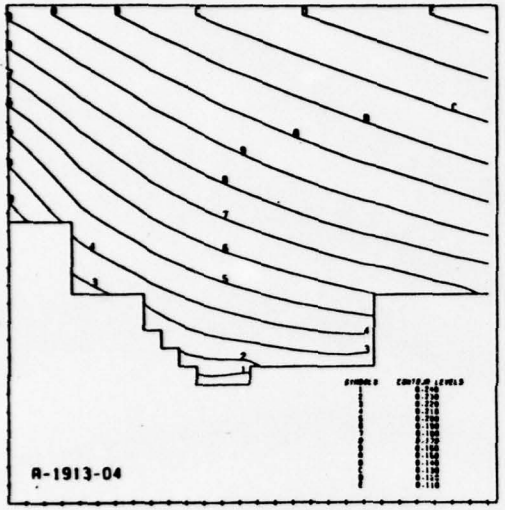


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

42 HOURS INTO STORM OF
1700 NOV 24 - 1000 NOV 26, 1950

Inclosure 3: 7-10 November 1913 Storm



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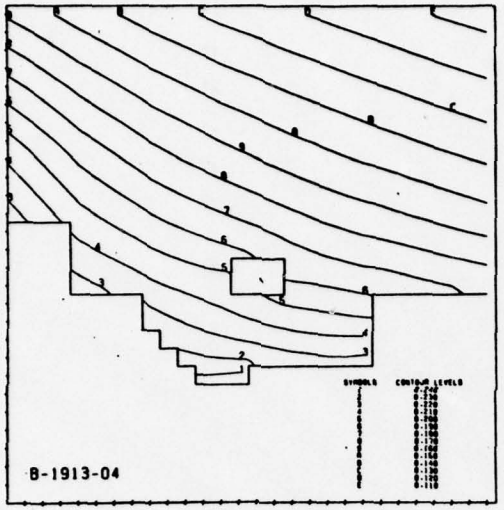

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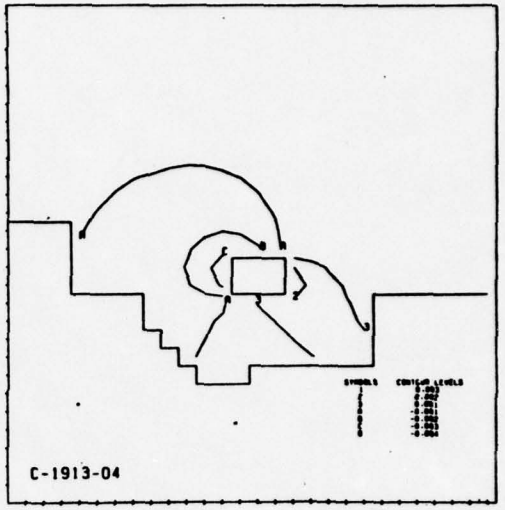
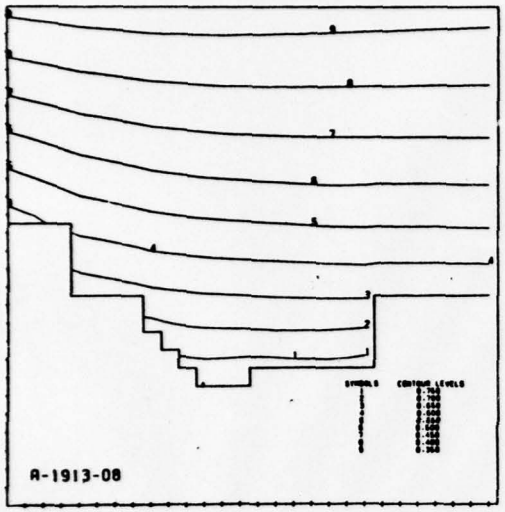


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

4 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913



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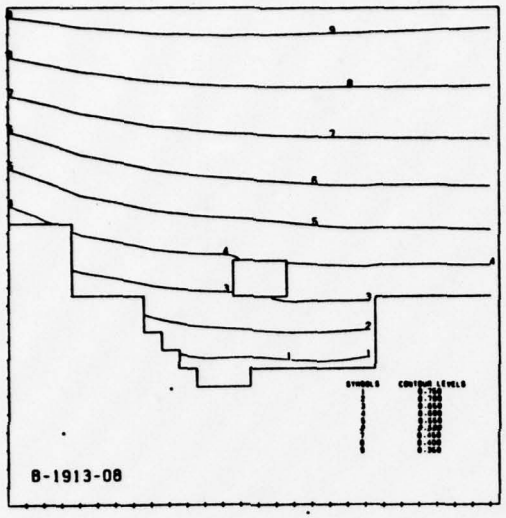
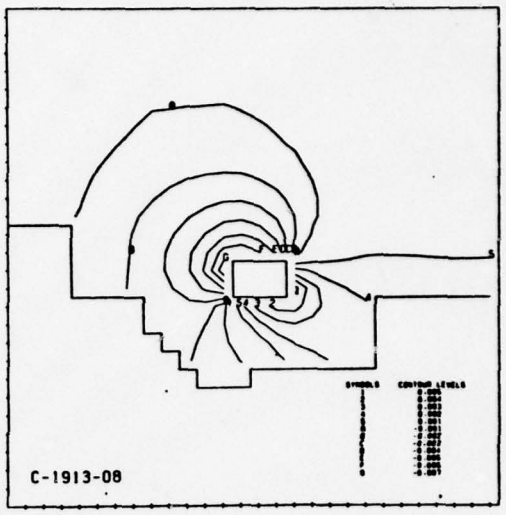


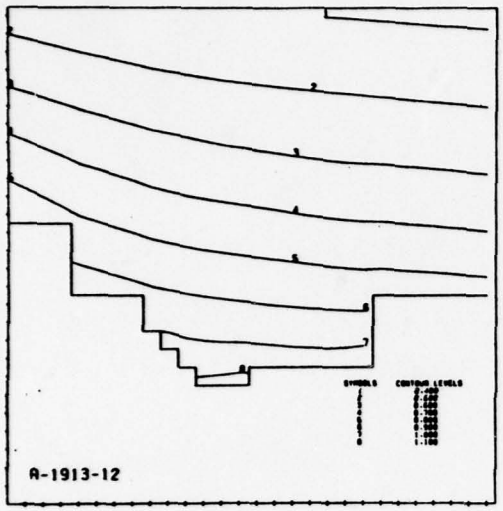
WITH JETPORT



DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

8 HOURS INTO STORM OF 0000 NOV 9 – 2300 NOV 10, 1913



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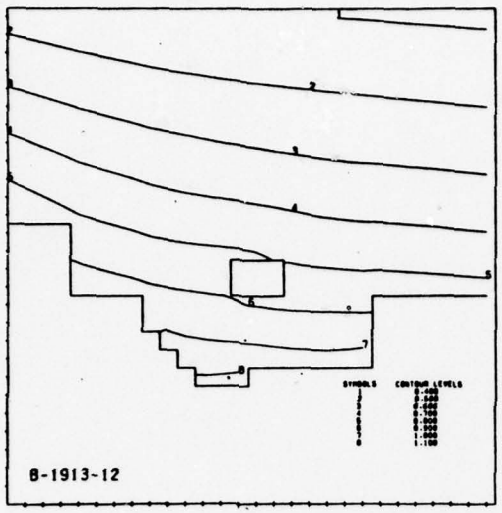

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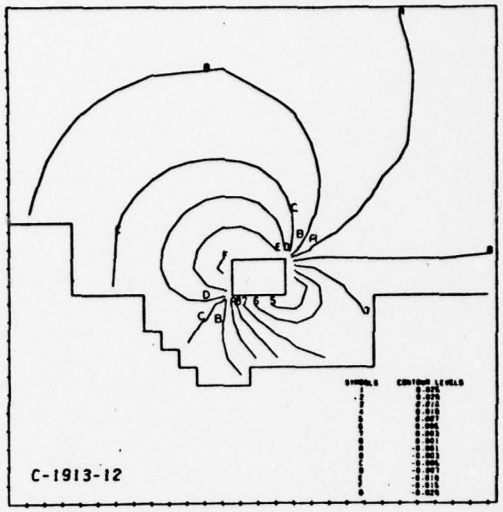
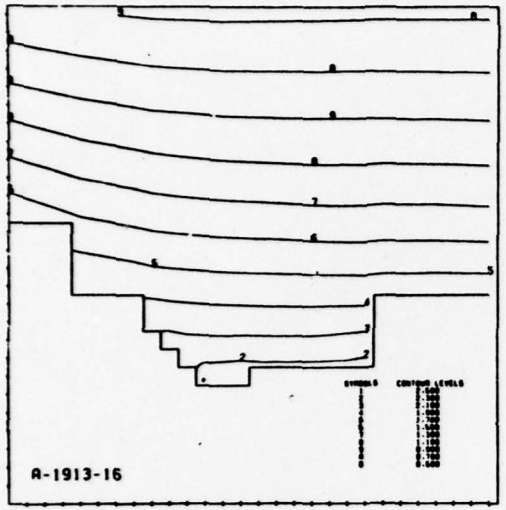


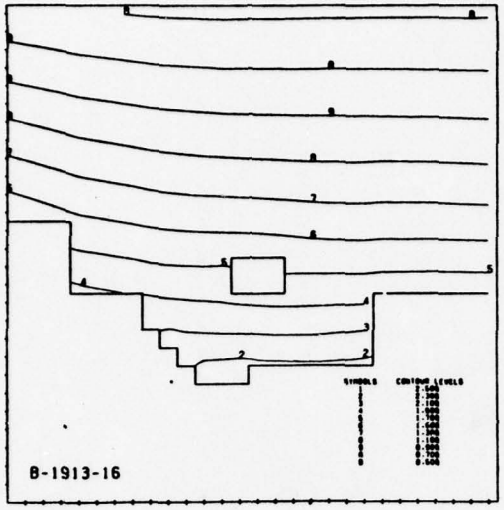
DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

12 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913



WITHOUT JETPORT



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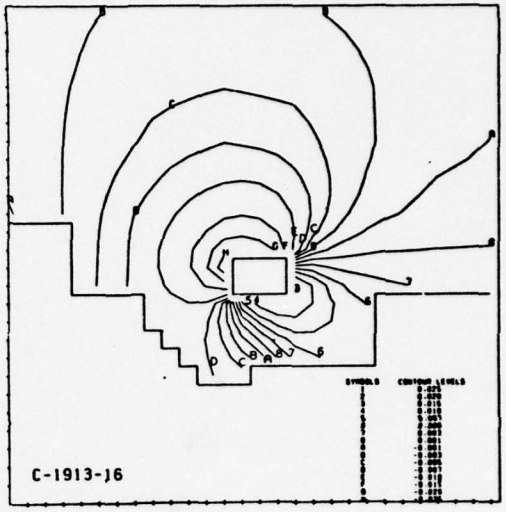
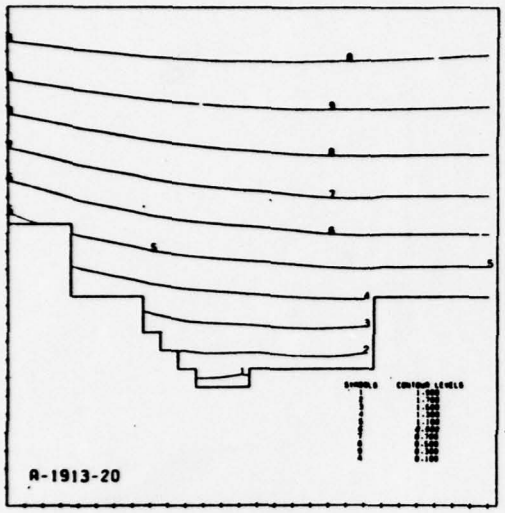


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

16 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913



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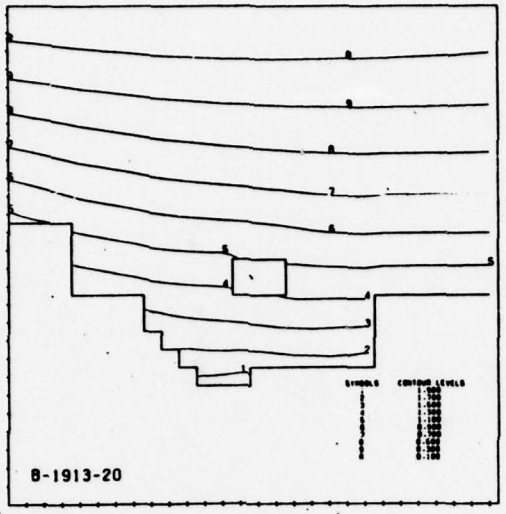
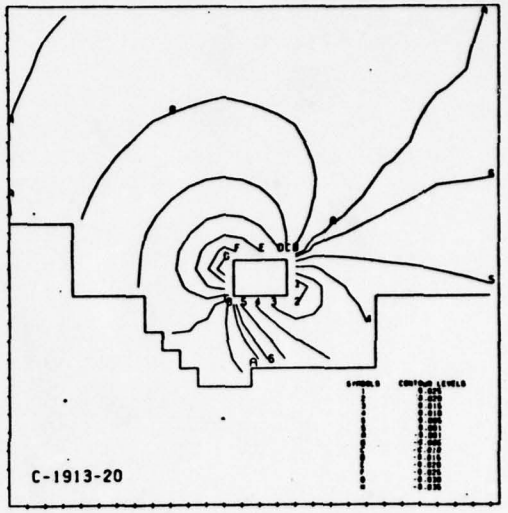


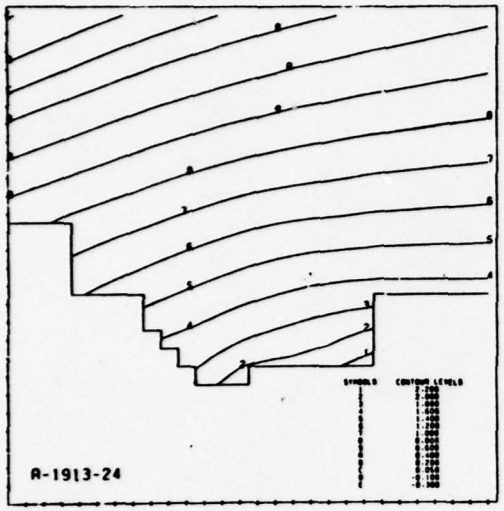
WITH JETPORT



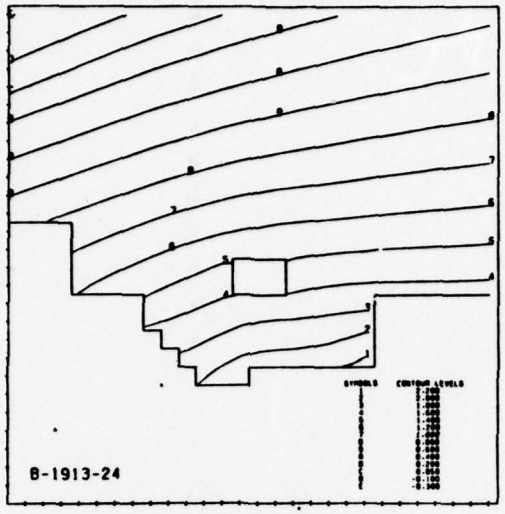
DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

20 HOURS INTO STORM OF 0000 NOV 9 - 2300 NOV 10, 1913



WITHOUT JETPORT



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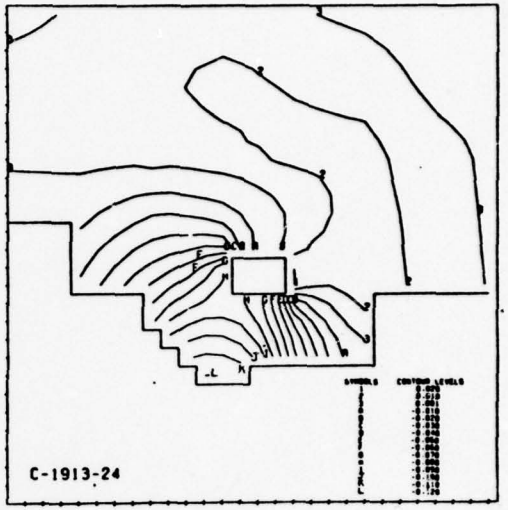
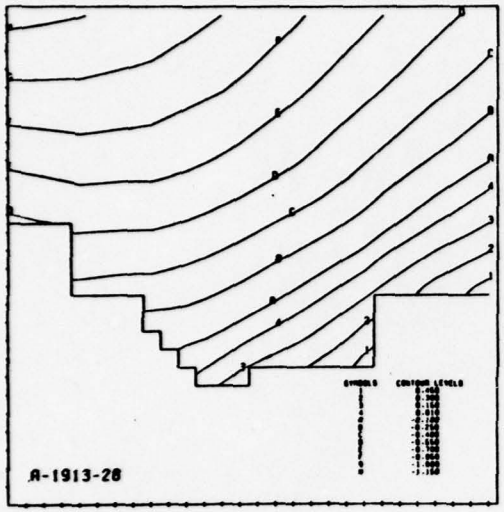


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

24 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913



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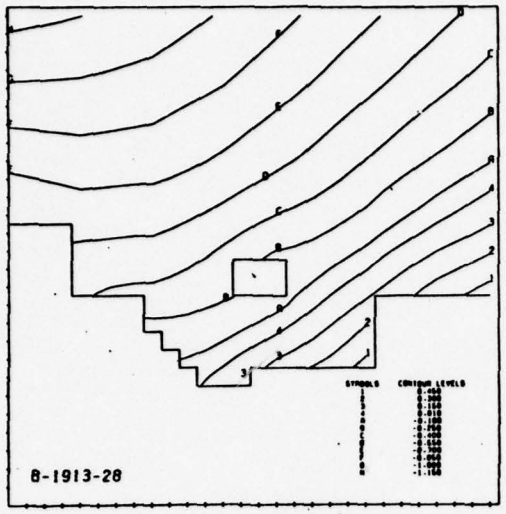

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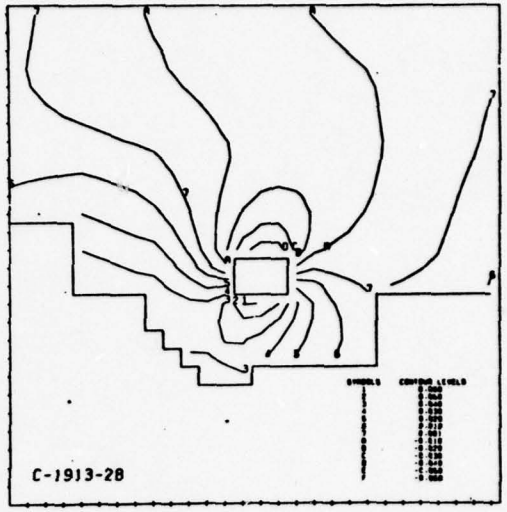
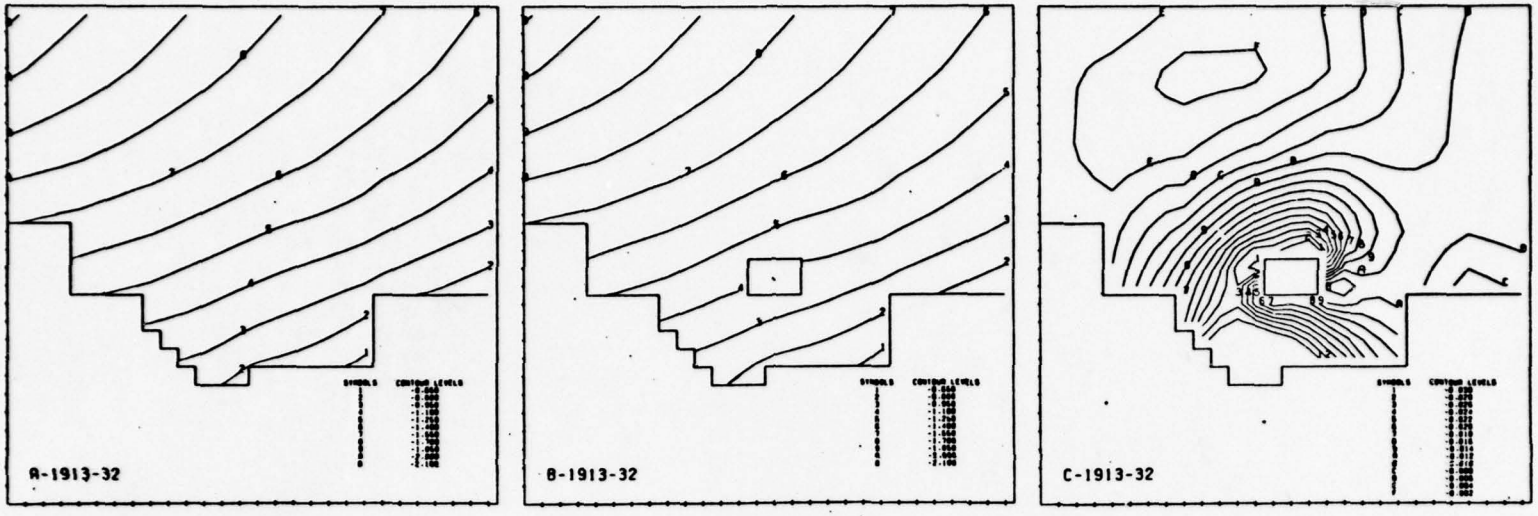


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

28 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913



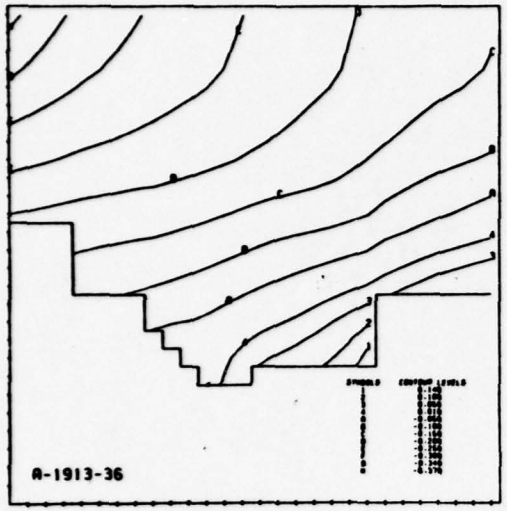
WITHOUT JETPORT

WITH JETPORT

DIFFERENCES

CONTOURS OF STORM
SURGE ELEVATIONS (FT)
IN NEARSHORE REGION

32 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913



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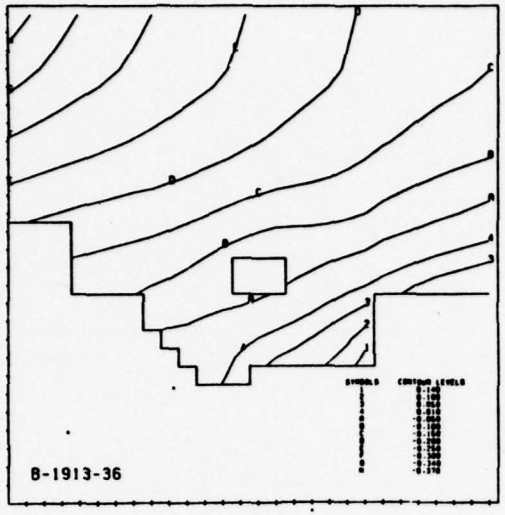

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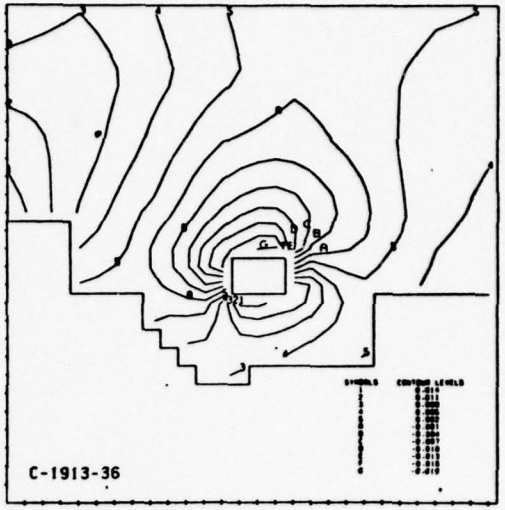
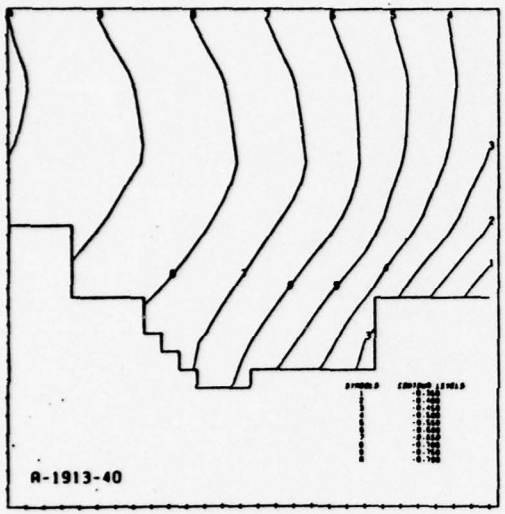


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

36 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913



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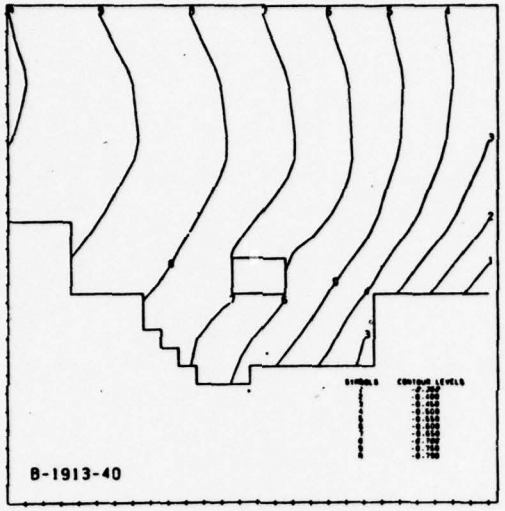

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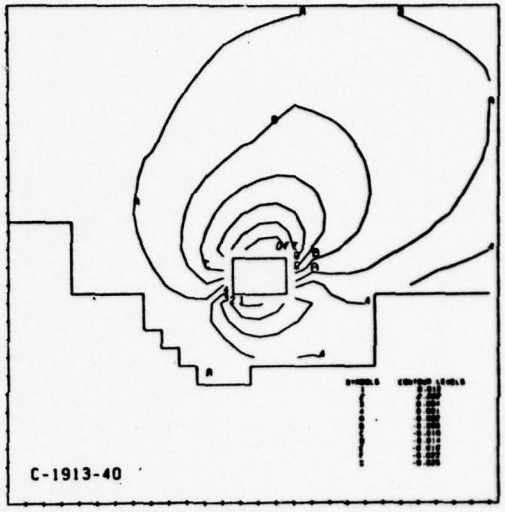
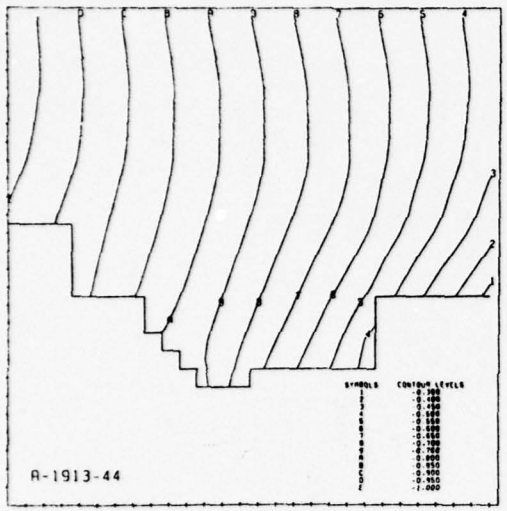


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

40 HOURS INTO STORM OF 0000 NOV 9 - 2300 NOV 10, 1913



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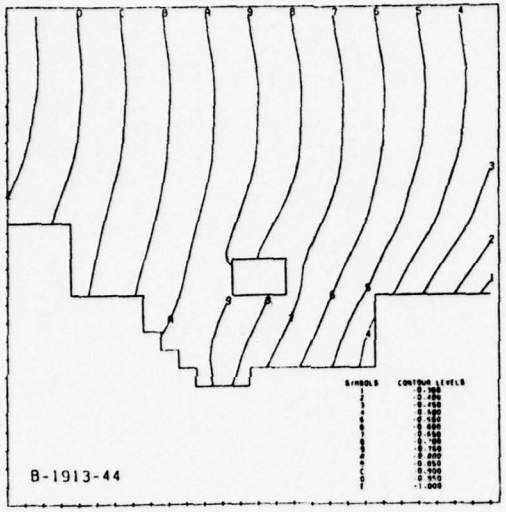

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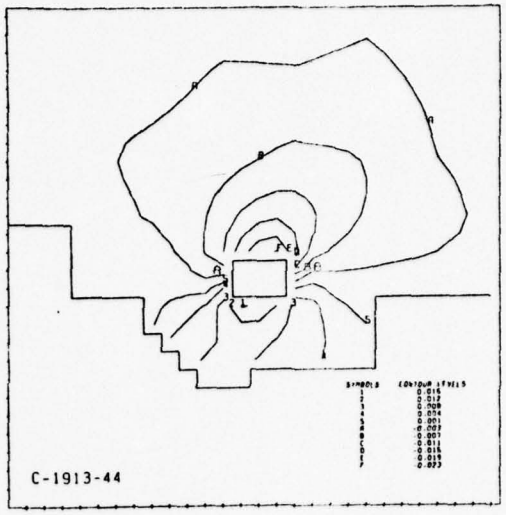
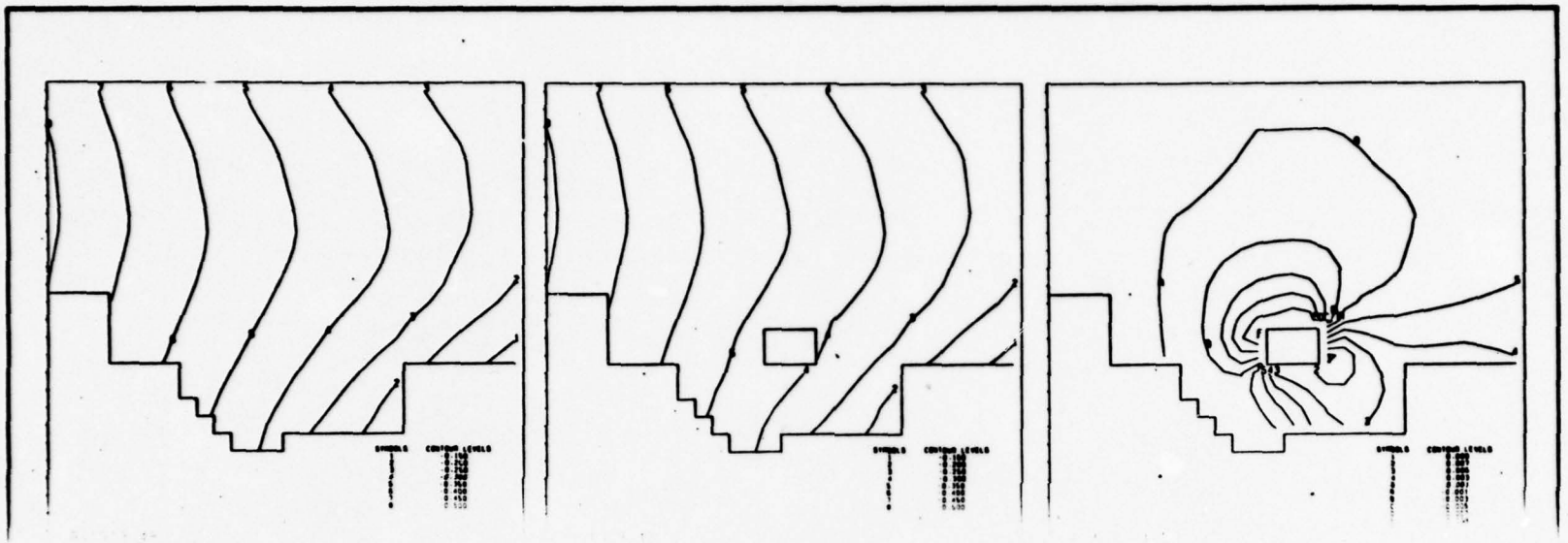


DIFFERENCES

CONTOURS OF STORM SURGE ELEVATIONS (FT) IN NEARSHORE REGION

44 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913



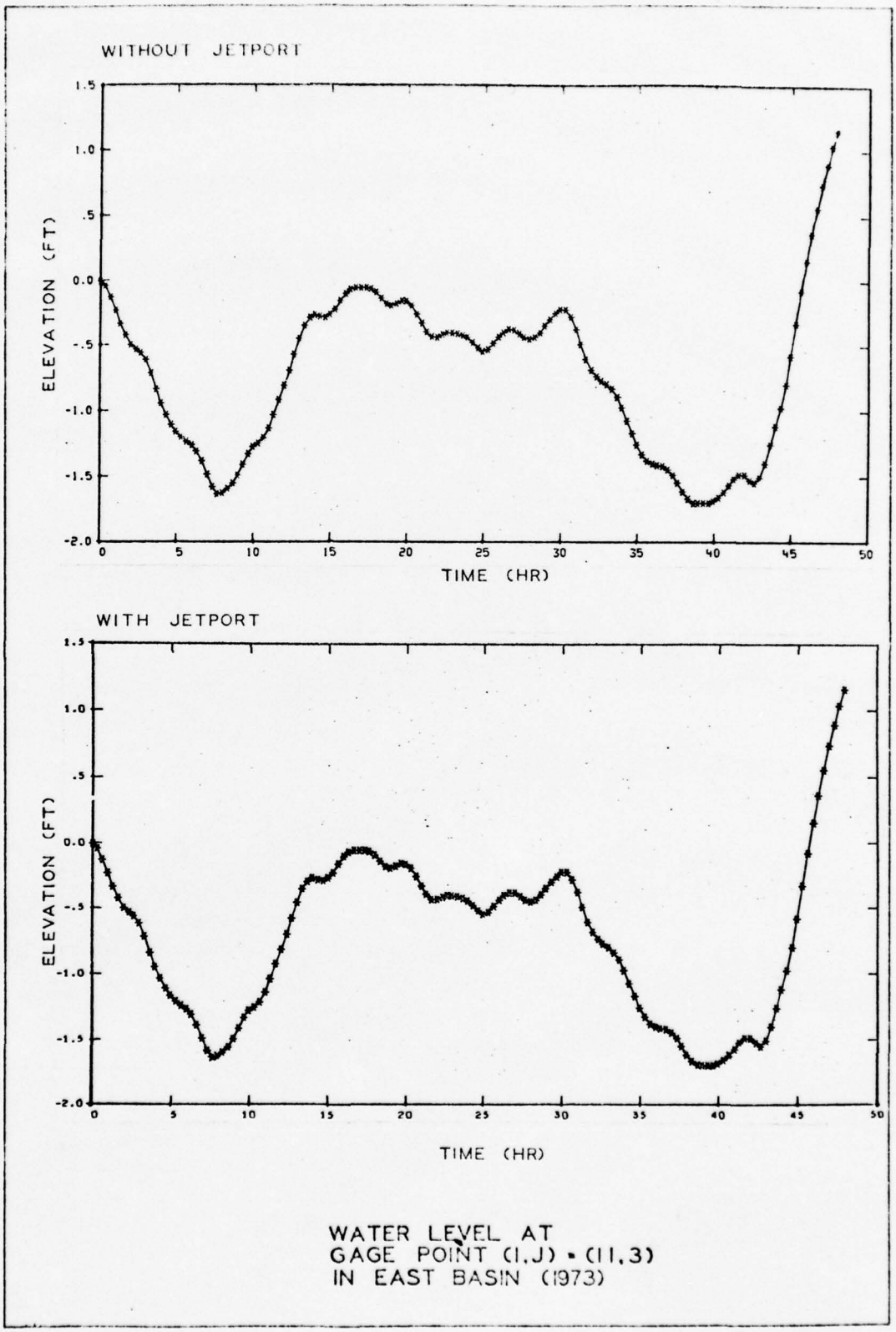
CONTOURS OF STORM
SURGE ELEVATIONS (FT)
IN NEARSHORE REGION

48 HOURS INTO STORM OF
0000 NOV 9 – 2300 NOV 10, 1913

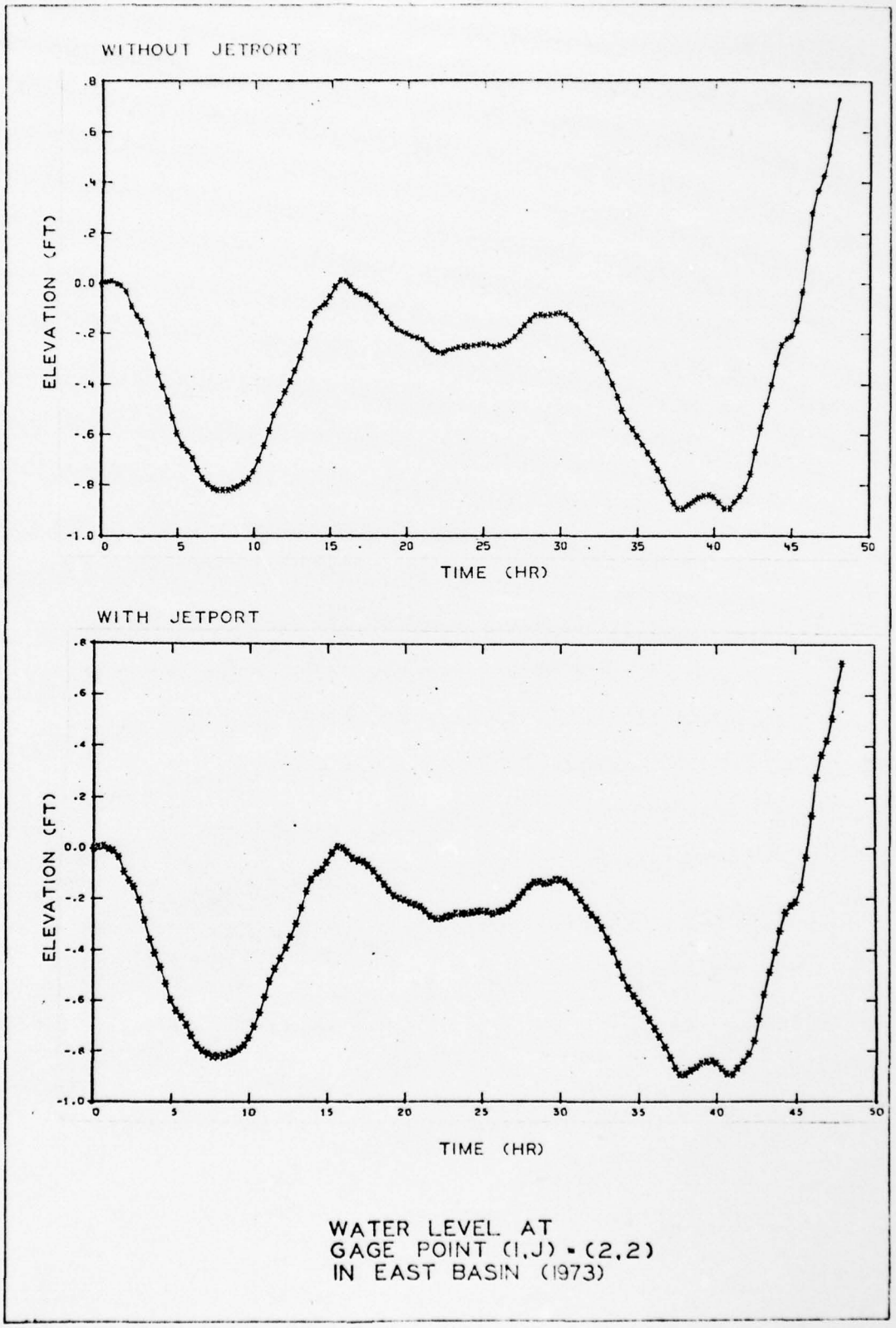
APPENDIX E: Time Histories of Storm Surge at Selected Locations

Inclosure 1: 8-9 April 1973 Storm
Inclosure 2: 25-27 November 1950 Storm
Inclosure 3: 7-10 November 1913 Storm

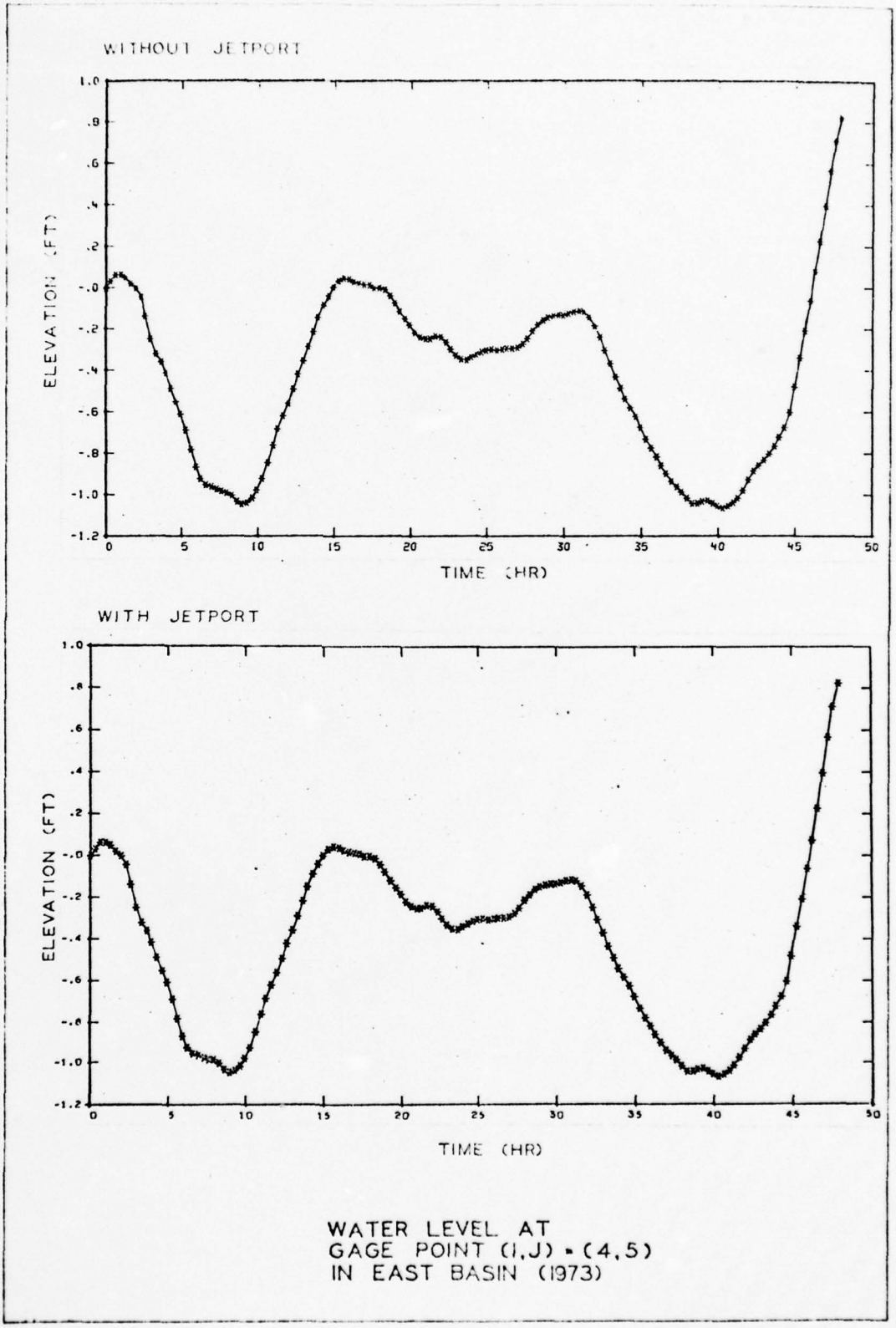
Inclosure 1: 8-9 April 1973 Storm



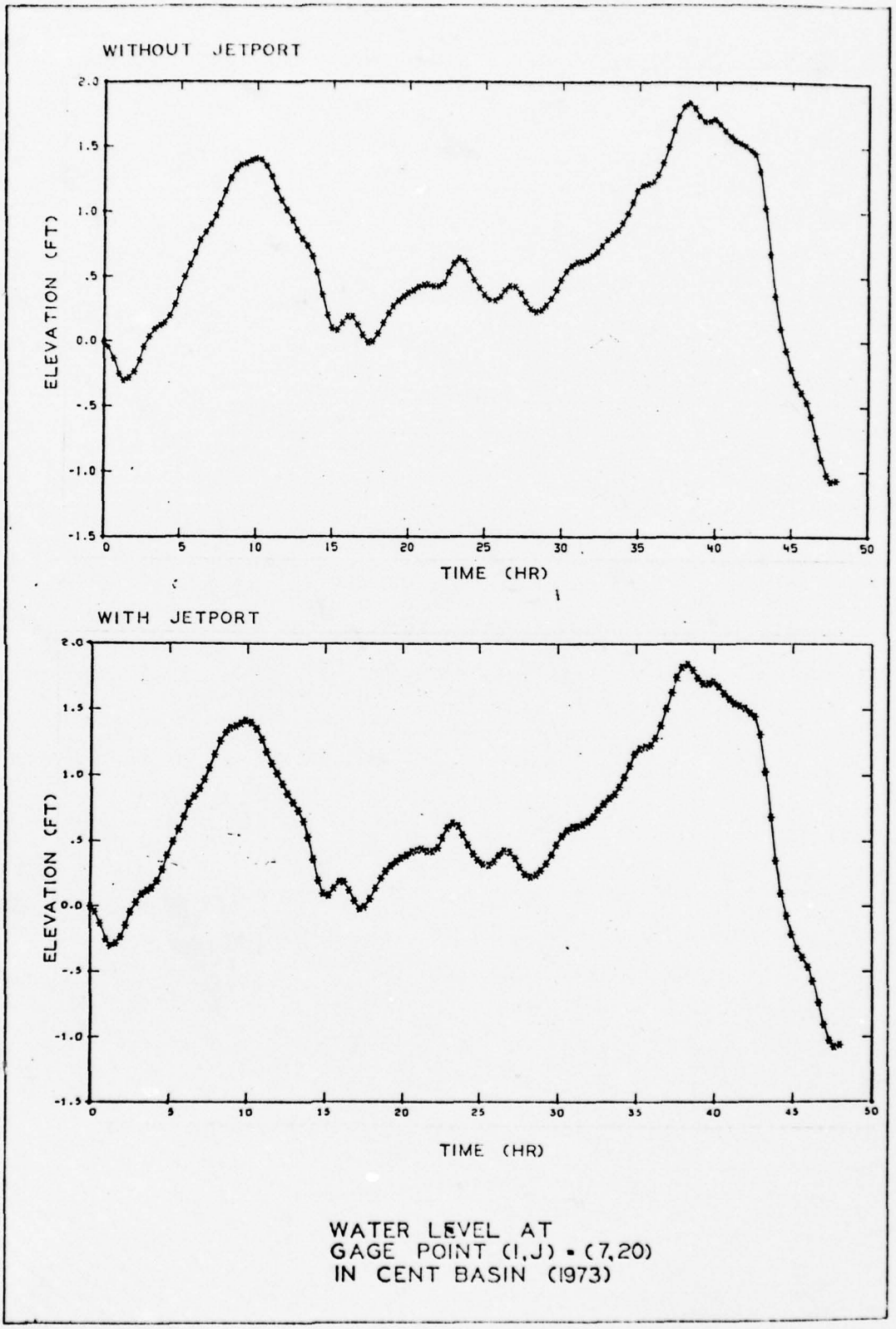
WATER LEVEL AT
GAGE POINT (1,J) = (11,3)
IN EAST BASIN (1973)



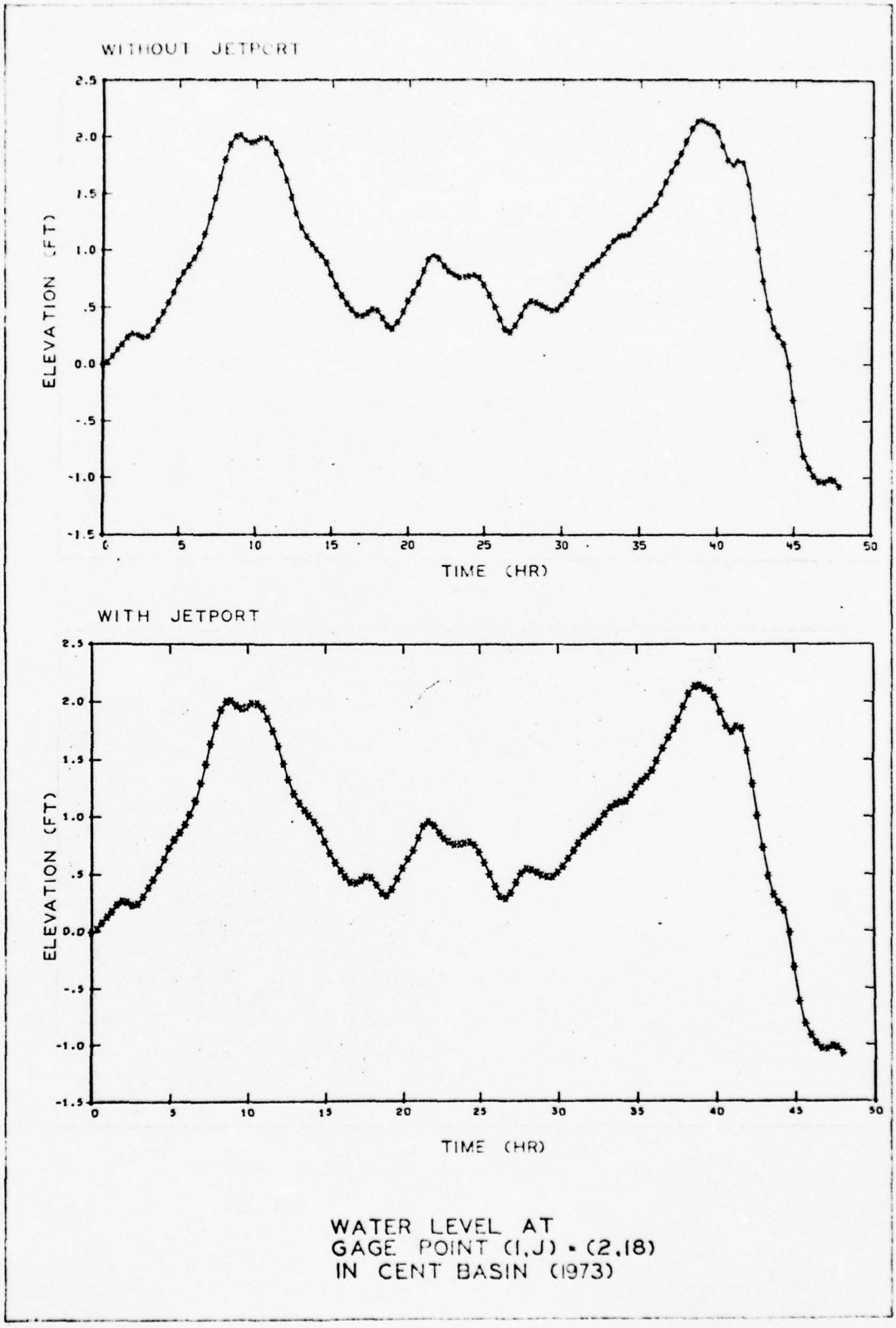
WATER LEVEL AT
GAGE POINT (I,J) = (2,2)
IN EAST BASIN (1973)



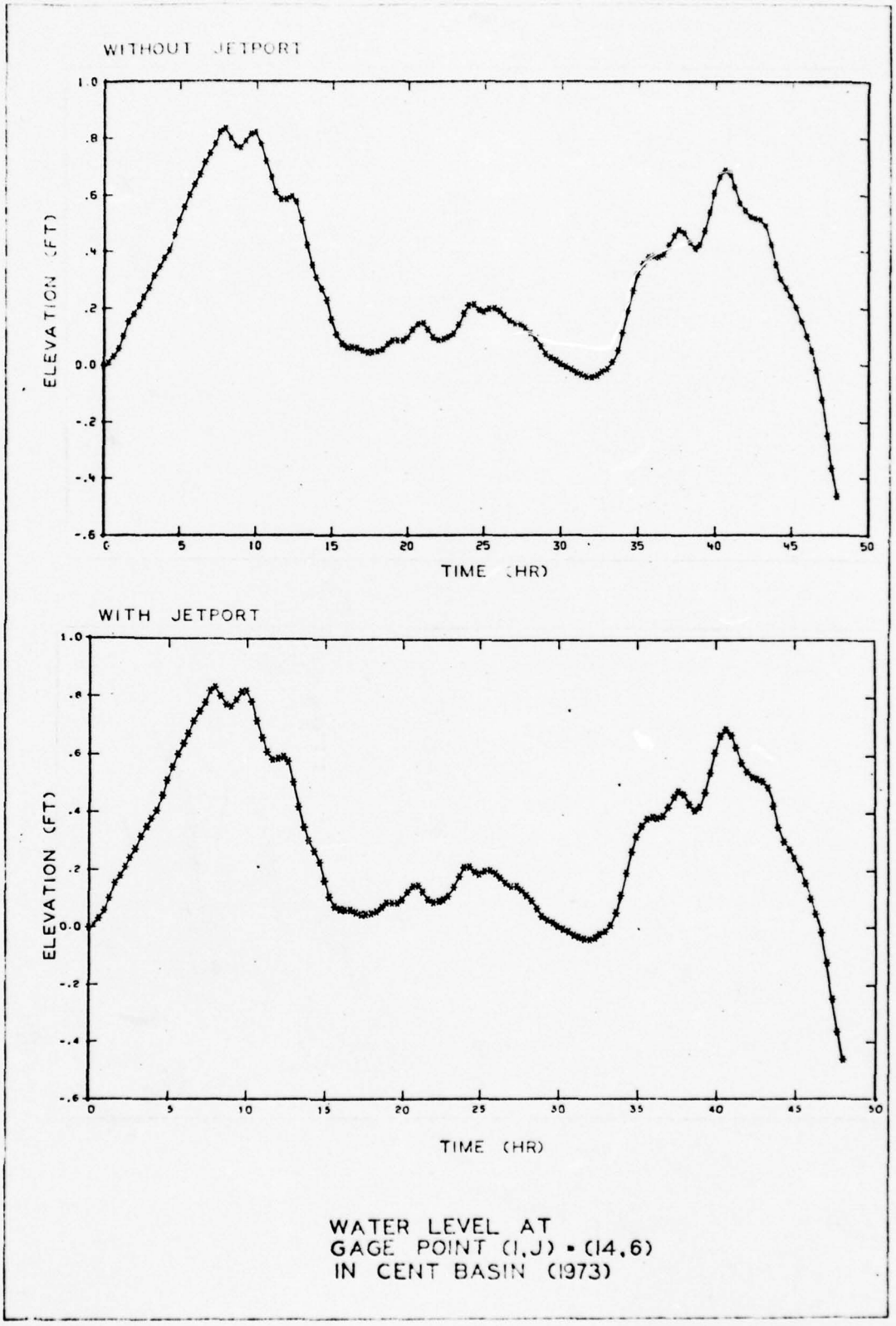
WATER LEVEL AT
GAGE POINT (I,J) = (4,5)
IN EAST BASIN (1973)



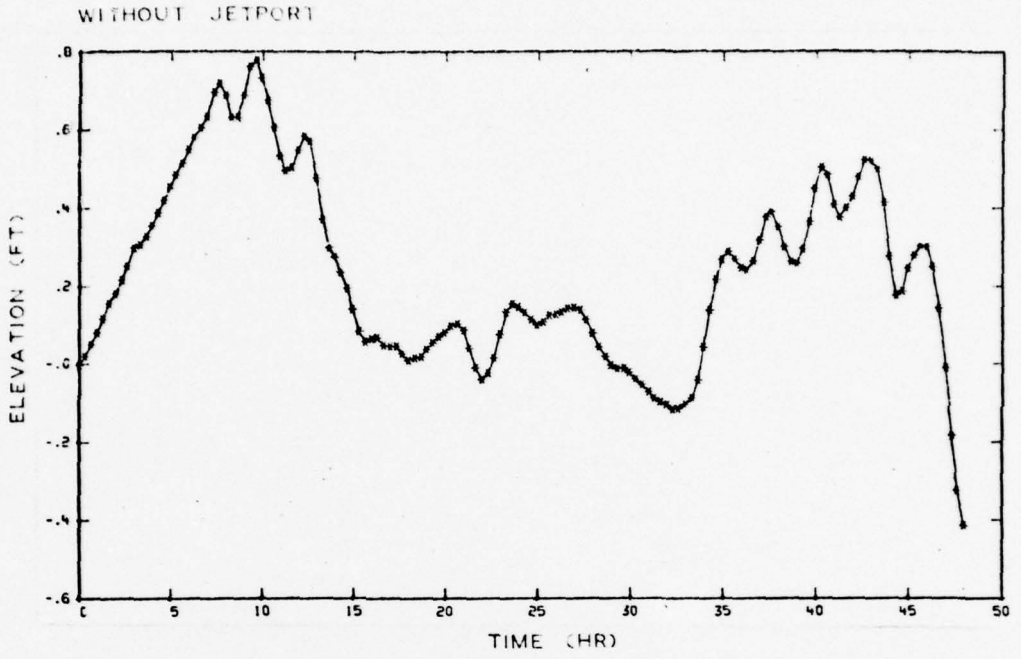
WATER LEVEL AT
GAGE POINT (I,J) = (7,20)
IN CENT BASIN (1973)

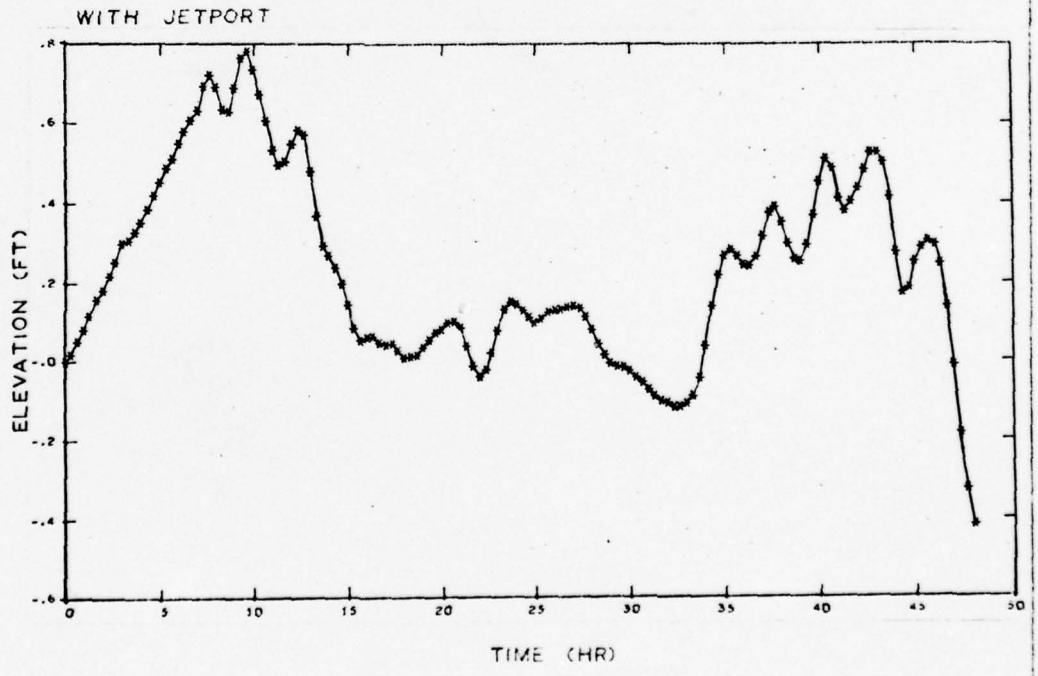


WATER LEVEL AT
GAGE POINT (I,J) = (2,18)
IN CENT BASIN (1973)

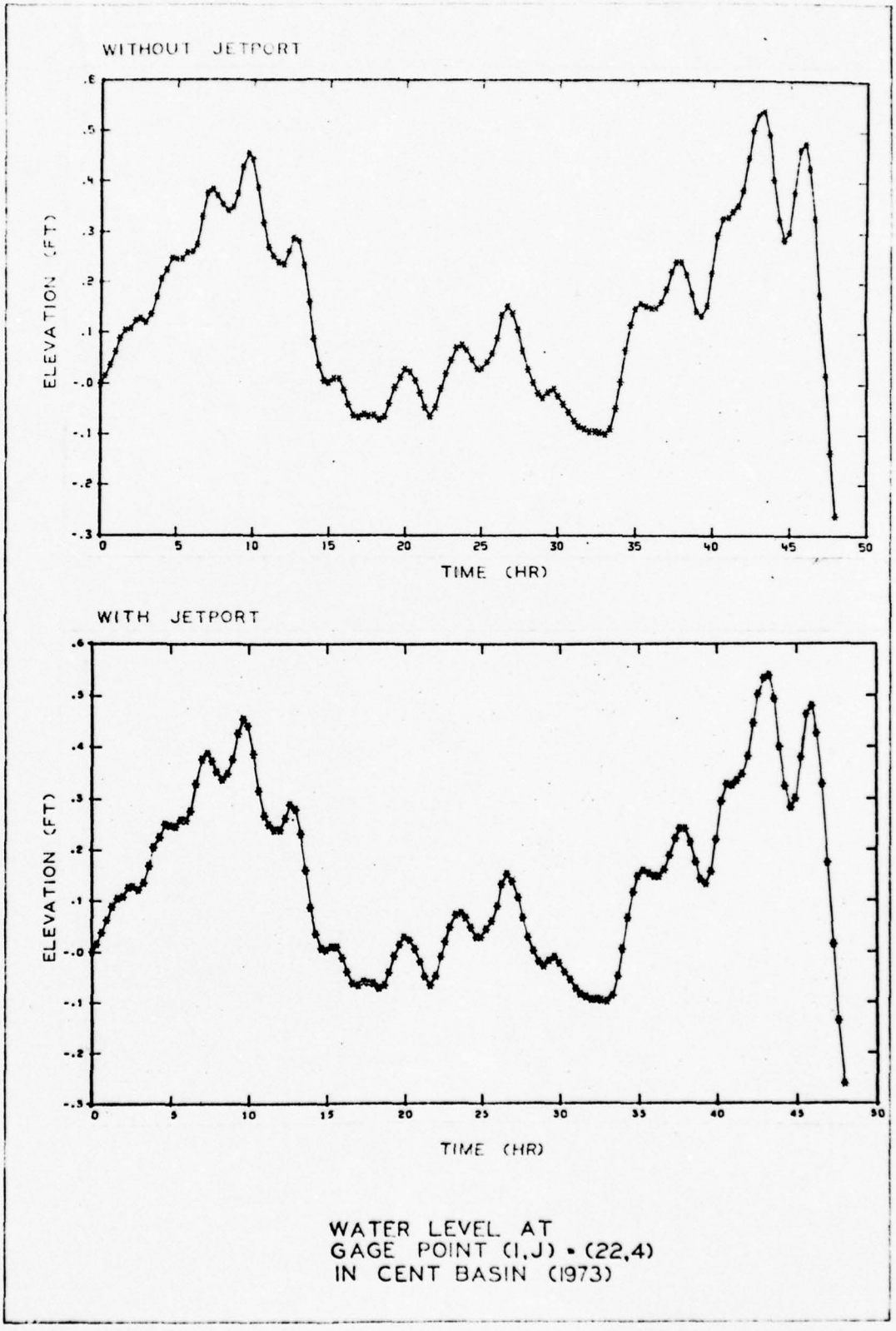


WATER LEVEL AT
GAGE POINT (I,J) = (14,6)
IN CENT BASIN (1973)

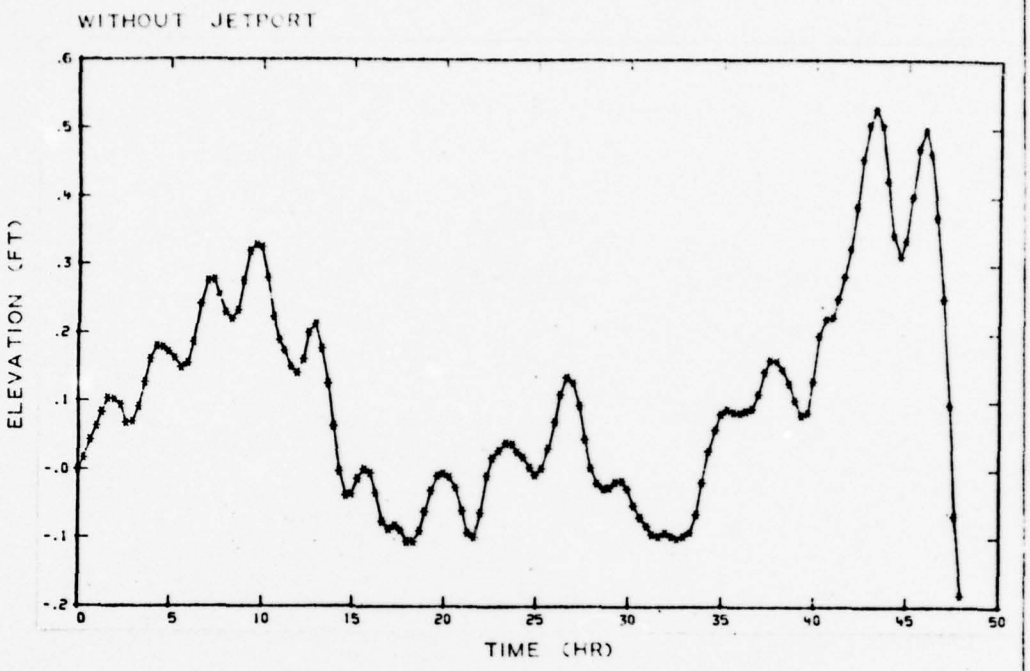


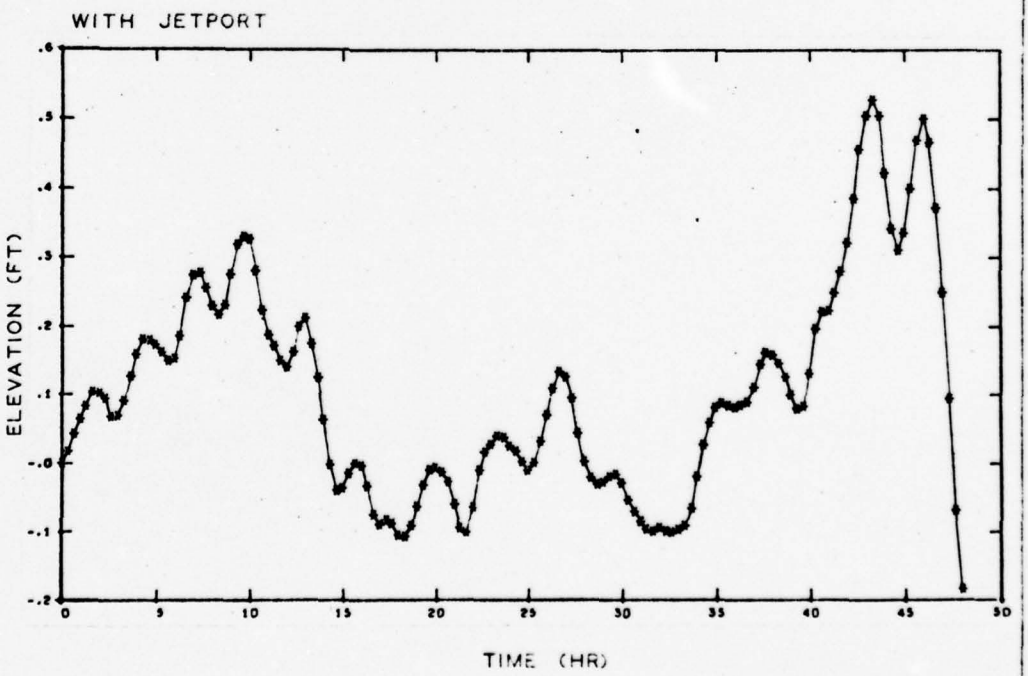


WATER LEVEL AT
GAGE POINT (I,J) = (16,4)
IN CENT BASIN (1973)

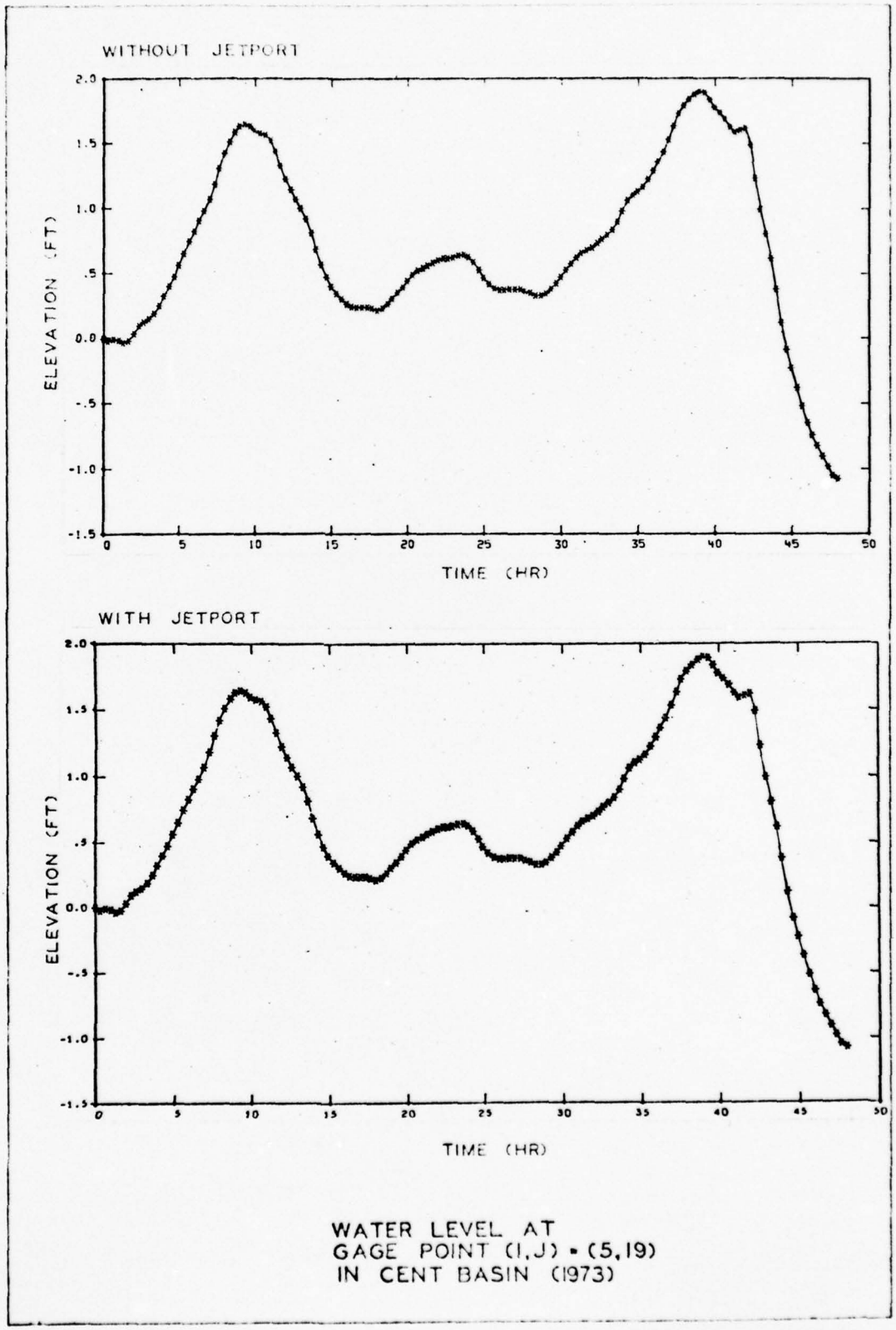


WATER LEVEL AT
GAGE POINT (I,J) = (22,4)
IN CENT BASIN (1973)

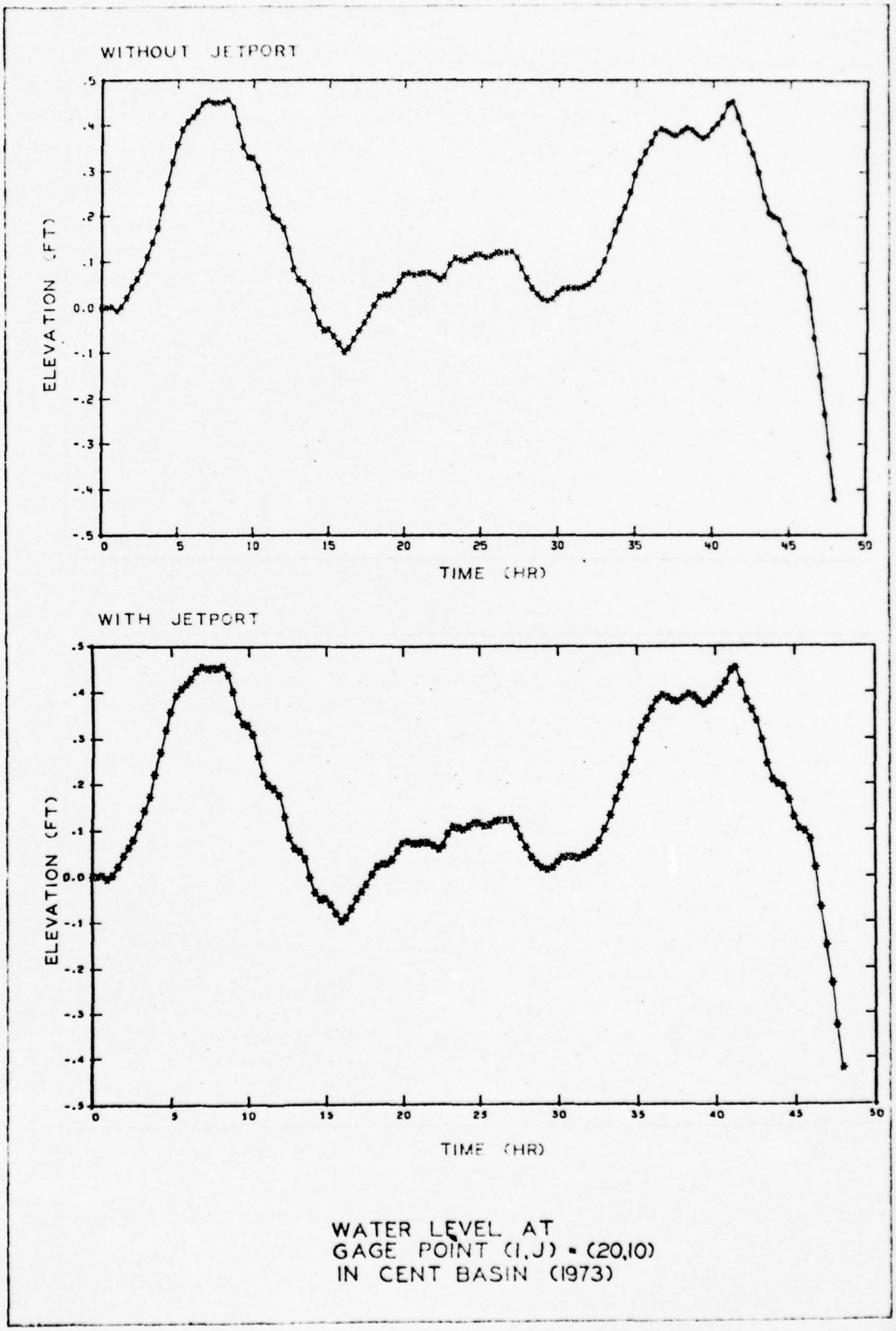




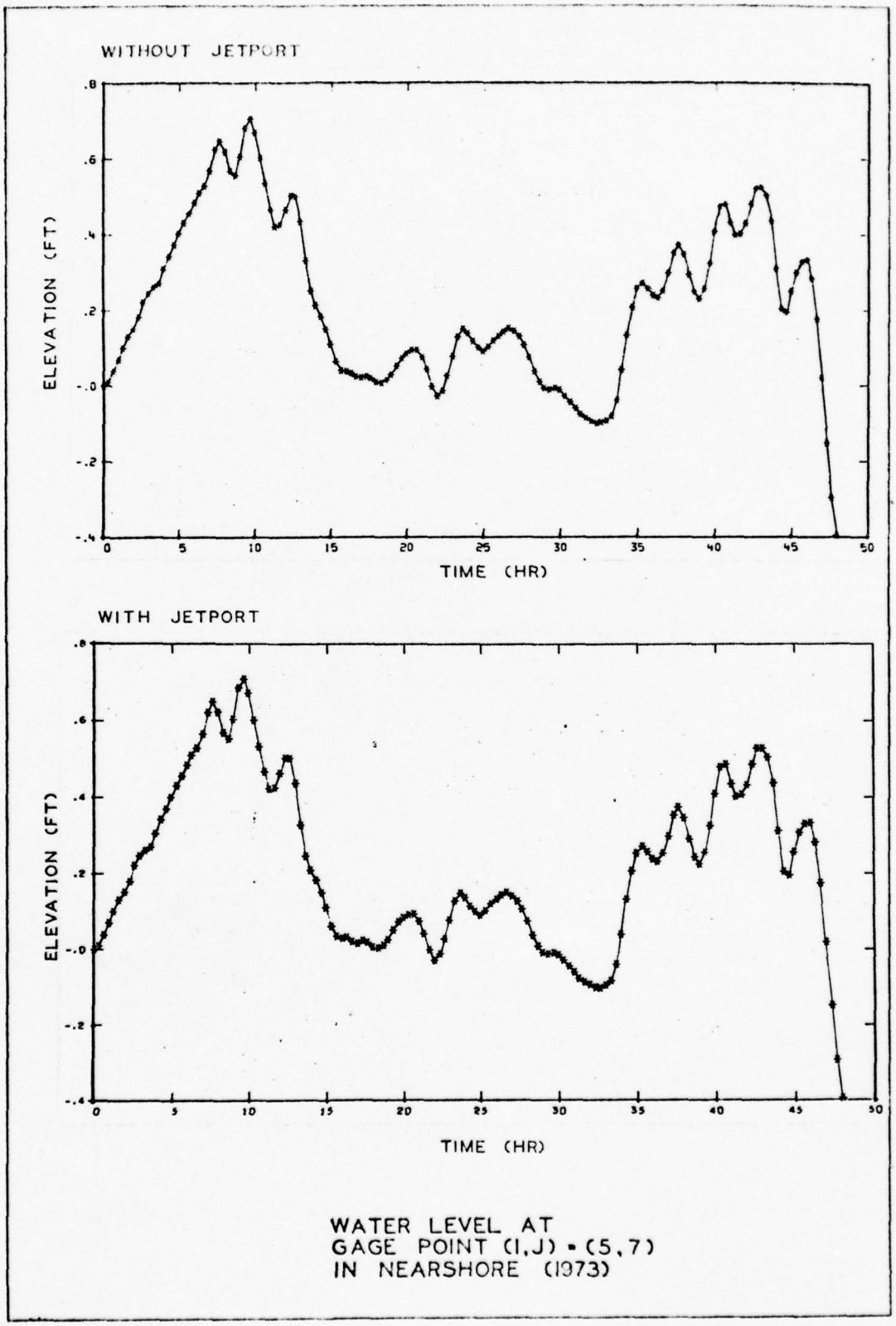
WATER LEVEL AT
GAGE POINT (I,J) = (24,4)
IN CENT BASIN (1973)



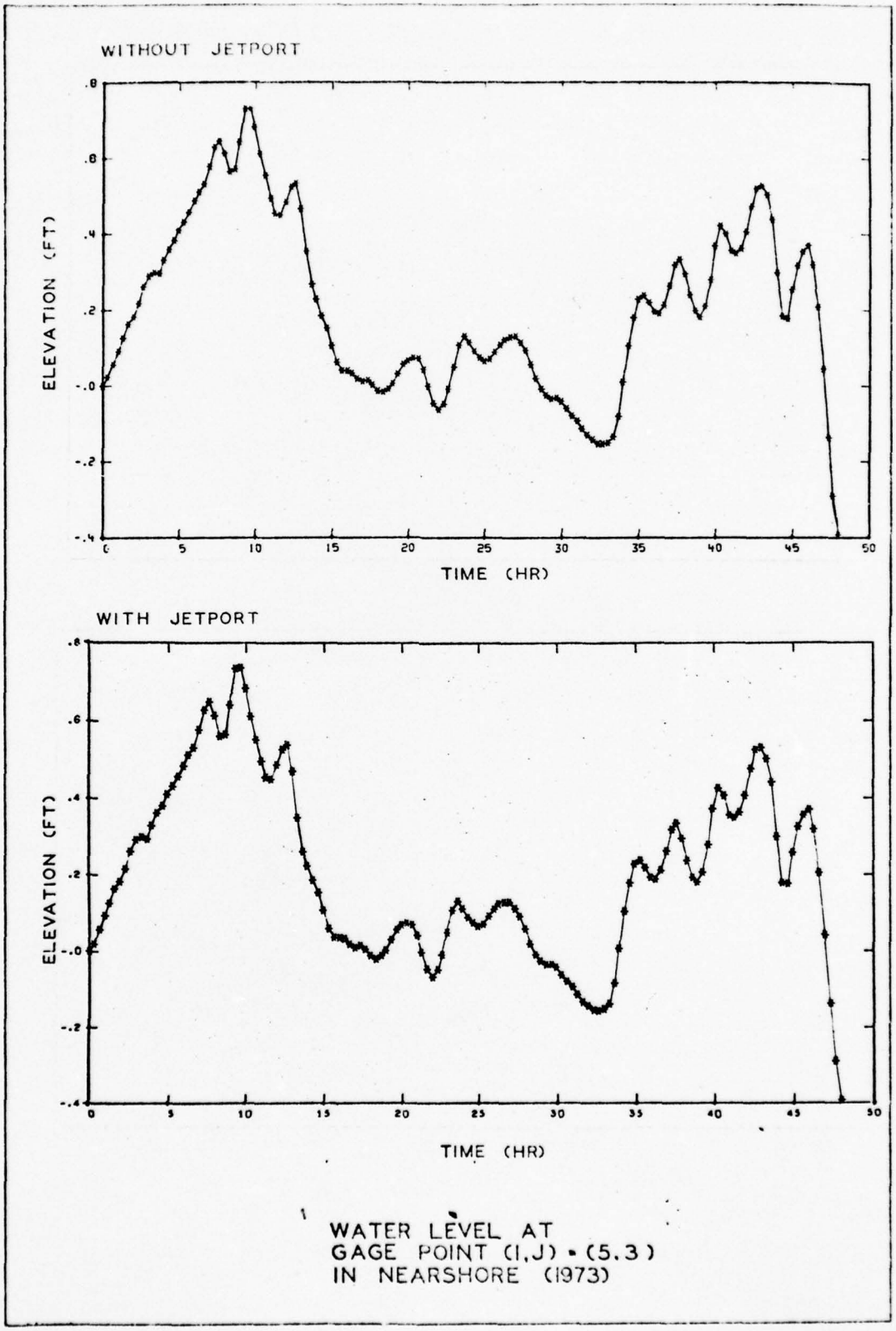
WATER LEVEL AT
GAGE POINT (I,J) = (5,19)
IN CENT BASIN (1973)



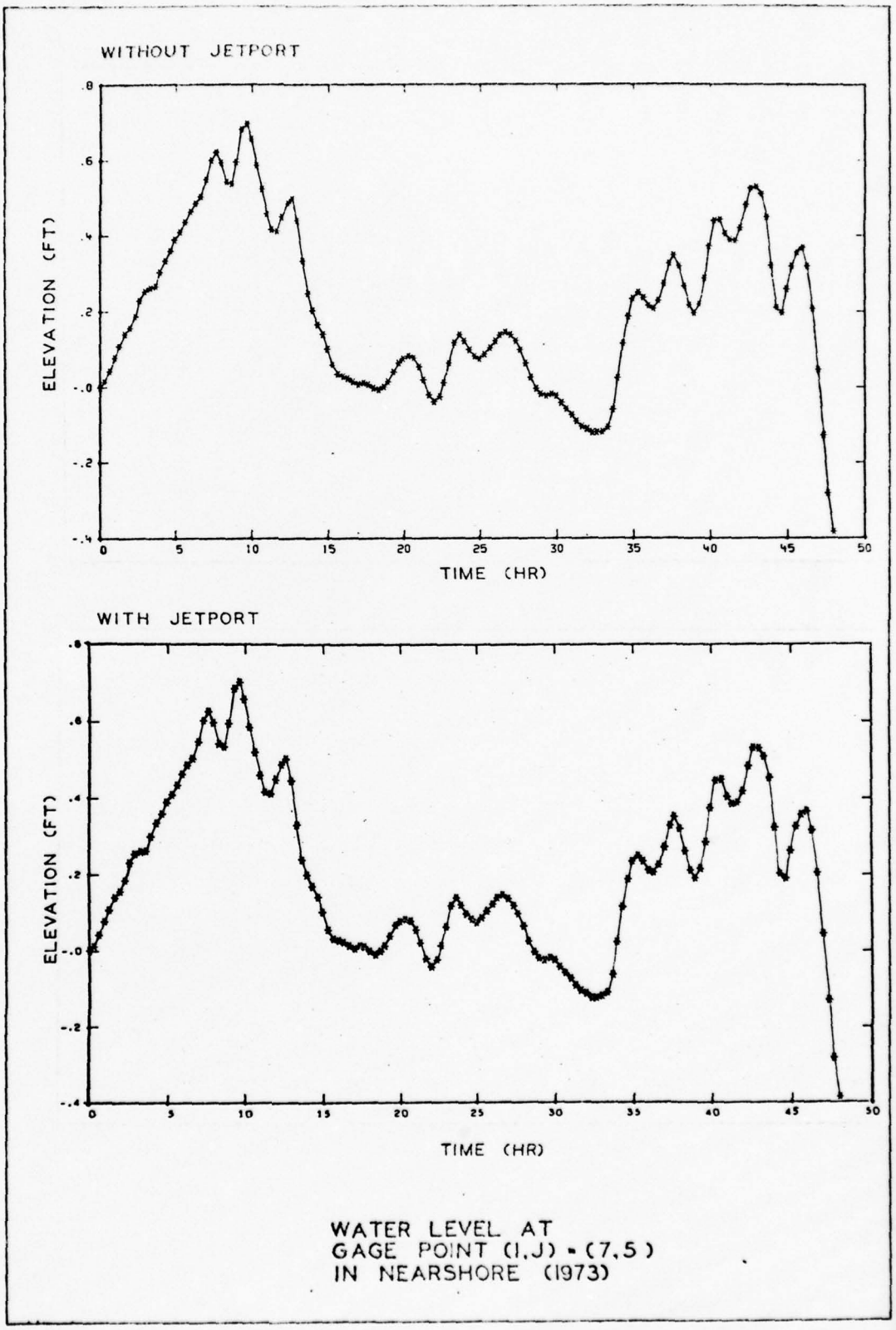
WATER LEVEL AT
GAGE POINT (I,J) = (20,10)
IN CENT BASIN (1973)



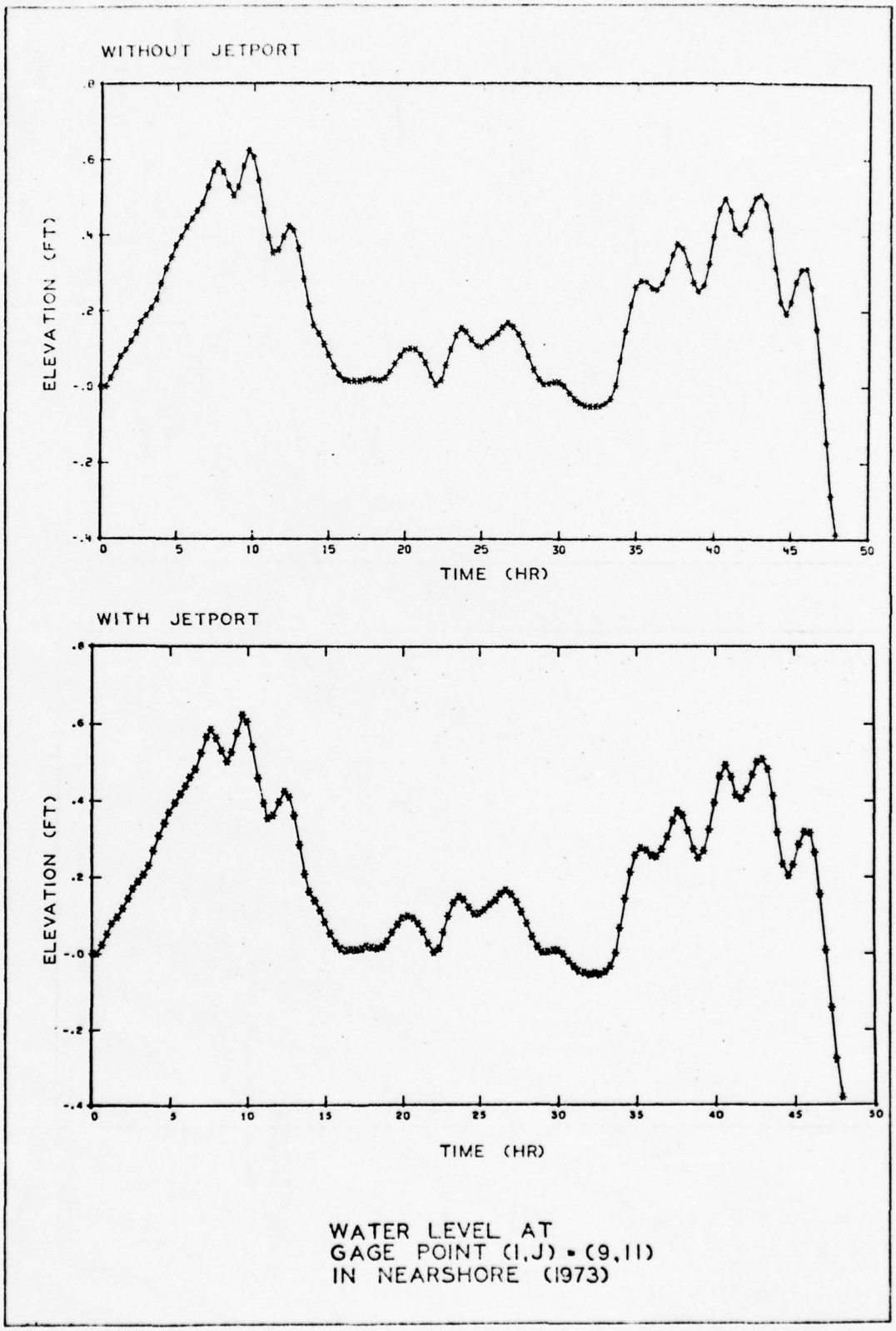
WATER LEVEL AT
GAGE POINT (I,J) = (5,7)
IN NEARSHORE (1973)



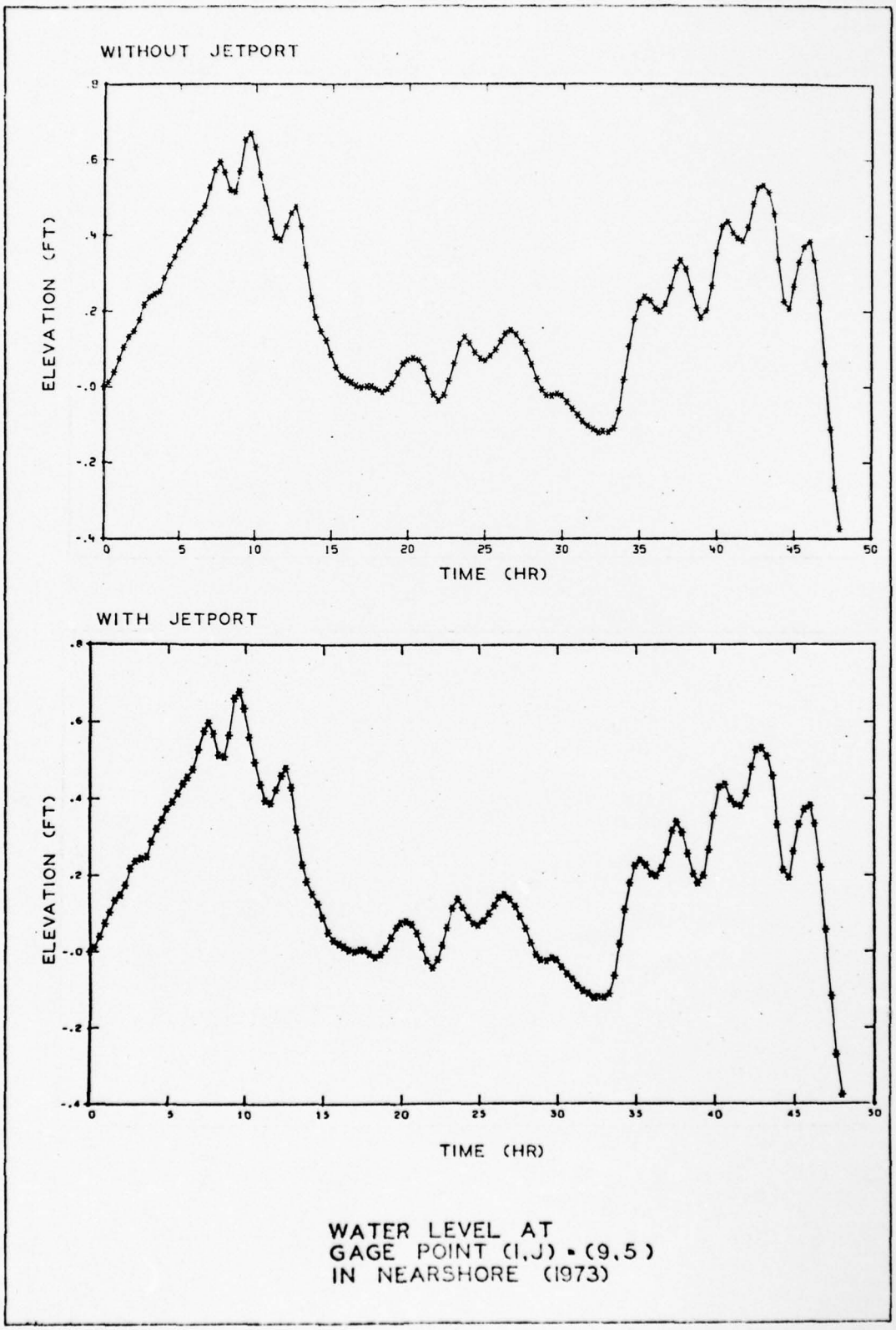
WATER LEVEL AT
GAGE POINT (I,J) = (5,3)
IN NEARSHORE (1973)



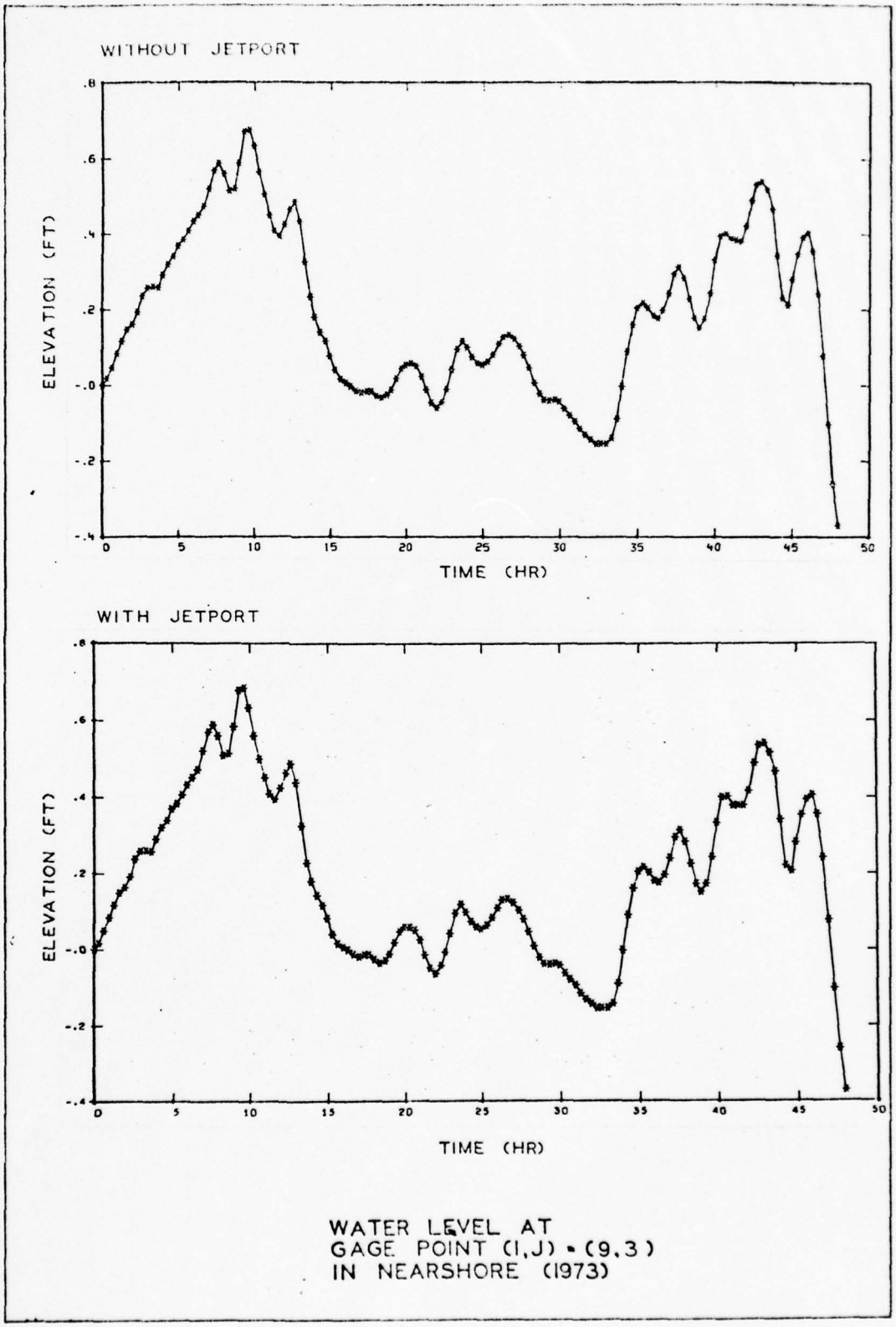
WATER LEVEL AT
GAGE POINT (I,J) = (7,5)
IN NEARSHORE (1973)



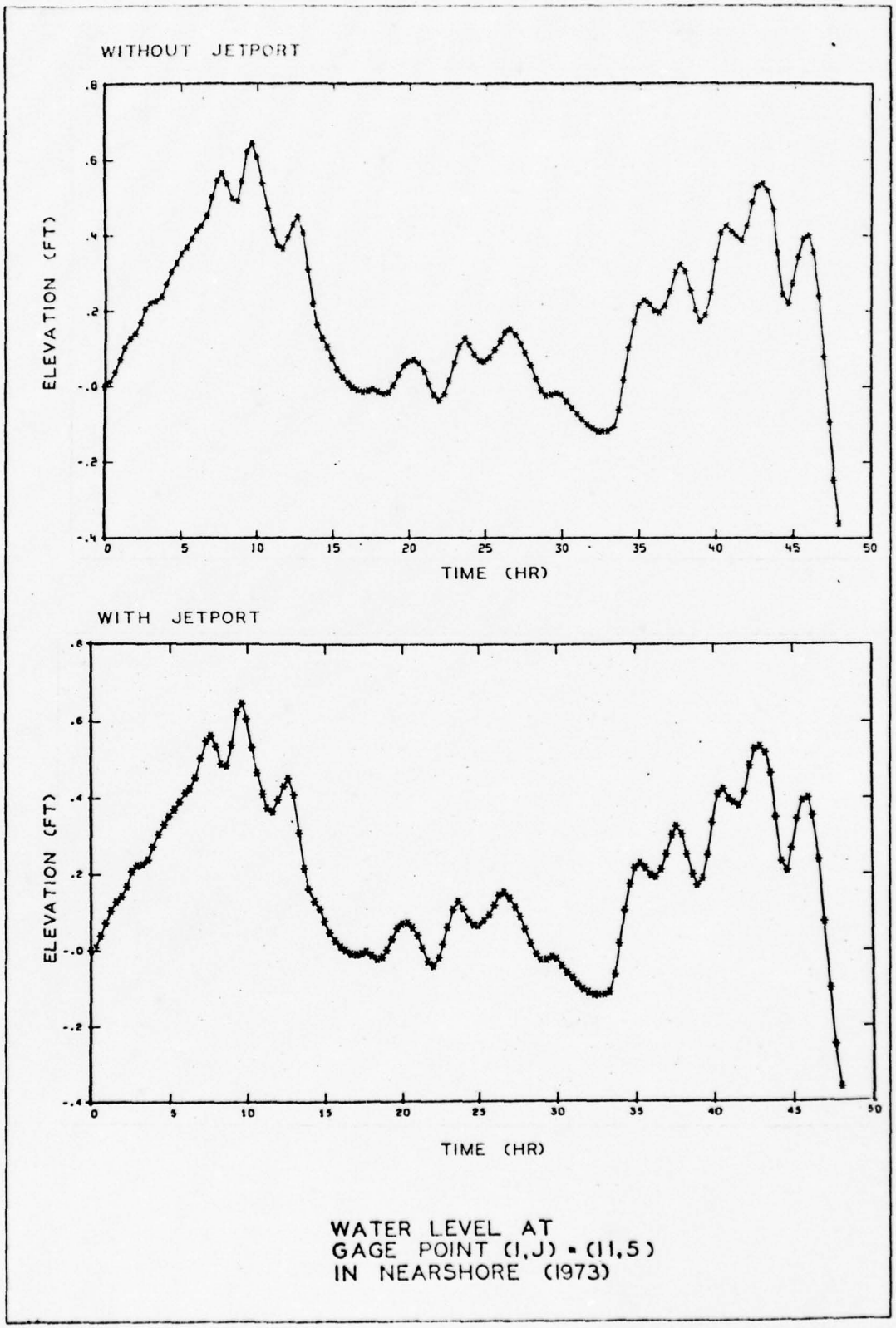
WATER LEVEL AT
GAGE POINT (I,J) = (9,11)
IN NEARSHORE (1973)



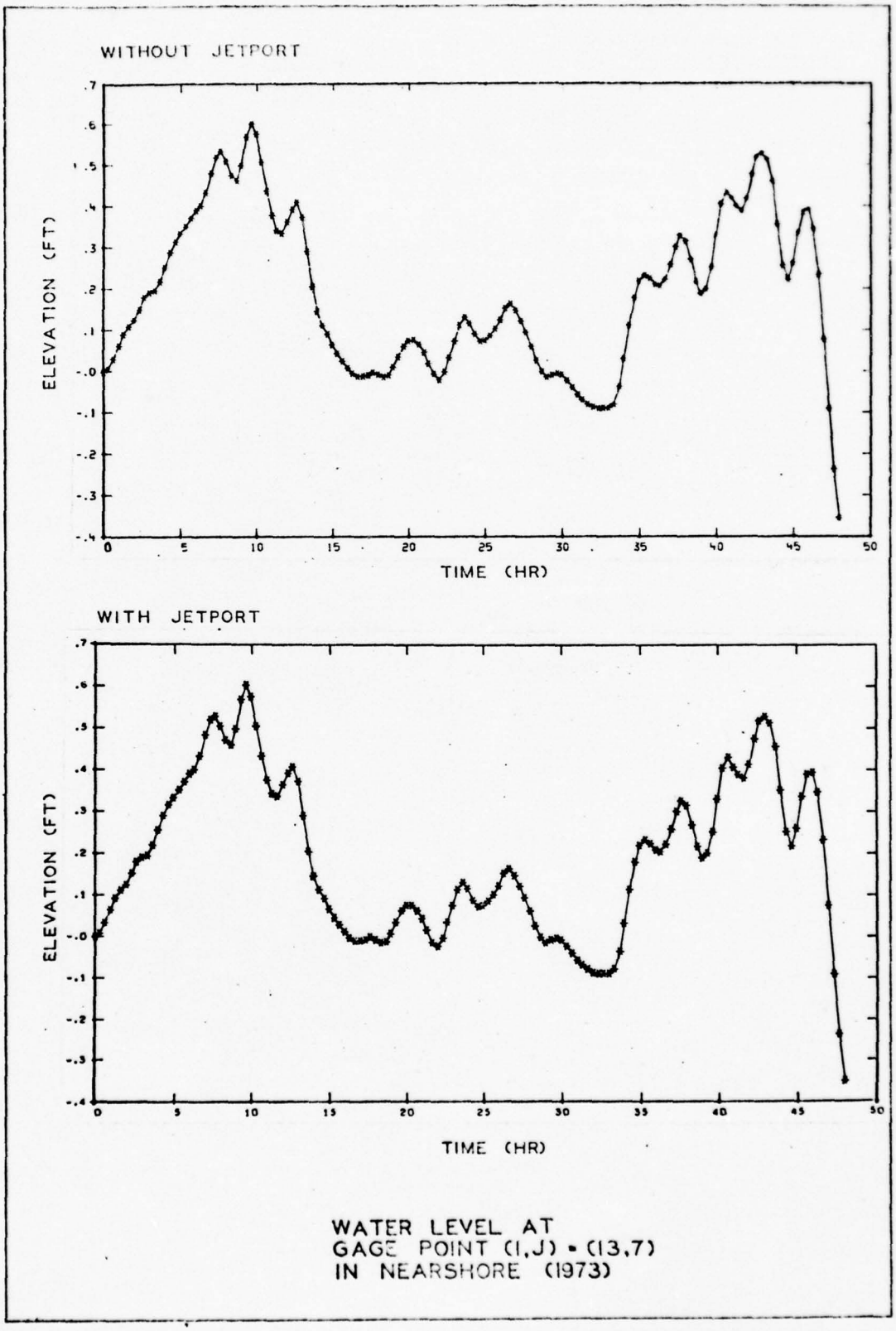
WATER LEVEL AT
GAGE POINT (I,J) = (9,5)
IN NEARSHORE (1973)



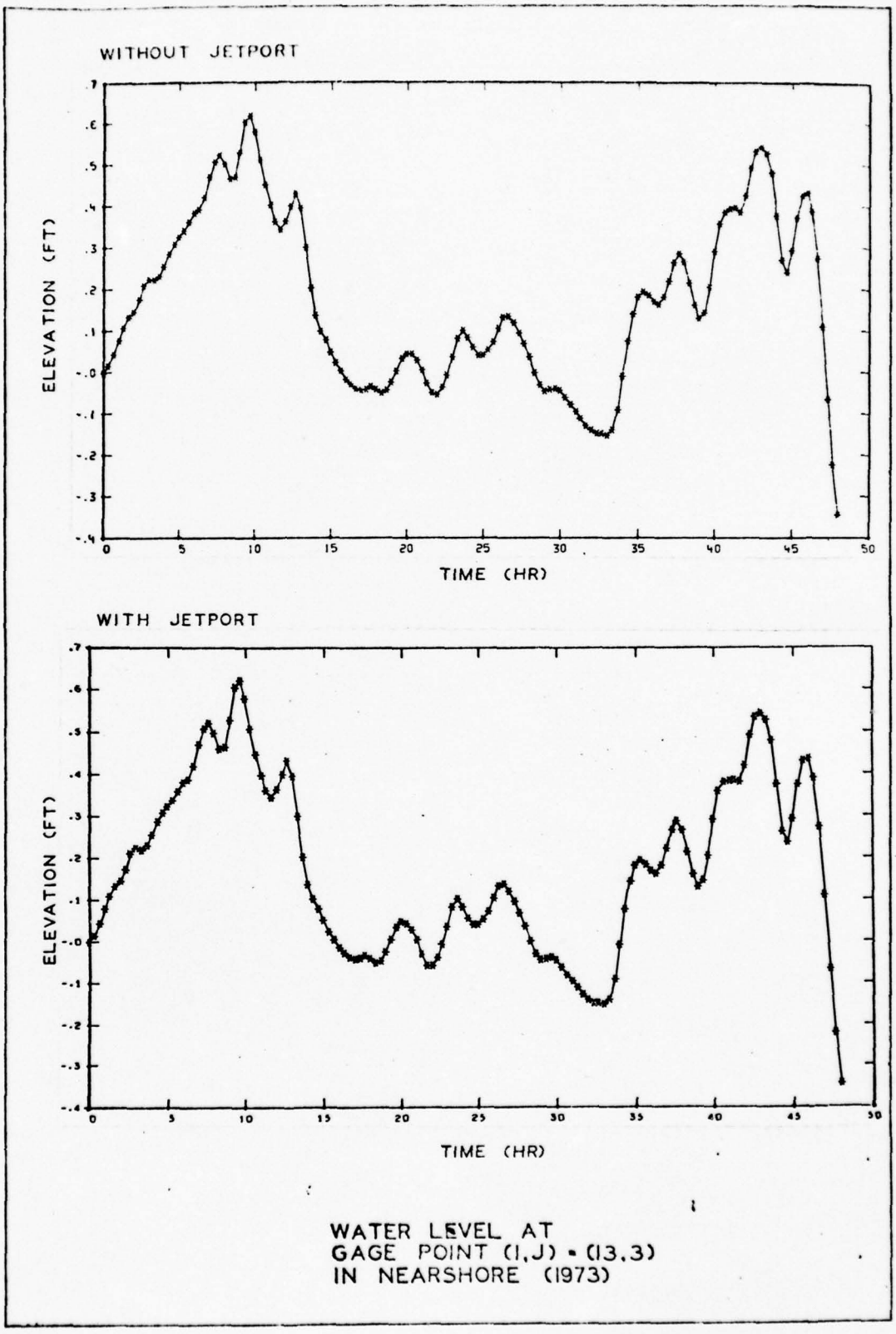
WATER LEVEL AT
GAGE POINT (I,J) = (9,3)
IN NEARSHORE (1973)



WATER LEVEL AT
GAGE POINT (I,J) = (11,5)
IN NEARSHORE (1973)

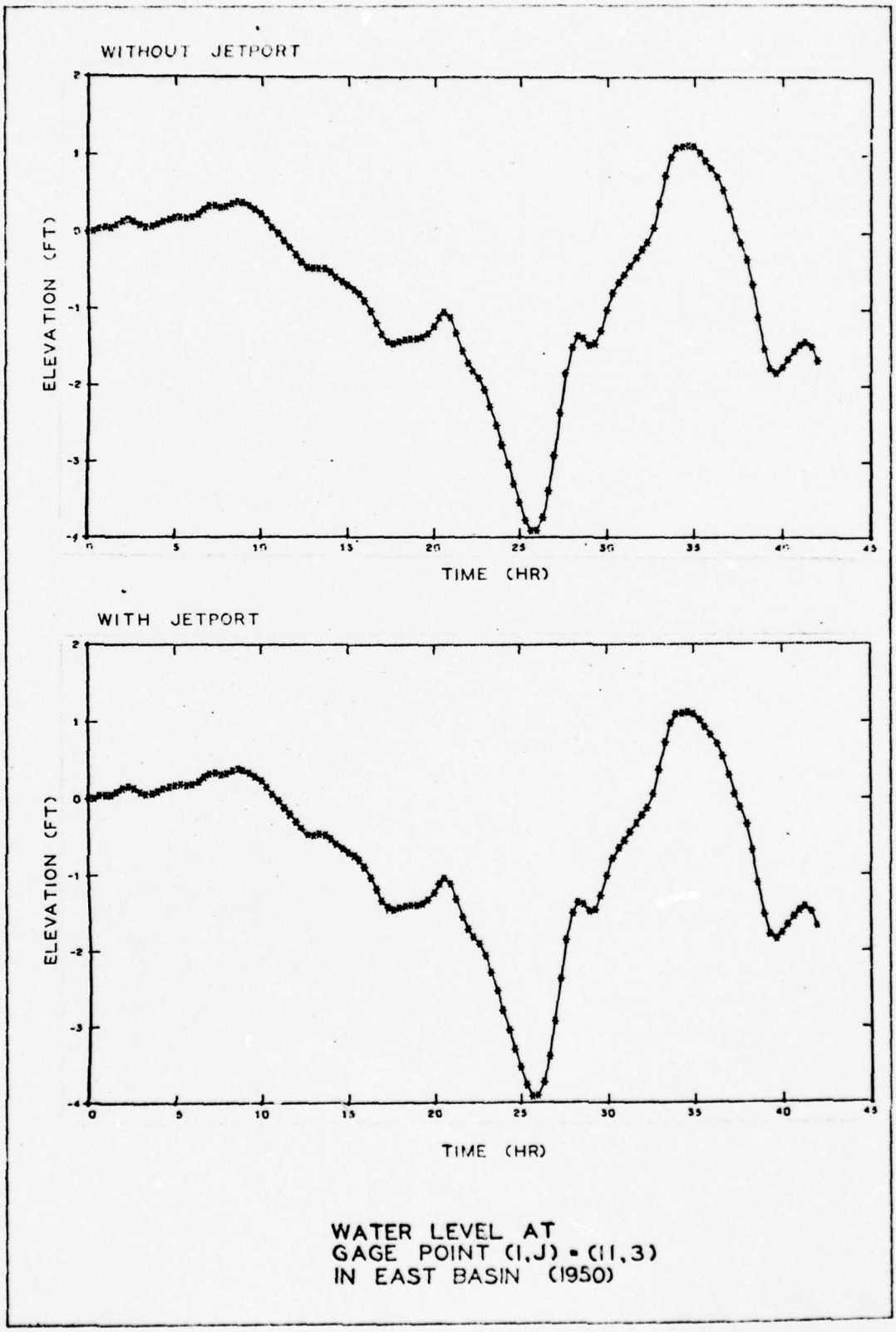


WATER LEVEL AT
GAGE POINT (I,J) = (13,7)
IN NEARSHORE (1973)

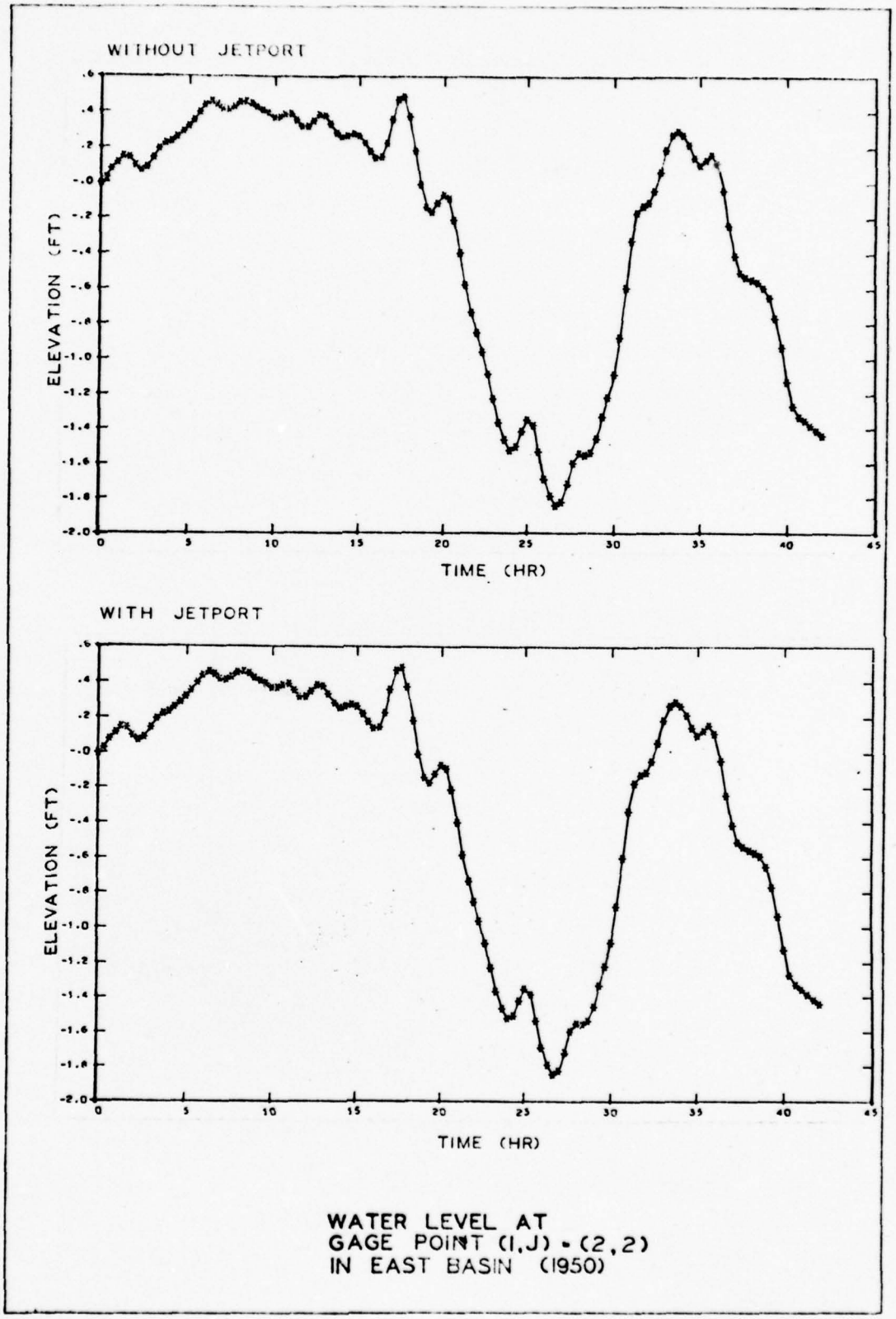


WATER LEVEL AT
GAGE POINT (I,J) = (13,3)
IN NEARSHORE (1973)

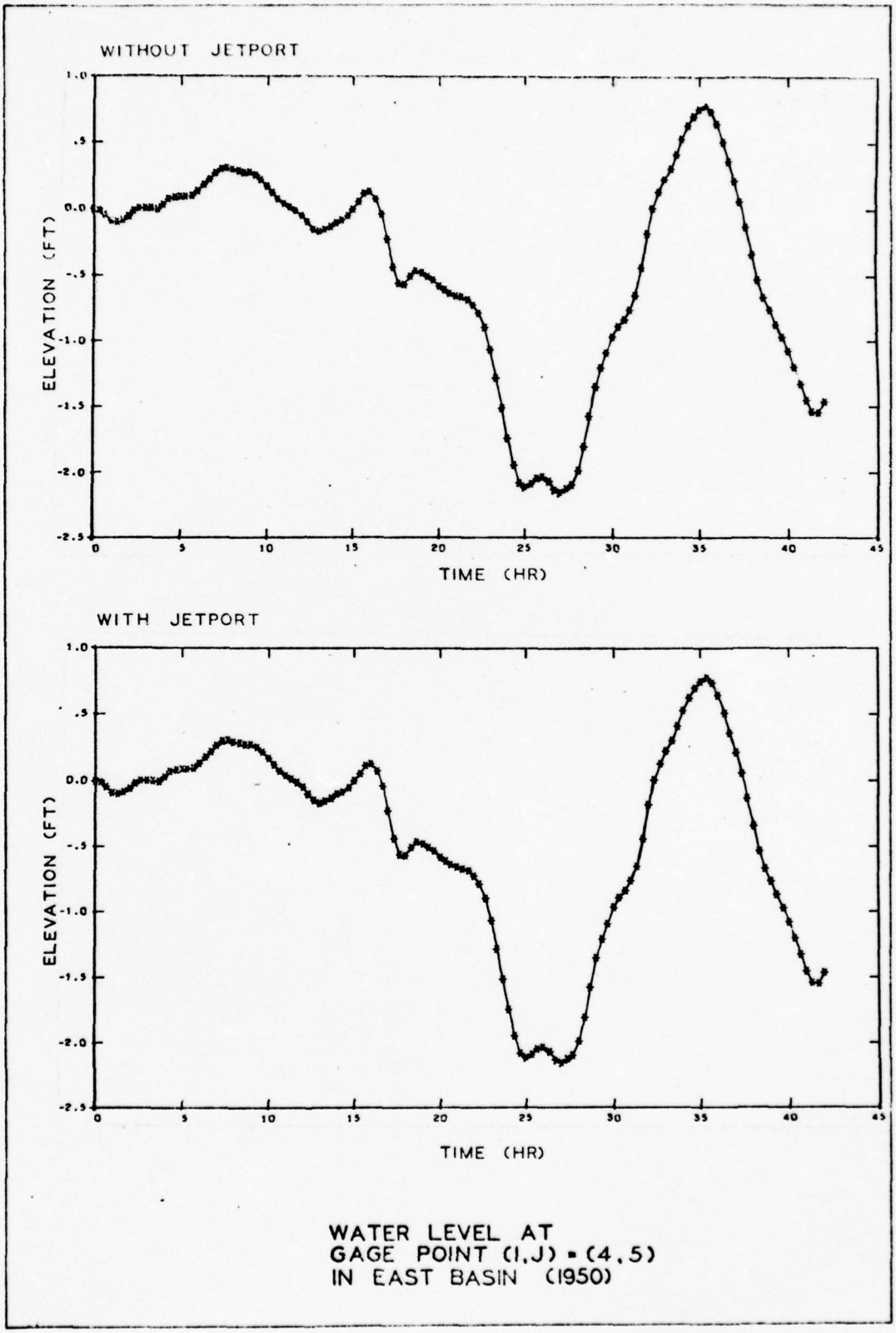
Inclosure 2: 25-27 November 1950 Storm



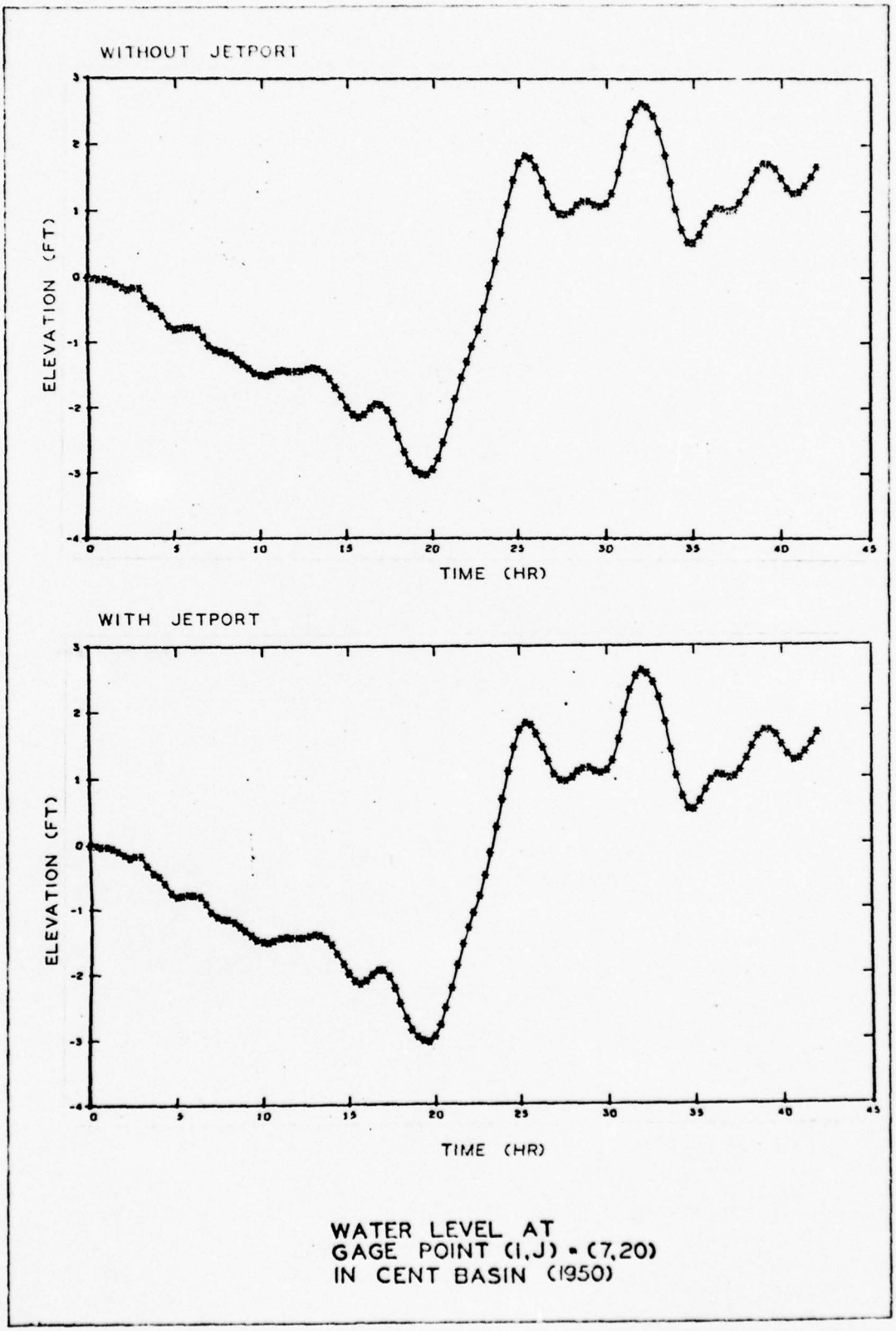
WATER LEVEL AT
GAGE POINT (I,J) = (11,3)
IN EAST BASIN (1950)



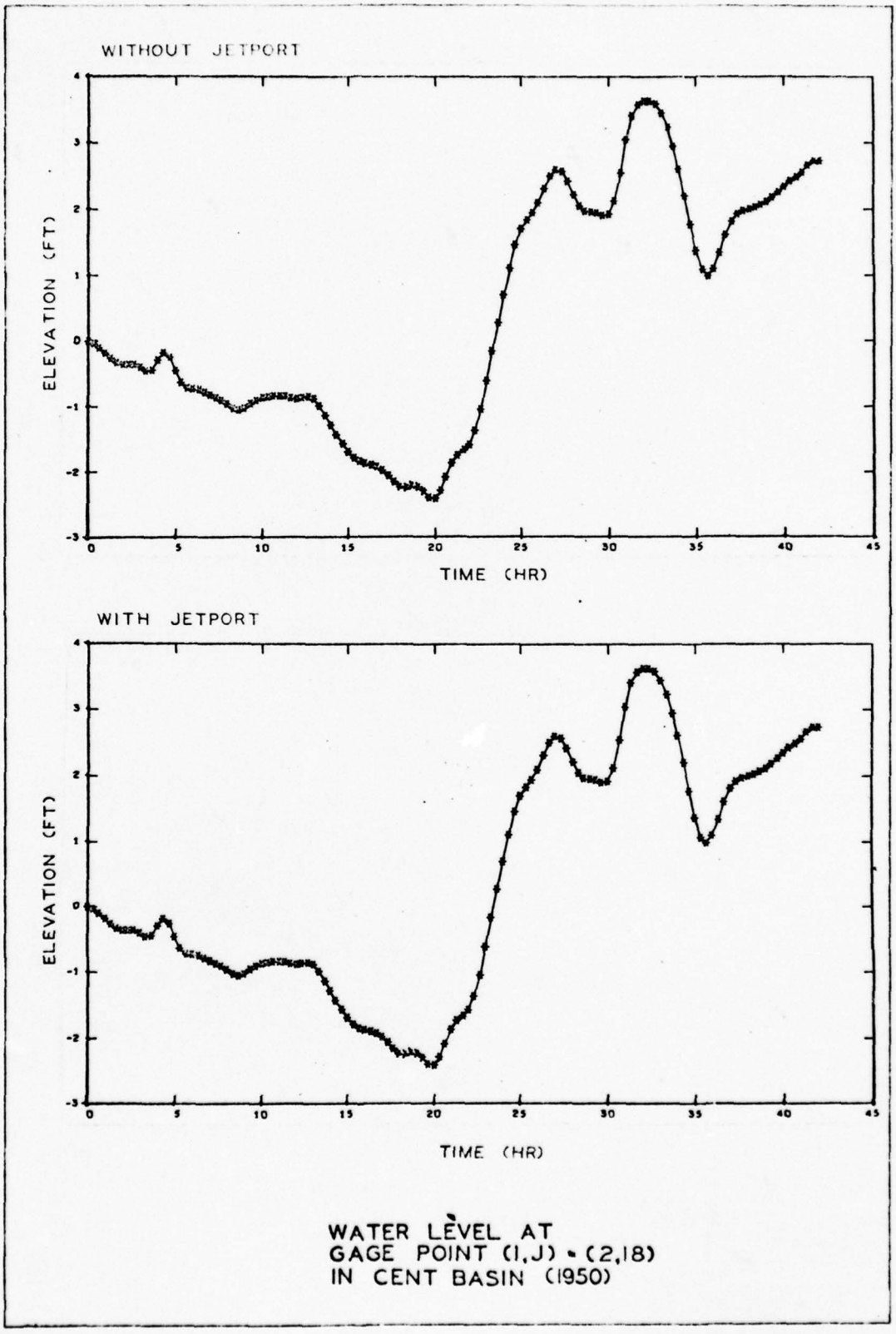
WATER LEVEL AT
GAGE POINT (I,J) = (2,2)
IN EAST BASIN (1950)



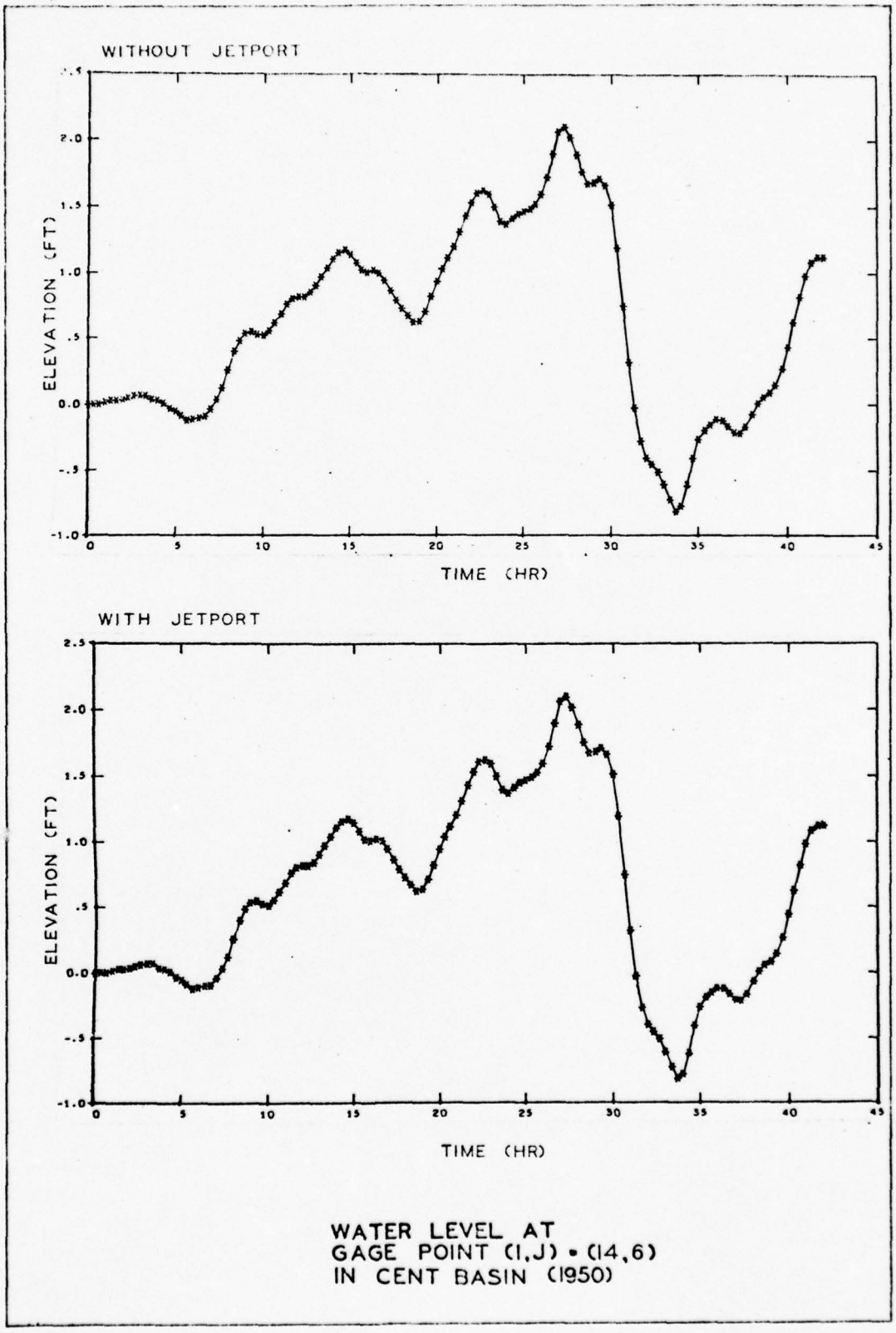
WATER LEVEL AT
GAGE POINT (I,J) = (4,5)
IN EAST BASIN (1950)



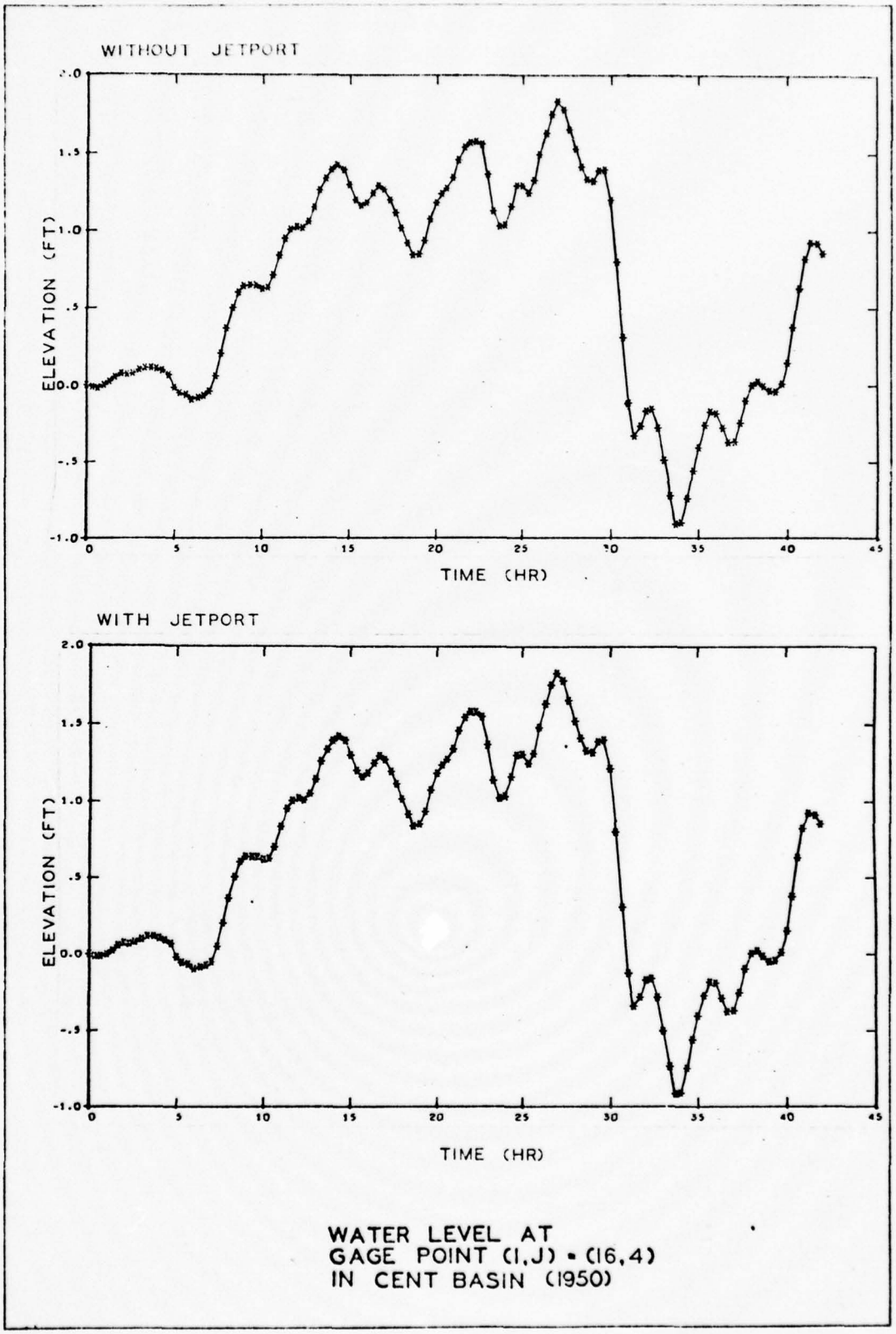
WATER LEVEL AT
GAGE POINT (I,J) = (7,20)
IN CENT BASIN (1950)



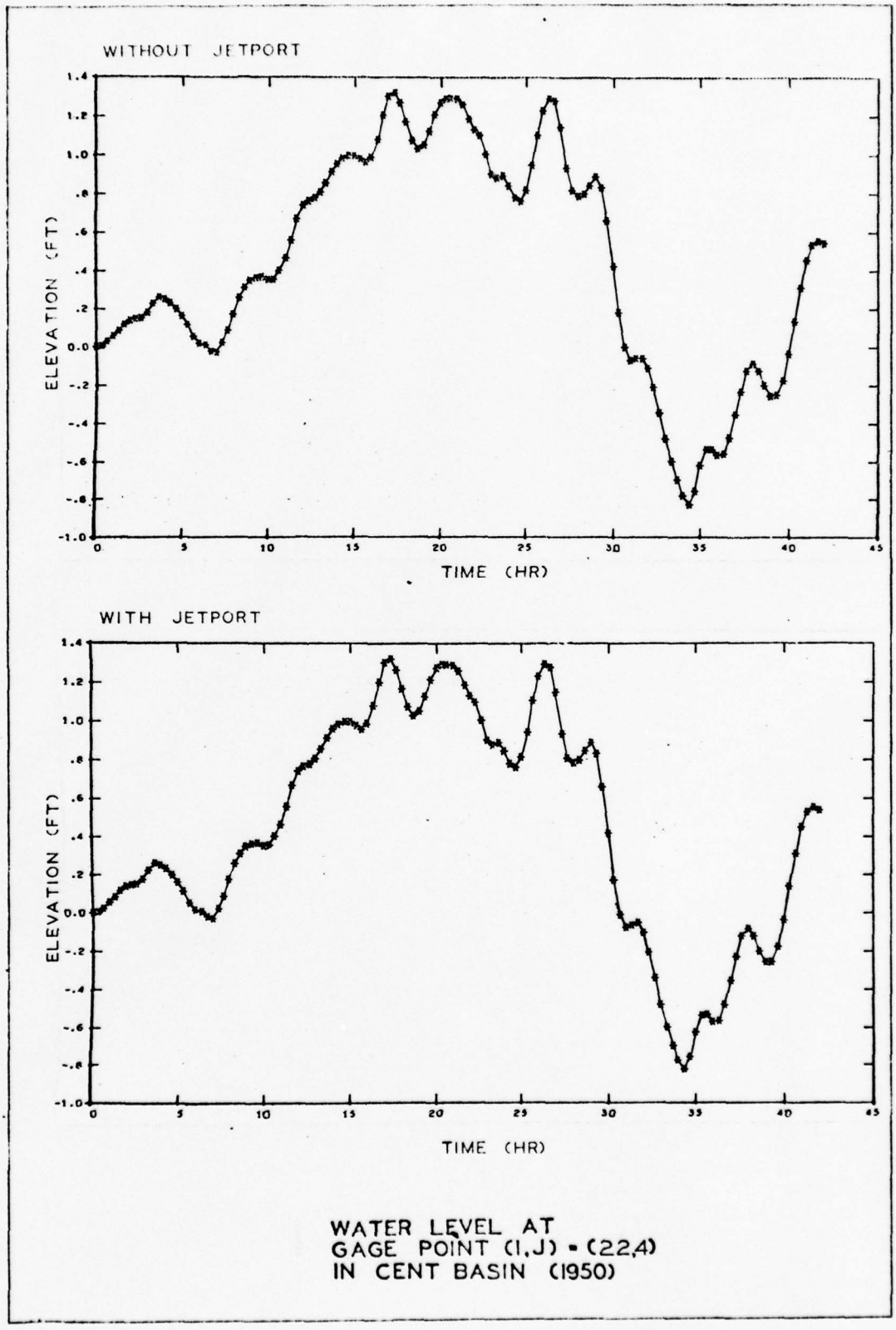
WATER LEVEL AT
GAGE POINT (I,J) = (2,18)
IN CENT BASIN (1950)



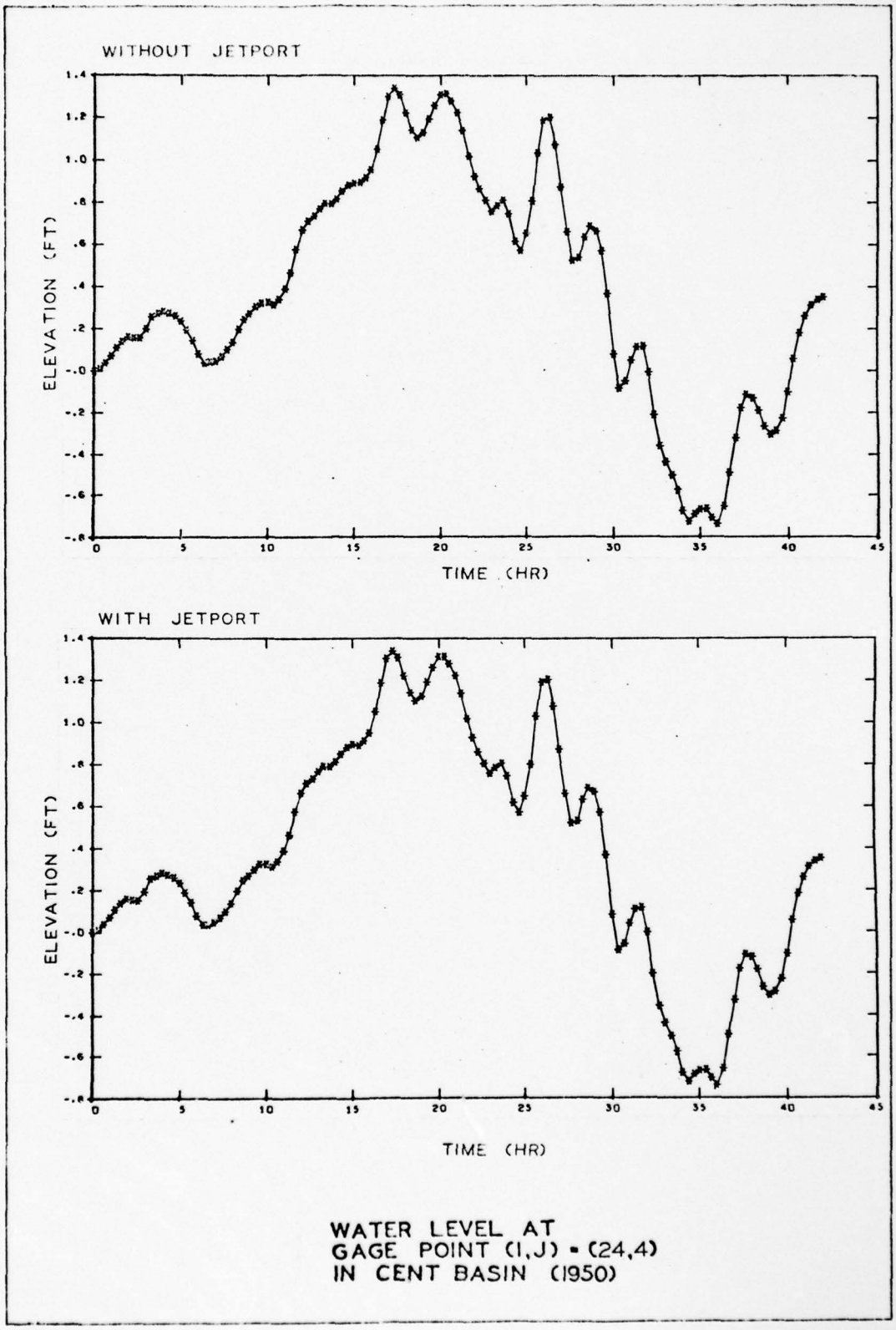
WATER LEVEL AT
GAGE POINT (I,J) = (14,6)
IN CENT BASIN (1950)



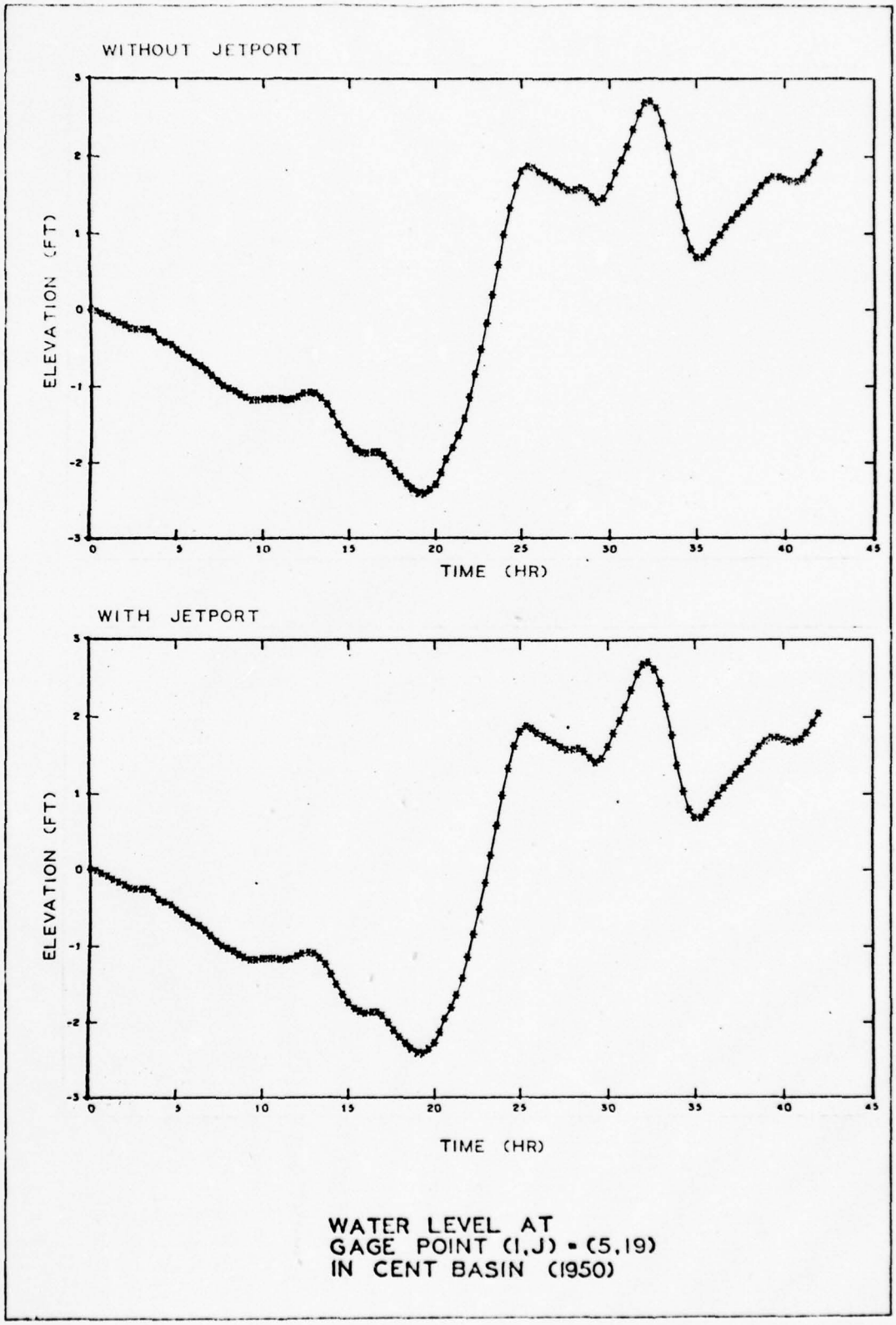
WATER LEVEL AT
GAGE POINT (I,J) = (16,4)
IN CENT BASIN (1950)



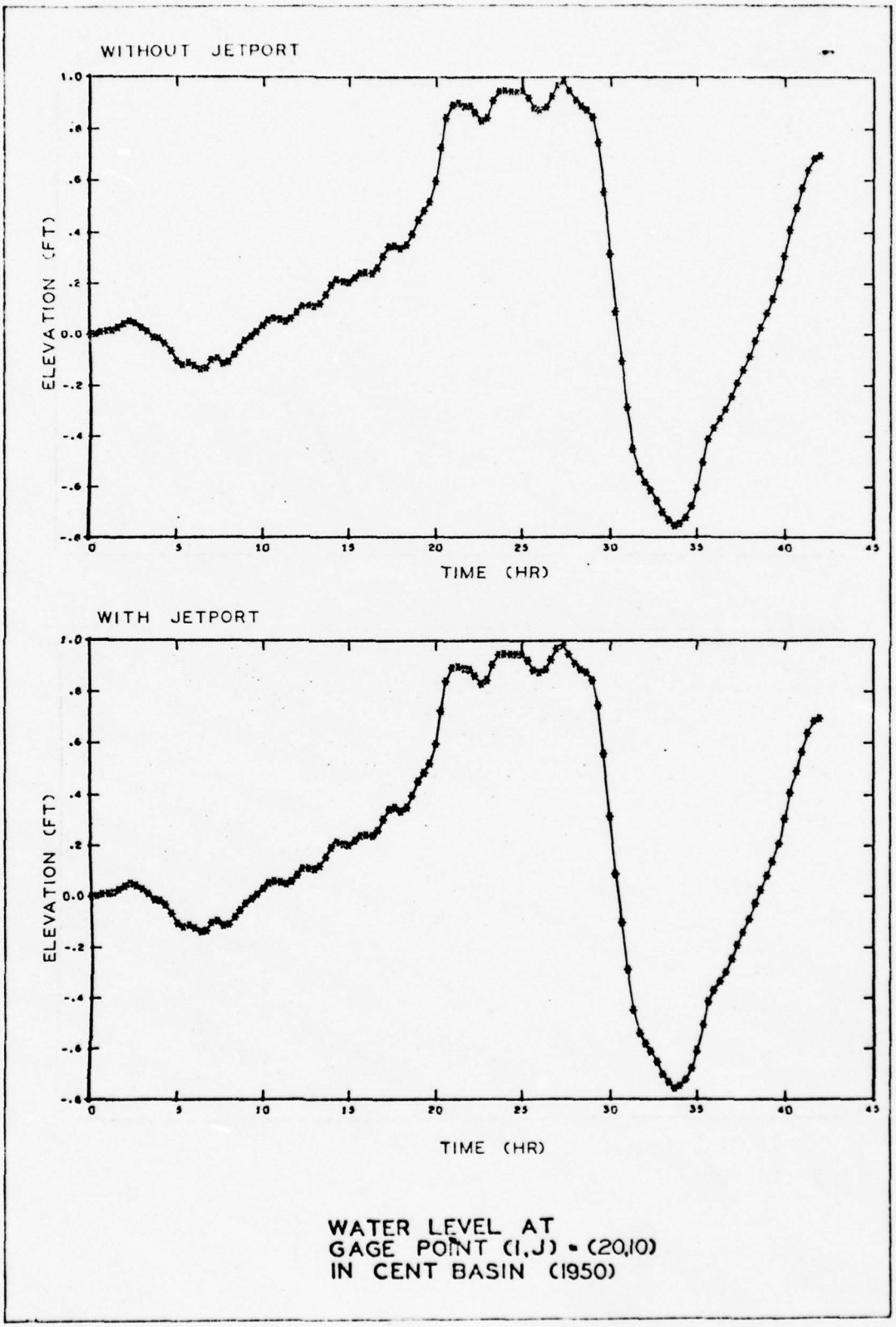
WATER LEVEL AT
GAGE POINT (I,J) = (22,4)
IN CENT BASIN (1950)



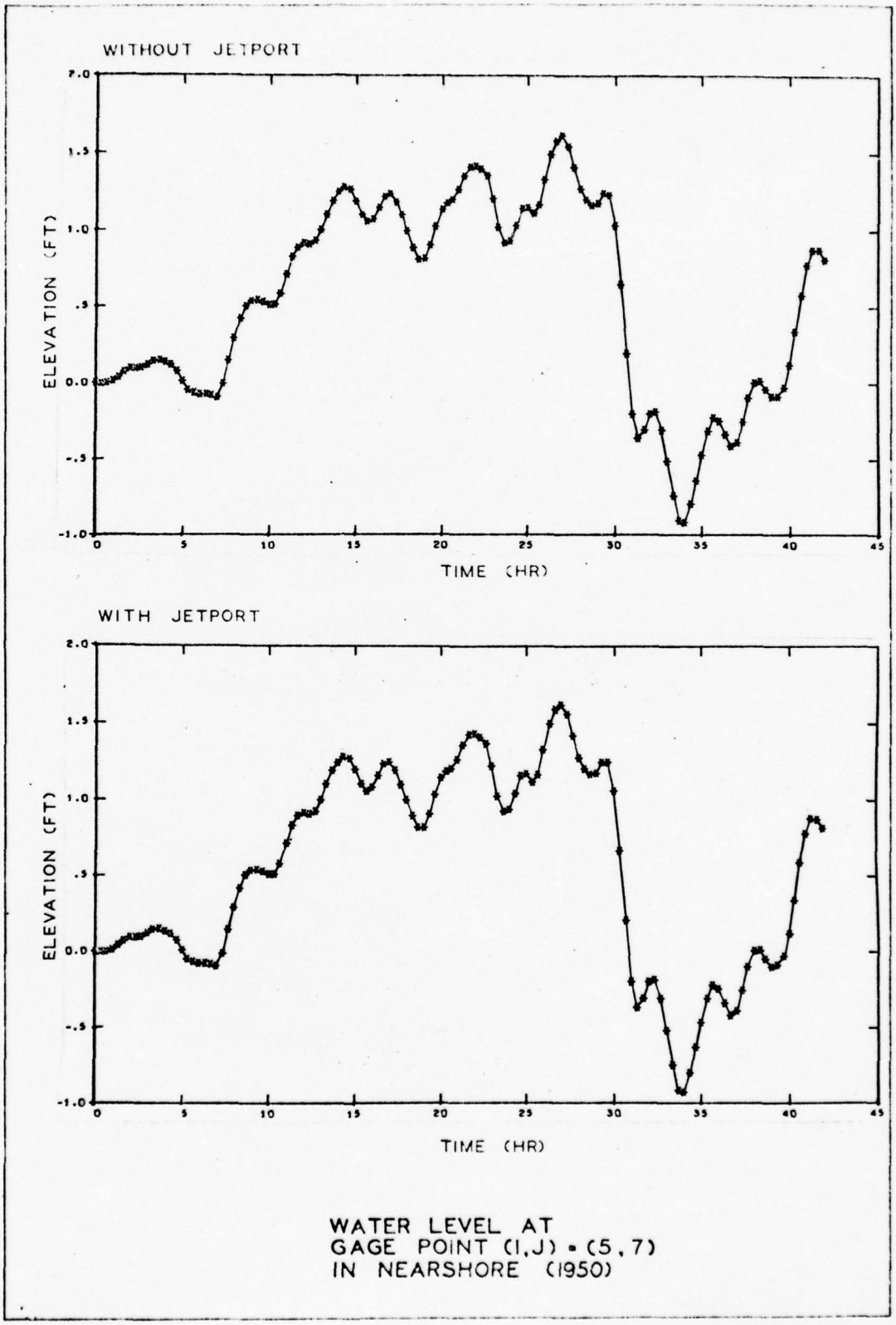
WATER LEVEL AT
GAGE POINT (I,J) = (24,4)
IN CENT BASIN (1950)



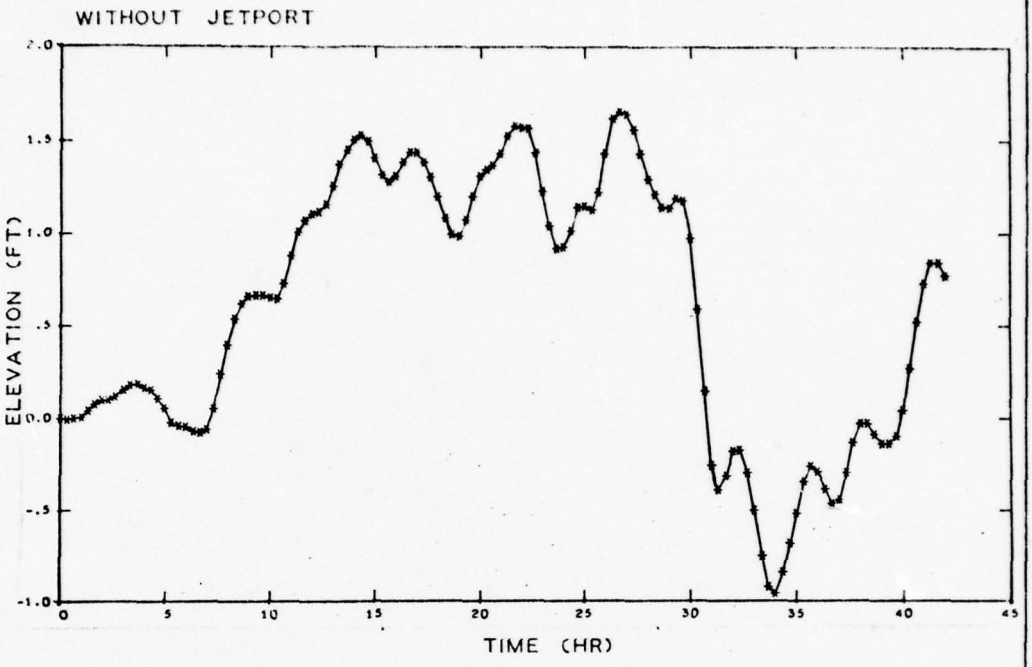
WATER LEVEL AT
GAGE POINT (I,J) = (5,19)
IN CENT BASIN (1950)

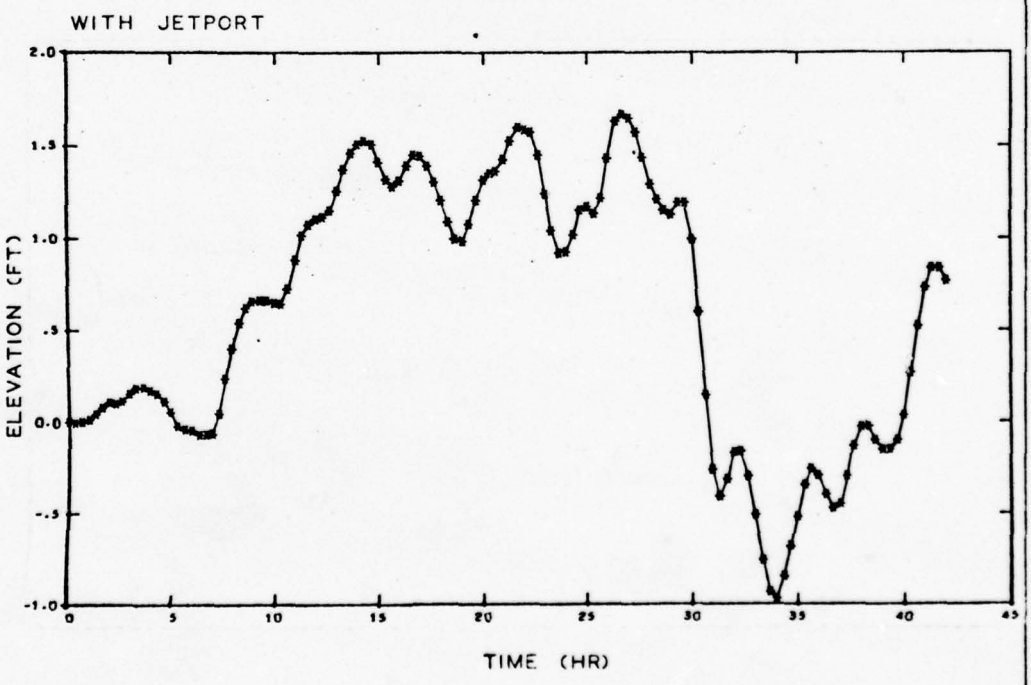


WATER LEVEL AT
GAGE POINT (I,J) = (20,10)
IN CENT BASIN (1950)

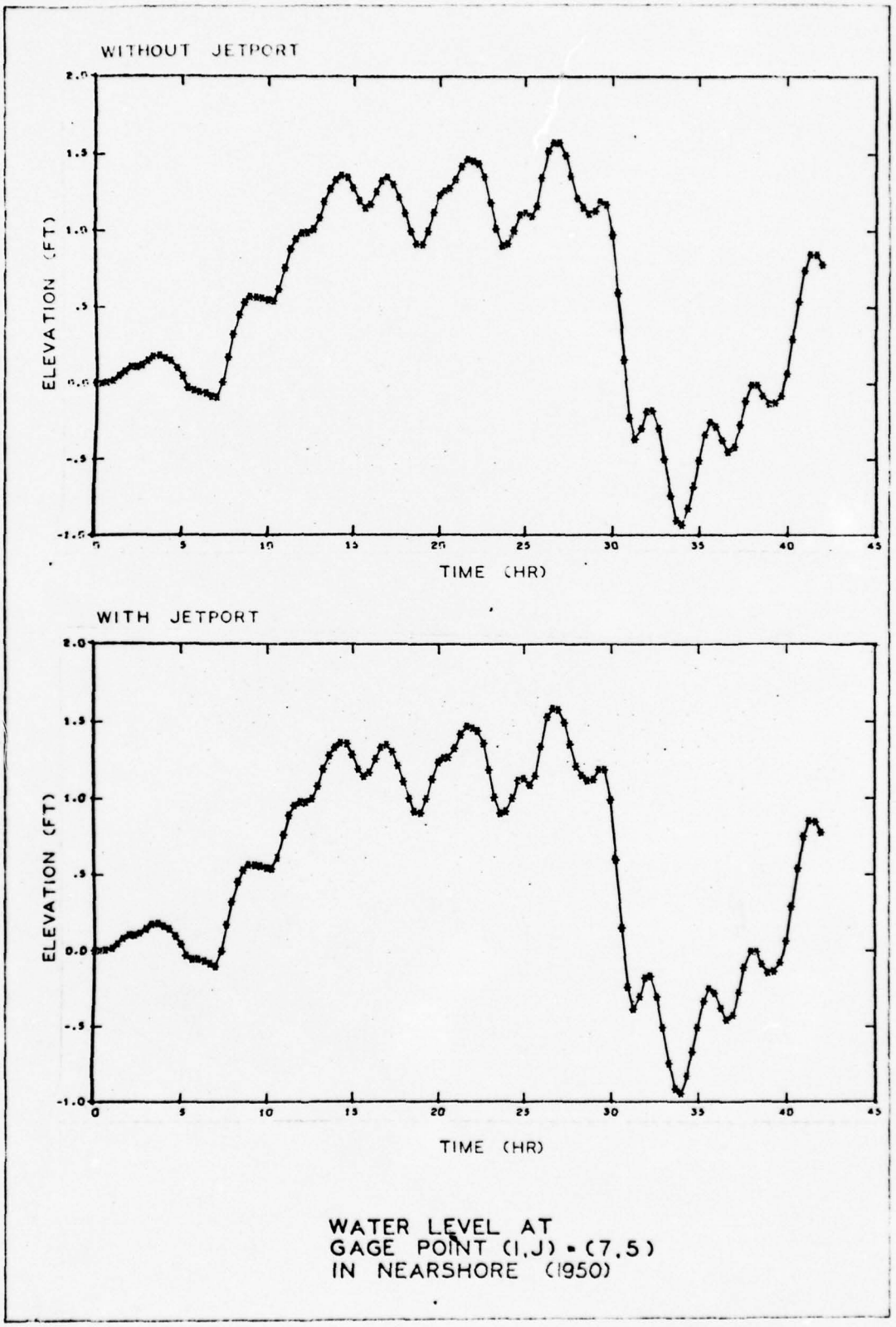


WATER LEVEL AT
GAGE POINT (I,J) = (5, 7)
IN NEARSHORE (1950)

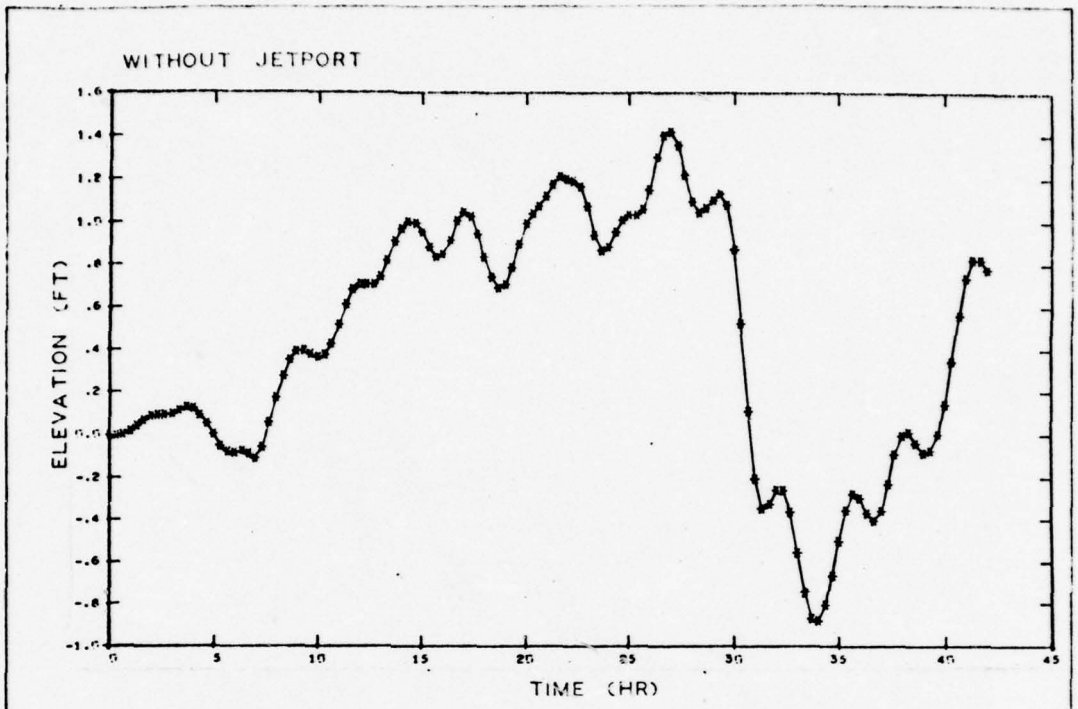


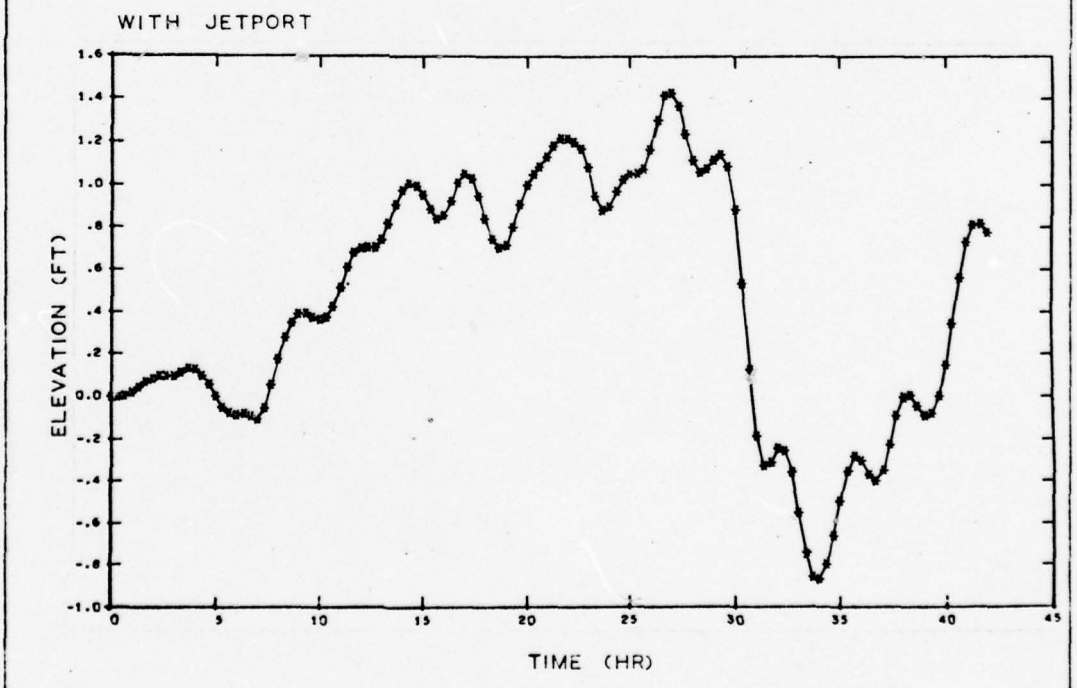


WATER LEVEL AT
GAGE POINT (I,J) = (5,3)
IN NEARSHORE (1950)

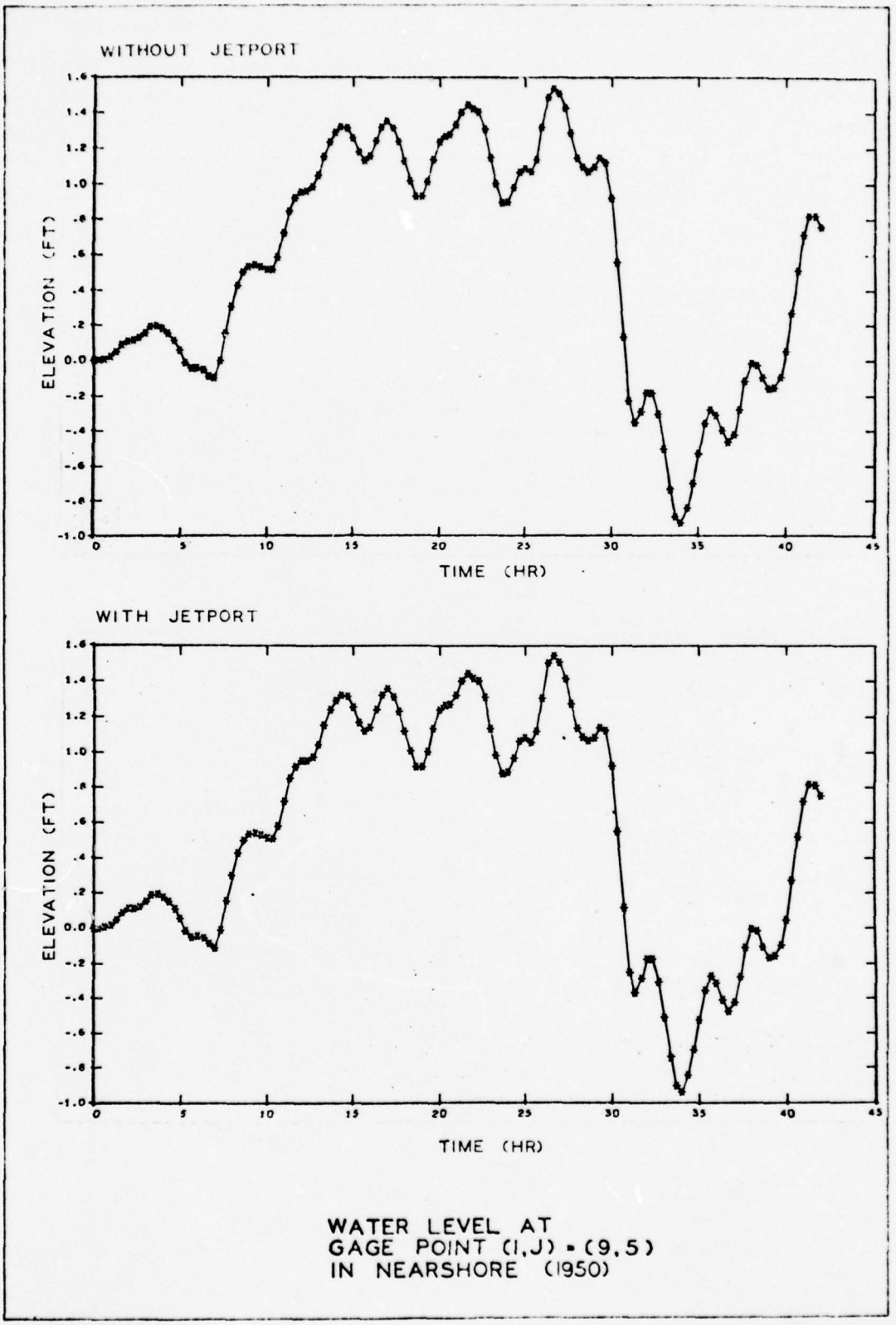


WATER LEVEL AT
GAGE POINT (I,J) = (7,5)
IN NEARSHORE (1950)

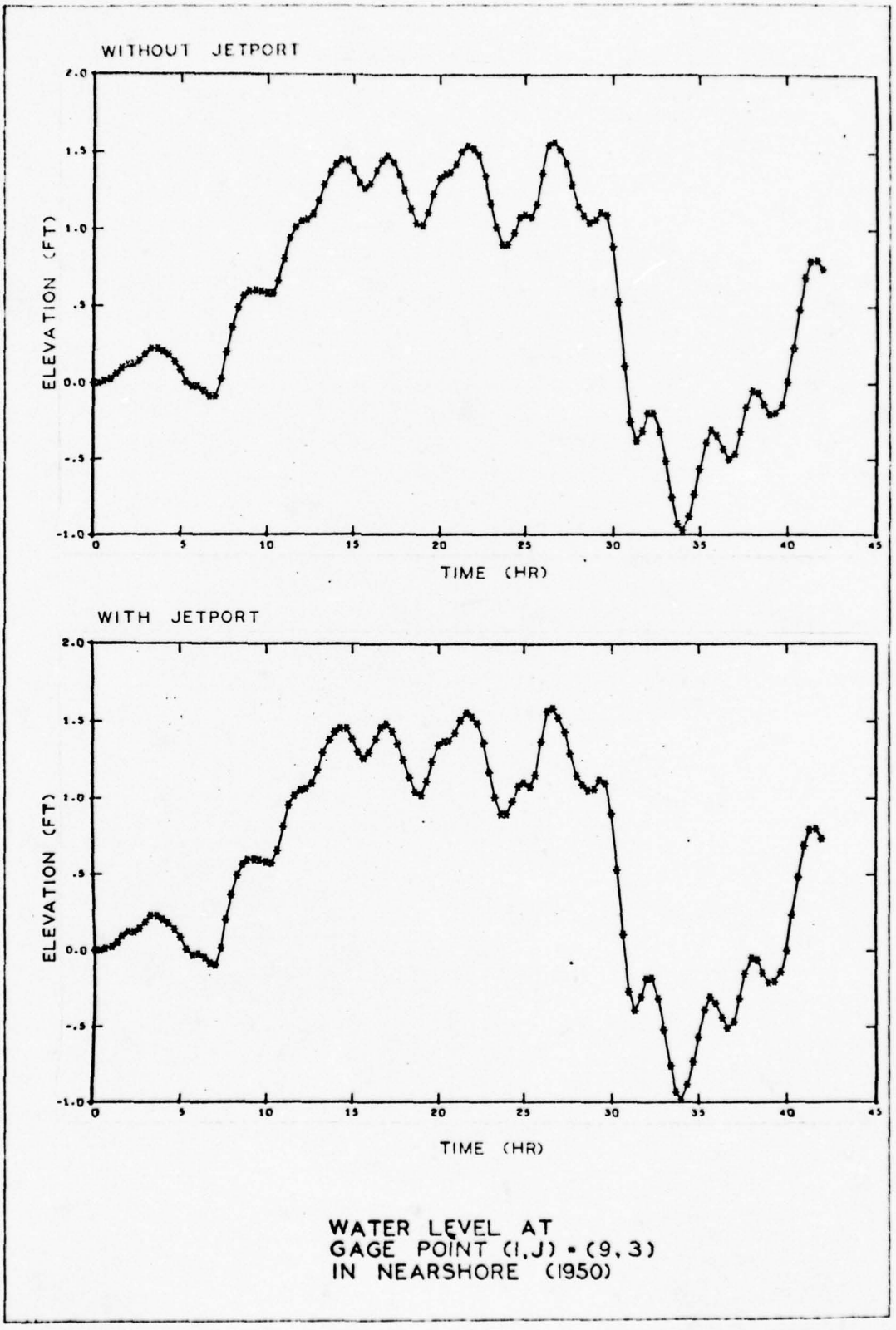




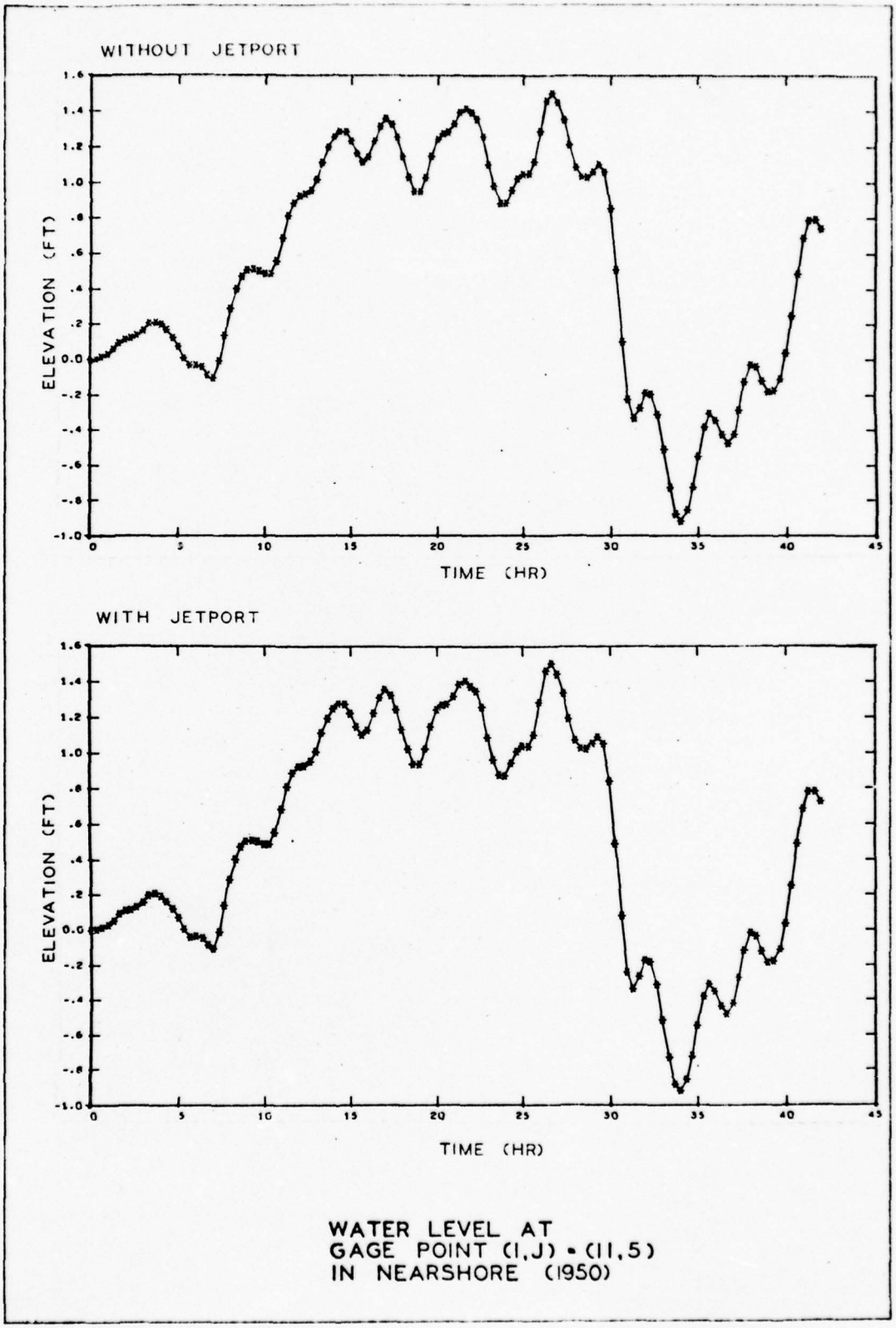
WATER LEVEL AT
GAGE POINT (I,J) = (9,11)
IN NEARSHORE (1950)



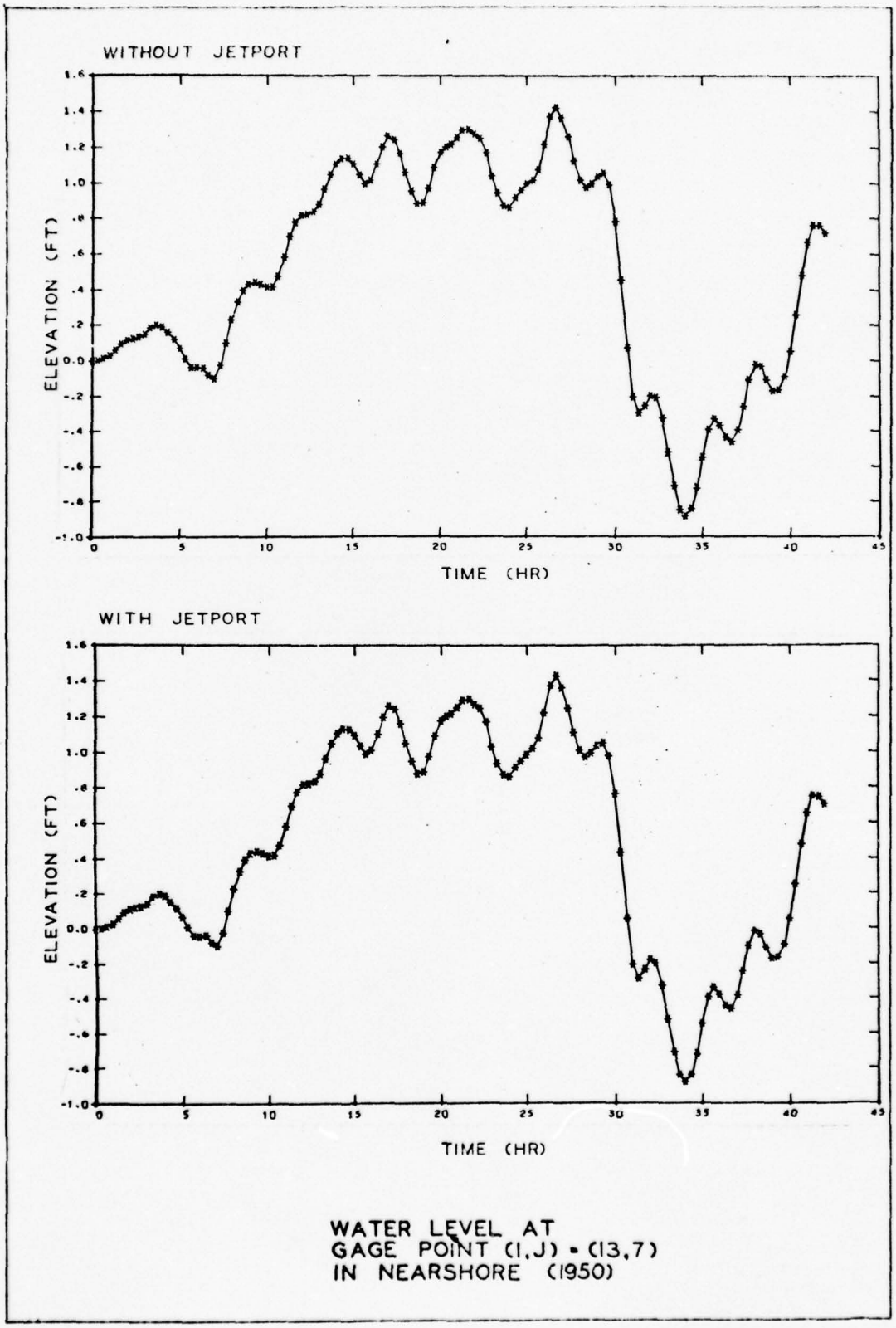
WATER LEVEL AT
GAGE POINT (I,J) = (9,5)
IN NEARSHORE (1950)



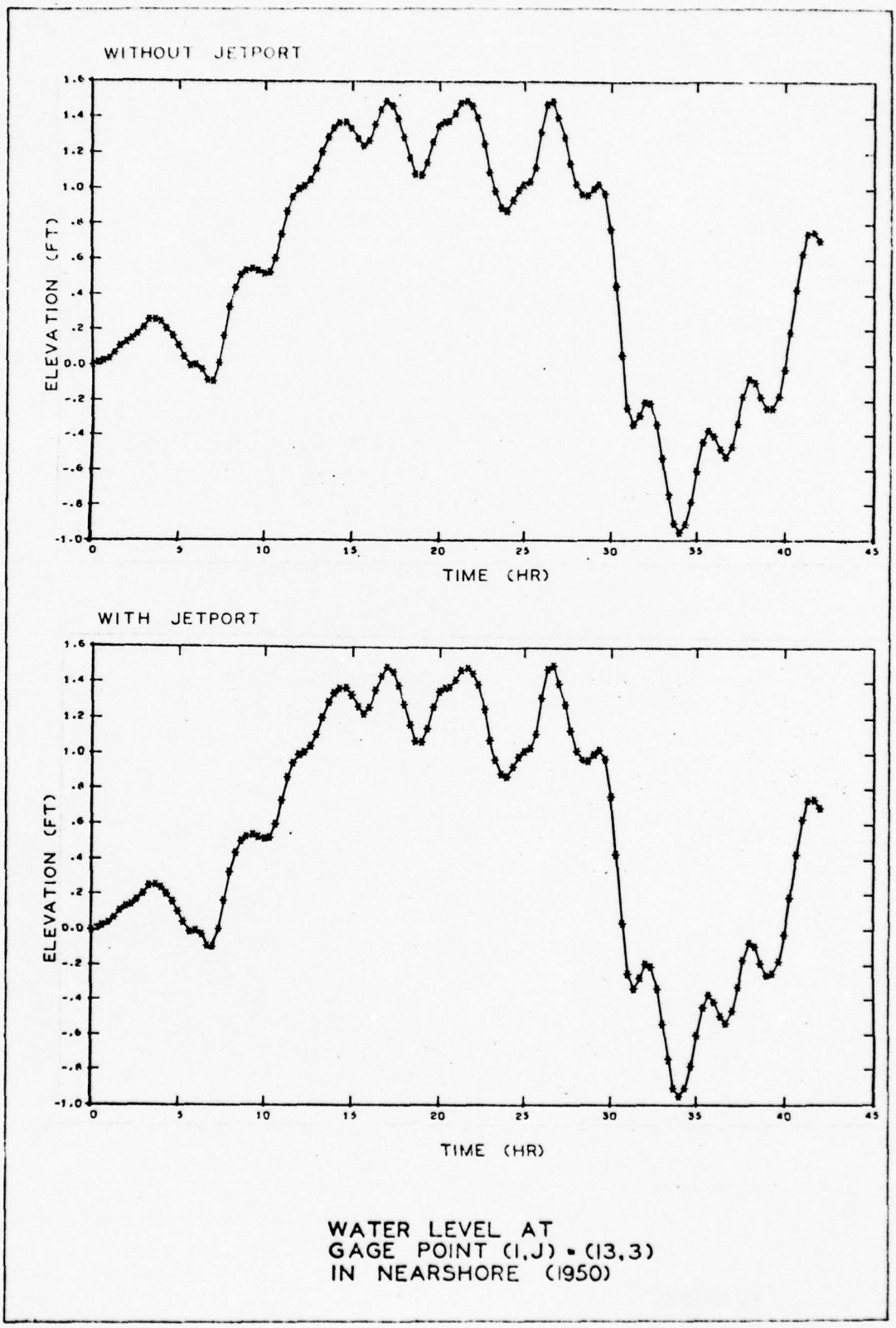
WATER LEVEL AT
GAGE POINT (I,J) = (9,3)
IN NEARSHORE (1950)



WATER LEVEL AT
GAGE POINT (I,J) = (11,5)
IN NEARSHORE (1950)

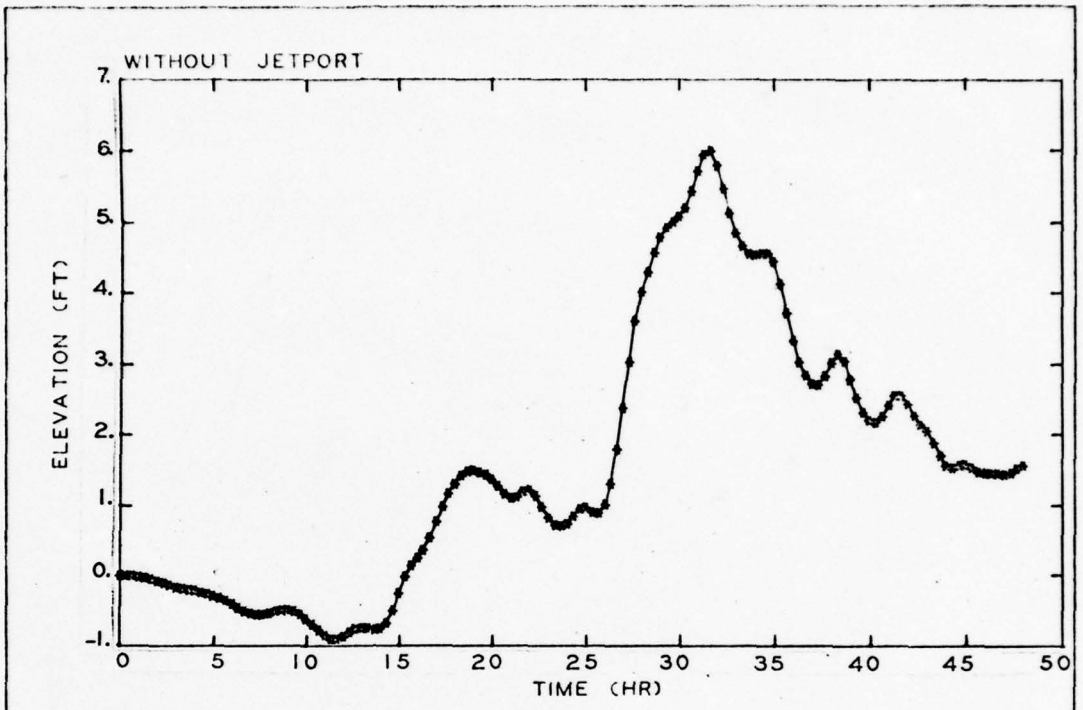


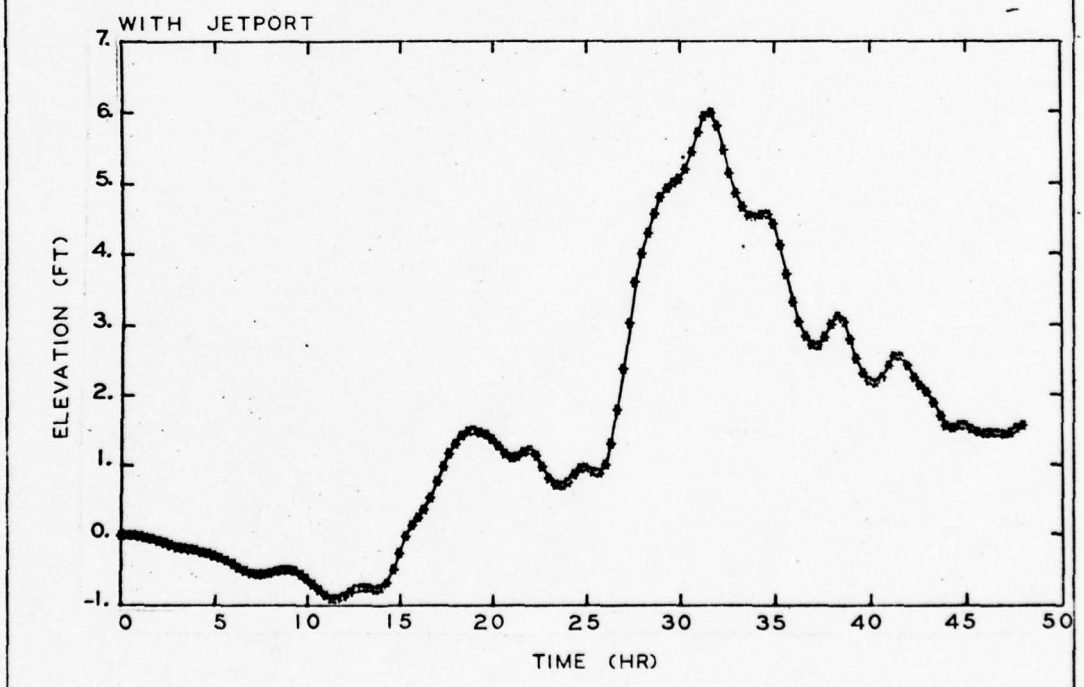
WATER LEVEL AT
GAGE POINT (I,J) = (13,7)
IN NEARSHORE (1950)



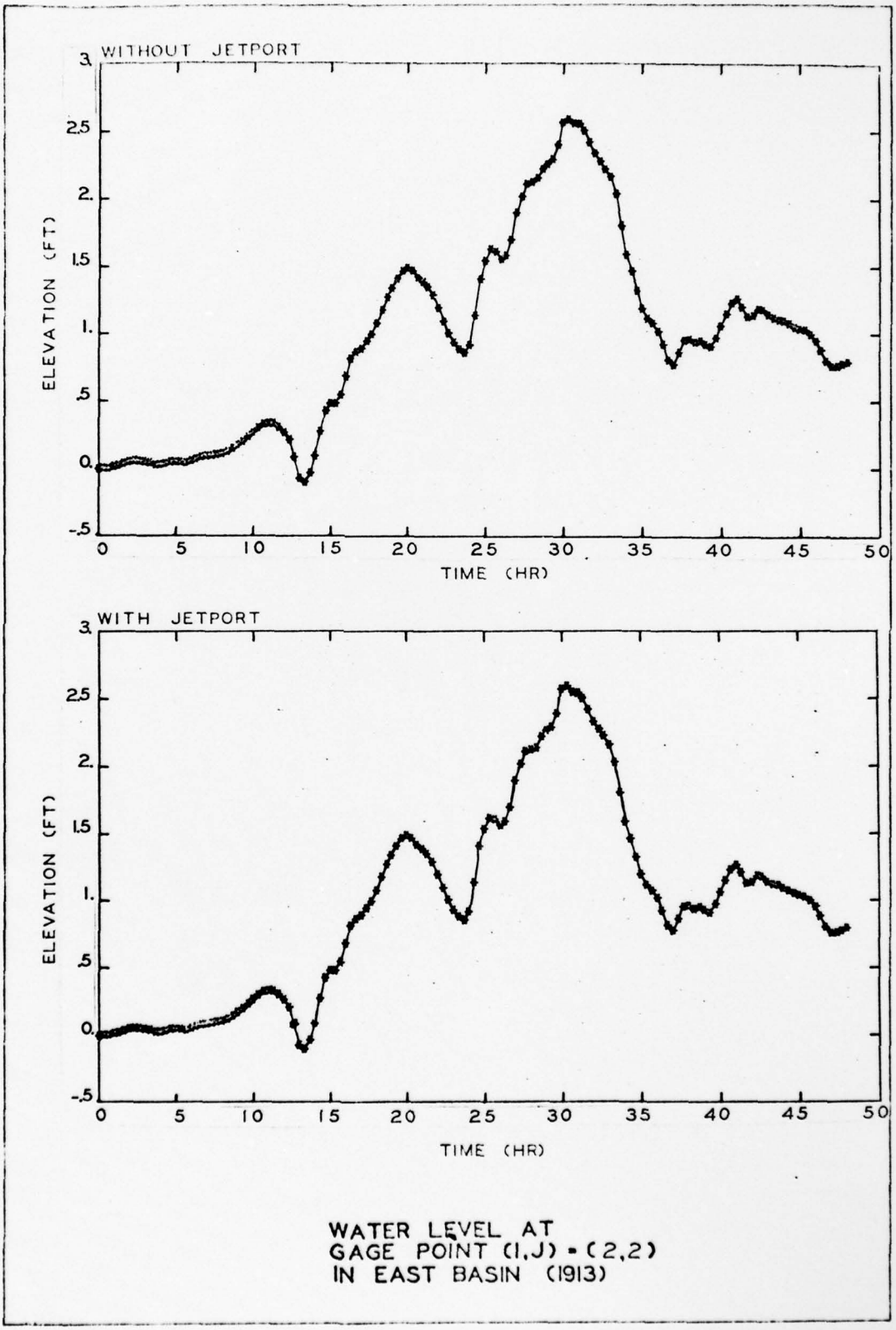
WATER LEVEL AT
GAGE POINT (I,J) = (13,3)
IN NEARSHORE (1950)

Inclosure 3: 7-10 November 1913 Storm

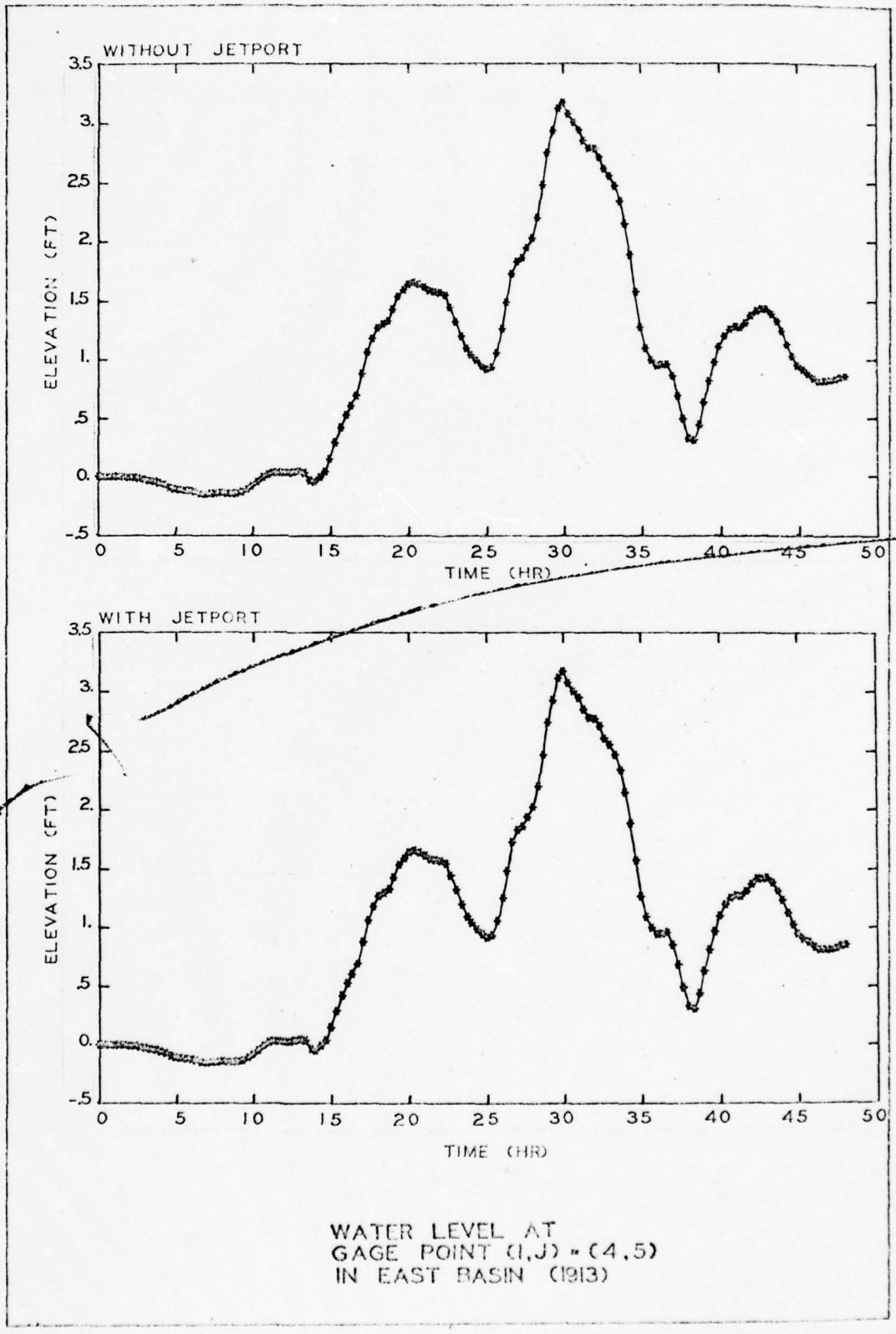




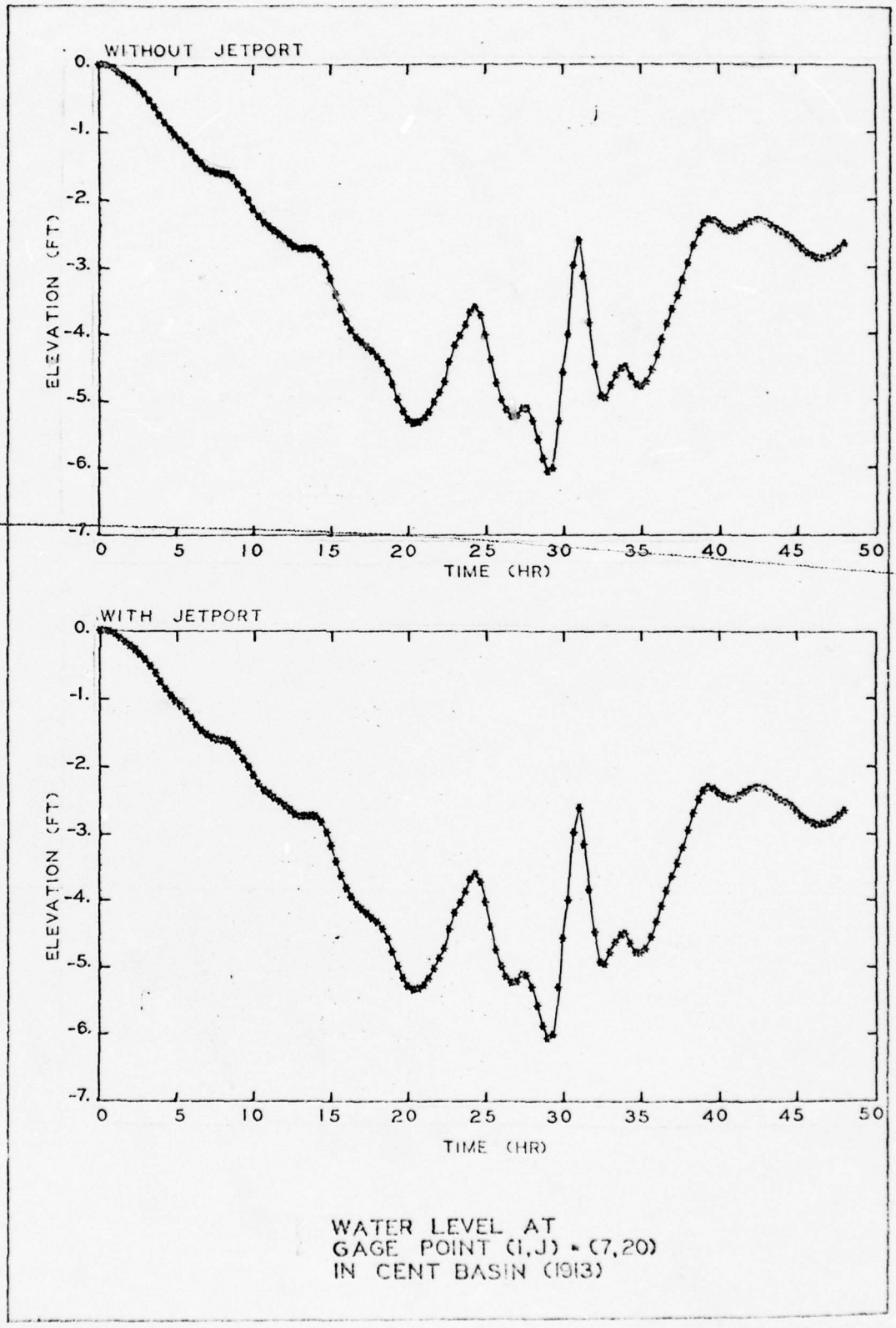
WATER LEVEL AT
GAGE POINT (I,J) = (11,3)
IN EAST BASIN (1913)



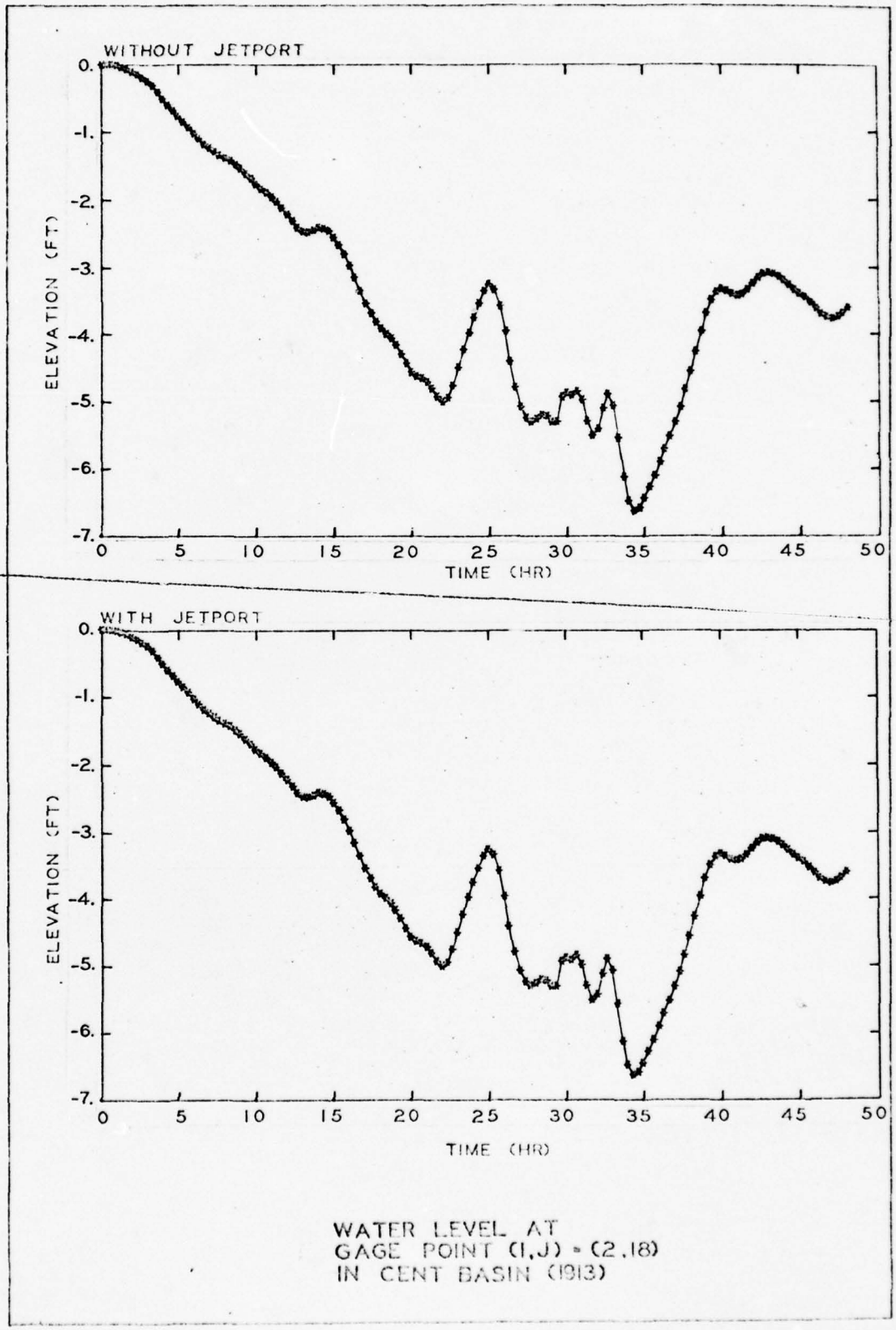
WATER LEVEL AT
GAGE POINT (I,J) = (2,2)
IN EAST BASIN (1913)



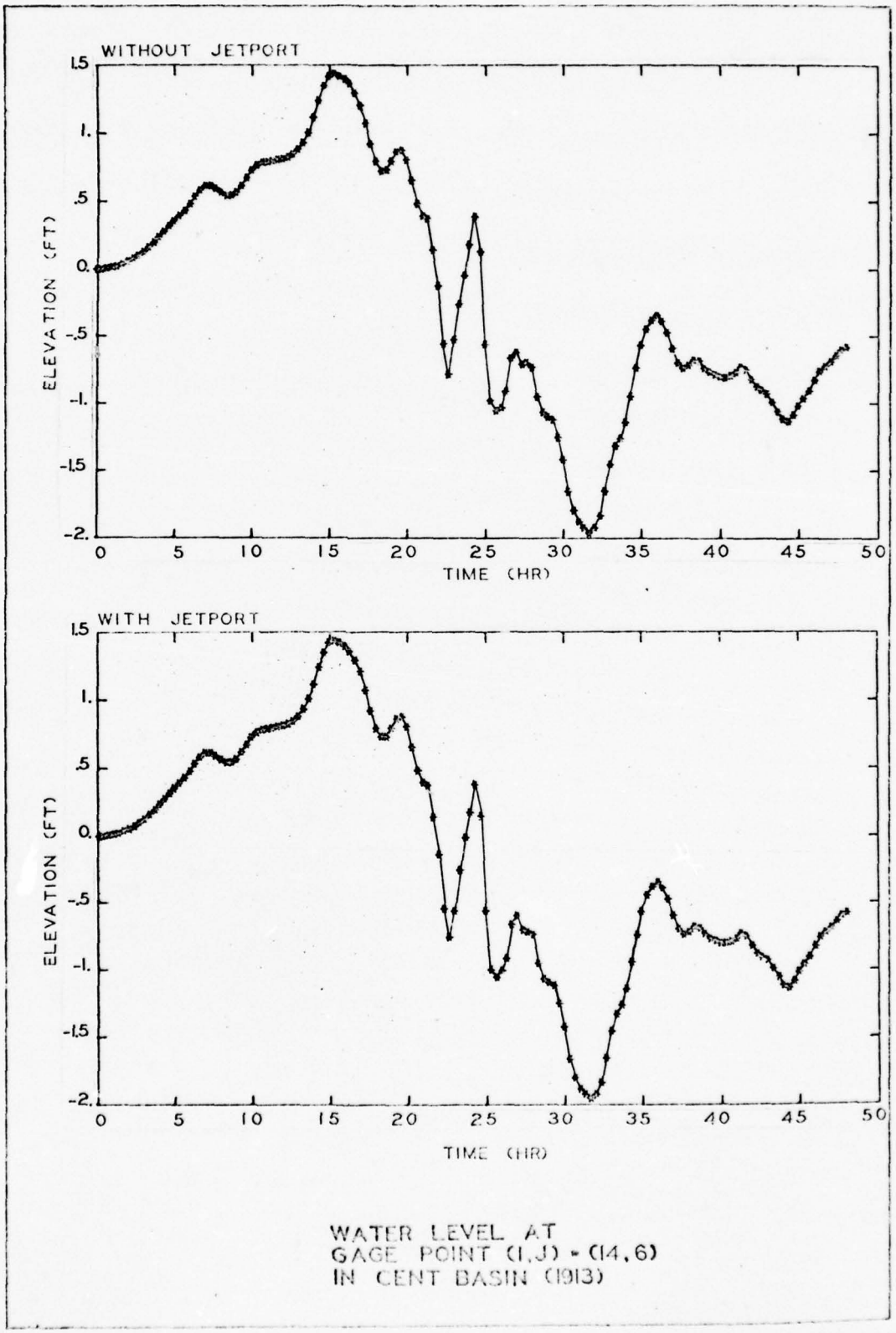
WATER LEVEL AT
GAGE POINT (I,J) = (4,5)
IN EAST BASIN (1913)



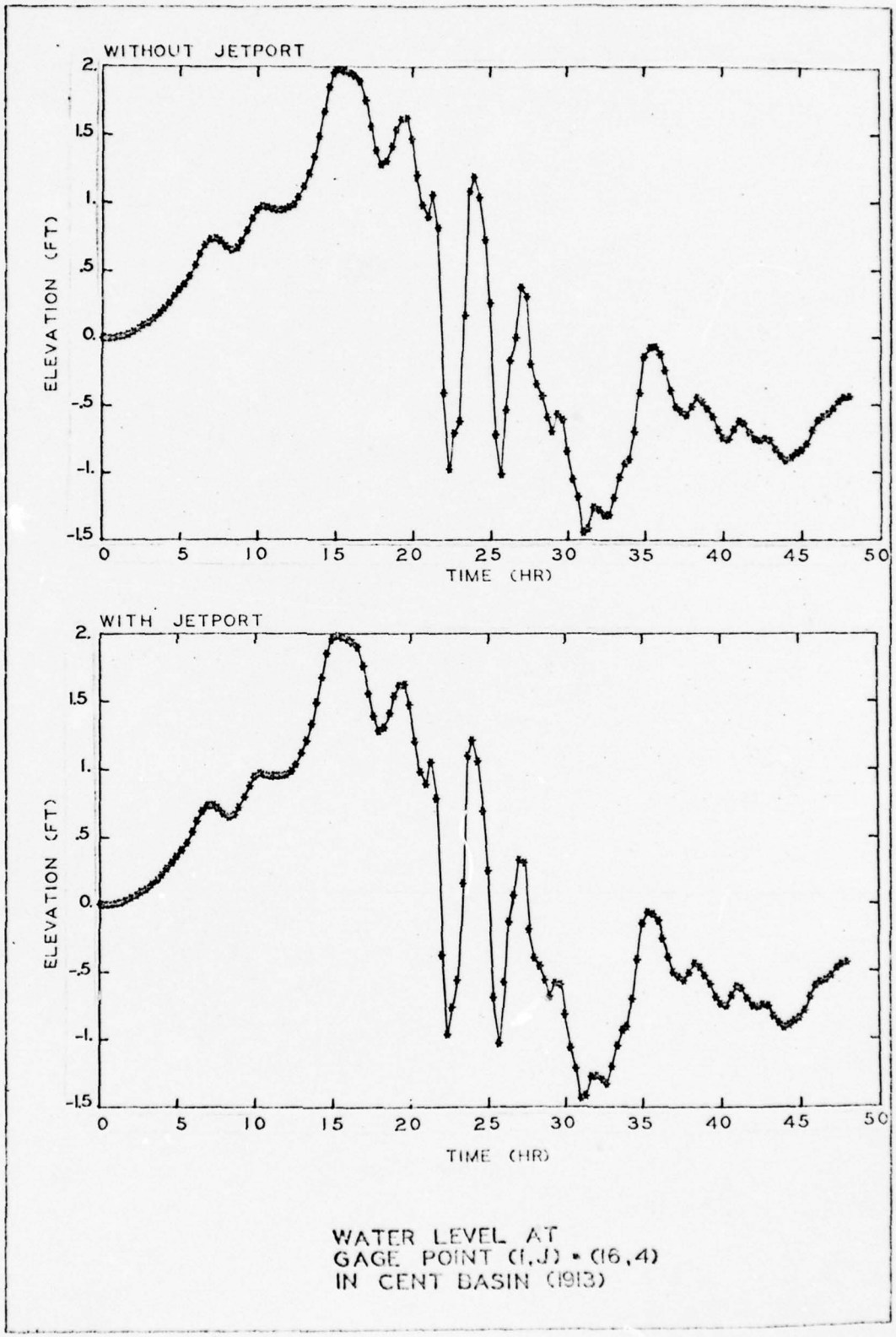
WATER LEVEL AT
GAGE POINT (I,J) = (7,20)
IN CENT BASIN (1913)



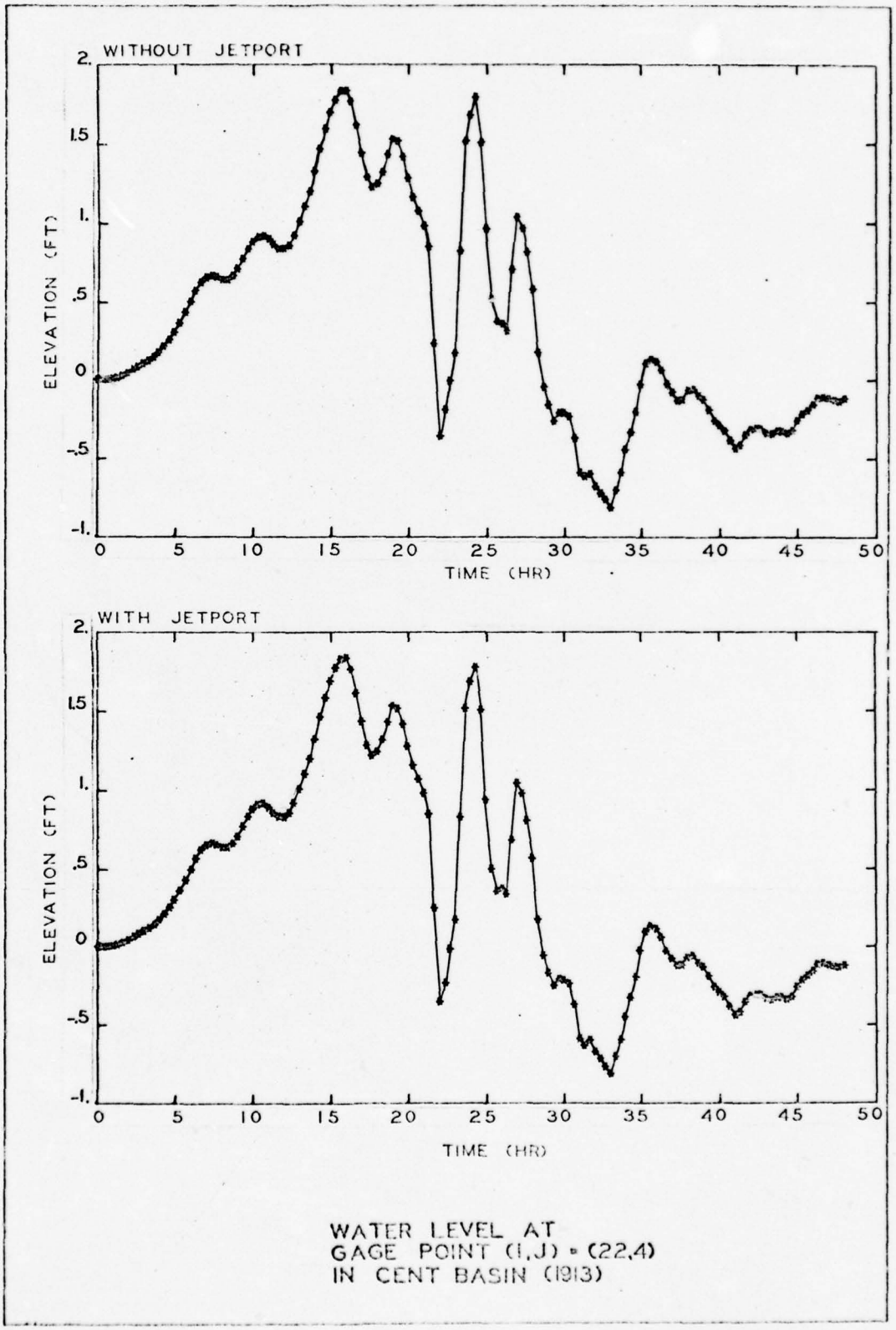
WATER LEVEL AT
GAGE POINT (I,J) = (2,18)
IN CENT BASIN (1913)



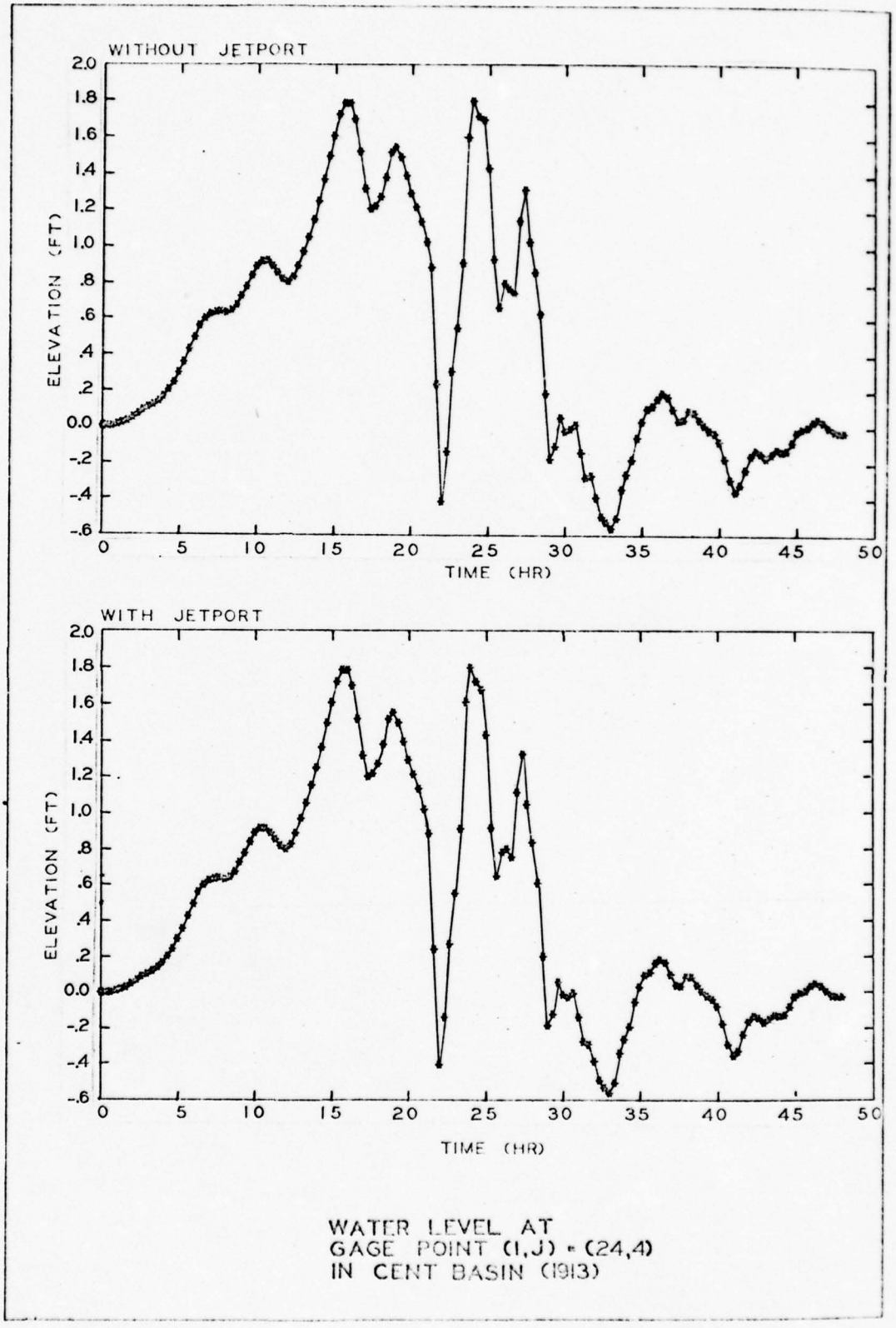
WATER LEVEL AT
GAGE POINT (I,J) = (14,6)
IN CENT BASIN (1913)



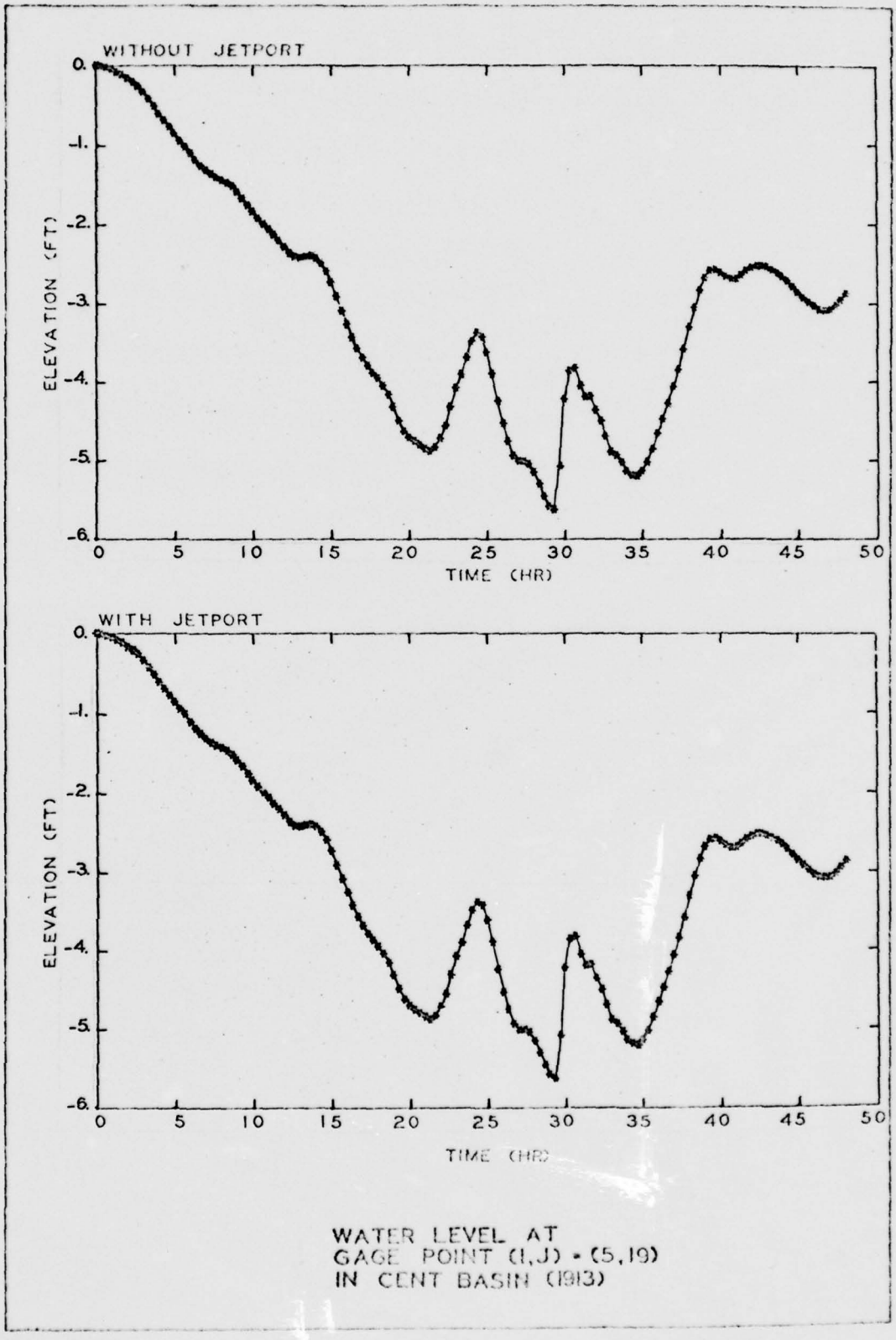
WATER LEVEL AT
GAGE POINT (I,J) = (16,4)
IN CENT BASIN (1913)



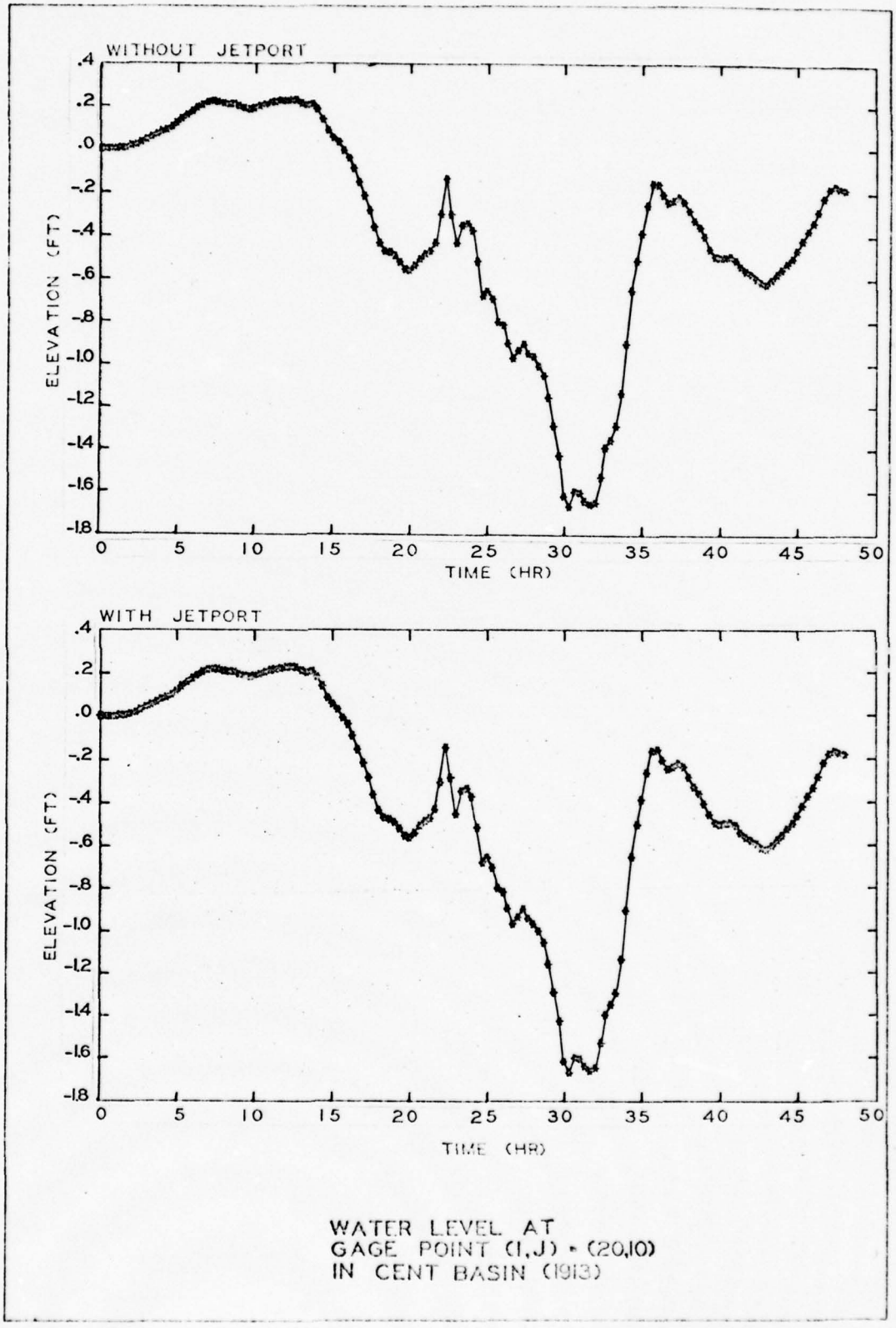
WATER LEVEL AT
GAGE POINT (I,J) = (22,4)
IN CENT BASIN (1913)



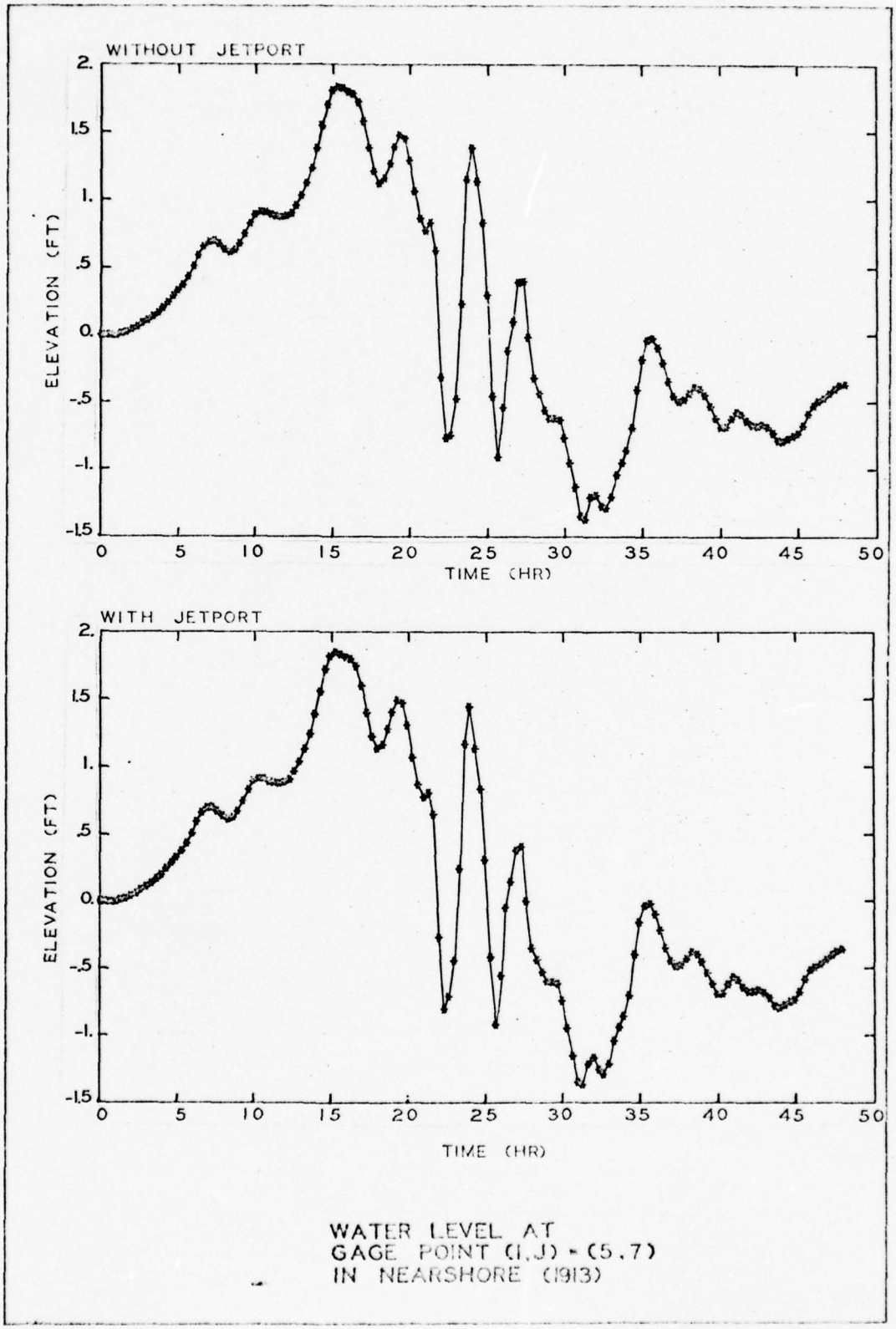
WATER LEVEL AT
GAGE POINT (I,J) = (24,4)
IN CENT BASIN (1913)



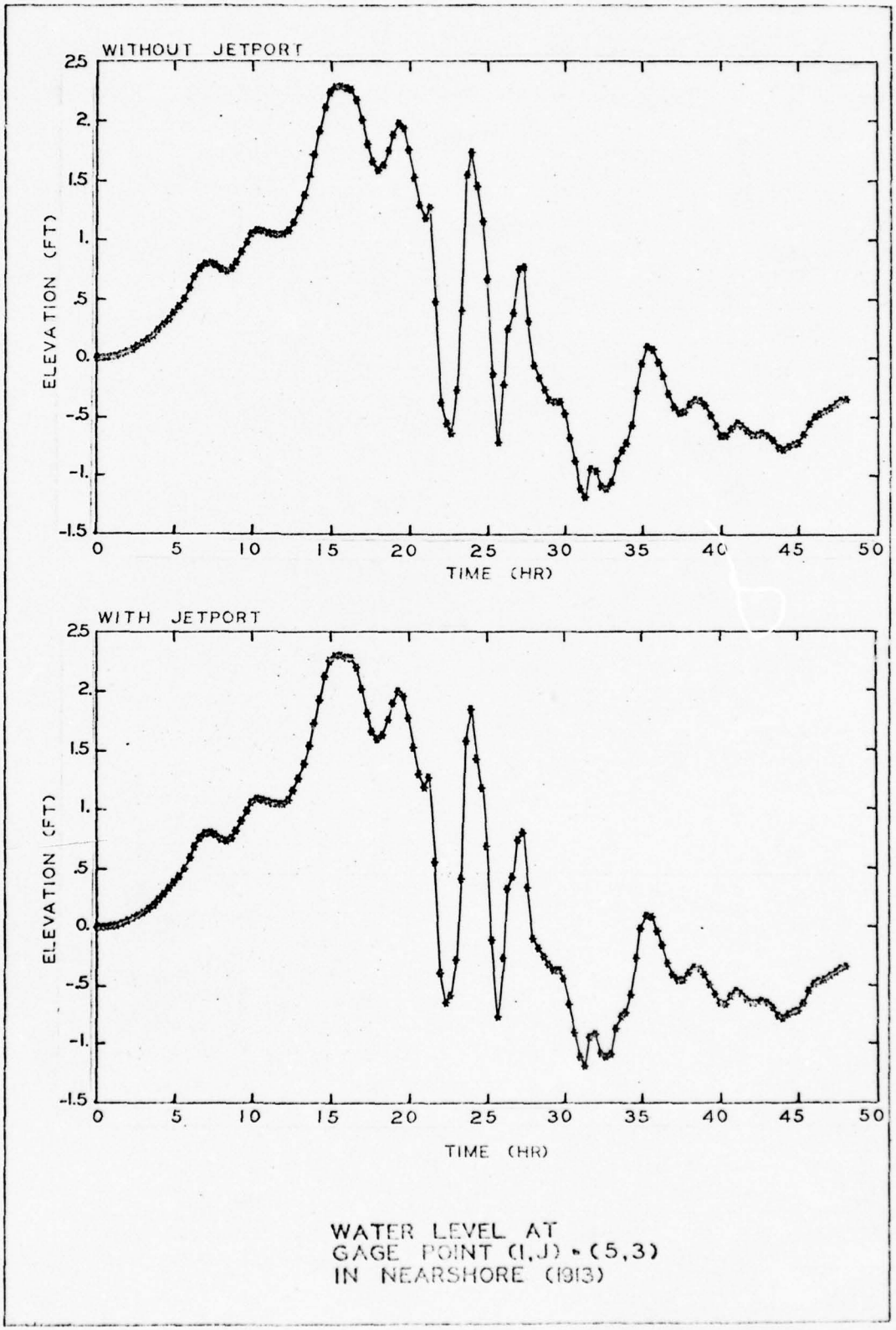
WATER LEVEL AT
GAGE POINT (I,J) = (5,19)
IN CENT BASIN (1913)



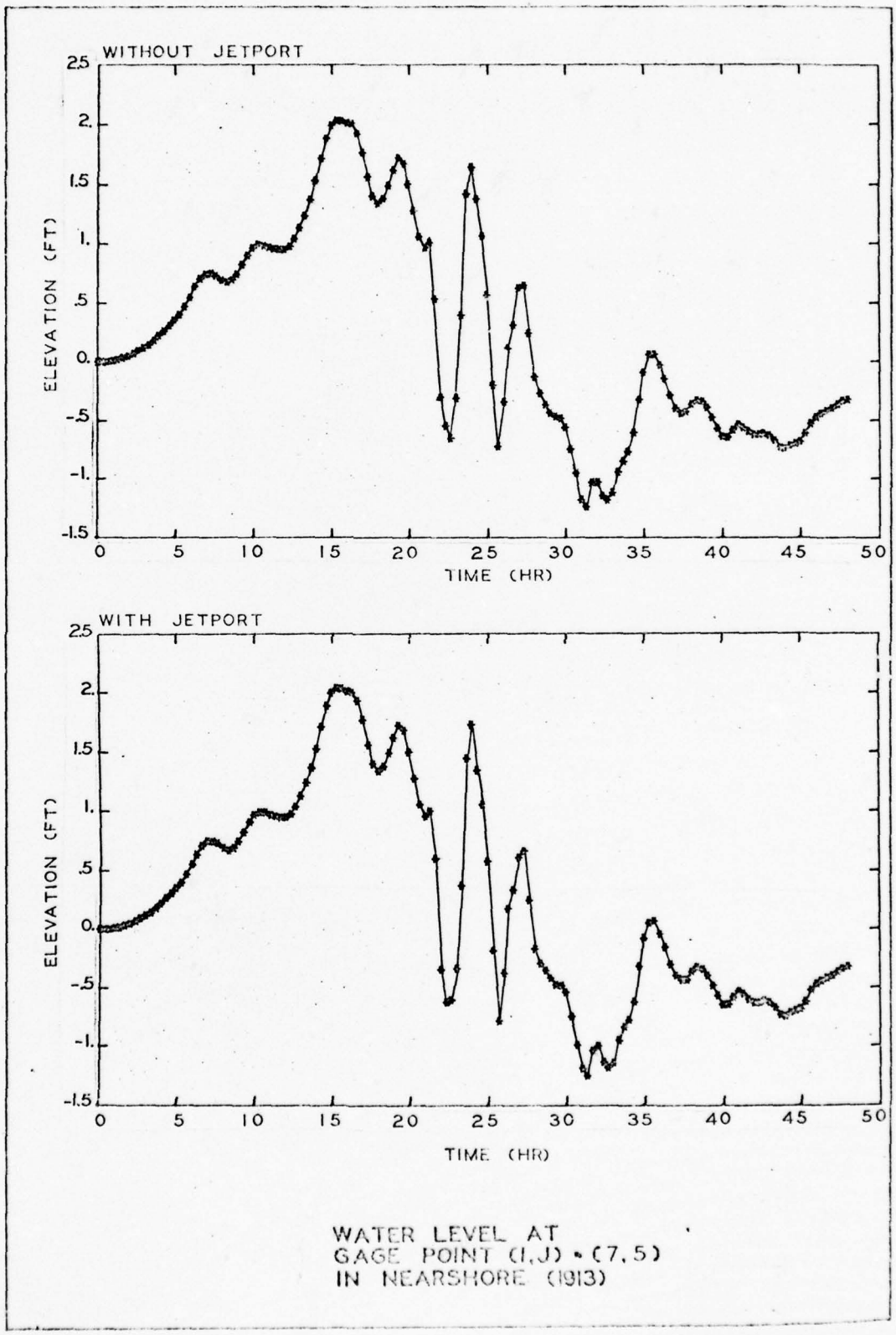
WATER LEVEL AT
GAGE POINT (I,J) = (20,10)
IN CENT BASIN (1913)



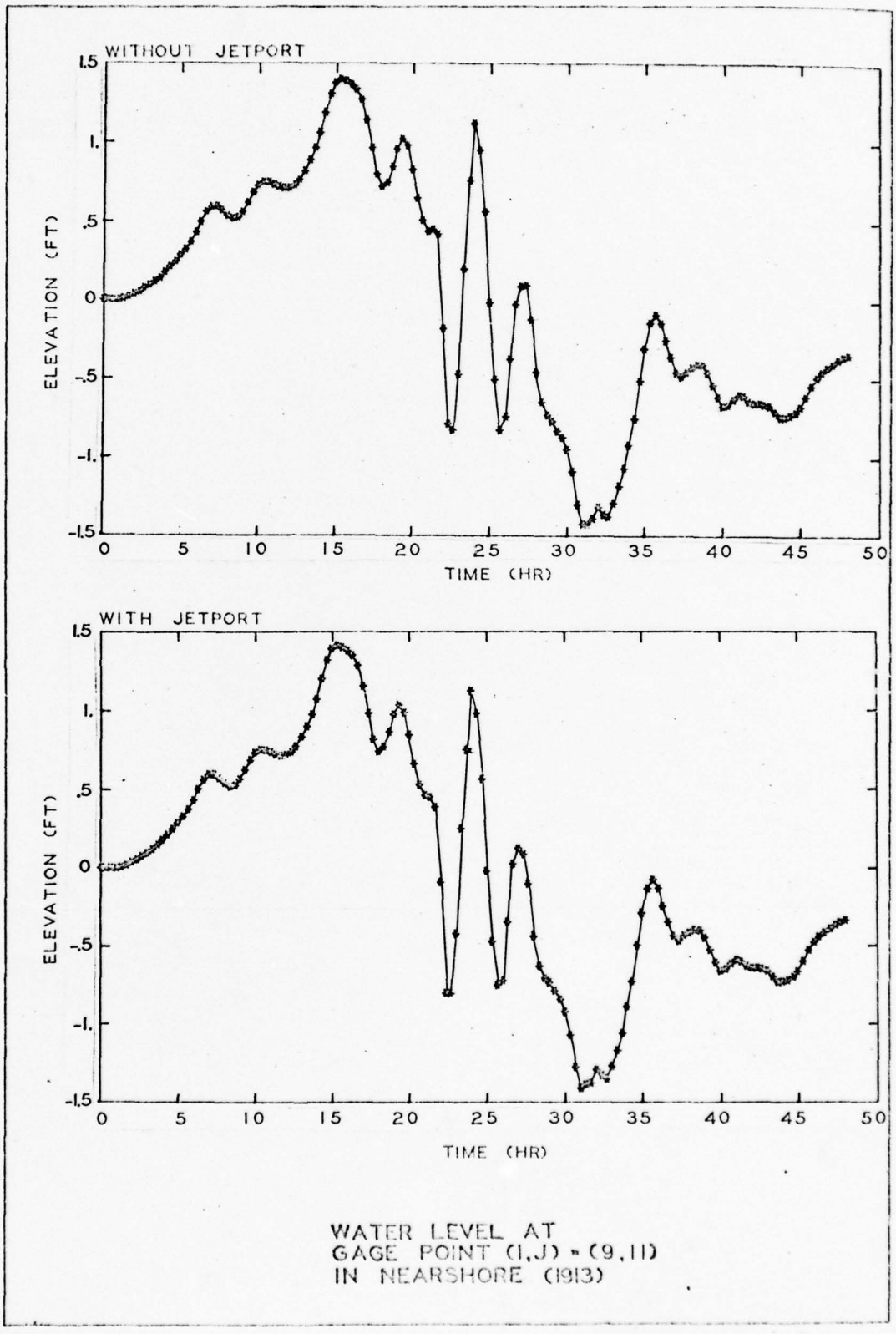
WATER LEVEL AT
GAGE POINT (I,J) = (5,7)
IN NEARSHORE (1913)



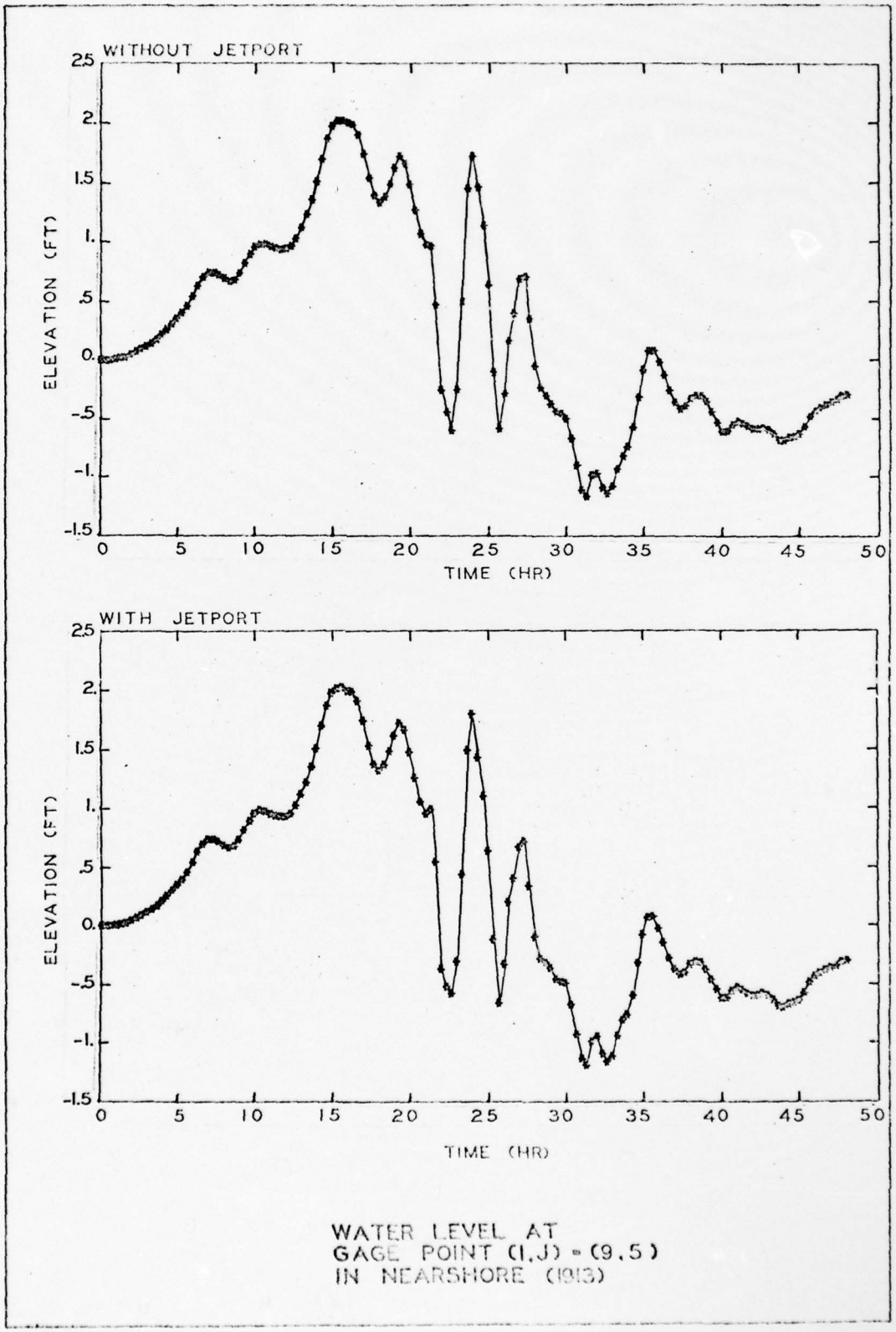
WATER LEVEL AT
GAGE POINT (I,J) = (5,3)
IN NEARSHORE (1313)



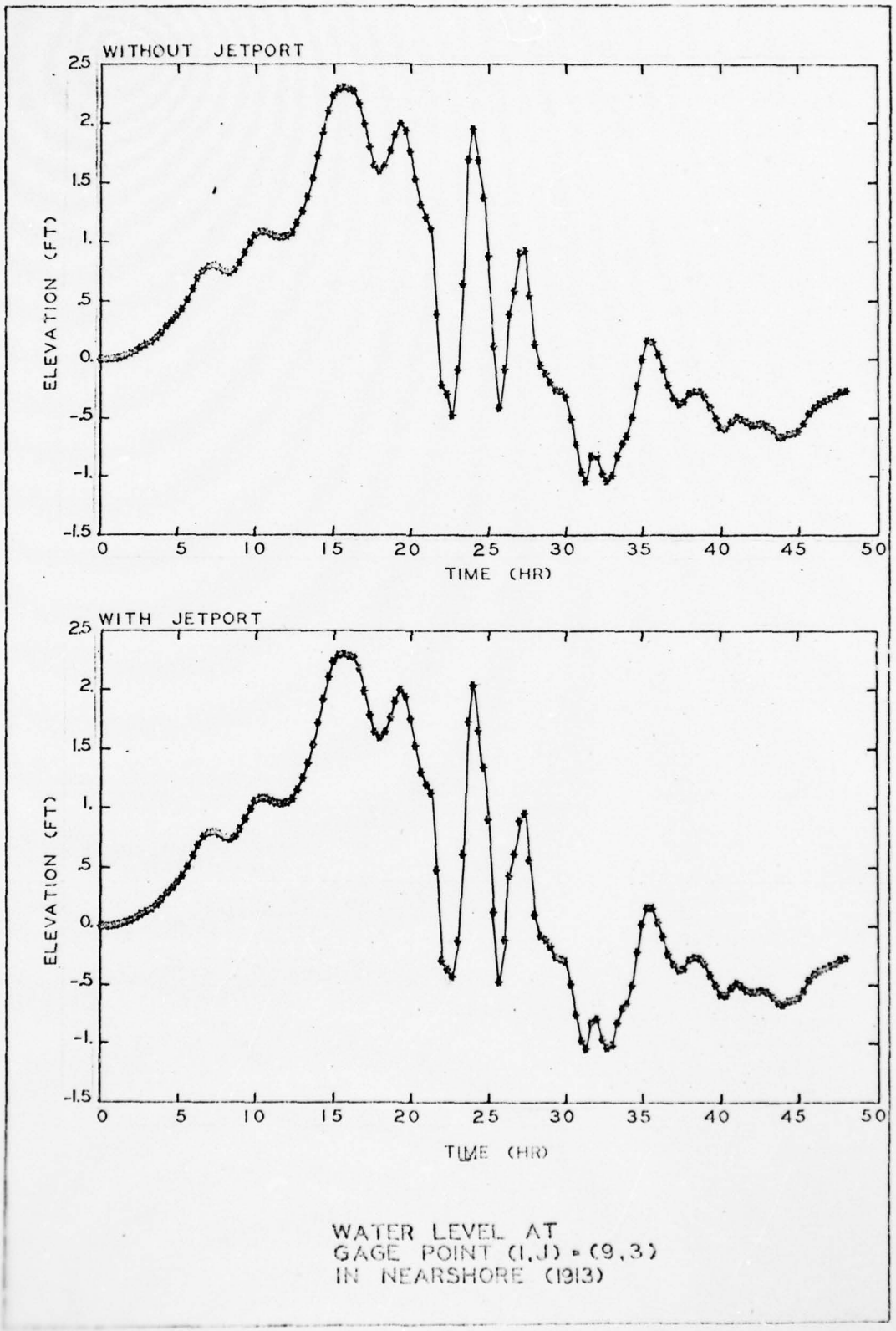
WATER LEVEL AT
GAGE POINT (I,J) = (7,5)
IN NEARSHORE (1913)



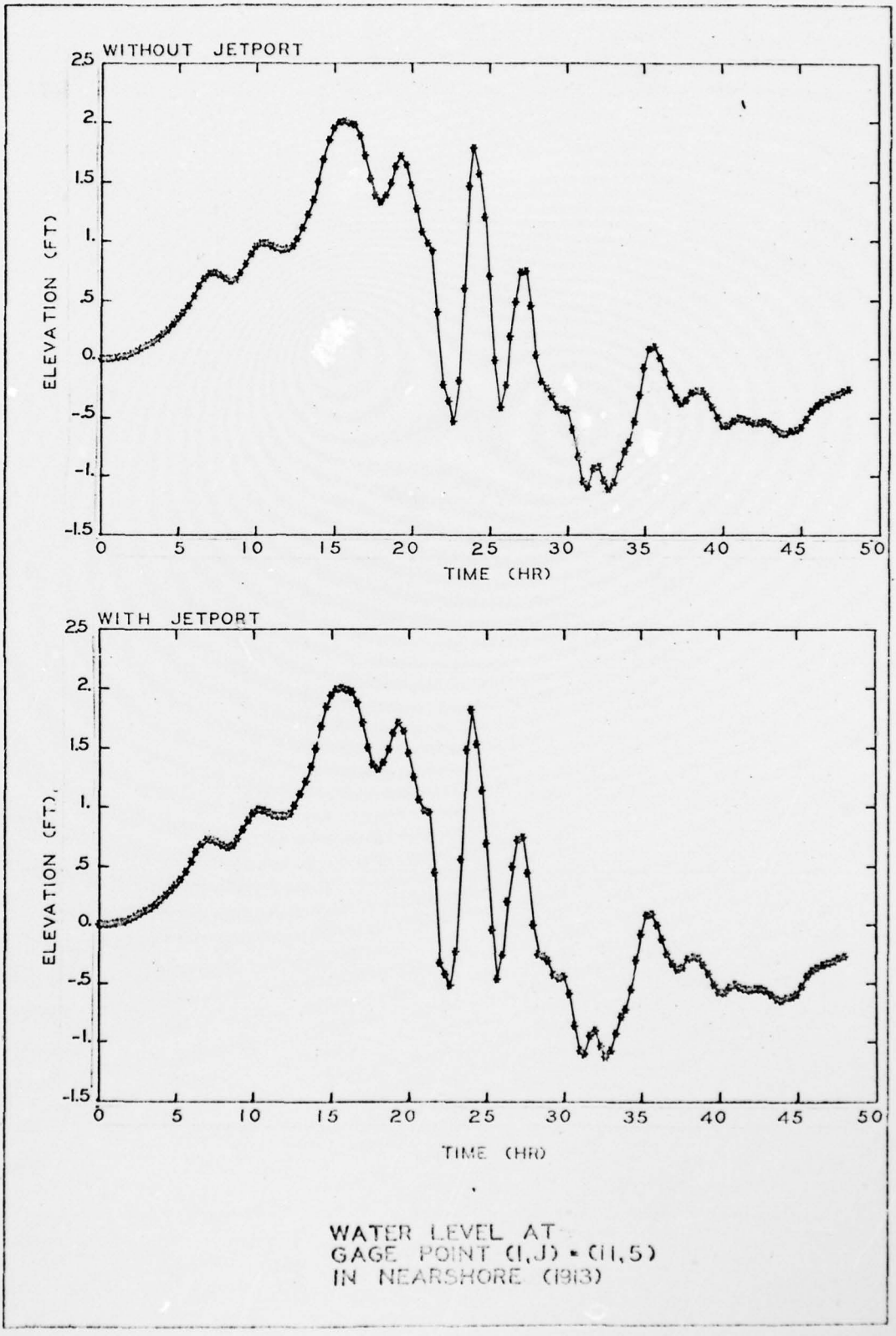
WATER LEVEL AT
GAGE POINT (I,J) = (9,11)
IN NEARSHORE (1913)



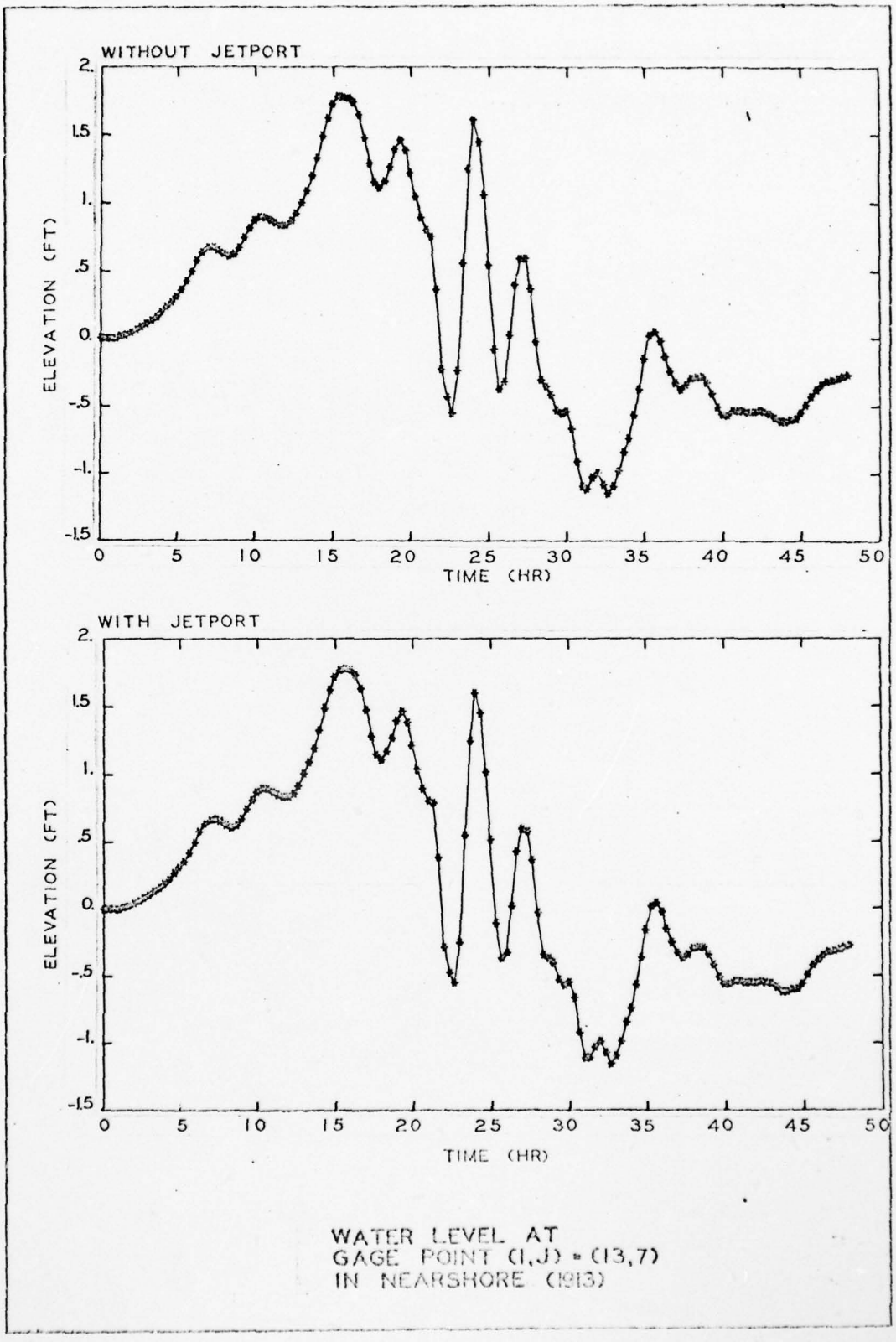
WATER LEVEL AT
GAGE POINT (I,J) = (9,5)
IN NEARSHORE (1913)



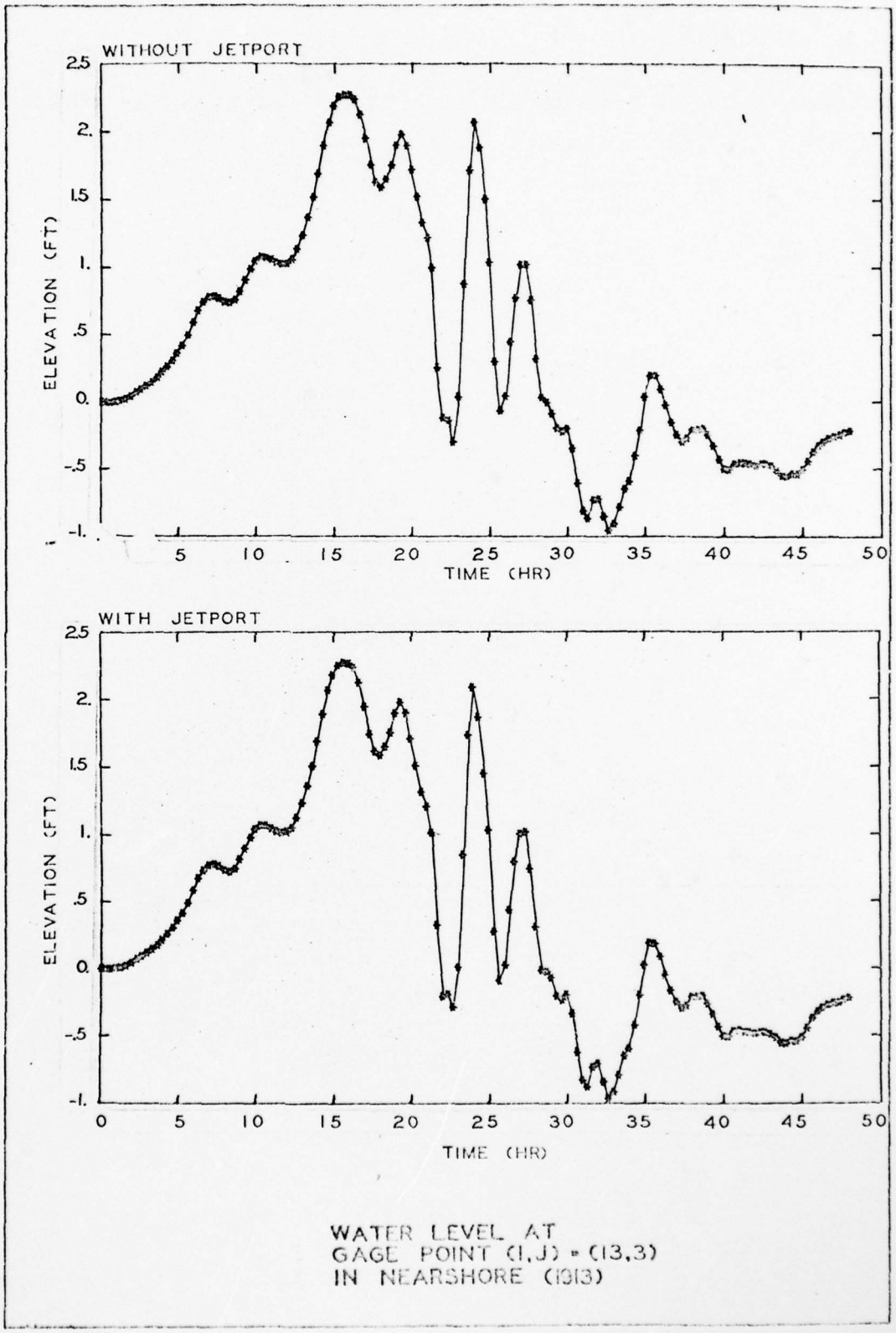
WATER LEVEL AT
GAGE POINT (I,J) = (9,3)
IN NEARSHORE (1313)



WATER LEVEL AT
GAGE POINT (I,J) = (11,5)
IN NEARSHORE (1313)



WATER LEVEL AT
GAGE POINT (I,J) = (13,7)
IN NEARSHORE (1913)

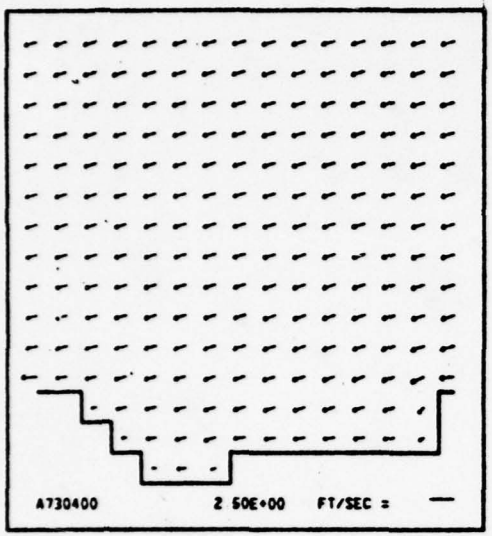


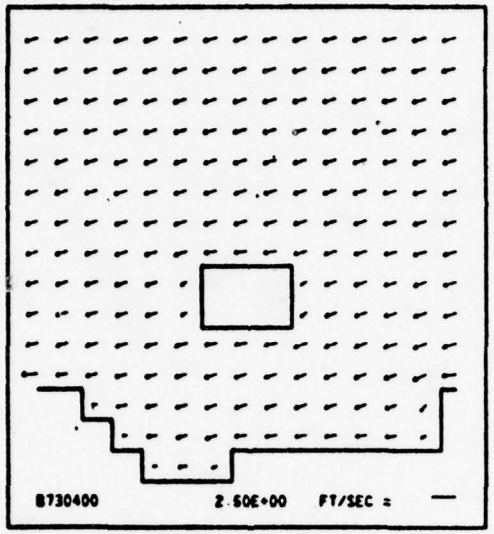
WATER LEVEL AT
GAGE POINT (I,J) = (13,3)
IN NEARSHORE (1313)

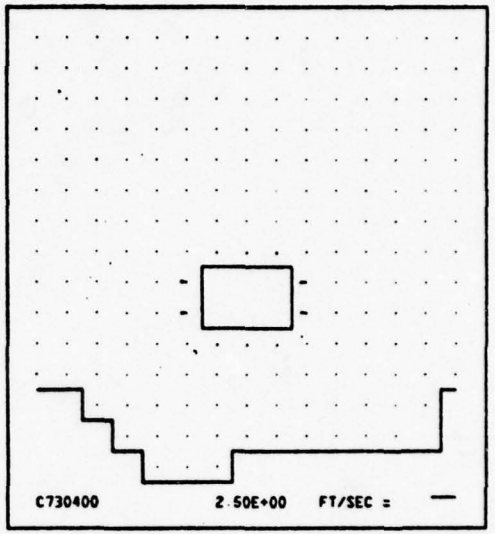
APPENDIX F: Nearshore Horizontal Velocity Field

Inclosure 1: 8-9 April 1973 Storm
Inclosure 2: 25-27 November 1950 Storm
Inclosure 3: 7-10 November 1913 Storm

Inclosure 1: 8-9 April 1973 Storm







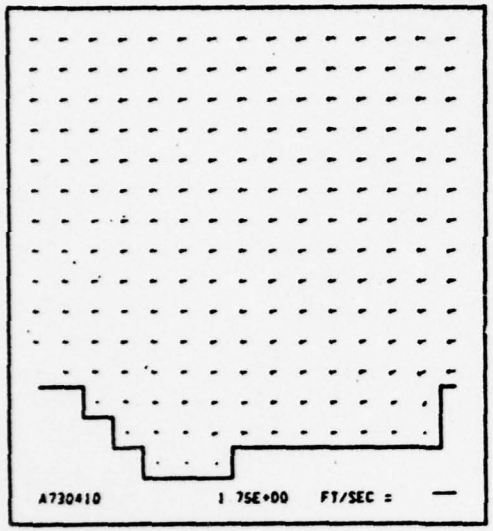
NEARSHORE HORIZONTAL VELOCITIES

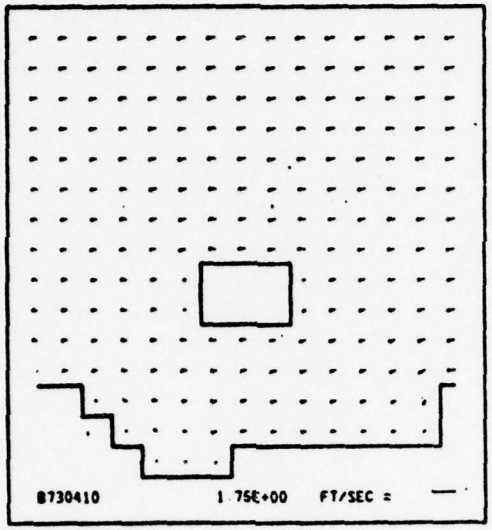
Velocity plots are identified in lower left hand corner by plot number.

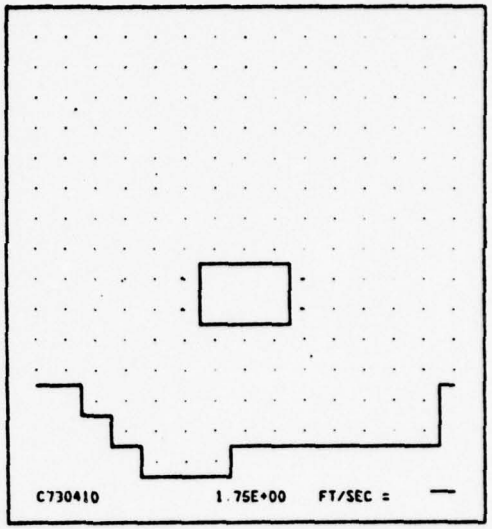
Plot Number Code

1 Alpha character:
- A = without jetport
- B = with jetport
- C = differences

2 numerical characters = year
2 numerical characters = hour
2 numerical characters = depth (ft)







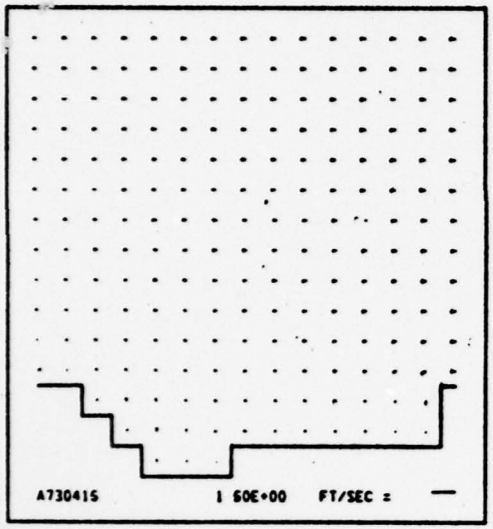
NEARSHORE HORIZONTAL VELOCITIES

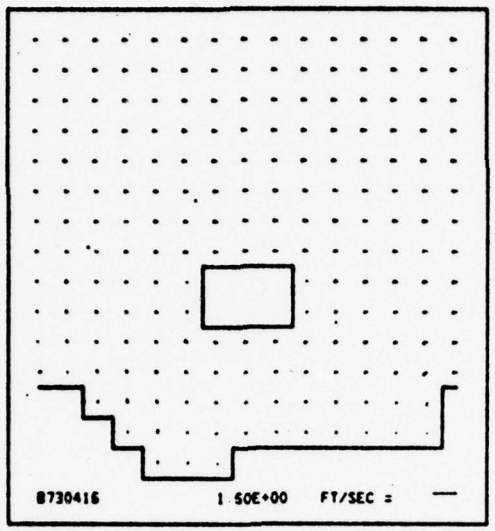
Velocity plots are identified in lower left hand corner by plot number.

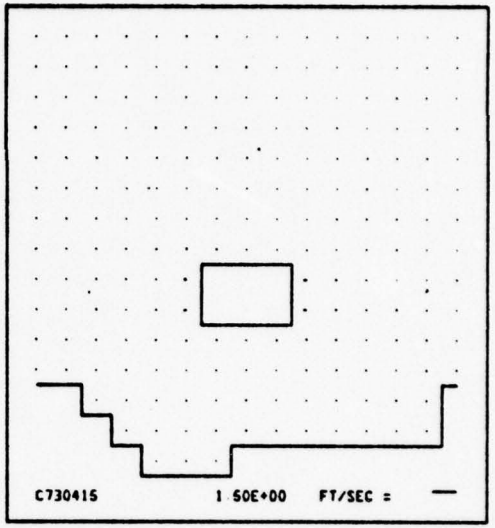
Plot Number Code

1 Alpha character:
- A = without jetport
- B = with jetport
- C = differences

2 Numerical characters = year
2 Numerical characters = hour
2 Numerical characters = depth (ft)







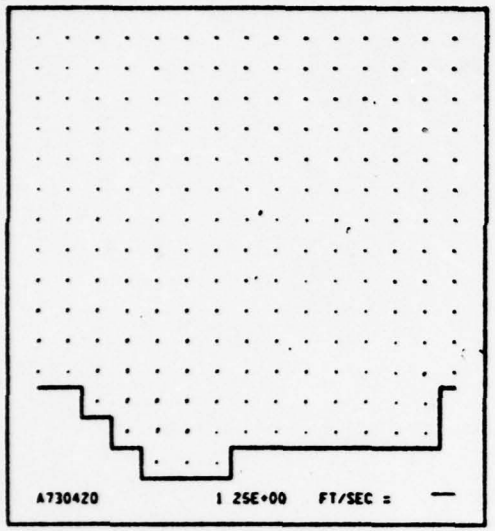
NEARSHORE HORIZONTAL VELOCITIES

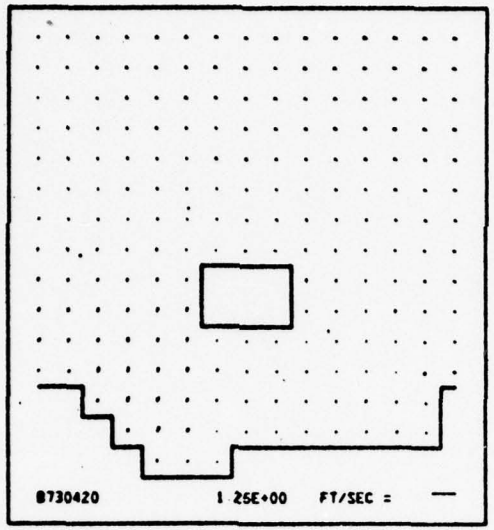
Velocity plots are identified in lower left hand corner by plot number.

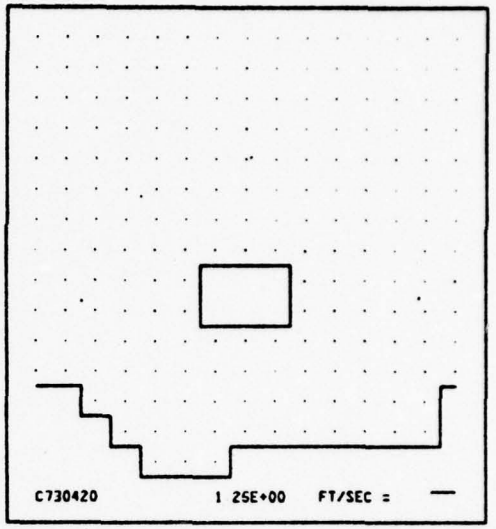
Plot Number Code

1 Alpha character:
- A = without jetport
- B = with jetport
- C = differences

2 Numerical characters = year
2 Numerical characters = hour
2 Numerical characters = depth (ft)







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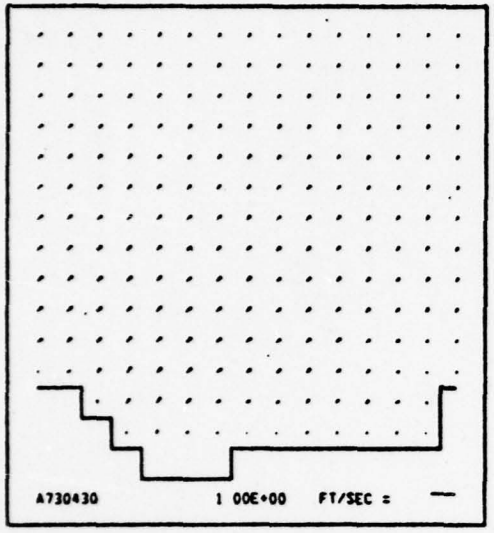

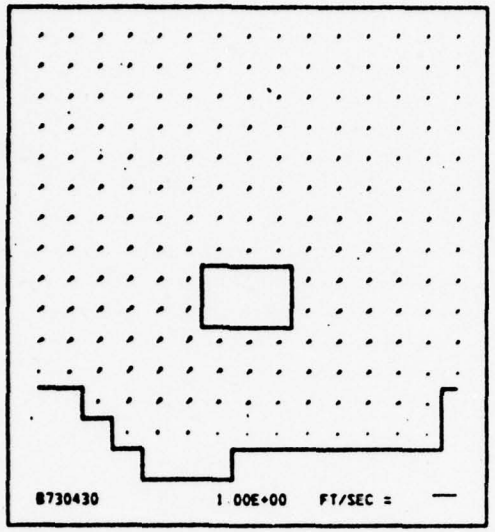

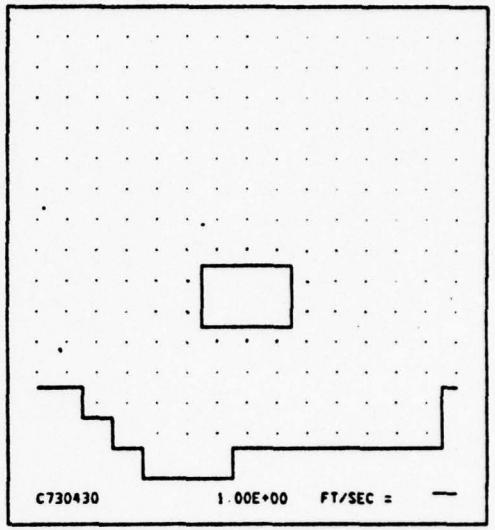

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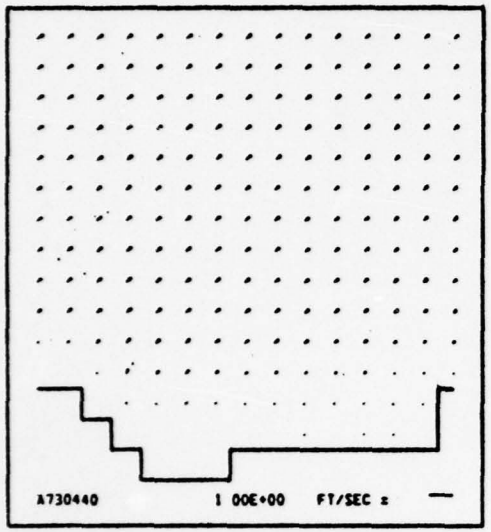

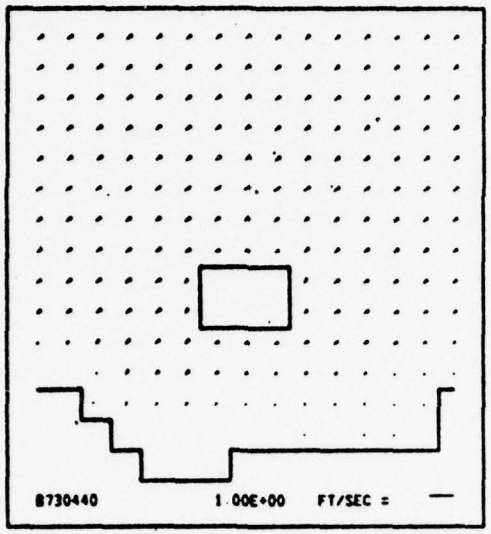

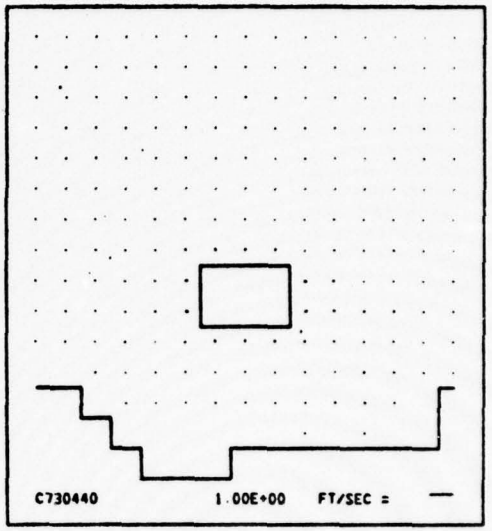

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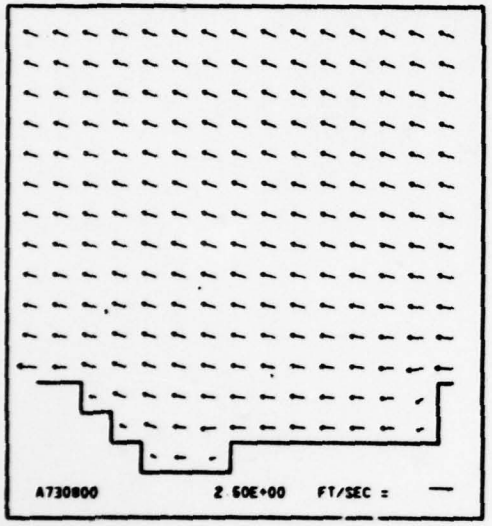

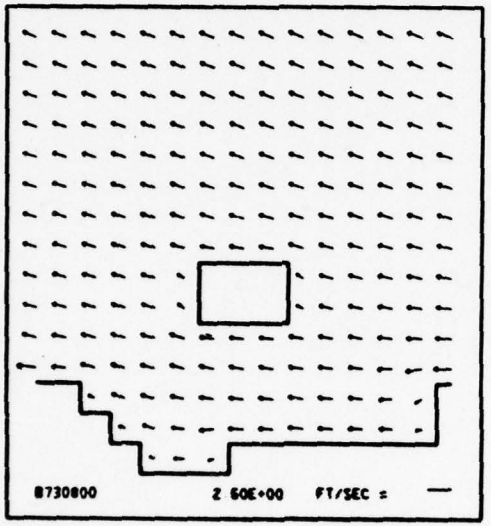

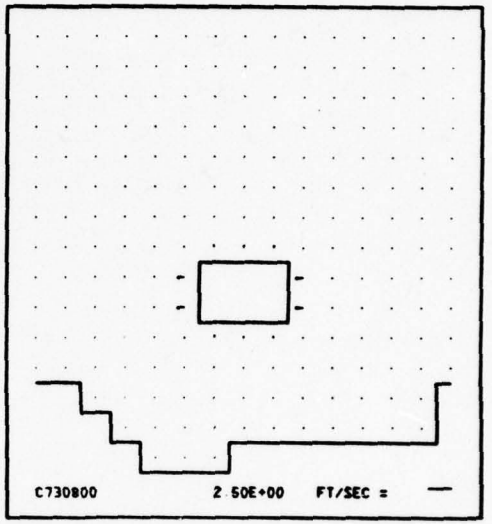

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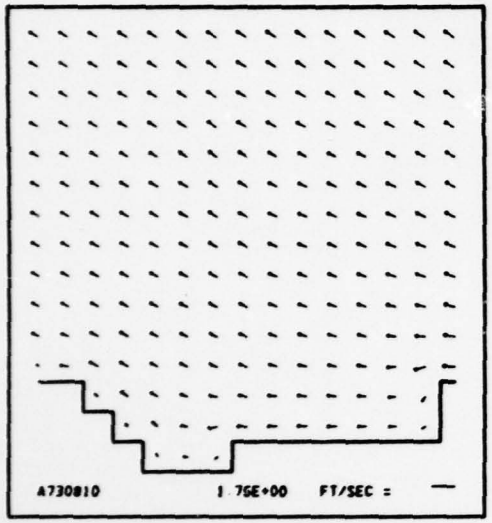

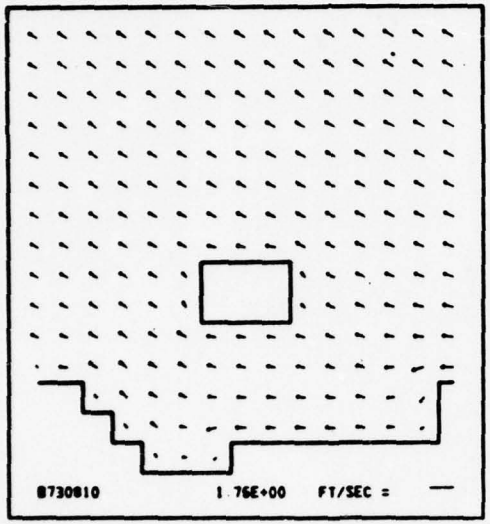

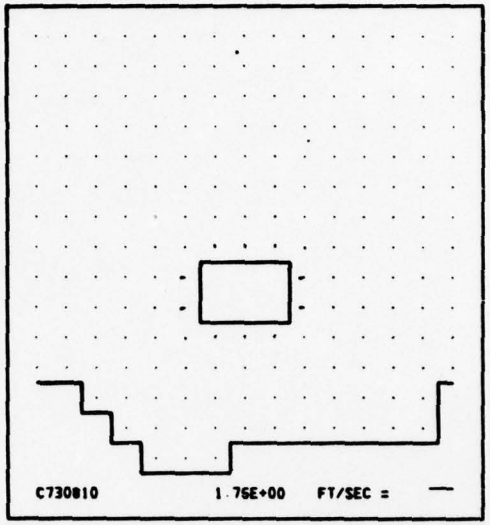

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AD-A036 243 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 1/5
LAKE ERIE INTERNATIONAL JETPORT MODEL FEASIBILITY INVESTIGATION--ETC(U)
OCT 76 D L DURHAM, H L BUTLER, D C RANEY

UNCLASSIFIED WES-MP-H-76-3-8 NL

3 OF 5
AD
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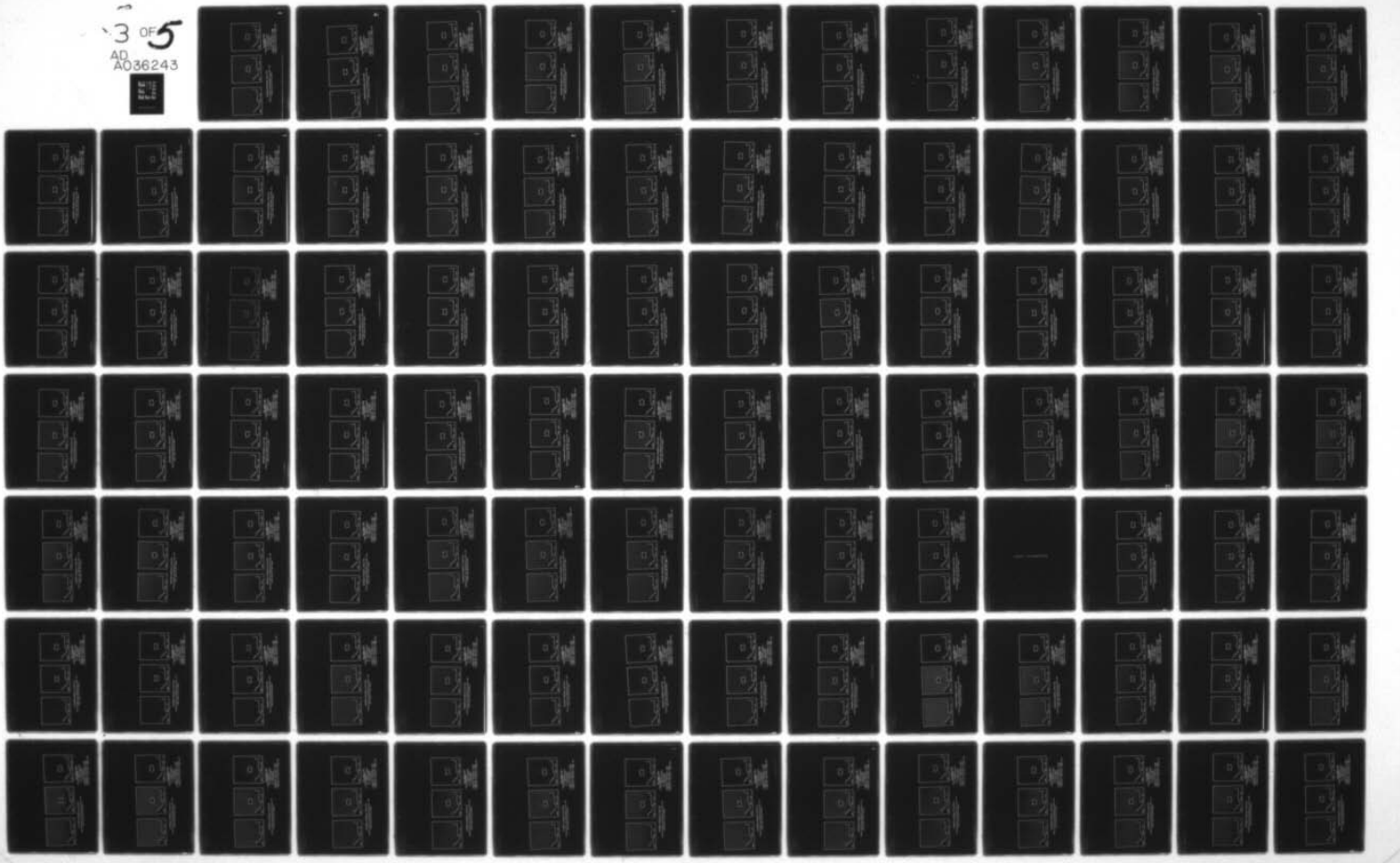

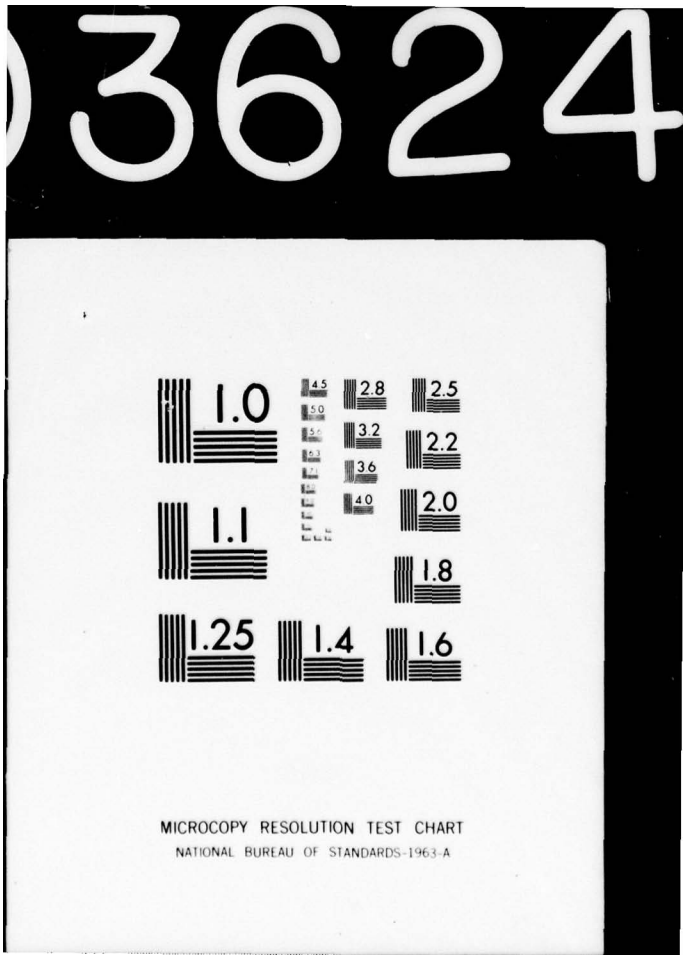
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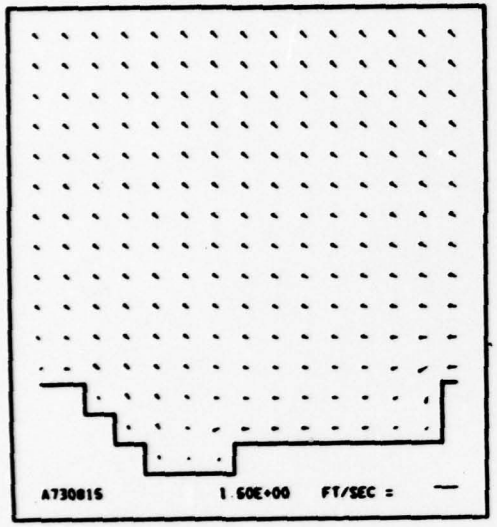
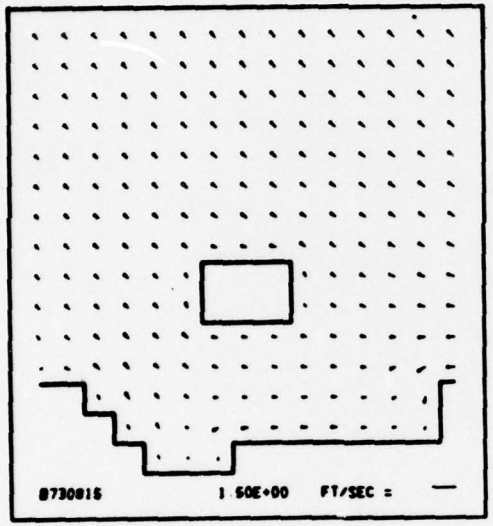
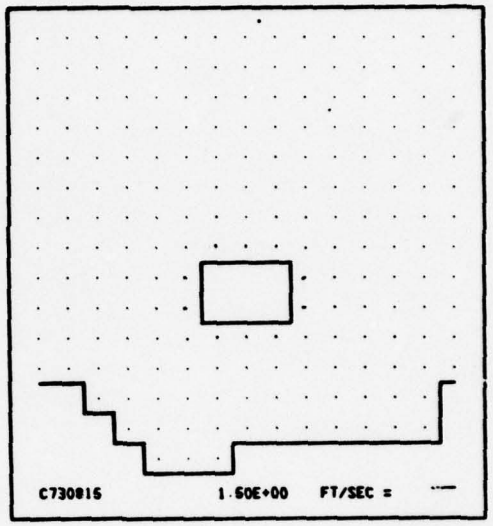
NATIONAL BUREAU OF STANDARDS-1963-A







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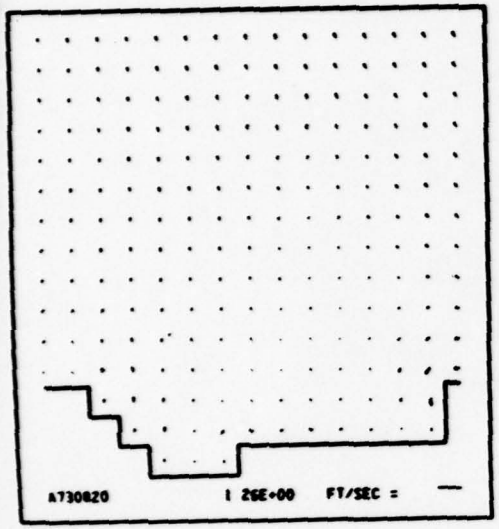

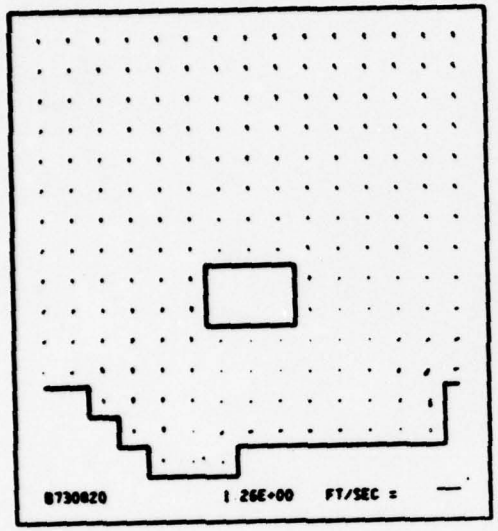

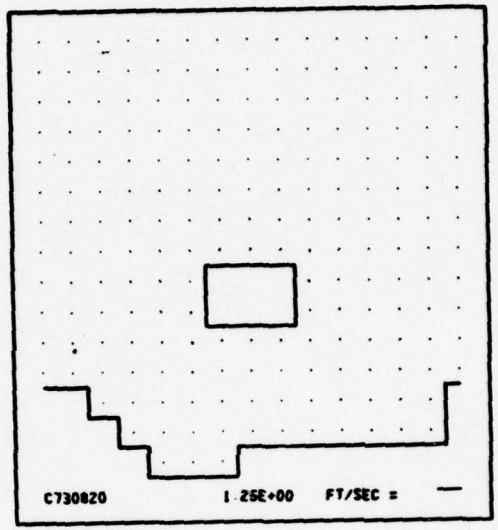

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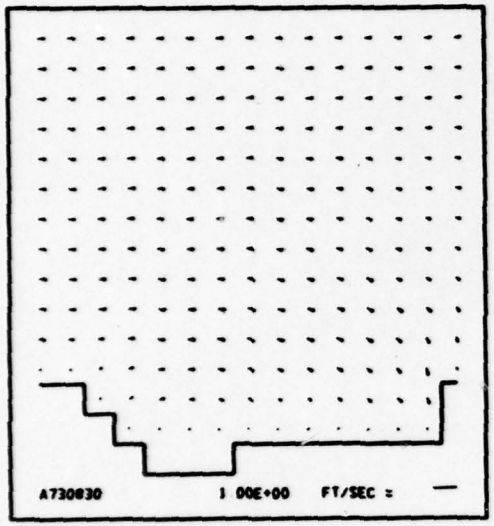

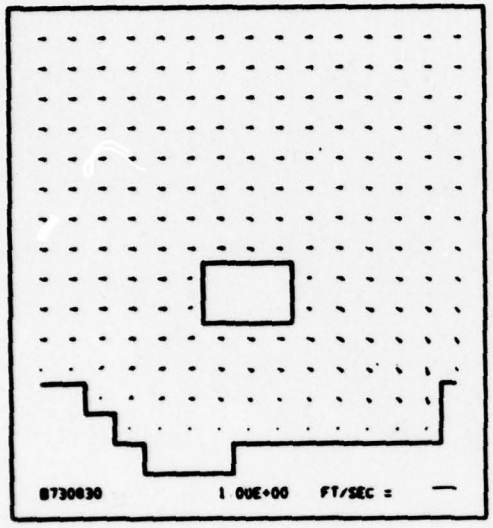

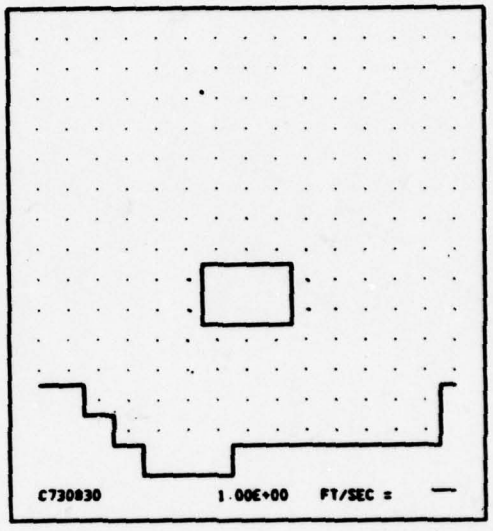

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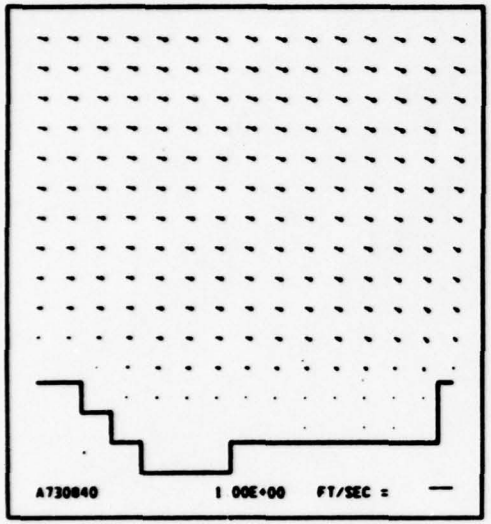

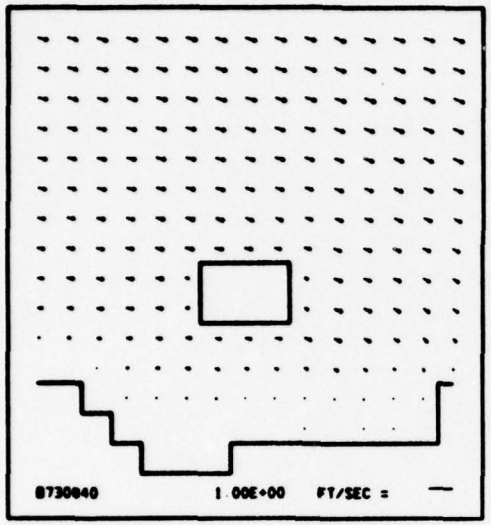

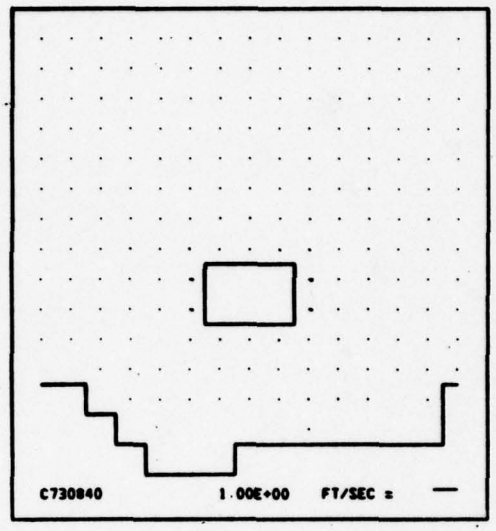

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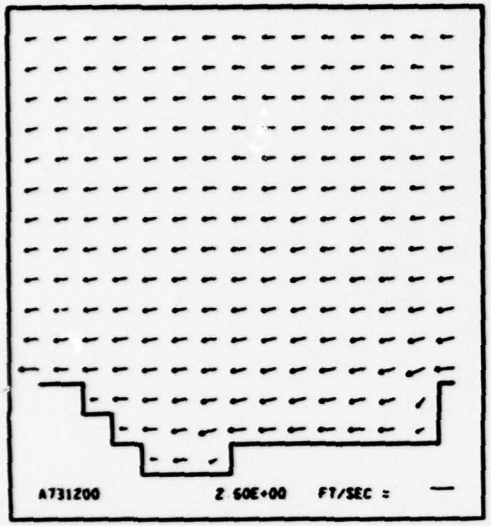

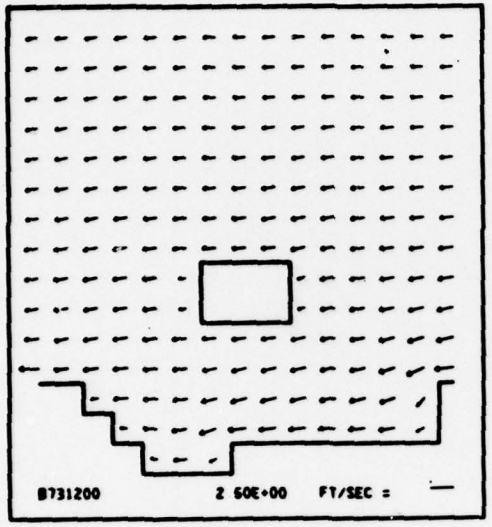

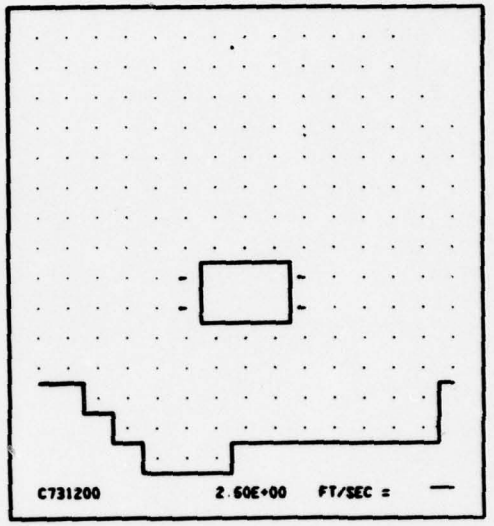

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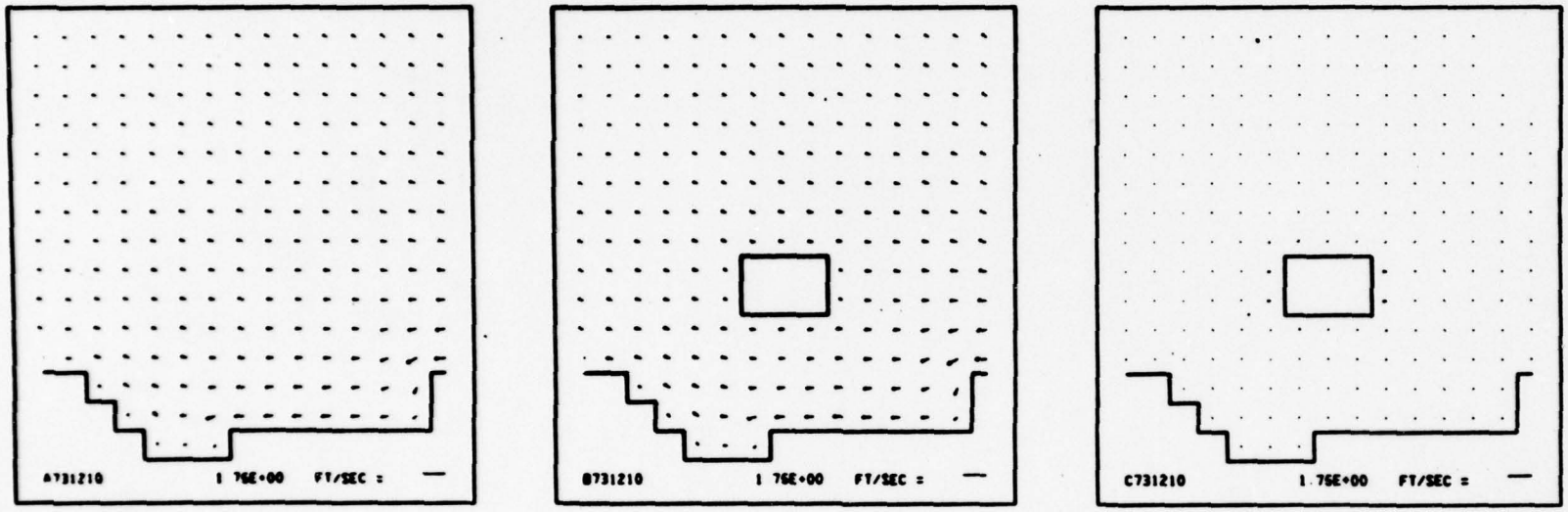

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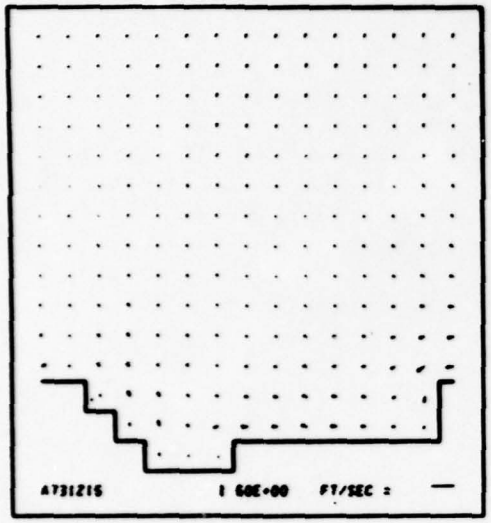

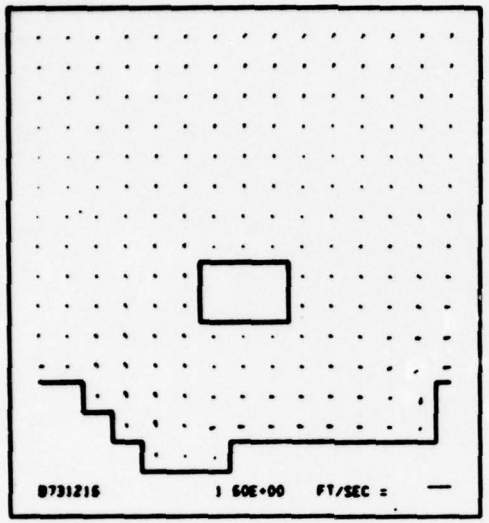

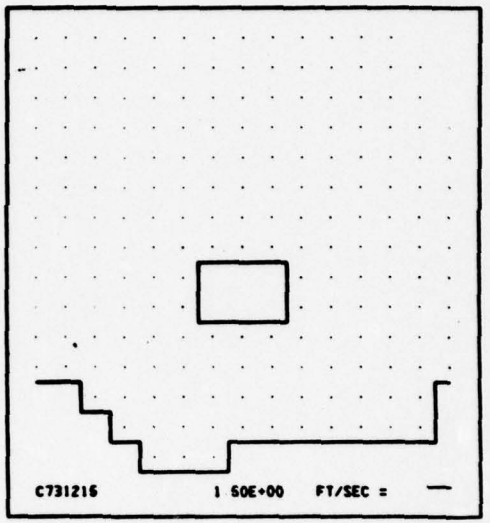

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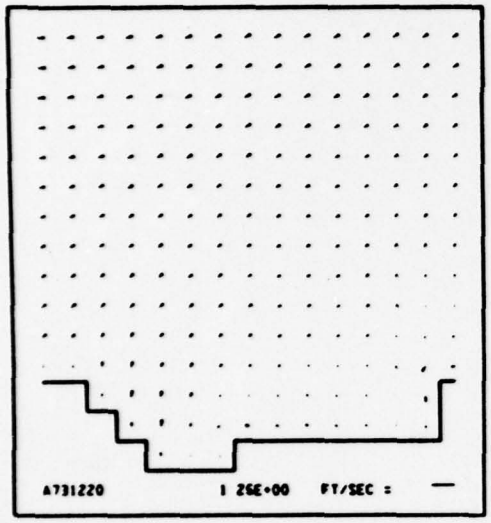

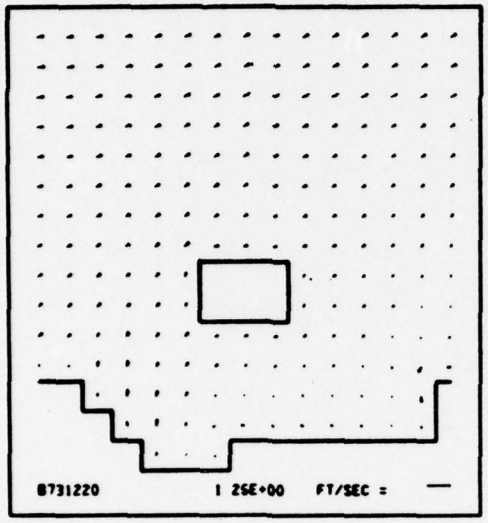

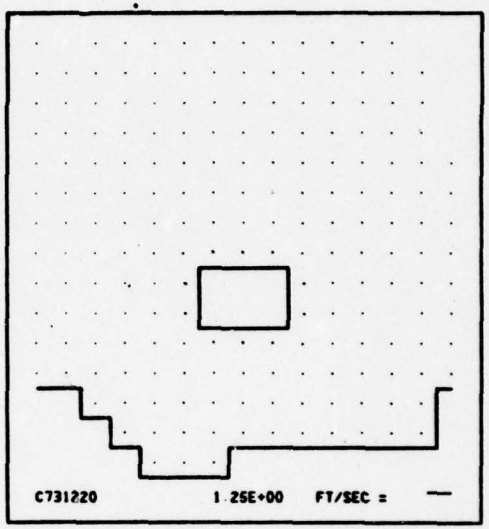

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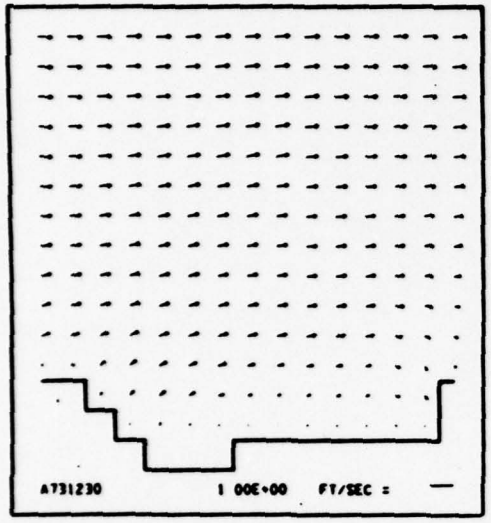

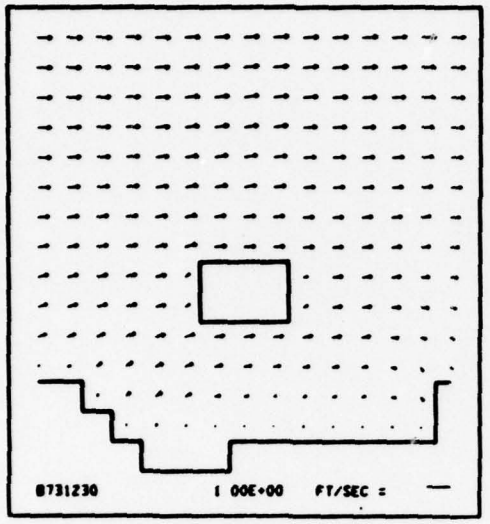

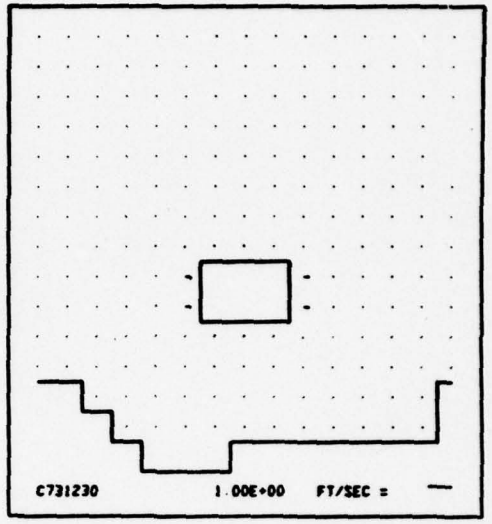

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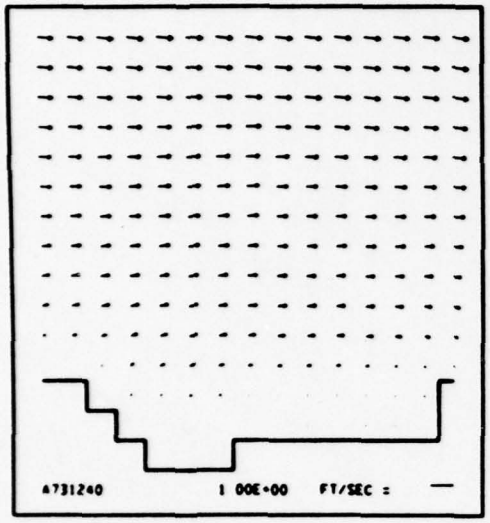

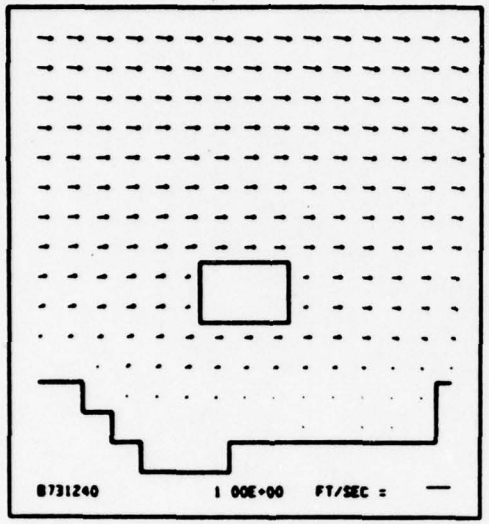

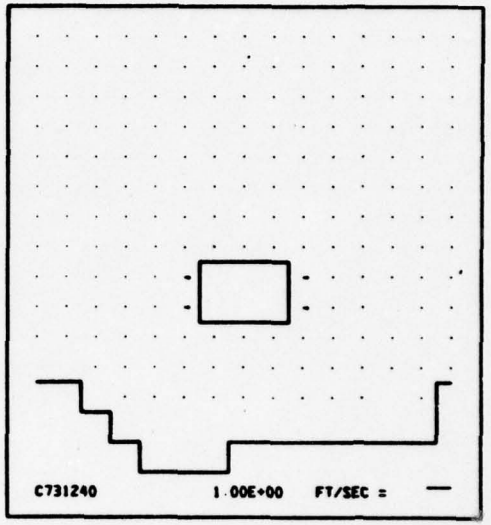

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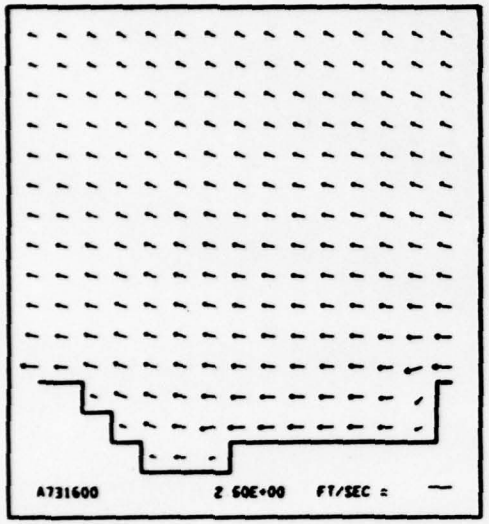

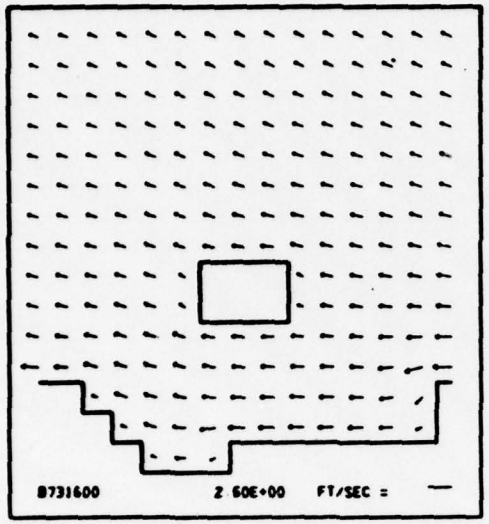

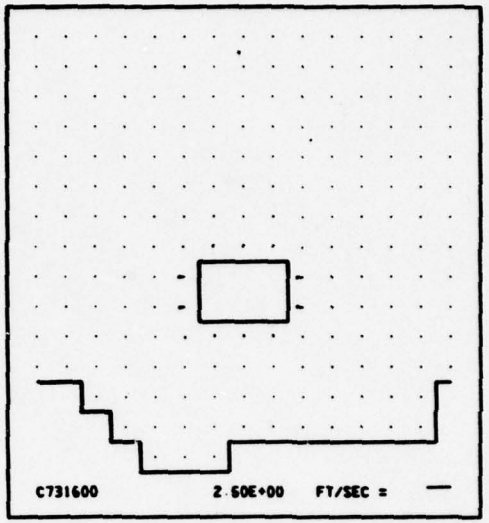

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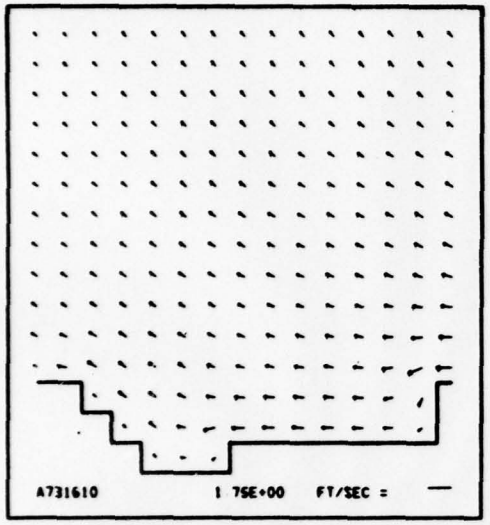

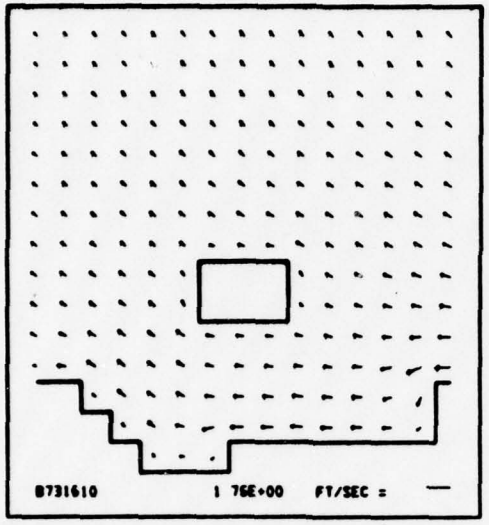

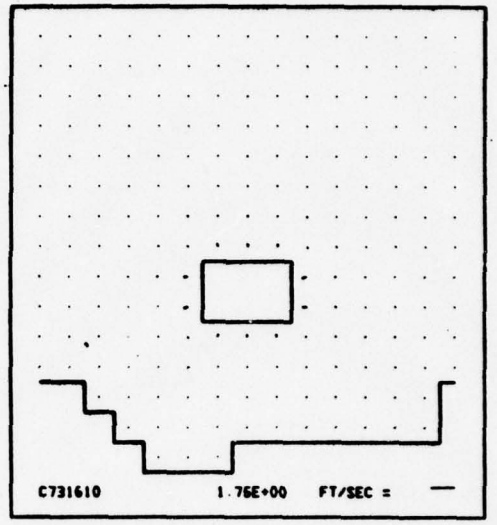

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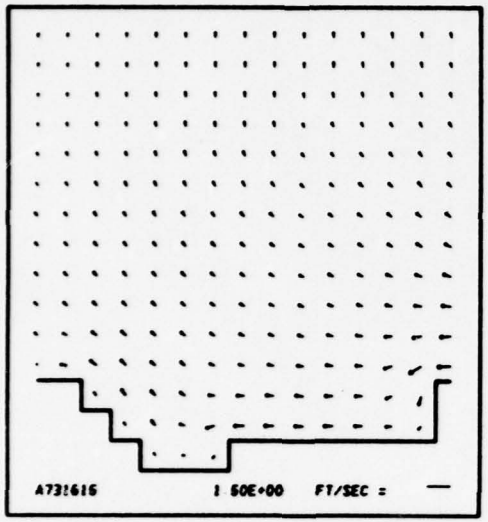

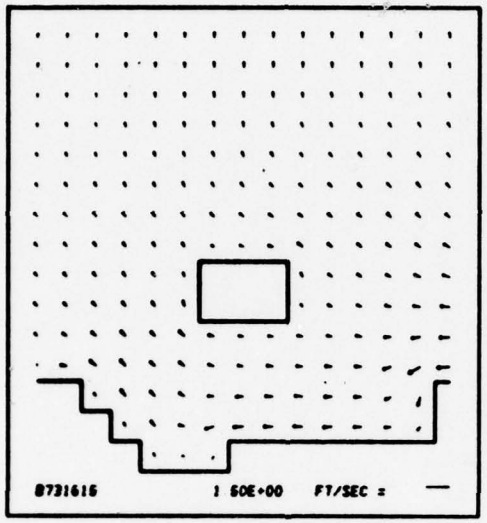

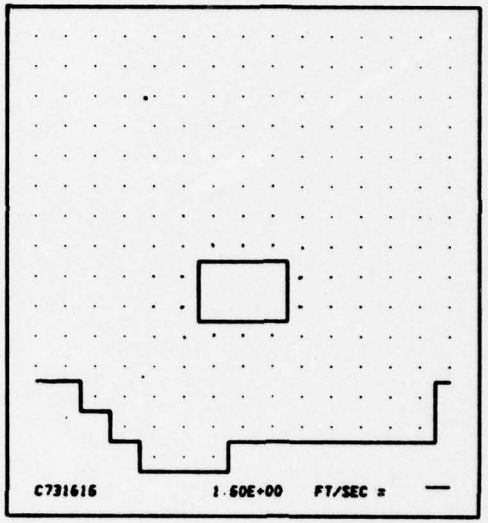

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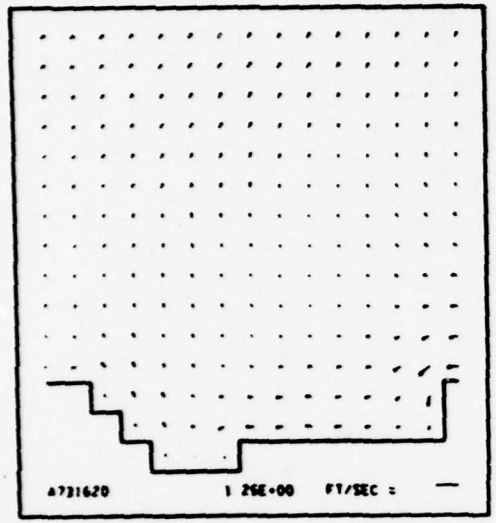

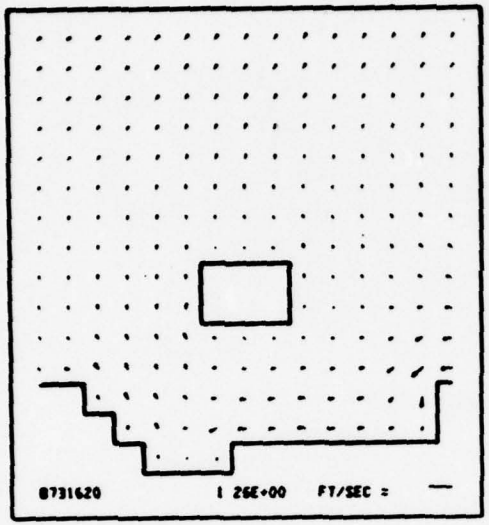

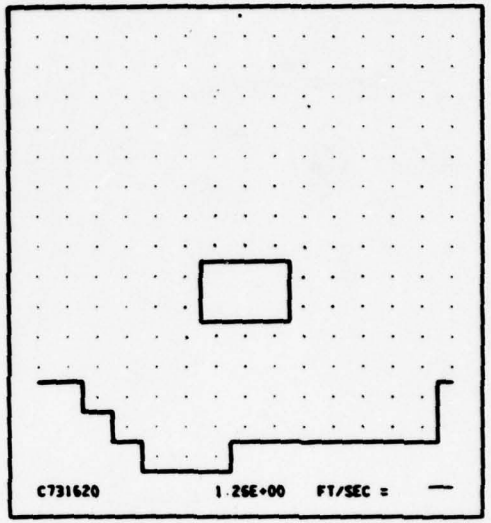

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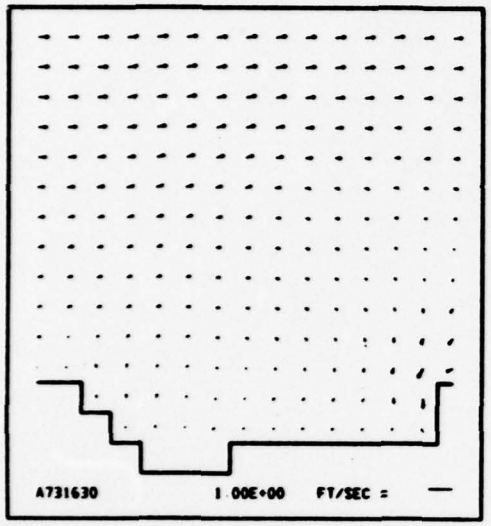

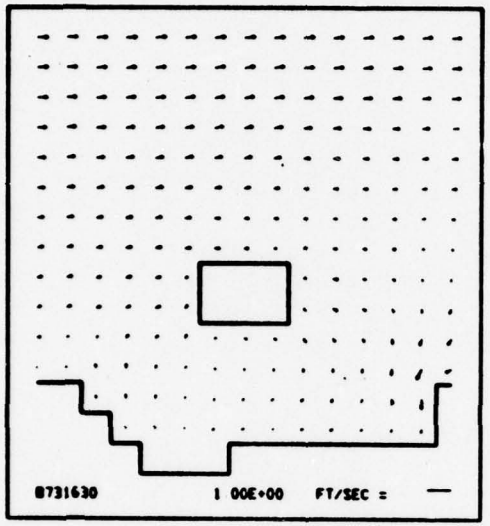

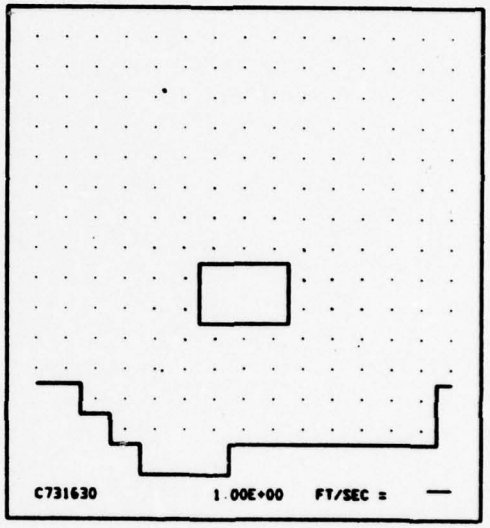

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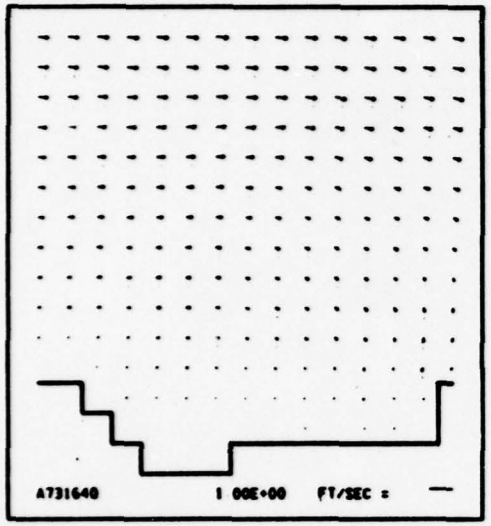

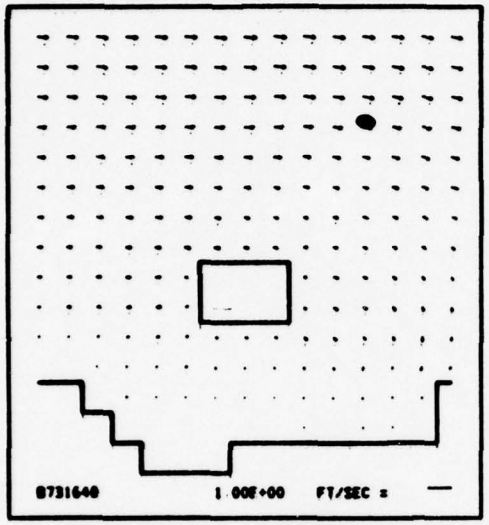

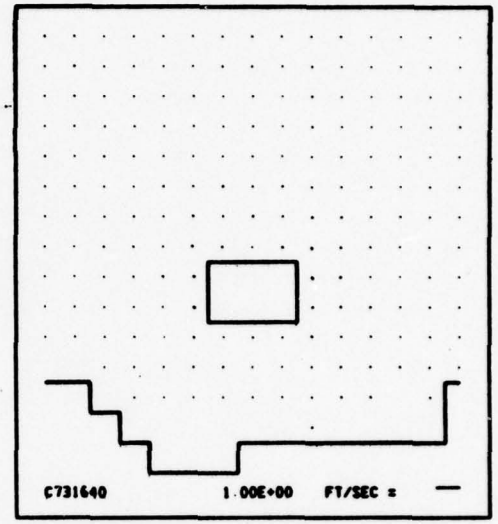

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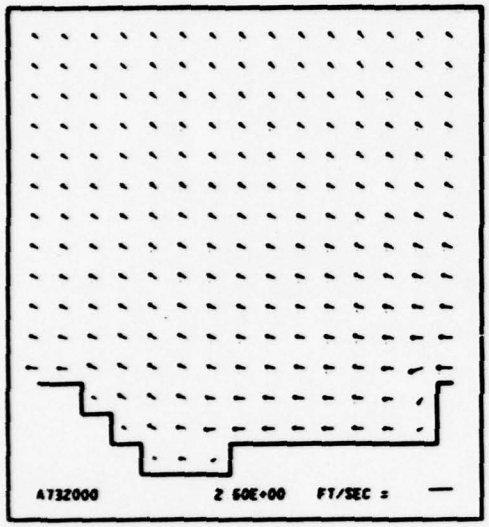

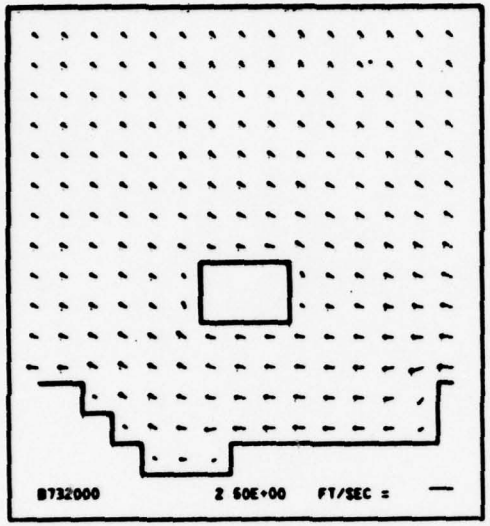

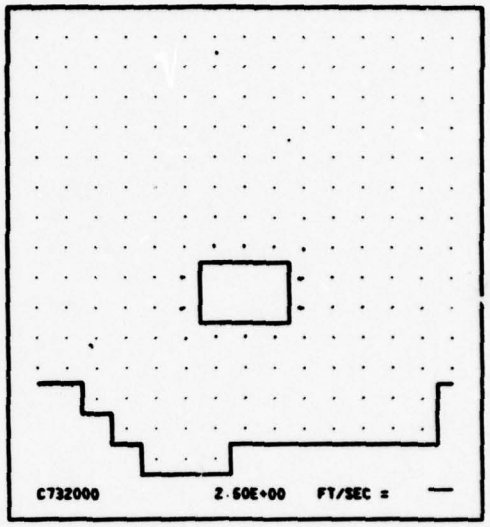

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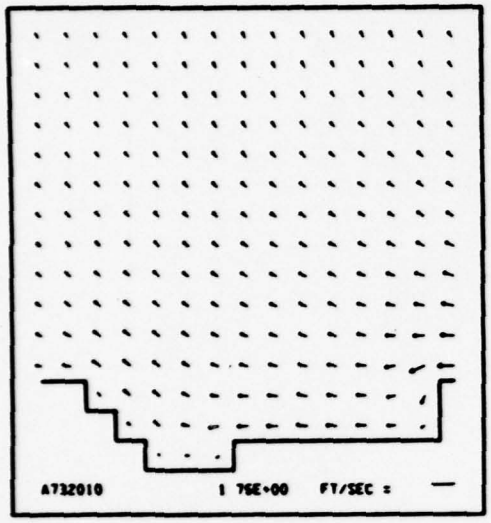

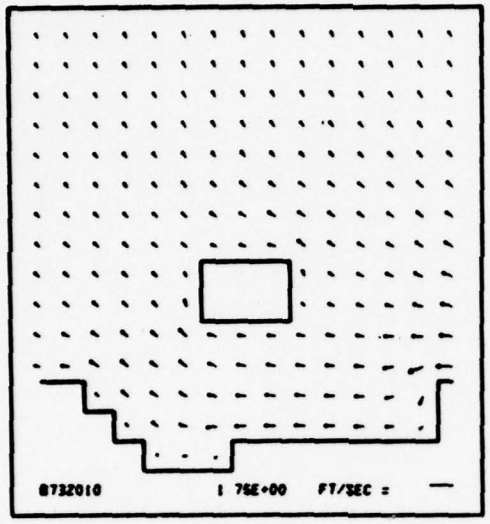

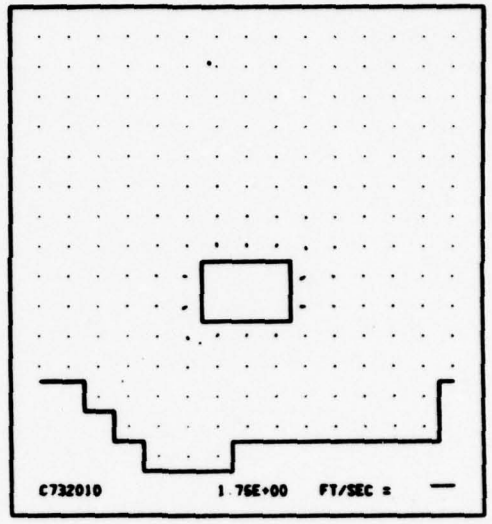

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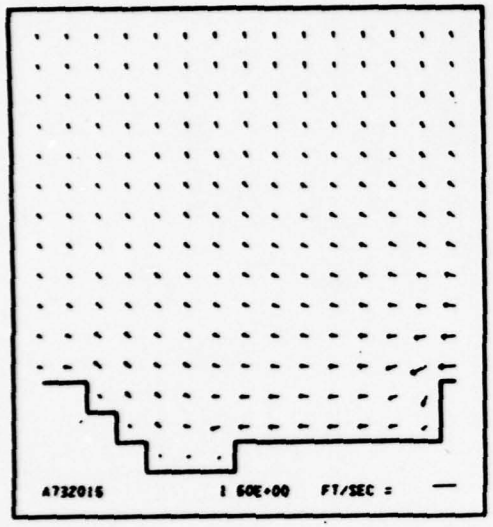

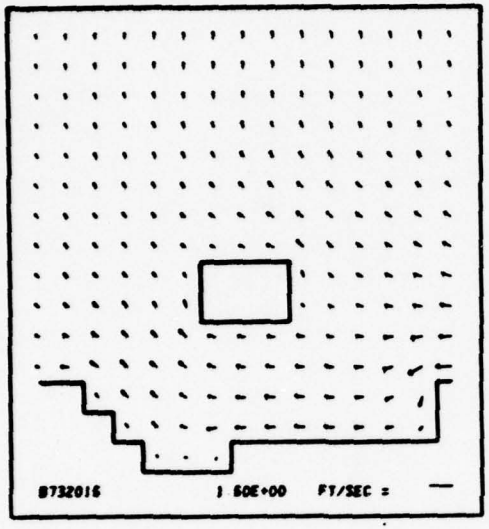

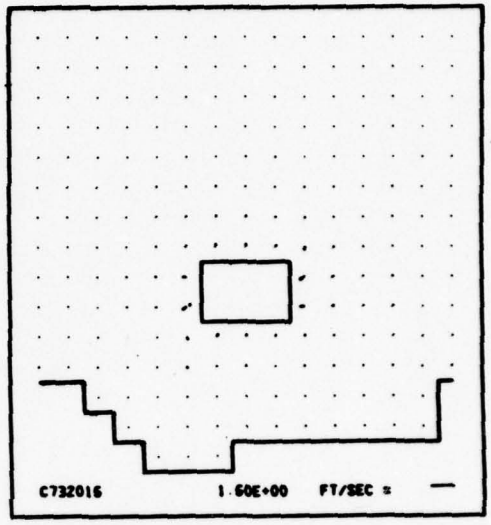

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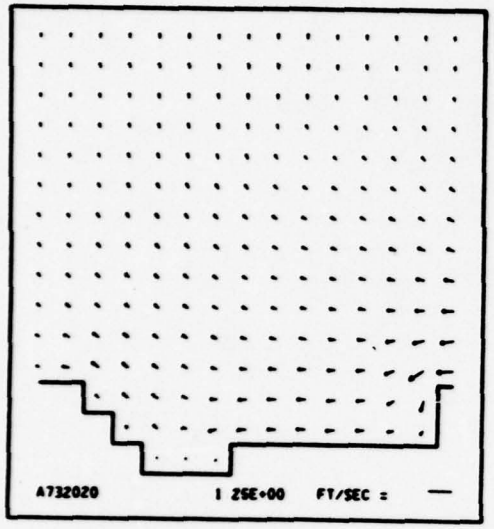

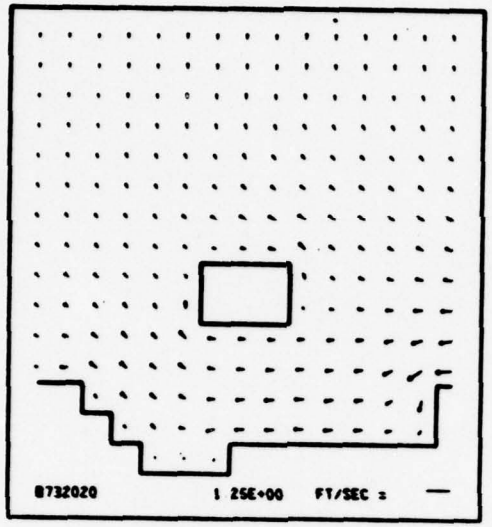

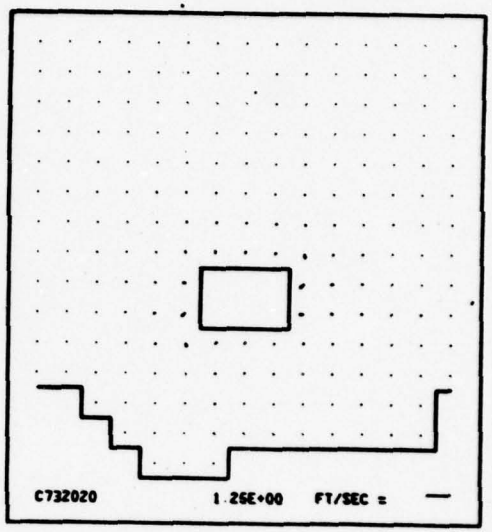

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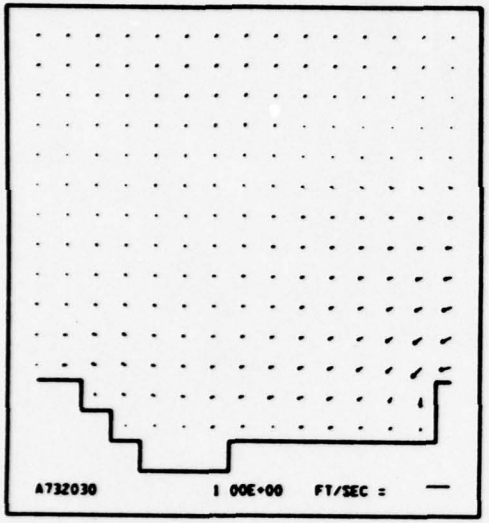

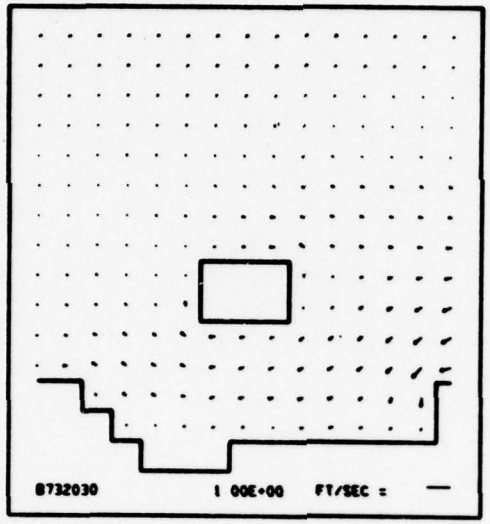

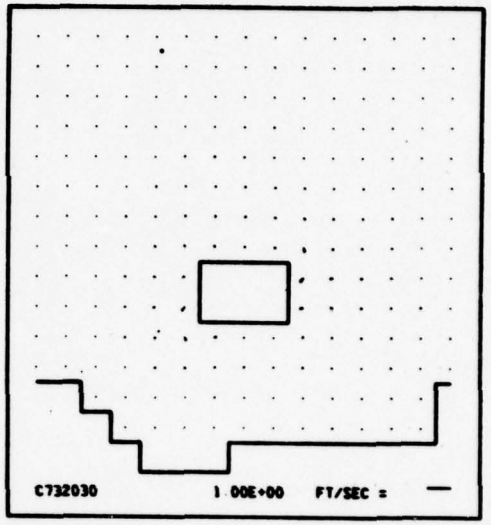

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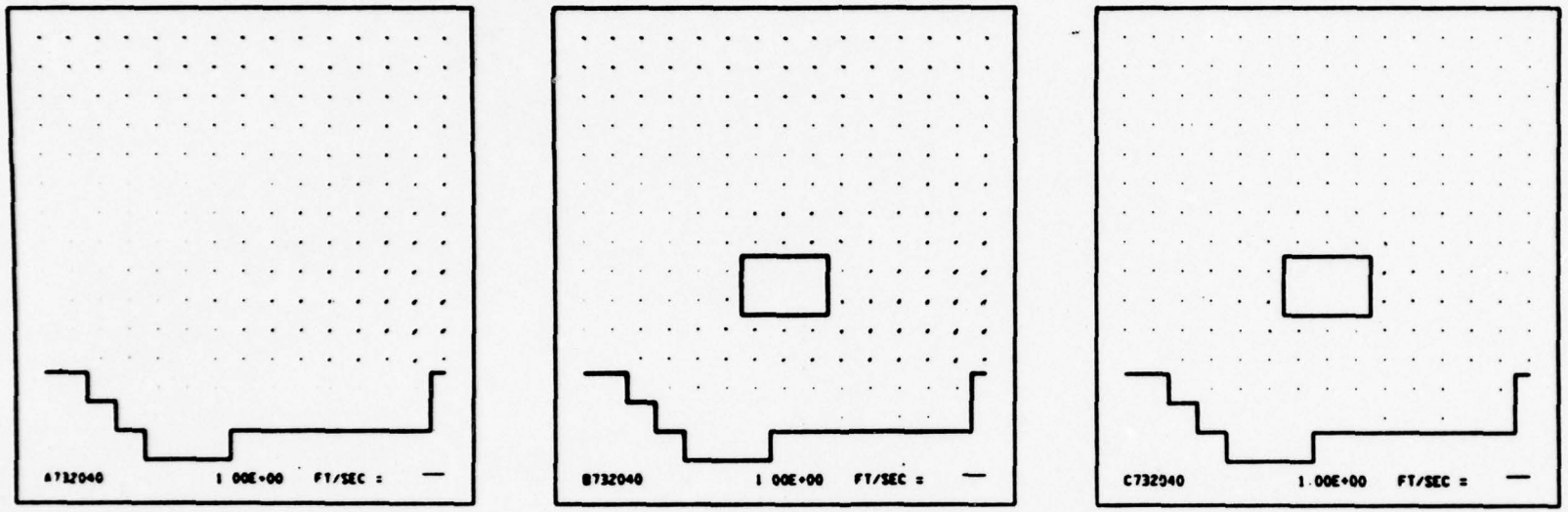

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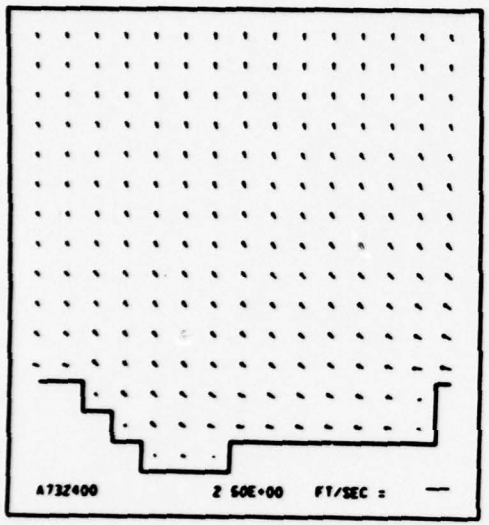

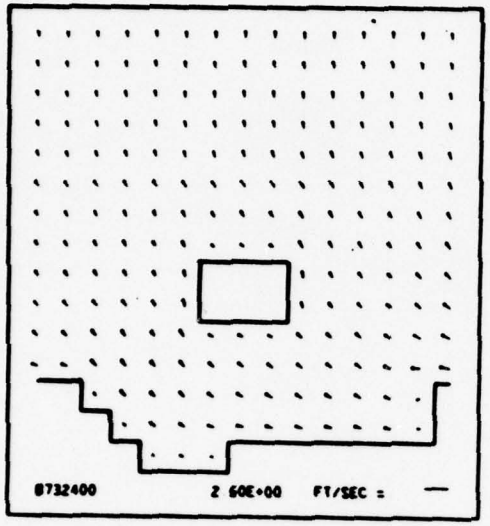

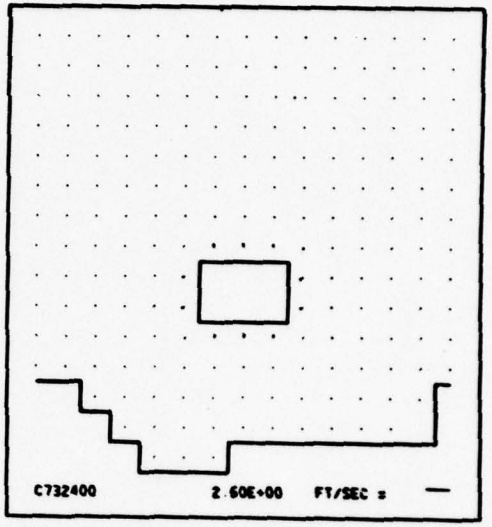

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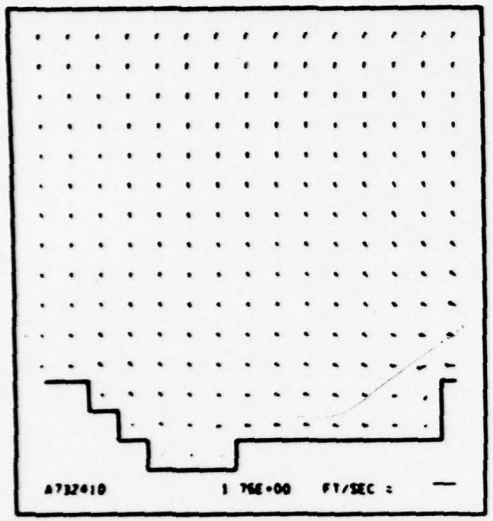

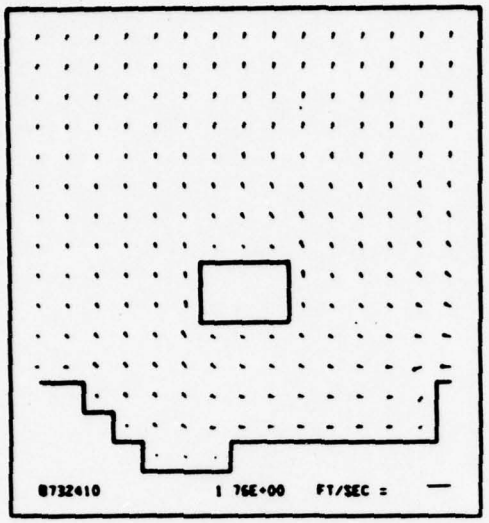

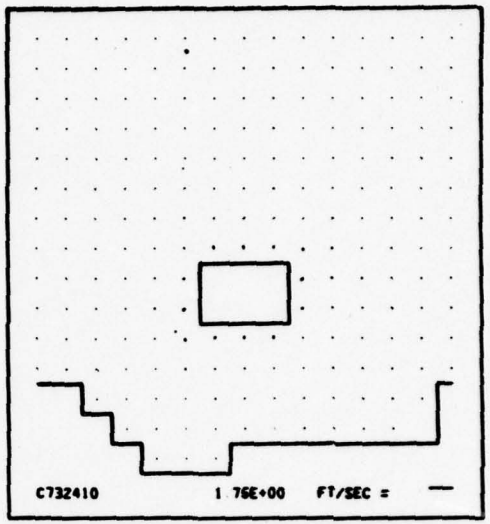

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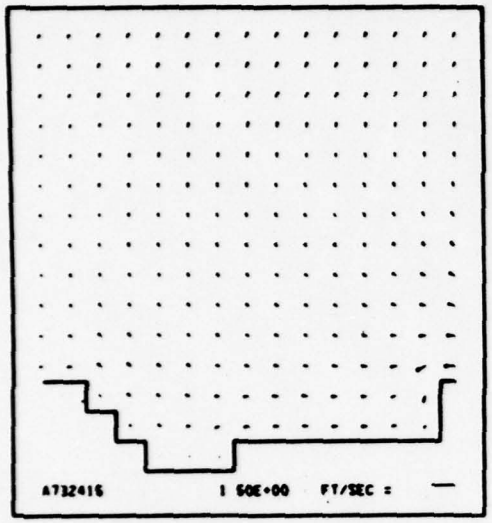

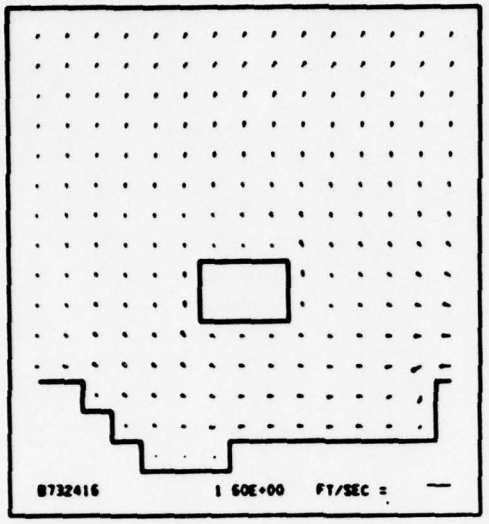

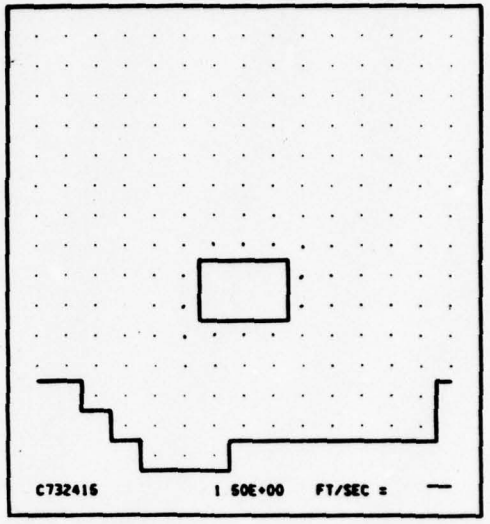

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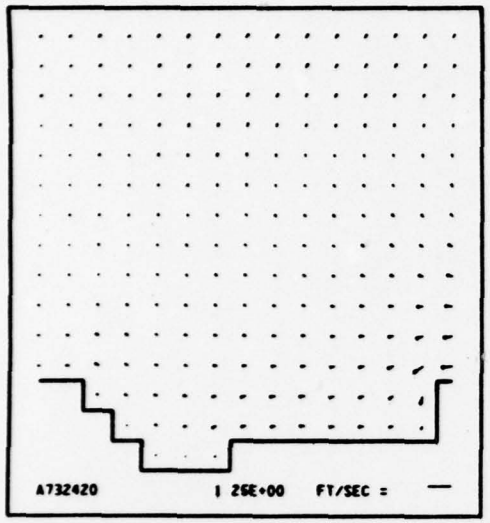

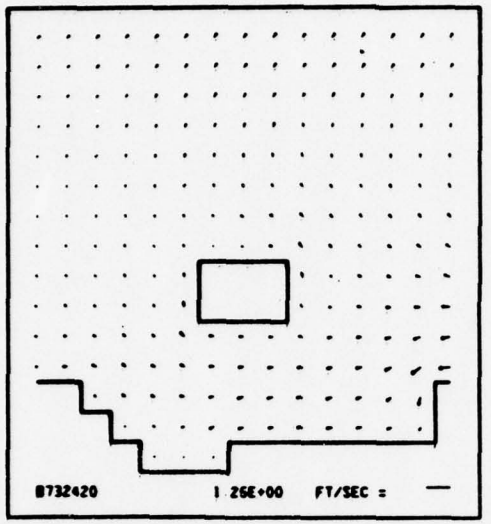

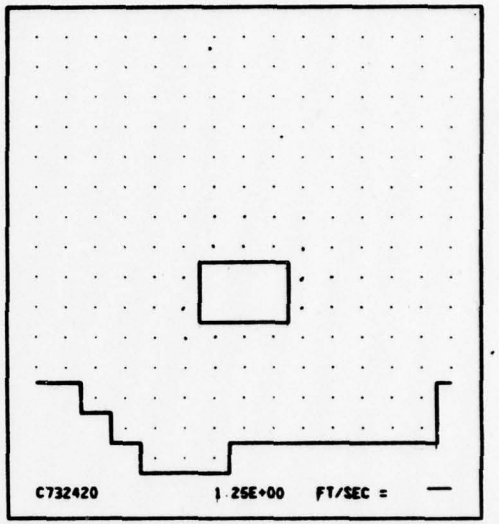

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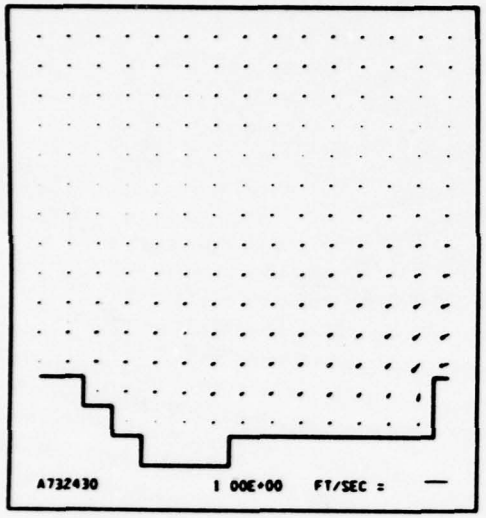

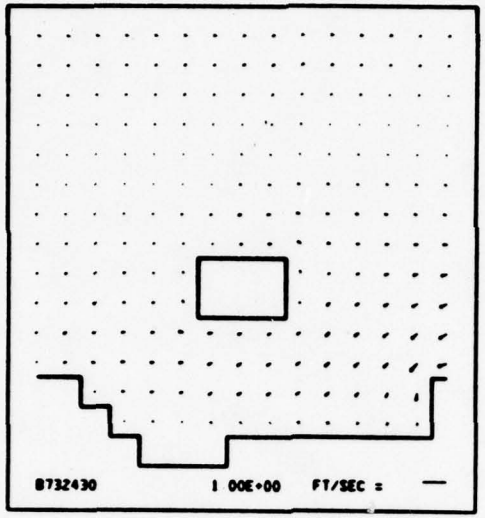

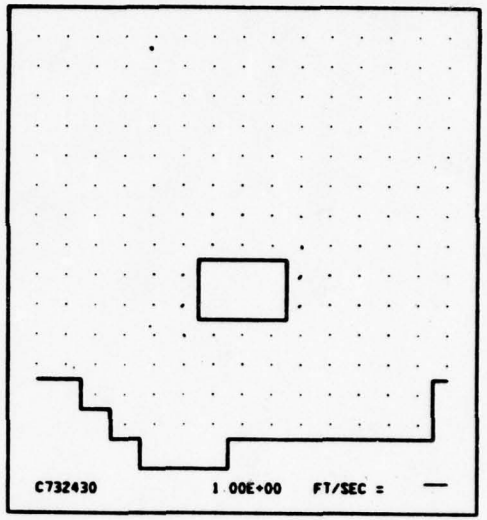

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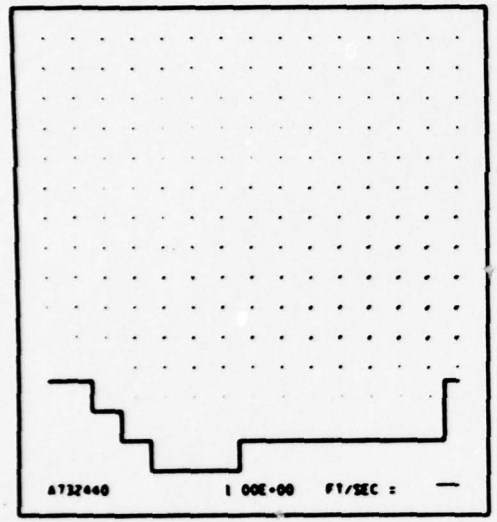

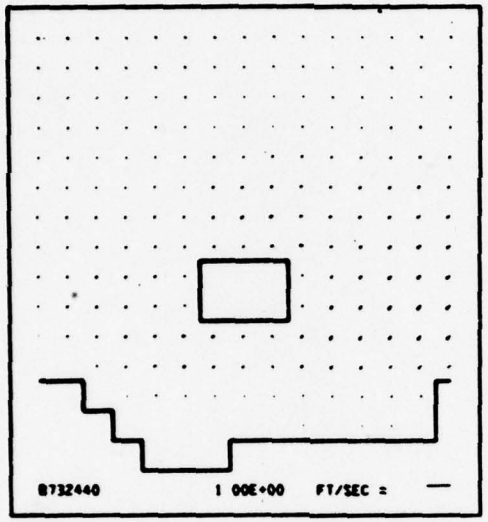

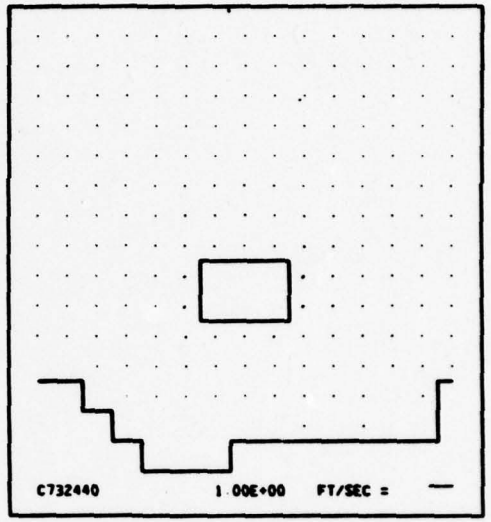

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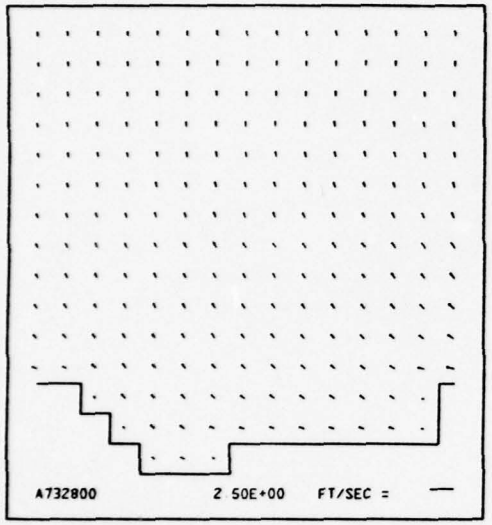

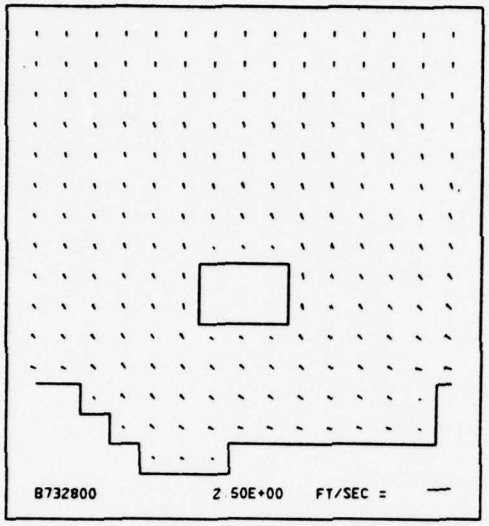

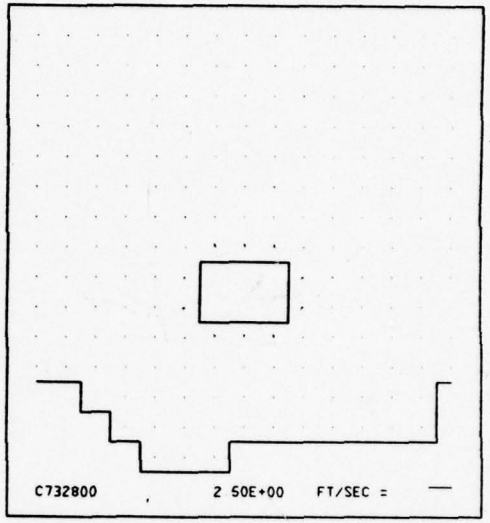

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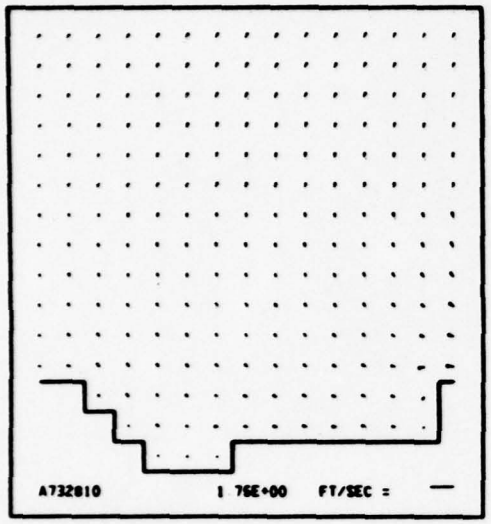

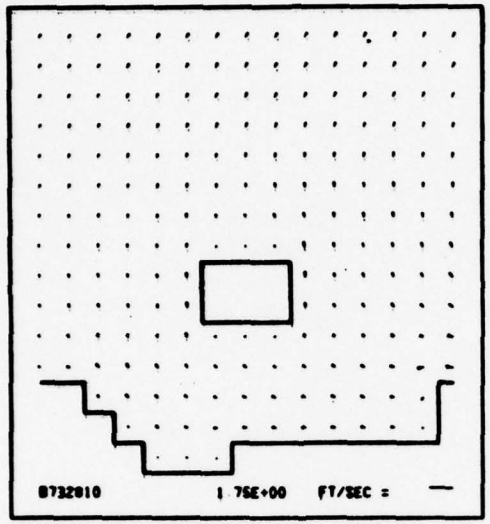

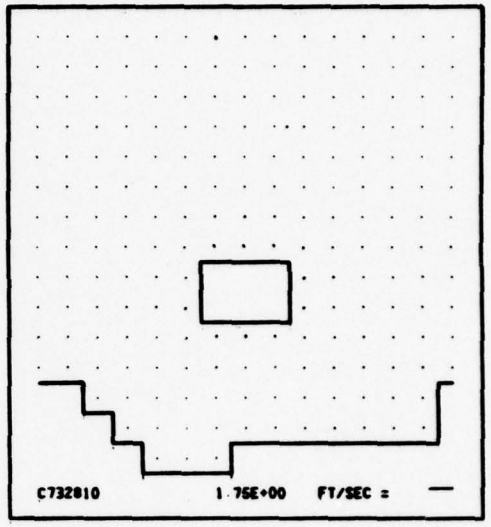

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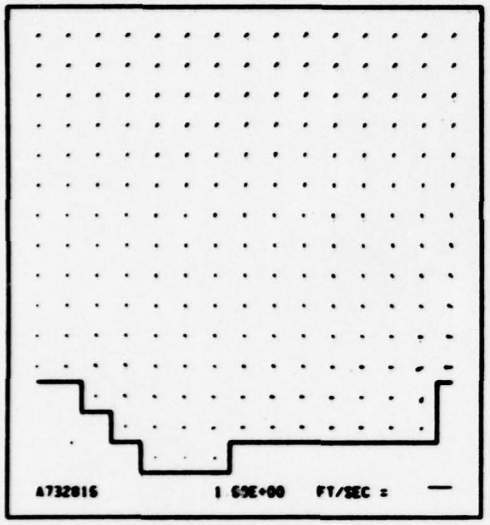

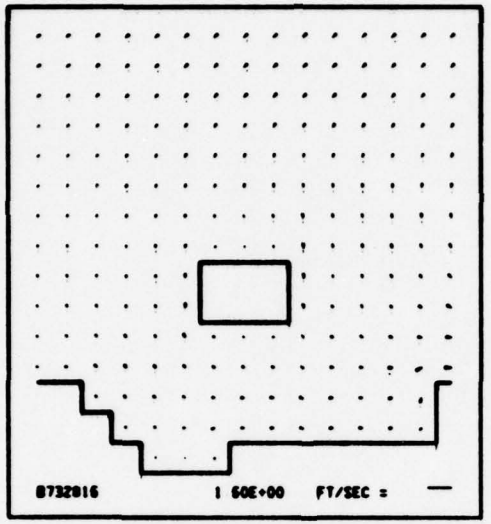

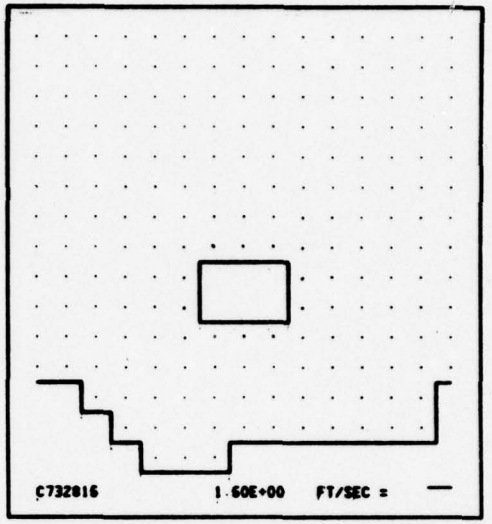

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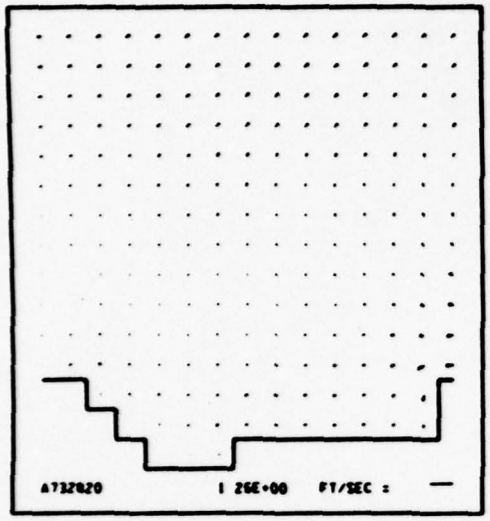

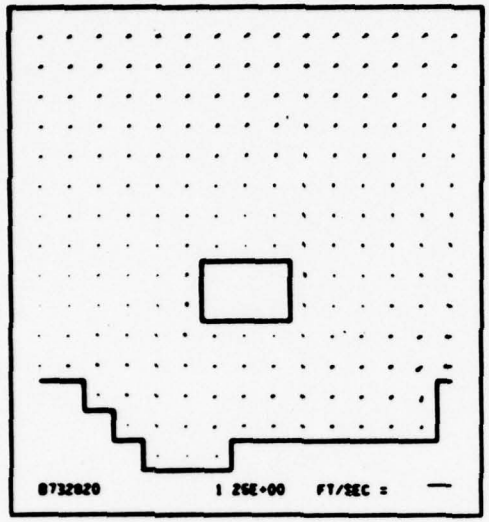

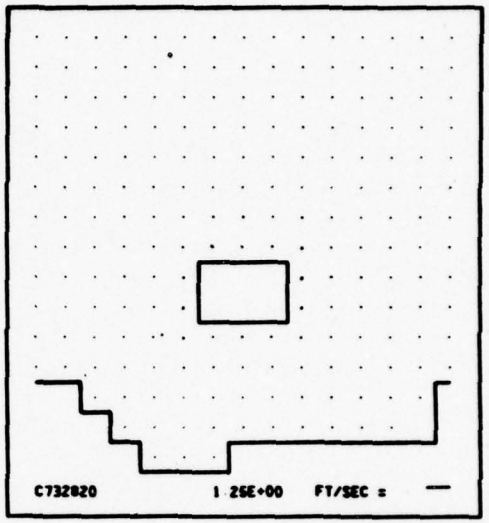

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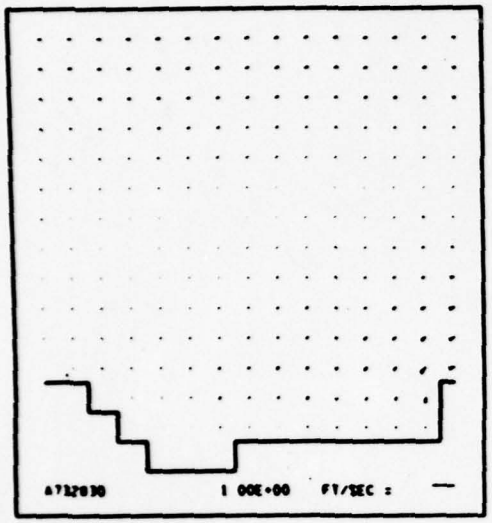

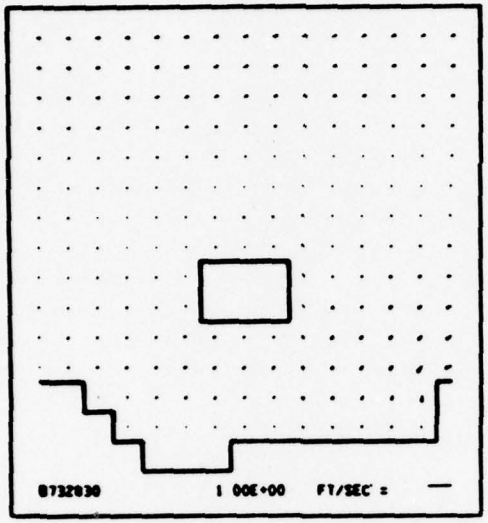

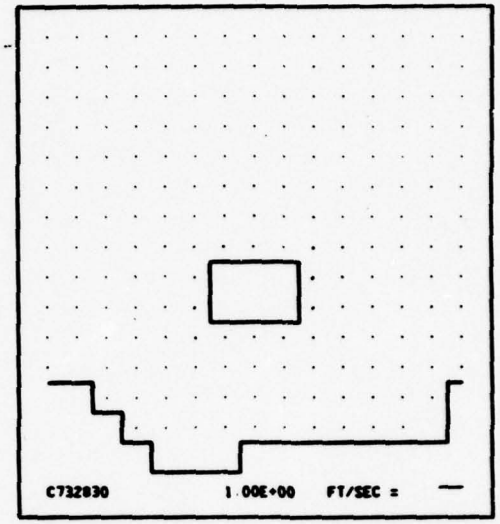

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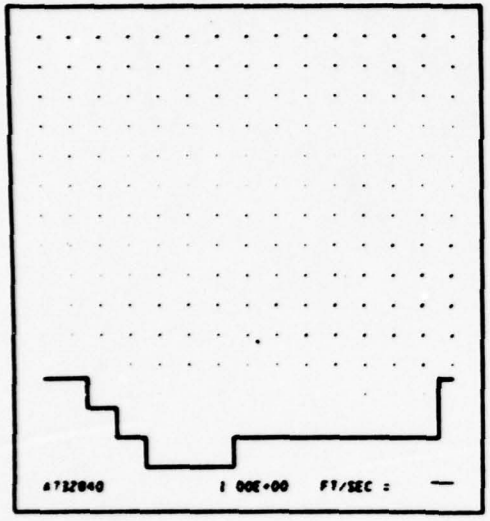

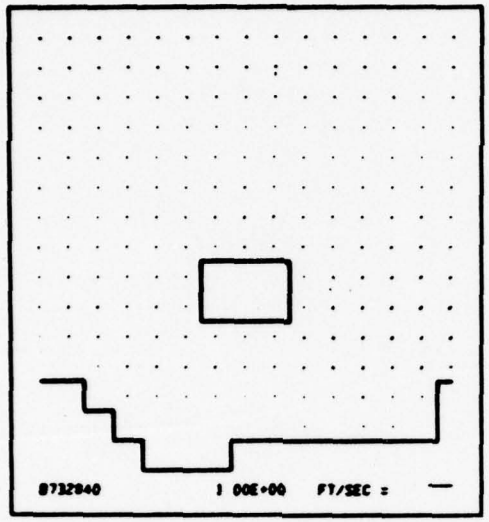

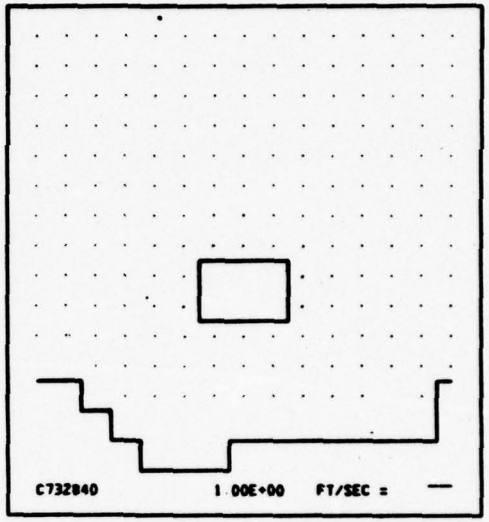

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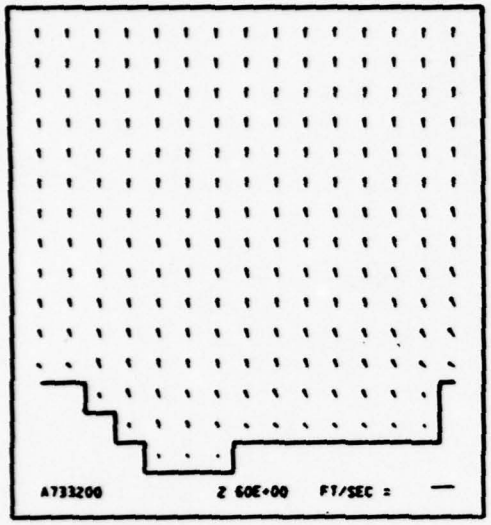

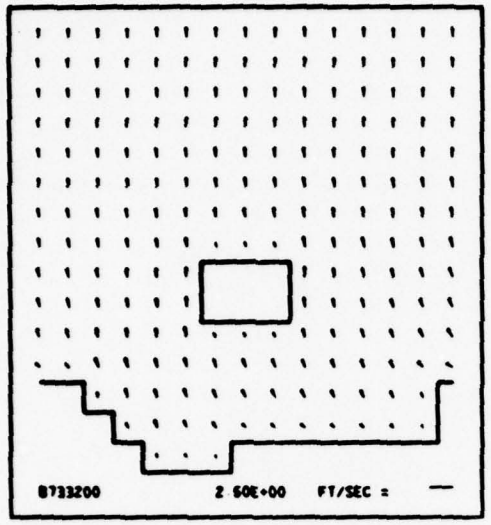

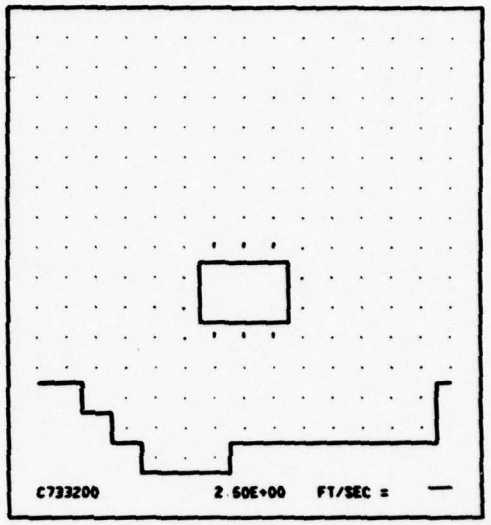

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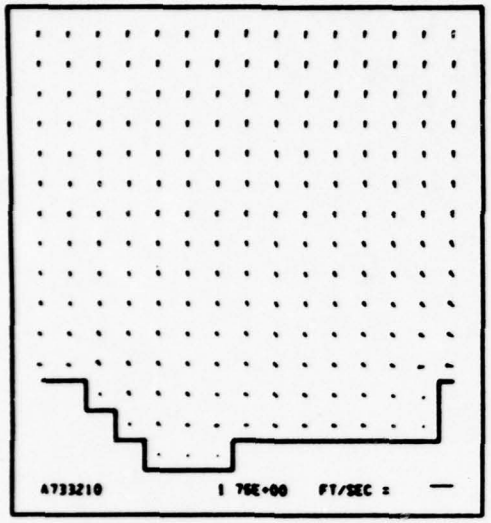

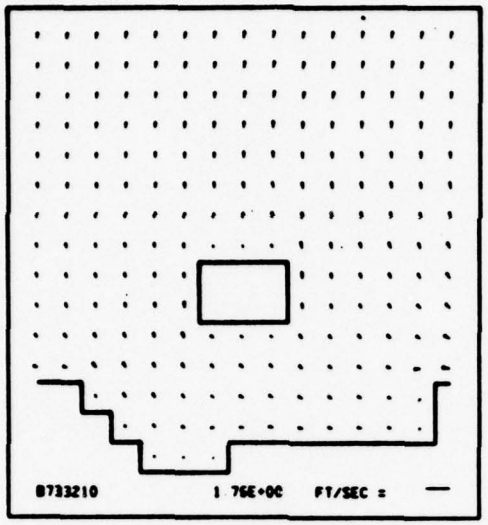

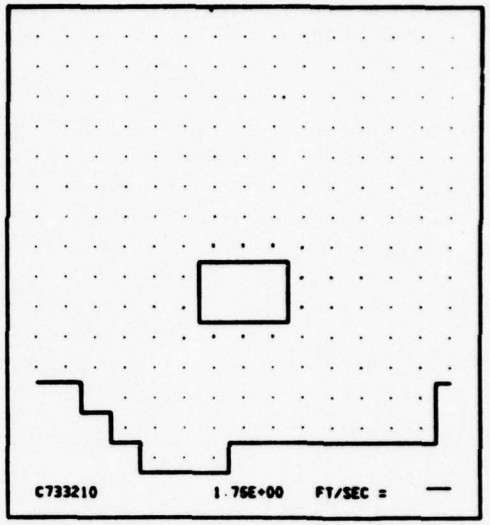

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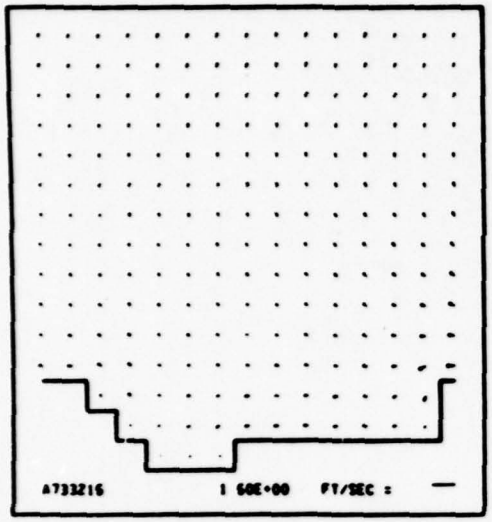

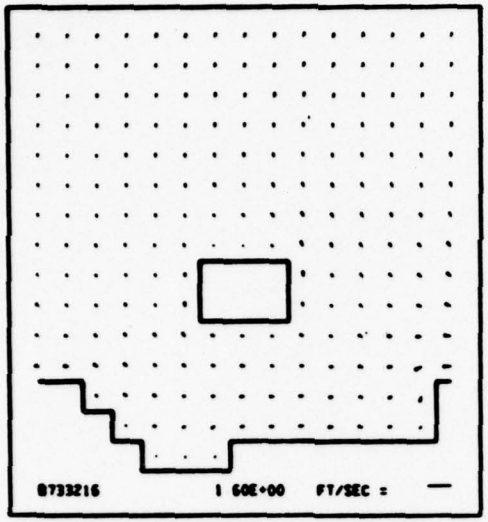

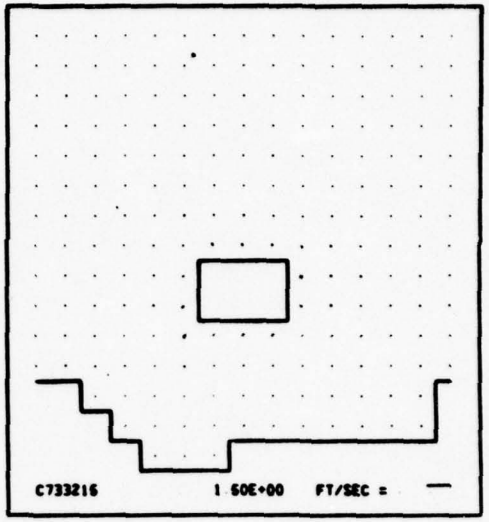

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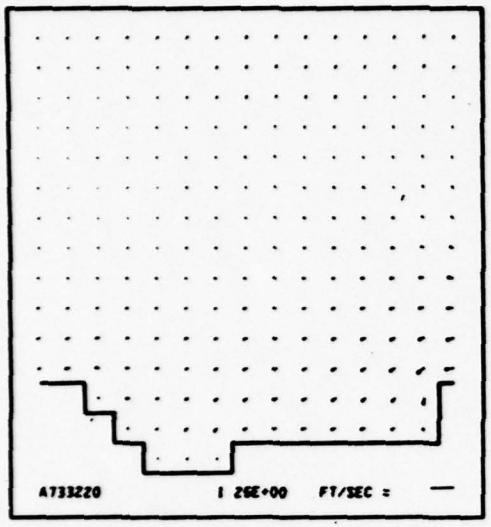

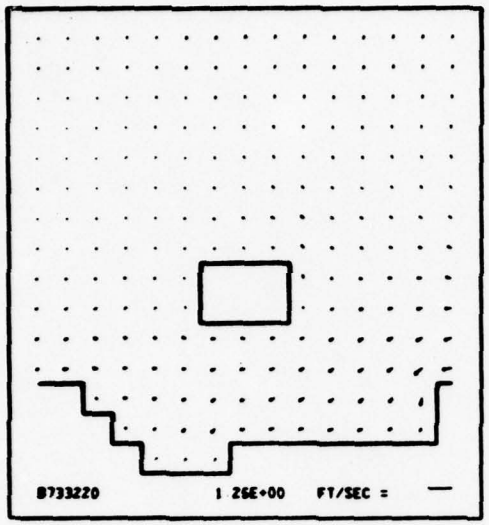

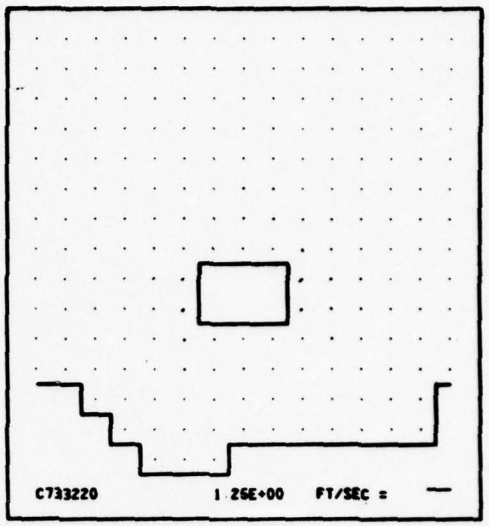

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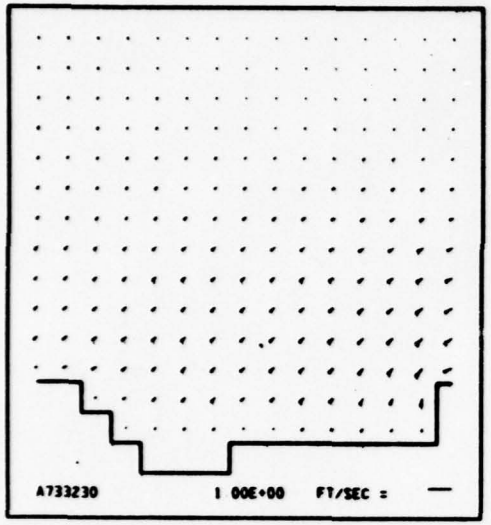

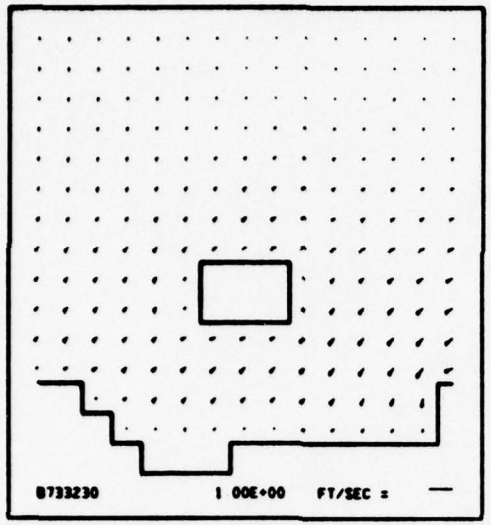

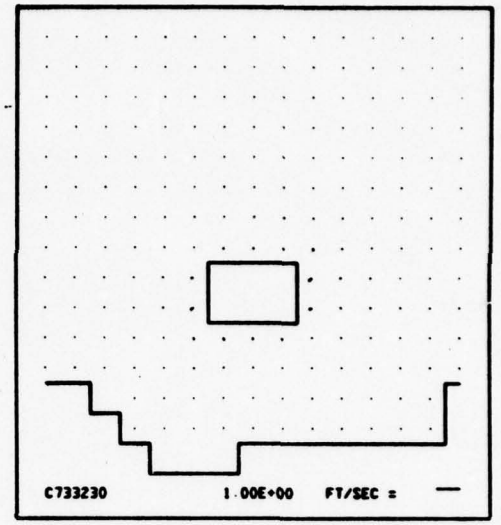

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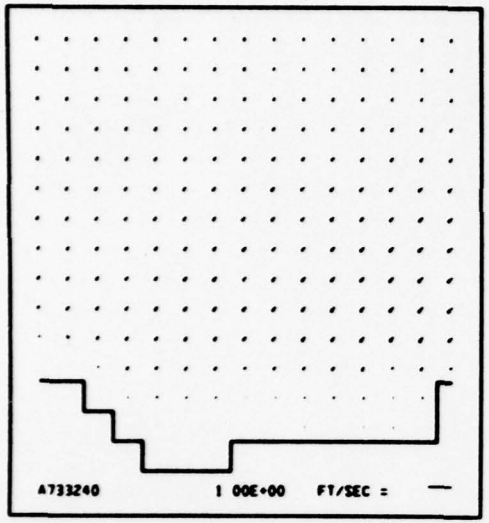

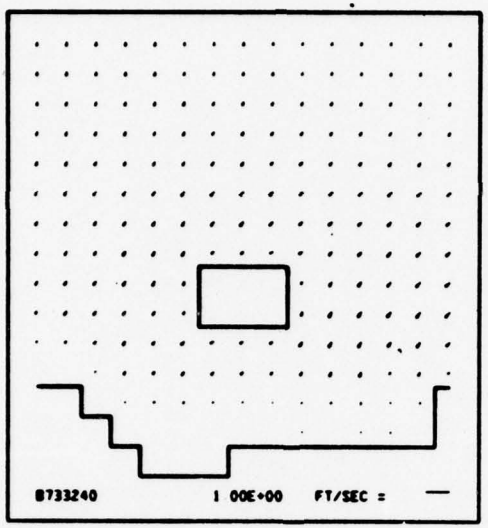

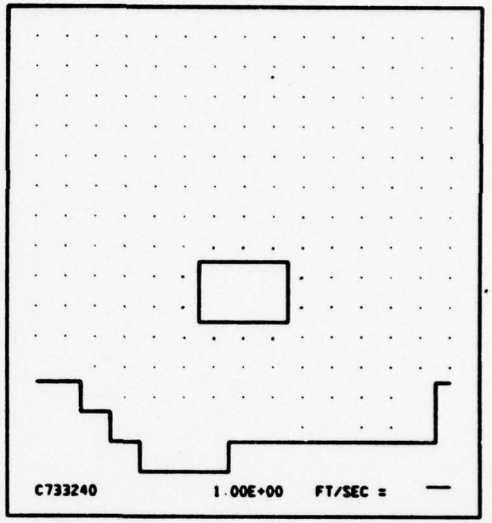

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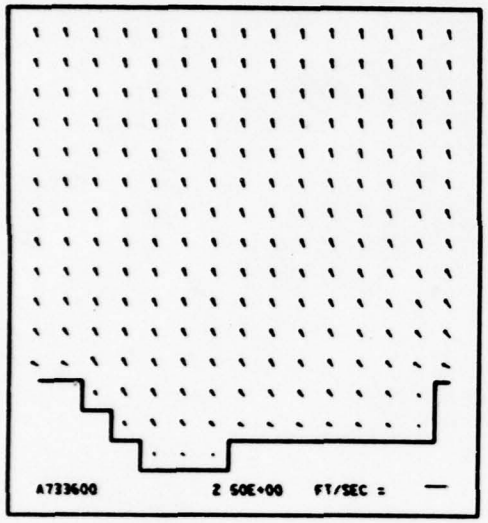

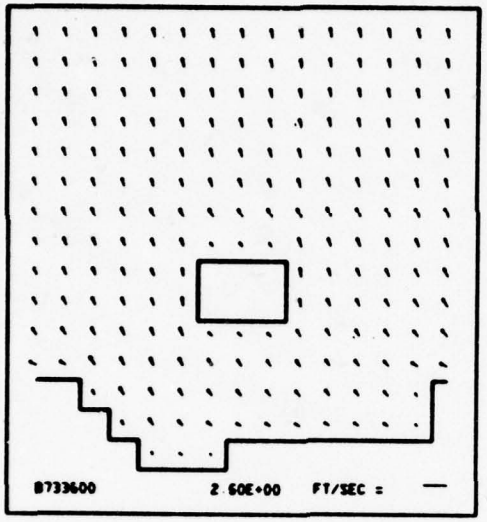

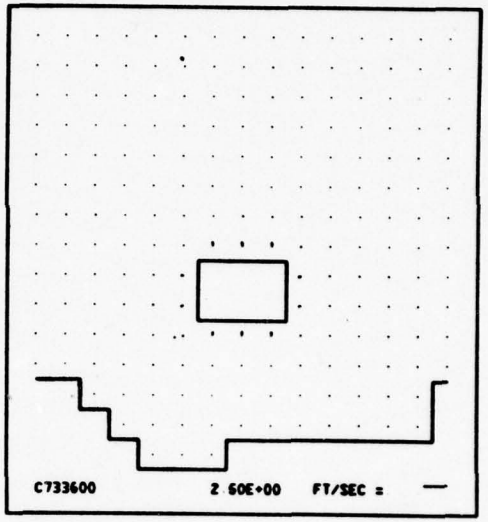

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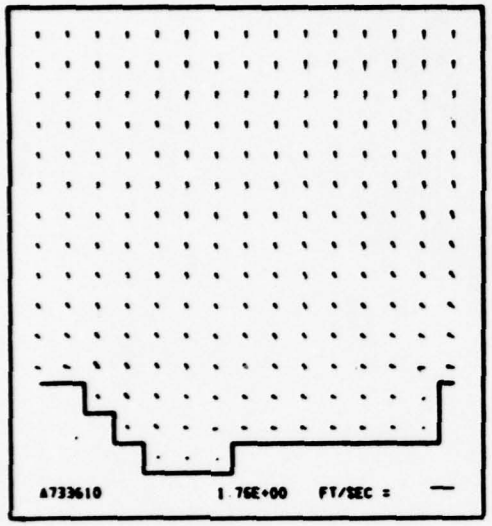

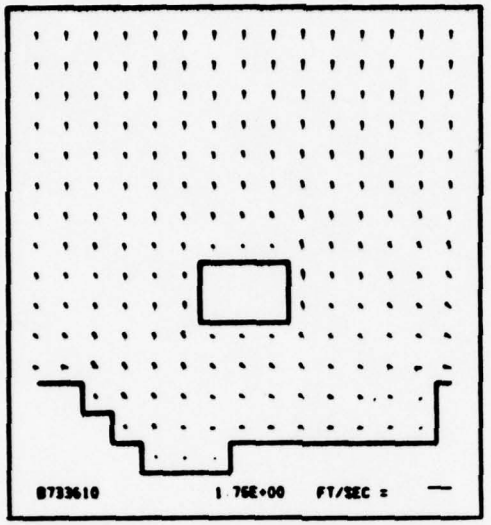

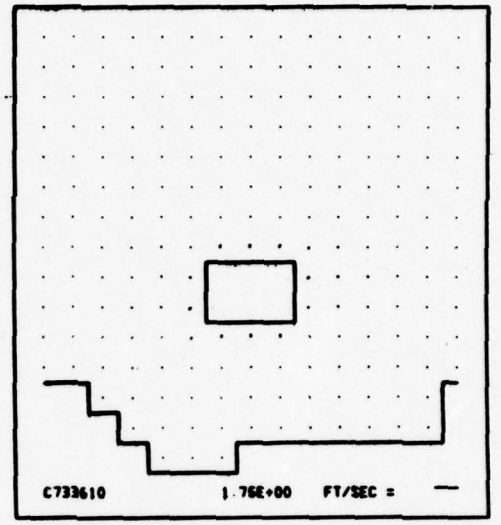

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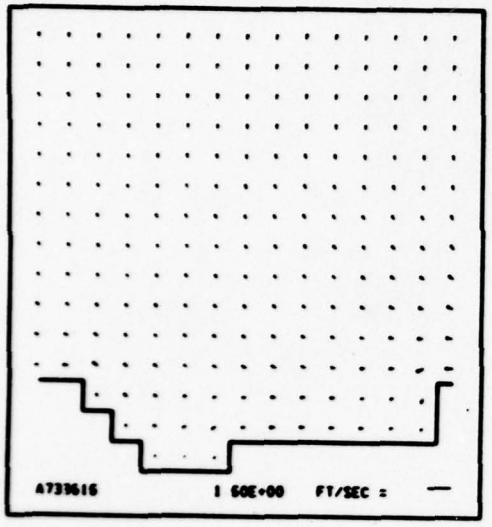

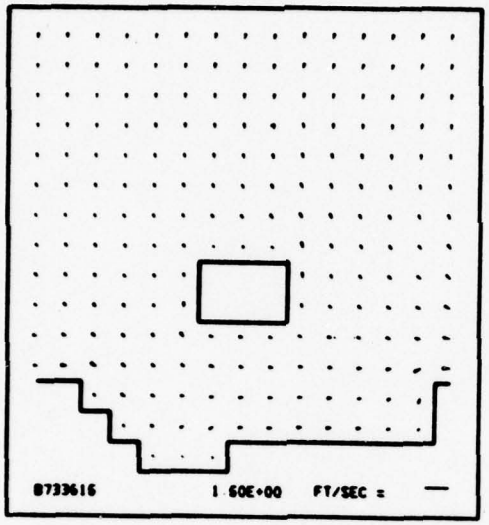

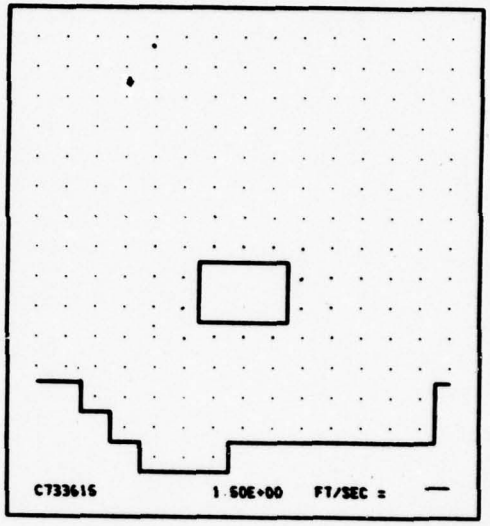

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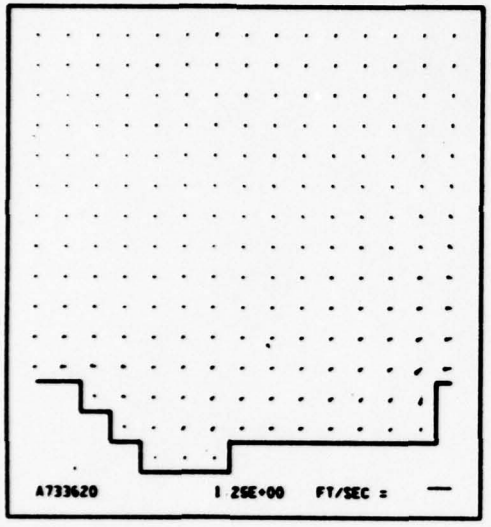

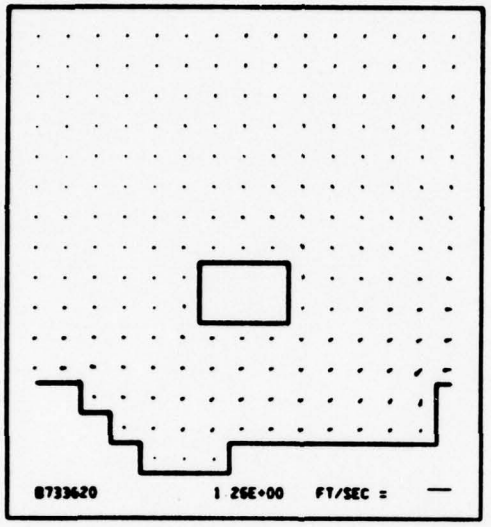

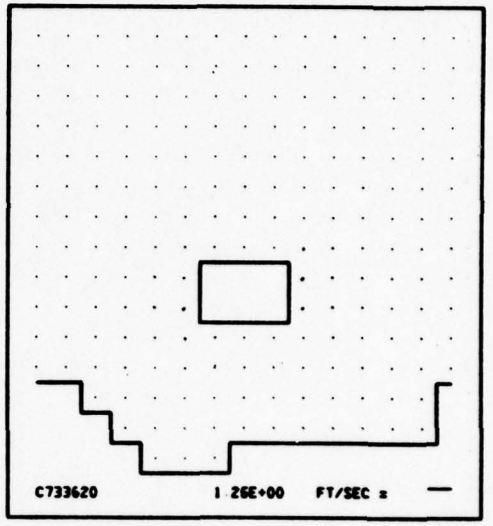

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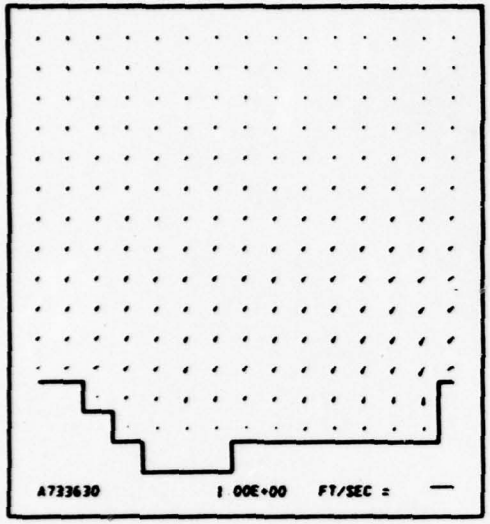

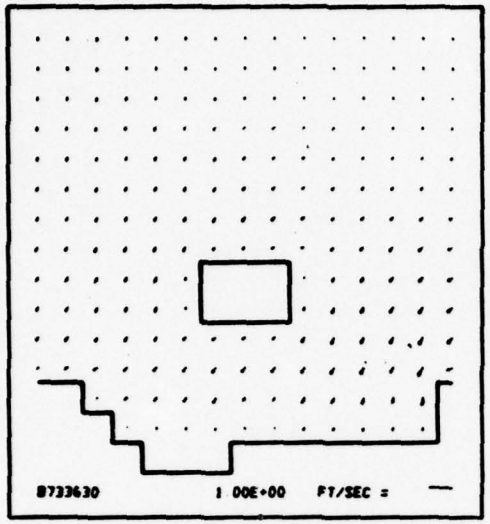

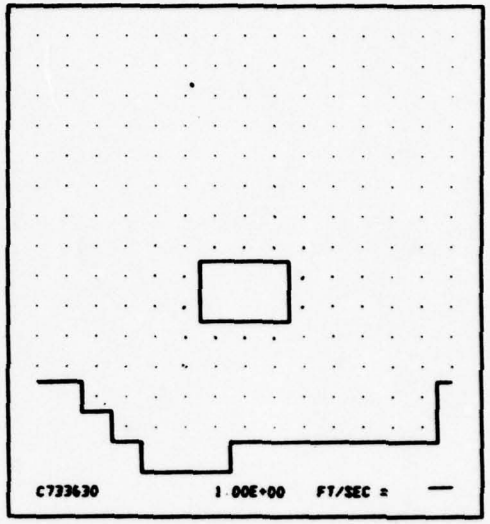

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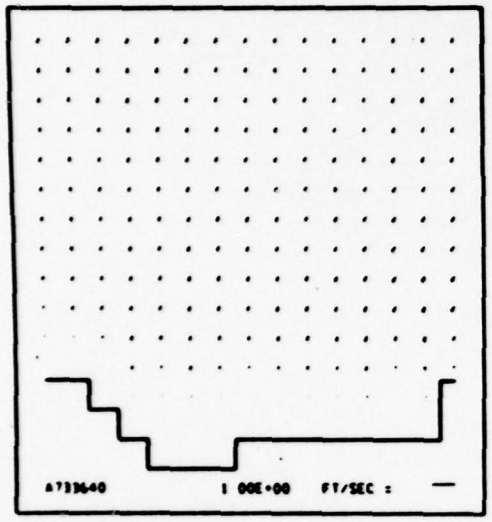

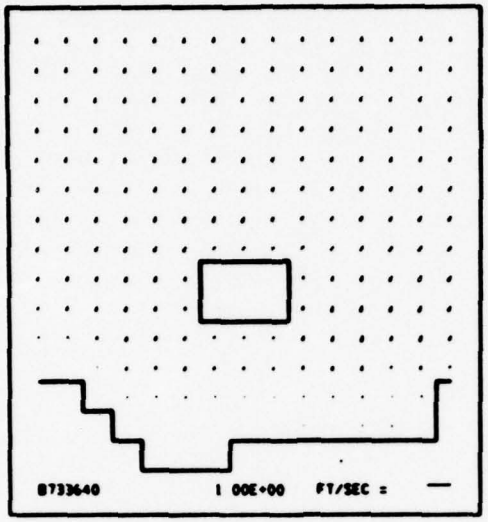

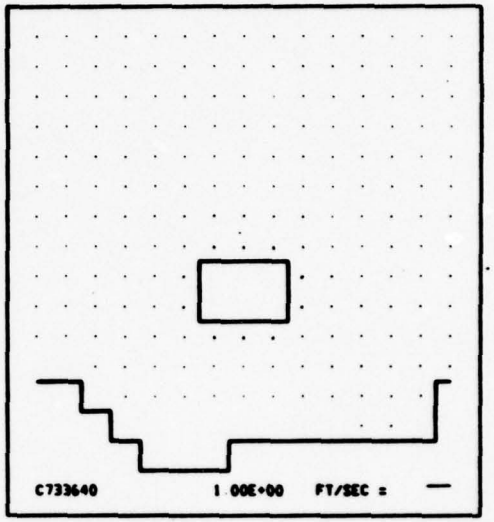

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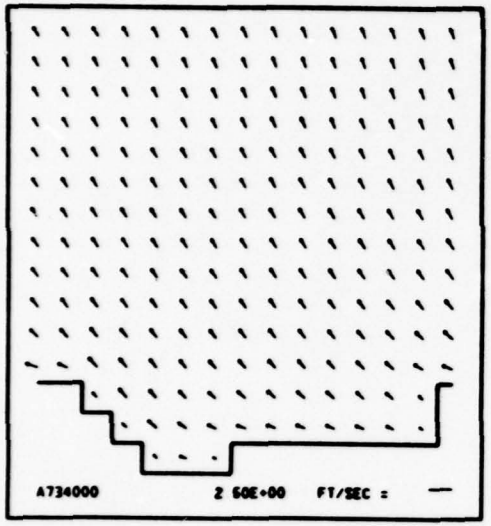

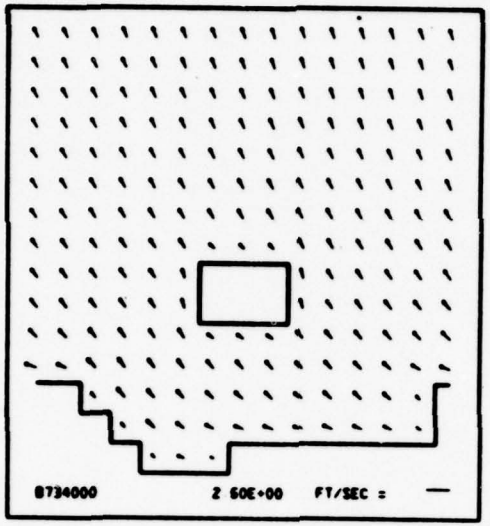

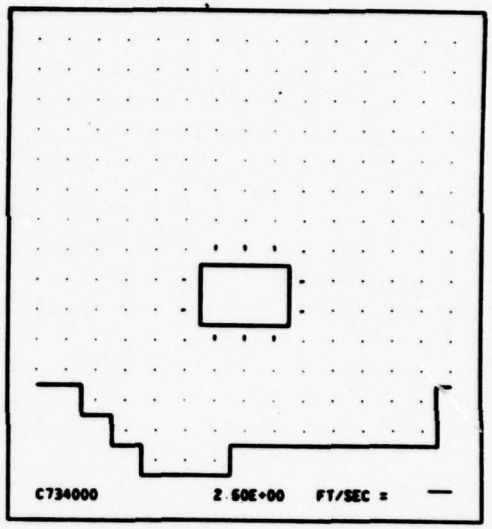

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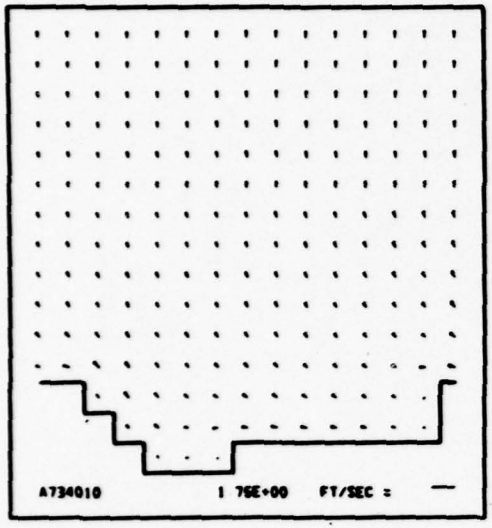

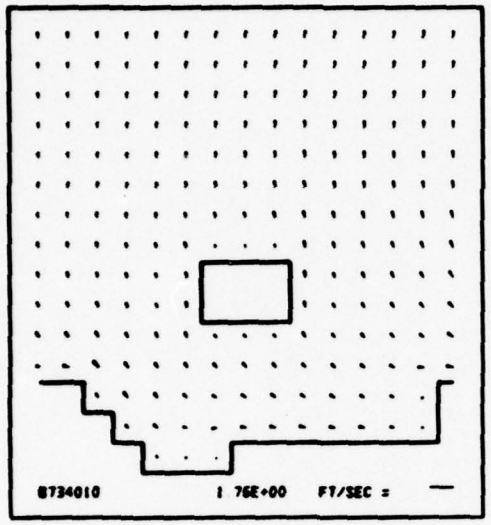

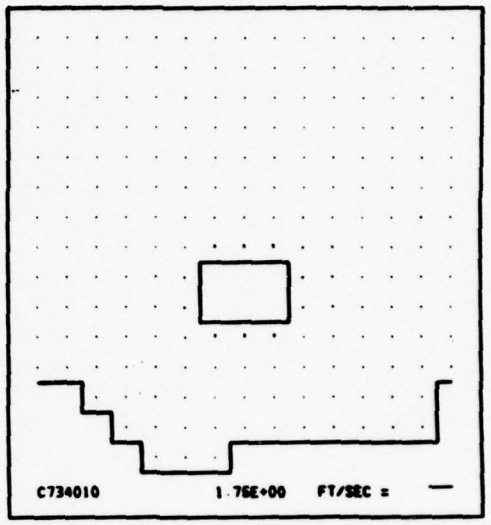

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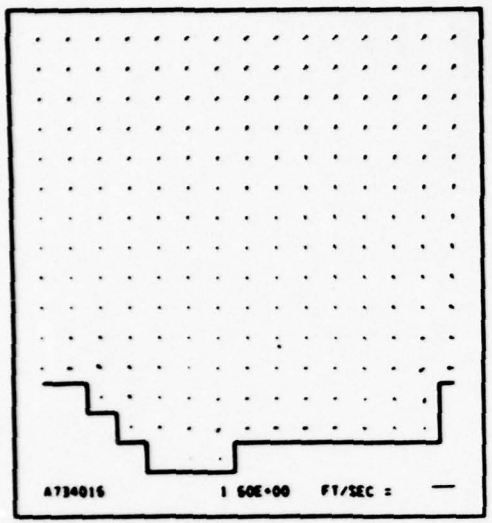

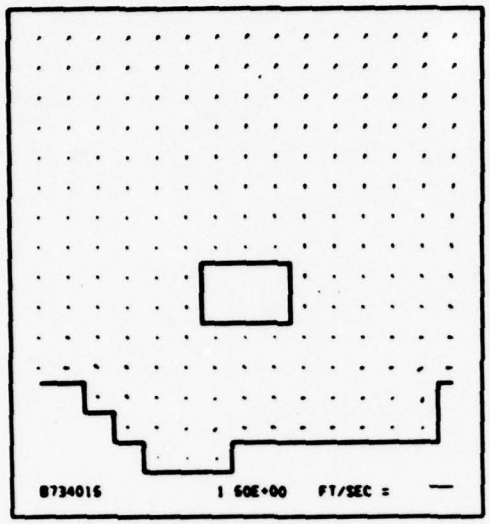

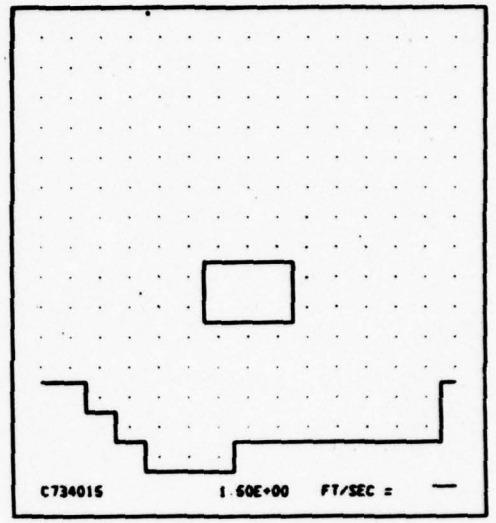

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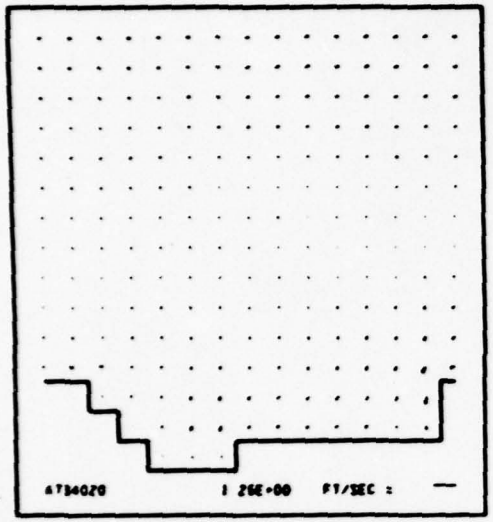

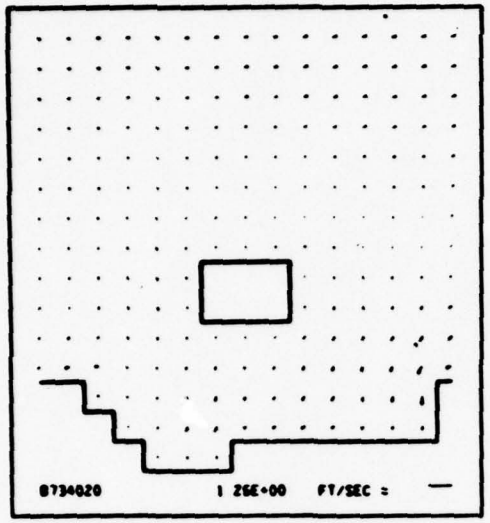

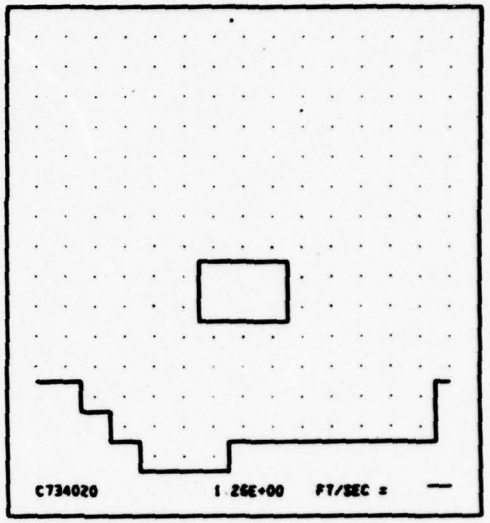

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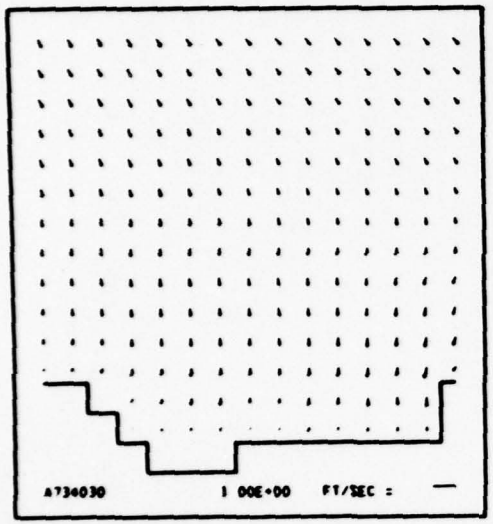

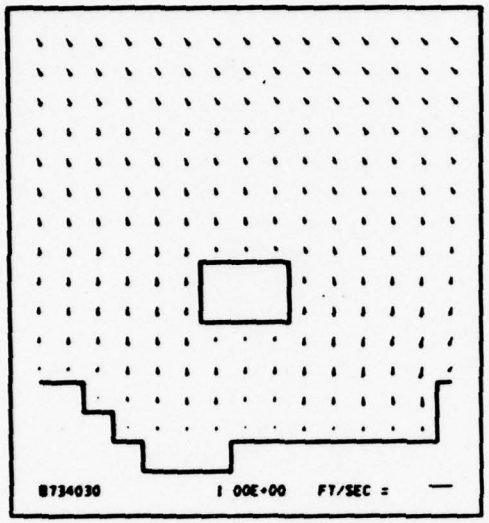

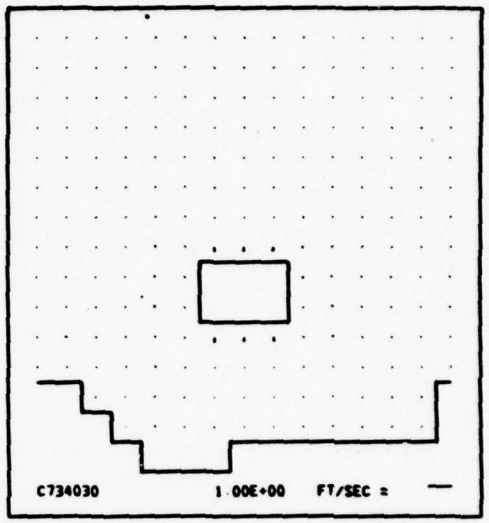

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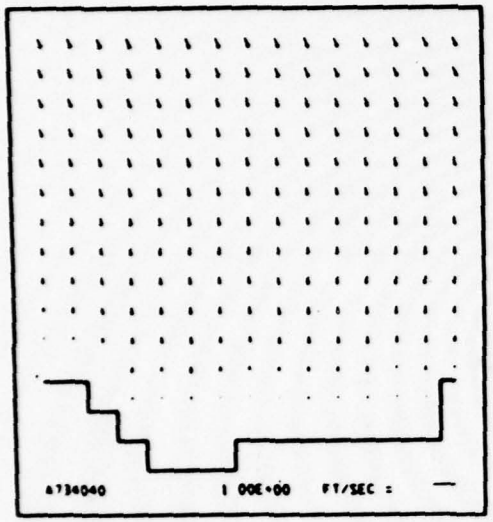

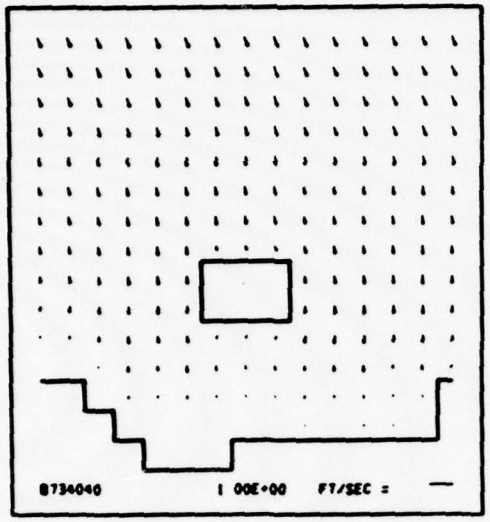

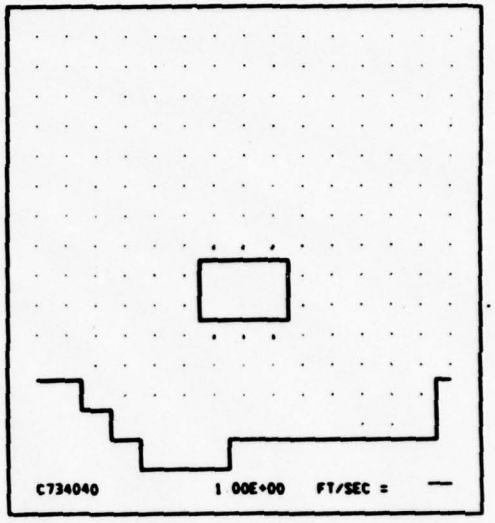

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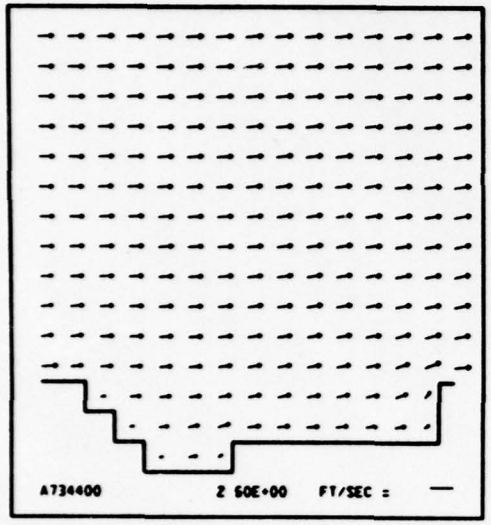

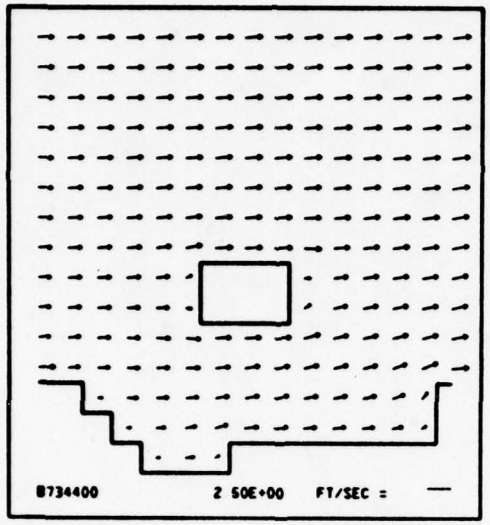

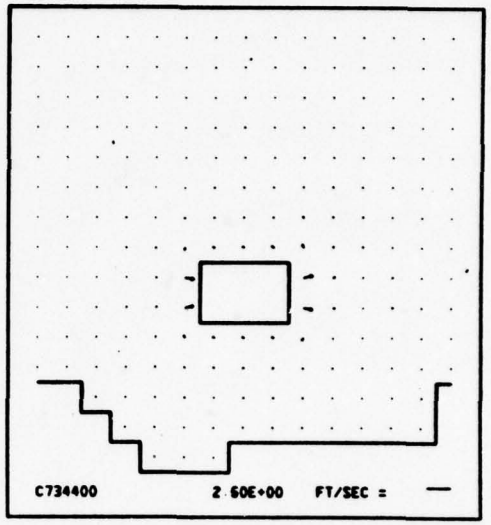

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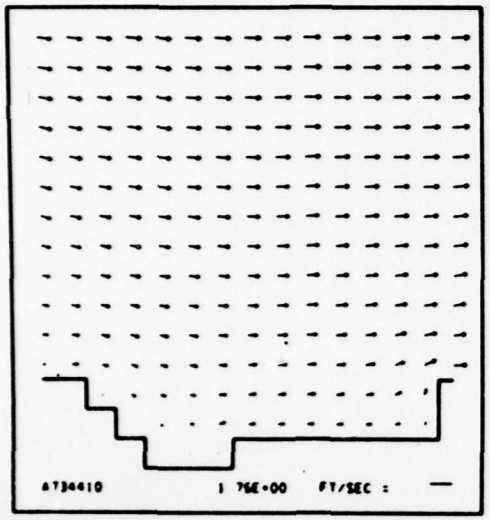

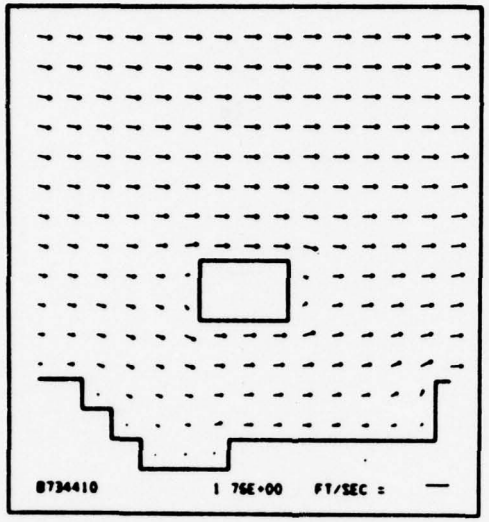

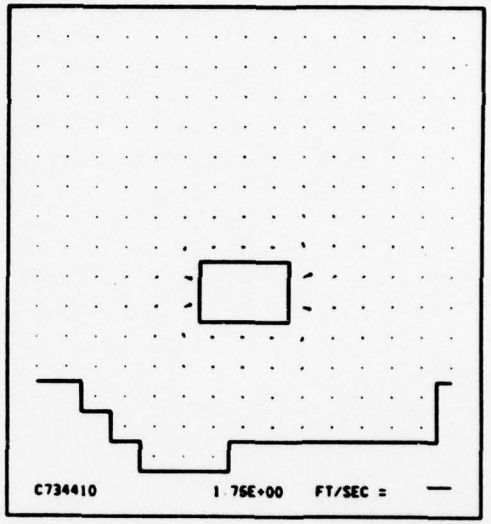

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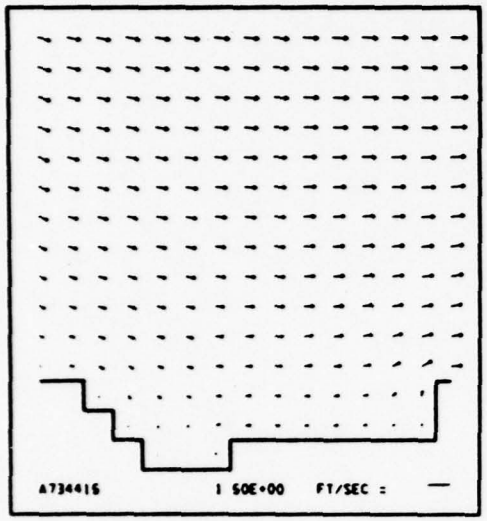

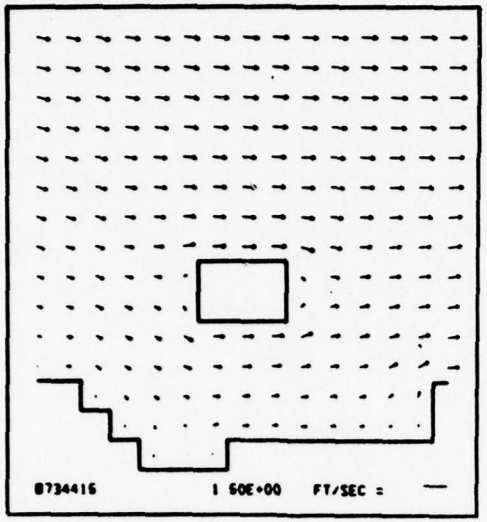

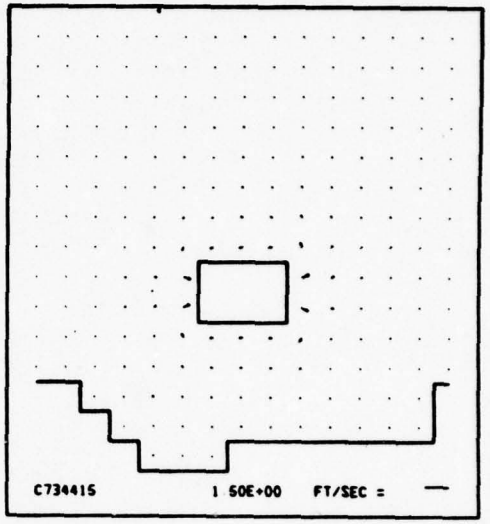

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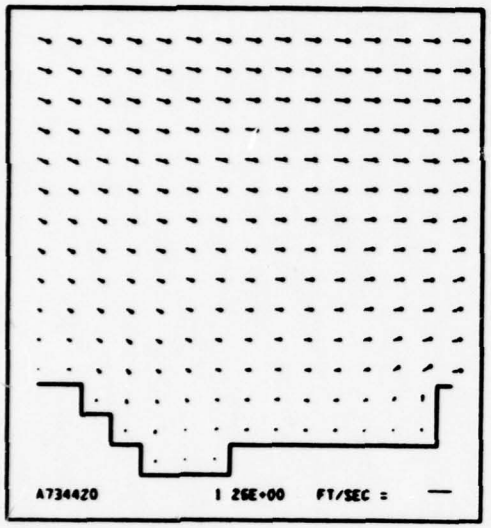

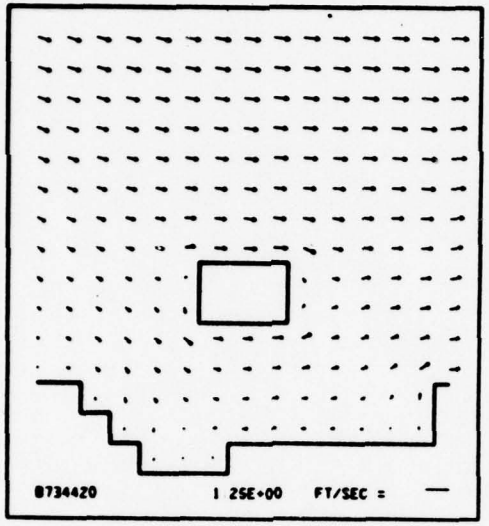

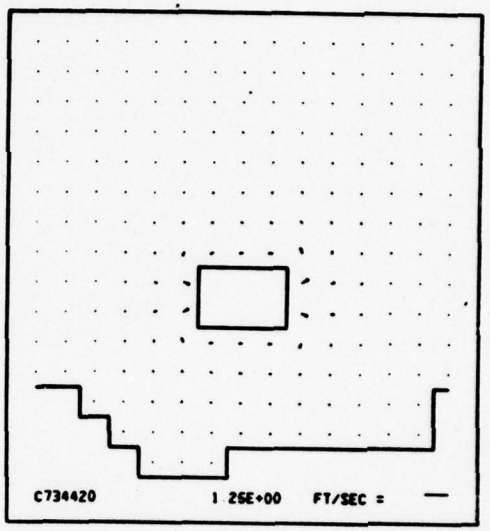

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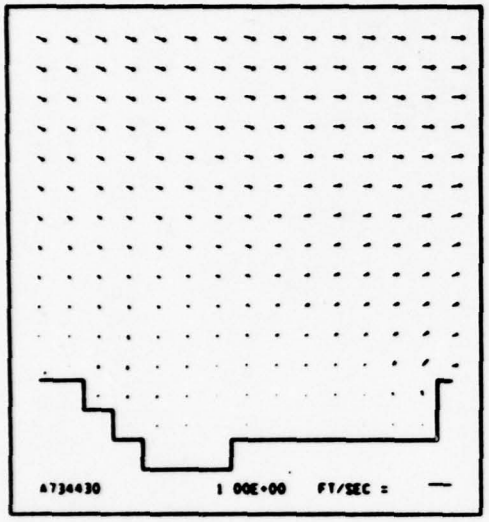

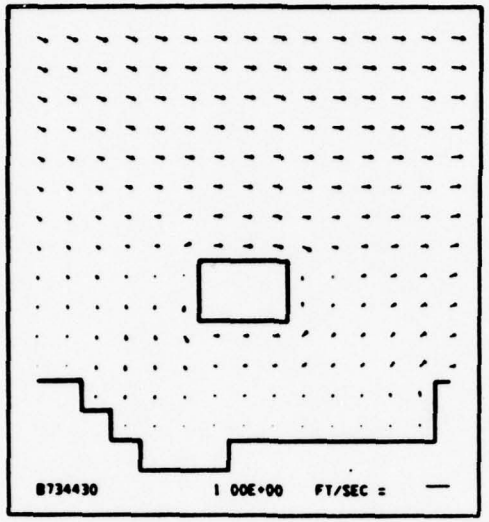

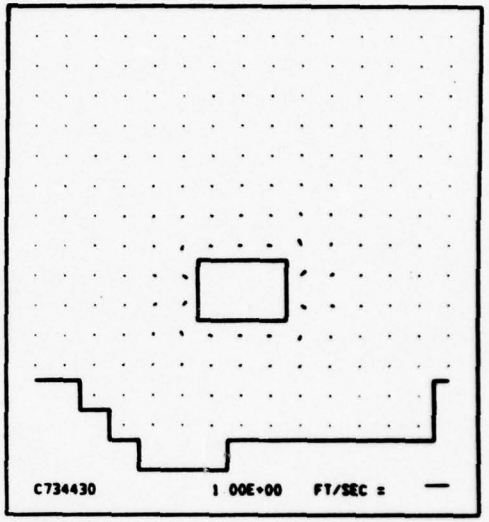

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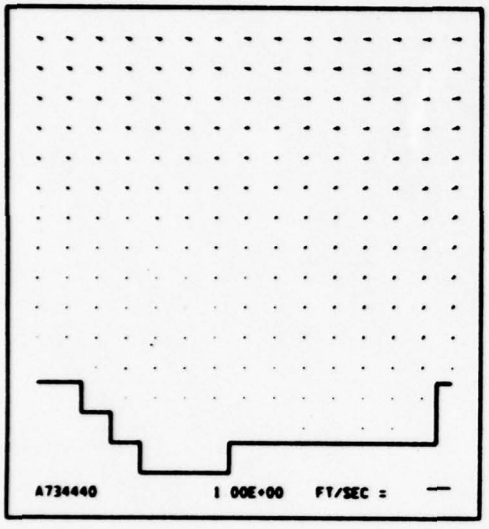

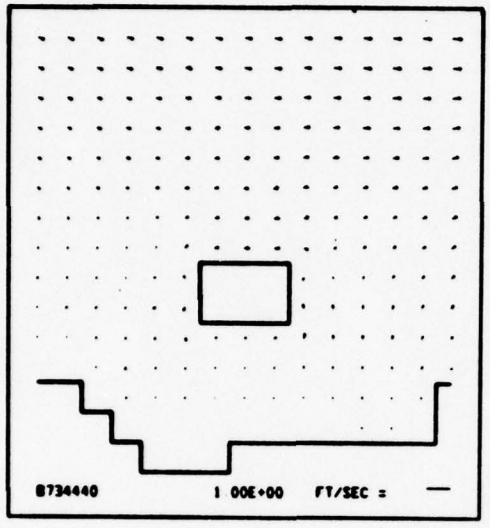

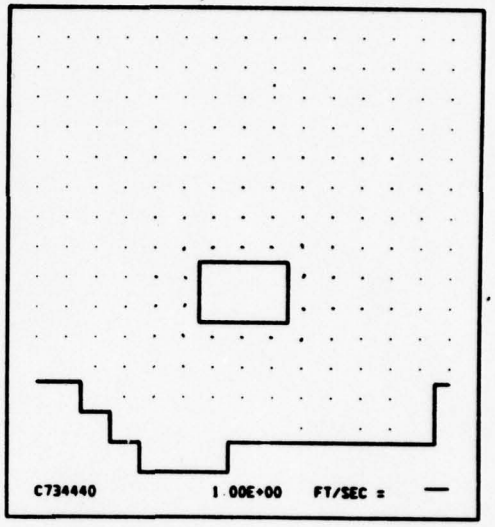

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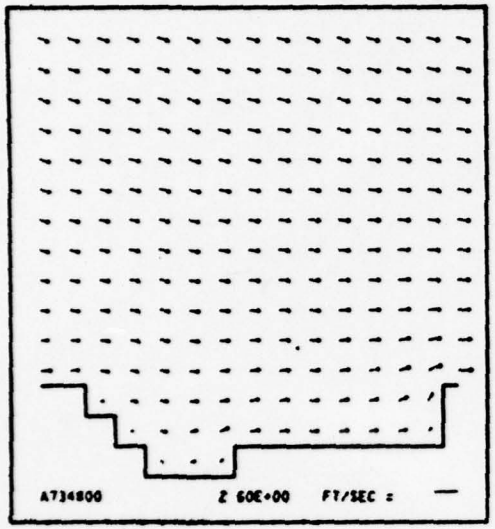

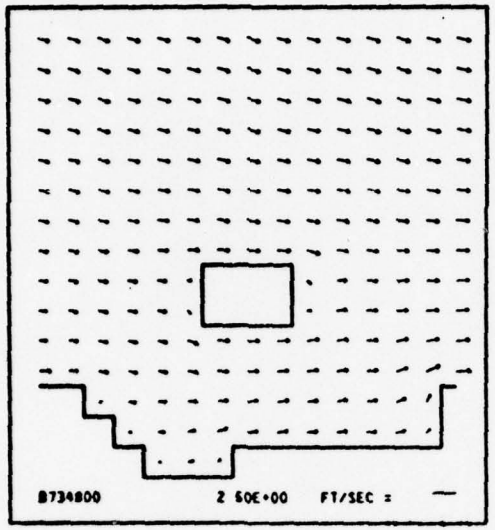

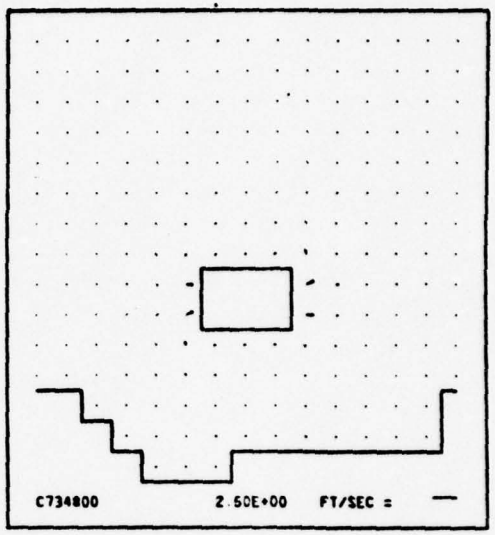

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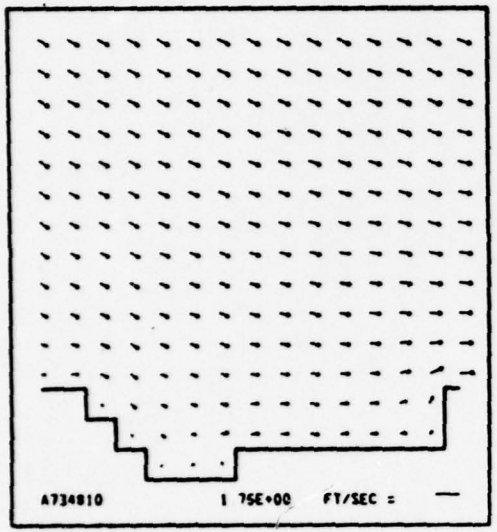

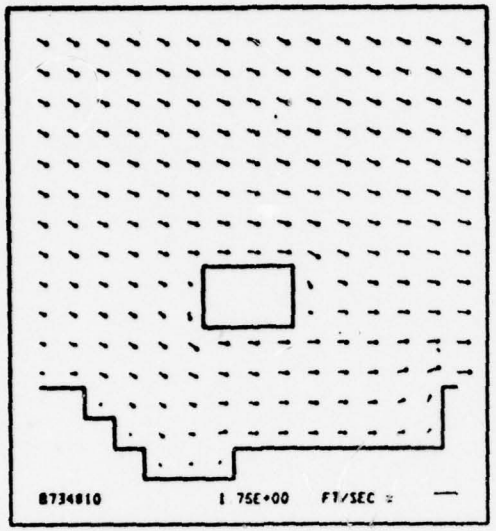

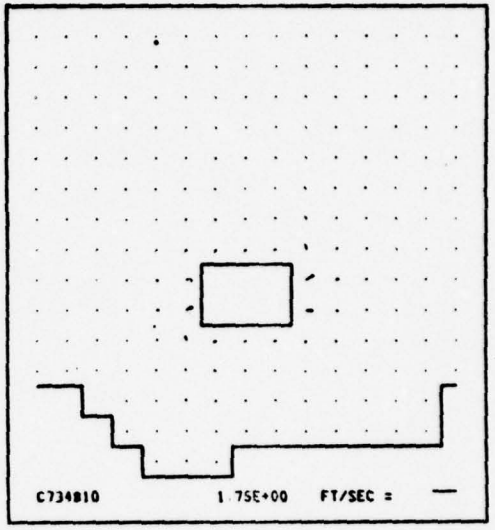

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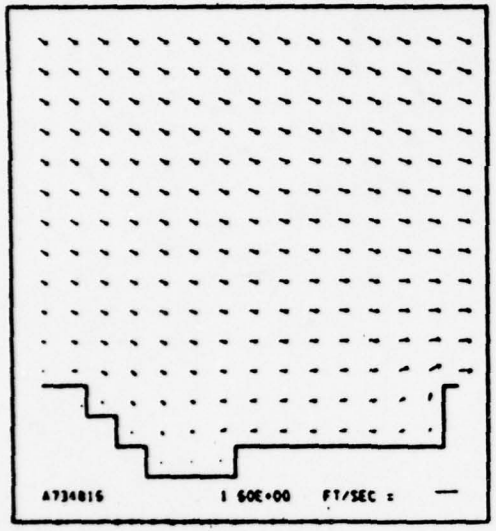

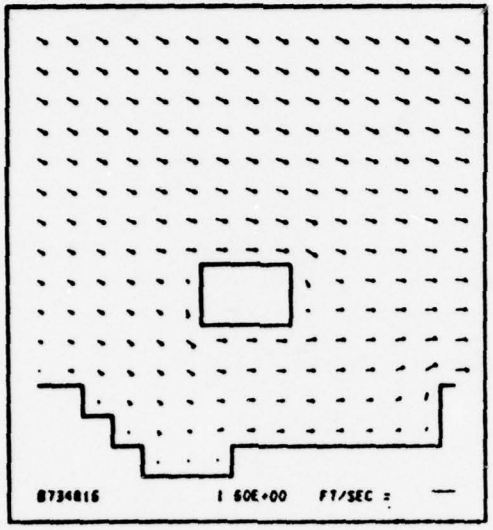

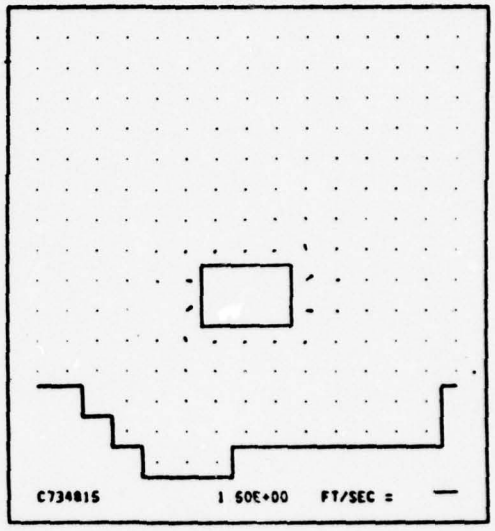

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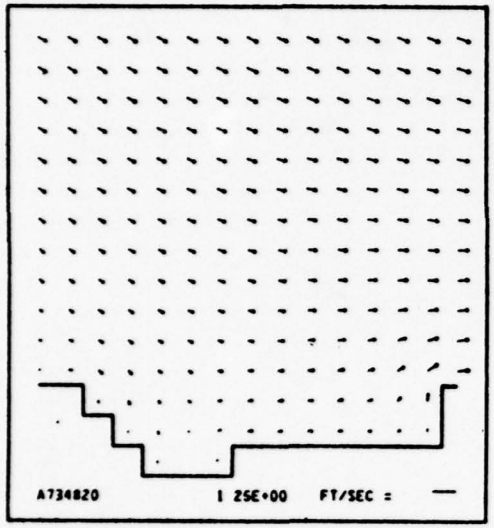

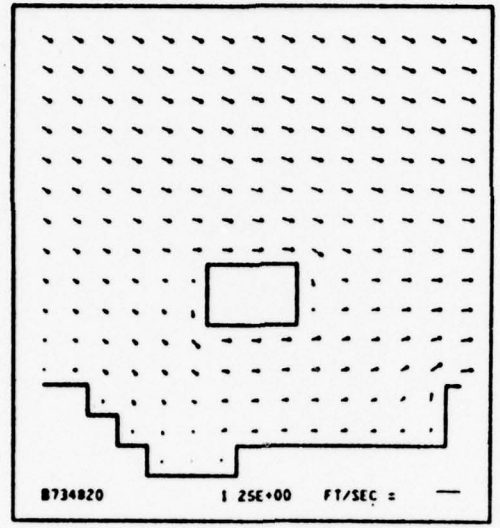

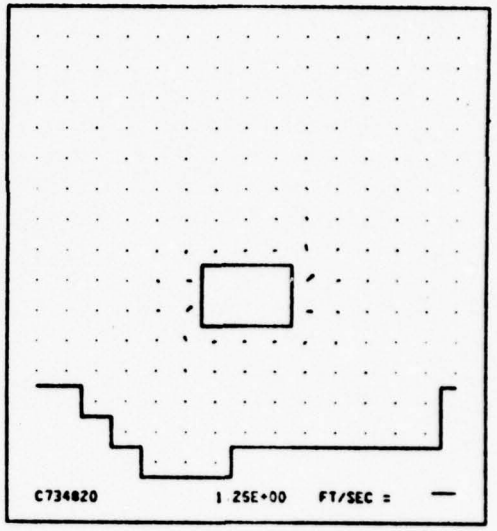

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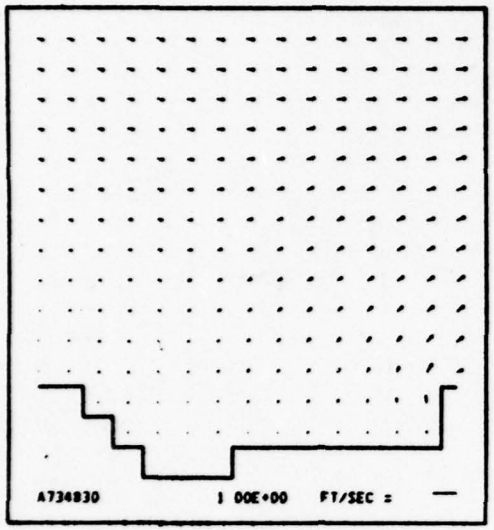

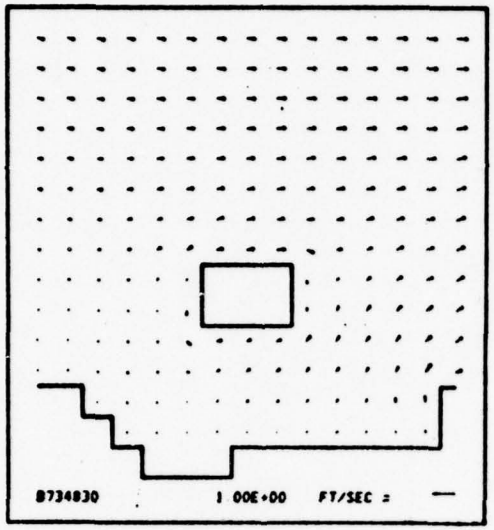

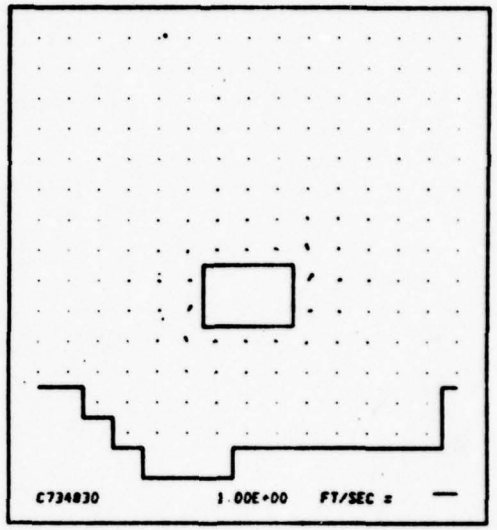

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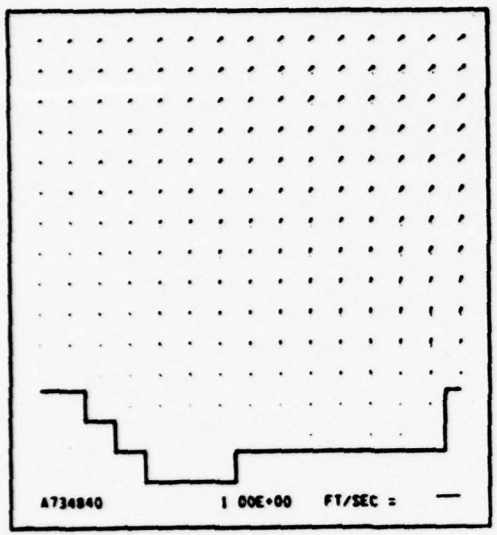

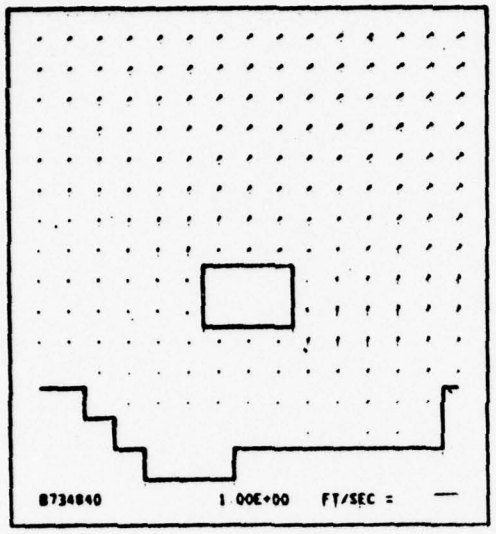

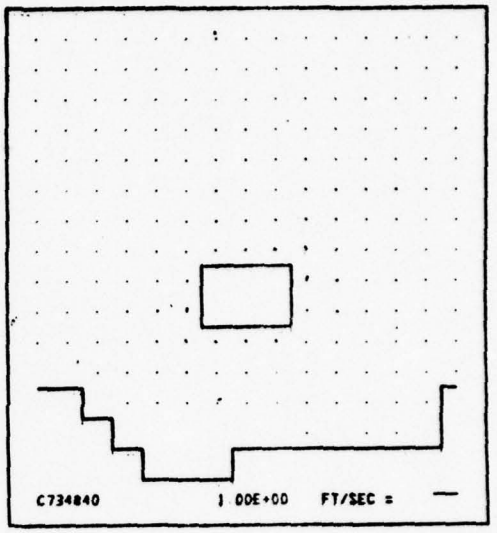

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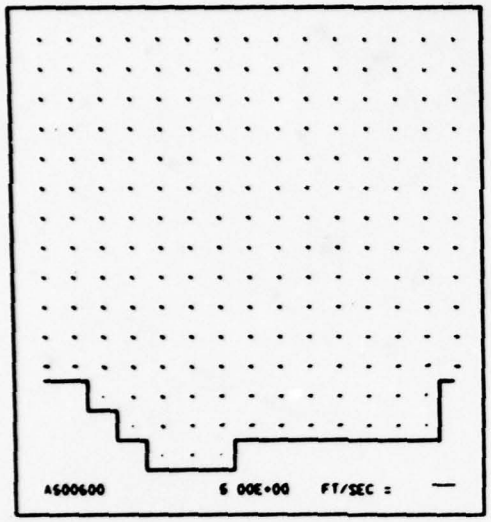
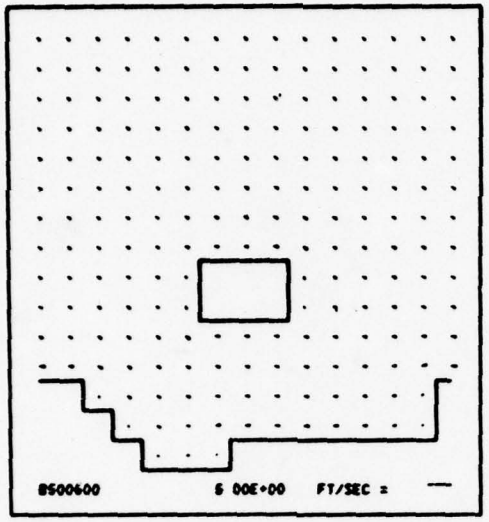
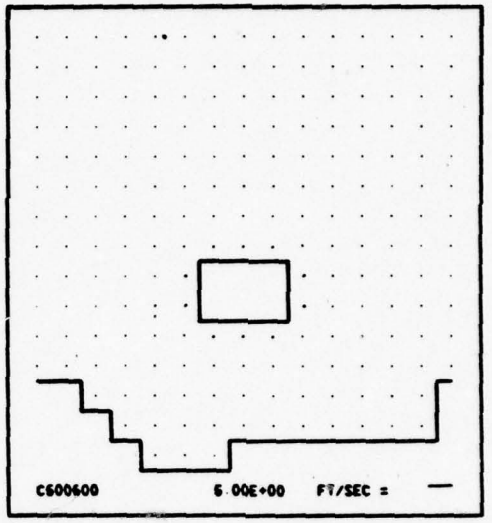
Inclosure 2: 25-27 November 1950 Storm







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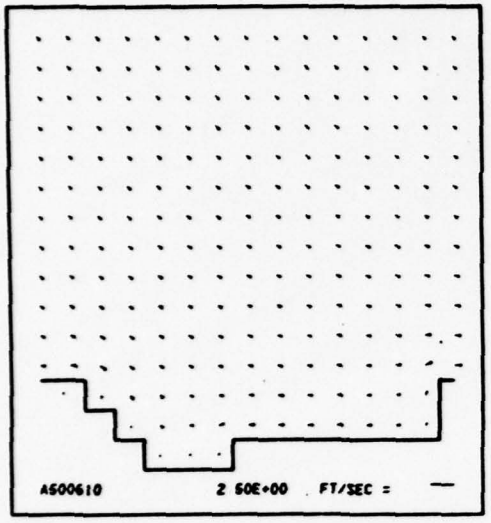

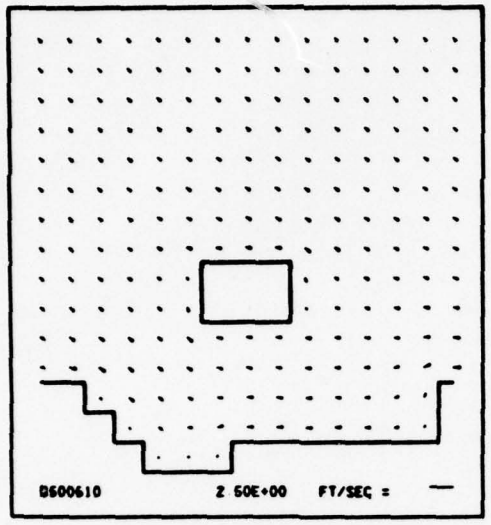

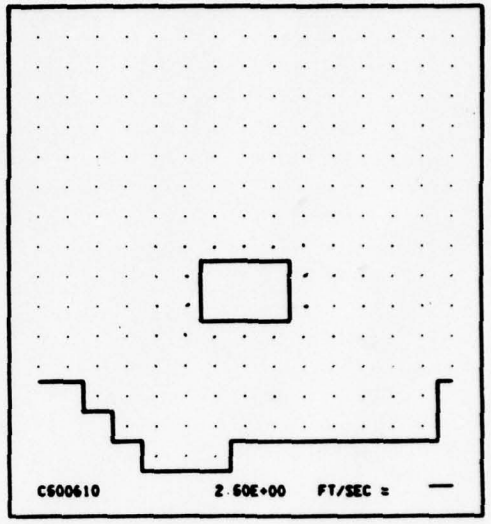

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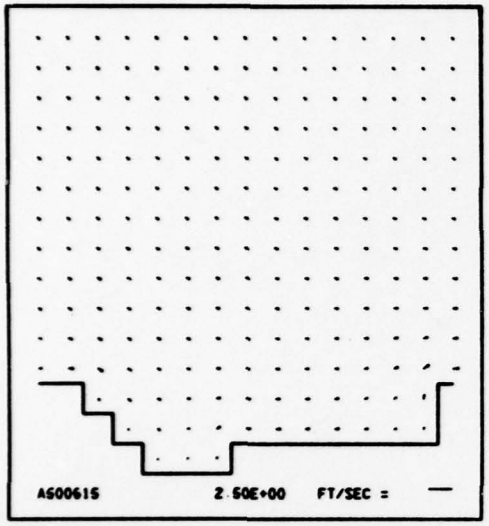

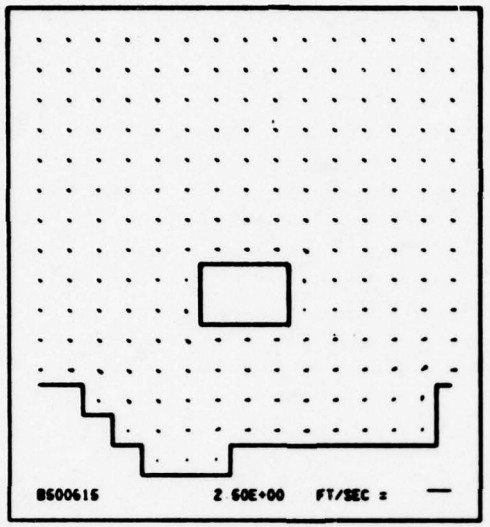

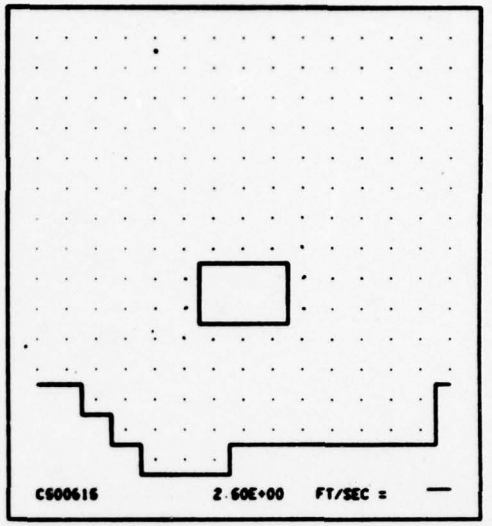

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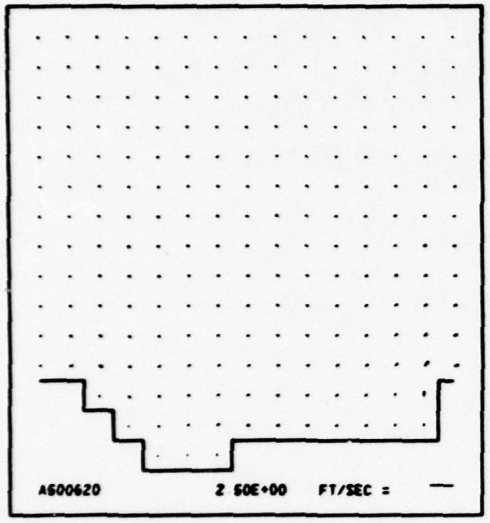

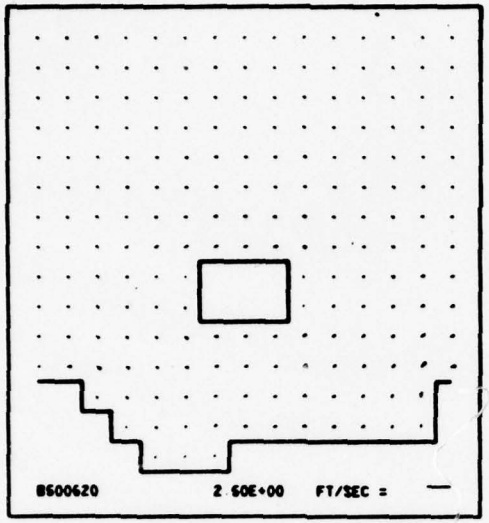

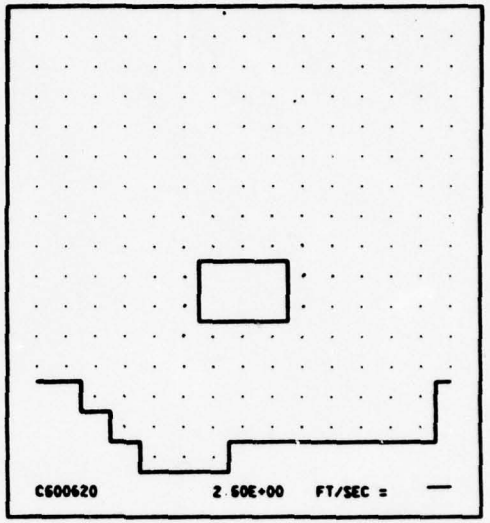

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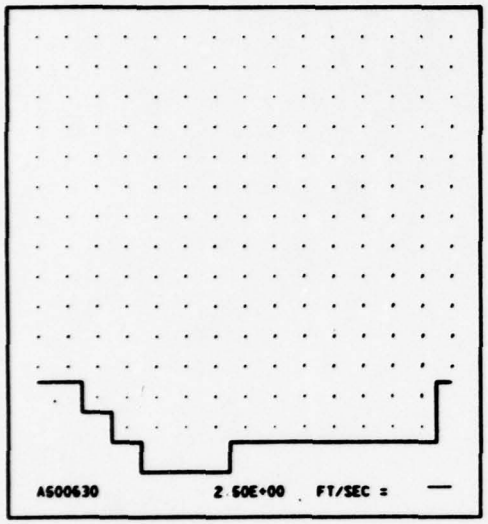

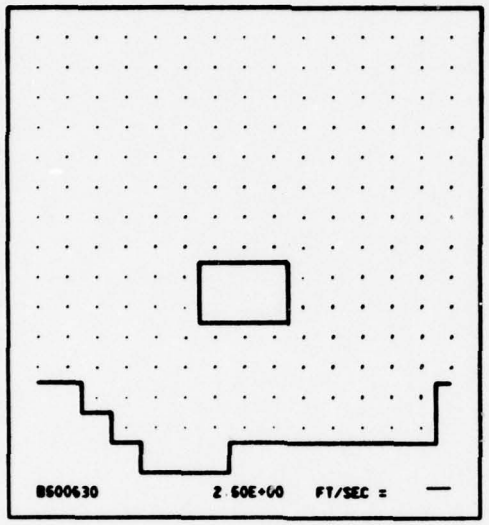

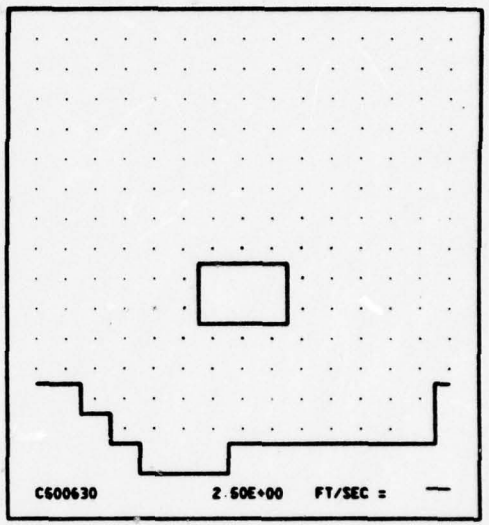

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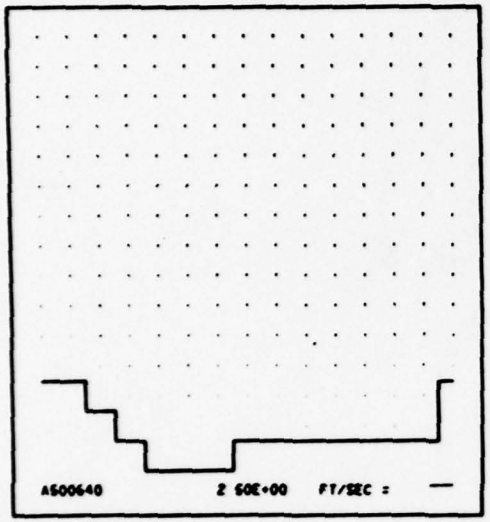

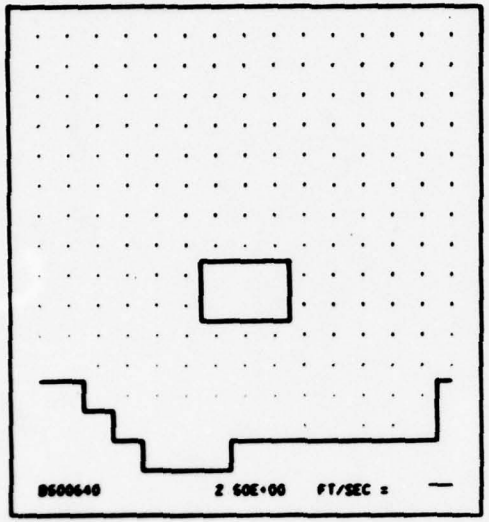

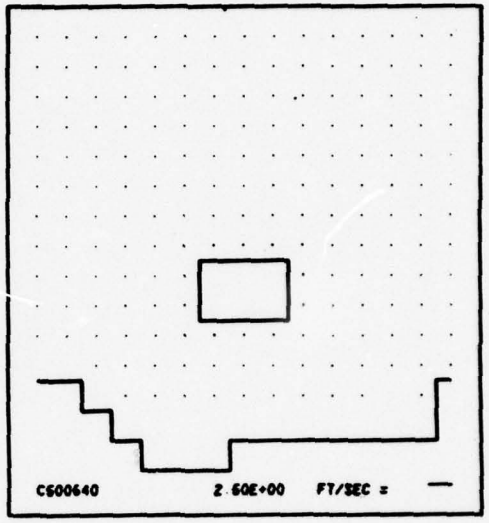

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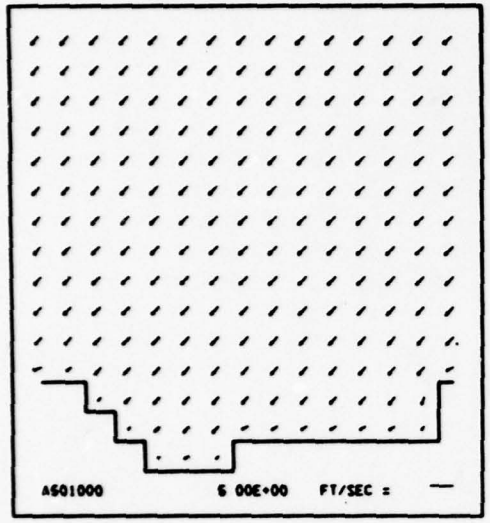

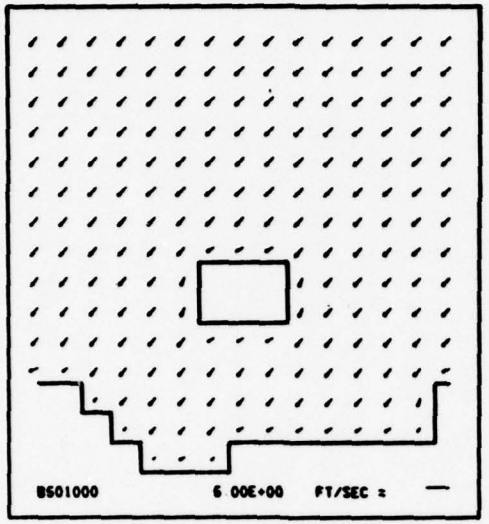

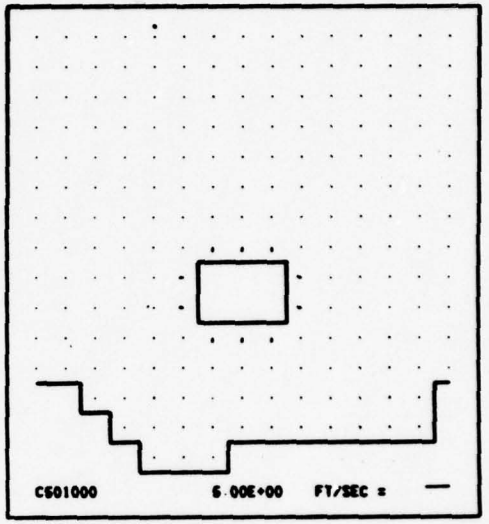

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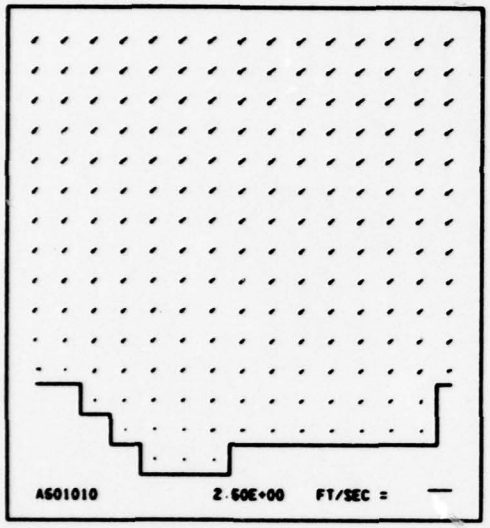

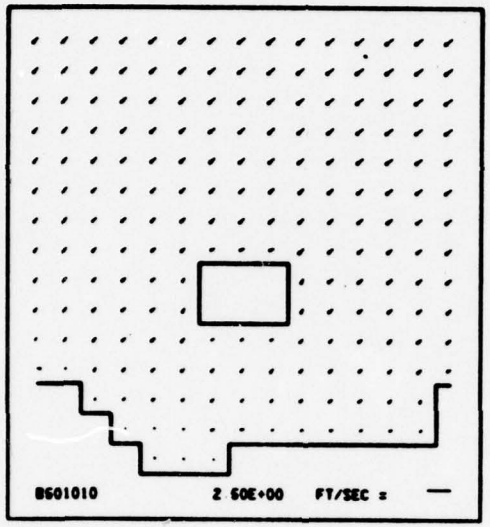

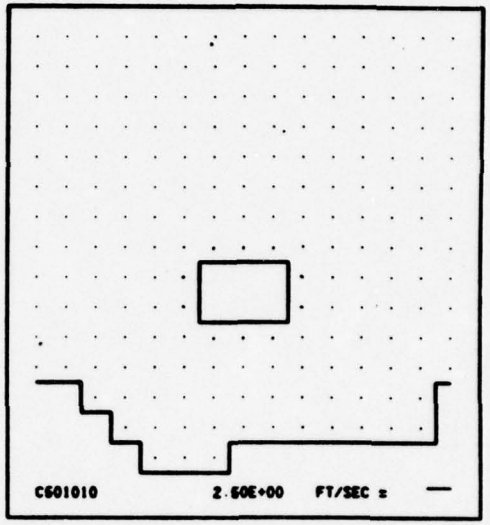

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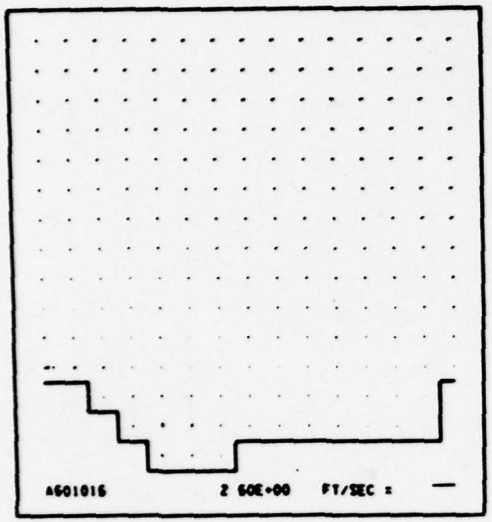

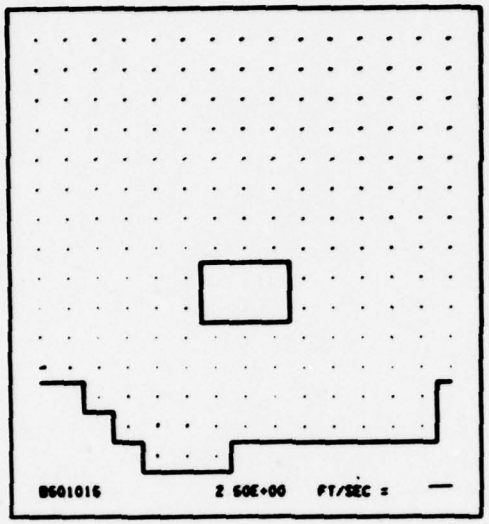

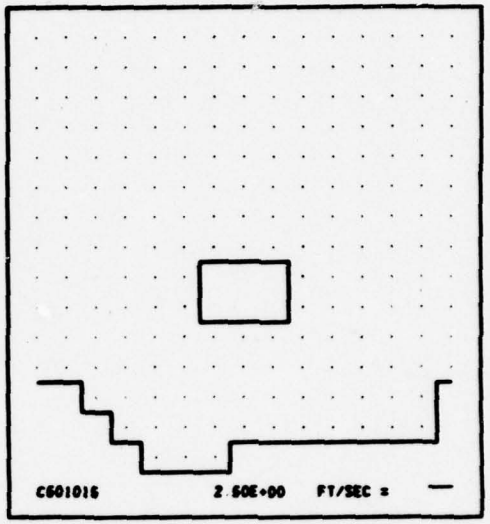

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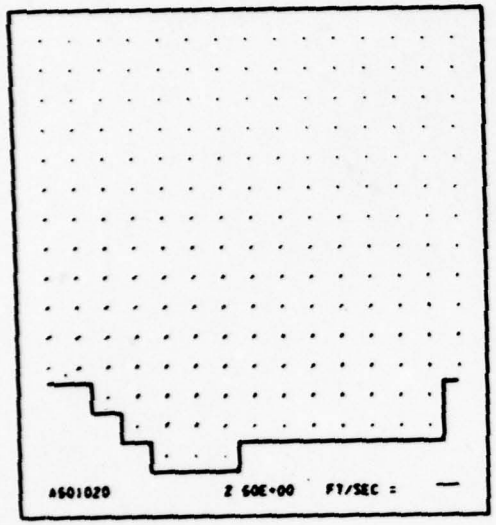

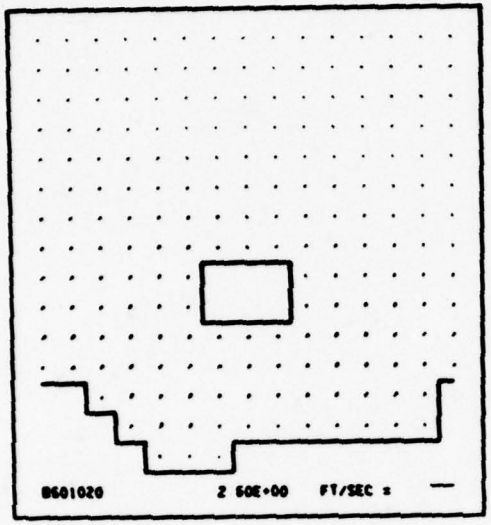

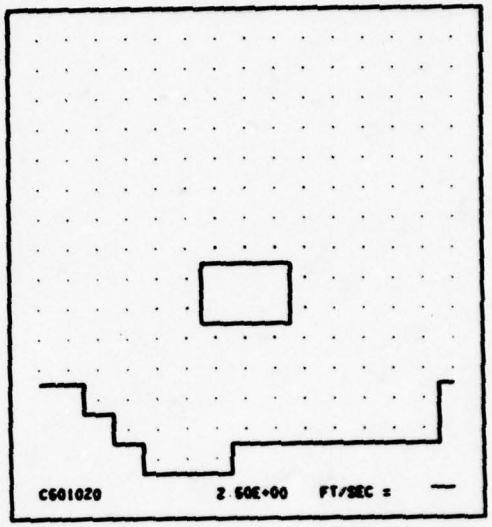

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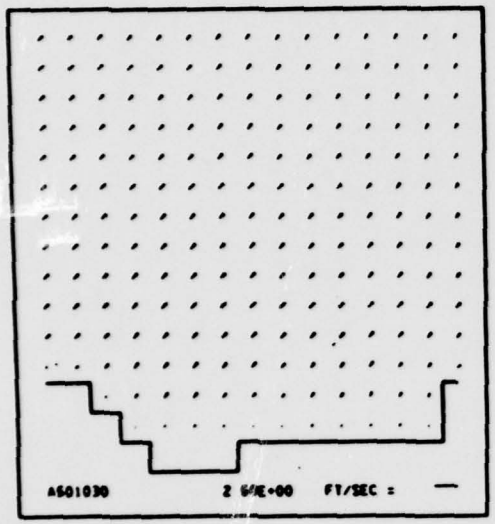

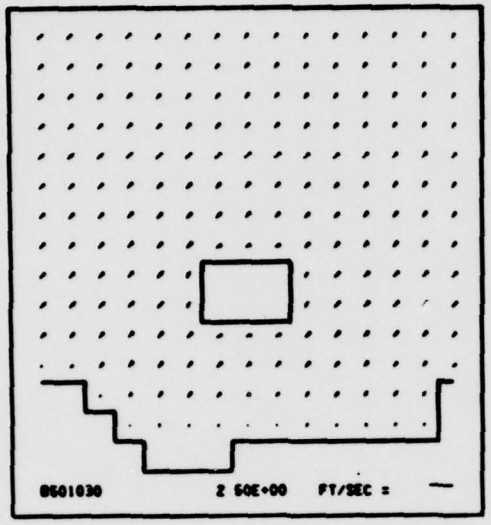

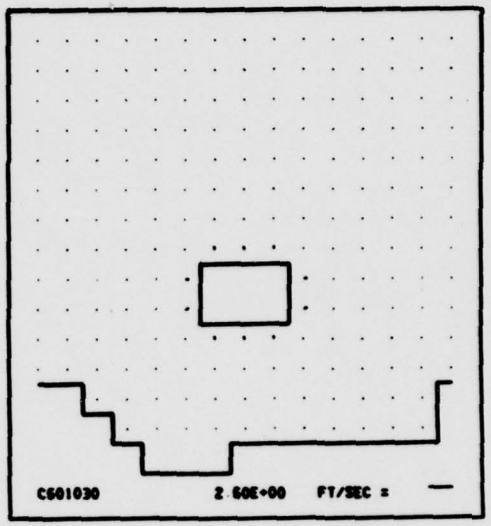

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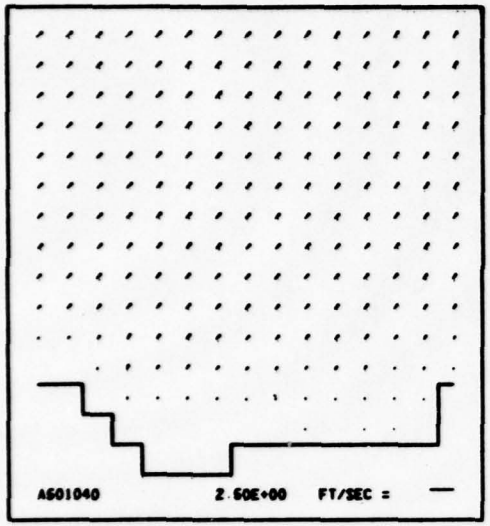

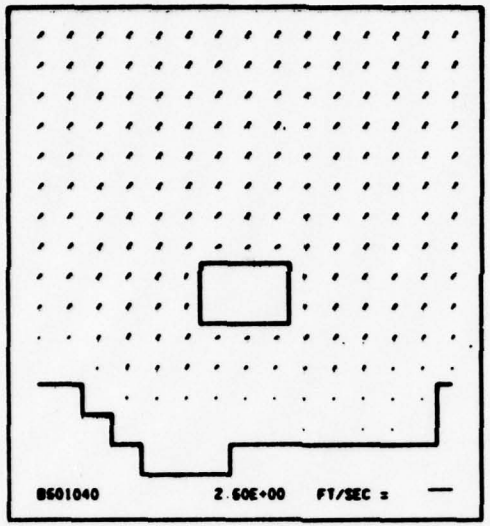

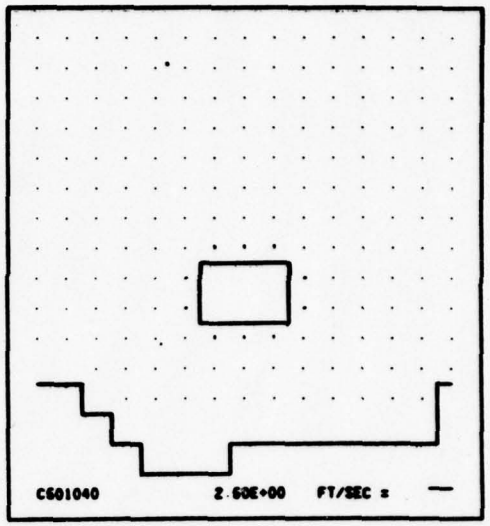

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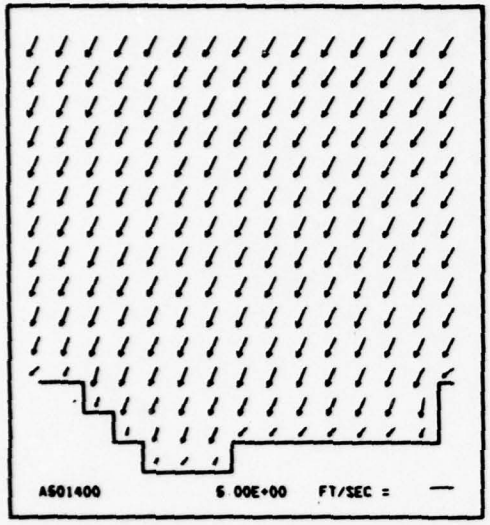

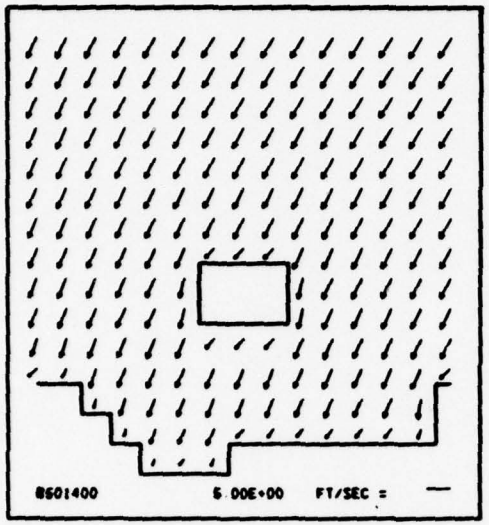

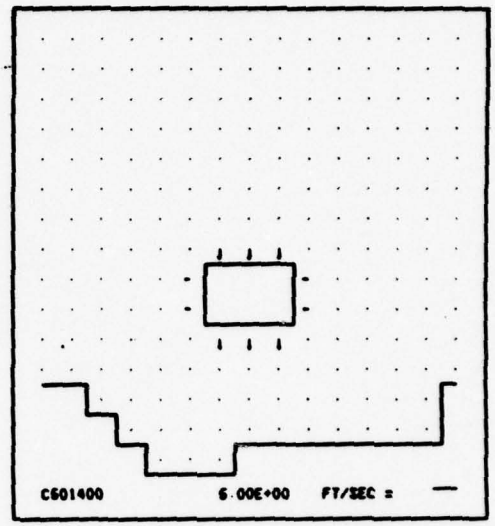

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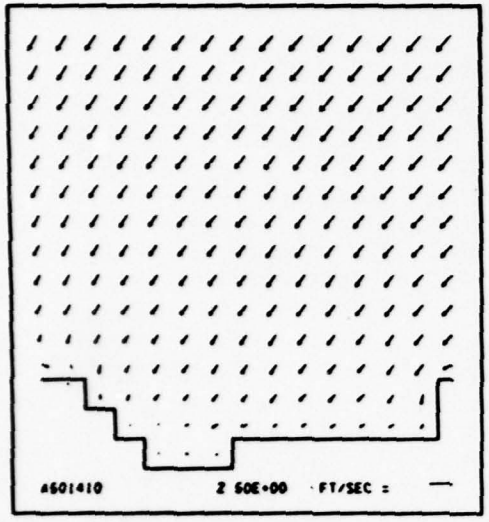

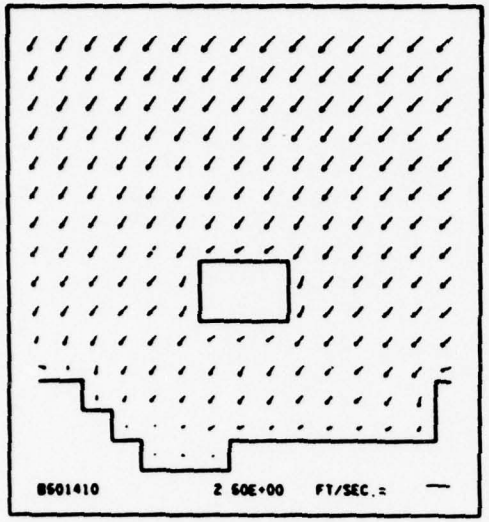

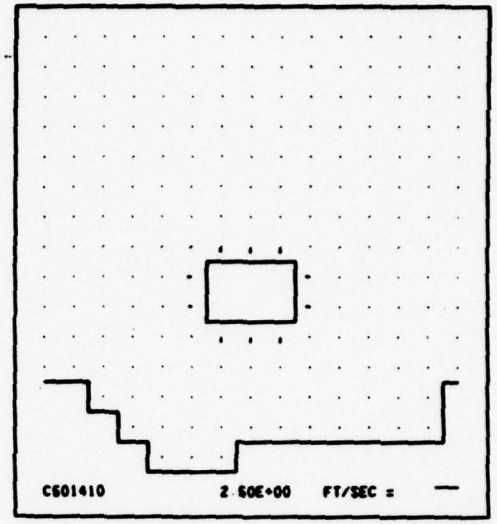

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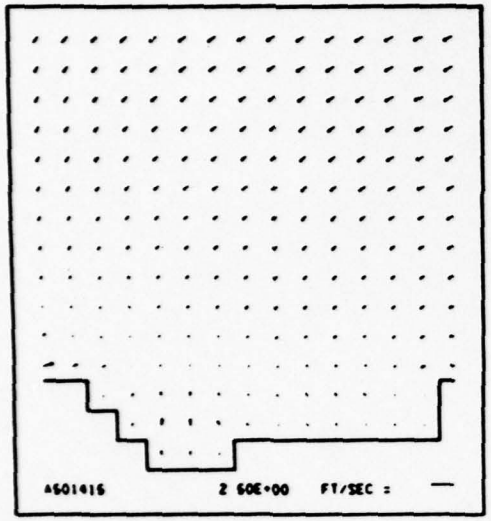

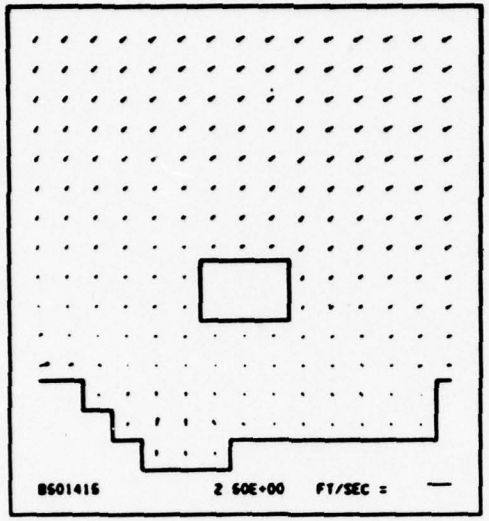

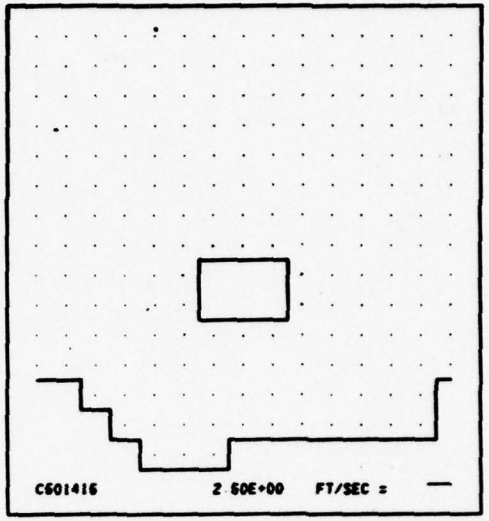

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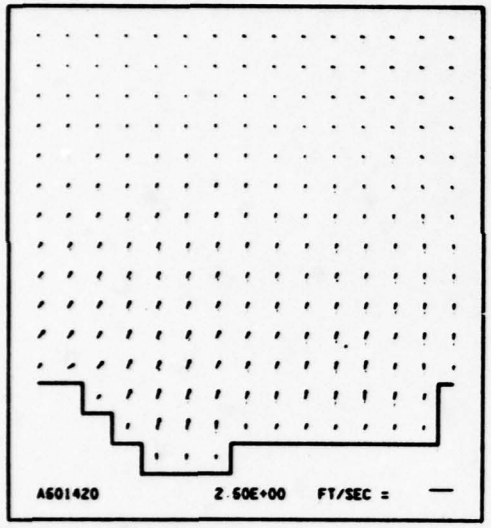

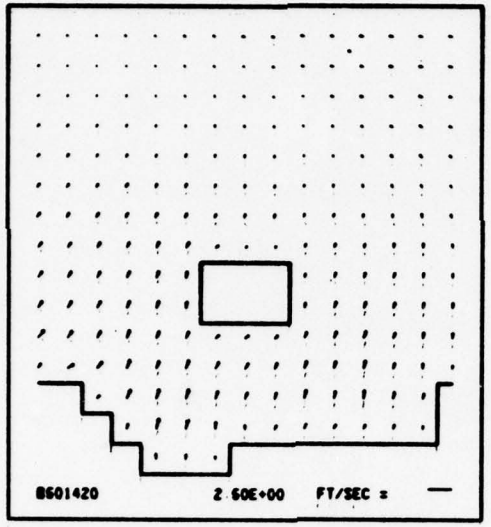

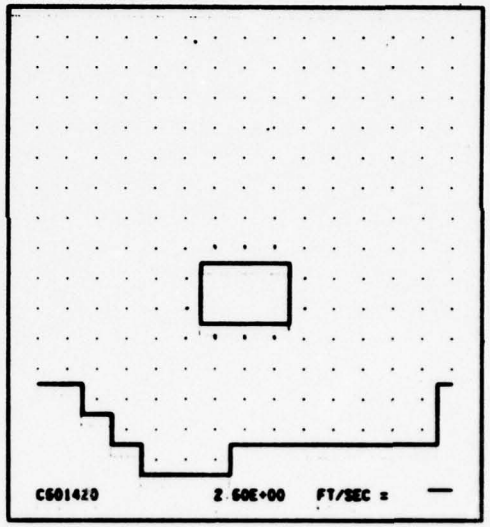

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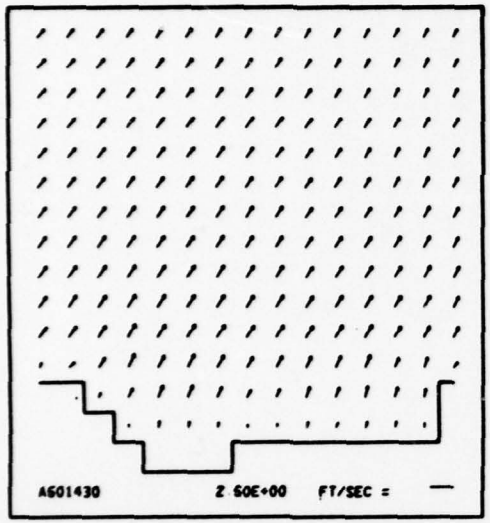

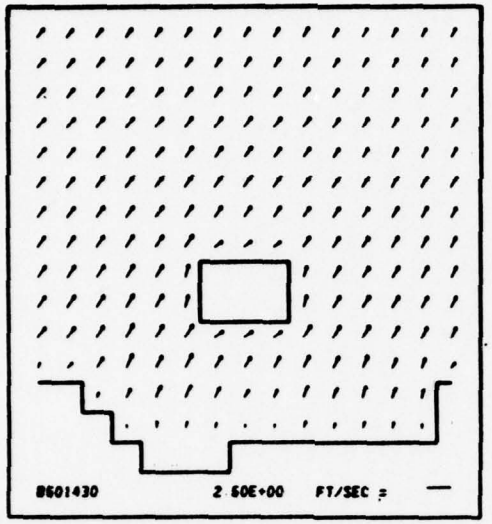

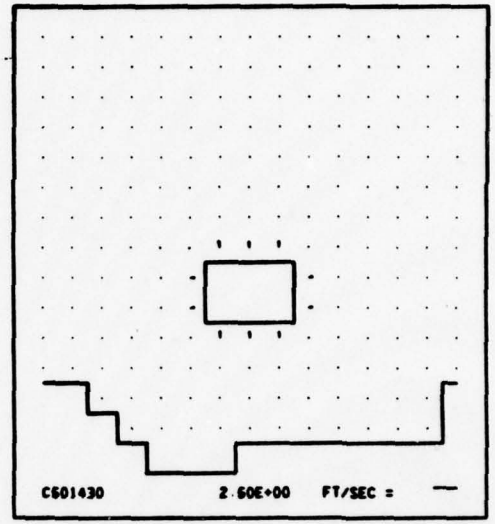

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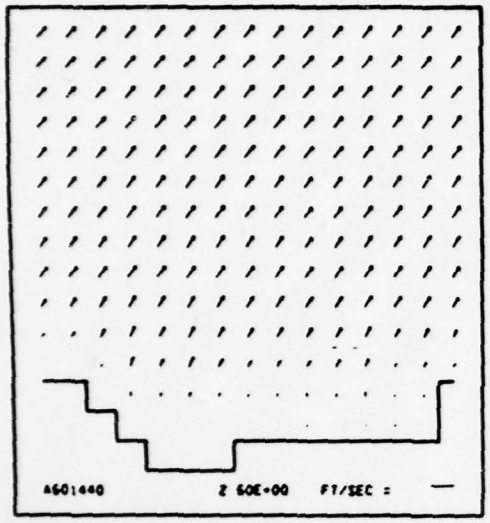

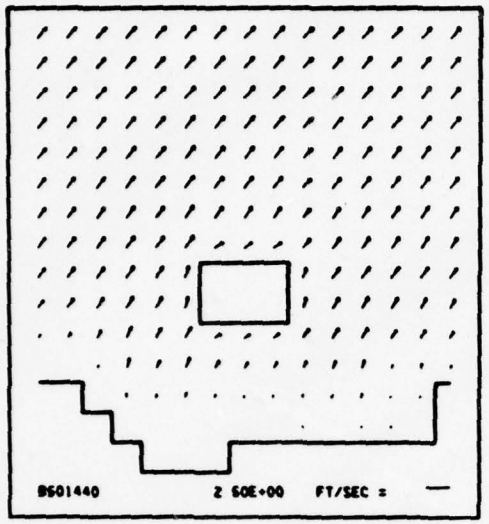

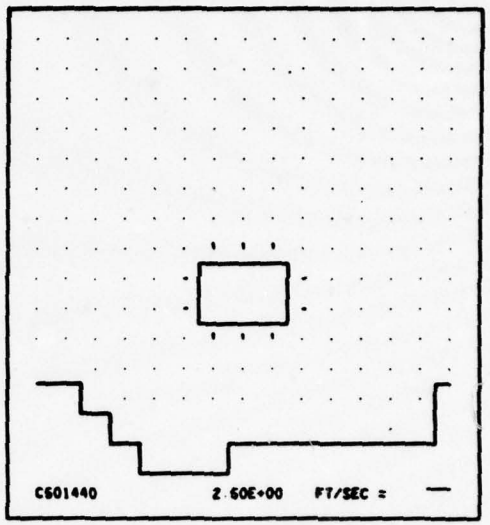

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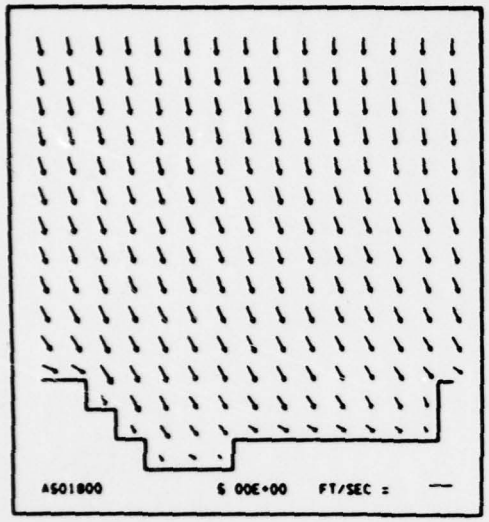

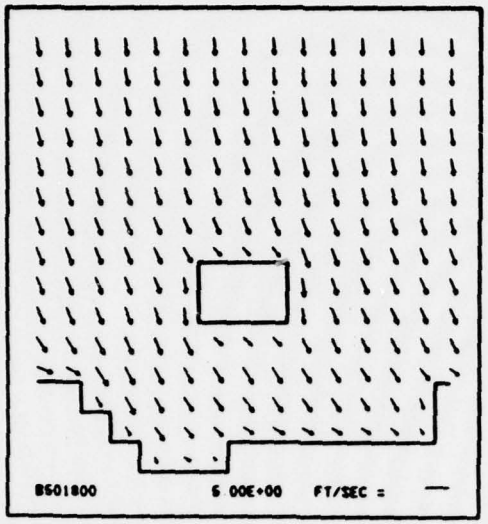

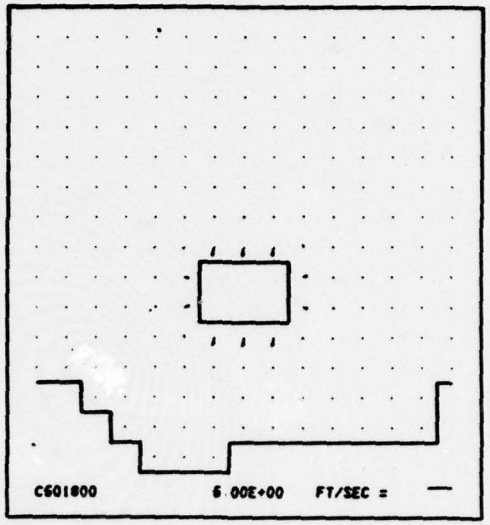

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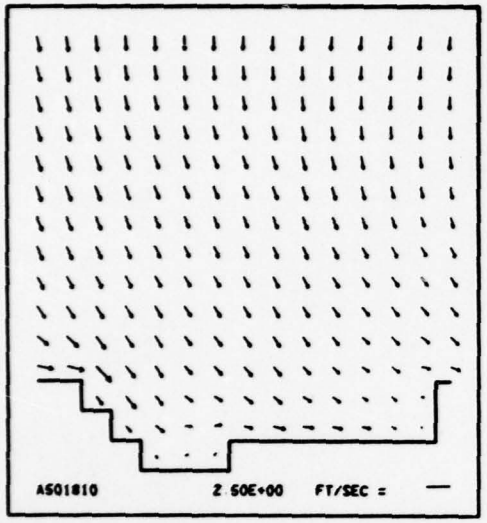

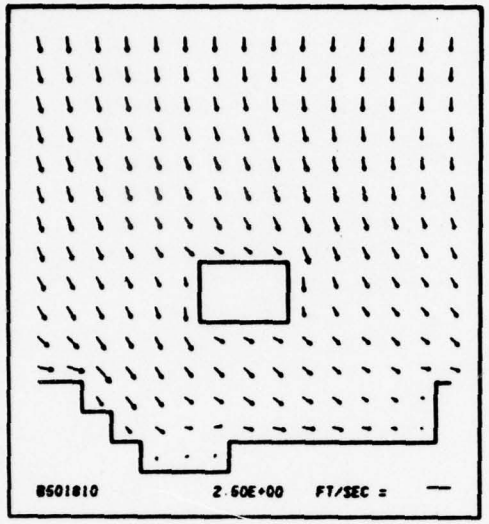

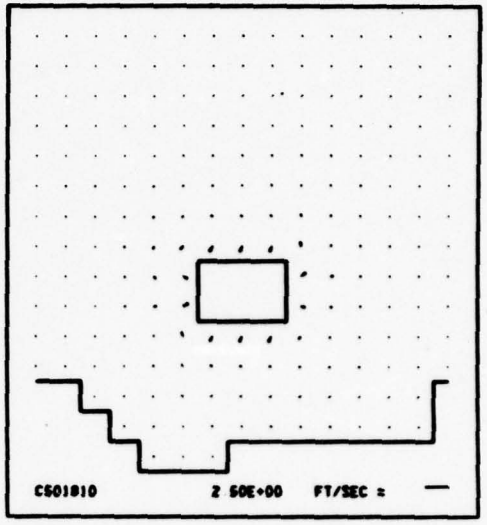

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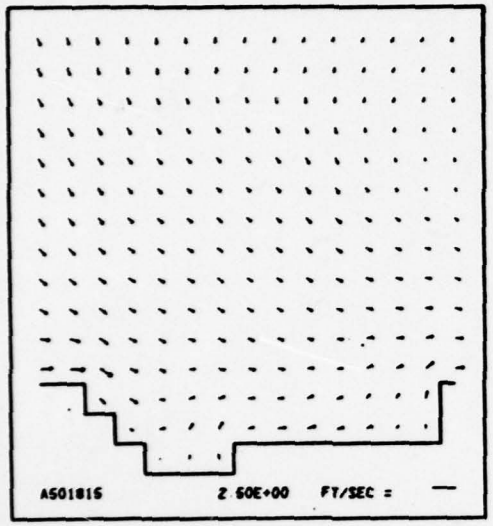

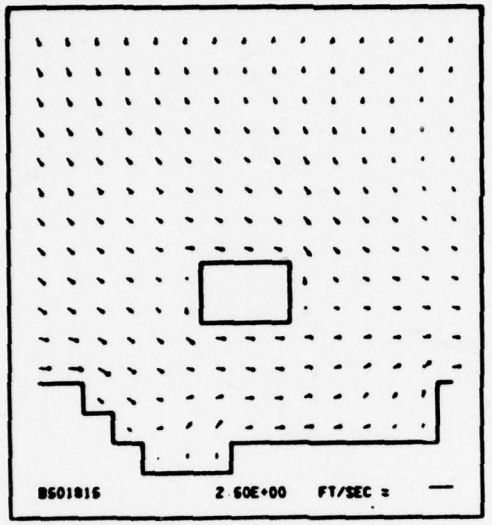

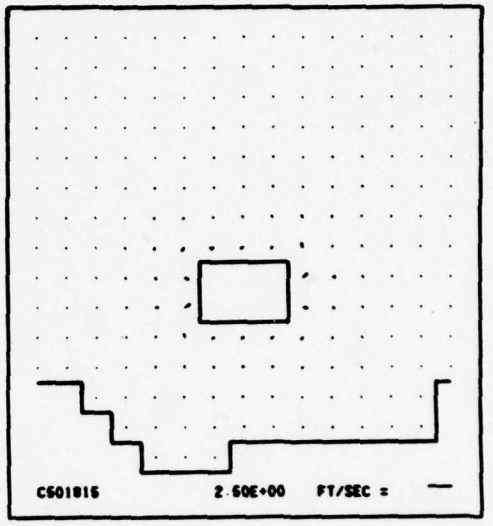

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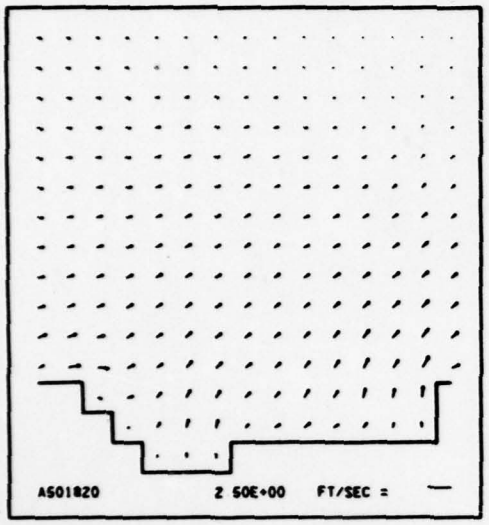

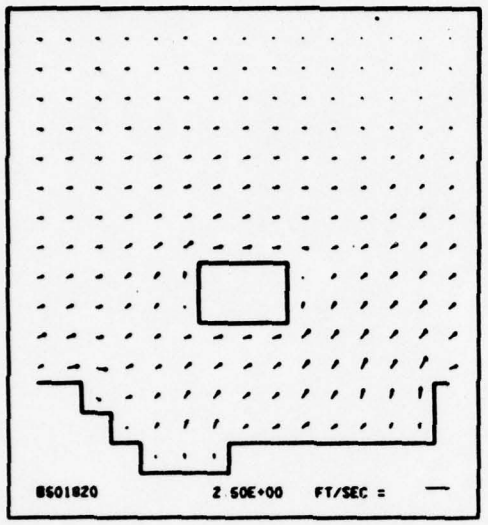

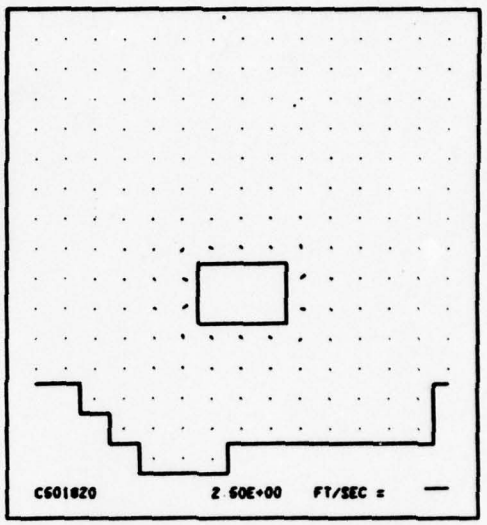

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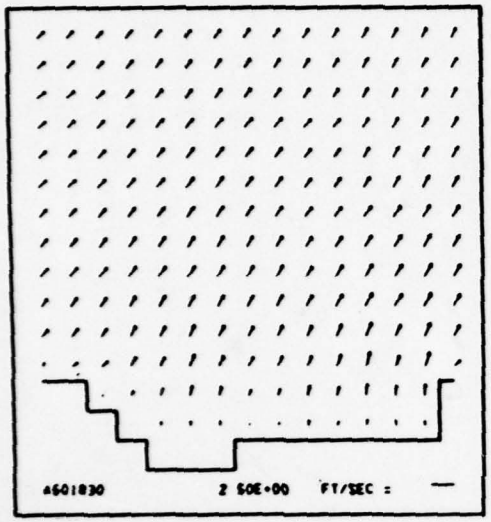

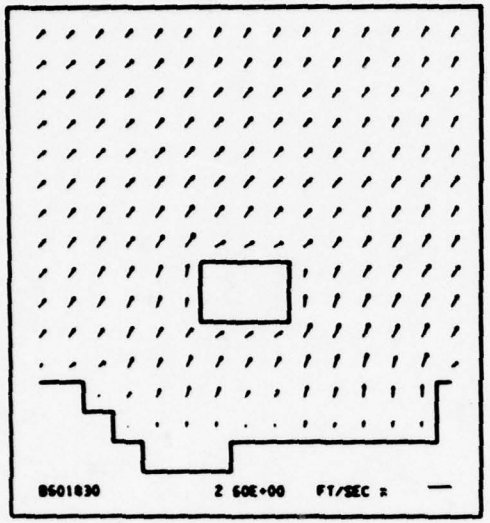

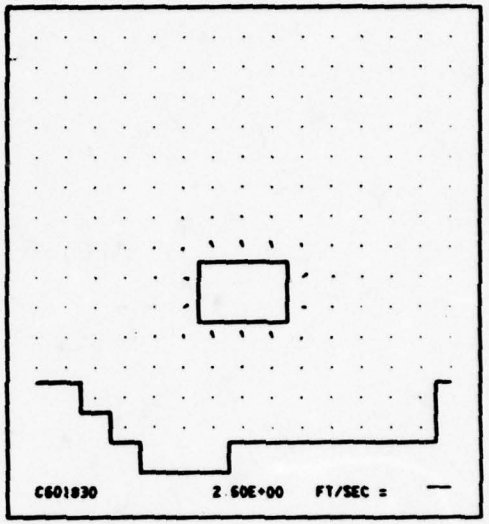

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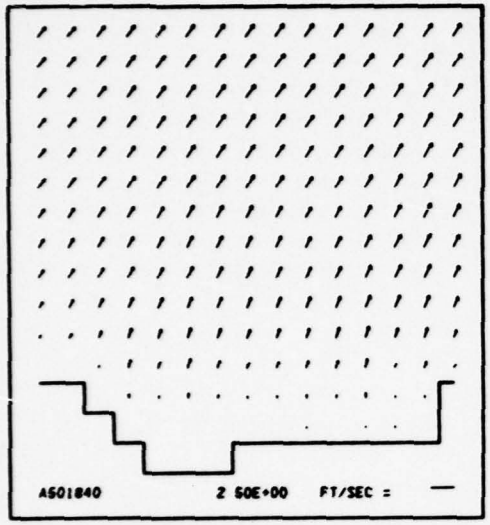

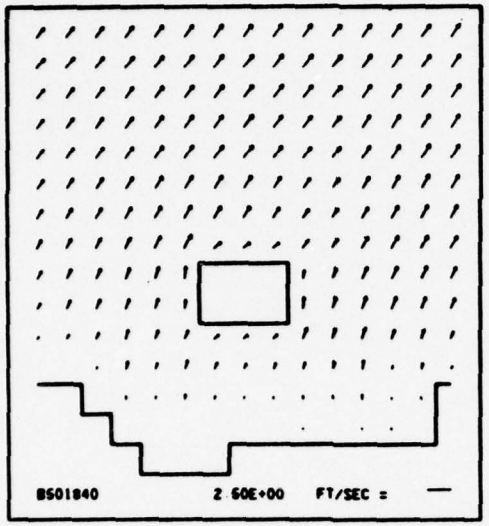

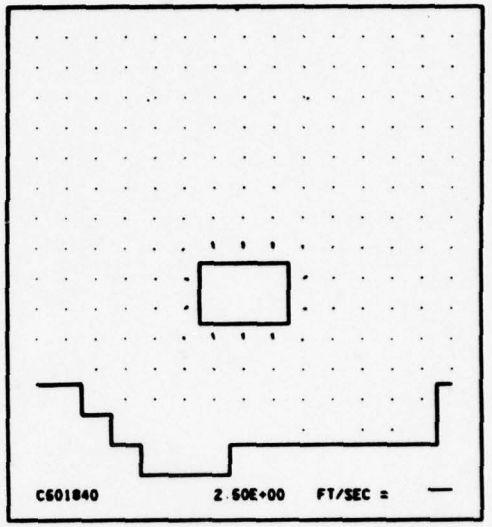

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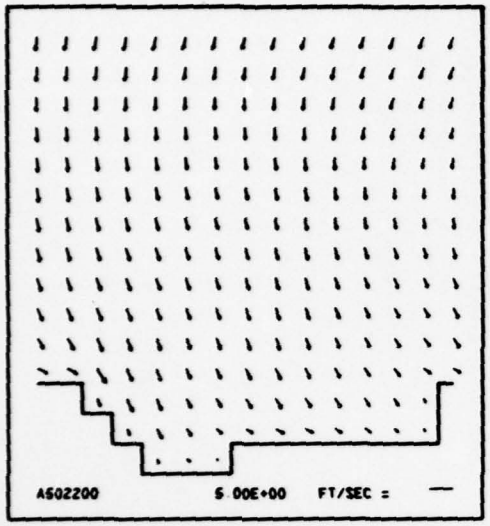

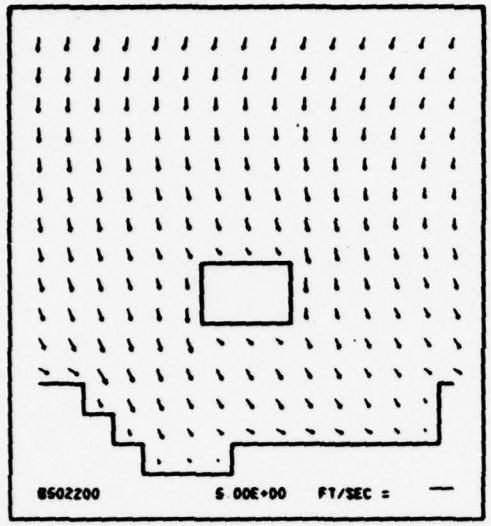

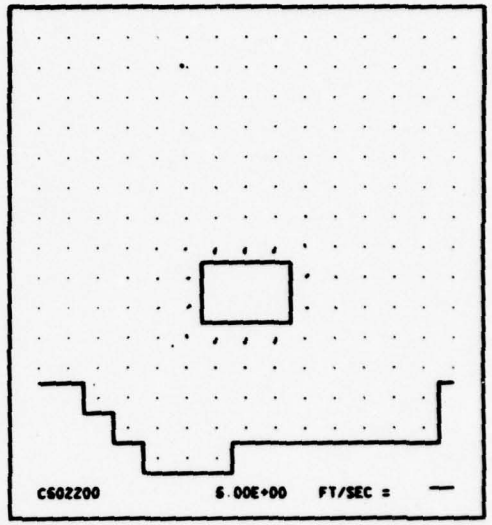

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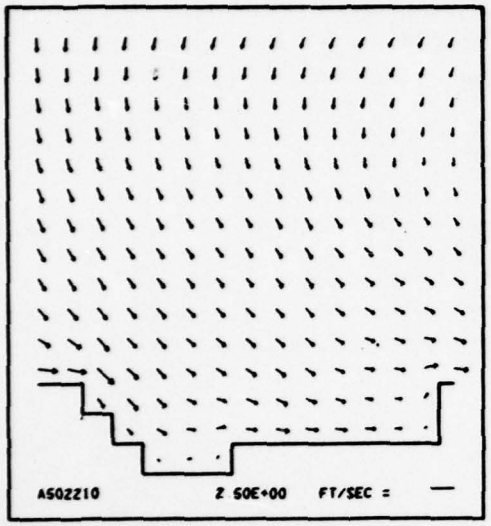

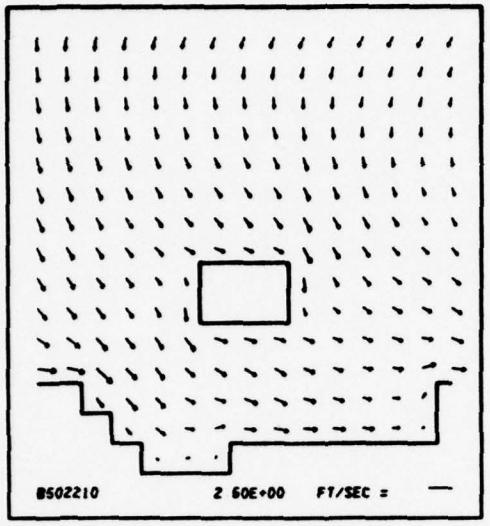

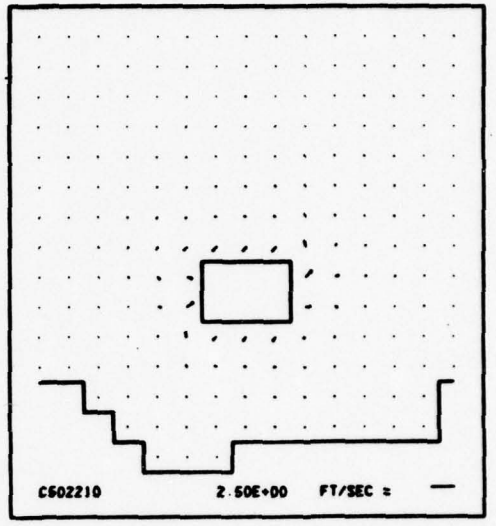

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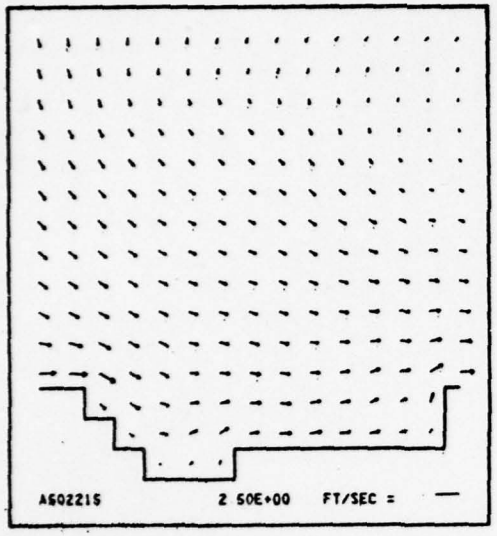

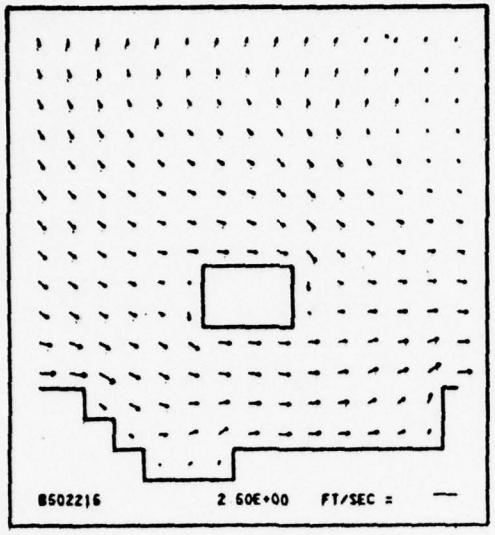

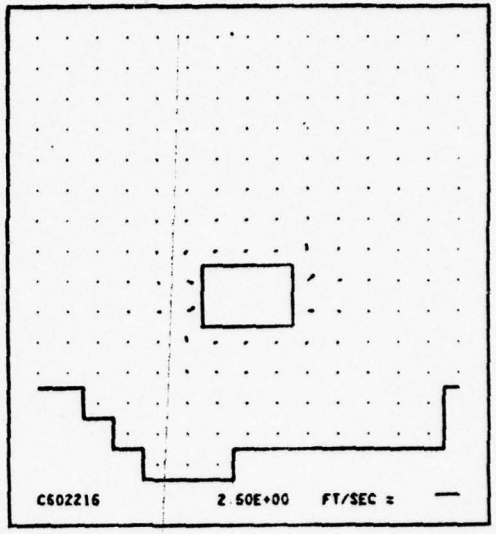

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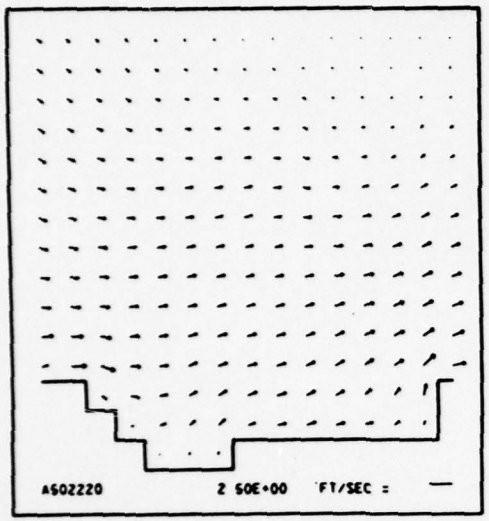

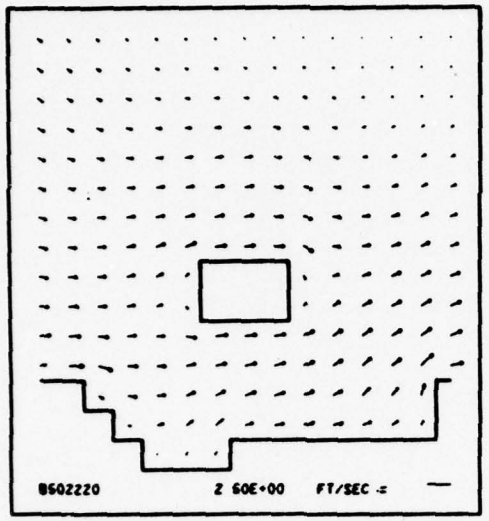

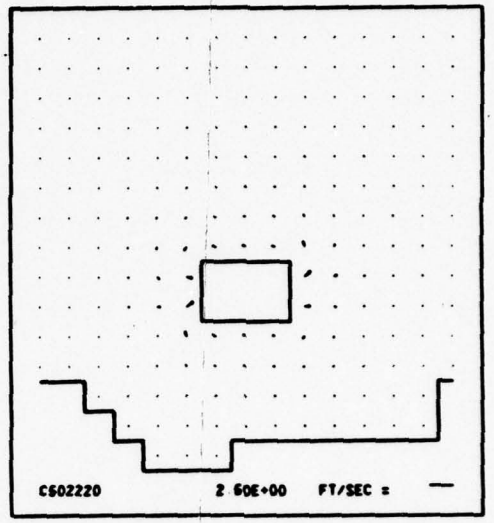

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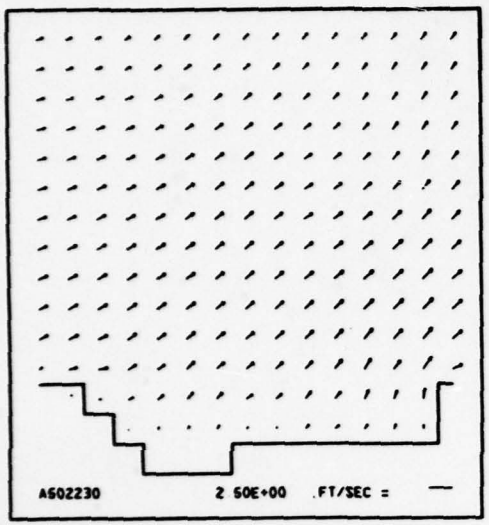

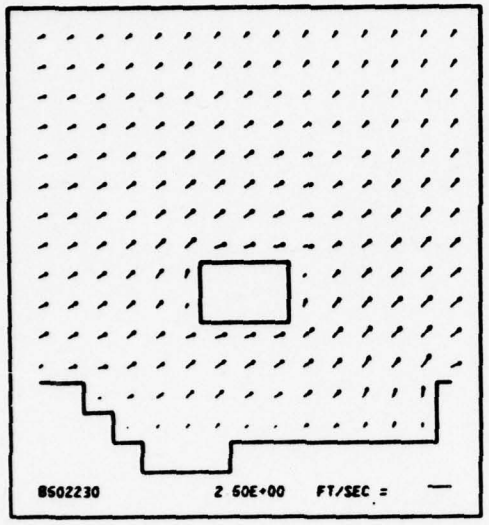

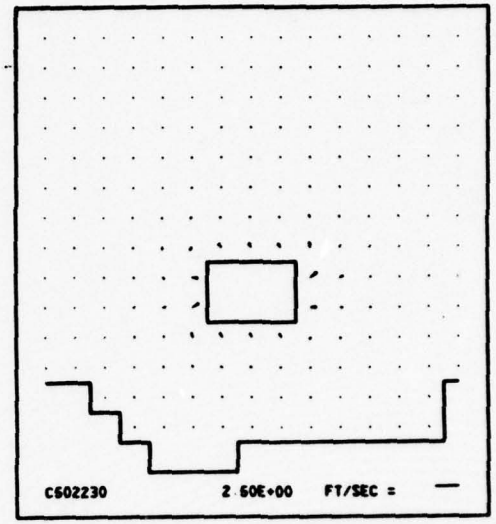

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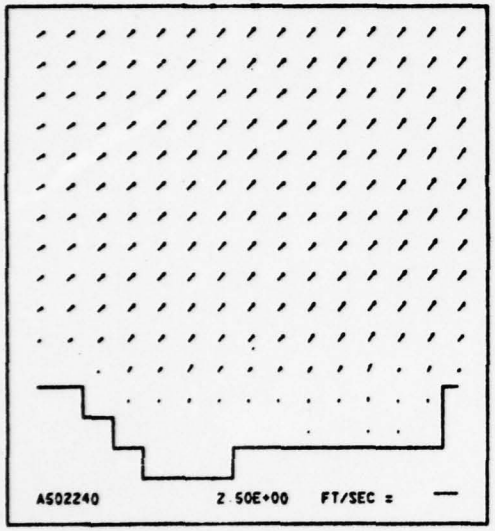

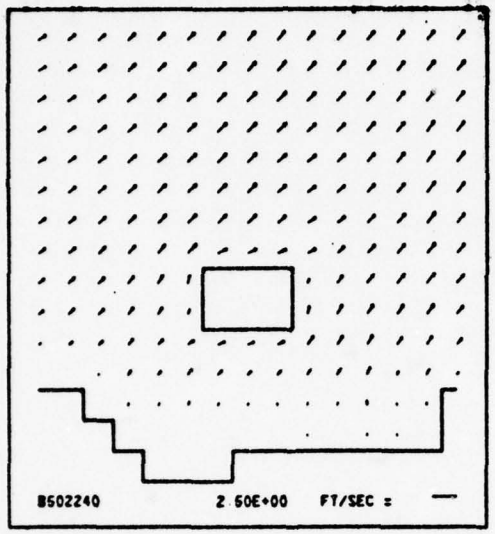

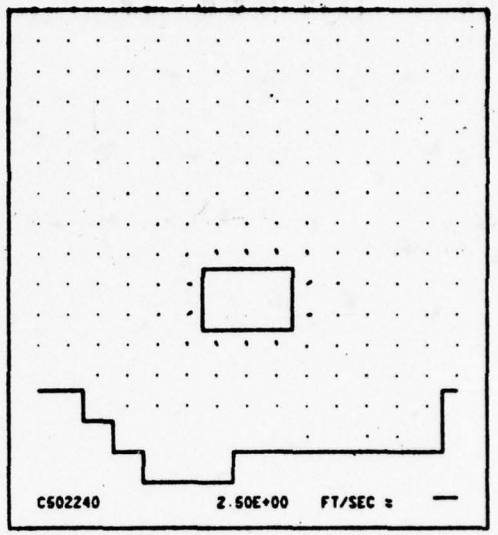

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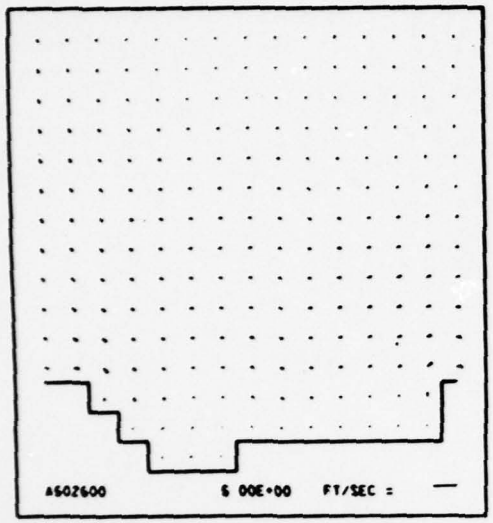

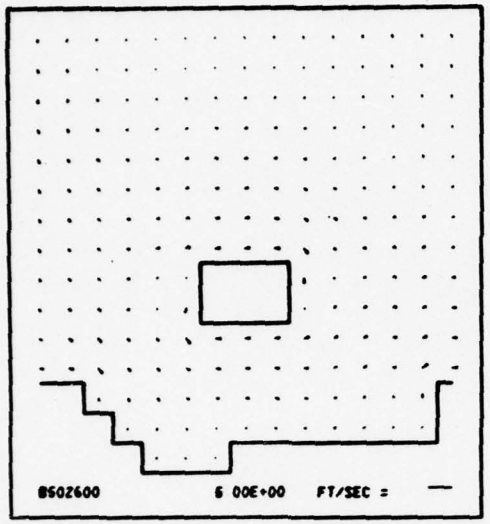

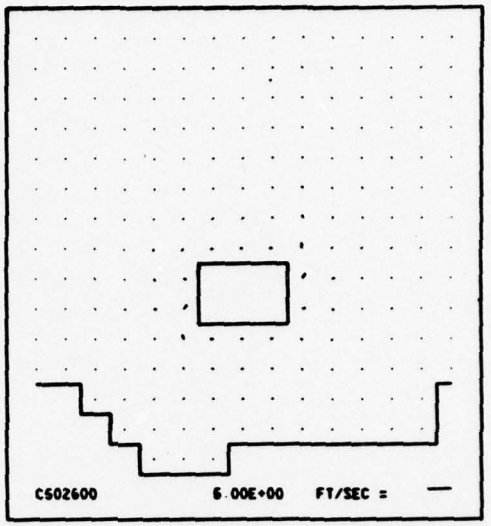

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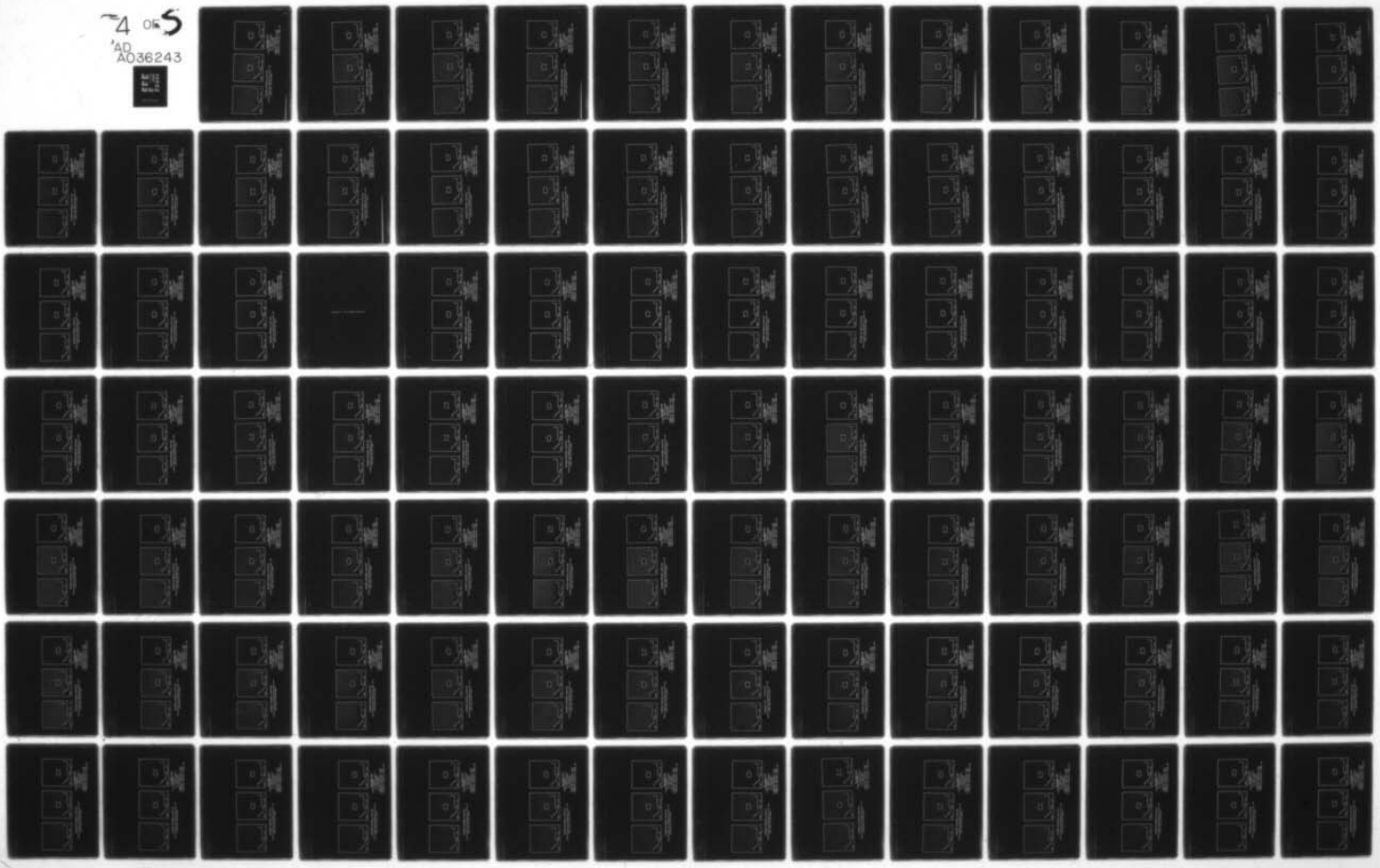
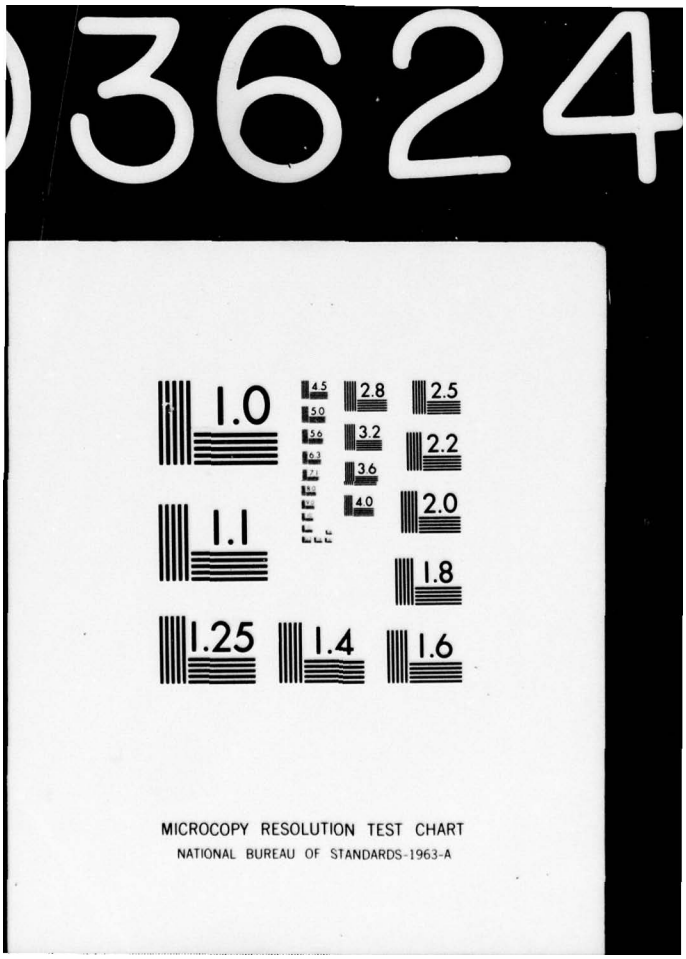
AD-A036 243 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 1/5
LAKE ERIE INTERNATIONAL JETPORT MODEL FEASIBILITY INVESTIGATION--ETC(U)
OCT 76 D L DURHAM, H L BUTLER, D C RANEY

UNCLASSIFIED WES-MP-H-76-3-8 NL

4 OF 5
AD A036243




03624
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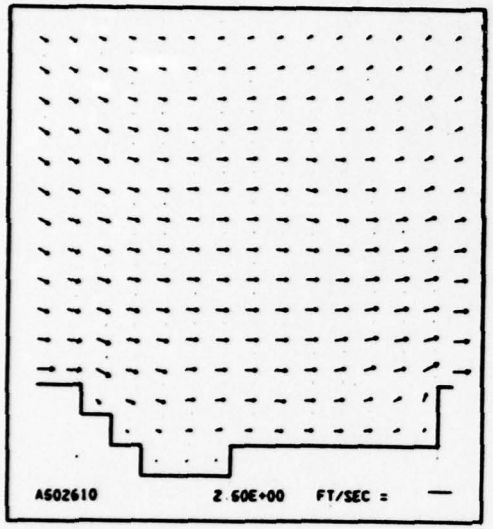
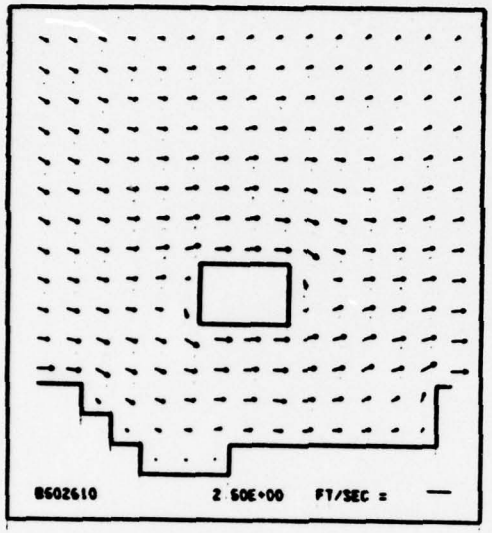
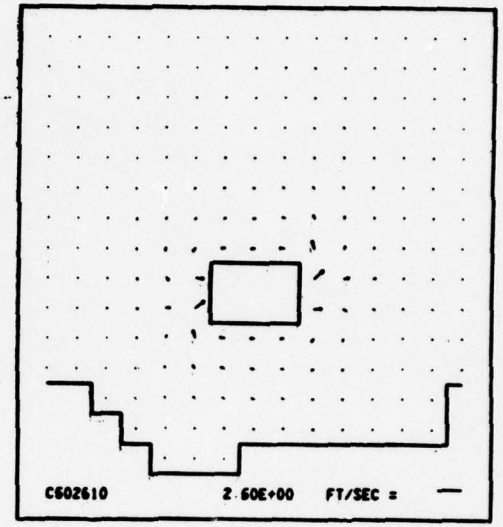
7.1
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A







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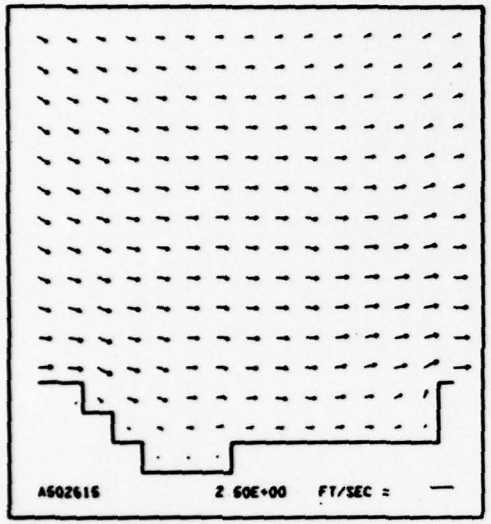

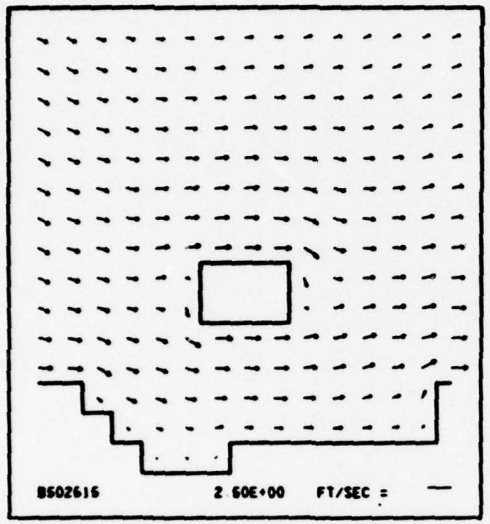

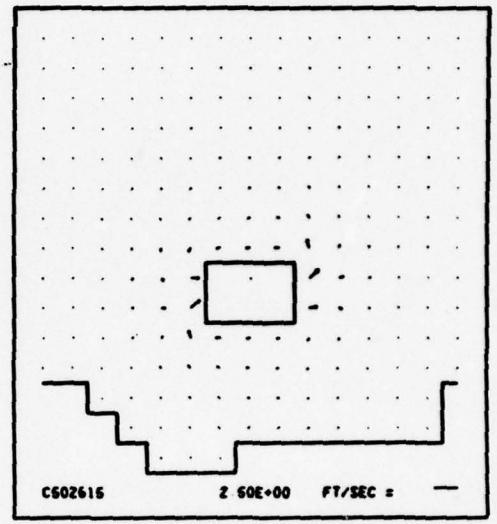

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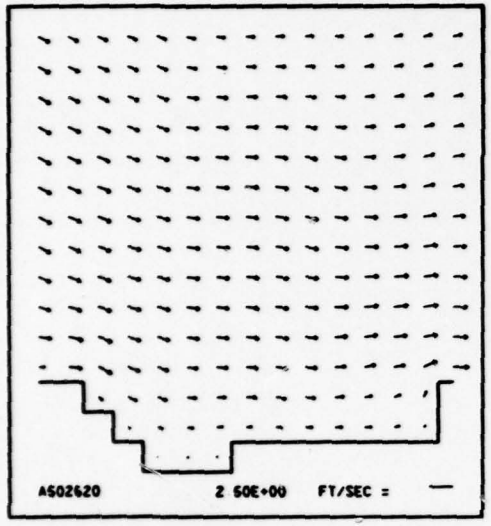

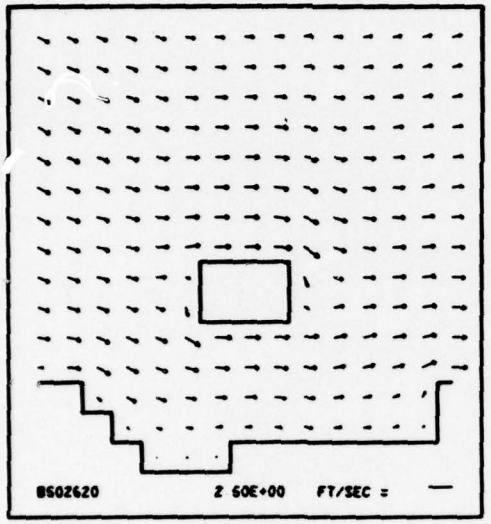

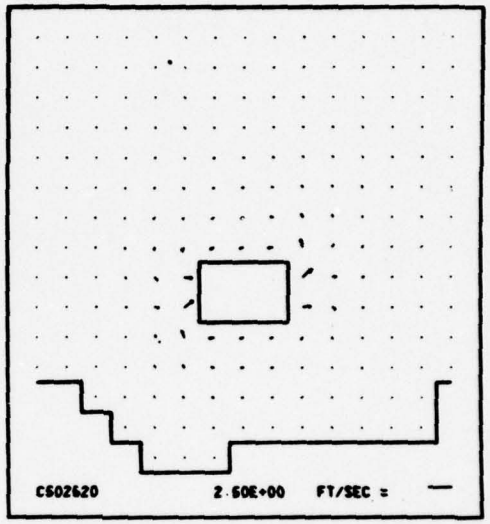

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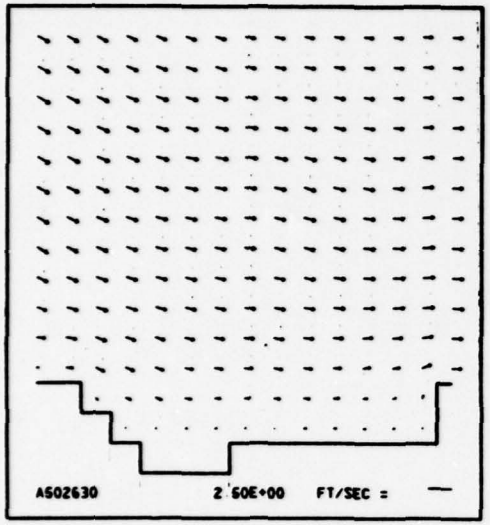

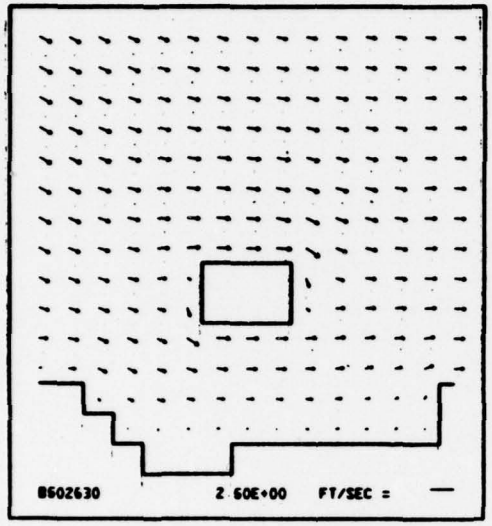

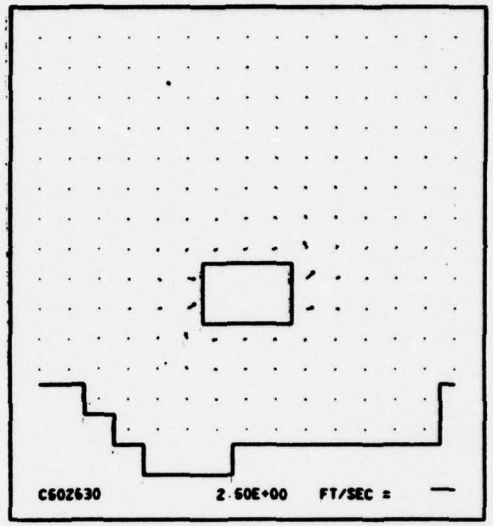

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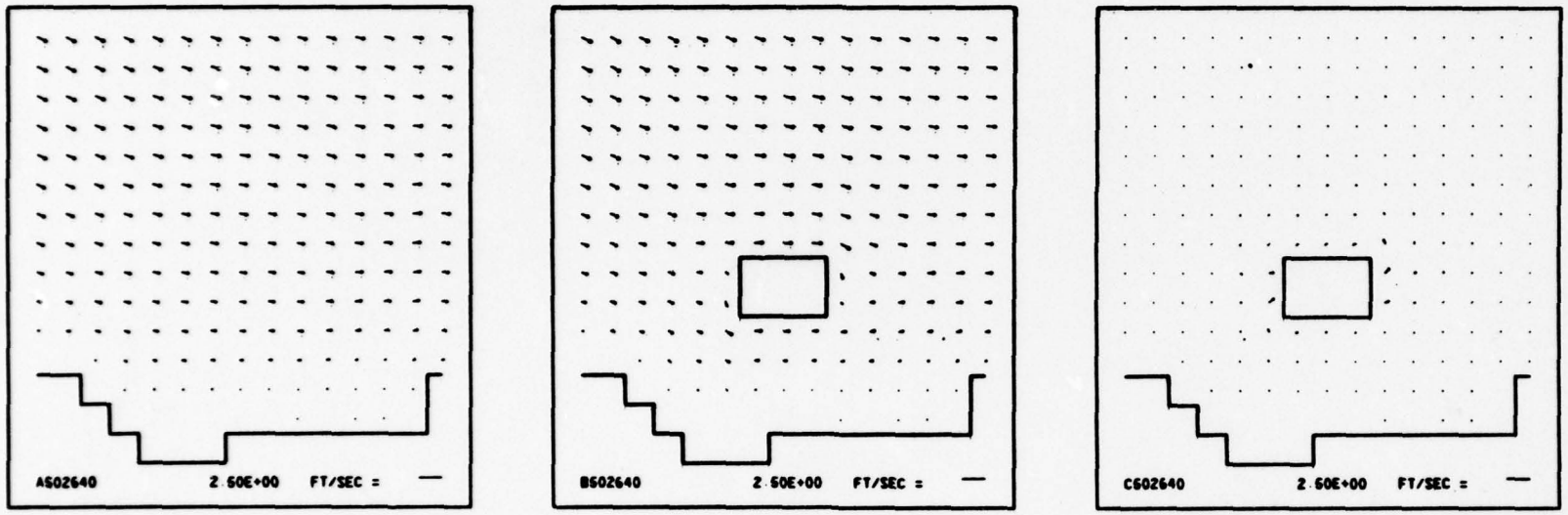

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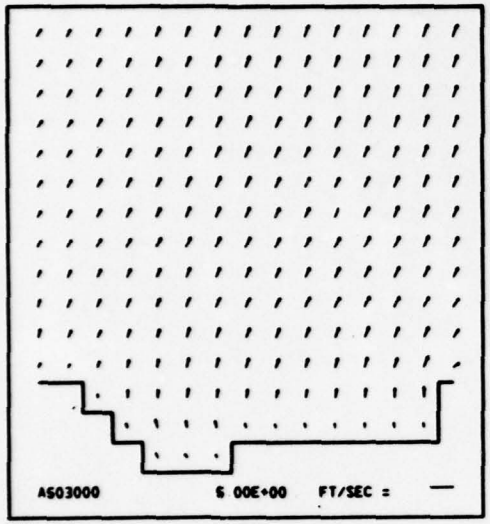

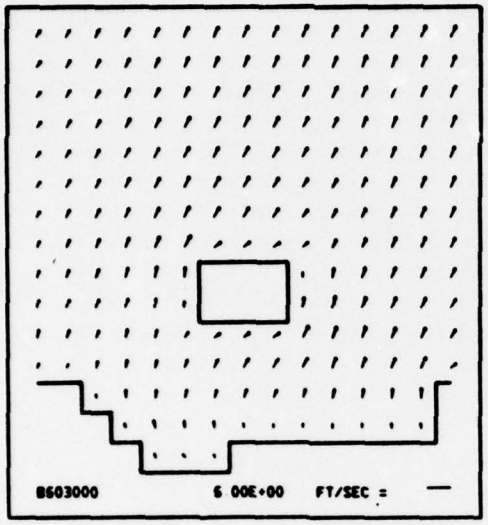

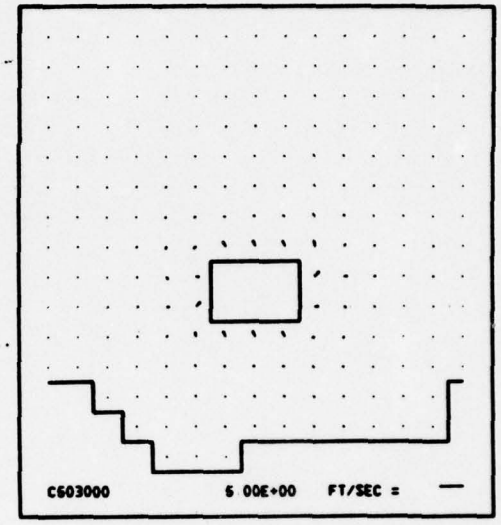

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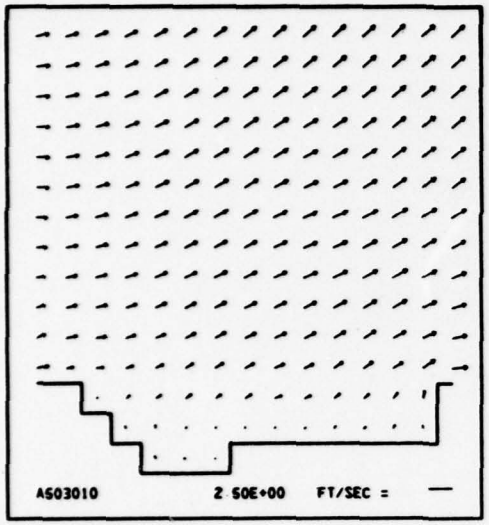

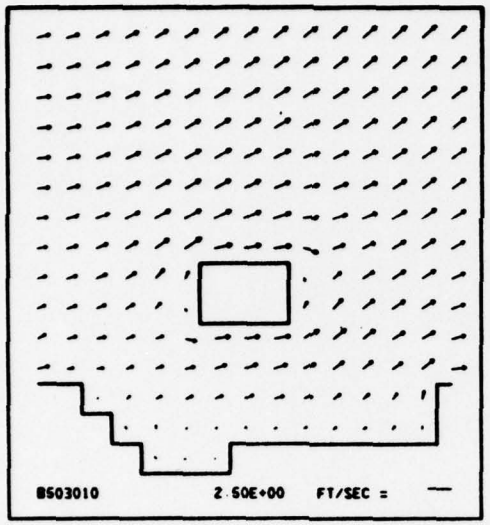

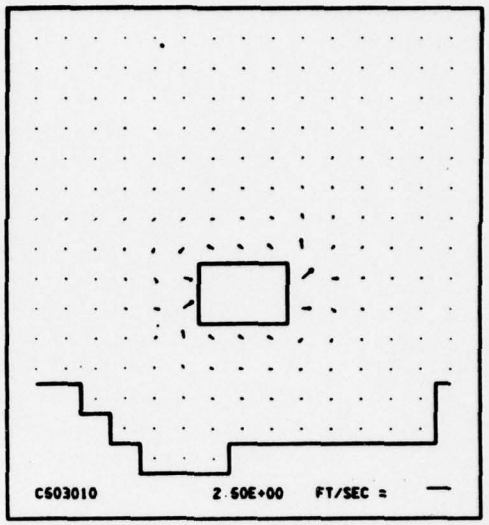

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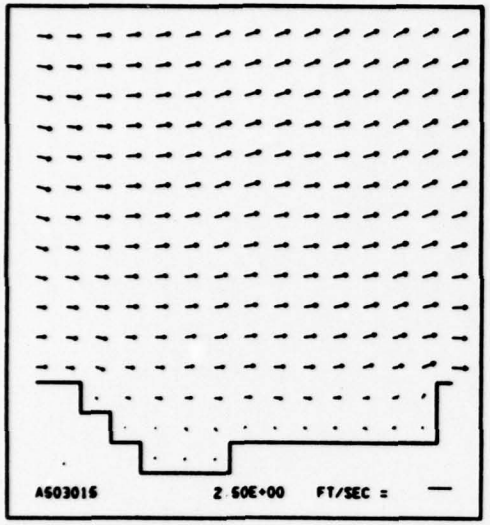

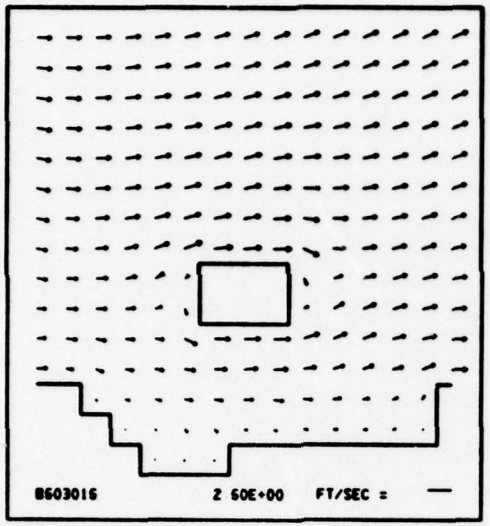

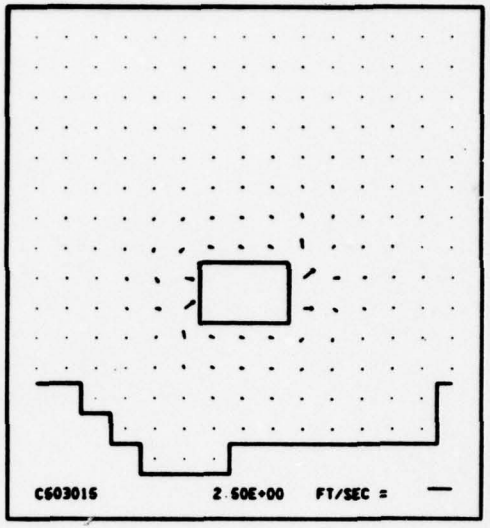

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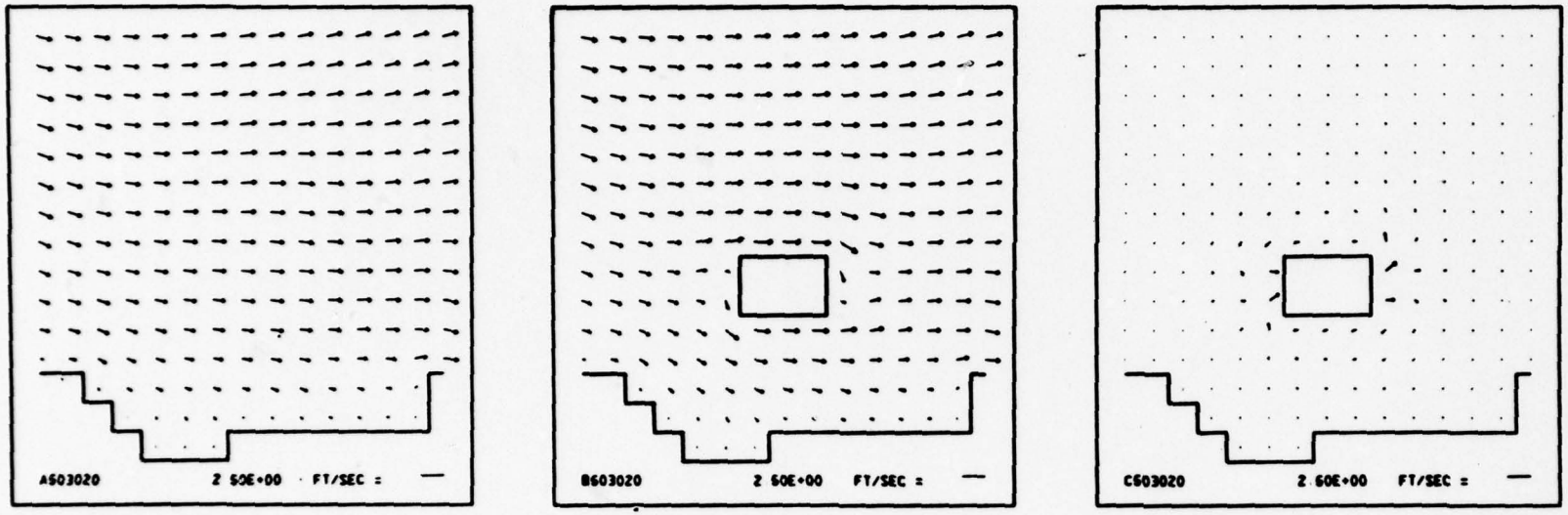

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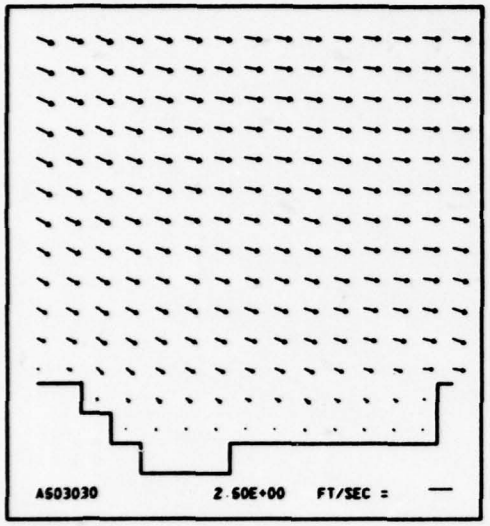

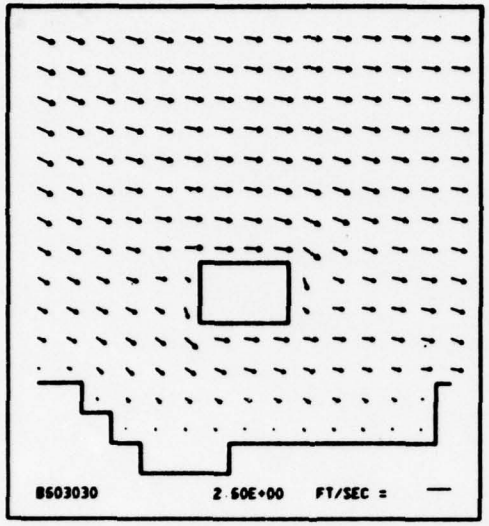

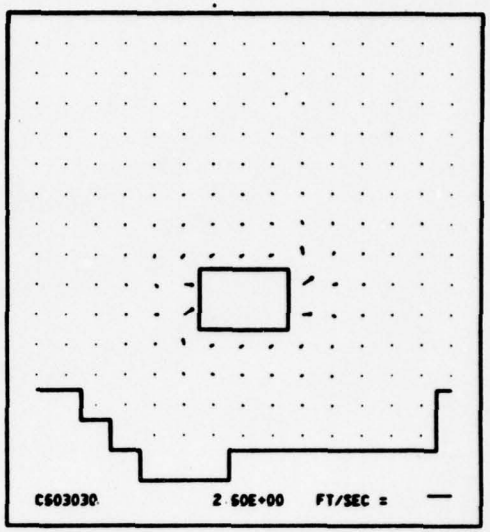

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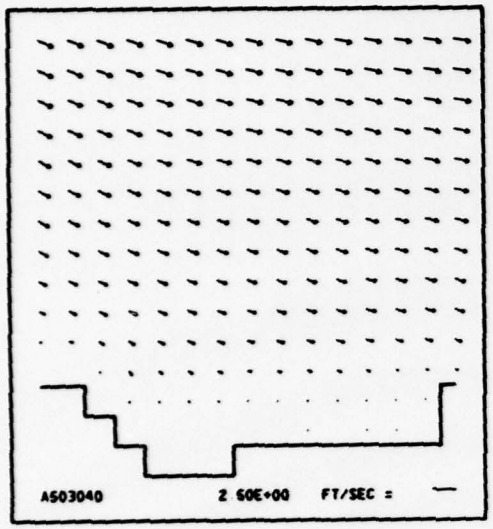

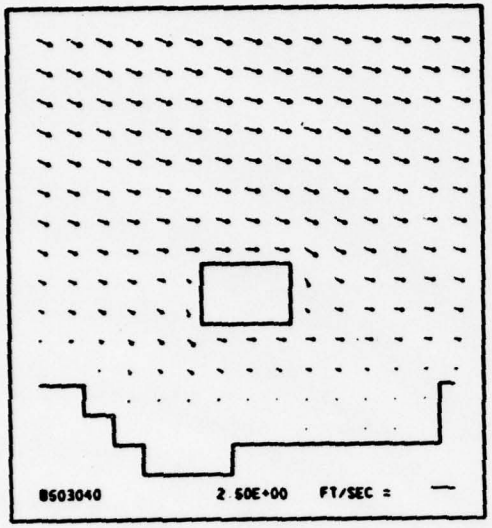

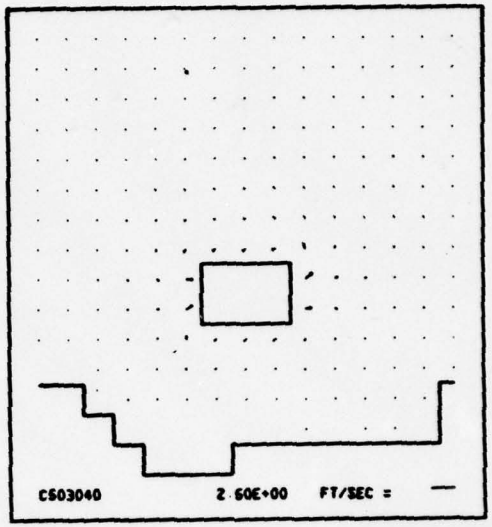

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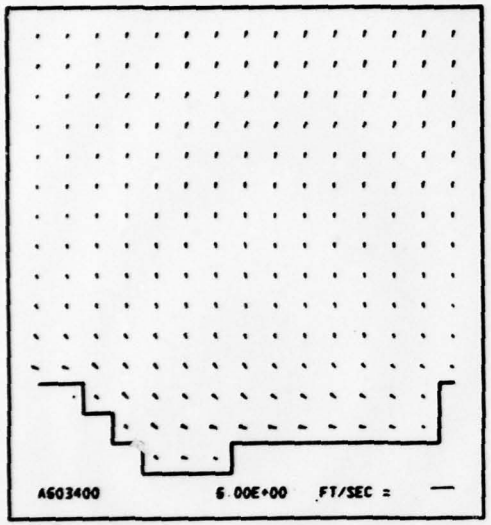

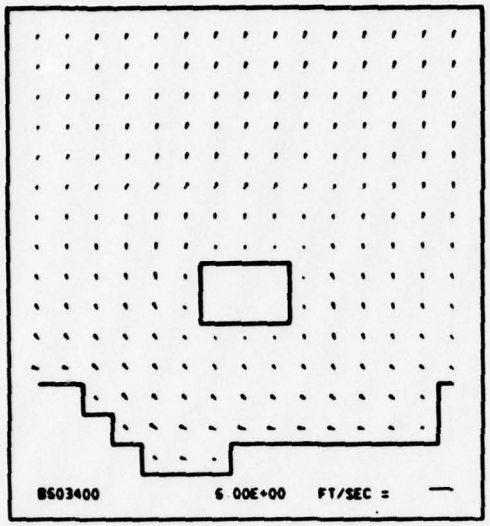

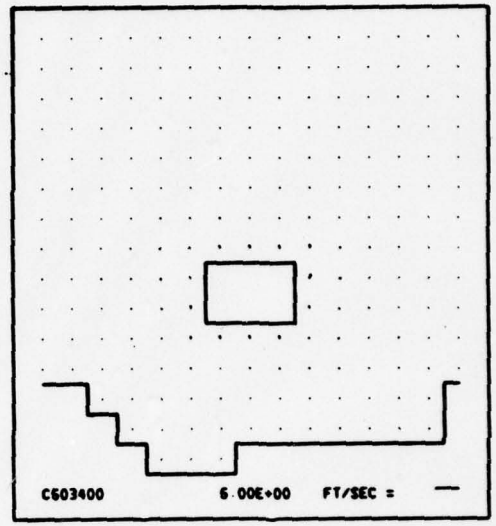

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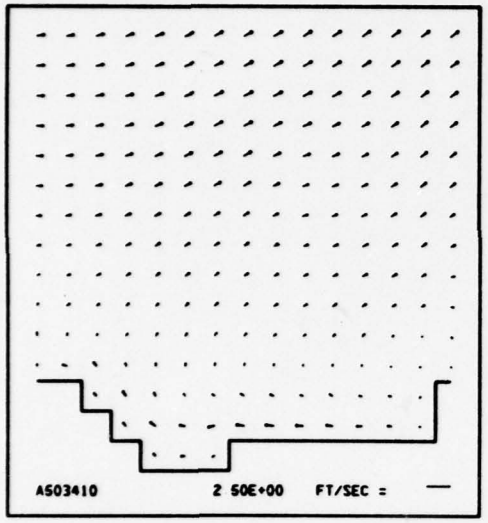

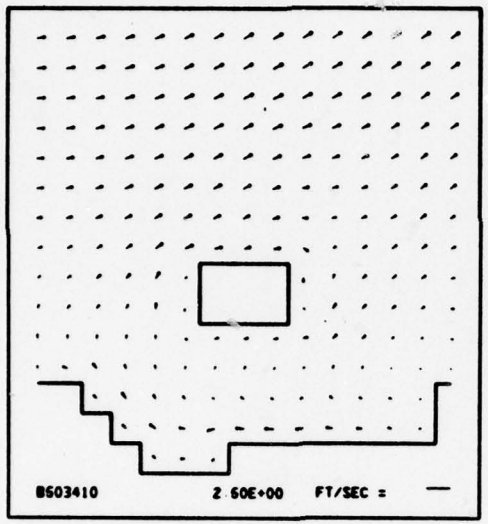

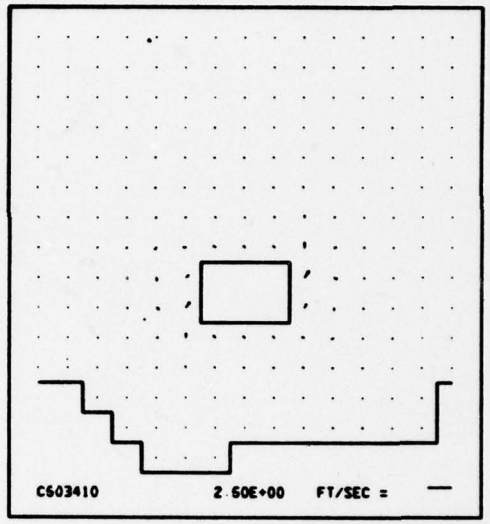

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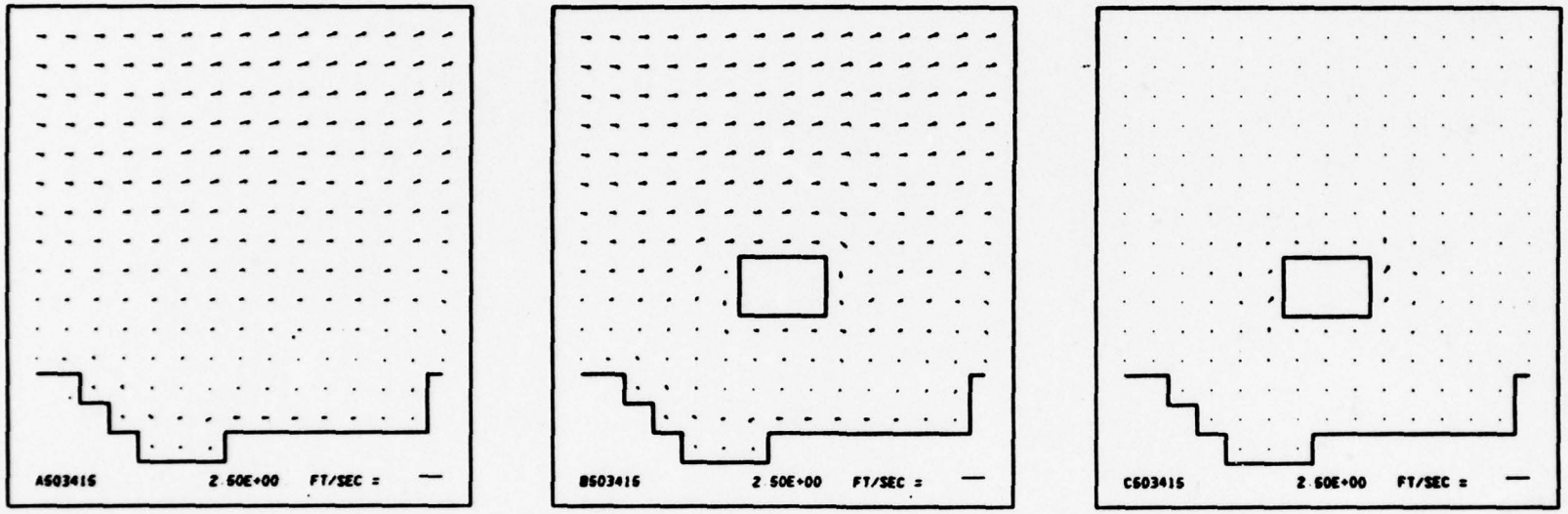

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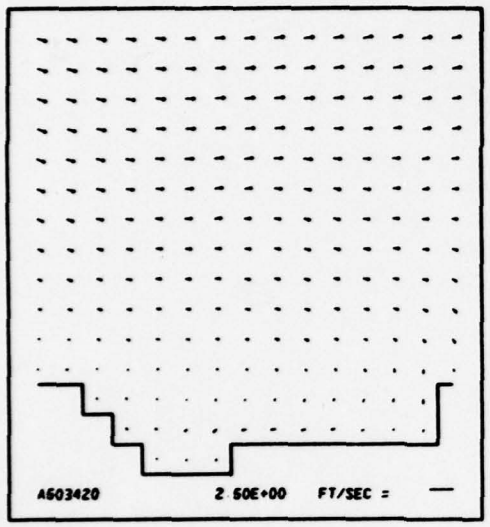

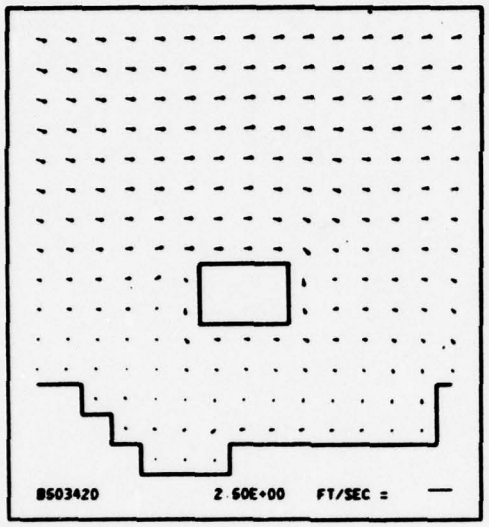

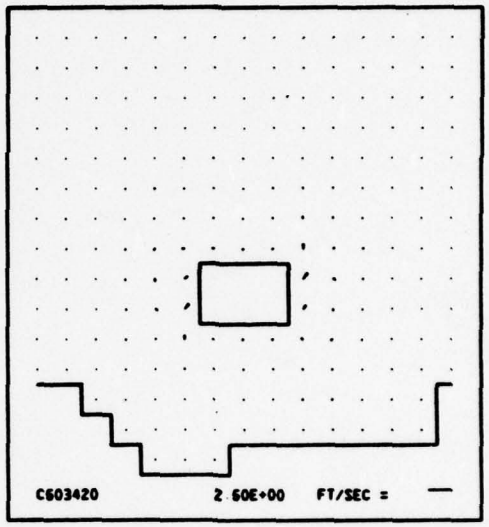

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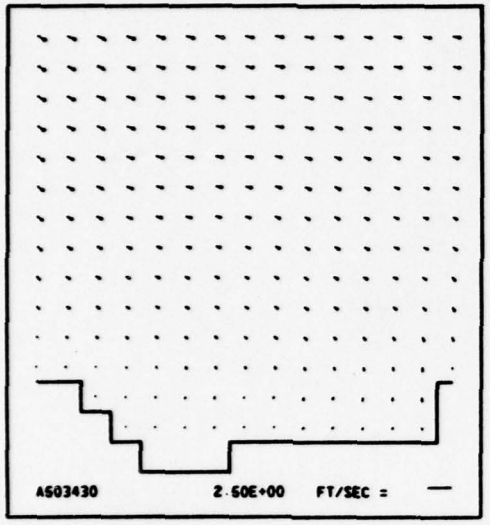

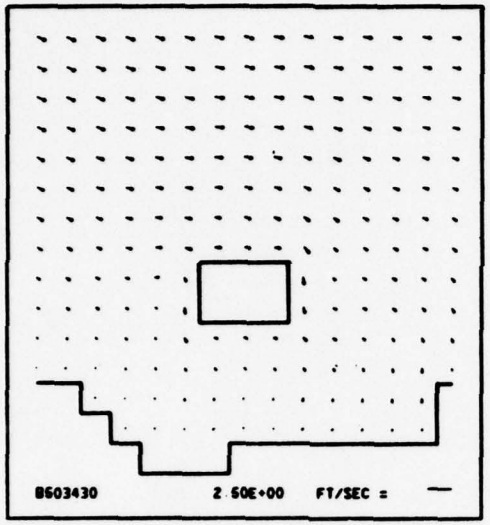

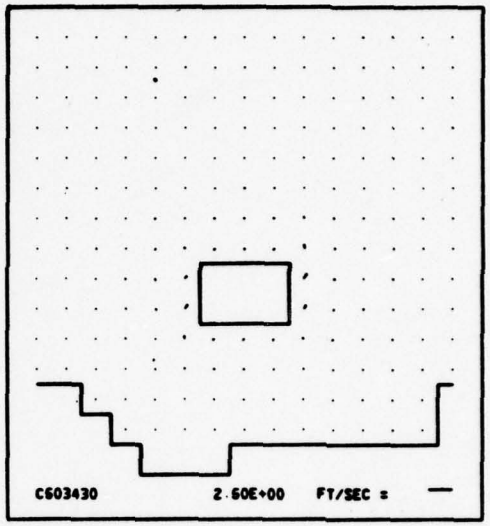

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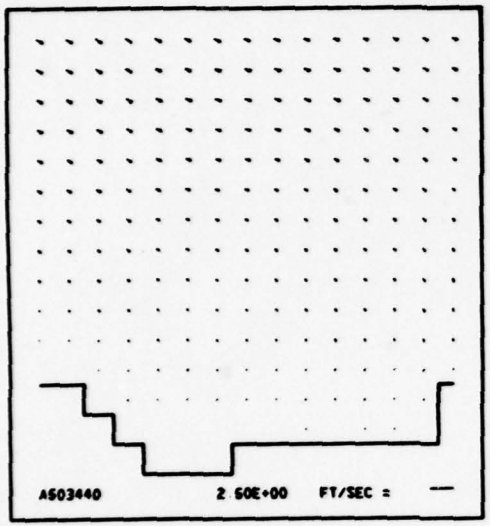

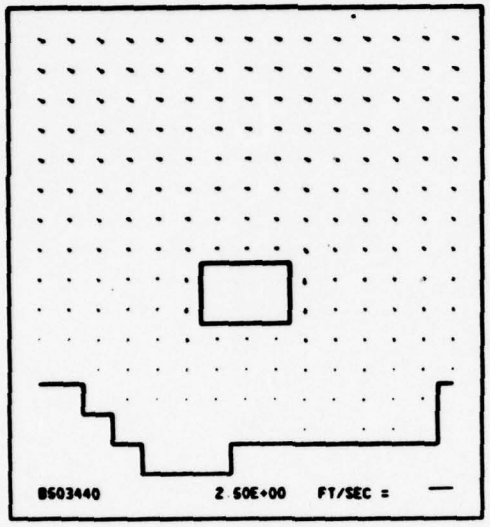

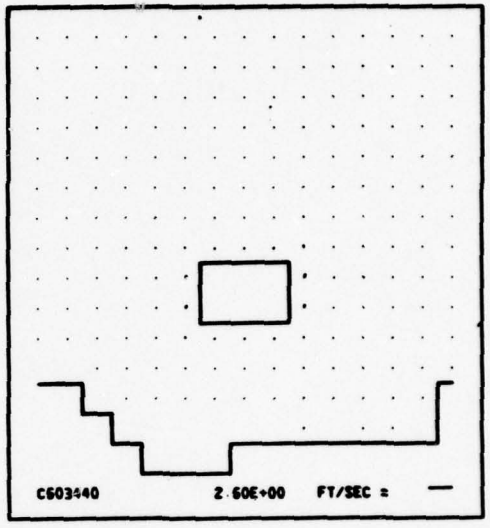

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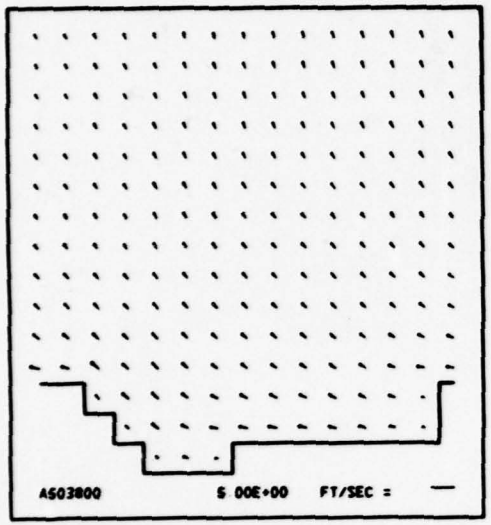

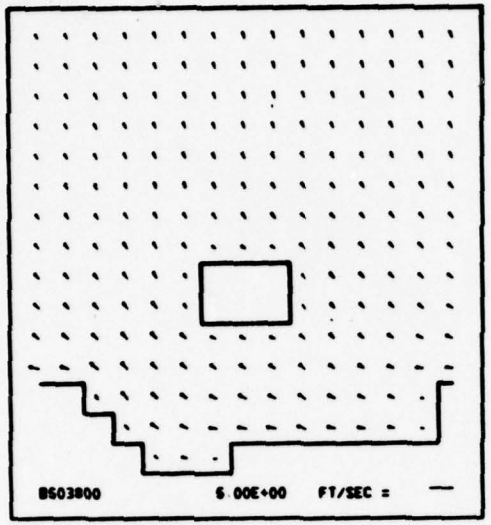

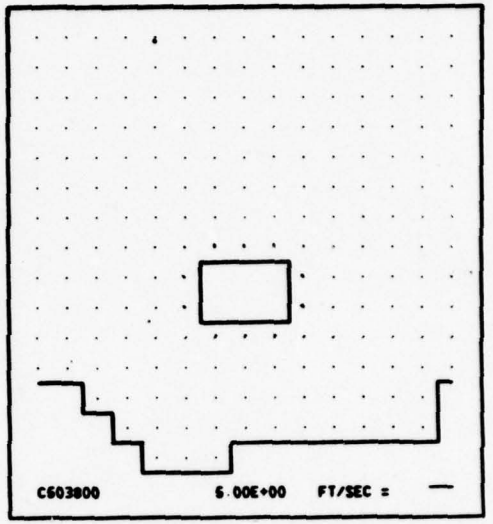

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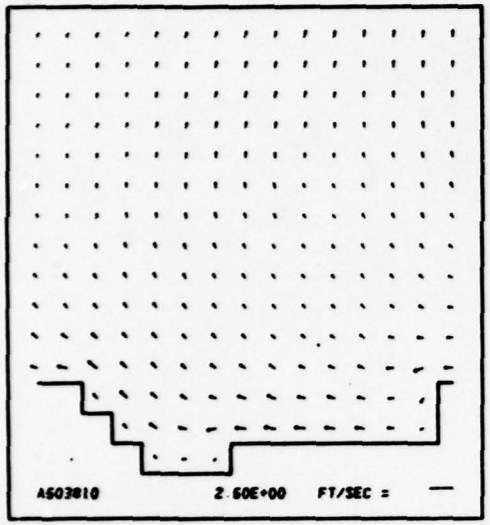

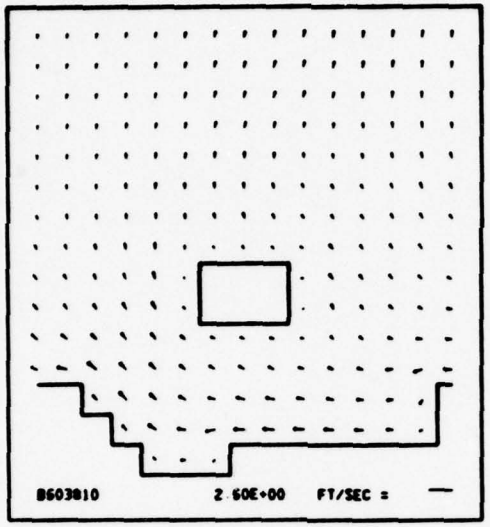

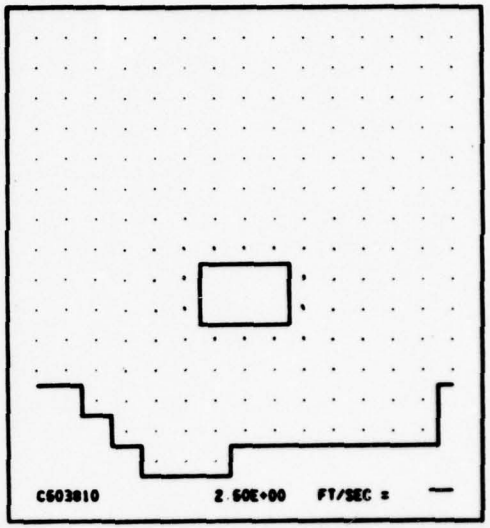

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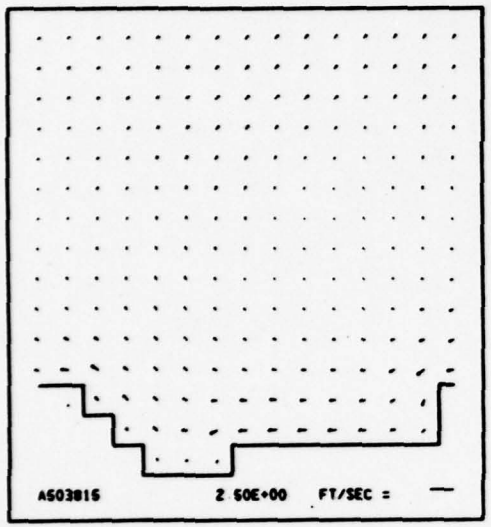

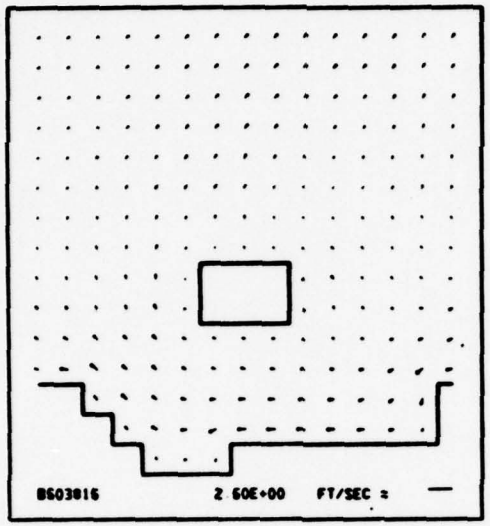

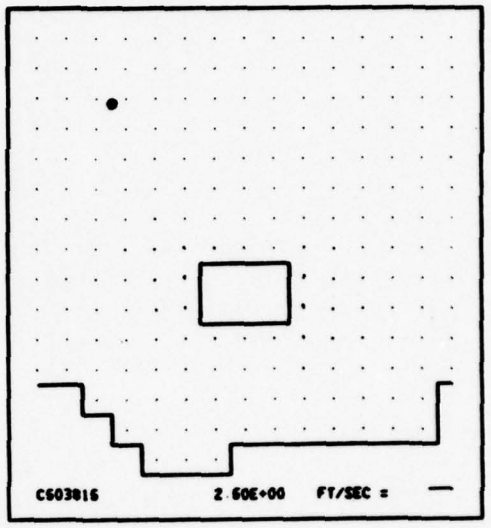

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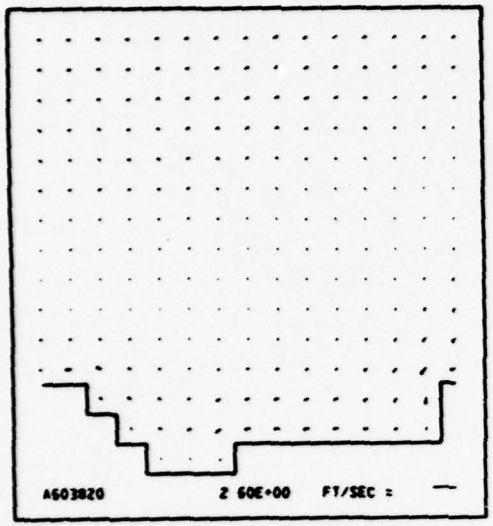

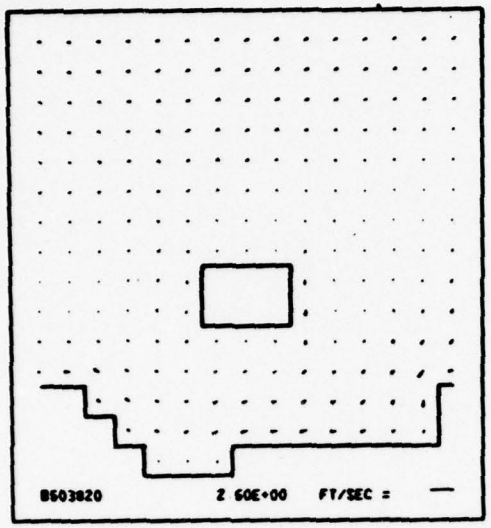

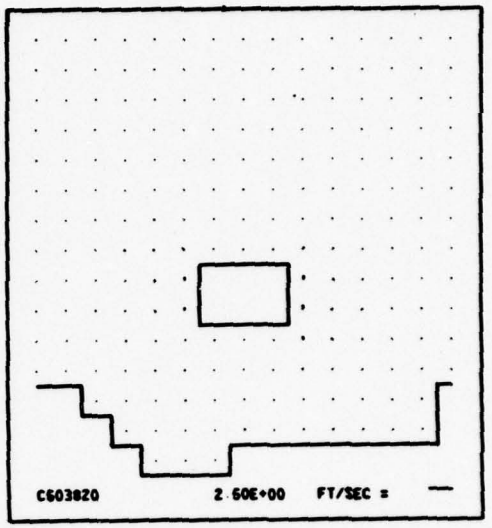

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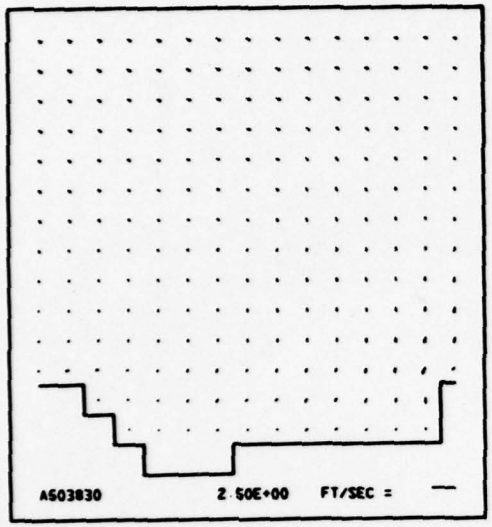

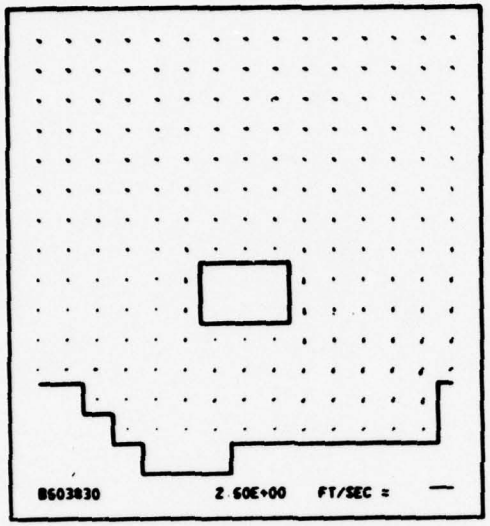

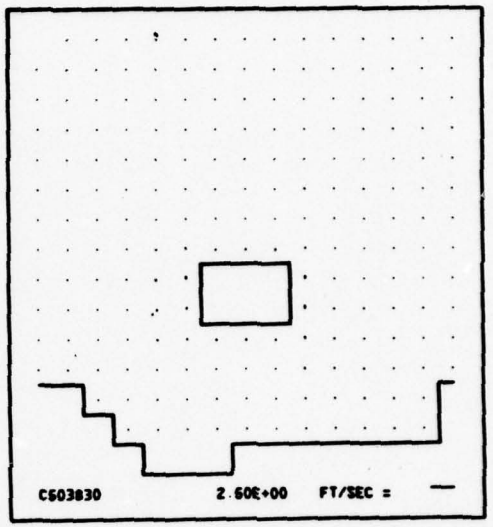

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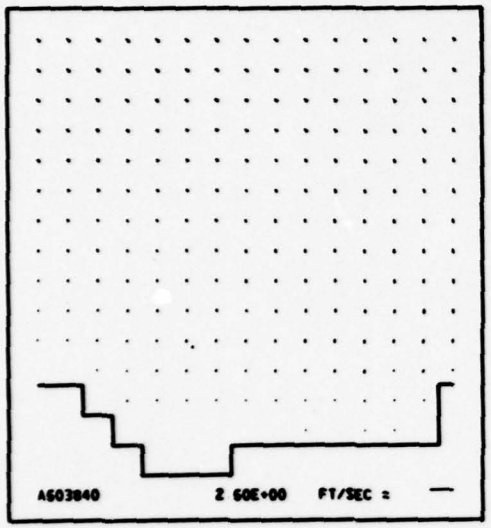

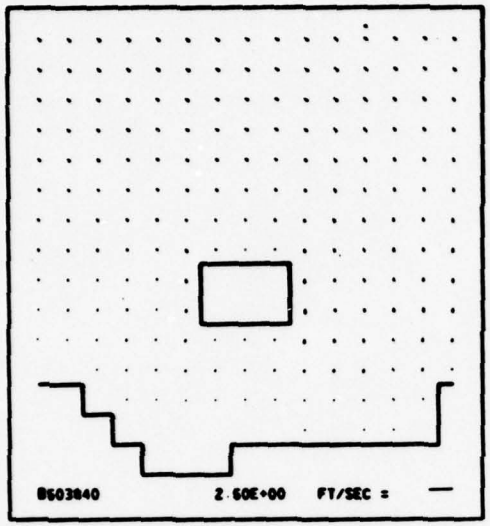

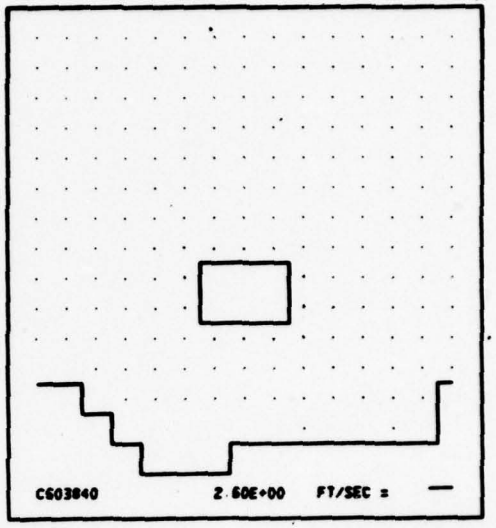

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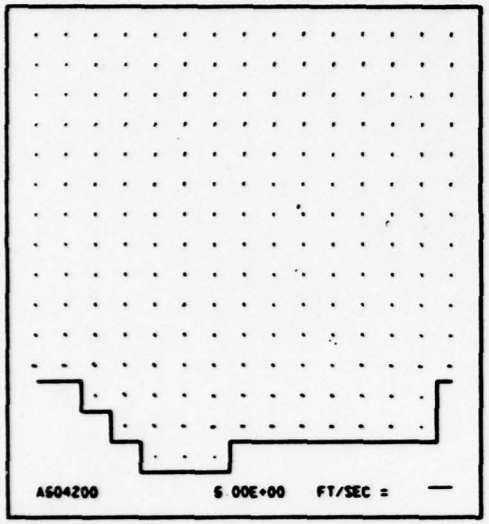

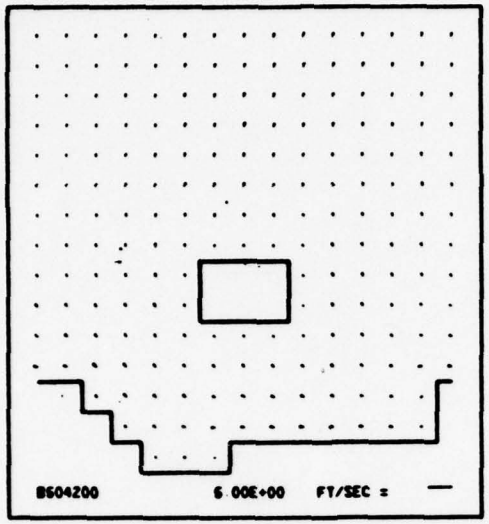

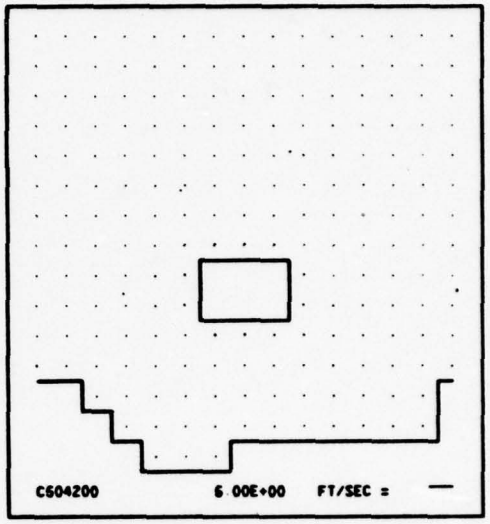

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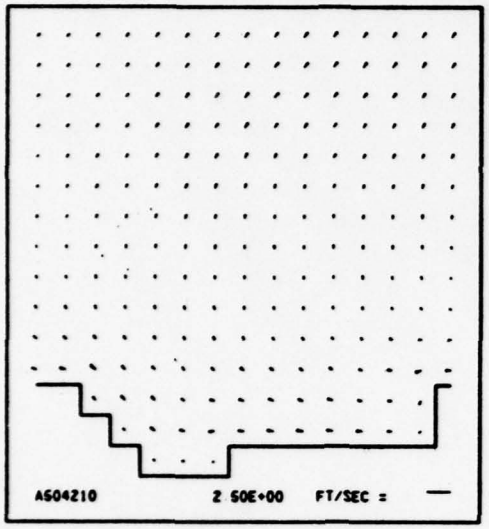

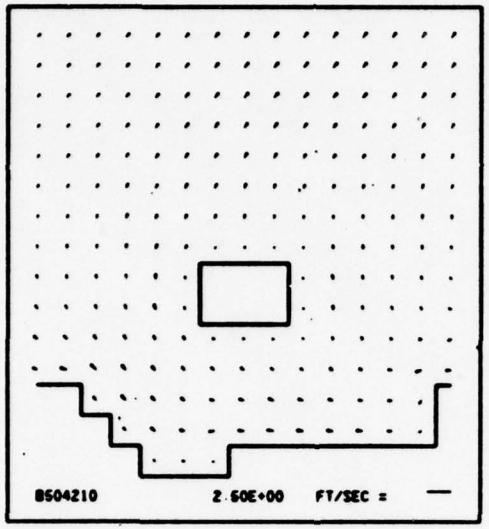

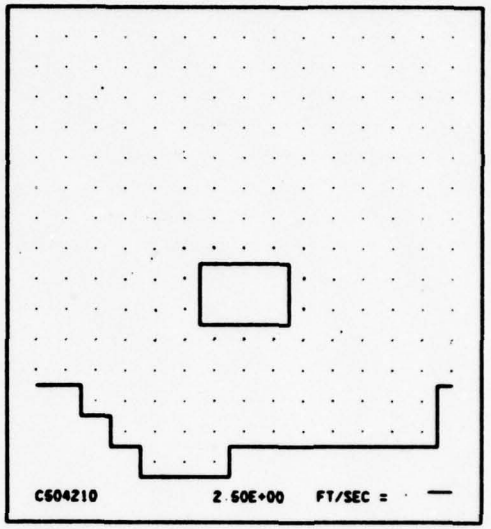

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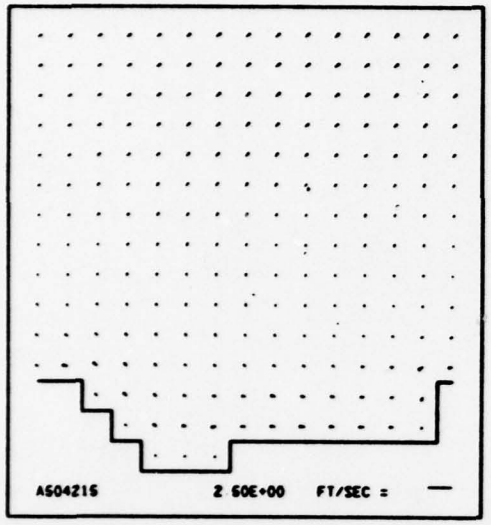

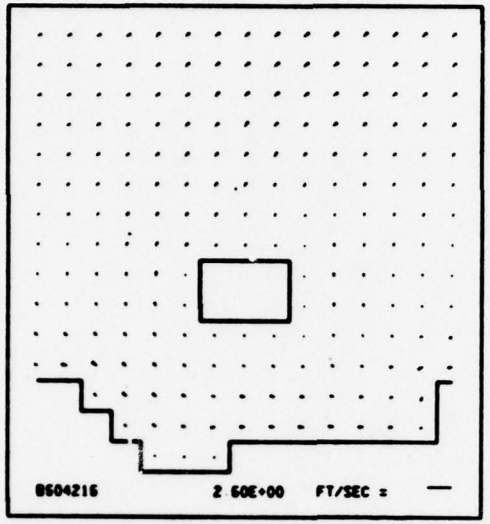

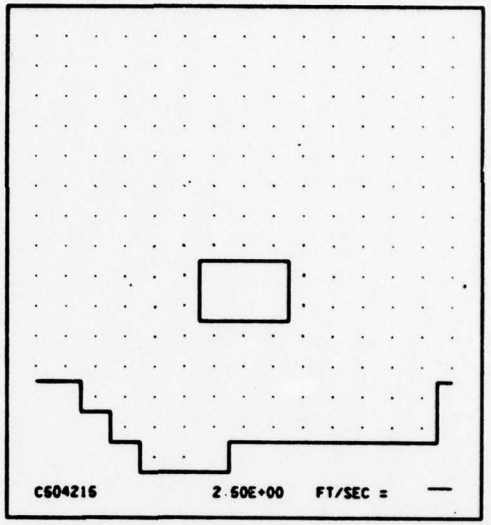

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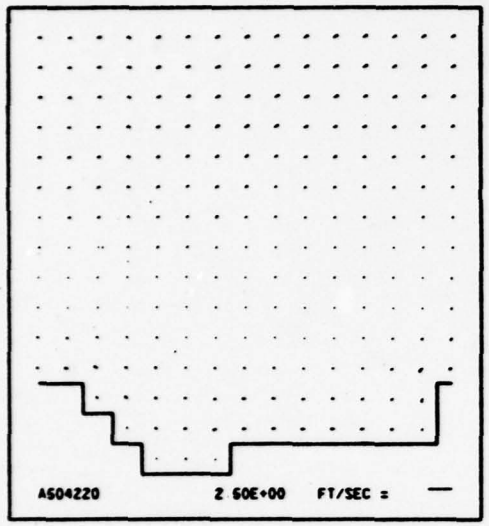

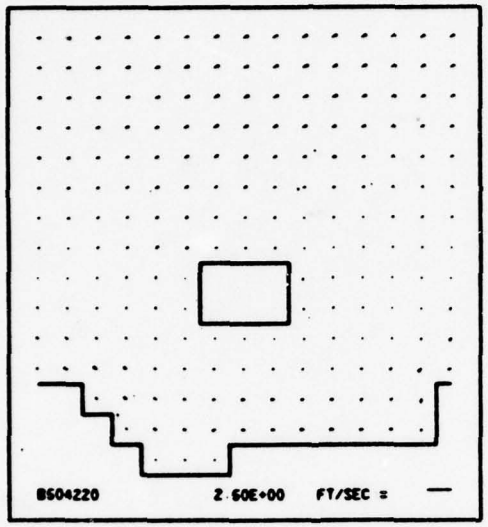

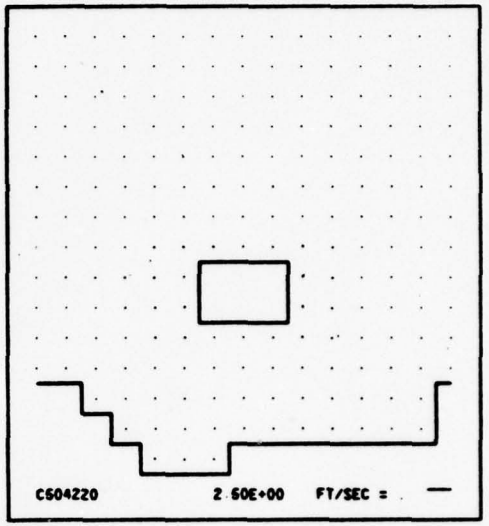

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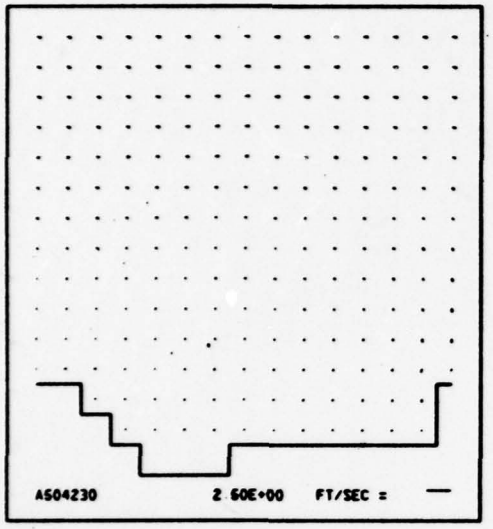

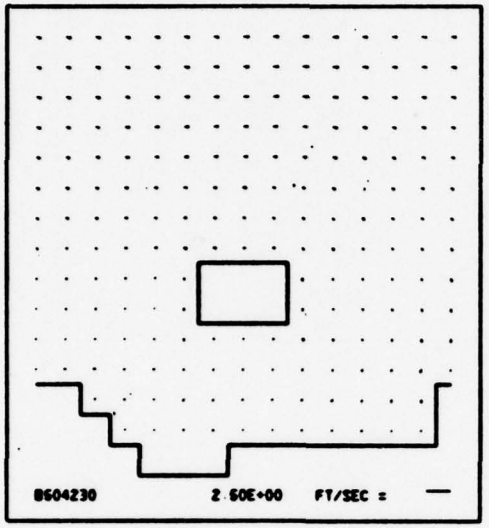

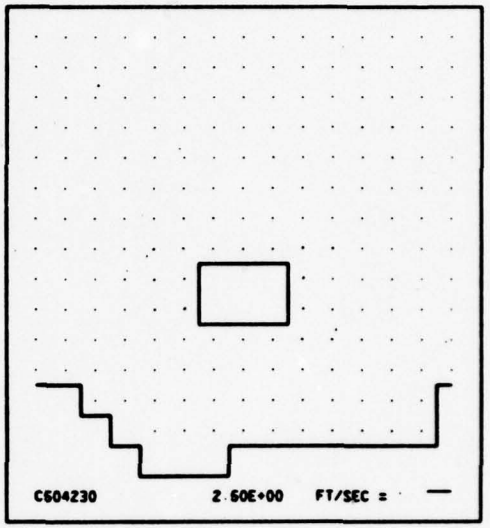

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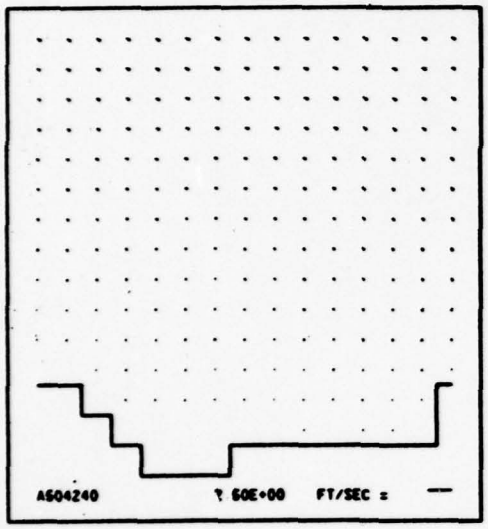

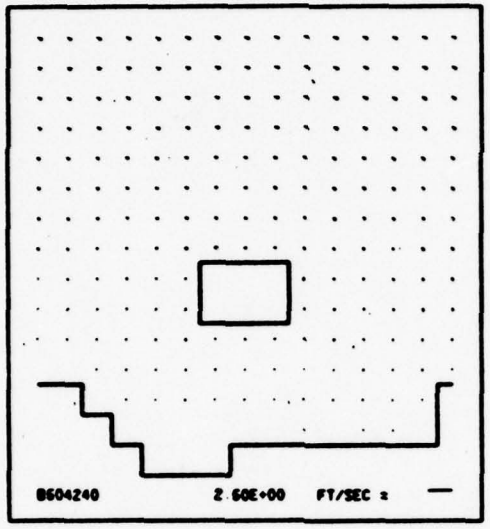

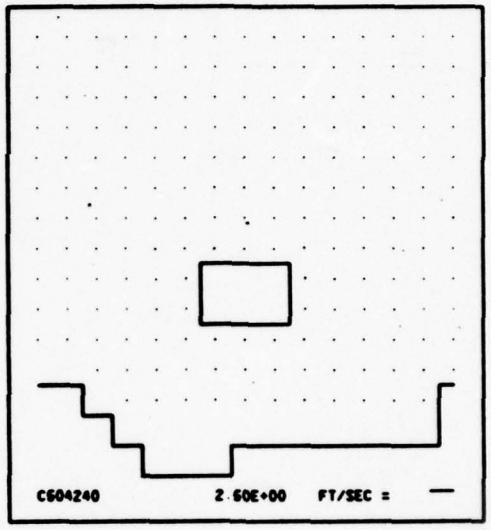

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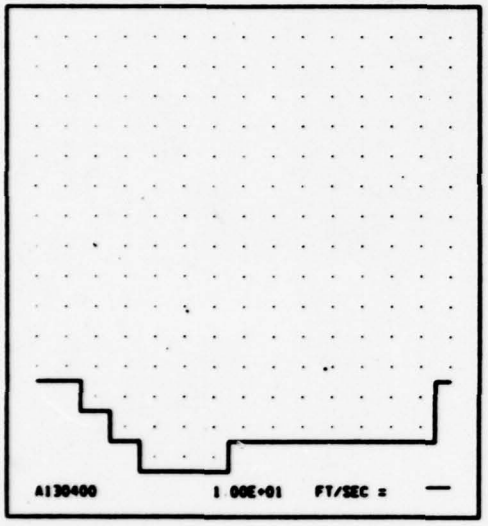
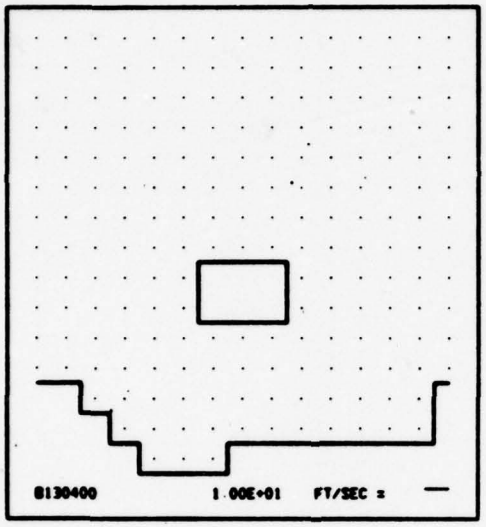
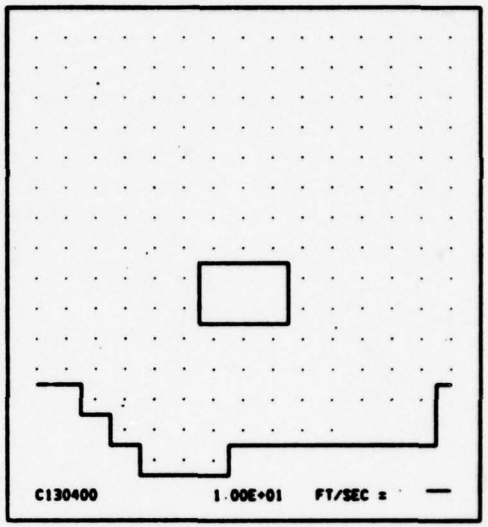
Inclosure 3: 7-10 November 1913 Storm







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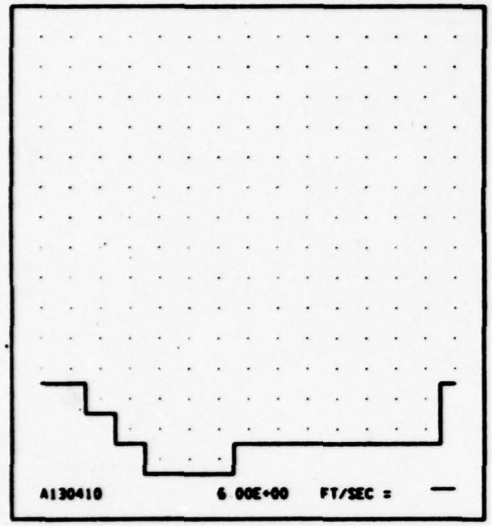

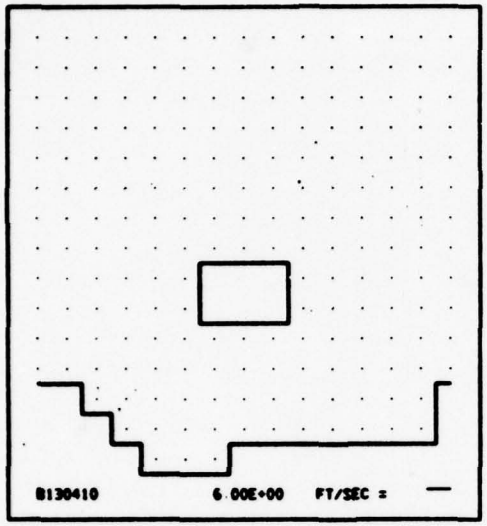

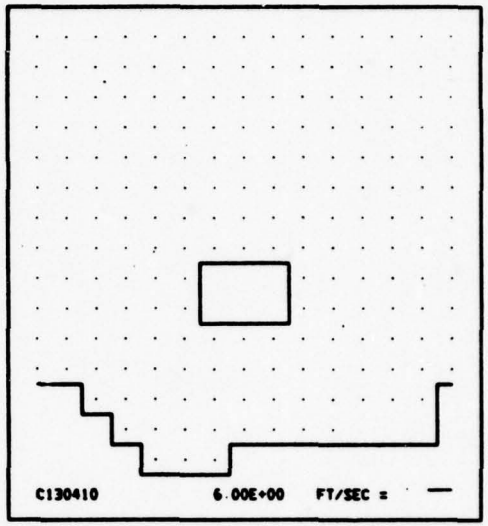

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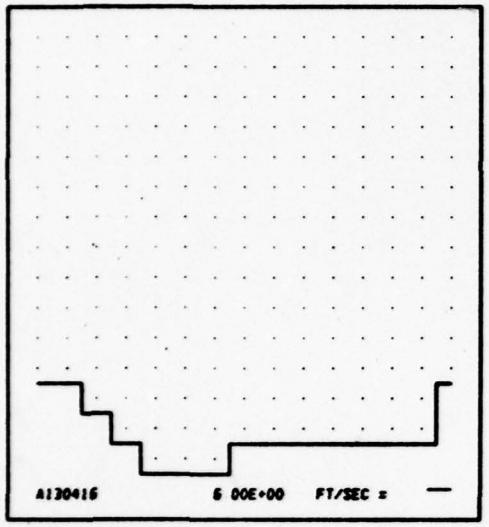

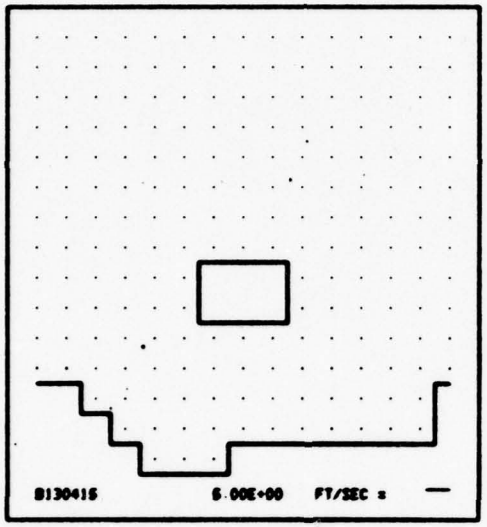

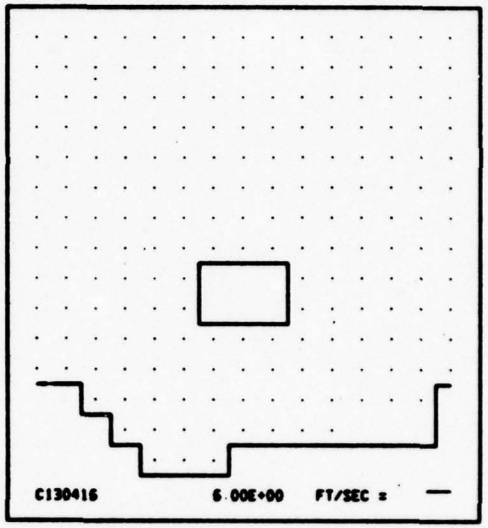

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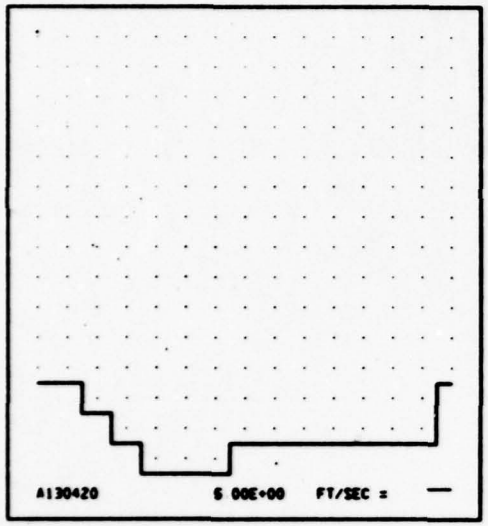

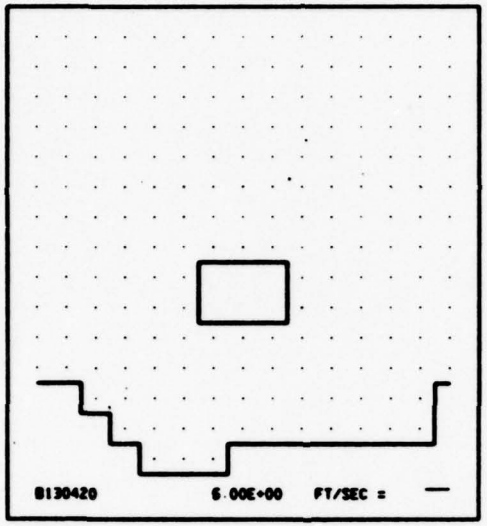

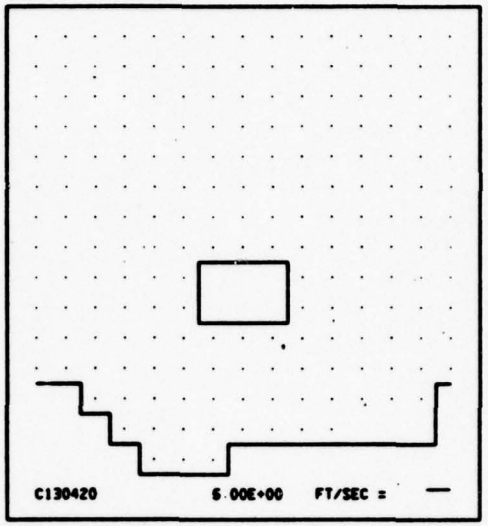

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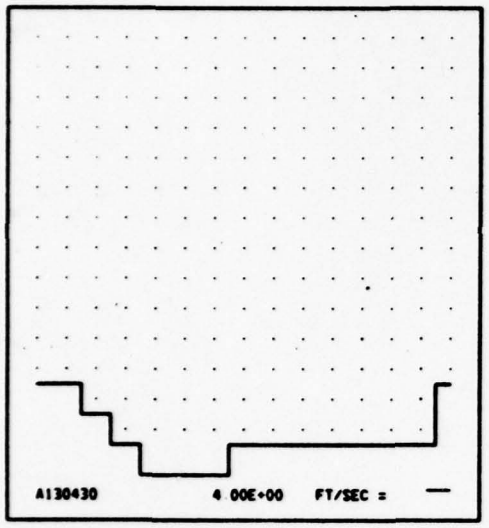

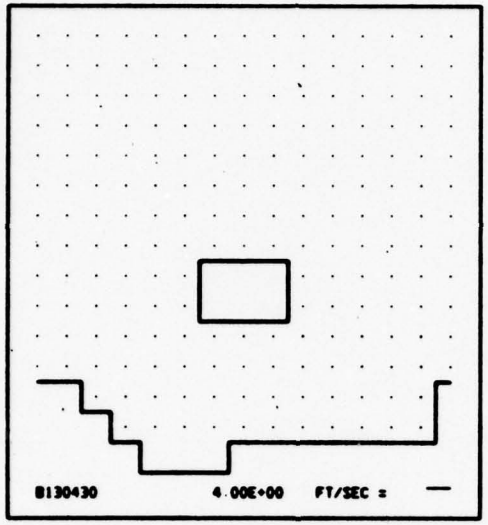

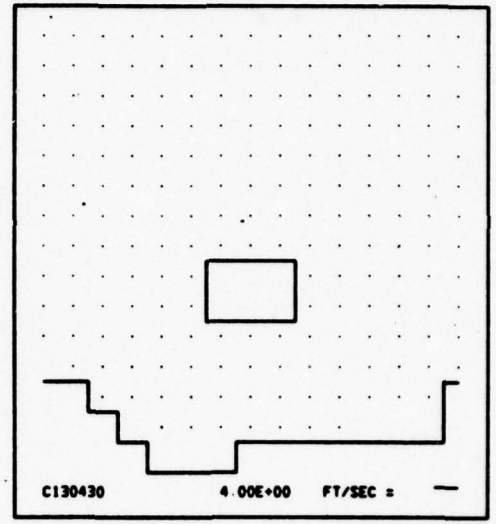

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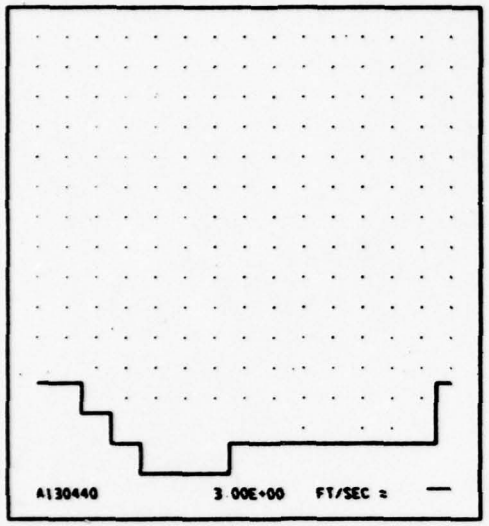

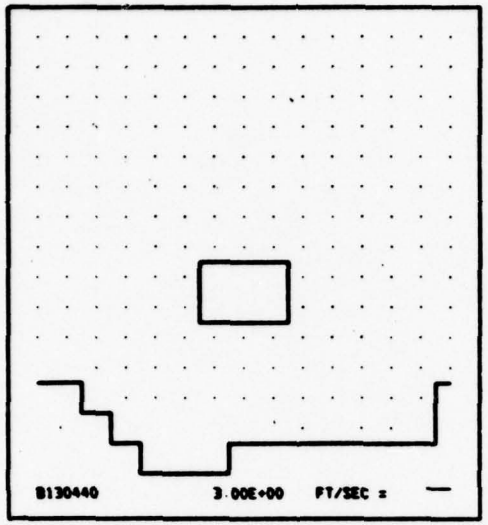

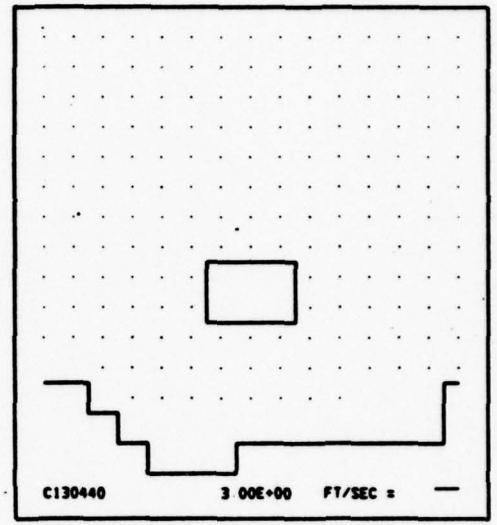

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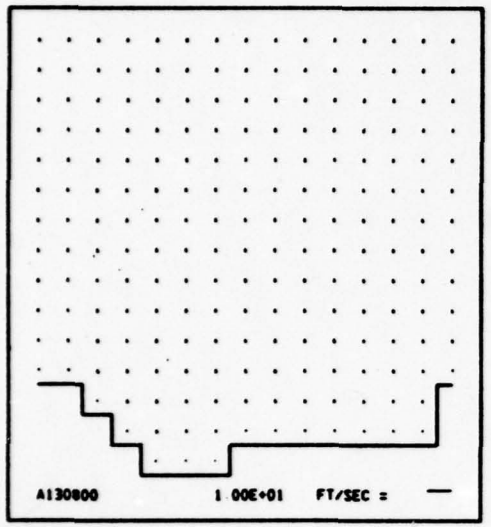

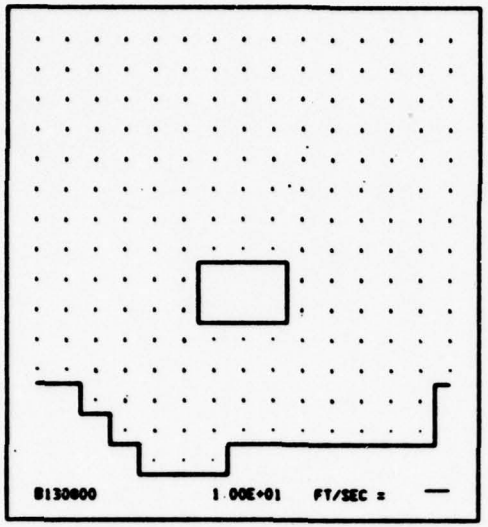

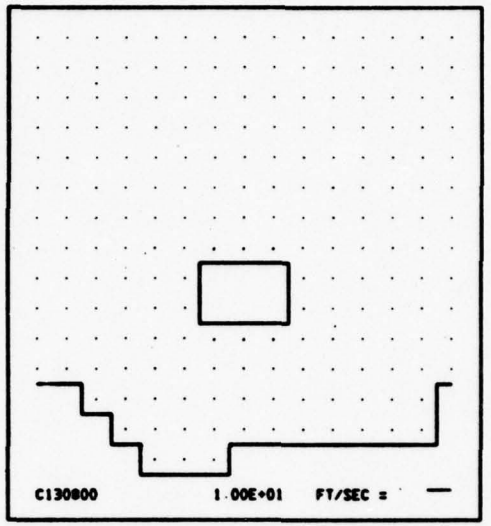

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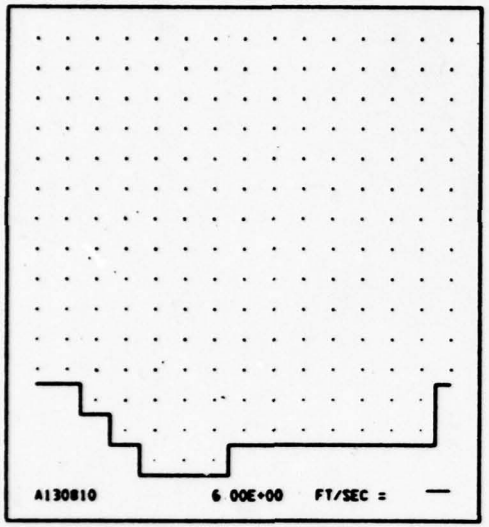

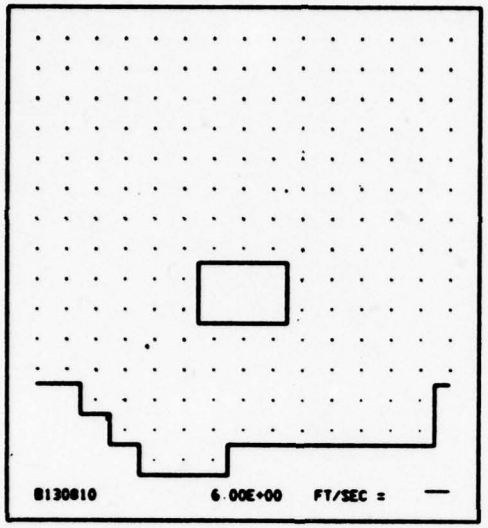

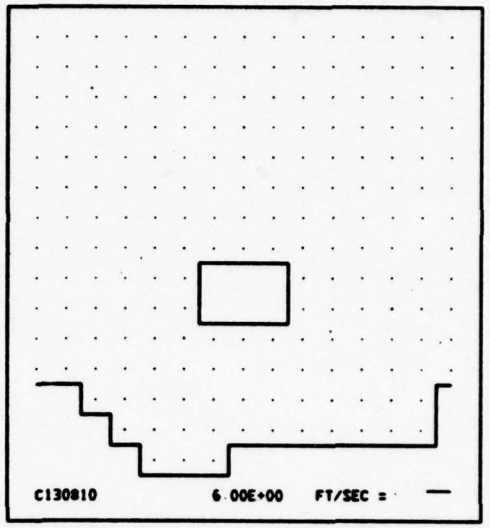

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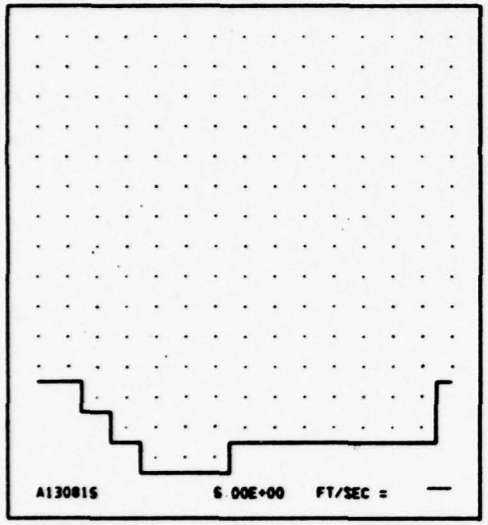

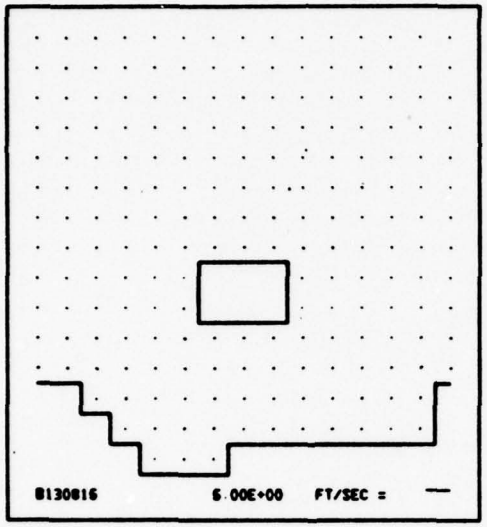

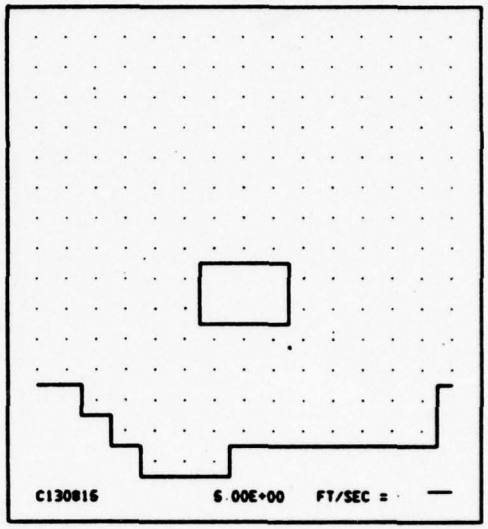

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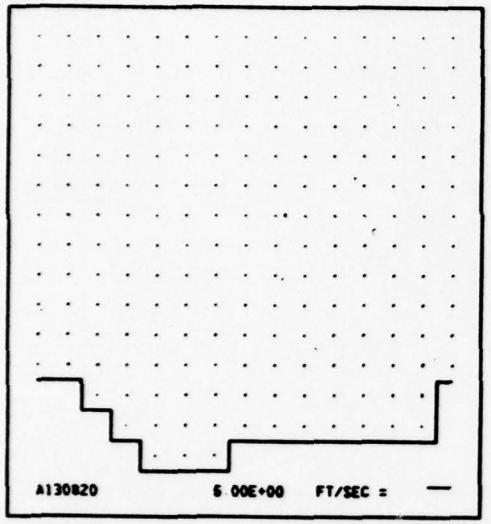

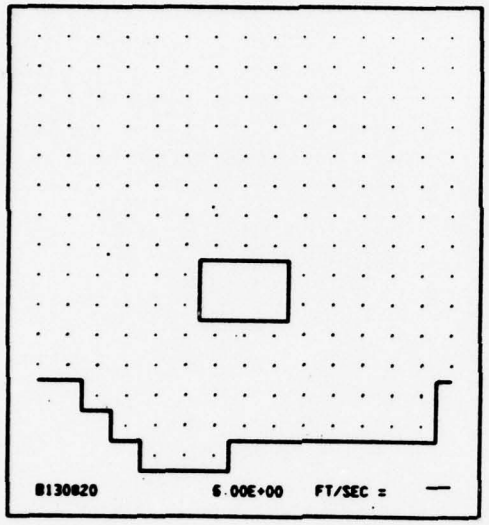

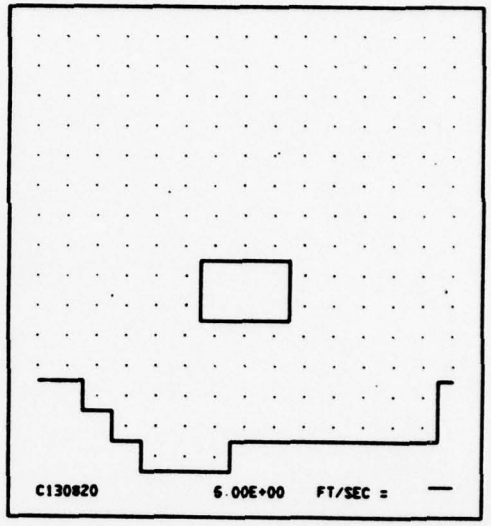

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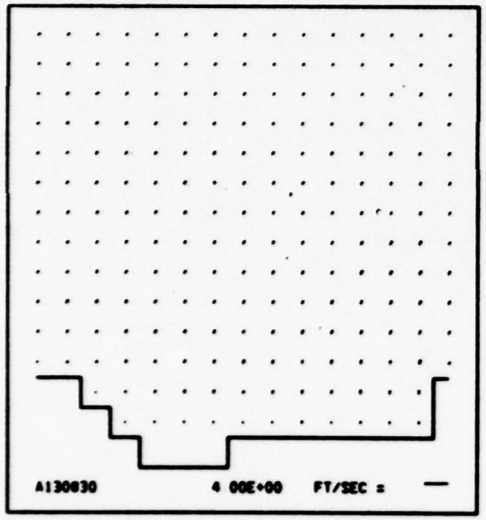

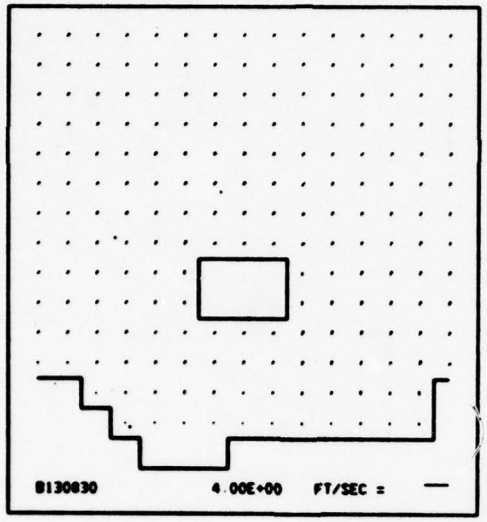

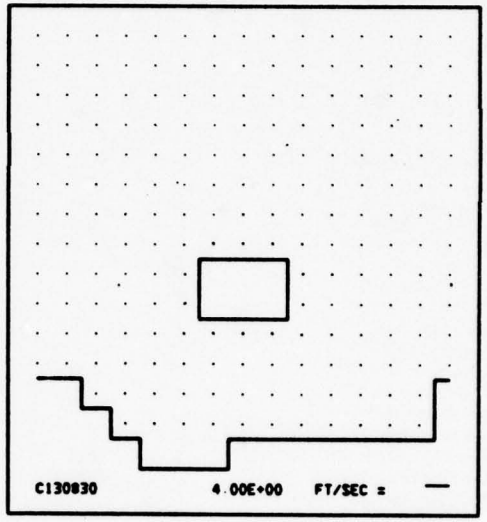

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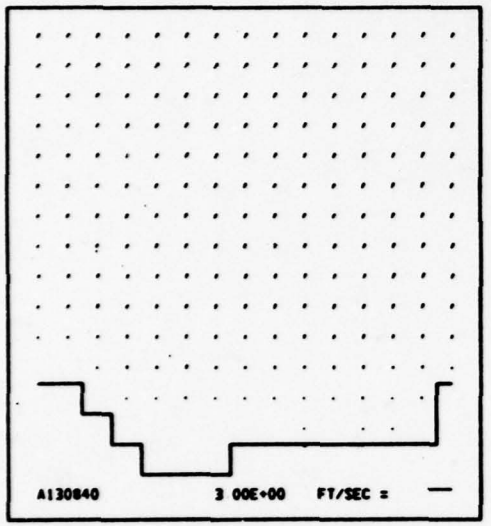

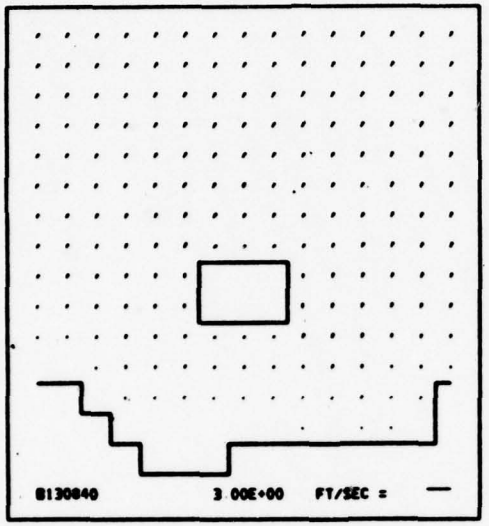

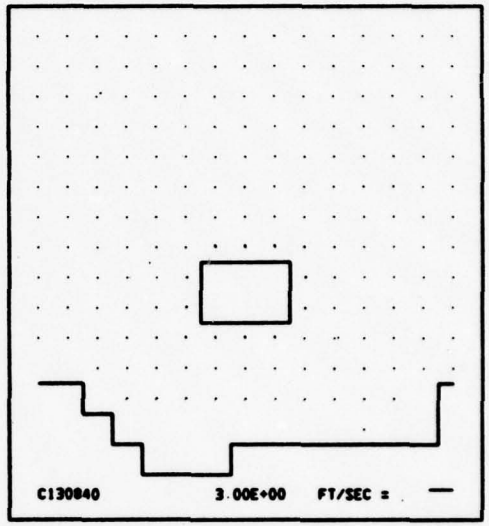

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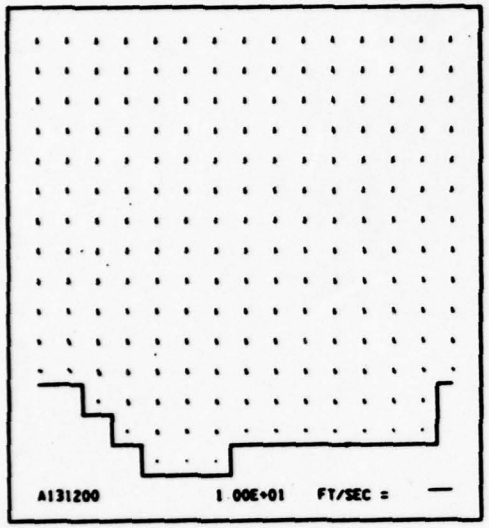

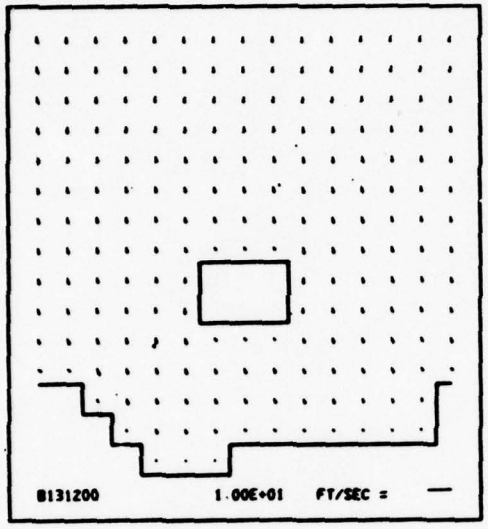

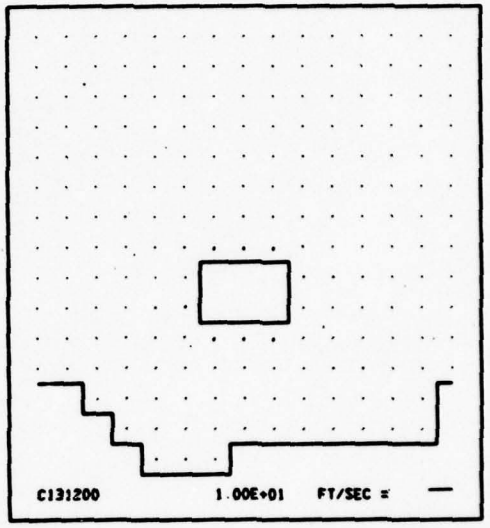

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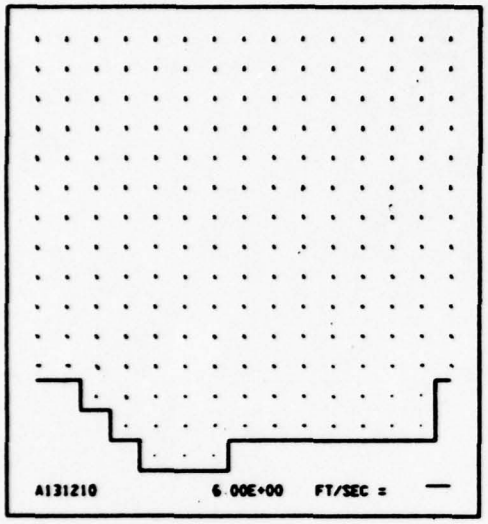

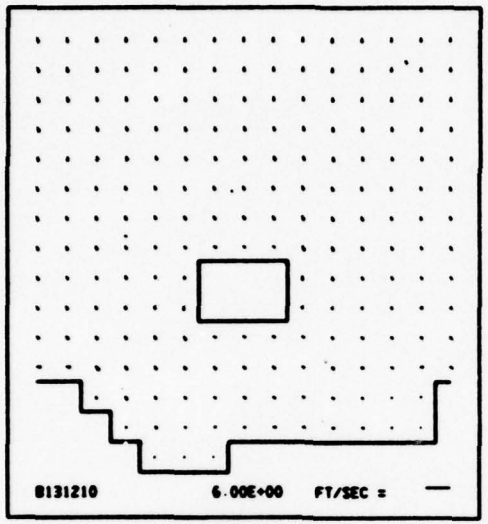

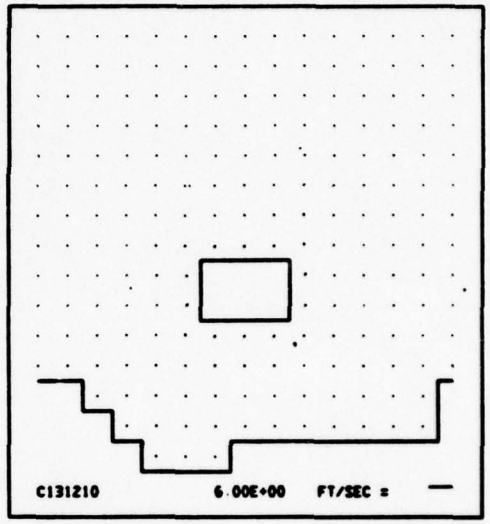

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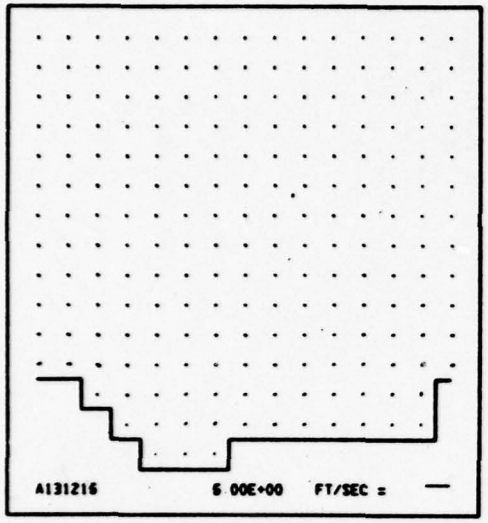

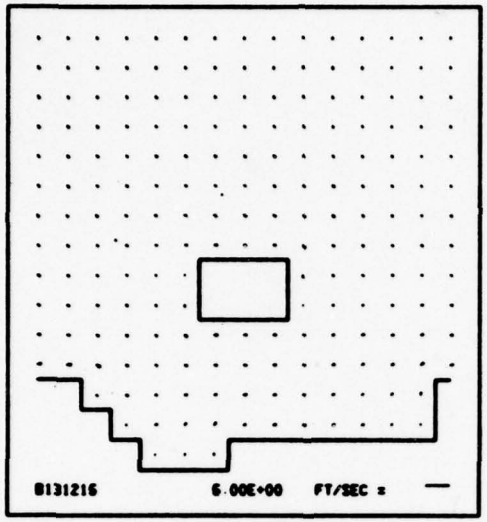

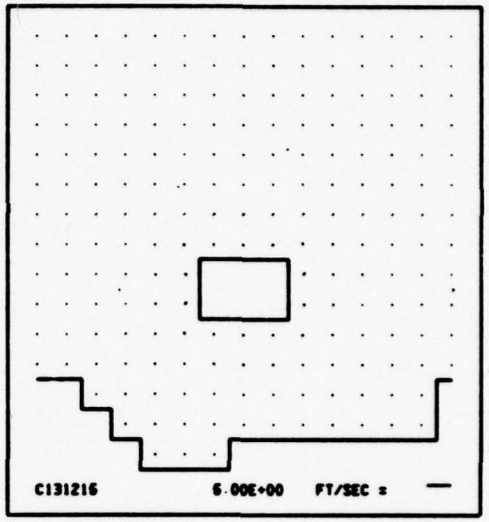

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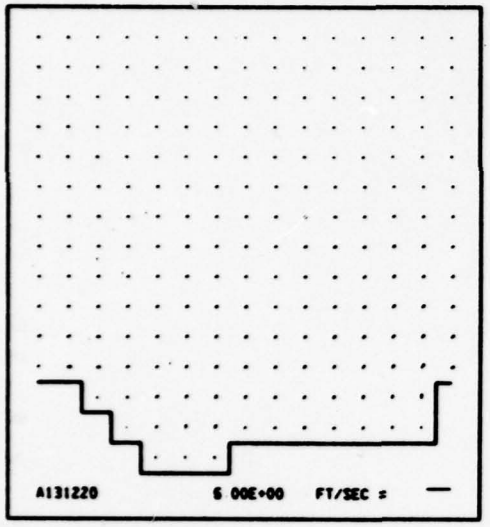

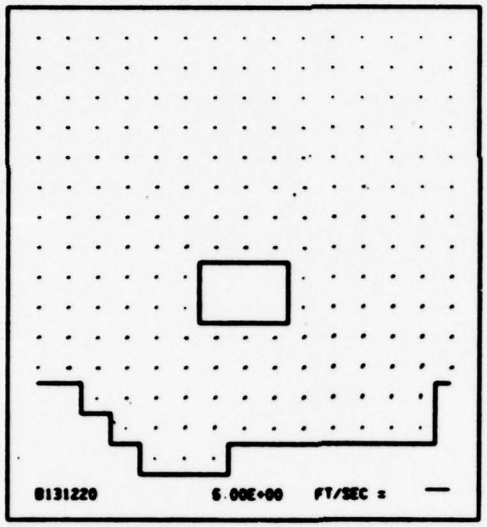

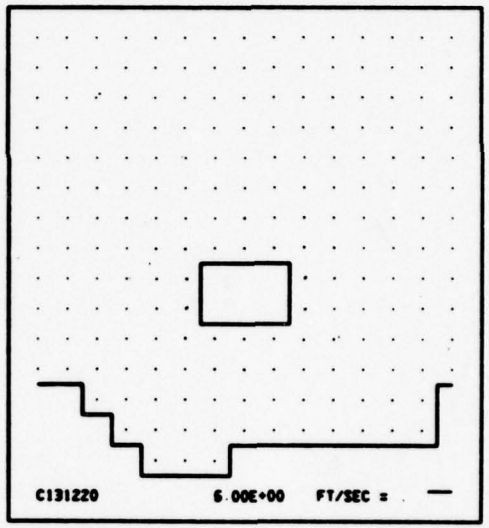

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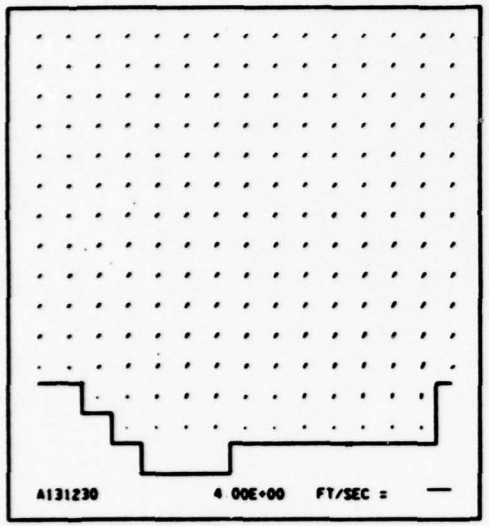

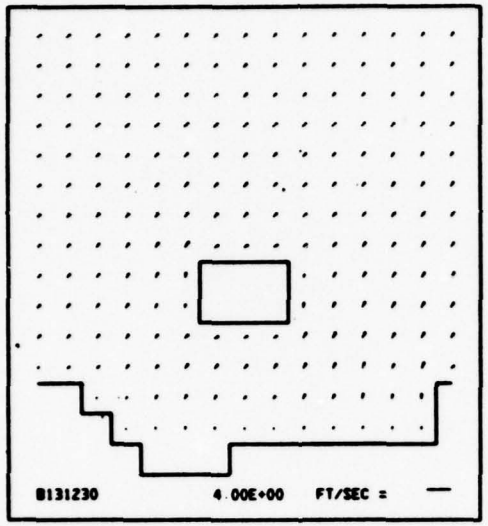

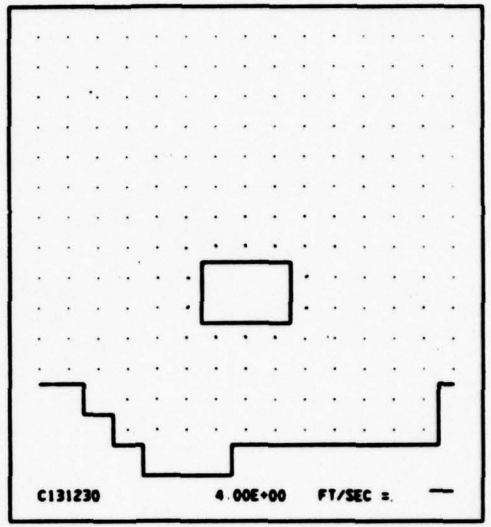

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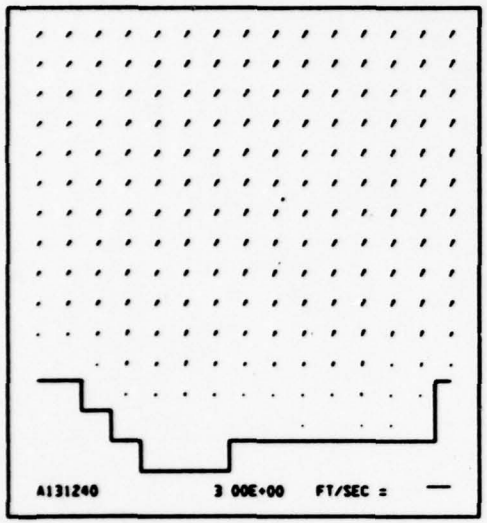

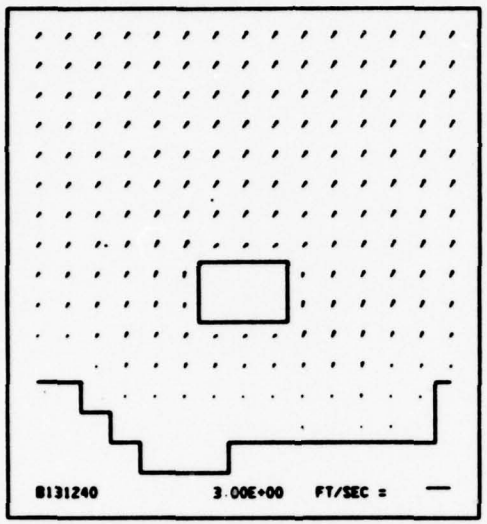

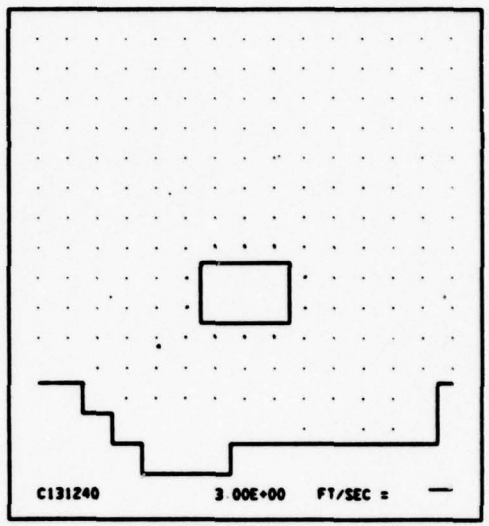

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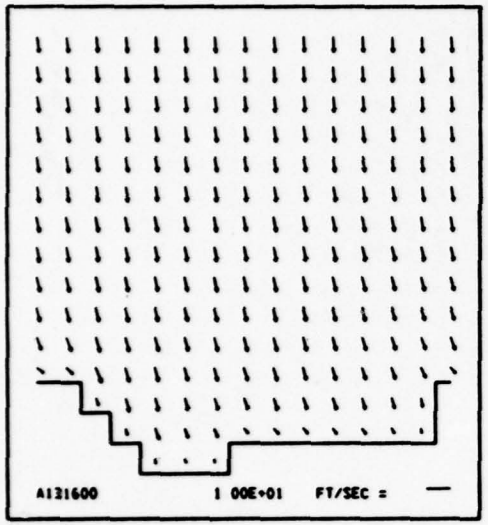

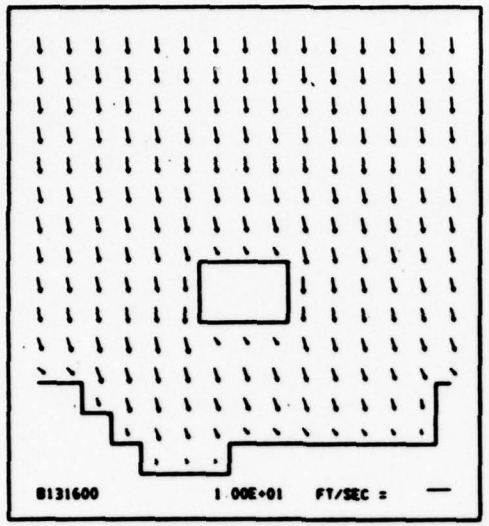

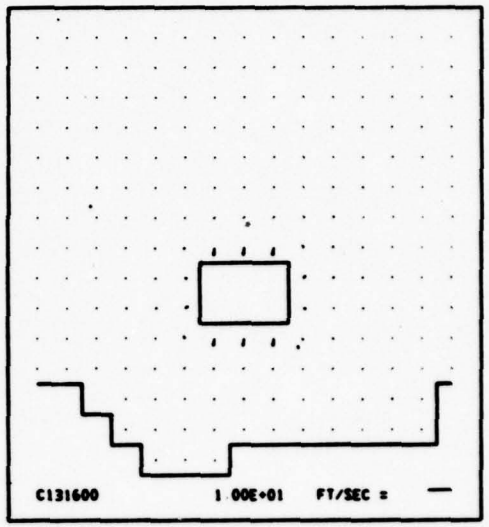

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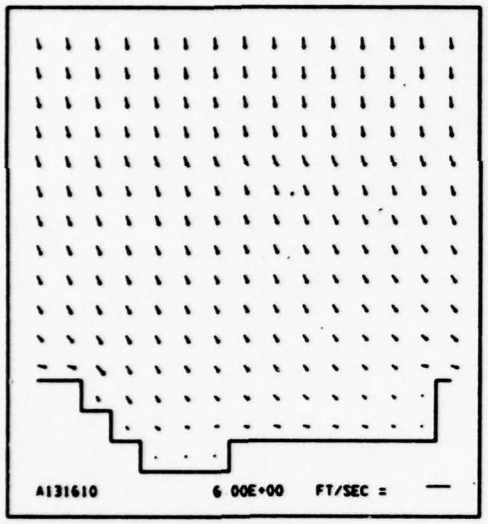

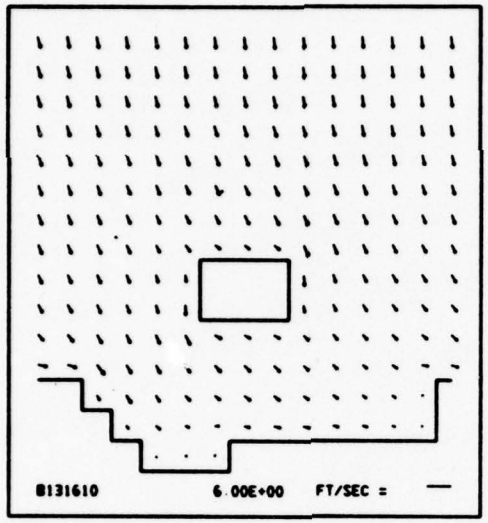

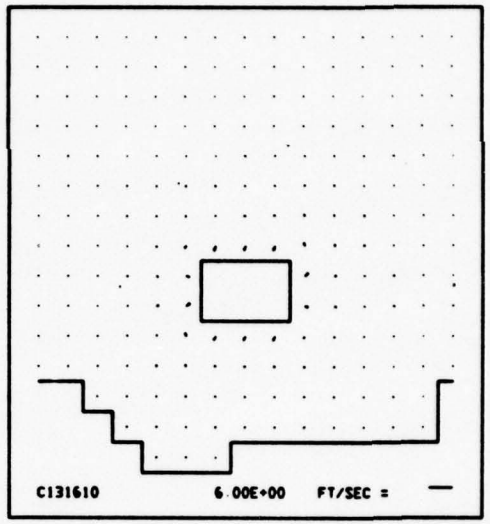

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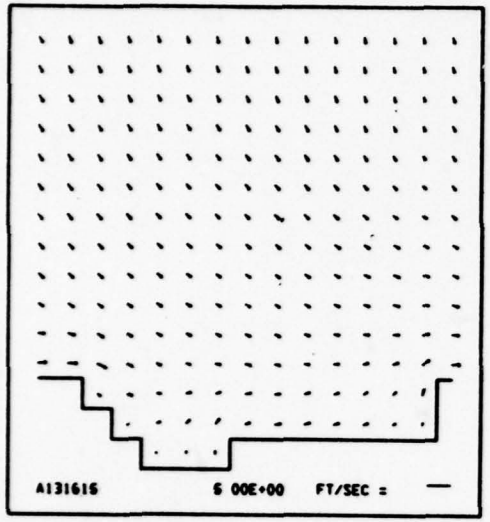

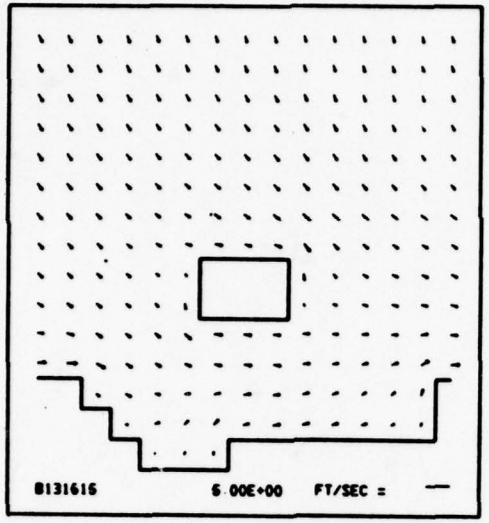

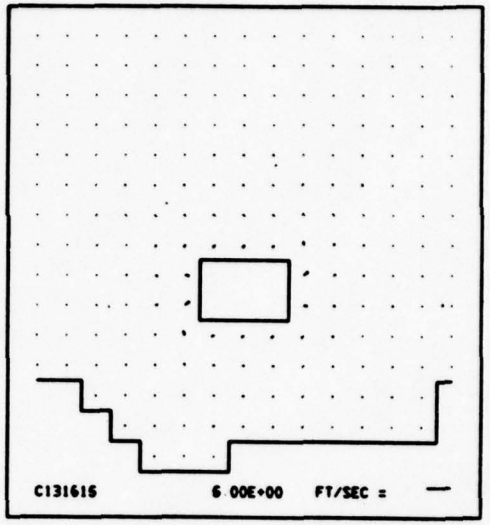

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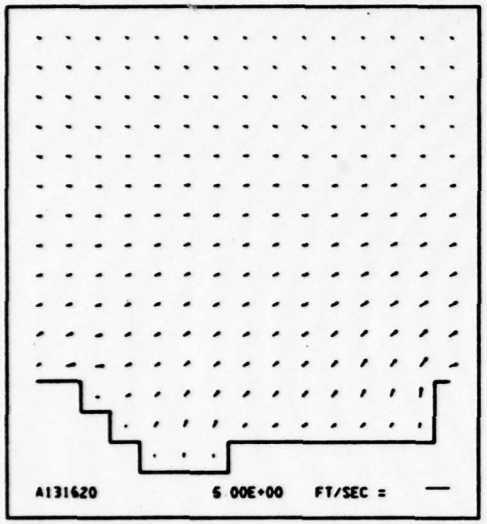

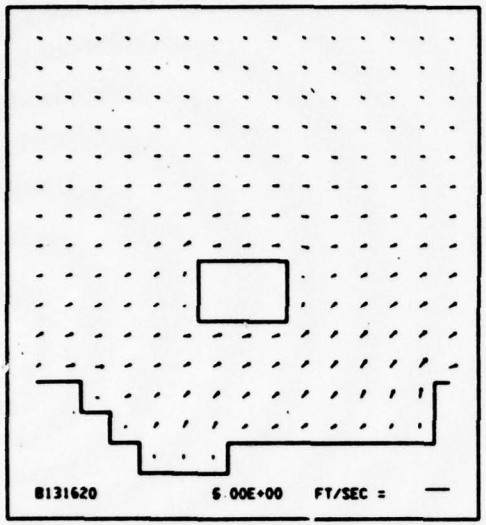

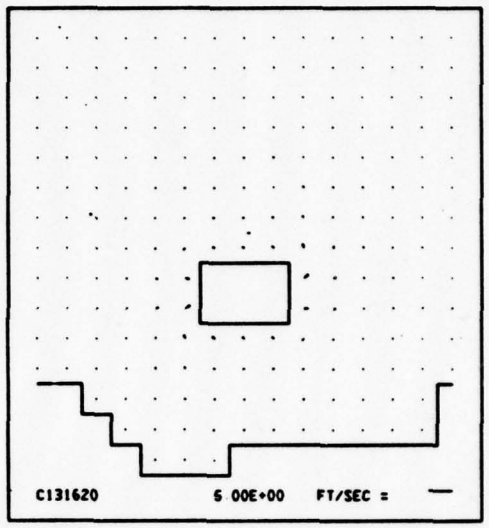

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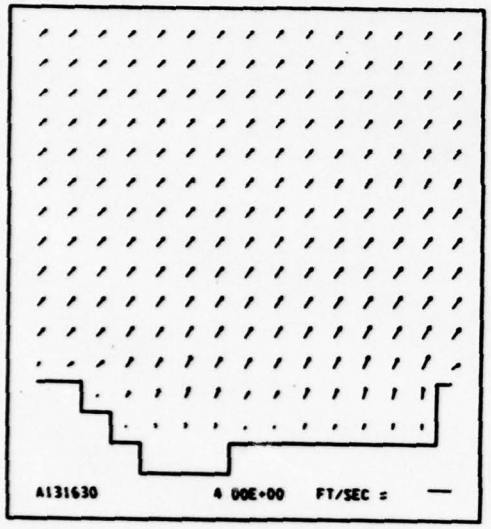

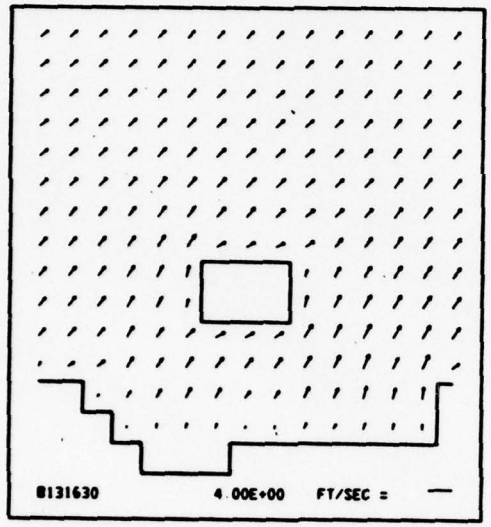

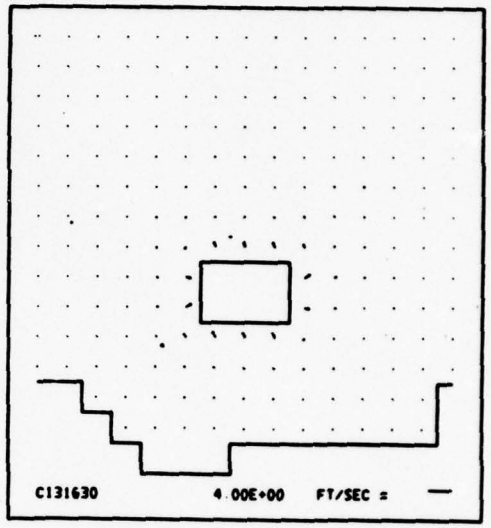

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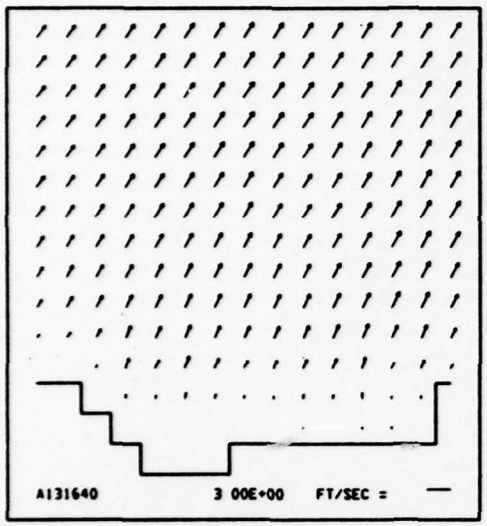

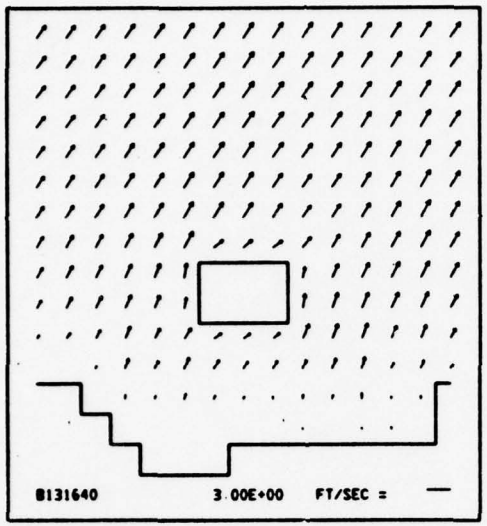

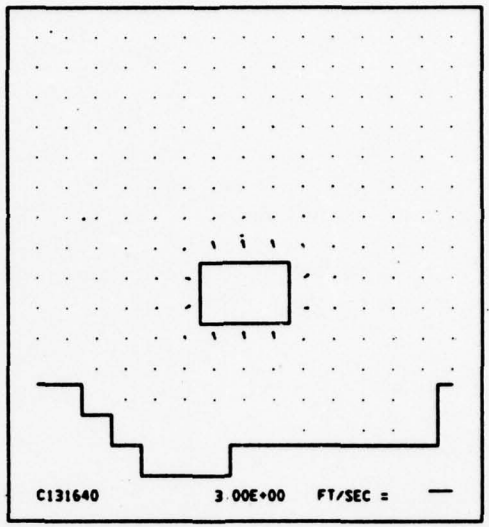

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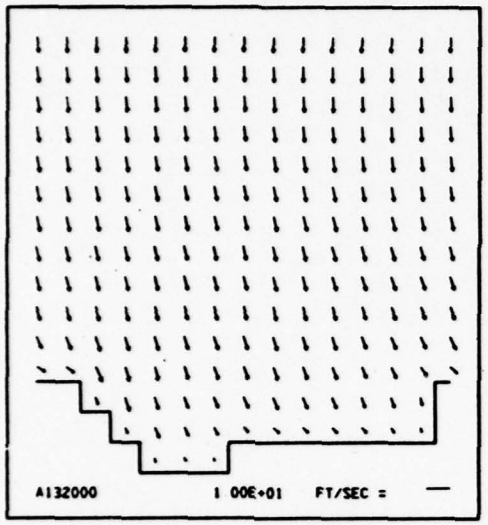

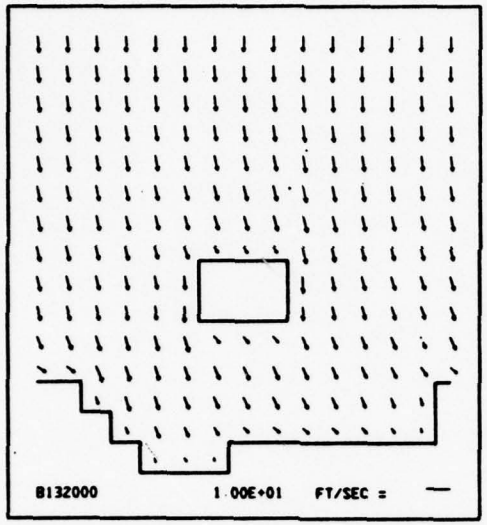

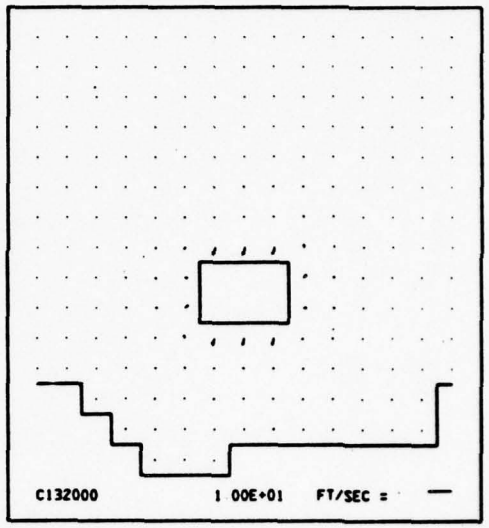

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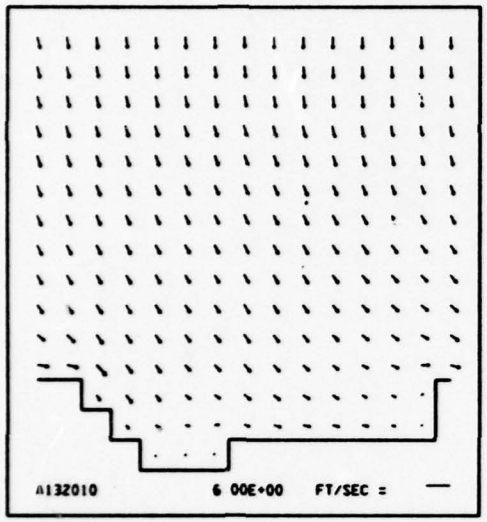

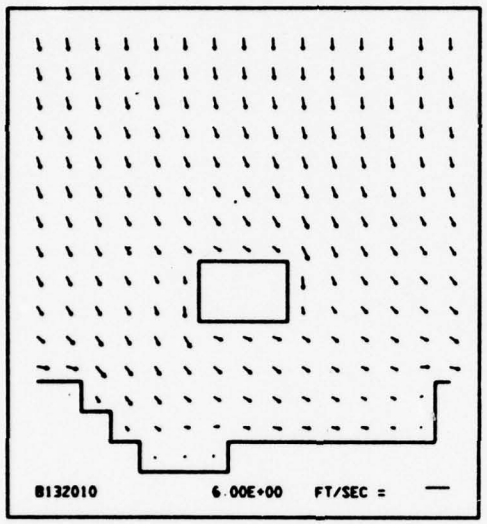

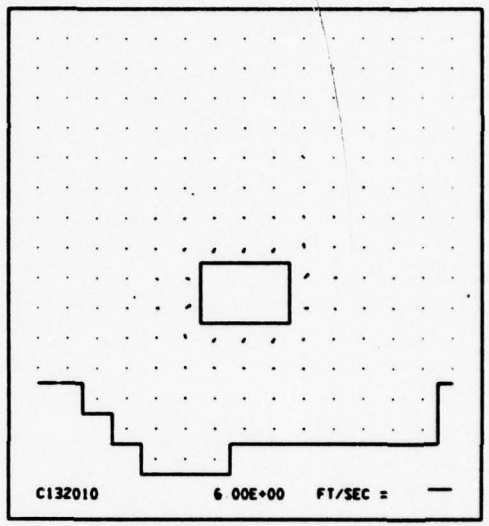

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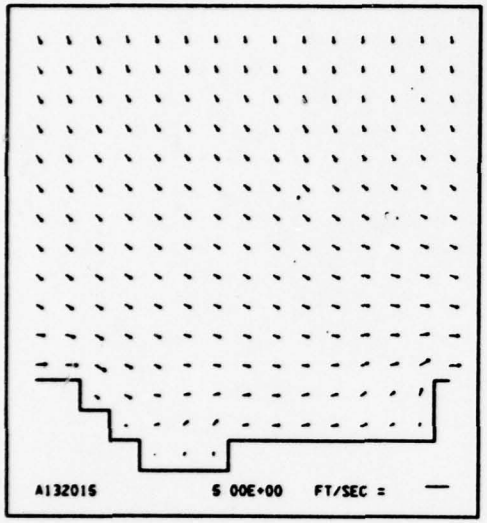

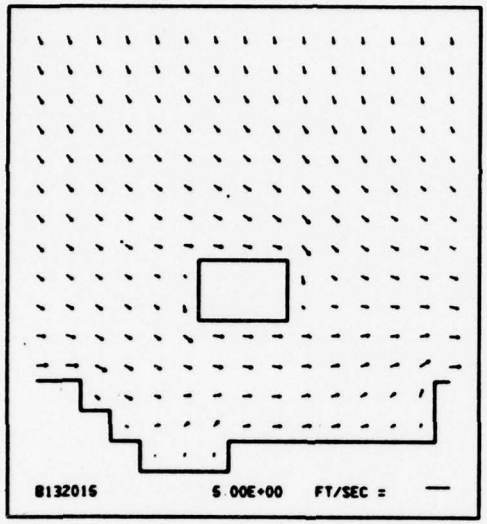

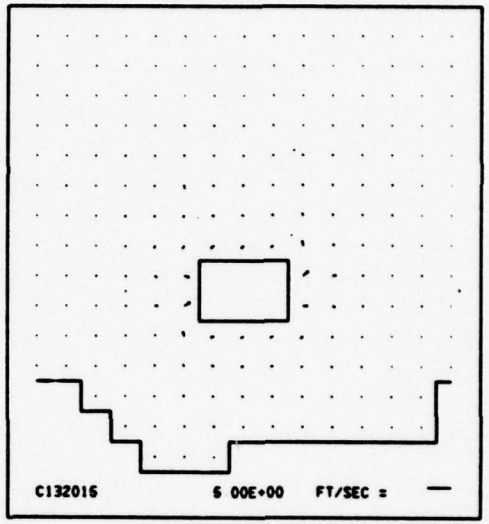

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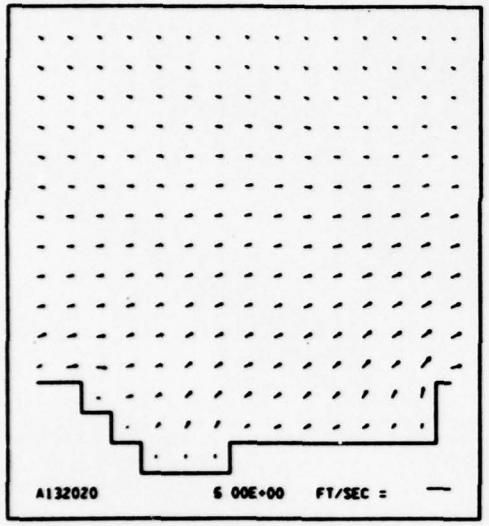

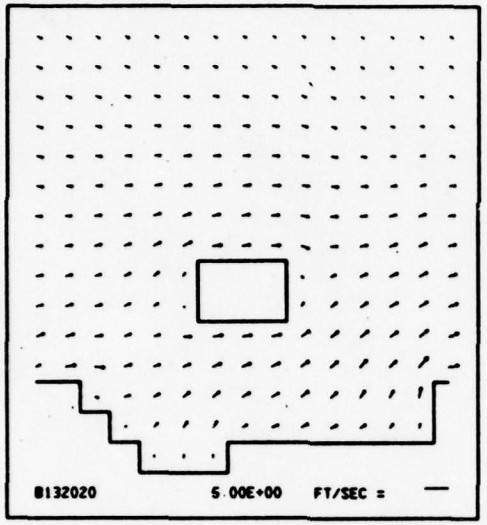

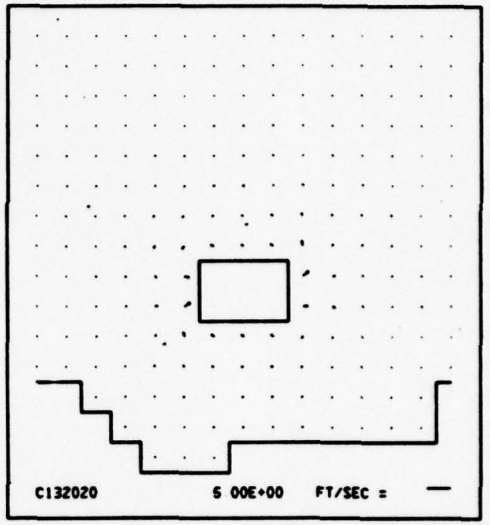

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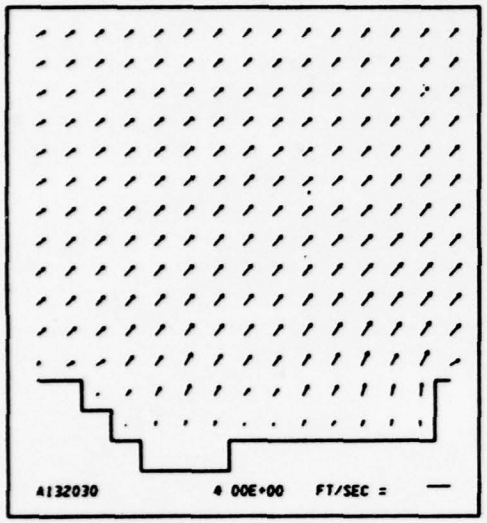

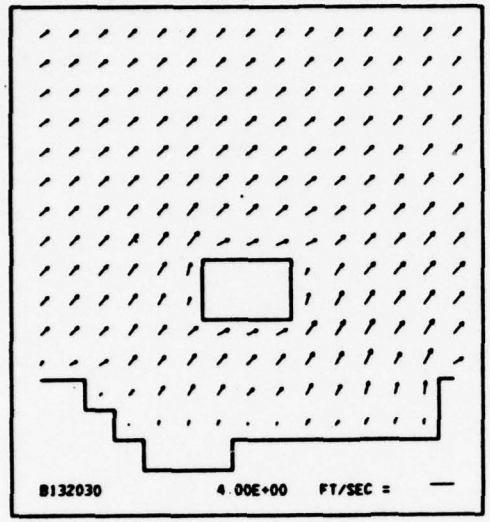

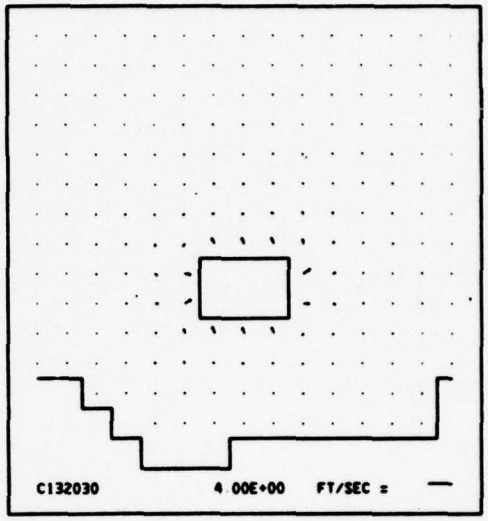

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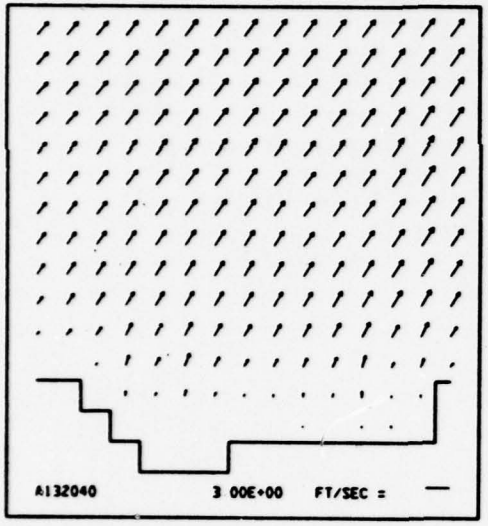

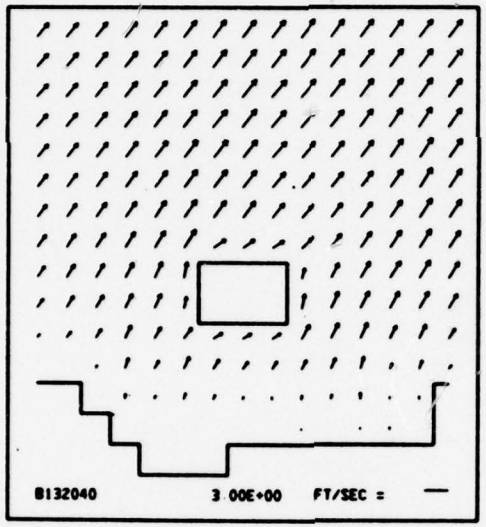

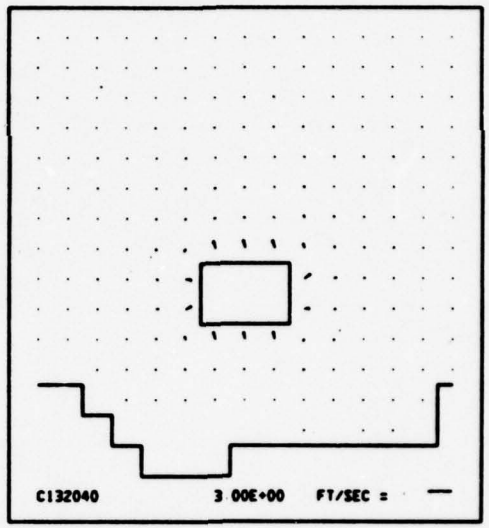

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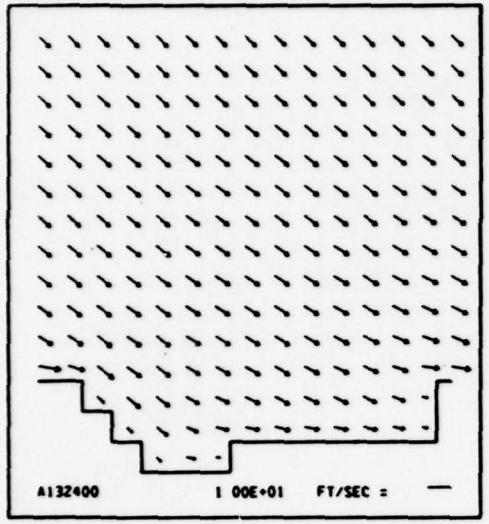

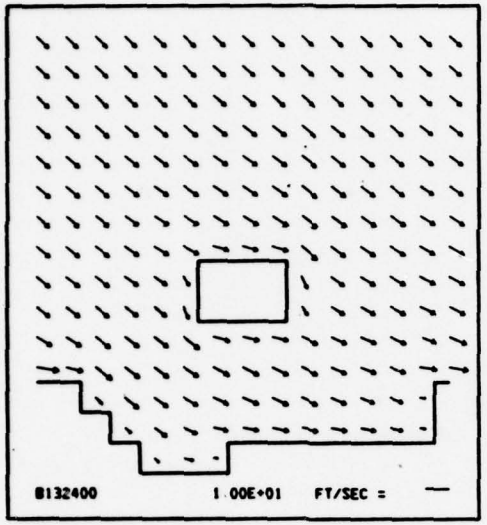

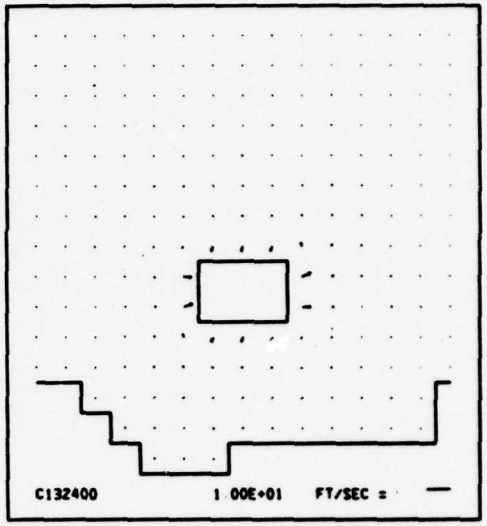

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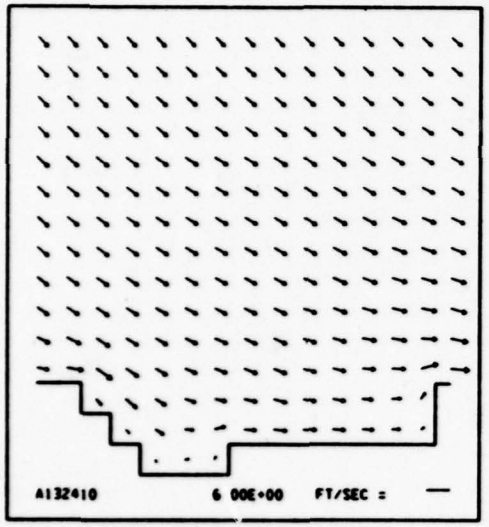

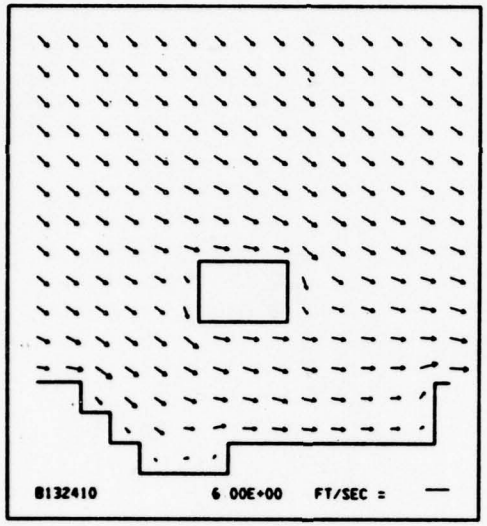

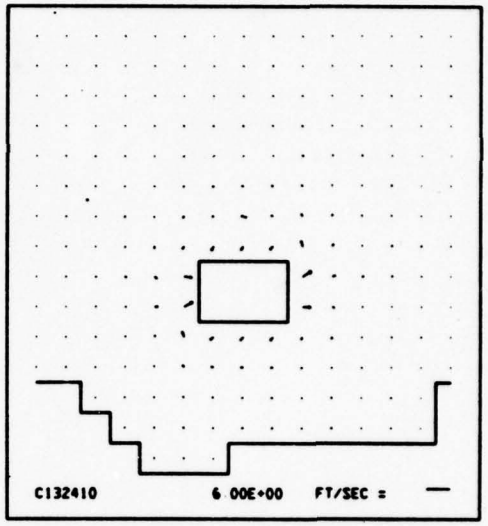

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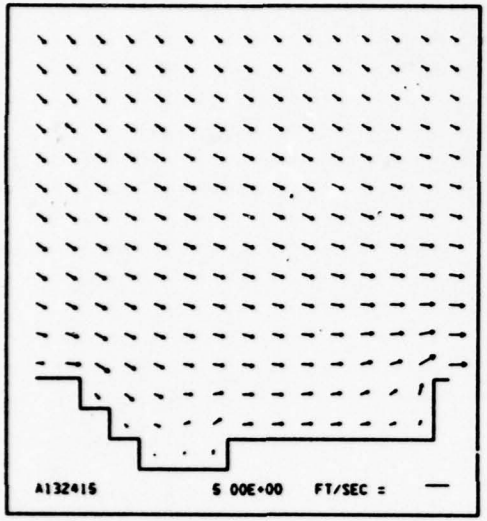

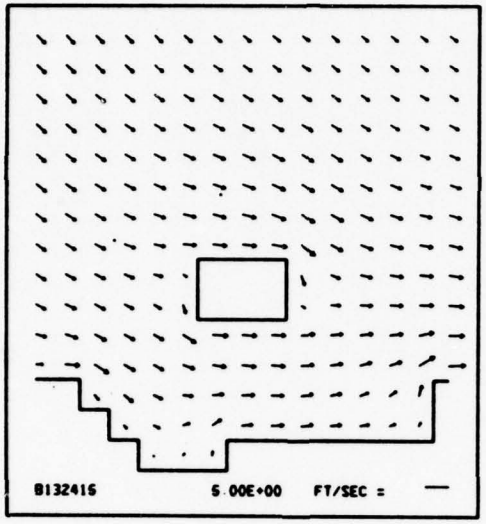

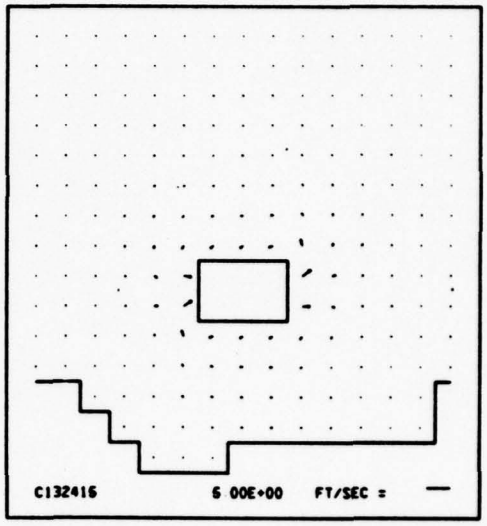

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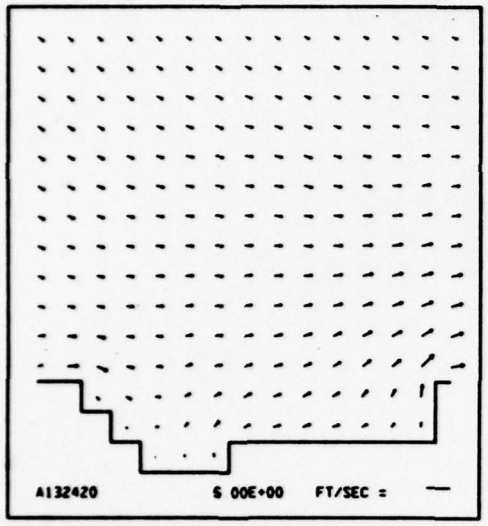

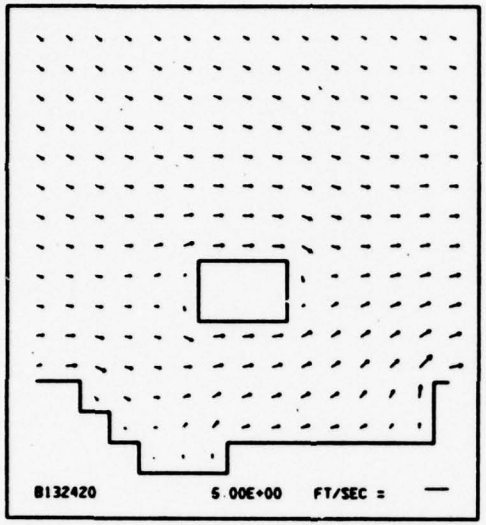

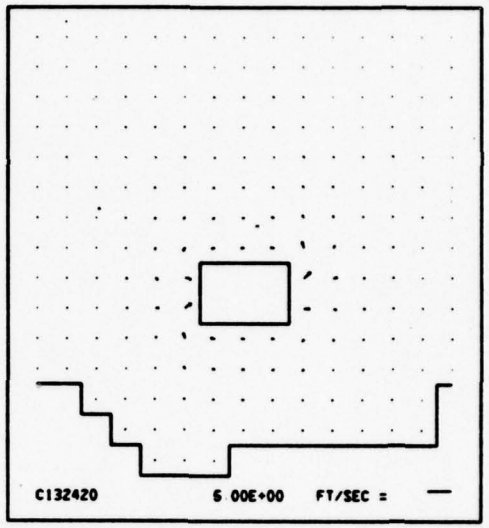

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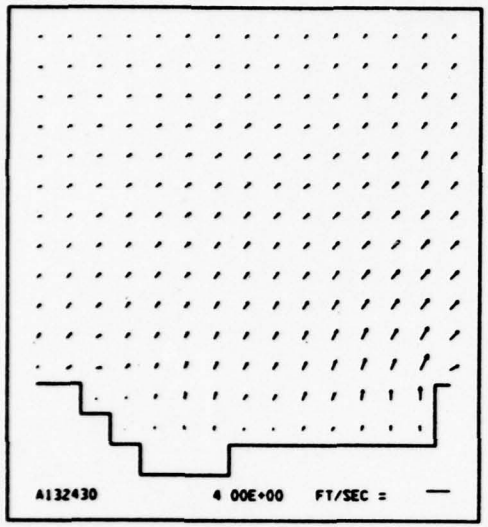

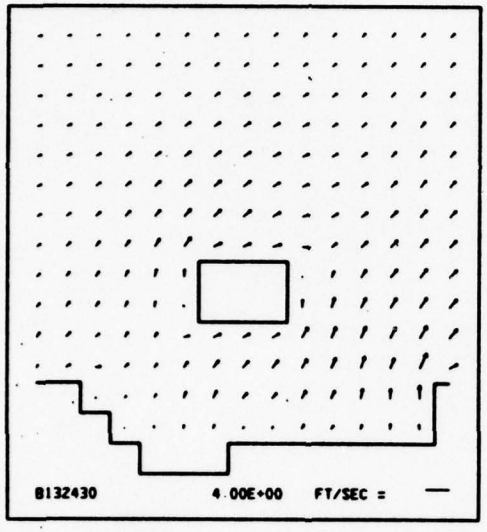

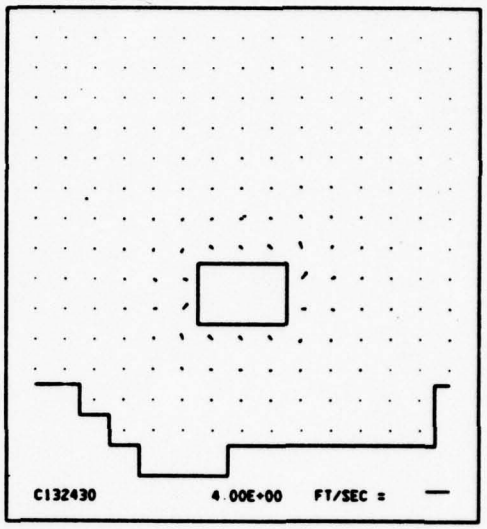

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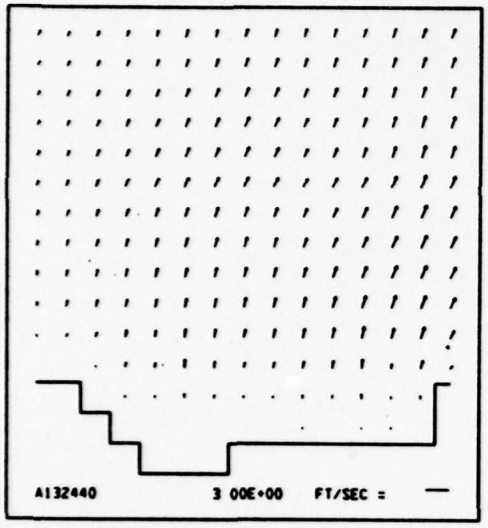

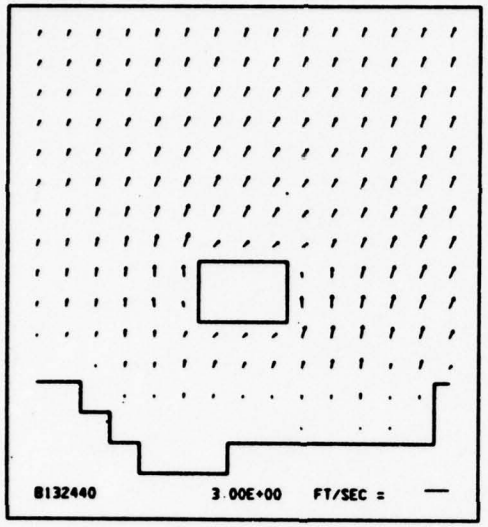

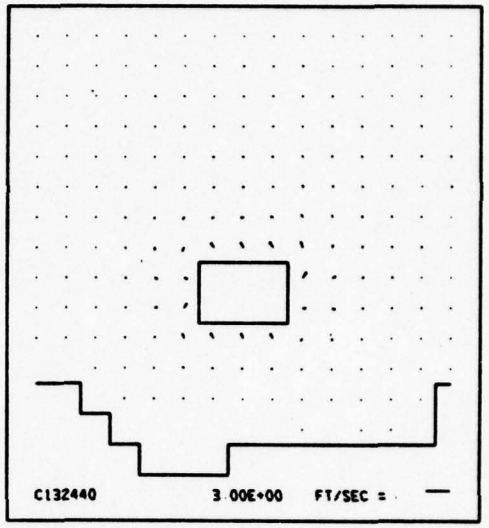

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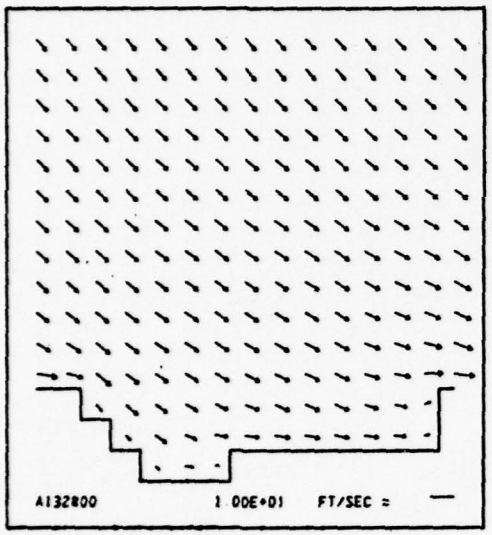

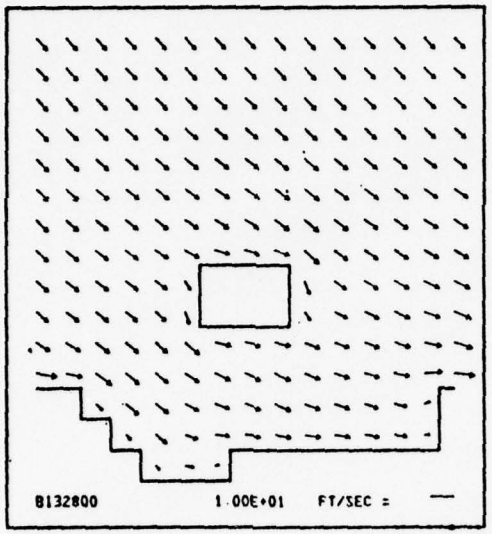

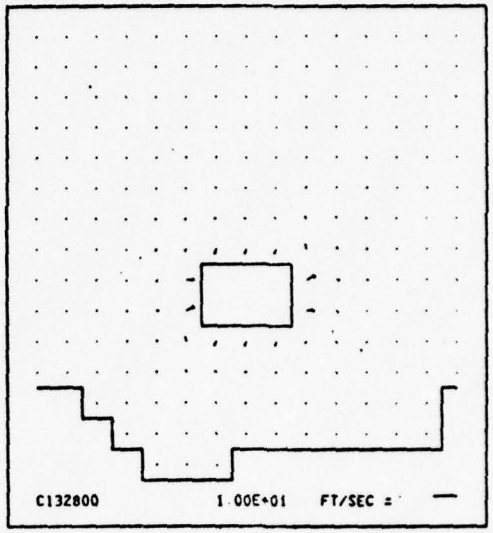

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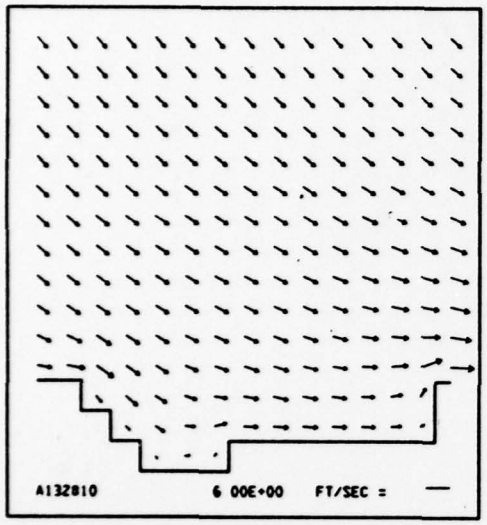

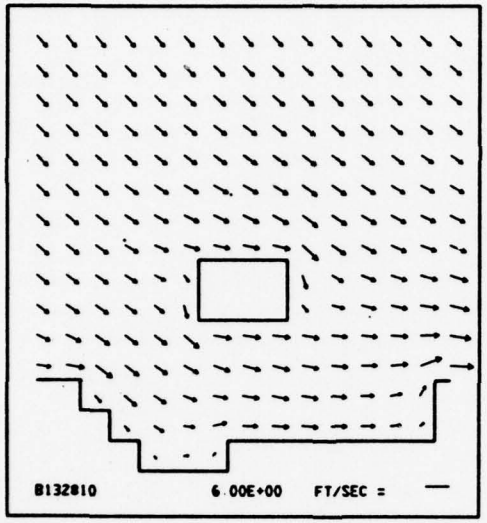

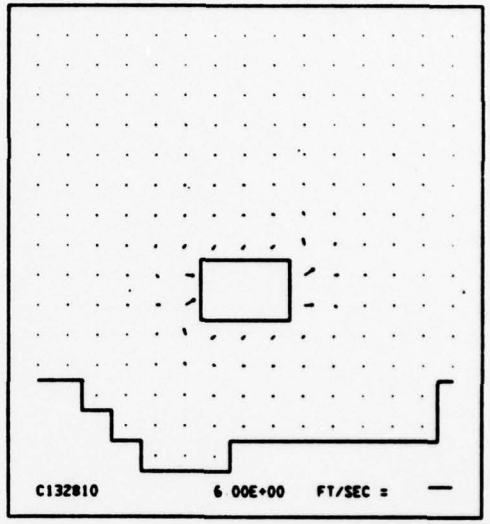

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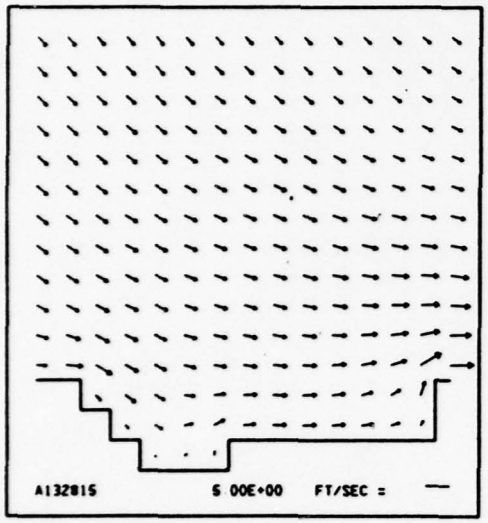

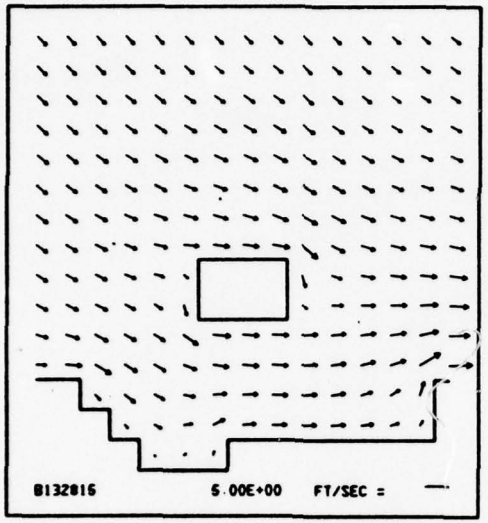

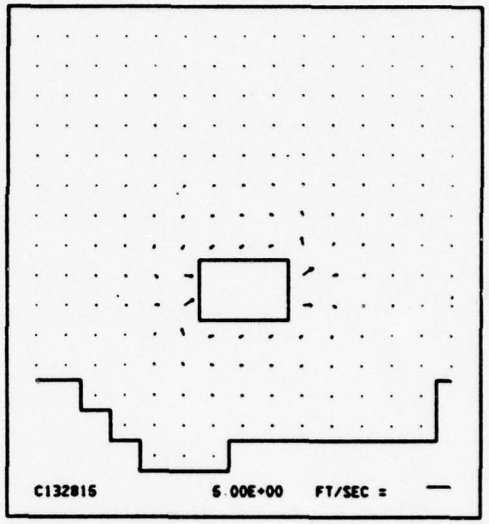

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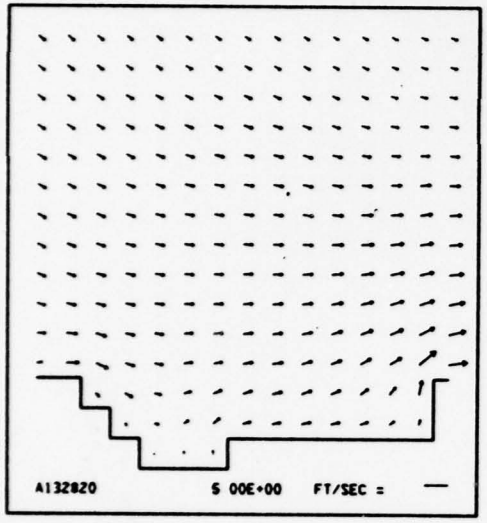

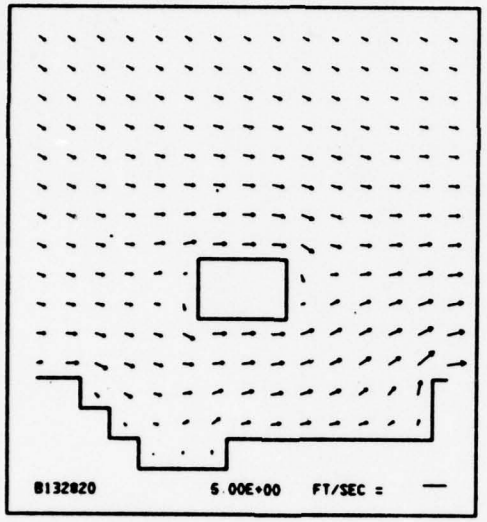

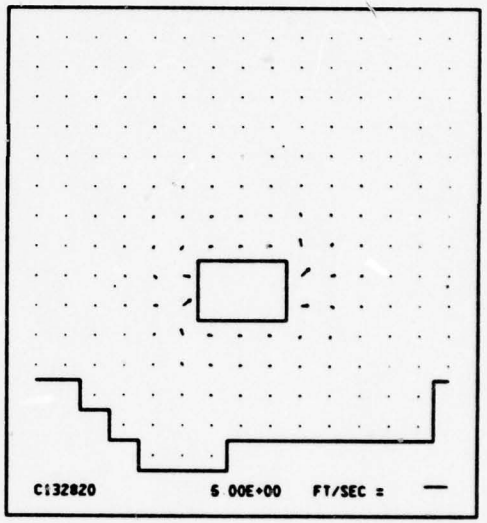

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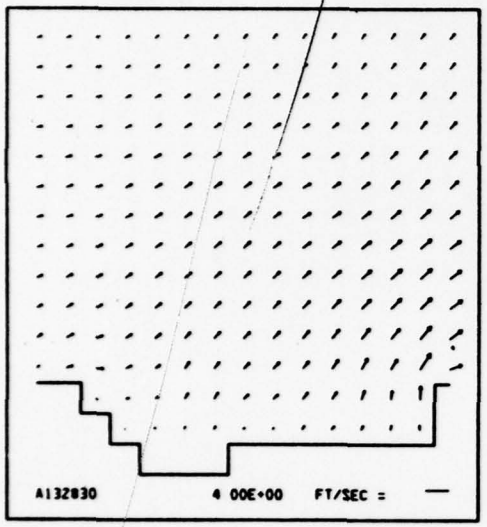

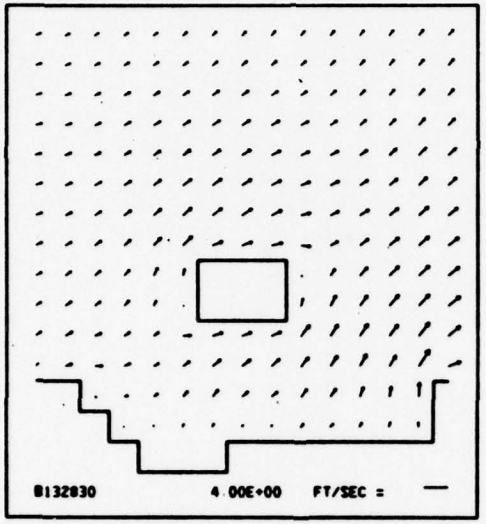

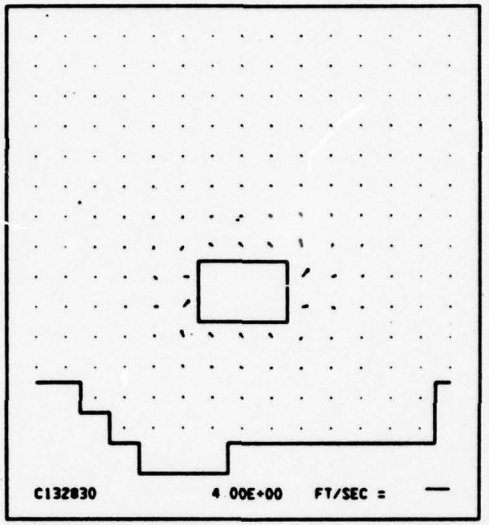

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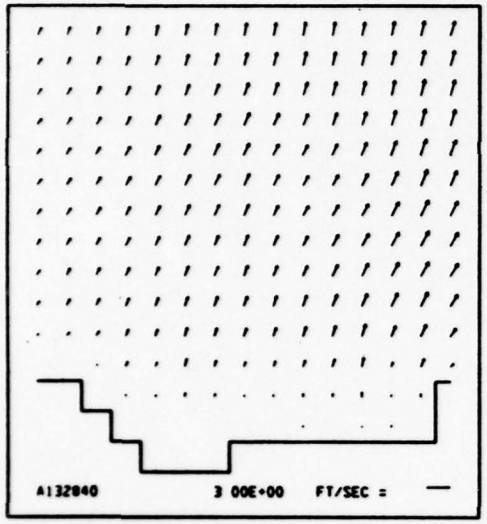

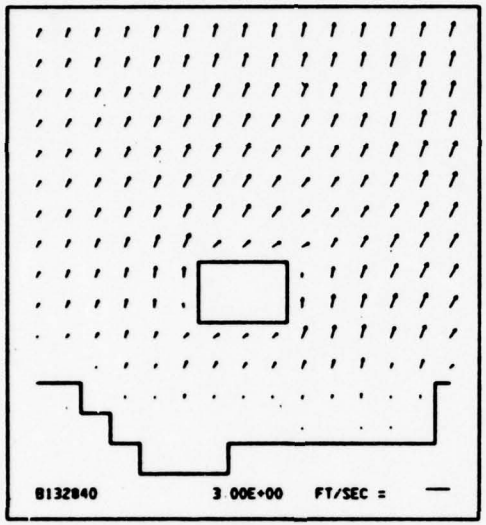

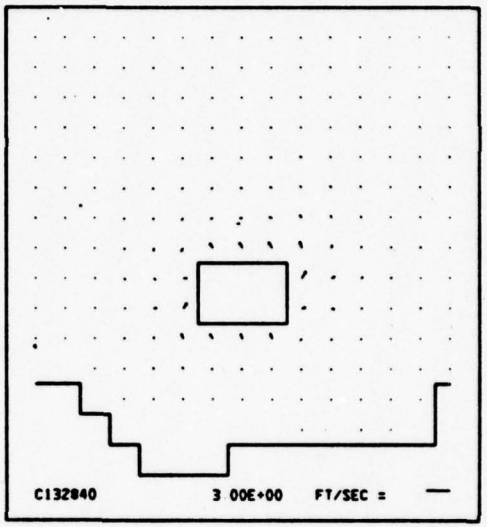

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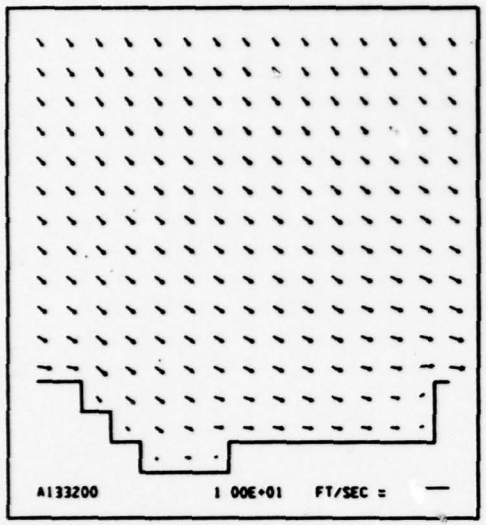

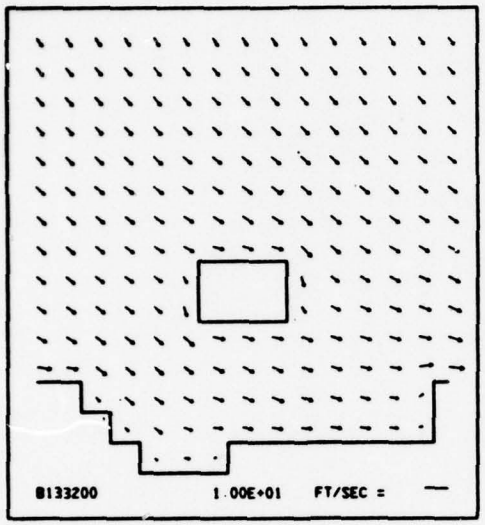

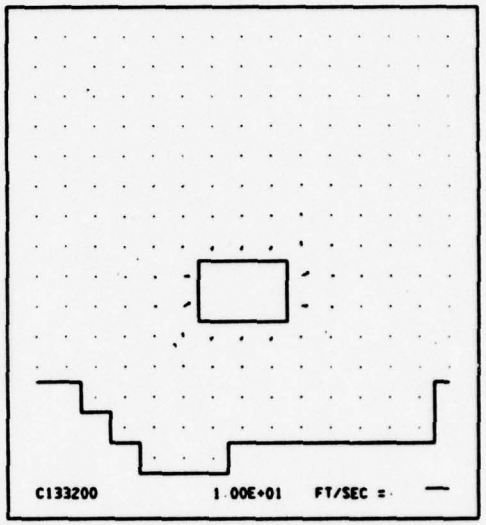

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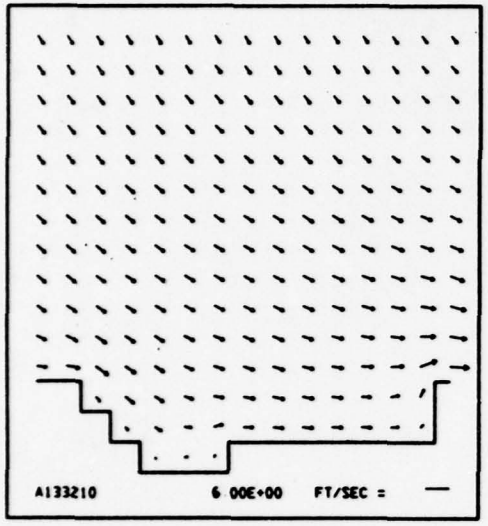

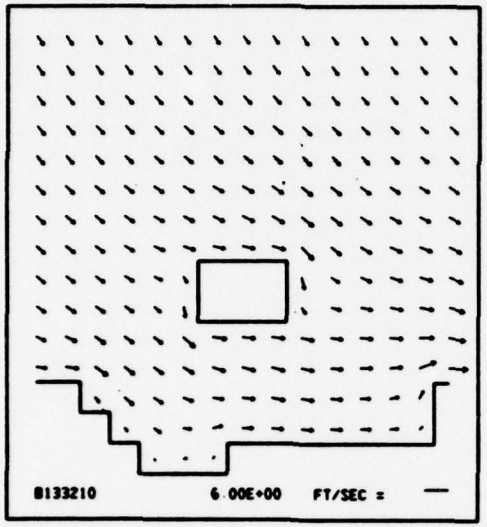

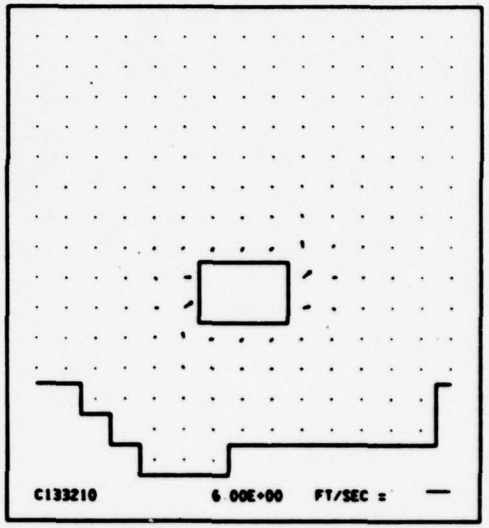

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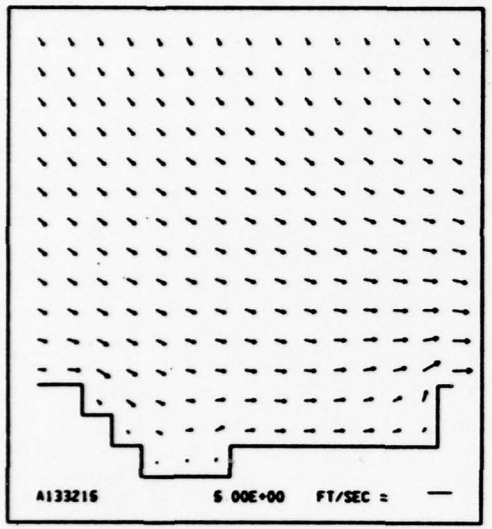

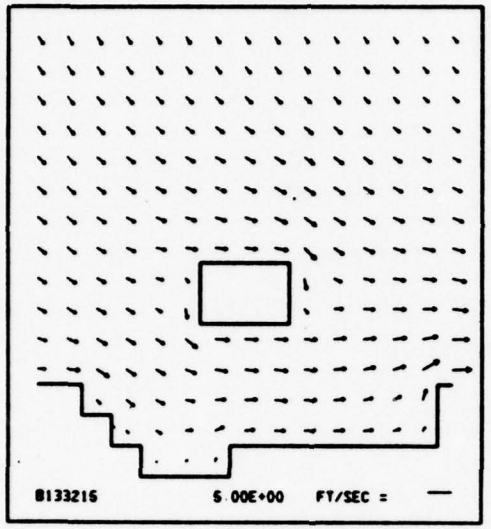

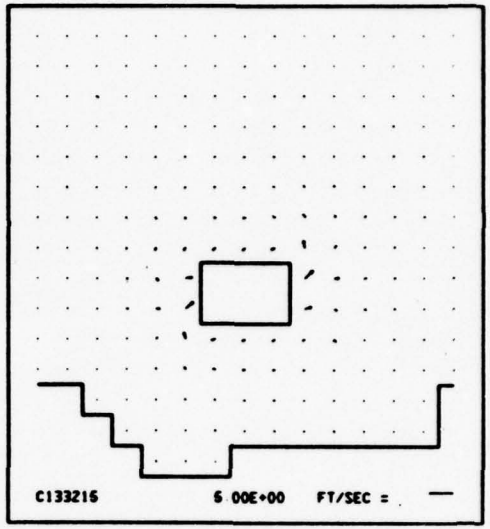

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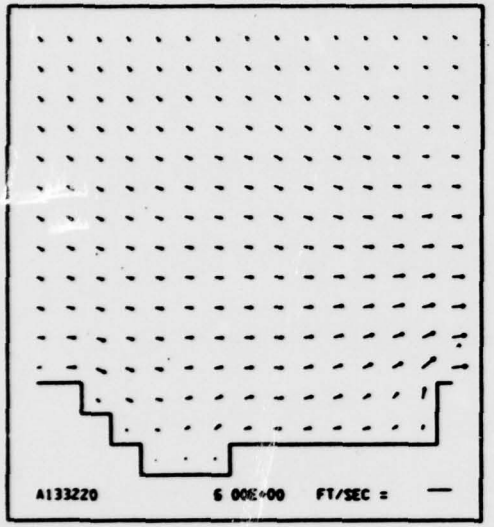

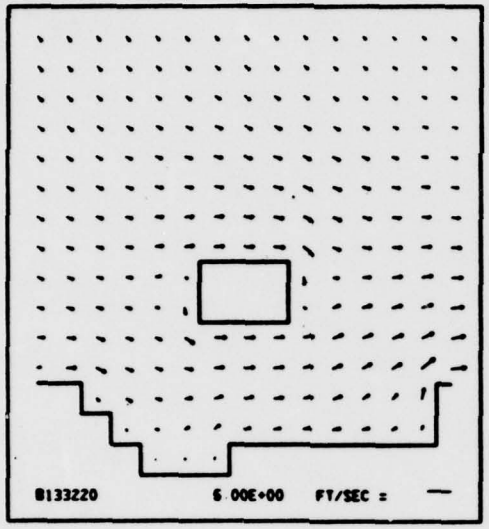

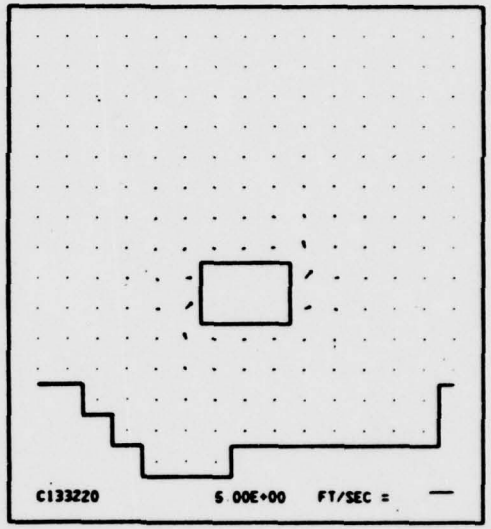

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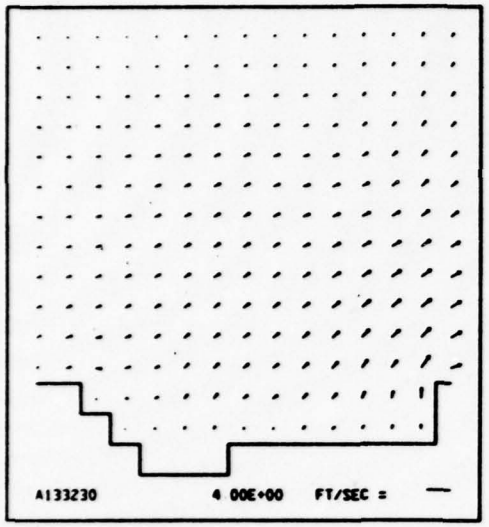

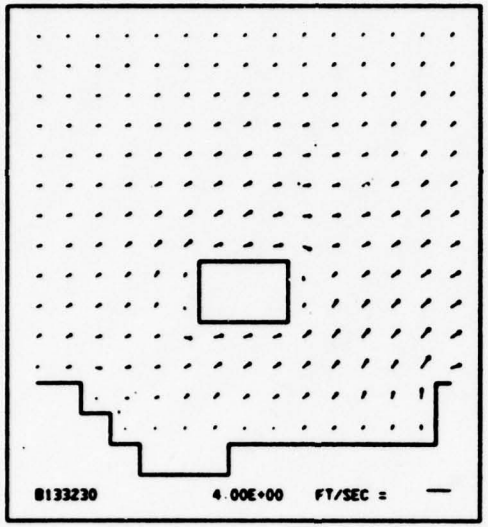

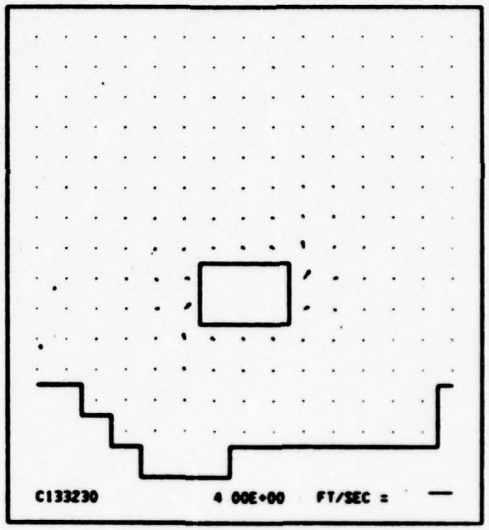

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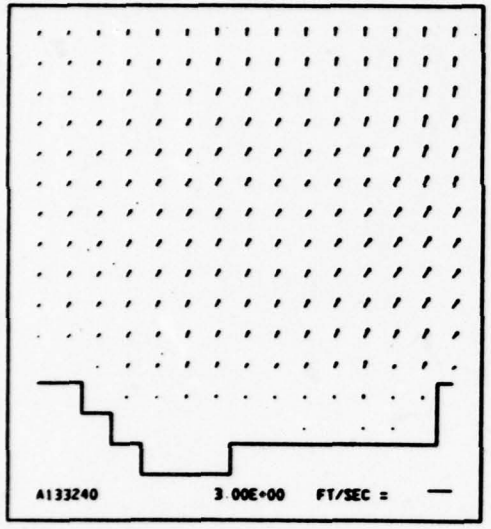

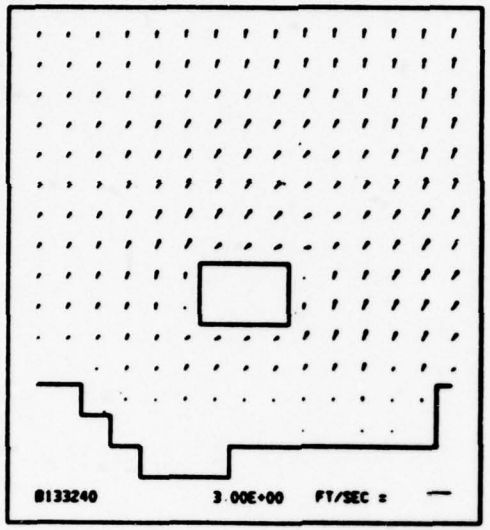

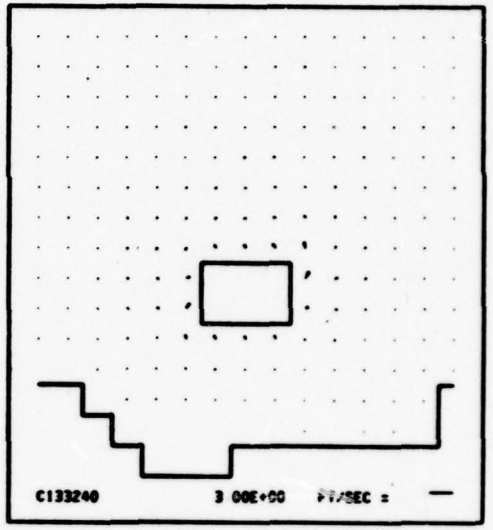

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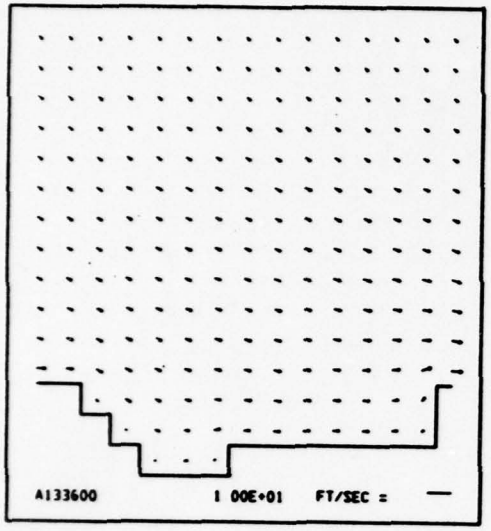

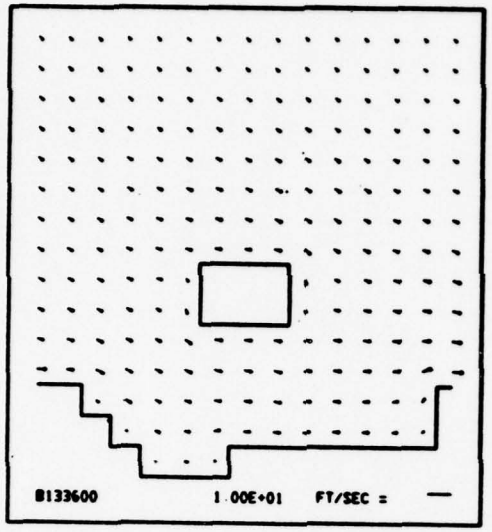

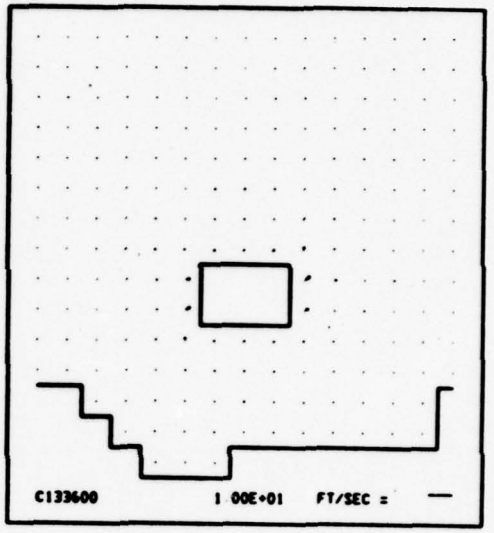

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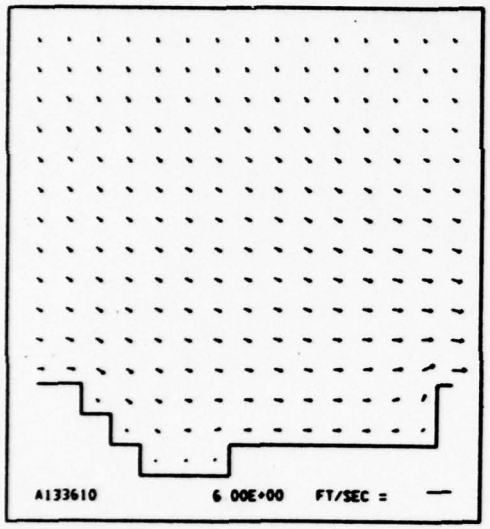

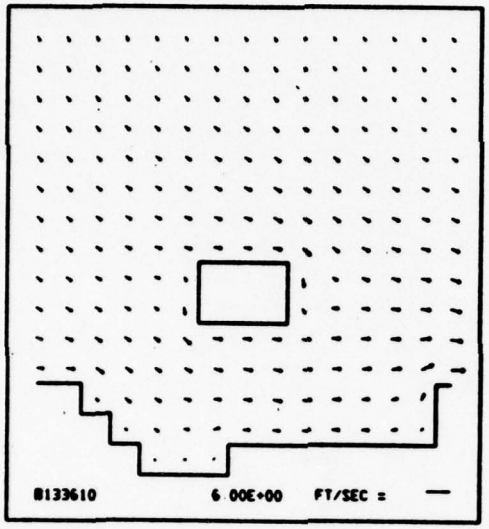

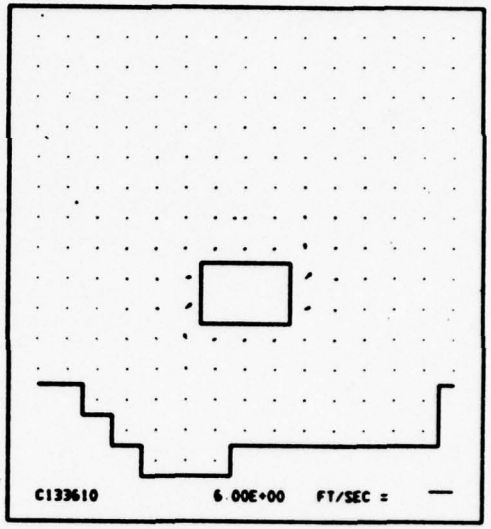

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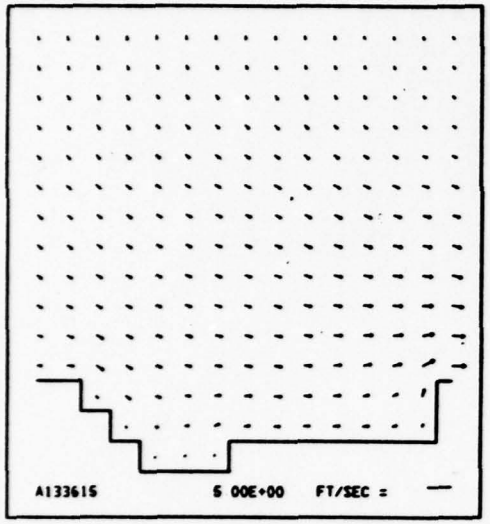

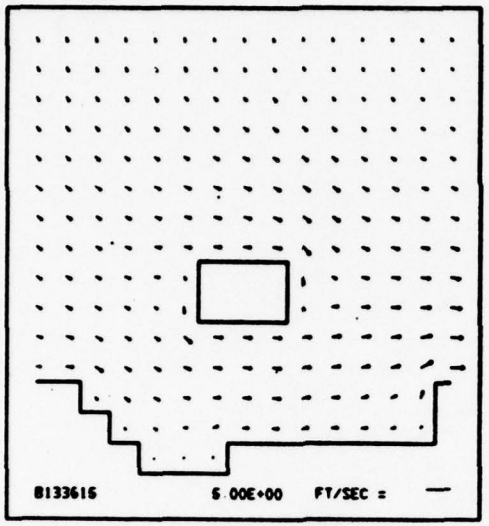

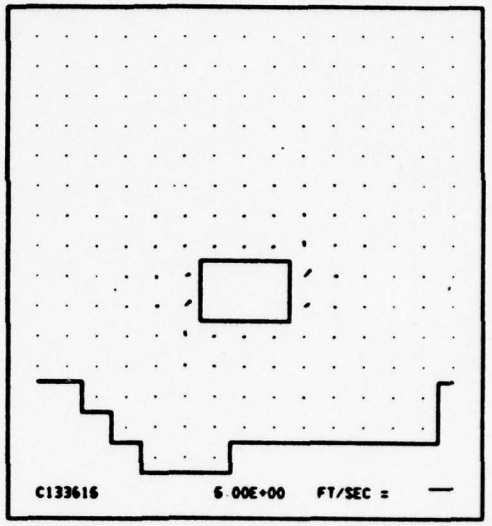

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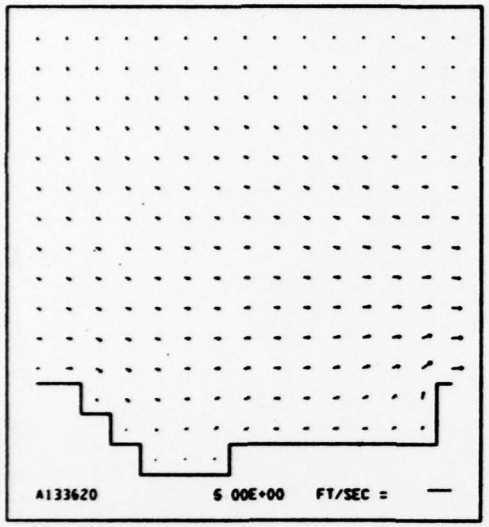

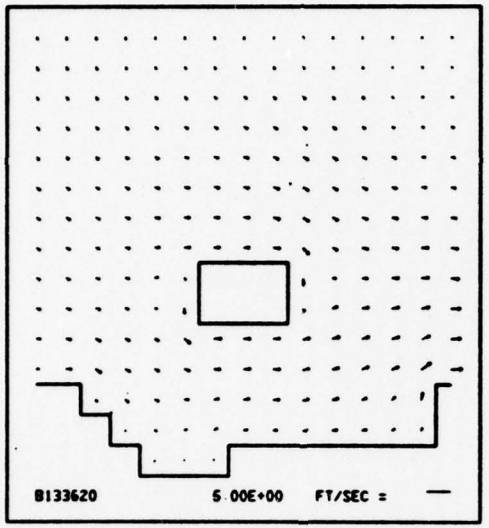

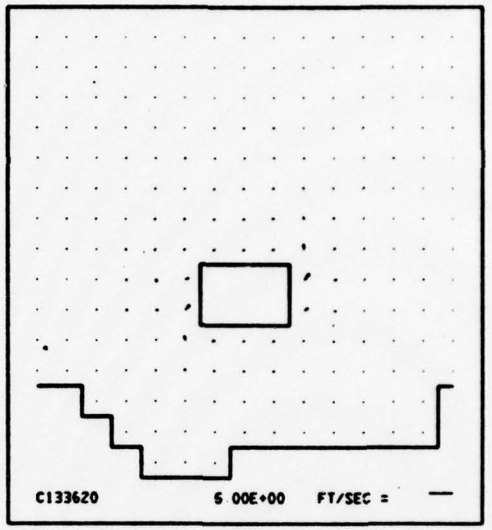

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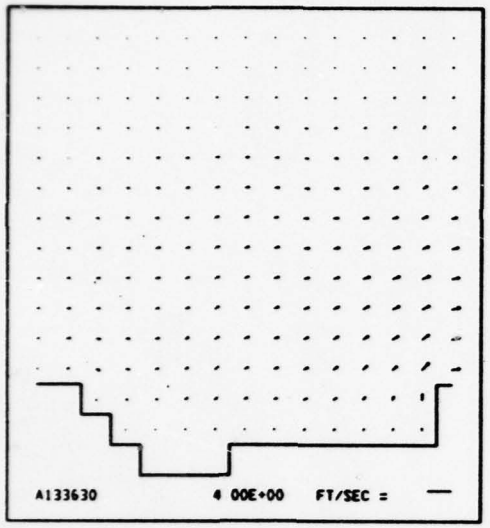

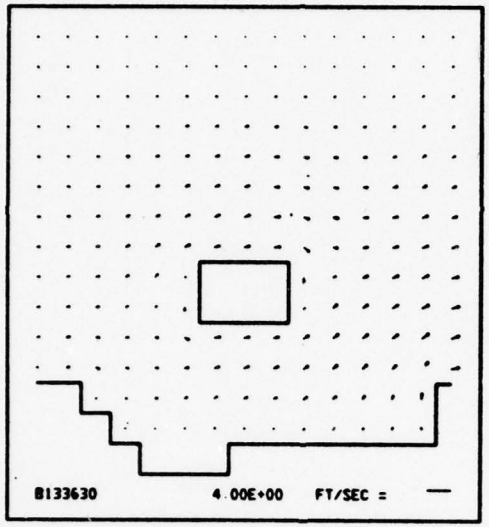

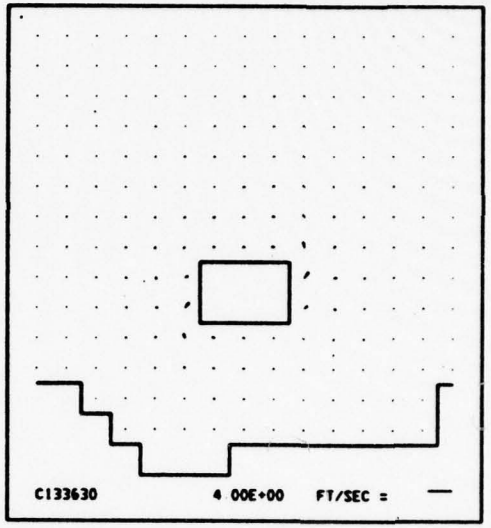

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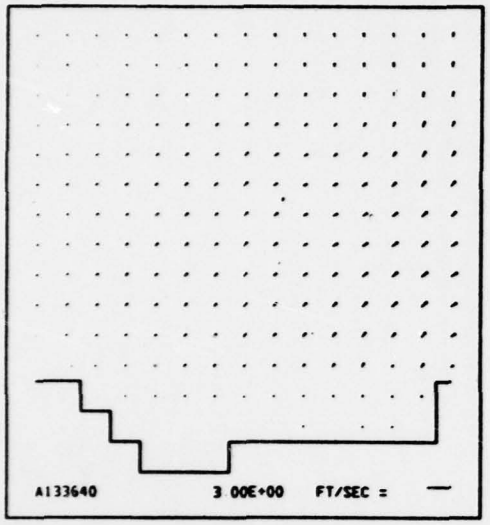

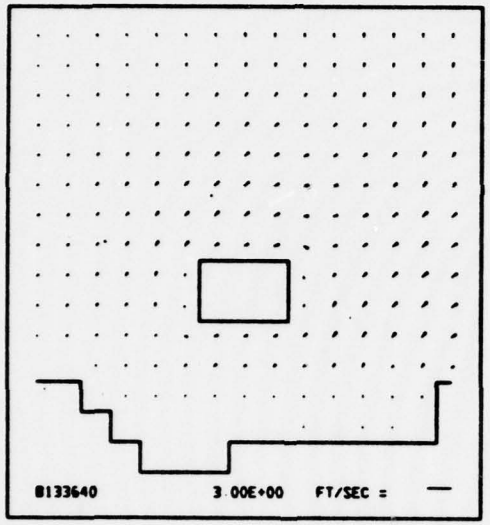

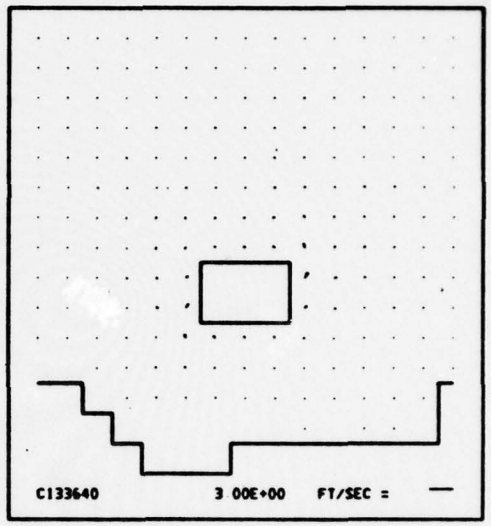

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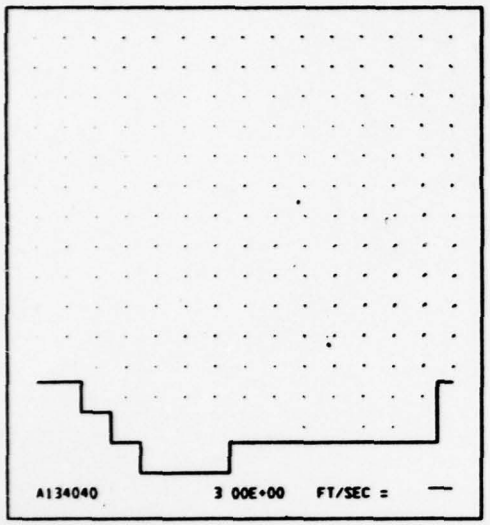

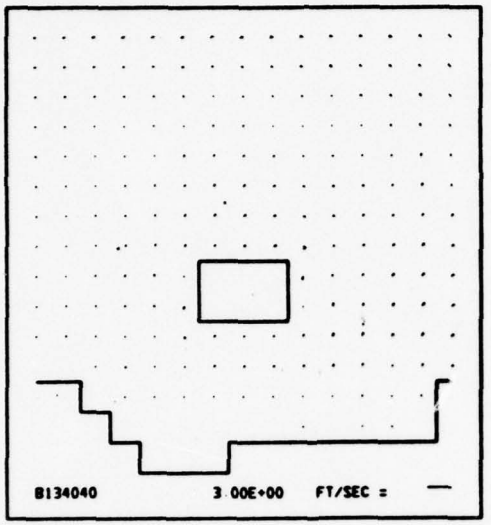

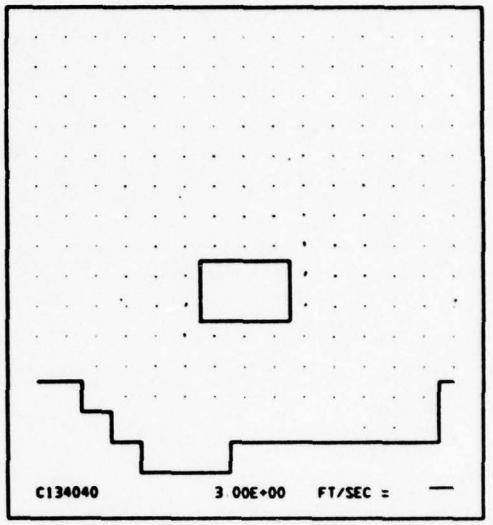

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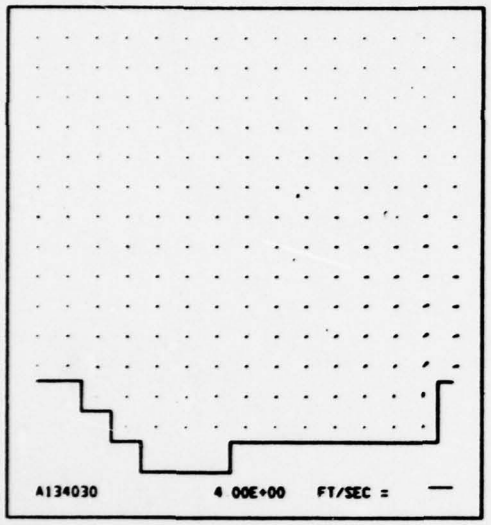

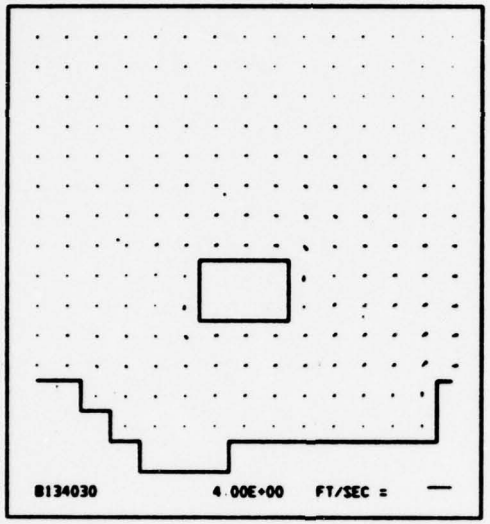

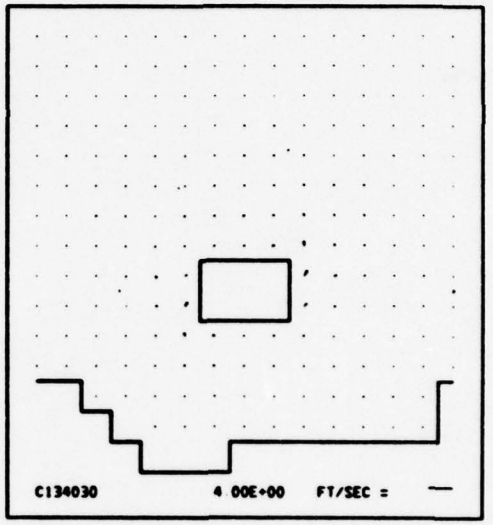

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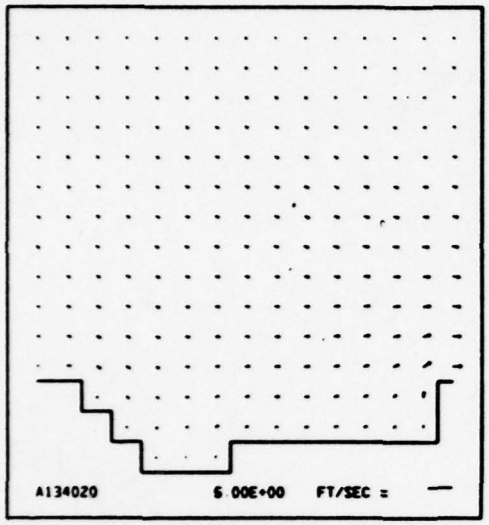

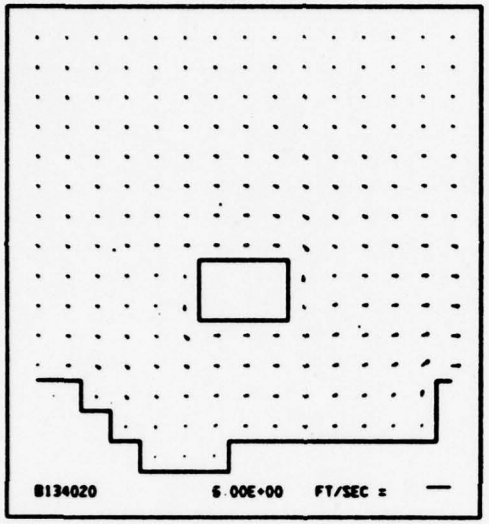

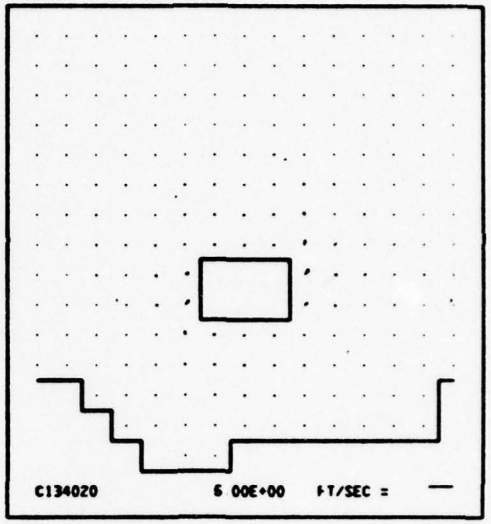

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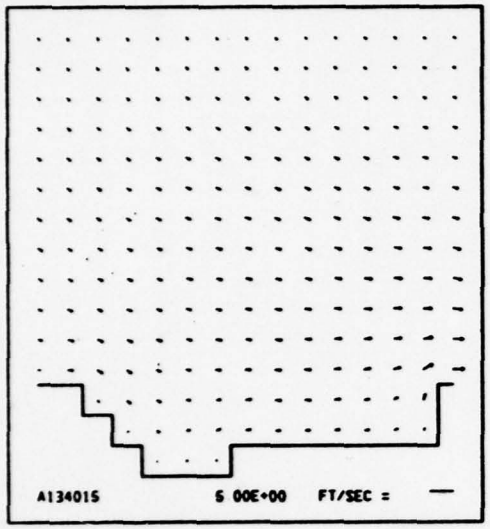

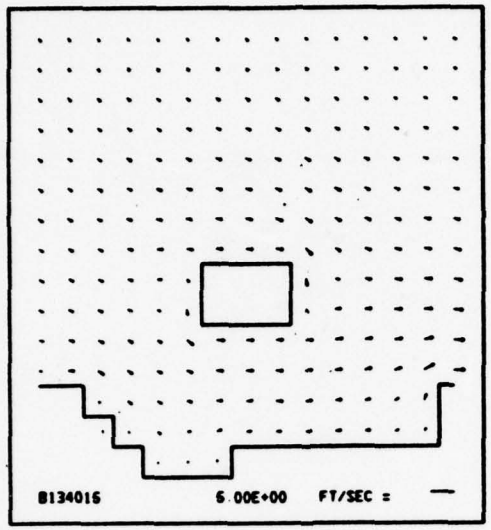

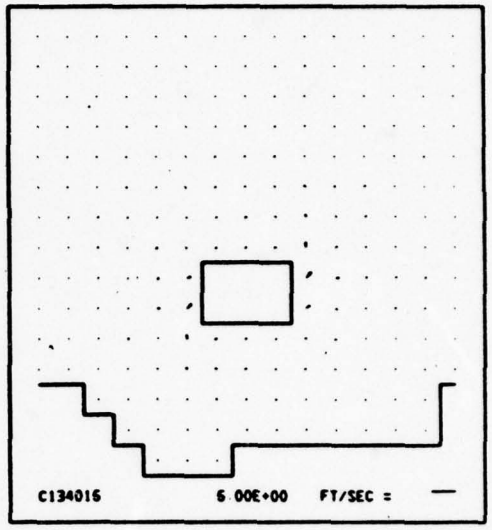

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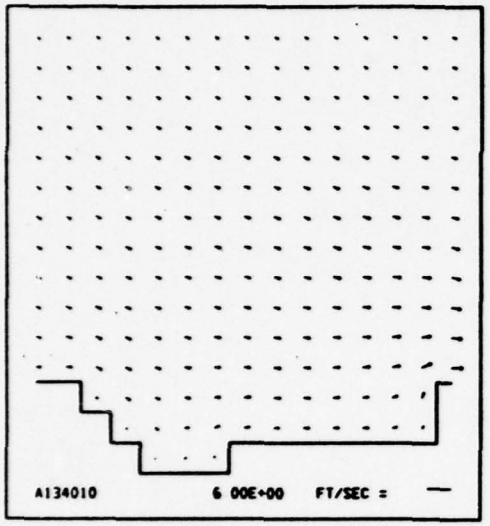

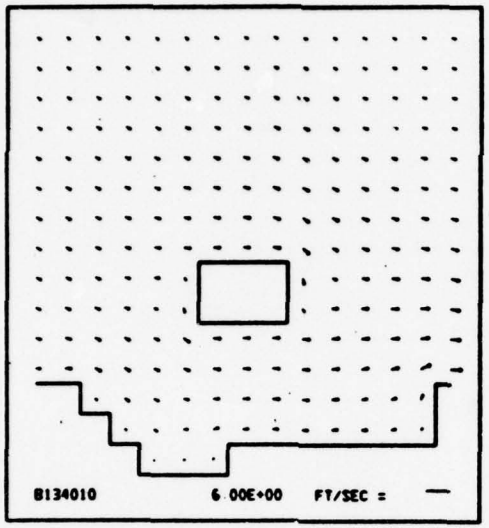

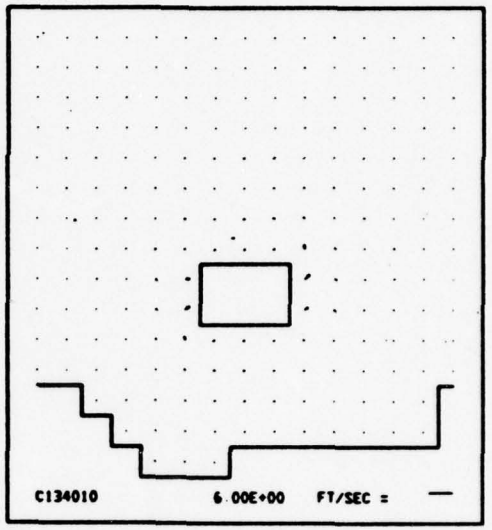

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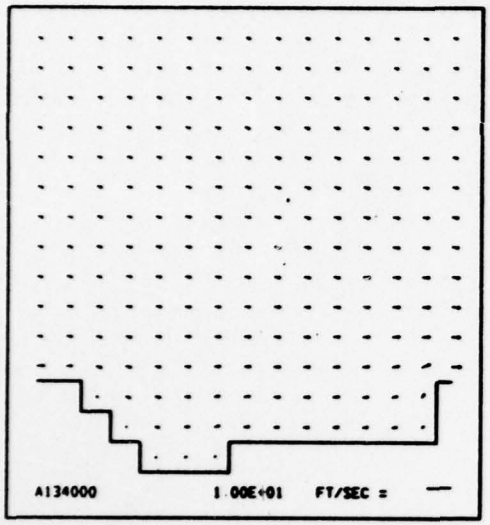

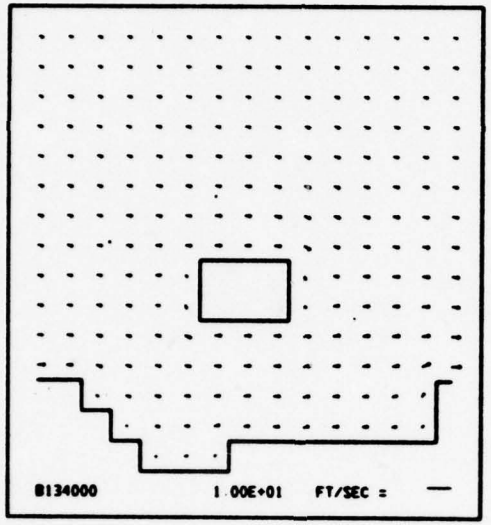

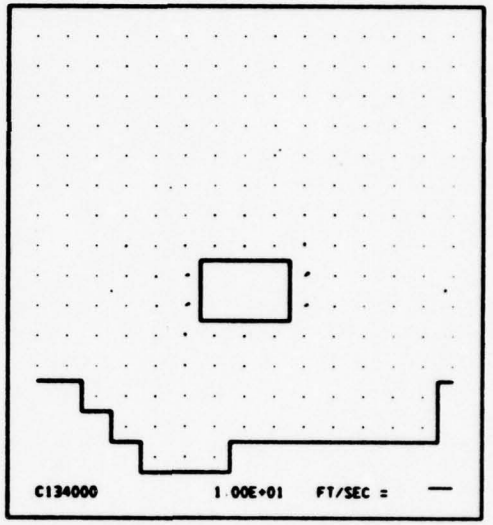

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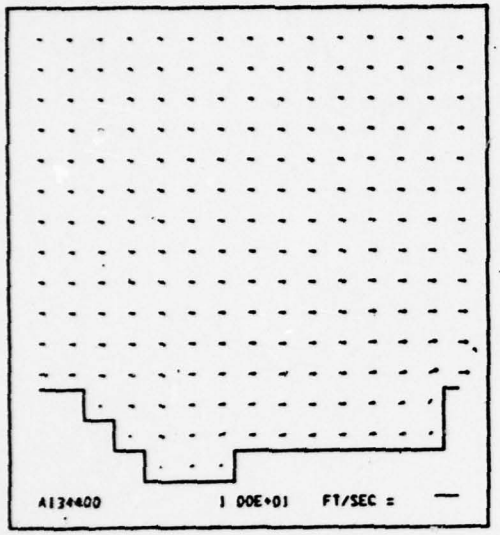

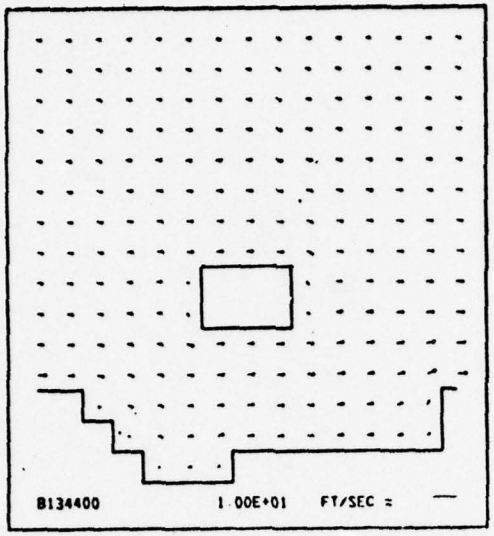

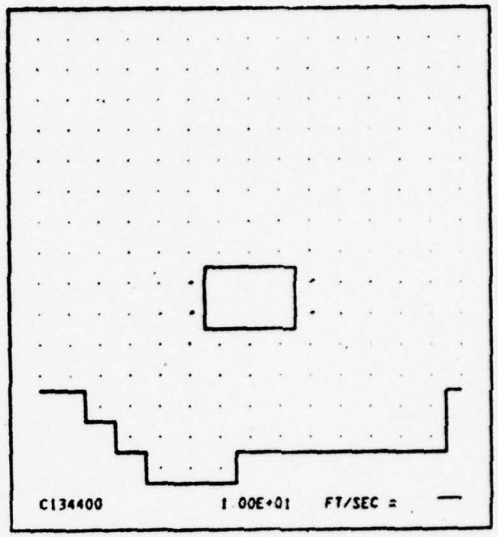

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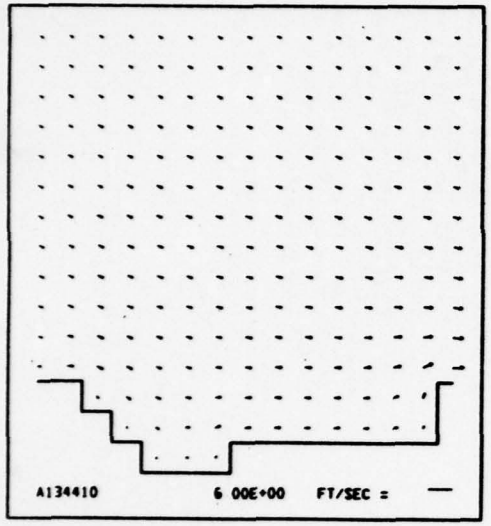

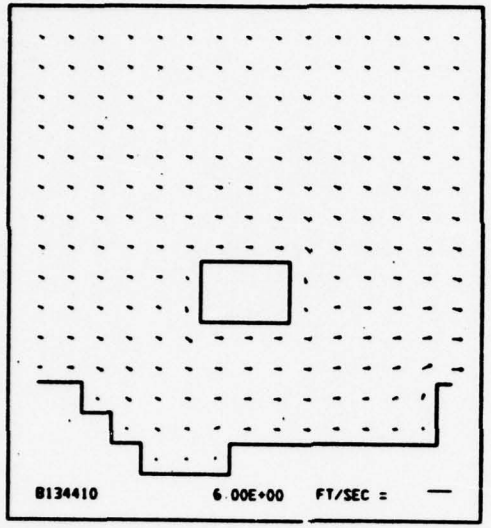

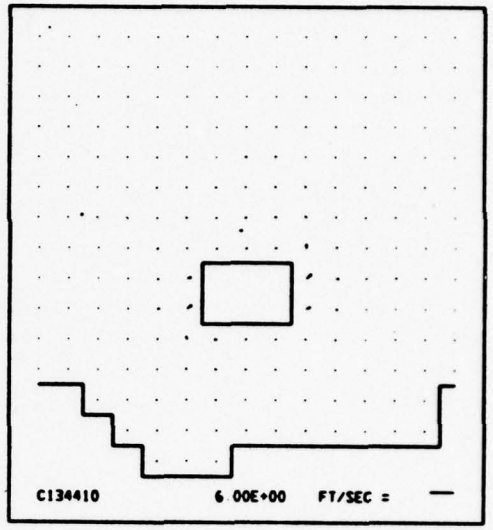

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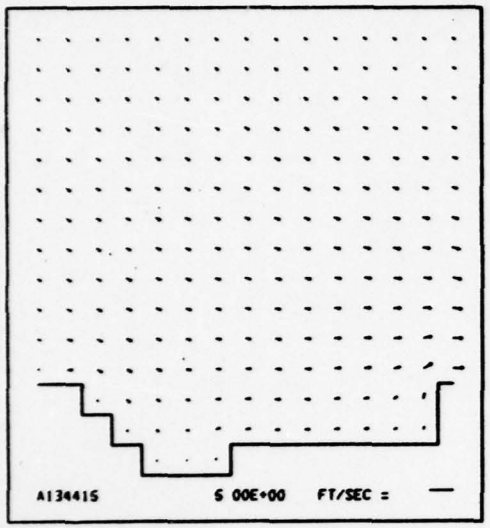

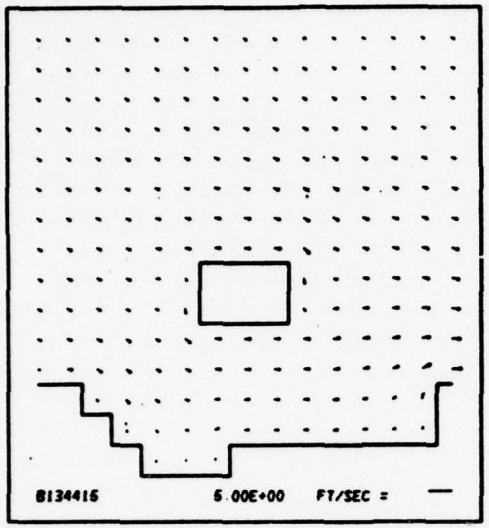

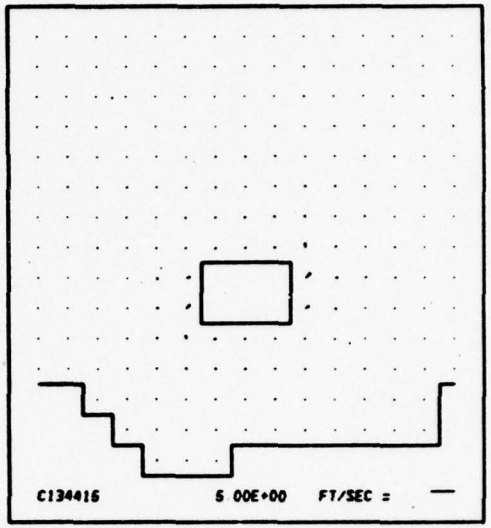

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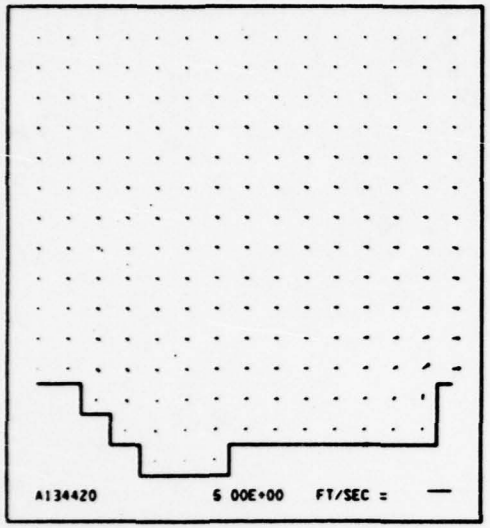

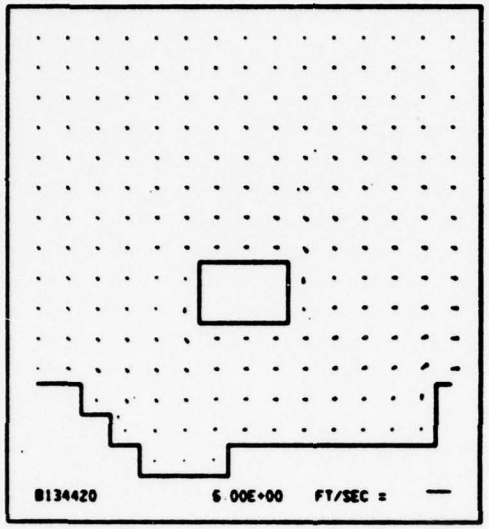

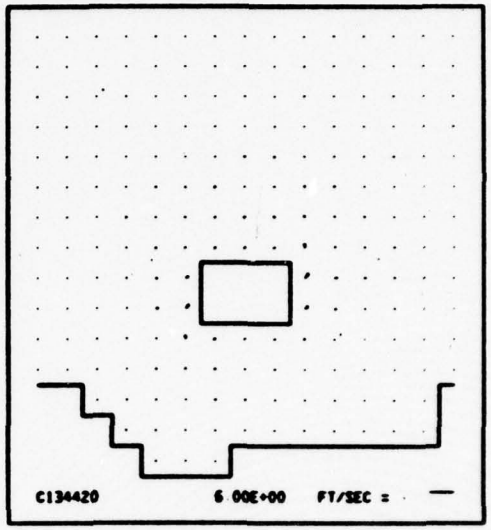

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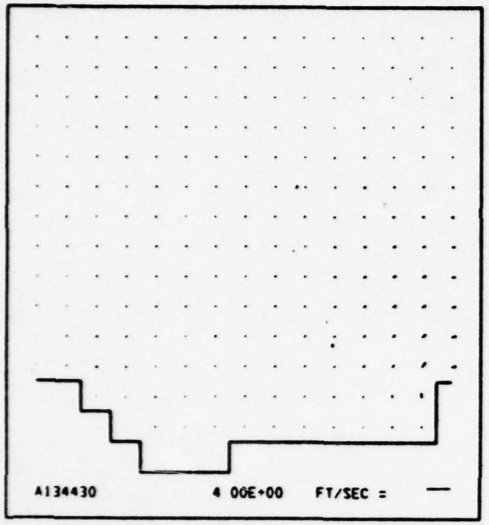

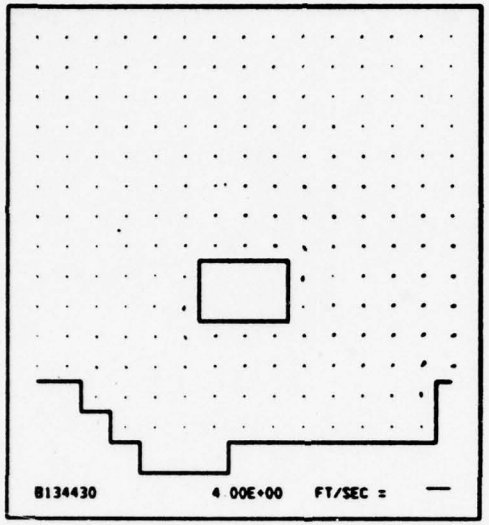

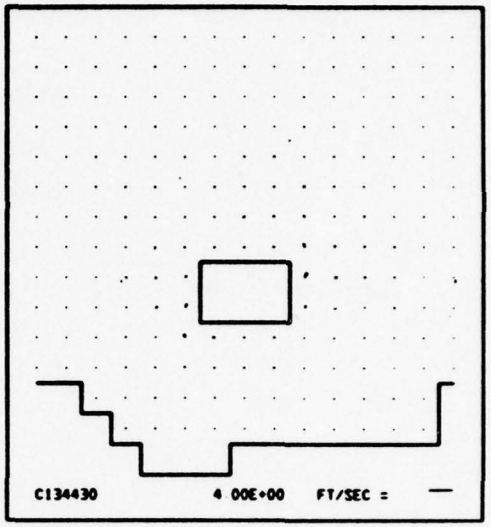

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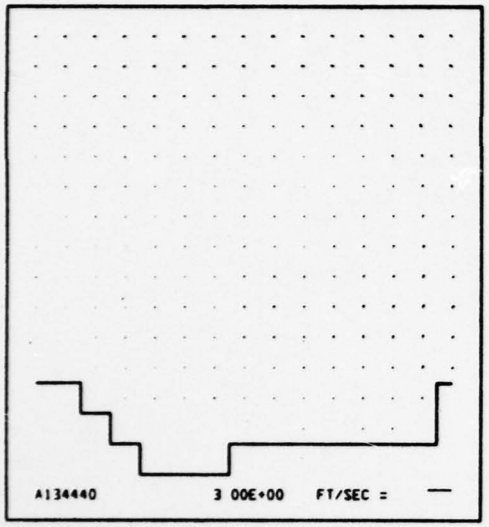

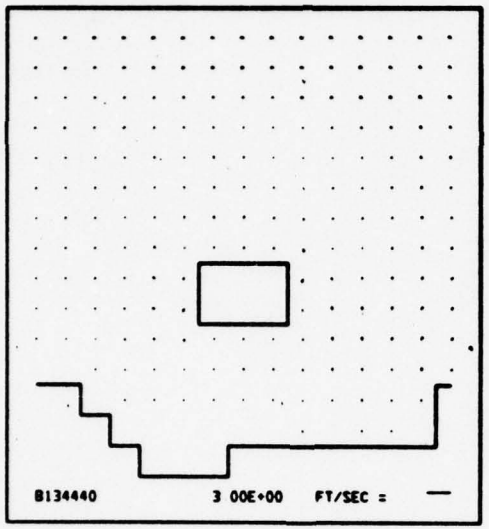

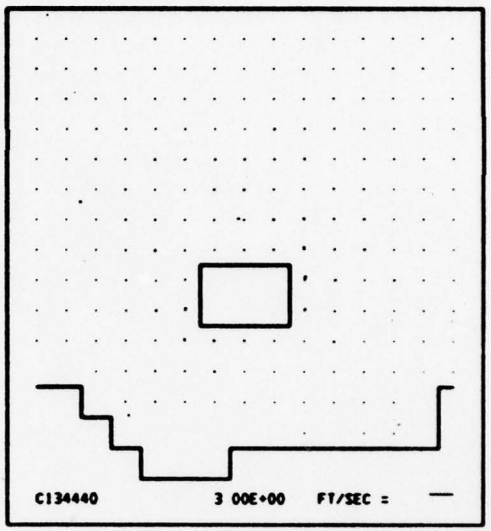

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AD-A036 243 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MISS F/G 1/5
LAKE ERIE INTERNATIONAL JETPORT MODEL FEASIBILITY INVESTIGATION--ETC(U)
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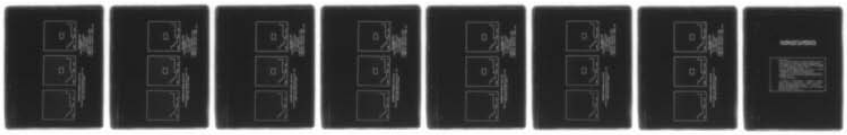

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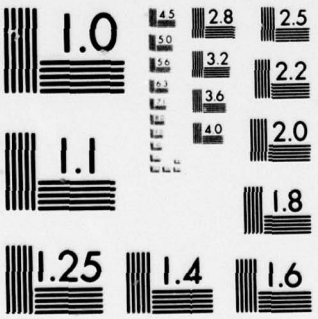

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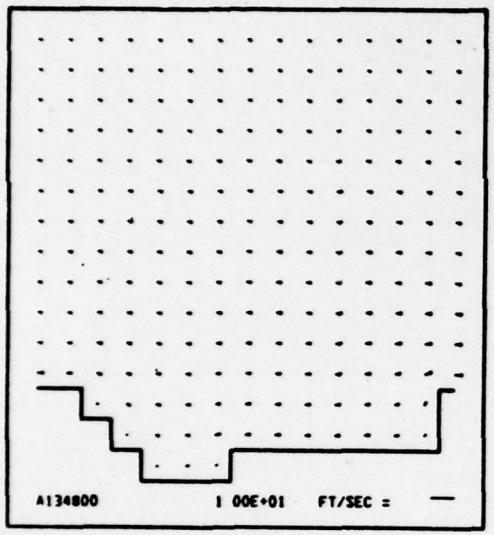
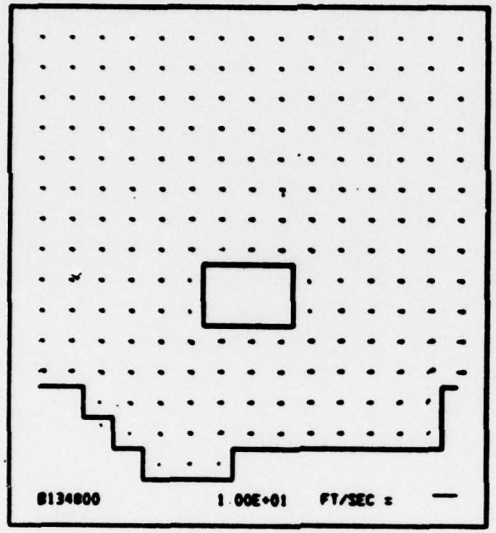
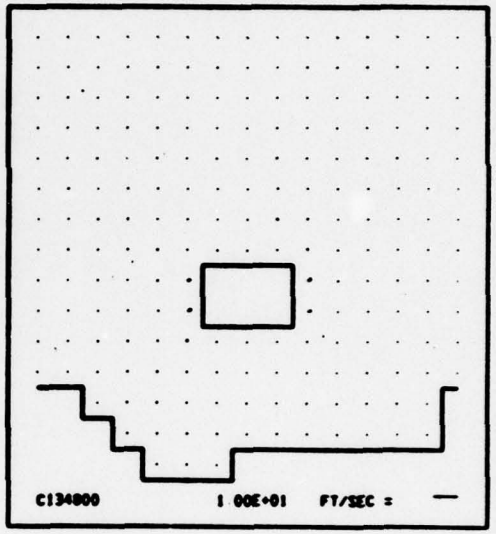
NATIONAL BUREAU OF STANDARDS-1963-A







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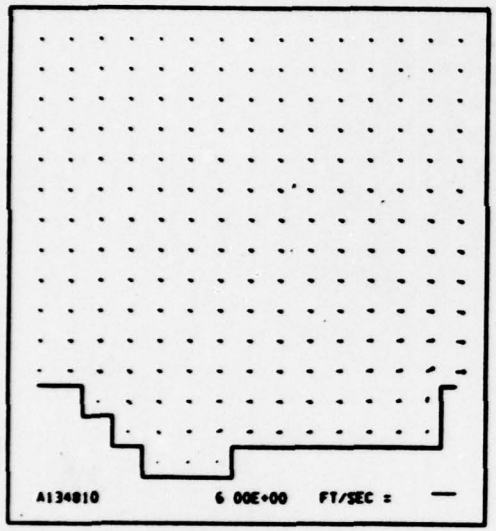

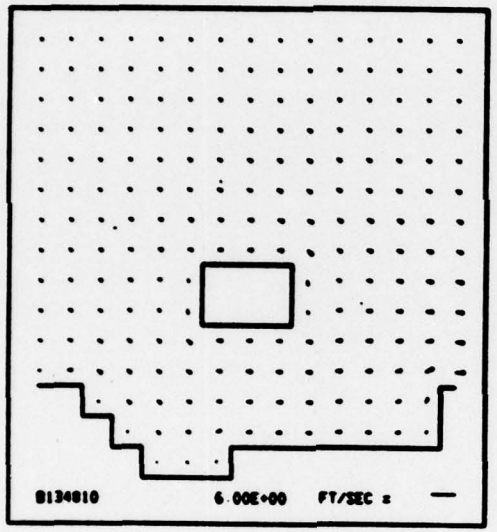

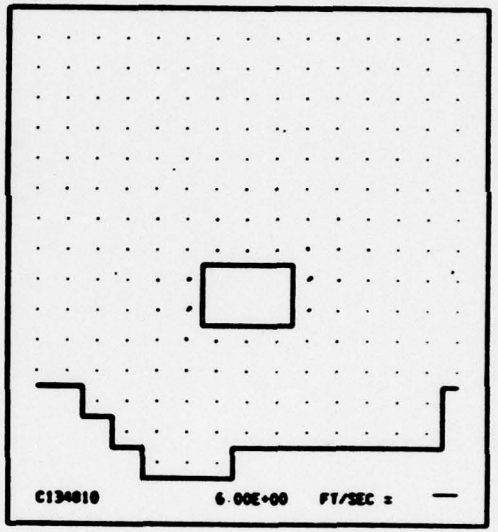

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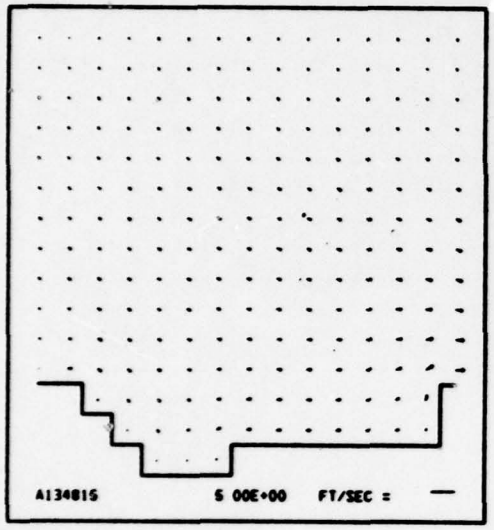

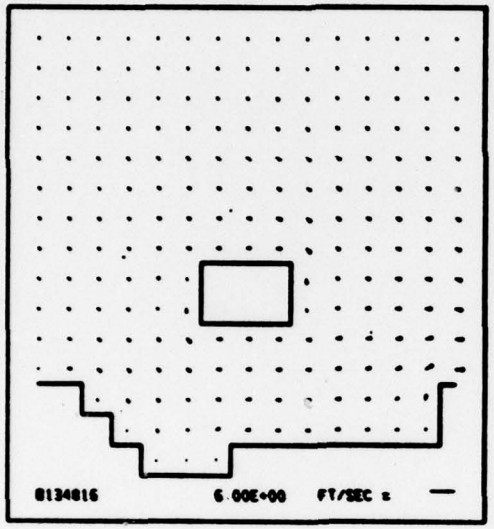

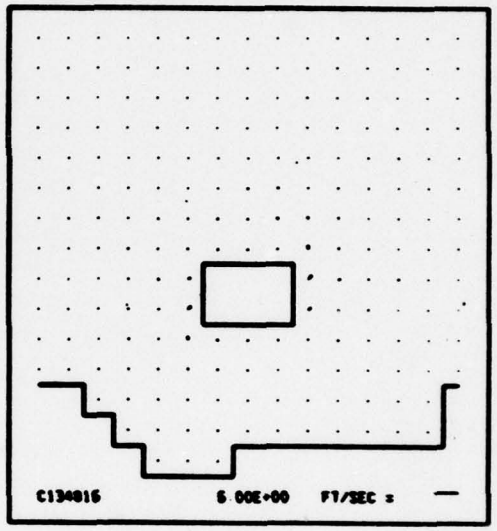

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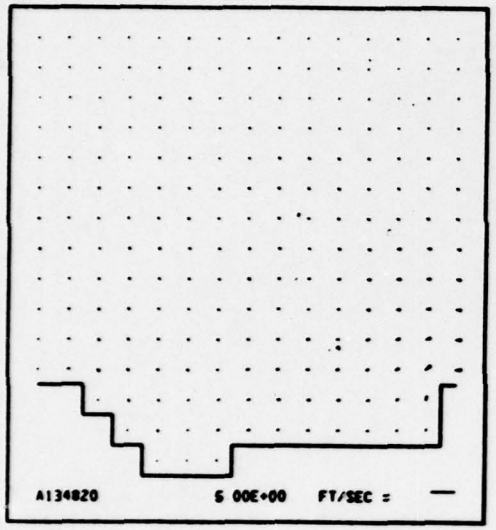

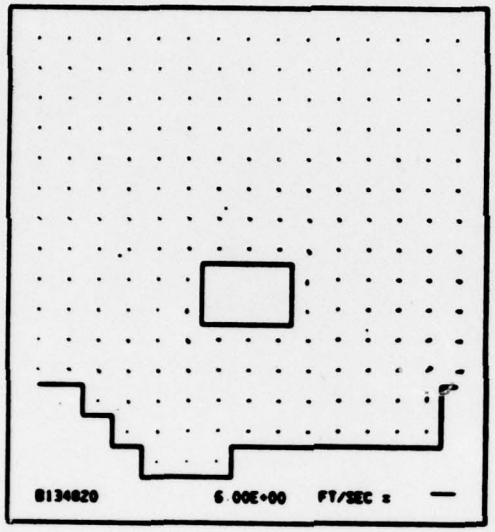

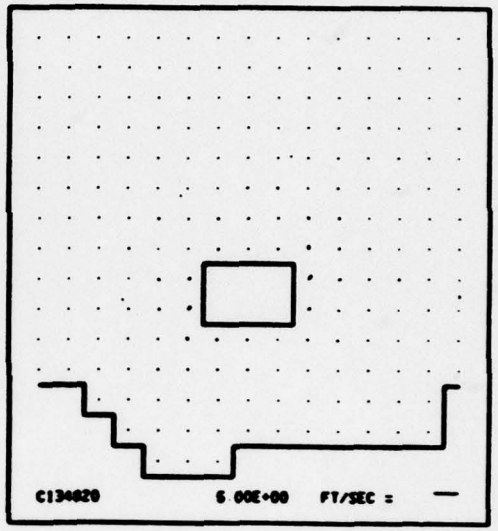

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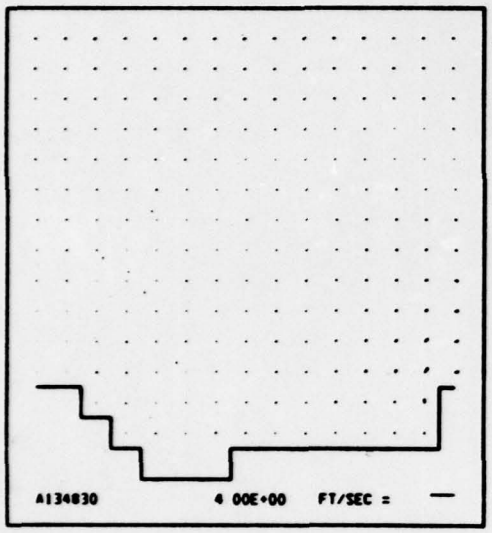

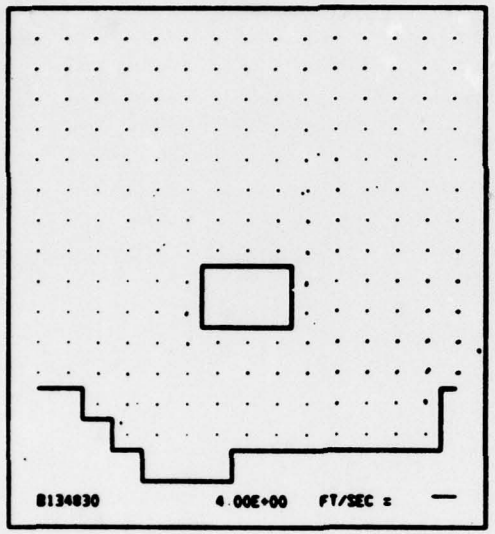

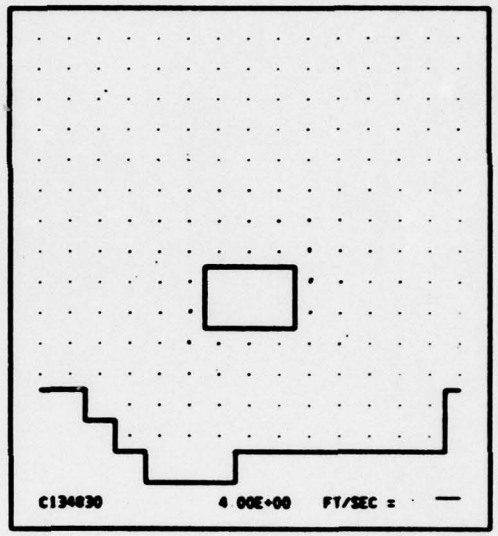

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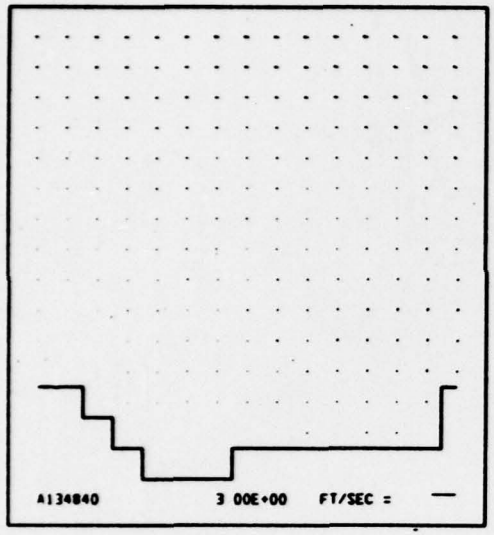

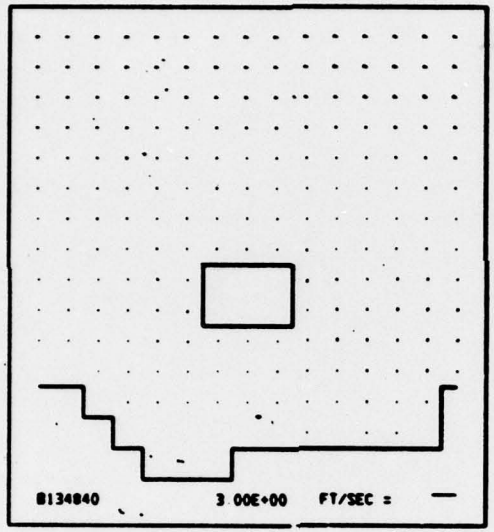

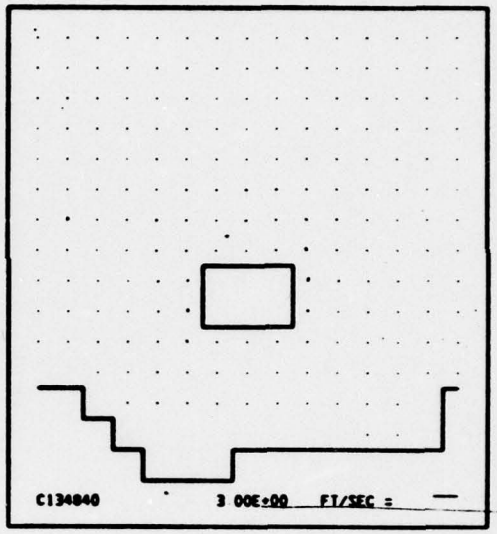

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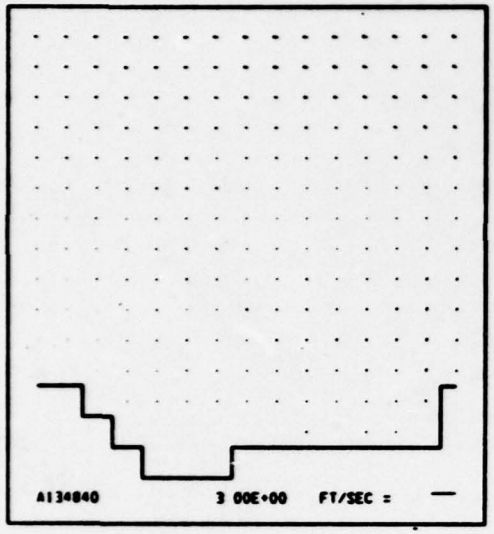

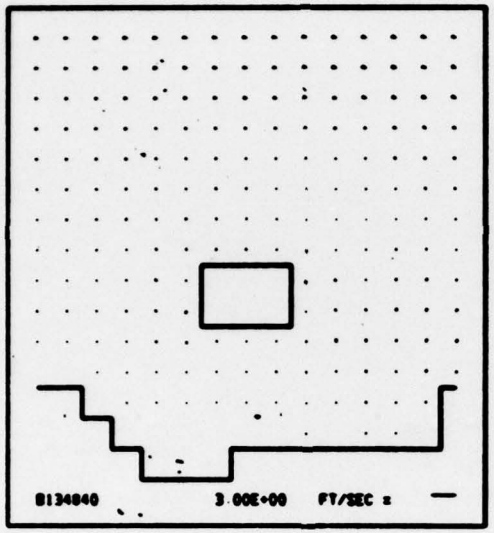

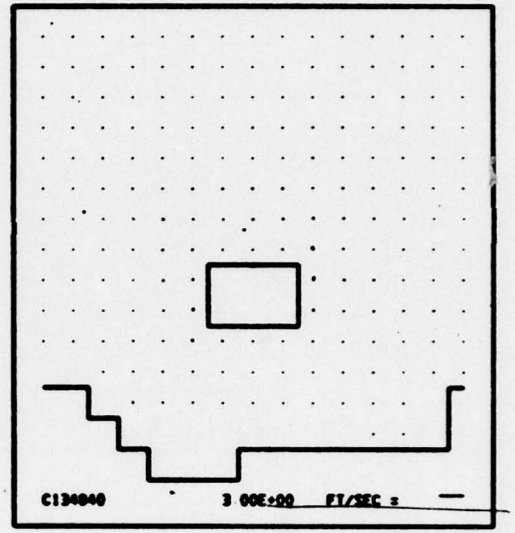

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In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Durham, Donald L

Lake Erie International Jetport model feasibility investigation; Report 17-8: Results of numerical time-dependent three-dimensional, storm surge analysis, by Donald L. Durham, H. Lee Butler [and] D. C. Raney. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1976.

[2] v. (various pagings) illus. 27 cm. (*U. S. Waterways* Experiment Station. Miscellaneous paper H-76-3)

Appendixes: A-G (Appendix G in separate vol.)

Prepared for Lake Erie Regional Transportation Authority. Cleveland, Ohio, under Task 17 of LERTA Second-Phase Airport Feasibility Study.

Includes bibliography.

1. Airports. 2. Lake currents. 3. Lake Erie. 4. Mathematical models. 5. Storm surge. I. Butler, H. Lee, joint author. II. Raney, Donald C., joint author. III. Lake Erie Regional Transportation Authority. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper H-76-3, Report 17-8)

TA7.W34m no.H-76-3 Report 17-8