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NUMERICAL MODELING OF EXPLOSION WAVES

by

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Numerical models are presented that calculate waves generated by an explosion and propagate them across deep and shallow water and through a wave-breaking zone to shore. The models are verified by comparisons with waves measured during both small- and large-scale field tests that used high explosives to generate waves. Detailed documentation of the models and sample calculations are provided.

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PREFACE

The investigation reported herein was authorized by the Office, Chief of Engineers (OCE), U. S. Army, in a letter dated 11 March 1981 and was performed for the Defense Nuclear Agency under Military Interdepartmental Purchase Requests 81-640 and 82-581.

The investigation was conducted from March 1981 to October 1982 by personnel of the Hydraulics Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, Dr. R. W. Whalin, former Chief of the Wave Dynamics Division, and Mr. C. E. Chatham, present Chief of the Wave Dynamics Division. Dr. J. R. Houston, Research Hydraulic Engineer, and Mrs. L. W. Chou, Mathematician, conducted the study and prepared this report.

Commanders and Directors of WES during the investigation and the preparation and publication of this report were COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

NUMERICAL MODELING OF EXPLOSION WAVES

PART I: INTRODUCTION

Background

1. Use of undersea explosions to generate water waves was first considered in detail during an experimental program conducted in 1944 under the code name Project Seal (Leach 1950). The advent of thermonuclear devices made it feasible to generate extremely large water waves by explosions.

2. In 1967, Dr. W. G. Van Dorn of the Scripps Institution of Oceanography successfully attracted the attention of the Department of Defense concerning the potential for damage to surface and subsurface ships presented by breaking and spilling waves (surf zone) that would develop on the continental shelf as a result of an explosion in deep water (Moulton and Warner 1967). Consequently, the large surf zone formed on the continental shelf by the breaking of explosion waves is sometimes called the "Van Dorn effect." Subsequent small-scale tests performed at the U. S. Army Engineer Waterways Experiment Station (WES) using conventional explosives demonstrated that surface and subsurface ships could be destroyed by breaking waves generated by explosions.

3. Numerical techniques have been developed to determine waves generated by explosions (Van Dorn 1964, Whalin 1967, and LeMéhauté 1970). These techniques rely upon a theoretical formulation presented by Kranzer and Keller (1959). This is a linear formulation and it also is applicable only to deep water. Thus this formulation is not valid in shallow water where the height-to-depth ratio becomes significant and the wavelength-to-depth ratio is large.

Purpose of This Study

4. The purpose of this study was to develop numerical models that could be used to generate explosion waves from initial deformations of

the water surface produced by explosions, propagate these waves across deep water to the continental shelf, and determine characteristics of the resulting breaking waves that develop on the continental shelf. These models had to be applicable both during propagation over deep water when the waves are linear but highly dispersive and during propagation onto the continental shelf when the waves are nonlinear and essentially nondispersive. In addition, the models had to handle the waves once breaking developed. Furthermore, the Defense Nuclear Agency required that these models be computationally efficient and easy to use.

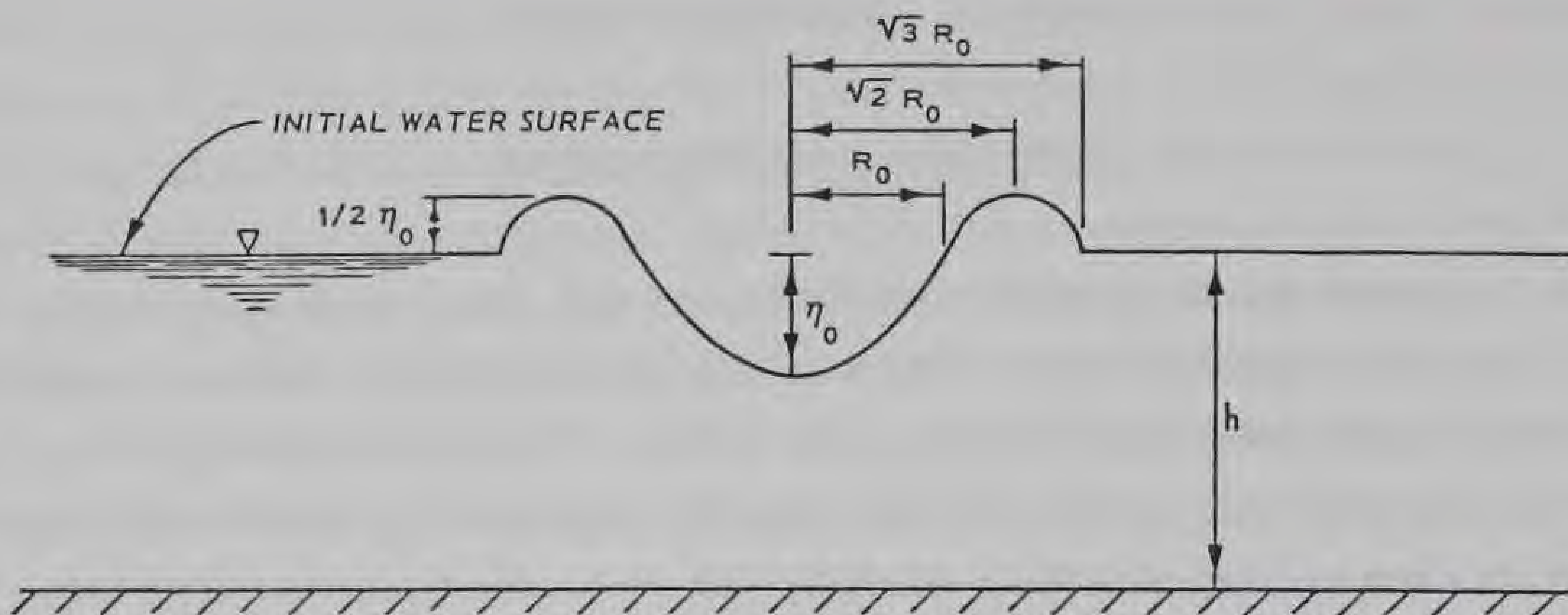
PART II: NUMERICAL MODELS

Generation and Propagation

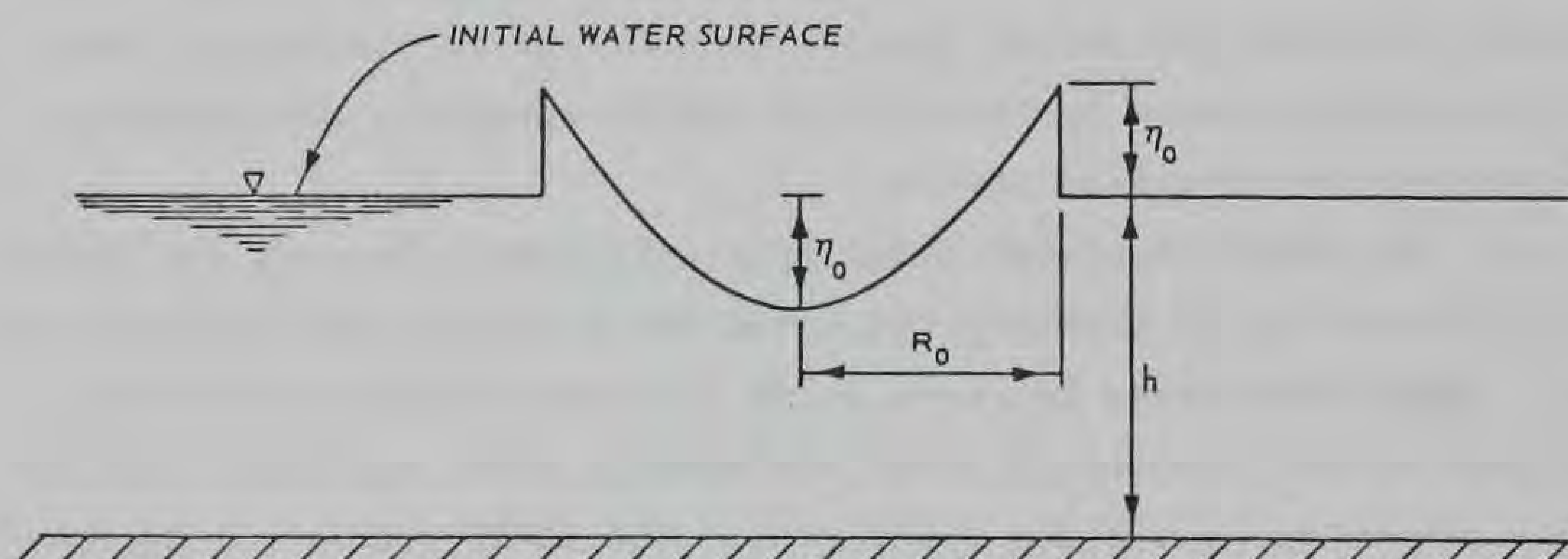
5. Generation of explosion waves and all major propagation effects except refraction were determined using the EXWAV (EXplosion WAVe) numerical model developed during this study. The EXWAV model can be applied to arbitrary sites without lengthy preparation of data for large numerical grids (lengthy data preparation is required for refraction models). The EXWAV model generates explosion waves, propagates them across the deep ocean by calculating radial spreading and frequency dispersion, propagates them across the continental slope by calculating nonlinear shoaling and radial spreading, and finally propagates them after breaking to shore by calculating radial spreading and assuming nonsaturated wave-breaking theory.

6. The EXWAV numerical model initially uses a Kranzer and Keller (1959) formulation to generate the waves and propagate them through deep water. This formulation has been shown in several studies (Van Dorn 1964; Whalin 1967; LeMéhauté 1970; and Whalin, Pace, and Lane 1970) to predict deepwater wave forms quite well. The EXWAV model is programmed to use either of two deformation mathematical models of the generating mechanism that have gained acceptance for realistically predicting deepwater wave forms (Whalin, Pace, and Lane 1970). Figure 1 shows these two surface deformations. In order to allow the option of operating the EXWAV computer code on a very simple computer, all special functions such as Bessel functions and hyperbolic functions are determined internally in the computer code and do not require calls to external library routines that a small computer may not possess.

7. In order to use the two deformations shown in Figure 1, it is necessary to determine η_o and R_o ; η_o is the depth and R_o the radius of the crater produced by the explosion (Figure 1). Van Dorn, LeMéhauté, and Hwang (1968) show that R_o can be related to the yield of the explosion using the expression $R_o = 9.6W^{0.3}$ (determined by scale tests), where W is the charge yield for the parabolic depression



a. Crater with lip



b. Parabolic depression and cylindrical elevation

Figure 1. Initial surface deformations available in WES model

and cylindrical elevation and $R_o = 7.0W^{0.3}$ for the crater with lip (Figure 1). W has units of pounds of TNT and R_o and η_o have units of feet. η_o can be determined for the parabolic depression and the cylindrical elevation using the expression $\eta_o R_o = 0.81H_{max}r$ and for the crater with lip using the expression $\eta_o R_o = 0.65H_{max}r$. H_{max} is the maximum wave height in an explosion-wave packet at a distance of r from the location of the detonation. η_o , H_{max} , and r have units of feet. The value of $H_{max}r$ is dependent upon the depth of submergence of the charge and can be determined for any depth of submergence using a plot presented by Whalin, Pace, and Lane (1970). At upper critical depth $(H_{max}r/W^{0.54}) \simeq 34$. LeMéhauté (1980) presents a somewhat greater value of $(H_{max}r/W^{0.54}) \simeq 36$. However, his plot includes data for 125-lb*-charge tests performed at WES that are apparently in error on his plot by a factor of two. They appear to be $H_{max}r$ instead of $\eta_{max}r$ values, where η_{max} is the maximum wave amplitude. For a surface detonation $(H_{max}r/W^{0.54}) \simeq 23$.

8. The Kranzer and Keller (1959) formulation is used only during deepwater propagation, since as waves enter shallow water nonlinear effects become important. LeMéhauté (1980) shows that nonlinear wave shoaling is an important correction prior to breaking of waves in shallow water. He suggests that each wave of a wave train be treated as a quasi-monochromatic wave and that a correction factor be obtained for the corresponding periodic nonlinear wave. The EXWAV model uses this approach in conjunction with the method developed by Iwagaki (1968) to determine the nonlinear shoaling for each wave. Iwagaki (1968) equated deepwater energy flux given by third-order Stokian theory as presented by LeMéhauté and Webb (1964), with shallow-water flux given by cnoidal theory. LeMéhauté (1971) recommends this approach of equating deepwater energy flux in terms of high-order Stokian theory with shallow-water energy flux in terms of cnoidal wave theory.

9. The change in wave height of each wave on a sloping beach is determined in the EXWAV model using the following equation derived by Iwagaki (1968):

$$\frac{H}{H_o} = \frac{3}{16}\left(\frac{1}{4}\right)^{1/3}\left(\frac{h}{L_o}\right)^{-1}\left(\frac{H_o}{L_o}\right)^{1/3}\left[1 + \pi^2\left(\frac{H_o}{L_o}\right)^2\right]$$
$$\cdot\left[1 - \frac{1}{K}\frac{H}{h} + \frac{1}{12}\frac{1}{K}\left(\frac{H}{h}\right)^2\right]^{-1/3} \cdot \left[1 - a\left(\frac{H}{h}\right)^n\right]^{2m/3} \qquad (1)$$
$$\cdot\left[1 - \frac{3}{2}\frac{1}{K} + \frac{H}{h_t}\left(\frac{2}{5} - \frac{5}{2}\frac{1}{K} + \frac{3}{K^2}\right) + \left(\frac{H}{h_t}\right)^2\left(-\frac{31}{112} - \frac{29}{160}\frac{1}{K} + \frac{13}{4}\frac{1}{K^2}\right)\right]^{-2/3}$$

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* Multiply pounds (force) by 4.48222 to obtain newtons.

where h_t is the water depth below the wave trough and is expressed as follows:

$$\frac{h_t}{H} = \frac{h}{H}\left[1 - \frac{1}{K}\frac{H}{h} + \frac{1}{12}\frac{1}{K}\left(\frac{H}{h}\right)^2\right] \quad (2)$$

K is the complete elliptic integral of the first kind which Iwagaki approximates by

$$\frac{K}{T\sqrt{\frac{g}{h}}} = \frac{\sqrt{3}}{4}\left(\frac{H}{h}\right)^{1/2}\left[1 - a\left(\frac{H}{h}\right)^n\right]^m \quad (3)$$

and

$$\frac{H}{h} = \frac{H}{H_o}\frac{H_o}{L_o}\left(\frac{h}{L_o}\right)^{-1} \quad (4)$$

T = wave period

g = acceleration due to gravity

h = water depth

H = wave height

a = 1.3 , n = 2 , and m = 1/2 for H/h = 0.55

a = 0.54 , n = 3/2 , and m = 1 for H/h > 0.55

H_o = wave height in deep water

L_o = wavelength in deep water

Since H/H_o is on both sides of Equation 1, this equation must be solved along with Equation 4 using successive iterations. The wave crest height above still water is given by the following equation:

$$\frac{\eta}{H} = 1 - \frac{1}{K}\left(1 - \frac{1}{12}\frac{H}{h}\right) \quad (5)$$

where η is the wave crest height.

10. At some point on the continental slope or shelf, waves begin breaking and the EXWAV model uses nonsaturated wave-breaking theory developed specifically for explosion waves (LeMéhauté 1962, Divoky and LeMéhauté 1970) and now accepted as the leading theory for spilling breakers. This theory maintains that there is a maximum amount of

energy that can be transmitted by a wave over a given water depth on a gentle slope. If frictional effects do not damp the wave to the energy level dictated by the local water depth, the wave will break and dissipate energy at a rate such that the proper energy level is continuously maintained. The relation between wave height and water depth given by measurements of Divoky and LeMéhauté (1970) is used in the EXWAV model. Thus $H = 0.78h$, where H is the wave height and h the water depth.

11. The EXWAV model, therefore, uses a Kranzer and Keller (1959) formulation (two-dimensional and constant depth) over an average deep-water depth. This formulation allows the waves to be generated from an initial deformation and propagated over deep water to the continental shelf region. A quasi-two-dimensional formulation (which allows radial spreading but not refraction) is then used to determine the nonlinear shoaling and nonsaturated wave breaking. The model is thus able to predict the wave field over the complete region from generation to the shoreline including the area of the continental shelf where the Van Dorn effect is of concern. Refraction effects (which require time-consuming preparation of large grids) are considered in the next section of this report and neglected in the EXWAV model.

Wave Refraction

12. Wave refraction was calculated in this study using the numerical model REFRAC (REFRACtion) which is based on a method developed by Dobson (1967). This method solves two equations. One equation determines curvature of the wave ray and is given by the following:

$$P = \frac{1}{c}\frac{dc}{dh}\left(\sin\alpha\frac{\partial h}{\partial x} - \cos\alpha\frac{\partial h}{\partial y}\right) \tag{6}$$

where

P = curvature of the wave ray

c = wave celerity

h = water depth

α = direction of wave propagation x = a Cartesian coordinate

y = a Cartesian coordinate

The other equation is the wave intensity equation given by the following:

$$\frac{\partial^2 \beta}{\partial t^2} + p(t) \frac{\partial \beta}{\partial t} + q(t)\beta = 0 \qquad (7)$$

where

β = wave separation factor

t = time

p(t) is given by the equation

$$p(t) = -2 \frac{dc}{dh} \left(\cos \alpha \frac{\partial h}{\partial x} + \sin \alpha \frac{\partial h}{\partial y}\right) \qquad (8)$$

and q(t) by the equation

$$q(t) = c \frac{dc}{dh} \left\{ \sin^2 \alpha \left[\frac{\partial^2 h}{\partial x^2} + U\left(\frac{\partial h}{\partial x}\right)^2\right] + 2 \sin \alpha \cos \alpha \left[\frac{\partial^2 h}{\partial x \partial y} + U \left(\frac{\partial h}{\partial x}\right) \frac{\partial h}{\partial y}\right] + \cos^2 \alpha \left[\frac{\partial^2 h}{\partial y^2} + U\left(\frac{\partial h}{\partial y}\right)^2\right] \right\} \qquad (9)$$

where

$$U = \frac{-2\sigma c R_c}{\left[c R_c + \sigma h\left(1 - R_c^2\right)\right]^2} \qquad (10)$$

and

σ = wave angular frequency

$R_c = c/c_o$

where c_o is the wave celerity in deep water

13. Equations 6 and 7 are solved using finite differences. Since the points of interests will not in general fall on regular mesh points of a numerical grid, an interpolation scheme based upon the method of least squares is used. Since Equation 7 requires second-order

partial derivatives of the depth function, a second-degree polynomial was chosen to describe the surface of fit.

14. The method of Dobson (1967) differs significantly from typical wave-refraction methods. Typical wave-refraction methods only solve the curvature of the wave ray equation (Equation 6). The refracted wave height then must be determined manually by considering the separation between two adjacent wave rays. However, Dobson (1967) solves the wave intensity equation (Equation 7) in addition to the curvature of the wave ray equation. Thus, there is no necessity for manual measurements of ray separation. The method of Dobson (1967) continually calculates the refracted wave height along each wave ray so that the wave height is known along the complete path of a ray.

Verification

15. The EXWAV model was verified by comparisons of calculated wave forms with measured waves generated by a 9,250-lb TNT charge detonated at upper critical depth in 130 ft* of water during the 1965 Mono Lake test series. Figure 2 shows the test conditions and wave gage locations. Shot number 3 was detonated at a water depth of 1.40 ft (approximately upper critical depth). Figure 3 shows a comparison of calculated (using crater with lip initial deformation) and measured wave forms in deep water (107.6 ft) at a distance of 1,506 ft from the detonation location. Differences between measured and calculated wave forms are attributable to experimental scatter in the data used to establish the η_o and R_o values. The wave forms can be forced to be in better agreement by varying η_o and R_o values--as shown by the calculations of Whalin, Pace, and Lane (1970) for the same test (Figure 4). However, for all of the comparisons presented in this report, there are no adjustments of η_o and R_o values to force agreement between measured and computed wave forms.

16. Comparisons between measured and calculated wave forms in

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* Multiply feet by 0.3048 to obtain metres.

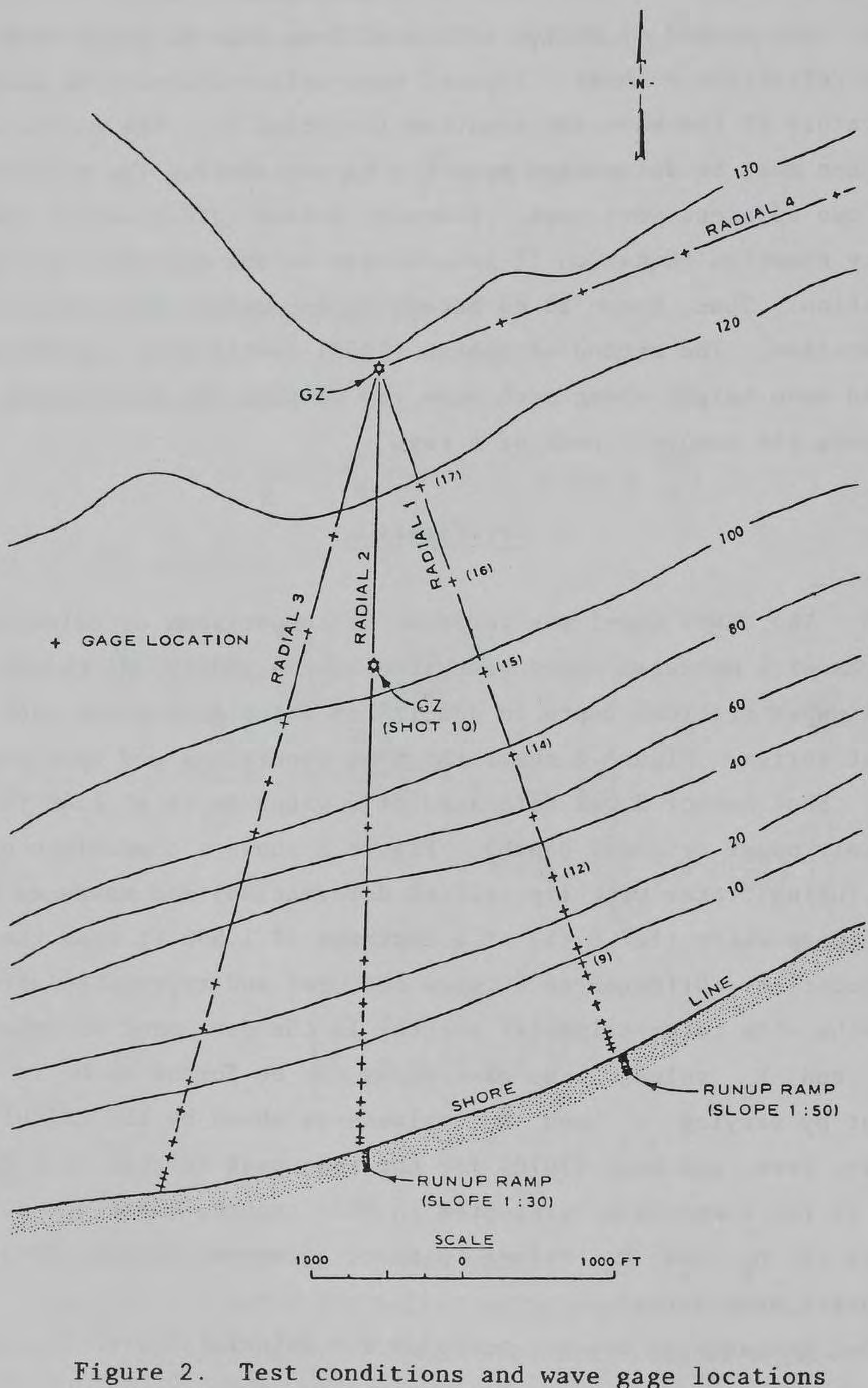


Figure 2. Test conditions and wave gage locations

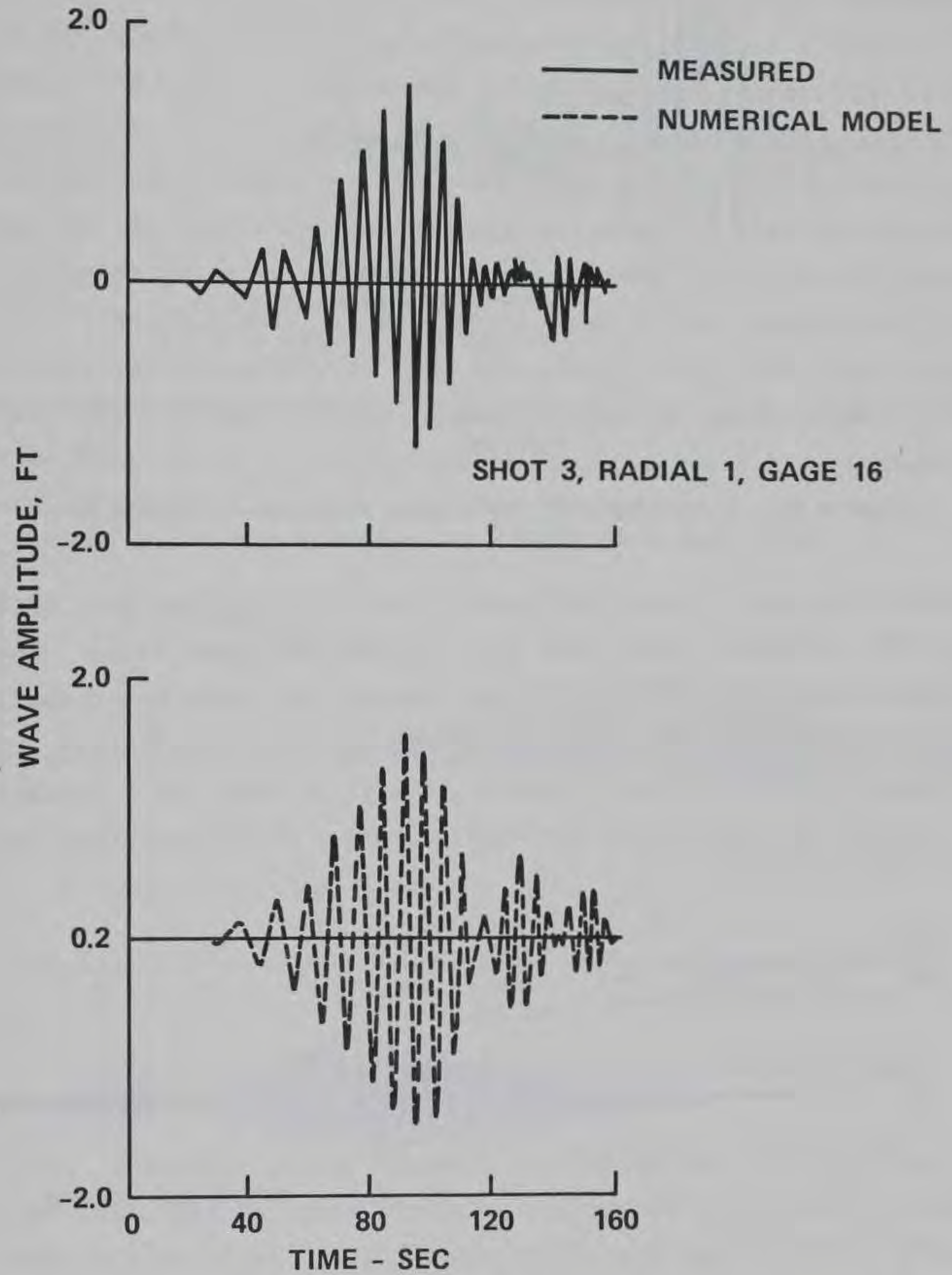


Figure 3. Comparison of calculated and measured wave forms (water depth of 107.6 ft)

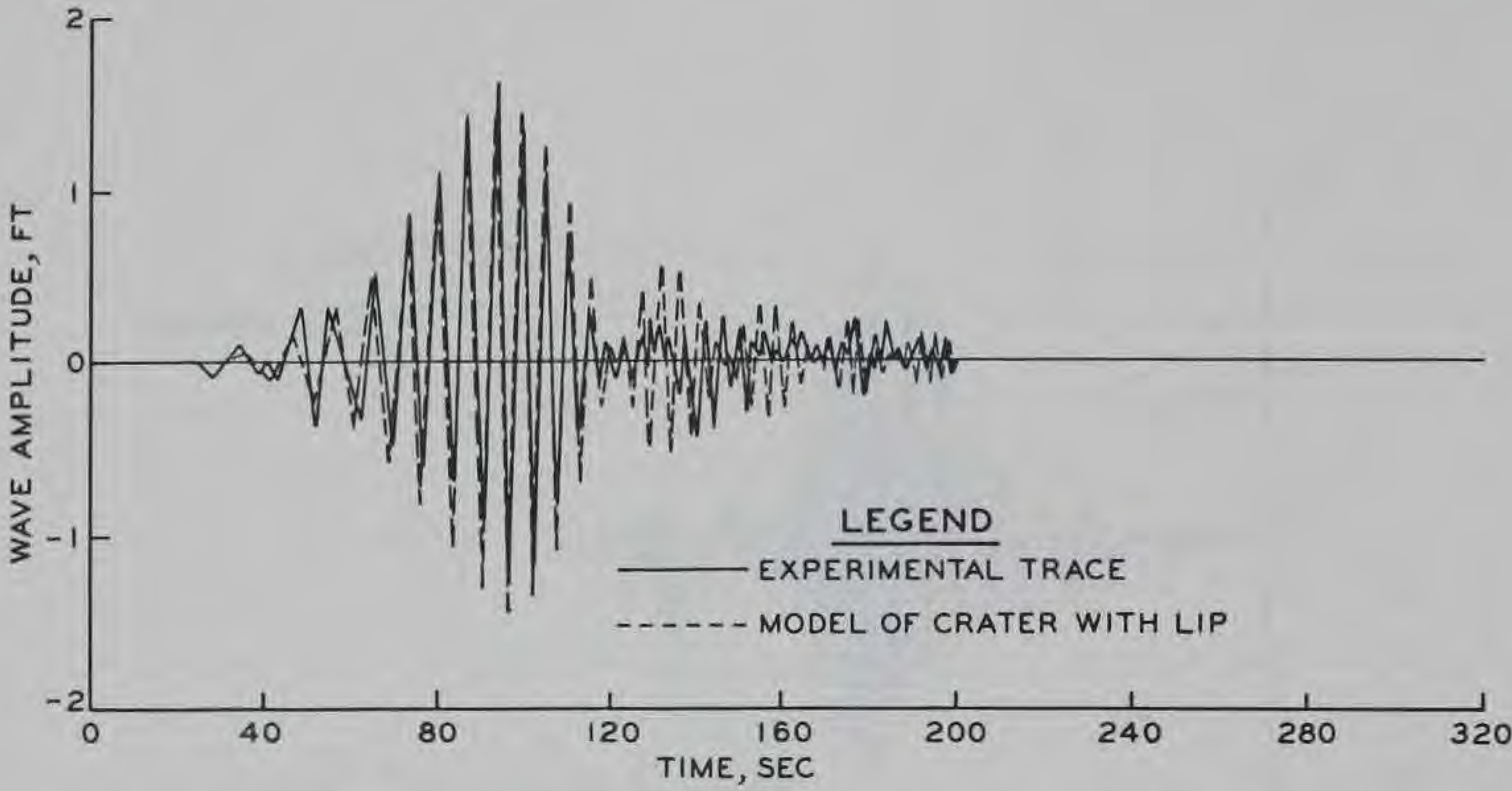


Figure 4. Comparison of wave form calculated by Whalin, Pace, and Lane (1970) and measured wave form

deep water have been presented by many investigators (Van Dorn 1964; Whalin 1967; LeMéhauté 1970; and Whalin, Pace, and Lane 1970). However, such comparisons have not been attempted once the waves enter shallow water. Using the shallow-water techniques described previously, the EXWAV model calculated a wave form in 11.2 ft of water at a distance of 4,074 ft from the detonation and Figure 5 presents a comparison with the

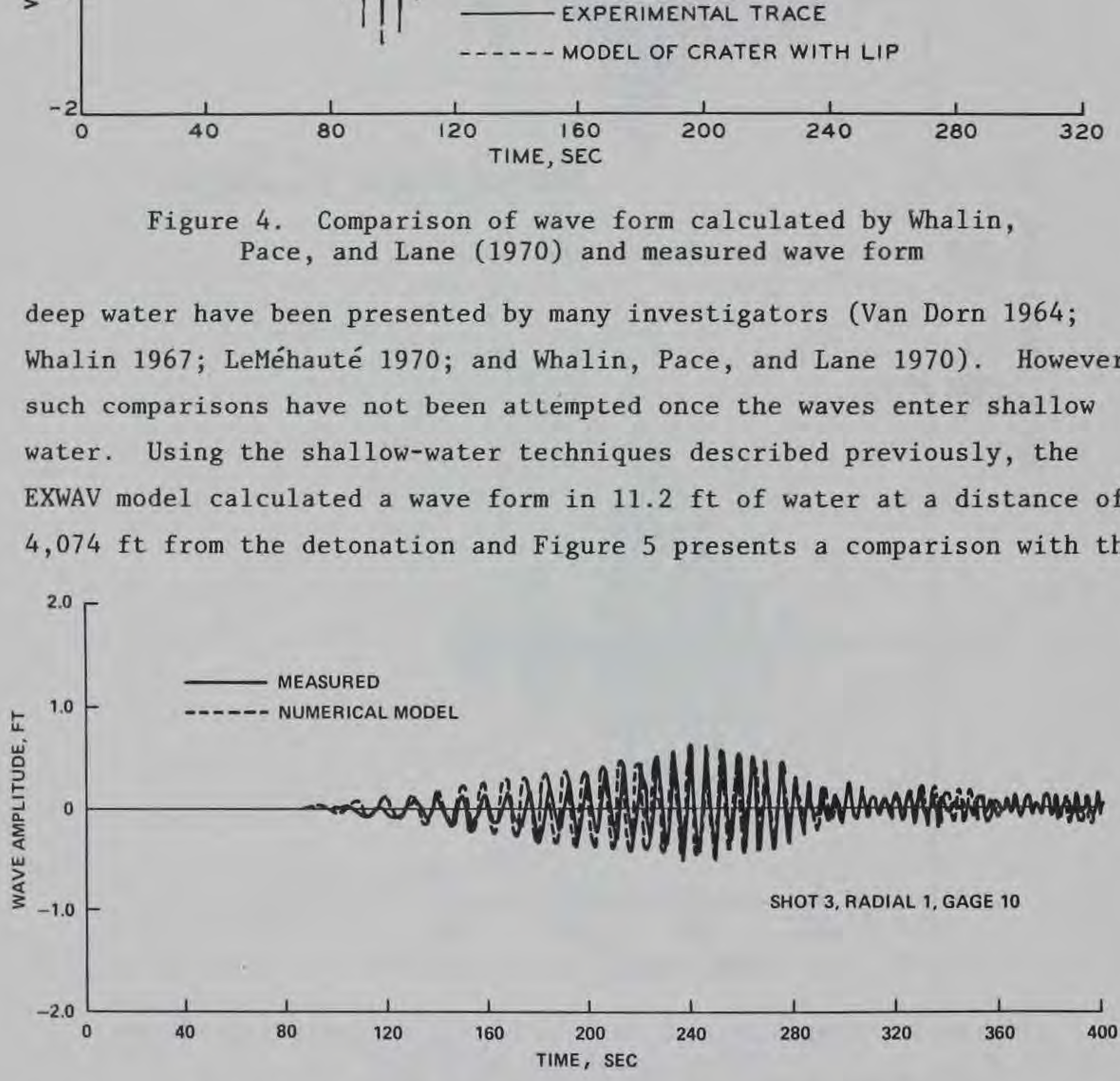


Figure 5. Comparison of calculated and measured wave form (water depth of 11.2 ft)

measured wave form. Similar comparisons are presented in Figures 6, 7, and 8 for waves measured in 4.0, 2.3, and 1.5 ft of water. The calculated and measured wave forms are in remarkable agreement considering the strong nonlinearity in such shallow water. The wave form in 1.5 ft of water is a breaking wave (note the energy loss between the 2.3-ft depth and the 1.5-ft depth). The difference between the measured and calculated values appears to be mainly related to data scatter in determining the η_o and R_o values. Again, there has been no adjustment of any parameter to force the excellent agreement presented in Figures 3 and 5-8. The only physical parameters used in the simulation of this event were the bathymetry of Mono Lake, the charge size, the distance of the gages from the detonation, the water depths at the gage locations, and the value of $H_{max}r$ for a detonation at upper critical depth as determined from Whalin, Pace, and Lane (1970).

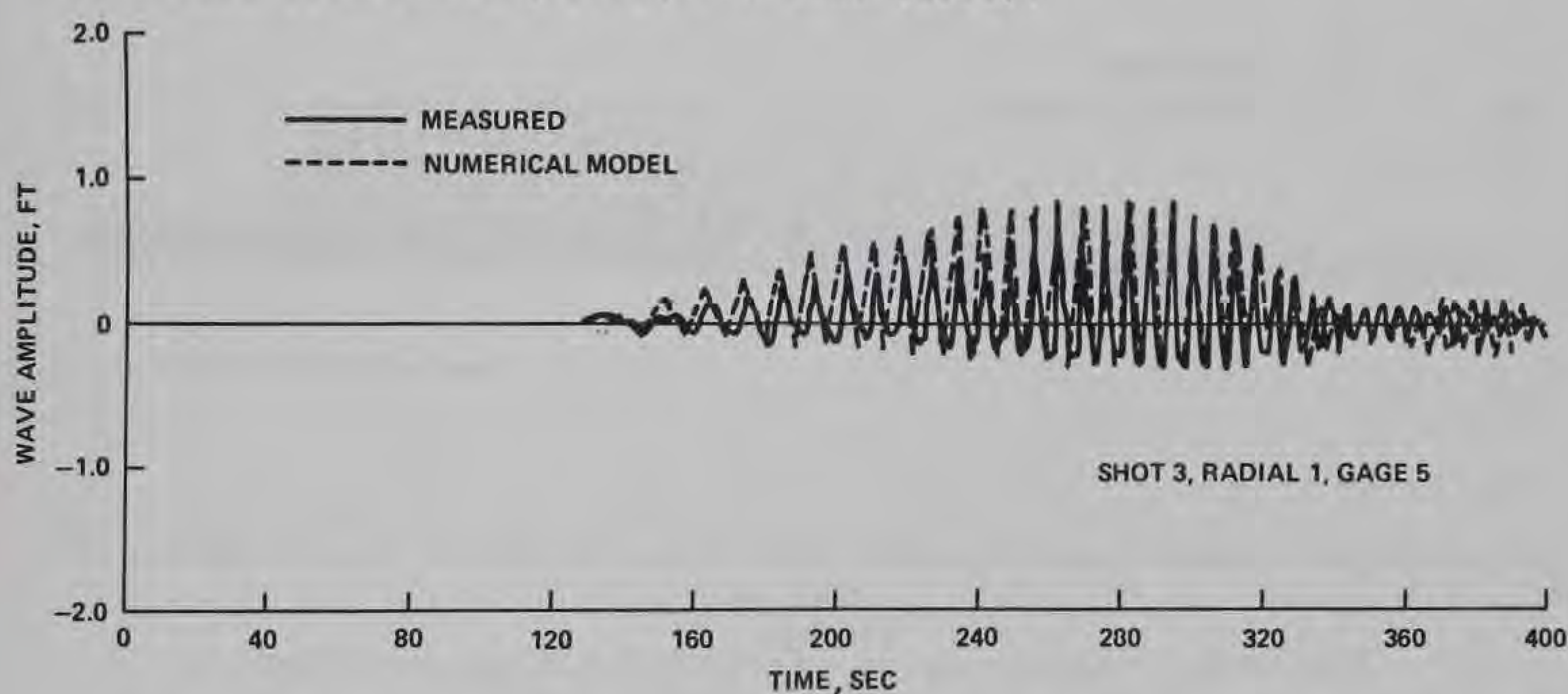


Figure 6. Comparison of calculated and measured wave forms (water depth of 4.0 ft)

17. The REFRAC model was verified by Dobson (1967). This model also has been used to calculate wave refraction in several studies at WES (e.g. Outlaw et al. 1977, Bottin 1977, and Bottin 1979). The REFRAC model calculated negligible refraction effects along radial 1 shown in Figure 2. This radial is perpendicular to bathymetric contours and thus refraction is small. Therefore, comparisons were made along radial 2 (Figure 2). The EXWAV model was used to determine frequency dispersion,

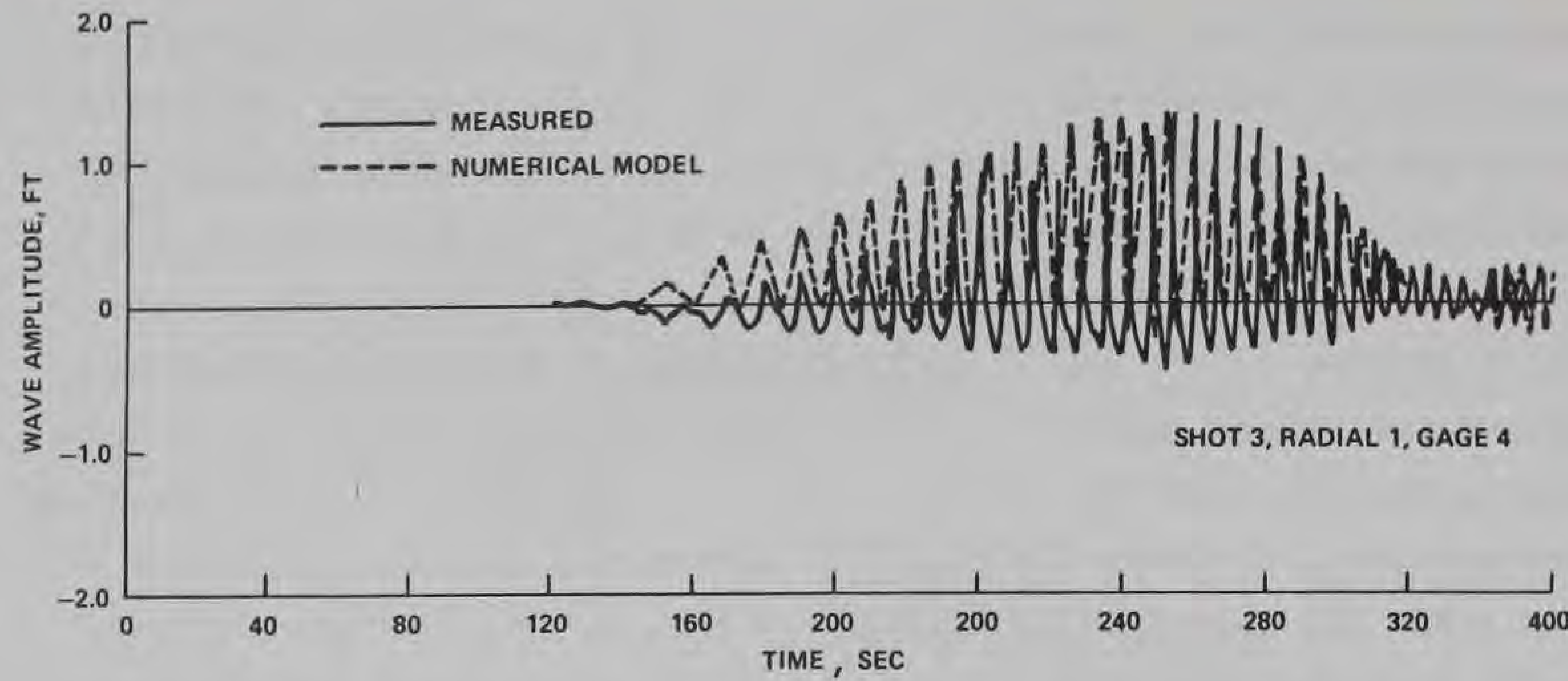


Figure 7. Comparison of calculated and measured wave forms (water depth of 2.3 ft)

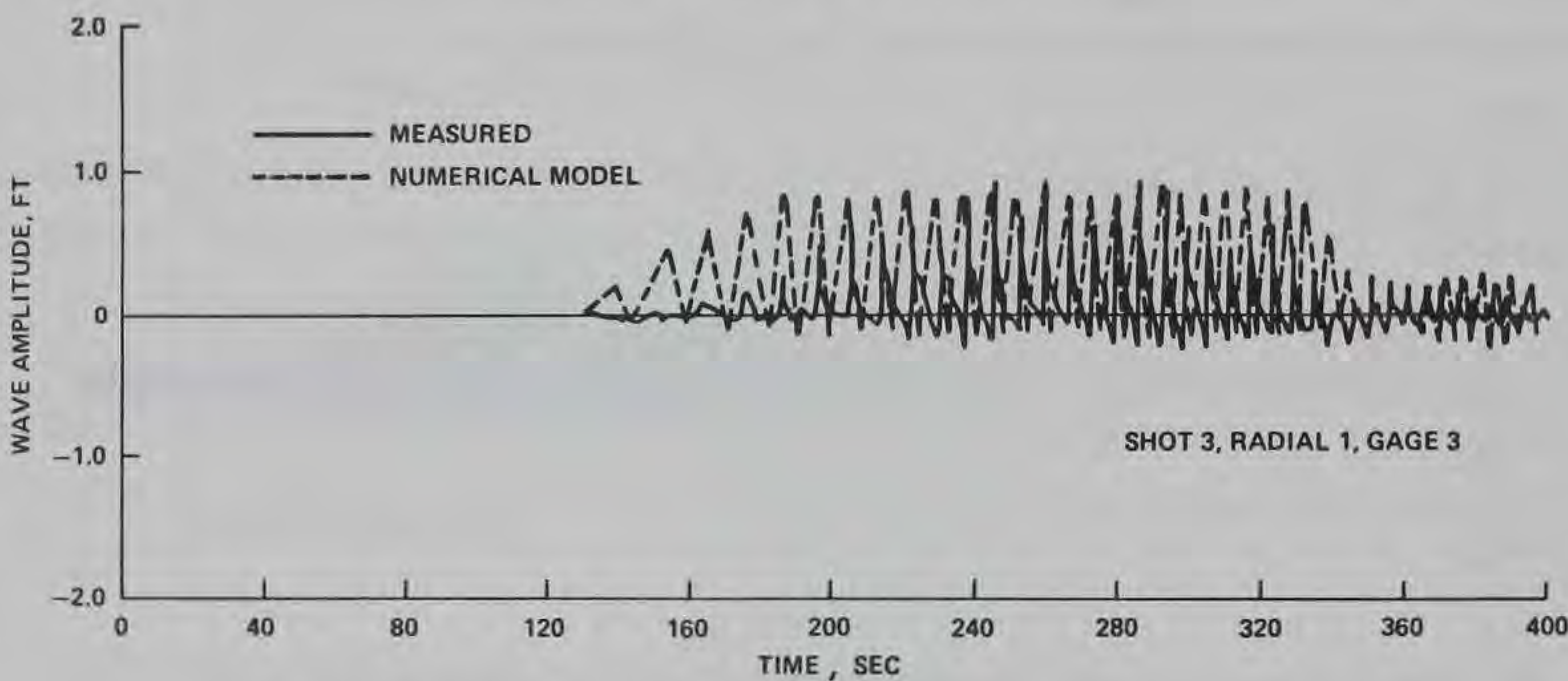


Figure 8. Comparison of calculated and measured wave forms (water depth of 1.5 ft)

radial spreading, and nonlinear shoaling and the REFRAC model was used to determine refraction effects. Refraction coefficients were determined by the REFRAC model for each crest and trough of the wave form determined by the EXWAV model. Wave heights were then multiplied by refraction coefficients. Figures 9 and 10 show good agreement between calculated and measured wave forms in 8.1- and 11.2-ft water depths.

18. In addition to calculating explosion-wave generation and propagation, the EXWAV model also has an optional feature that determines

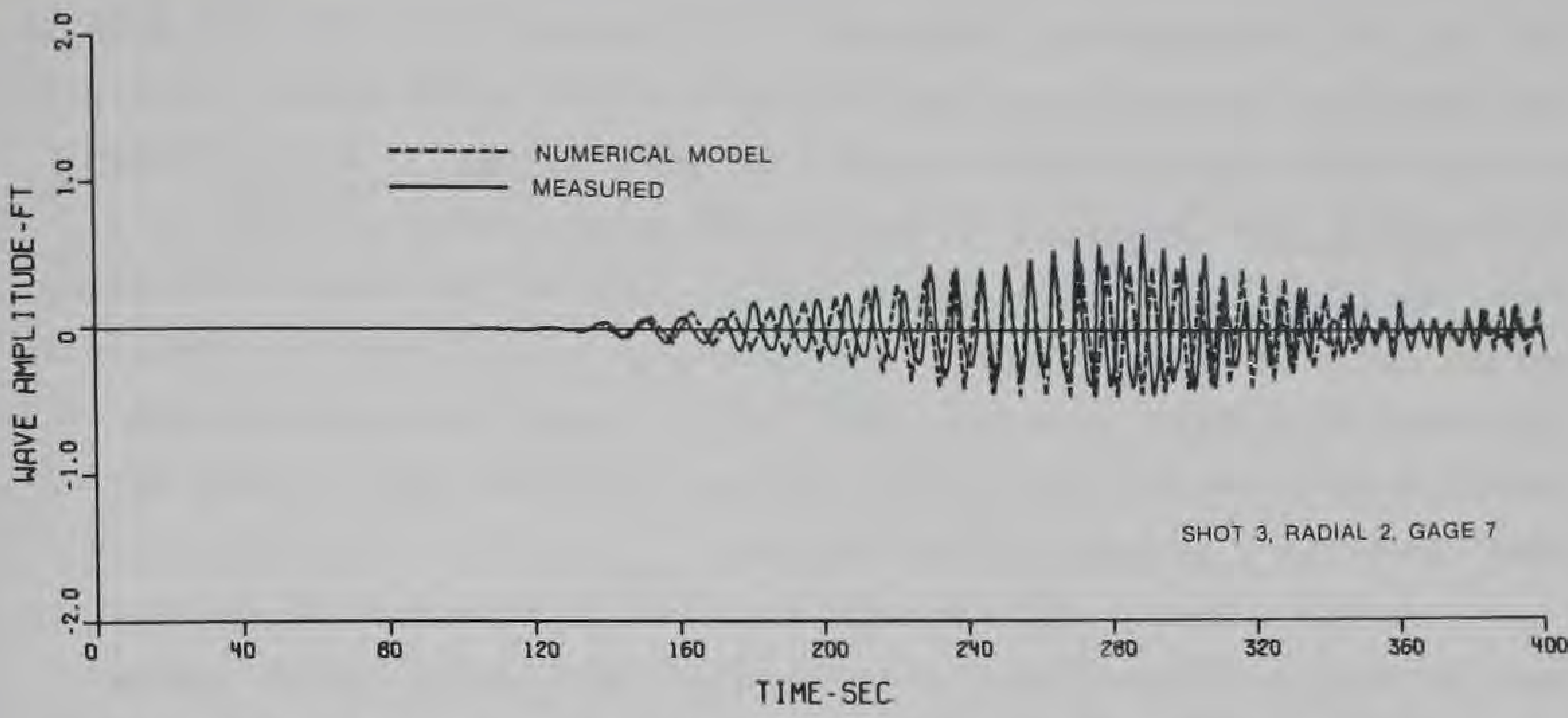


Figure 9. Comparison of calculated and measured wave forms along radial not perpendicular to contours (water depth of 8.1 ft)

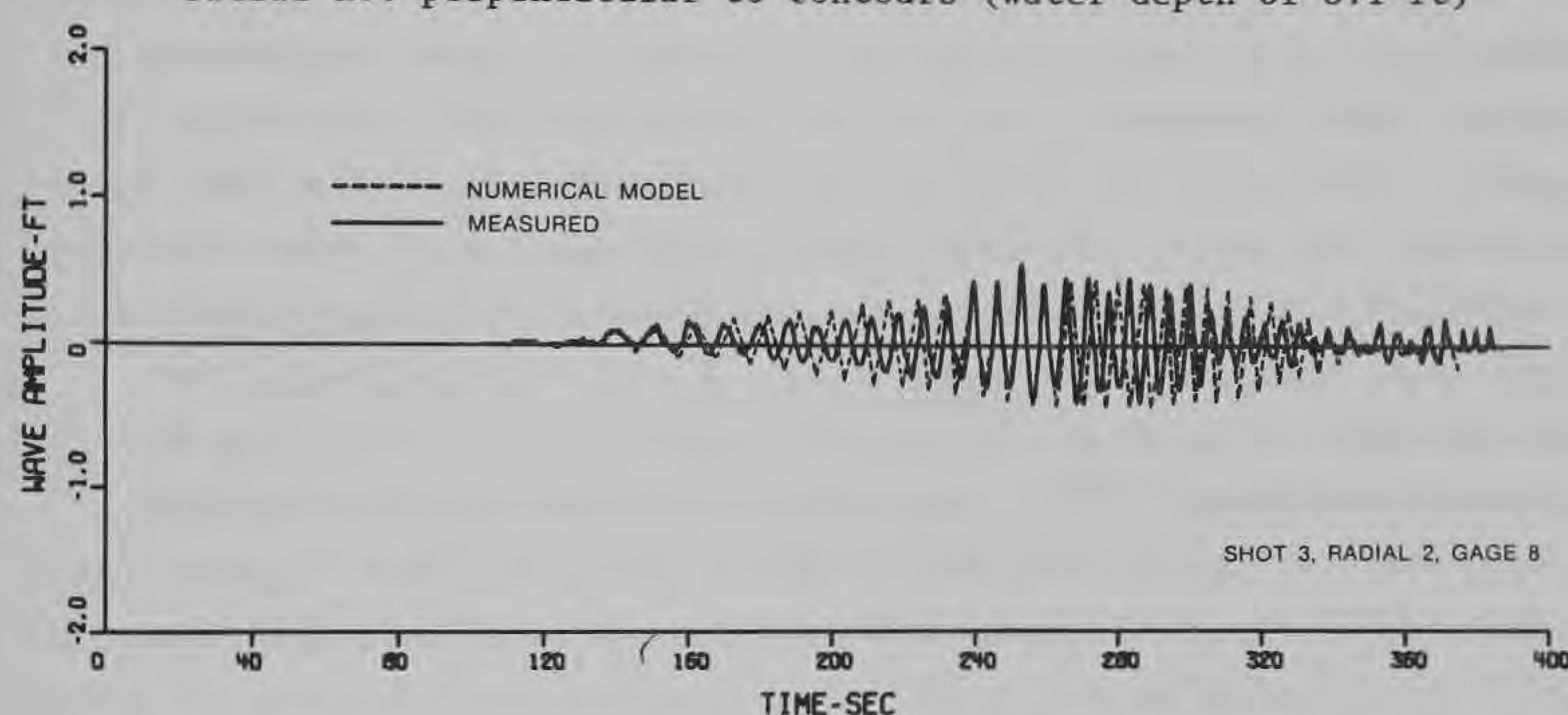


Figure 10. Comparison of calculated and measured wave forms along a radial not perpendicular to contours (water depth of 11.2 ft)

the optimum location to detonate an explosive device for a realistic situation. In the past, it was usually assumed that beyond the continental shelf the water depth increased rapidly to depths greater than 10,000 ft. The best location to detonate an explosive device for this case was at a water depth such that the bottom did not interfere with the generation process. LeMéhauté (1971) presents this water depth as satisfying the inequality $h/W^{0.3} \geq 6$. h is the water depth in feet and W the charge weight in pounds of TNT equivalent. However, much of the coastline of the United States does not follow the simple pattern of a single rapid decline from continental shelf depths to large depths. For example, off the coast of Georgia the water depths increase to a depth of 2,500 ft and then remain fairly constant for hundreds of miles before there is another rapid depth increase. If an explosive device is detonated at a depth given by $h/W^{0.3} \geq 6$, geometric spreading and frequency dispersion will reduce wave heights to quite small values before they reach the continental shelf region.

19. In order to consider all possible shelf areas, it is necessary to analyze detonations in intermediate and shallow-water depths where $h/W^{0.3} \leq 6$. In these water depths, the bottom interferes with the wave generation process and smaller waves are generated than can be generated by a deepwater detonation. However, if these intermediate and shallow depths are much closer to the continental shelf than deepwater depths, larger waves may result on the continental shelf from explosions in the shallow water. The EXWAV uses an empirical relationship presented by LeMéhauté (1971) to determine the reduction of wave heights due to explosions in intermediate depth water. A similar relationship for shallow-water detonations was derived in this study by analyzing data presented by Strange (1955). The EXWAV model then considers bottom interference in wave generation, geometric spreading, and frequency dispersion to determine the optimum depth to detonate an explosive device.

Application

20. There are no data for large explosion waves propagating on an actual continental slope and shelf. However, scale model tests have been performed in the past at WES (Bucci, Whalin, and Strange 1971). An actual continental shelf location (classified) was modeled in this test series. Since the model scale and all prototype units are classified, only the unclassified model units are presented in this report.

21. Figure 11 shows a comparison between wave heights measured in

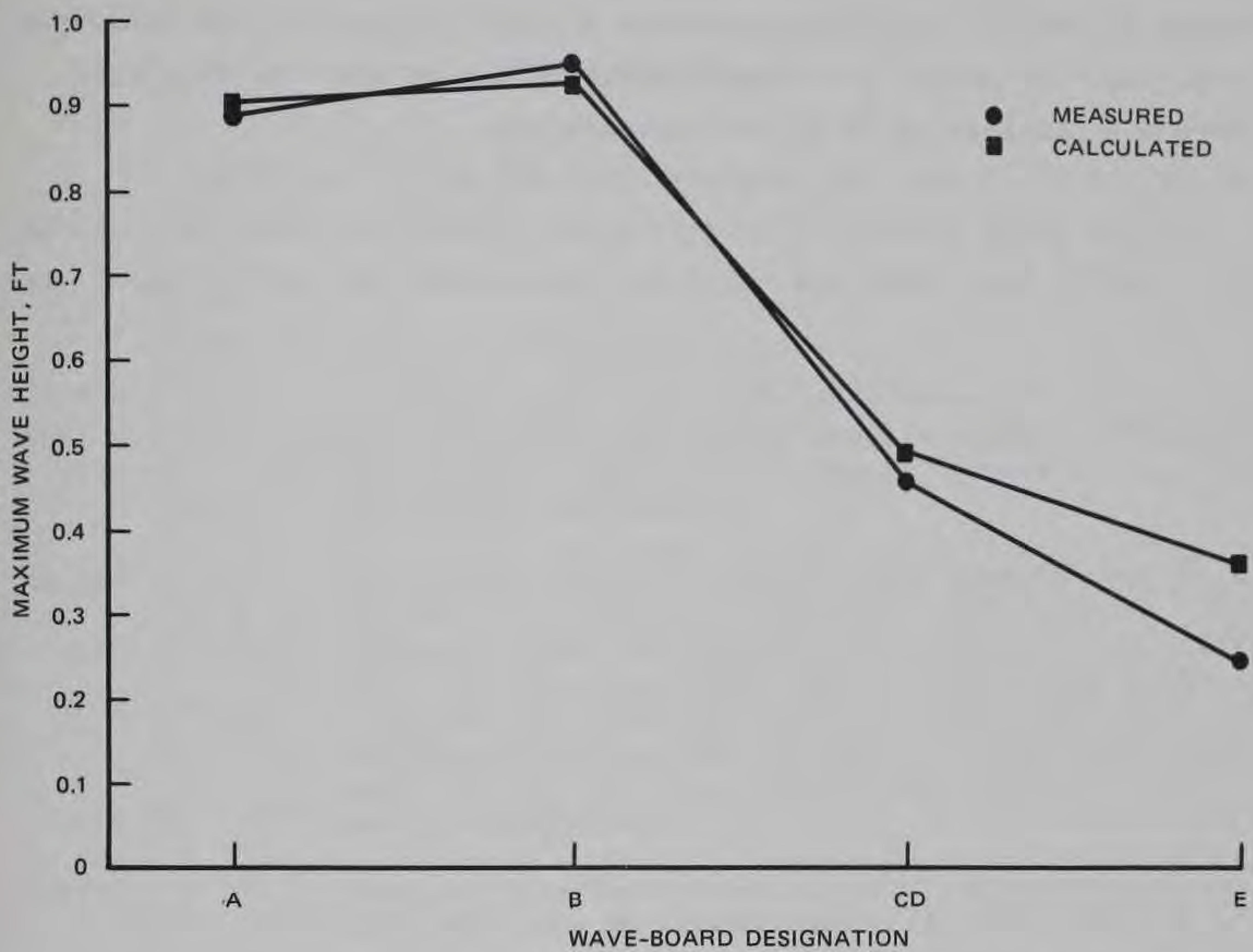


Figure 11. Comparison of calculated and measured wave heights surf zone basin model (27-lb charge)

the scale model tests and wave heights calculated using the EXWAV model (since the model results were measured along a line perpendicular to the bottom bathymetric contours, refraction effects are small and the REFRAC model is not needed). Comparisons are at wave board locations reported in the scale model tests (Bucci, Whalin, and Strange 1971). Wave heights on wave boards C and D were reported as a single average wave height, therefore this average wave height is presented in Figure 11 for wave board CD.

22. Figure 11 shows good agreement between measured and calculated maximum wave heights. The wave heights decrease beyond wave board B as a result of wave breaking.

23. The EXWAV model can handle large-scale nuclear explosions in

addition to small-scale conventional explosions. The variable ISCALE defined in PART III determines whether a large- or small-scale explosion is desired. An actual prototype bathymetry can be used for realistic full-scale simulations of nuclear detonations.

PART III: PROGRAM EXWAV

Data Definition

24. All data except the profile depths are entered into program EXWAV in an interactive mode from a terminal. Program EXWAV will request the user to specify a numerical value for each input variable.

Variable	Description
NUNITS	Specifies the units of the profile depths. NUNITS=1 for depths in feet, =2 for depths in metres, =3 for depths in fathoms.
ISCALE	Establishes whether explosion uses conventional high explosives or nuclear explosives. ISCALE=1 for conventional high explosives, =2 for nuclear explosives. This variable establishes whether the charge yield is in pounds (for high explosives) or megatons (for nuclear explosives) and whether grid cell size is in units of feet (for high explosives) or miles (for nuclear explosives).
LOC(I)	The grid locations at which calculations are desired. The number of grid locations is NNL.
KZERO	The grid location of the detonation.
IWPER	If wave periods are not needed for later refraction IWPER=1, otherwise IWPER=2.
IREF	IREF=1 refraction coefficients are not available. IREF=2 refraction coefficients are available from previous run.
NREF	The number of refraction coefficients at shallow-water locations.
IDEPTH	Specifies whether detonation is at upper critical depth or is a surface detonation. IDEPTH=1 for upper critical depth, =2 for surface detonation.
DELTA	Specifies the grid cell size along a depth profile (distance between depth recordings in the profile). Units of feet if ISCALE=1 and miles if ISCALE=2.

Variable	Description
WP(J)	Specifies the charge yield. In units of pounds if ISCALE=1 and megatons if ISCALE=2.
NPTS	Specifies the number of grid cells in a depth profile.
NNL	Specifies the number of locations at which wave height calculations are desired.

Data Input

25. The procedure to connect the DNA Tektronix 4051 terminal to the DNA computer at the Air Force Weapons Laboratory (AFWL), Kirtland, New Mexico, is described in detail in Appendix A.

26. All data except profile depths are submitted to program EXWAV through an interactive mode. The profile depths are submitted to program EXWAV by establishing a data file. A data file can be established either by submitting cards containing depth values through a batch terminal or using the EDITOR mode on an interactive terminal. The job control cards for submitting the data on a batch terminal are as follows (all information on control cards begins in column 1):

Card 1: NAME,CM20000.

This card identifies the job. NAME can be the user's last name (not over 7 characters). CM20000 is the maximum octal field length for the job.

Card 2: USER(,)

This card identifies the user. The user's ID is the first term in the parentheses. The user's password then follows the comma.

Card 3: CHARGE(,)

This card identifies the charge account. The first term after the parenthesis is the charge number. The project number then follows the comma.

Card 4: COPY(INPUT,A)

This card copies the profile data read by the card reader onto local file A.

Card 5: REWIND,A.

This card rewinds local file A.

Card 6: SAVE(A,FILENAME)

This card copies local file A onto a permanent disc file. An arbitrary FILENAME should be specified.

Card 7: 789 multipunch.

That is, the numbers 7, 8, and 9 all punched in column 1. This card separates the control cards from the data file.

DATA cards:

As many profile depth values as desired should be placed on cards with a format of 7F10.2.

Final Card: 6789 multipunch.

That is, the numbers 6, 7, 8, and 9 all punched in column 1. This card indicates the end of the job.

27. The above control cards establish and save a data file. Such a file is called an indirect access permanent file. To access an indirect access permanent file, it is necessary to use the "GET" command instead of the "ATTACH" command, such as "GET,A=B." Where A is a local (arbitrary) file name and B is a permanent file name.

28. A data file also can be established using the EDITOR mode on an interactive terminal. After connecting with the DNA computer (the login procedure for a Tektronix 4051 terminal is explained in Appendix A) the following steps are taken to establish a data file:

Step 1: Type in

NEW, File name (arbitrary name not exceeding 7 characters).

Step 2: Type in

TRMDEF,PW=74

DNA computer will respond with TRMDEF PROCESSING COMPLETE.

Step 3: Type in

TEXT

DNA computer will respond with ENTER TEXT MODE.

Step 4: Type in Data and use the format as stated in the Data Definition section.

Step 5: Press down both control key and T in order to get out of the TEXT mode. DNA computer will respond with

EXIT TEXT MODE

Step 6: Type in

SAVE, FILE NAME (File name should be the same name that is used in Step 1).

Step 7: Type in

CATLIST

29. The terminal will respond with a listing of the user's cataloged file name. Check and make sure that name of the newly created permanent file is on the list.

Example Problem

30. The purpose of this example problem is to calculate wave forms generated by a 9,250-lb TNT charge detonated at upper critical depth in 130 ft of water (this simulates shot number 3 and radial 2 of the Mono Lake test series).

Preparation of input data

31. In this example, the profile depths are submitted to the program EXWAV by establishing an indirect access permanent file (MONOR2), and other data are entered into the computer at run times.

Preparation of data file

32. The data file is established by reading data cards using a batch terminal. The values are then stored in an indirect access permanent file (MONOR2). The procedure for creating the indirect access permanent file is shown in Table 1.

Table 1

```
LUCIA,CM20000.
USER(USAEXLC,PEANUTS)
CHARGE(USAEWES,M8202)
COPY(INPUT,A)
REWIND,A.
SAVE(A,MONOR2)
789
```

129.00	128.54	128.07	127.61	127.14	126.68	126.21
125.75	125.28	124.82	124.35	123.89	123.42	122.96
122.49	122.03	121.56	121.10	120.63	120.17	119.70
118.91	118.12	117.34	116.55	115.76	114.97	114.18
113.40	112.61	111.82	111.03	110.24	109.46	108.67
107.88	107.09	106.30	105.52	104.73	103.94	103.15
102.36	101.58	100.79	100.00	98.57	97.14	95.71
94.29	92.86	91.43	90.00	88.57	87.14	85.71
84.29	82.86	81.43	80.00	75.35	70.70	66.79
62.88	58.97	55.06	51.14	47.23	43.32	39.41
35.50	33.98	32.45	30.93	29.40	27.88	26.35
24.83	23.30	22.57	21.83	21.10	20.37	19.63
18.90	17.13	15.35	13.58	11.80	10.93	10.05
9.18	8.30	7.90	7.50	7.10	6.60	6.10
5.60	5.30	3.40	1.50	1.00	.50	

```
6789
```

Running EXWAV

33. To run EXWAV on the DNA Tektronix 4051 a column width of 74 characters must first be established using the command TRMDEF,PW=74. Since EXWAV actually runs in a batch mode through submission by an interactive terminal, the command BATCH must be given. EXWAV is stored as a permanent file and must be obtained using the command OLD,EXWAV. The data file MONOR2 must be placed on TAPE9. The FTN command compiles EXWAV (L=0 suppresses a listing of EXWAV), EXWAV is executed using the LGO command. The following statements are used to run EXWAV (after the LGO statement EXWAV asks the user a series of questions which the user answers by placing an appropriate number after the question mark):

Actual Computer Run of EXWAV

```
 TRMDEF,PW=74
 TRMDEF COMPLETE.
/BATCH
RFL,0.
/OLD,EXWAV
/GET,TAPE9=MONOR2
/FTN,I=EXWAV,L=0.
      .989 CP SECONDS COMPILATION TIME
/LGO.
```

Note: The statements after the "/" mark are entered by the user.

34. The following questions are asked by EXWAV:

```
 IF DEPTH UNITS ARE FEET ENTER '1', IF METERS ENTER '2', IF FATHOMS ENTER
'3'
? 1

 IF HE TESTS ENTER '1', IF NUCLEAR TESTS ENTER '2'
? 1

 IF UPPER CRITICAL DEPTH ENTER '1', IF SURFACE DETONATION ENTER '2'
? 1

 INPUT THE GRID SIZE ALONG A PROFILE(FEET FOR HE TESTS AND MILES FOR
 NUCLEAR)
? 50

 INPUT THE CHARGE YIELD (LBS FOR HE TESTS AND MEGATONS FOR NUCLEAR)
? 9250

 INPUT THE NUMBER OF GRID POINTS IN PROFILE
? 104
```

PROFILE DEPTHS

1	2	3	4	5	6	7
129.00	128.54	128.07	127.61	127.14	126.68	126.21
8	9	10	11	12	13	14
125.75	125.28	124.82	124.35	123.89	123.42	122.96
15	16	17	18	19	20	21
122.49	122.03	121.56	121.10	120.63	120.17	119.70
22	23	24	25	26	27	28
118.91	118.12	117.34	116.55	115.76	114.97	114.18
29	30	31	32	33	34	35
113.40	112.61	111.82	111.03	110.24	109.46	108.67
36	37	38	39	40	41	42
107.88	107.09	106.30	105.52	104.73	103.94	103.15
43	44	45	46	47	48	49
102.36	101.58	100.79	100.00	98.57	97.14	95.71
50	51	52	53	54	55	56

94.29	92.86	91.43	90.00	88.57	87.14	85.71
57	58	59	60	61	62	63
84.29	82.86	81.43	80.00	75.35	70.70	66.79
64	65	66	67	68	69	70
62.88	58.97	55.06	51.14	47.23	43.32	39.41
71	72	73	74	75	76	77
35.50	33.98	32.45	30.93	29.40	27.88	26.35
78	79	80	81	82	83	84
24.83	23.30	22.57	21.83	21.10	20.37	19.63
85	86	87	88	89	90	91
18.90	17.13	15.35	13.58	11.80	10.93	10.05
92	93	94	95	96	97	98
9.18	8.30	7.90	7.50	7.10	6.60	6.10
99	100	101	102	103	104	0
5.60	5.30	3.40	1.50	1.00	.50	0.00

```
 INPUT THE NUMBER OF LOCATIONS AT WHICH CALCULATIONS ARE DESIRED
? 1

 INPUT GRID LOCATIONS WHERE CALCULATIONS ARE DESIRED
? 90

 ENTER '1' IF YOU WISH TO SET LOCATION OF DETONATION, ENTER '2' IF YOU
WISH THAT COMPUTER CODE DETERMINE APPROXIMATE OPTIMUM LOCATION
? 1

 ENTER THE NUMBER OF GRID LOCATION OF EXPLOSION
? 1

 IF WAVE PERIODS ARE NOT NEEDED FOR LATER REFRACTION, ENTER '1'.
IF NEEDED, ENTER '2'
? 1

 IF REFRACTION COEFFICIENTS NOT AVAILABLE, ENTER '1'.  IF AVAILABLE, ENTER
 '2'
? 1

 NL=     1
```

WATER DEPTH = 10.93000000

MAXIMUM WAVE HEIGHT(FT)= .892

POINT	HEIGHT(FT)	TIME(SEC)	POINT	HEIGHT(FT)	TIME(SEC)
1	.050	105.624	2	-.074	113.624
3	.094	120.624	4	-.112	126.624
5	.129	132.624	6	-.145	138.624
7	.161	143.624	8	-.176	149.124
9	.190	154.124	10	-.205	158.624
11	.219	163.624	12	-.234	168.124
13	.248	172.624	14	-.258	177.124
15	.275	181.124	16	-.284	185.624
17	.301	189.624	18	-.314	193.624
19	.326	197.624	20	-.337	201.624
21	.346	205.624	22	-.357	209.124
23	.371	213.124	24	-.377	216.624
25	.389	220.624	26	-.401	224.124
27	.407	227.624	28	-.411	231.124
29	.417	234.624	30	-.424	238.124
31	.433	241.624	32	-.441	245.124
33	.444	248.624	34	-.436	252.124
35	.448	255.124	36	-.444	258.624
37	.447	261.624	38	-.437	265.124
39	.442	268.124	40	-.433	271.124
41	.417	274.624	42	-.417	277.624
43	.411	280.624	44	-.401	283.624
45	.422	286.624	46	-.412	289.624
47	.400	292.624	48	-.383	295.624
49	.360	298.624	50	-.337	301.124
51	.324	304.124	52	-.298	307.124
53	.269	309.624	54	-.250	312.624
55	.214	315.124	56	-.194	318.124
57	.161	320.624	58	-.136	323.624
59	.108	326.124	60	-.077	328.624
61	.050	331.624	62	-.024	334.124
63	.002	336.124	64	-.007	337.124
65	.030	339.624	66	-.056	342.124
67	.078	344.624	68	-.100	347.124
69	.119	349.624	70	-.135	352.124
71	.149	354.624	72	-.160	357.124
73	.168	359.624	74	-.171	361.624
75	.182	364.124	76	-.188	366.624
77	.188	369.124	78	-.179	371.624
79	.180	373.624	80	-.177	376.124
81	.163	378.624	82	-.159	380.624
83	.147	383.124	84	-.134	385.124
85	.123	387.624	86	-.106	389.624
87	.093	392.124	88	-.076	394.124
89	.059	396.624	90	-.045	398.624
91	.028	400.624	92	-.012	402.624
93	-.006	405.624	94	.020	407.624
95	-.035	409.624	96	.047	411.624
97	-.058	413.624	98	.069	416.124
99	-.081	418.124	100	.091	420.124
101	-.098	422.124	102	.103	424.124
103	-.105	426.124	104	.105	428.124
105	-.105	430.624	106	.106	432.624
107	-.106	434.624	108	.103	436.624
109	-.099	438.624	110	.093	440.624

111	-.085	442.624	112	.078	444.124
113	-.072	446.124	114	.064	448.124
115	-.055	450.124	116	.045	452.124
117	-.034	454.124	118	.023	456.124
119	-.012	457.624	120	.003	459.624
121	.009	462.124	122	-.019	463.624
123	.029	465.624	124	-.036	467.624
125	.045	469.124	126	-.054	471.124
127	.059	473.124	128	-.063	474.624
129	.071	476.624	130	-.072	478.624
131	.074	480.124	132	-.079	482.124
133	.073	484.124	134	-.078	485.624
135	.074	487.624	136	-.071	489.124
137	.069	491.124	138	-.061	492.624
139	.060	494.624	140	-.050	496.124

```
  1.099 CP SECONDS EXECUTION TIME.
/REWIND,TAPE11
REWIND,TAPE11.
/SAVE(TAPE11=DATA90)
```

Note: Data for later plotting are saved in file DATA90.

Plotting the results obtained after executing the program EXWAV

35. In order to plot the wave heights at certain time periods, perform the following steps:

1. Run the program EXWAV as usual.
2. Right after the end of the run of the program EXWAV, type the command

   REWIND, TAPE11.

   The computer will respond with the message

   REWIND,TAPE11.

   (TAPE11 contains data for plotting followed.)
3. Type in the command

   SAVE(TAPE11=FILE NAME)

   This will save the contents of TAPE11 as a permanent file with the given file name. The file name has to be within 1 - 7 alphanumeric characters. In this example, the file name is chosen to be DATA90.

4. Run the plot program (PLOTWAV)

Step 1. Type in

TRMDEF,PW=74

DNA computer will respond with TRMDEF PROCESSING COMPLETE.

Step 2. Type in

BATCH

DNA computer will respond with REL,0.

Step 3. Type in

OLD,PLOTWAV

Step 4. Type in

GET, TAPE11 = File name (file name should be the same as used in No. 3)

Step 5. Type in

ATTACH,DISSPLA/UN=APPLLIB.

Step 6. Type in

FTN,I=PLOTWAV,L=0.

DNA computer will respond with xxxCP seconds compilation time.

Step 7. Type in

ENTER.+LDSET(LIB=DISSPLA)+LGO.

DNA computer will start to print output which is the information used in the plot. At the end of the print, DNA computer will print $REVERT.CCL.

Step 8. Type in

REWIND,PLFILE.

Step 9. Type in

SAVE(PLFILE = File name, an arbitrary name)

5. Actual Computer Run of program PLOTWAV.

```
 TRMDEF,PW=74
 TRMDEF COMPLETE.
/BATCH
RFL,0.
/OLD,PLOTWAV
/GET,TAPE11=DATA90
/ATTACH,DISSPLA/UN=APPLLIB.
/FTN,I=PLOTWAV,L=0.
     .335 CP SECONDS COMPILATION TIME
/ENTER.+LDSET(LIB=DISSPLA)+LGO.
   500.00      40.00     100.00         2.00         .40      -2.00
1
                         PLOTTING COMMENCING
                         ...................

 ..... DISSPLA VERSION 8.2 .....
 NO. OF FIRST PLOT   0

      .050    -.074      .094    -.112      .129    -.145      .161    -.176
      .190    -.205      .219    -.234      .248    -.258      .275    -.284
      .301    -.314      .326    -.337      .346    -.357      .371    -.377
      .389    -.401      .407    -.411      .417    -.424      .433    -.441
      .444    -.436      .448    -.444      .447    -.437      .442    -.433
      .417    -.417      .411    -.401      .422    -.412      .400    -.383
      .360    -.337      .324    -.298      .269    -.250      .214    -.194
      .161    -.136      .108    -.077      .050    -.024      .002    -.007
      .030    -.056      .078    -.100      .119    -.135      .149    -.160
      .168    -.171      .182    -.188      .188    -.179      .180    -.177
      .163    -.159      .147    -.134      .123    -.106      .093    -.076
      .059    -.045      .028    -.012     -.006      .020     -.035      .047
     -.058      .069     -.081      .091     -.098      .103     -.105      .105
     -.105      .106     -.106      .103     -.099      .093     -.085      .078
     -.072      .064     -.055      .045     -.034      .023     -.012      .003
      .009    -.019      .029    -.036      .045    -.054      .059    -.063
      .071    -.072      .074    -.079      .073    -.078      .074    -.071
      .069    -.061      .060    -.050
   105.624  113.624  120.624  126.624  132.624  138.624  143.624  149.124
   154.124  158.624  163.624  168.124  172.624  177.124  181.124  185.624
   189.624  193.624  197.624  201.624  205.624  209.124  213.124  216.624
   220.624  224.124  227.624  231.124  234.624  238.124  241.624  245.124
   248.624  252.124  255.124  258.624  261.624  265.124  268.124  271.124
   274.624  277.624  280.624  283.624  286.624  289.624  292.624  295.624
   298.624  301.124  304.124  307.124  309.624  312.624  315.124  318.124
   320.624  323.624  326.124  328.624  331.624  334.124  336.124  337.124
   339.624  342.124  344.624  347.124  349.624  352.124  354.624  357.124
   359.624  361.624  364.124  366.624  369.124  371.624  373.624  376.124
   378.624  380.624  383.124  385.124  387.624  389.624  392.124  394.124
   396.624  398.624  400.624  402.624  405.624  407.624  409.624  411.624
   413.624  416.124  418.124  420.124  422.124  424.124  426.124  428.124
   430.624  432.624  434.624  436.624  438.624  440.624  442.624  444.124
   446.124  448.124  450.124  452.124  454.124  456.124  457.624  459.624
   462.124  463.624  465.624  467.624  469.124  471.124  473.124  474.624
   476.624  478.624  480.124  482.124  484.124  485.624  487.624  489.124
   491.124  492.624  494.624  496.124

 END OF DISSPLA 8.2 --     1632 VECTORS GENERATED IN     1 PLOT FRAMES.
 -ISSCO-  4186 SORRENTO VALLEY BLVD.,SAN DIEGO CALIF. 92121

 DISSPLA IS A CONFIDENTIAL PROPRIETARY PRODUCT OF ISSCO AND ITS USE
    IS SUBJECT TO A NONDISSEMINATION AND NONDISCLOSURE AGREEMENT.

 $REVERT.CCL
/REWIND,PLFILE.
REWIND,PLFILE.
/SAVE(PLFILE=PLT90)
/LOGOUT
```

Note: The statements after the "/" mark are entered by user.

6. To plot the results on a Tektronix Terminal.

Step 1. Type in

GET,PLFILE=FILE NAME (File name should be the same as used in step 9, No. 4

Step 2. Type in

ATTACH,TKAPOP/UN=APPLLIB.

Step 3. Type in

TKAPOP.

DNA computer will respond with the TEKTRONIX POST PROCESSOR and then ENTER DIRECTIVES and the question (?) mark.

Step 4. If a Model 4014 Tektronix terminal is used, type in

DRAW=n (where n is the number of plots to be plotted)

If a Model 4012 or 4051 Tektronix terminal is used, type in

DRAW=1-n*MODI=1-n(SCAL=0.6) (where n is the number of plots to be plotted)

and the user should hit the carriage return key to answer the two question (?) marks followed.

DNA computer will respond with ENTER MODEL NUMBER.

Step 5. Type in

4051 (Model number of the Tektronix terminal)

Step 6. Enter line speed, 30 for the Baud Rate at 300 and 120 for a Baud Rate at 1200.

Step 7. Type in 0 (zero) for the Resolution Index and then answer the next question (?) mark by hitting the carriage return key.

Step 8. Wait until the DNA computer responds with the CP seconds for the execution time then type in "REWIND,ZZZZOUT." and "COPY,ZZZZOUT,OUTPUT." Plot will start after this command.

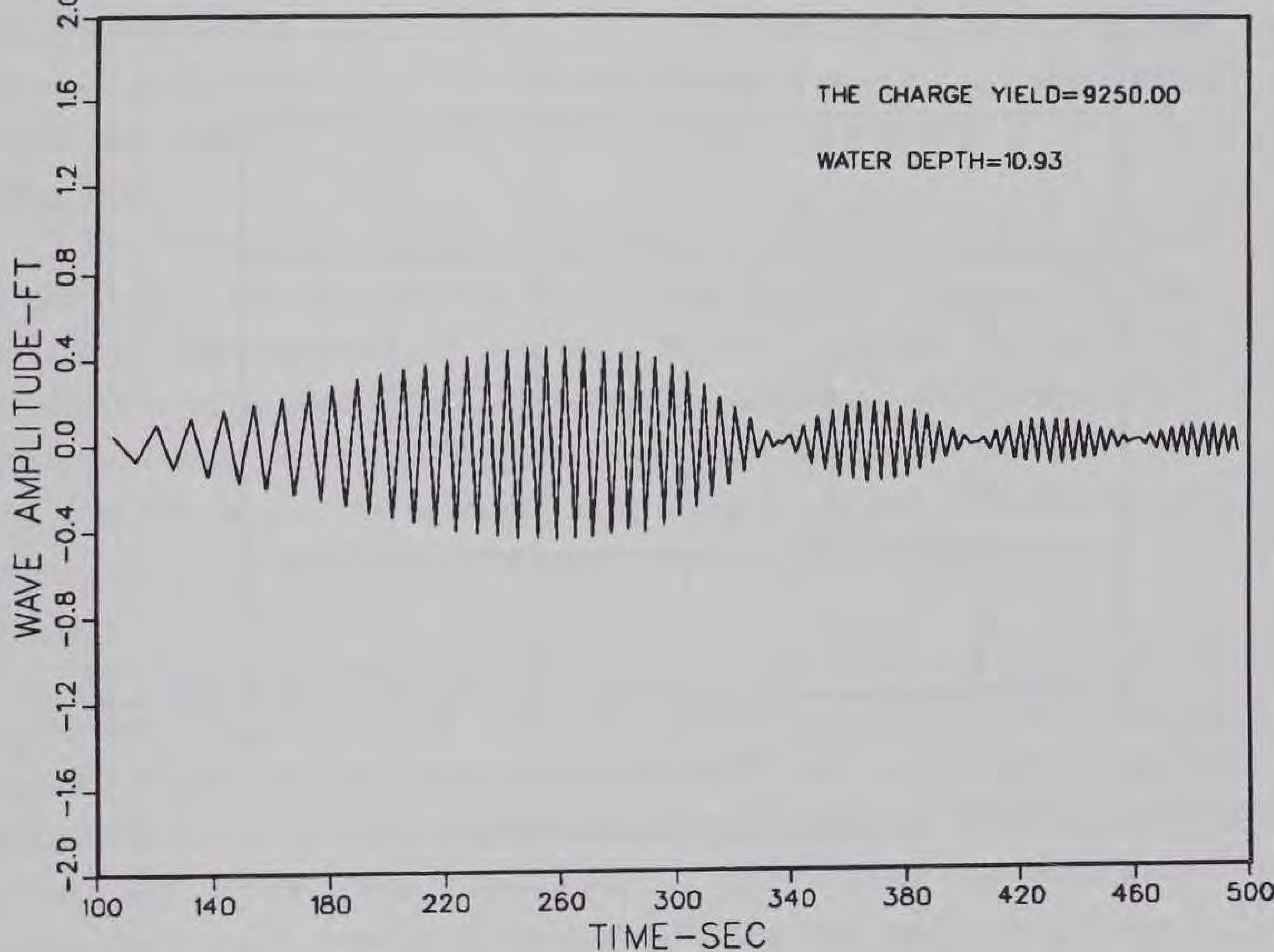
Step 9. Type in "RETURN,PLFILE." and "RETURN,ZZZZOUT." at the end of the plot operation. This must be done to clear the local file.

7. Actual Computer Run for Plot Operation.

```
GET,PLFILE=PLT90.
/ATTACH,TKAPOP/UN=APPLLIB.
/TKAPOP.
      TEKTRONIX POST PROCESSOR
      ENTER DIRECTIVES
? DRAW=1 - 1*MODI=1 - 1(SCAL=0.6)
?
?


          PLOT FILE GENERATED BY USAE
     AT 09.38.17  ON 07/28/82
 ENTER MODEL NUMBER
? 4051
 ENTER LINE SPEED AS CHARS/SEC
? 120
 ENTER RESOLUTION INDEX: 0-1024, 1-4096
? 0
?
 ........................ END OF POSTPROCESSOR .........................

     0.094 CP SECONDS EXECUTION TIME.
/REWIND,ZZZZOUT.
REWIND,ZZZZOUT.
/COPY,ZZZZOUT,OUTPUT.
```



PART IV: PROGRAM REFRAC

Introduction

36. To use program REFRAC an area of interest must first be covered by a rectilinear coordinate grid system. Evenly spaced lines within the system are drawn to form a square mesh, as shown in Figure 12. The major axes of the grid system are designated as X and Y. The origin (the intersection of the major axes) of the system is placed on the ocean side and unit distances of I and J are spaced along the X and Y axes, respectively. Therefore, any point on the grid can be expressed in terms of I and J, with I varying from 1 to MI and J from 1 to MJ, where MI and MJ are the number of grid lines crossing the Y and X axes, respectively.

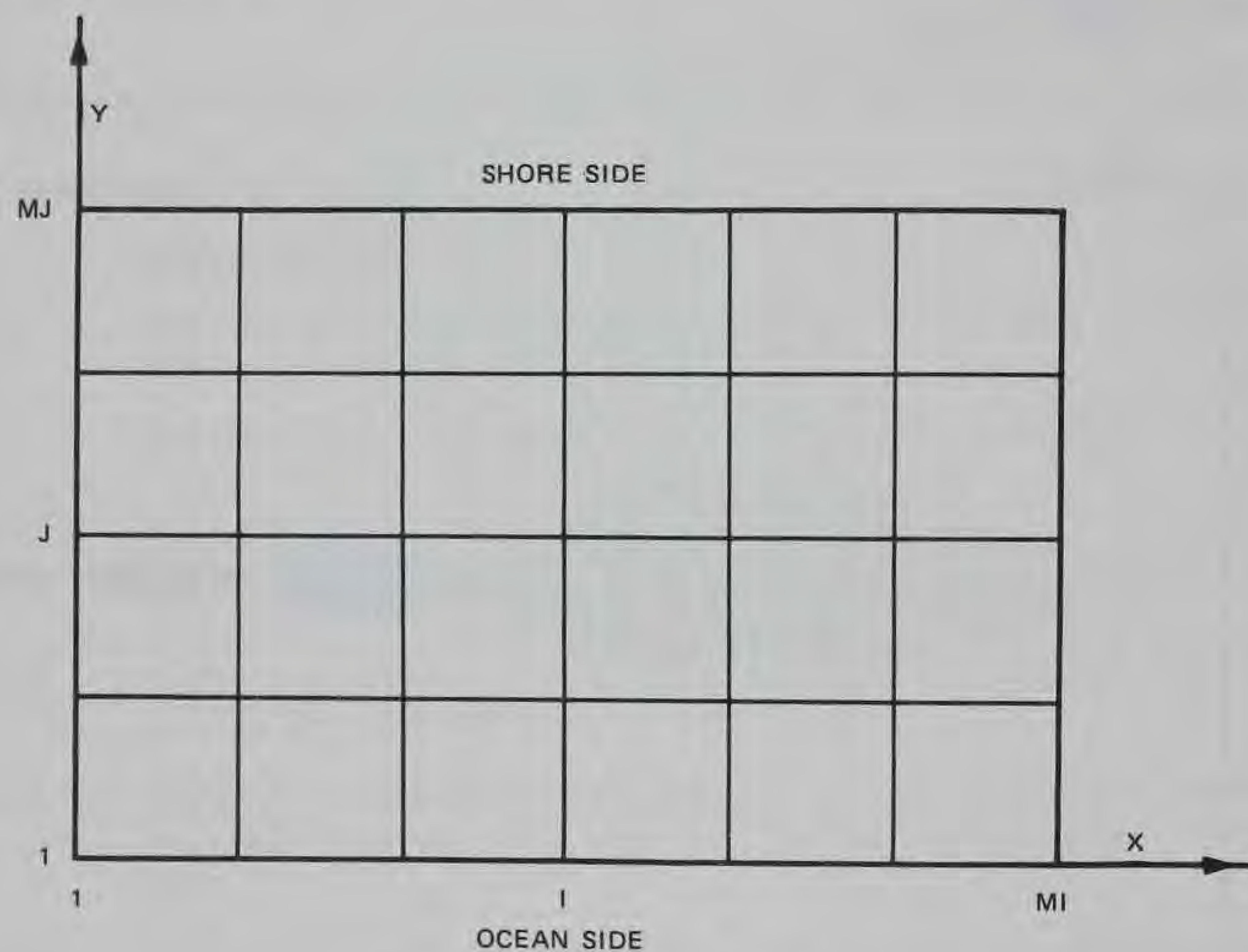


Figure 12. Grid system

37. The grid system should be positioned so that the waves will propagate from deep to shallow water. The position of the grid is important because if the waves travel from a shallow zone to a deeper one, the numerical solution will become unstable. The computations, therefore, would be incorrect.

38. Grid spacing will be dependent upon the size of the area to be studied and the complexity of the bathymetry (water depth values). The grid spacing should be small enough to provide a close representation of the bathymetry. If a small computer with a limited memory capacity is used and a problem requires inclusion of small areas of highly irregular bathymetry within a larger area, the REFRAC program has a special feature that requires a fine grid to be used only within the small areas. This feature can greatly reduce computer memory requirements. The feature is called window plots. The small area (window) is outlined with a larger scale map than the one used for the overall study. After the program has made the calculations for the large area, the program is run again using as input the previously calculated wave ray data and the grid for the window. Thus a trace of the rays through the window area is obtained in a highly detailed manner.

Depth data

39. The bathymetry is represented by depth values at each point on the grid. The depth values are usually obtained from maps of the area which show underwater contours. This will require interpolation of the depth at the grid points from the contour data on the maps. The depth values may be in any length dimension that can be converted to feet. Values below the water-surface datum are input as positive and values above the water-surface datum are entered as negative.

Ray data

40. The required input data for the wave characteristics are the period and direction of the wave ray at the starting position. The wave period is expressed in seconds and the direction is defined by the azimuth of the wave ray (the clockwise angle (in degrees) between north on the map and the wave ray). For example, a wave front traveling from east to west would have a direction of 90 deg, whereas a wave front

traveling from west to east would have a direction of 270 deg. The starting position of a ray must be at least one-and-one-half grid spacings within the boundaries of the grid.

Definition of Data Input

41. Input to the program is through data cards and parameter cards. Data cards contain the water depth values, coordinates of land features to be plotted, and starting location of the wave rays. The parameter cards specify information about the plots and printed output, and indicate which options have been chosen.

42. The following instructions set forth the data and format requirements for the cards necessary to obtain wave-refraction diagrams and associated printer output for a desired location. The input data format specification used in this FORTRAN program is shown in parentheses. Also included is the name of the program variable that identifies the data.

Title Card

43. This card contains the alphanumeric title that appears on the plot and printer output for job identification.

Col	Format	Variable Name	Description
1-40	(NA4)	ITILE	Alphanumeric title
			N is the number of characters in title

Parameter Set 1

44. This card contains eight variables that provide the program with information pertaining to the grid and the time-step.

Col	Format	Variable Name	Description
1-5	(I5)	MI	Number of grid lines in X-direction.
6-10	(I5)	MJ	Number of grid lines in Y-direction.
11-15	(I5)	LIMNPT	Maximum number of time-steps to be computed for one ray.
16-20	(I5)	NPRINT	Print interval for time-step information.
21-30	(F10.4)	GRID	Length of a side of a grid square expressed in map feet.
31-40	(F10.4)	DCON	Conversion factor for depth values to feet. If depths are in feet this variable is equal to one.
41-50	(F10.4)	DELTAS	Minimum step length expressed as a fraction of a grid square.
51-60	(F10.4)	DF	Factor to convert depth values from one water-surface datum to another. Factor will be added to depth values. If not needed, leave blank.
61-70	(F10.4)	DLIMFT	Depth beyond which all data are not printed.

Parameter Set 2

45. This card is used to tell the program information about the large area plots and the window plots.

Col	Format	Variable Name	Description
1-10	(F10.5)	BOUND	The maximum overall height (Y-direction) of the plot depends upon the dimension that is set in the statement "call page (X,Y)". 0.5 inches is required for labeling the plot. Therefore a magnitude of (Y-0.5) inch* is the maximum height that can be used for the ray plot. Sometimes, because of the available maps or the desire to look at large views, higher grid than the (Y-0.5) inch may be used. In this case, the part of grid and wave rays not in

* Multiply inches by 25.4 to obtain millimetres.

Col	Format	Variable Name	Description
			the problem area can be deleted from the plots. This variable specifies that portion of the grid that will not be shown of the plot. It is expressed in plot inches and always is subtracted from the deepwater end.
11-20	(F10.5)	SCX	Scale factor or length of a grid square expressed in plot inches.
21-30	(F10.5)	XSG	X-coordinate of lower left corner of window. If a window plot is not desired, set this variable equal to the value at the grid point MI and leave the remainder of the card blank.
31-40	(F10.5)	YSG	Y-coordinate of lower left corner of window.
41-50	(F10.5)	SCNV	Magnification of window. It is equal to the number of grid squares of the window grid contained in one grid square of the large area.
51-60	(F10.5)	DGXL	Length (X dimension) of window expressed in plot inches.
61-70	(F10.5)	DGYL	Height (Y dimension) of window expressed in plot inches.

Data Set 1

46. This data set supplies all the water depth values for the grid. The values are read in rows, starting at the origin and proceeding from left to right along the X-axis from I = 1 to MI. The next row is read starting again at the left end and this continues until all the rows are read. The number of data points in this set is equal to MI times MJ. These two variables were defined in parameter set 1.

Col	Format	Variable Name	Description
1-10	(F10.2)	DEP(1,1)	Water depth value at origin of axes.
11-20	(F10.2)	DEP(2,1)	Water depth value at point to right of origin on X-axis.

Col	Format	Variable Name	Description
21-80	(F10.2)	DEP(I,J)	Continue in like manner until up to eight water depth values are recorded on the card. Continue on subsequent cards with eight values per card with enough cards to supply MI times MJ depth values. The remaining positions on the last card are left blank, if MI times MJ is not an integral multiple of 8.

Parameter Set 3

47. This card tells the program how many sets of rays are to be processed for this run and the number of points needed to plot land features.

Col	Format	Variable Name	Description
1-5	(I5)	NOSETS	Number of sets of rays to be processed. A set is defined as a group of rays having the same wave period and deepwater wave direction. One plot will be generated for each set.
6-10	(I5)	NOSL	Number of points needed to plot selected land feature or underwater contours. Value is limited to 300 points.

Data Set 2

48. This data set provides the coordinates of the points needed to plot land features or underwater contours. A card is required for each point; therefore, the number of cards in this data set must equal the value specified by NOSL in parameter set 3.

Col	Format	Variable Name	Description
1-10	(F10.2)	XSLINE	X-coordinate for defining a point.
11-20	(F10.2)	YSLINE	Y-coordinate for defining a point.

Col	Format	Variable Name	Description
21-25	(I5)	JPEN	Pen position when moving from an old plot point. If =1, the plotter will trace the line to a new position three times to make a heavy line; if =2, go to new position with pen down (light time); and if =3, go to new position with pen up (no line).

Parameter Set 4

49. Two cards are needed for set 4, which supply information on the wave characteristics. There should be two of these cards for each set of rays; a set of rays was defined in parameter set 3.

Card 1

Col	Format	Variable Name	Description
1-5	(I5)	LPLOT	Number of time-steps between plot points on a ray. The smoothness of the ray trace on the plot is controlled by the variable, with smaller values giving smoother traces. However, for small values running time is extended. So a compromise should be made and it was found that a value of 10 gives reasonable results.
6-10	(I5)	NORAYS	Number of wave rays in this set of rays.
11-20	(F10.2)	T	Wave period for all rays in this set, expressed in seconds.
21-30	(F10.2)	HO	Deepwater wave height for all rays in this set. If not known, a value of one is suggested.
31-40	(F10.2)	SK	Shoaling coefficient at water depth for present time-step.
41-50	(F10.2)	SK1	Shoaling coefficient at water depth for starting location of a ray. Set equal to one if ray starts in deep water.

Col	Format	Variable Name	Description
51-60	(F10.2)	TMI	Clockwise angle between north on map and Y-axis of grid system.
61-70	(F10.2)	STAZ	Azimuth from which the rays come of the set of rays. Azimuth is measured with north as zero and expressed in degrees.
Card 2			
1-10	(F10.2)	UNIT	Time-step expressed in seconds. Suggested value is about one-tenth of wave period.

Parameter Set 5

50. This card provides additional information about a particular set of wave rays.

Col	Format	Variable Name	Description
1-5	(I5)	ISP	Sets print option on check depth. Check depth is defined as a depth where output information is needed and would not necessarily be provided exactly at this point during execution of program. This check depth is useful in designing a hydraulic model of an area. If ISP =-1, program will provide desired output and continue processing of ray; if =0, does not look for check depth and; if =1, provides output at check depth and stops processing of that ray.
6-10	(I5)	LCK	Tells the program whether this set of rays is starting in deep water. If LCK =0, rays are starting in deep water and initial angle of rays will be deepwater azimuth; if LCK =1, rays are not starting in deep water and starting azimuth for each ray must be input.

Col	Format	Variable Name	Description
11-20	(F10.2)	WPI	Number of wave periods between the marks on a ray. The plot of the ray will have the marks drawn perpendicular to the ray at the location at the interval specified by this variable. Also, output information will be printed out for this time-step and an asterisk placed beside the column numbering the time-step.
21-30	(F10.2)	CKDEP	Depth desired for a check depth. If not needed, leave blank.

Data Set 3

51. This data set provides the program with starting location information of each ray in the set. A card is required for each ray, so the number of cards in this set must equal to NORAYS specified in parameter set 4. The coordinates are expressed in grid lines with the origin being equal to (1., 1.); for example, a point with coordinates of (10., 11.5) would be located on the tenth line along the X-axis and halfway between the 11 and 12 line on the Y-axis. There are five variables that may be input on these cards. If the ray is starting in deep water then LCK will be zero in parameter set 5 and only the first two variables will be input. The remainder of the card will be blank. If the ray is not starting in deep water then LCK is one in parameter set 5 and all five variables must be provided.

Col	Format	Variable Name	Description
1-10	(F10.5)	X	X-coordinate of starting location of ray.
11-20	(F10.5)	Y	Y-coordinate of starting location of ray.
21-30	(F10.5)	AZIMTH	Azimuth of wave ray at starting location. Azimuth is measured with north as zero and expressed in degrees.

Col	Format	Variable Name	Description
31-40	(F10.5)	RK1	Refraction coefficient of wave ray at the time-step previous to step at the starting location. This value and the value of the next variable must be computed by user but may be provided if this is a continuation of a previous run.
41-50	(F10.5)	RK	Refraction coefficient of wave ray at starting location.

Additional computations

52. If additional sets of rays are desired to be processed (NOSETS in parameter set 3 greater than 1), start back at parameter set 4 and supply all the cards through data set 3 for each new set.

Program output

53. The output to the program consists of a plot for each set of wave rays and printed information describing this ray at selected locations. The program also prints out the water depths it uses in the wave ray computations.

Data Input

54. Bathymetric data (Data set No. 1) are submitted to program REFRAC by establishing a direct access permanent data file. A direct access file must be established instead of an indirect access file (see PART III), since the bathymetric data for program REFRAC are extensive and generally require more storage than allowed for an indirect access file. A direct access permanent data file can be established by submitting cards containing depth values through a batch terminal as presented in the following paragraphs (all information should begin at column 1):

Card 1: NAME,CM20000.

This card identifies the job. Name can be user's last name (not exceed 7 characters). CMxxxxx is the maximum octal field length for the job. NTO means no tape is required for the job.

Card 2: USER(USERID,PASSWORD)

This card identifies the user. The user's ID is the first term in the parentheses. The user's password then follows the comma.

Card 3: CHARGE(,)

This card identifies the charge account. The first term after the parenthesis is the charge number. The project number then follows the comma.

Card 4: DEFINE(A=THE PERMANENT FILE NAME)

This command allows the user to create a direct access permanent file that contains no information initially. An arbitrary file name (not exceed 7 characters) should be specified. Data are placed on file in succeeding write operations.

Card 5: COPY,INPUT,A.

This card copies the profile depth data read by the card reader onto local file A that has been defined as a permanent file.

Card 6: 7 8 9 multipunch.

This card separates the control cards from the data file. The numbers 7, 8, and 9 are all punched in column 1.

DATA cards:

As many profile depth values as desired should be placed on cards with a format of (7F10.2).

Final Card: 6 7 8 9 multipunch.

That is, the numbers 6, 7, 8, and 9 are all punched in column 1. This card indicates the end of the job.

Note: To access the direct access permanent file, command ATTACH is used, such as "ATTACH,A=PERMANENT FILE NAME/M=RA.", where A is the local (arbitrary) file name, permanent file name is the direct access permanent file name that is desired, and the parameter M=RA indicates read permission only.

Example Problem

55. This example problem calculates the refraction effects along radial 2 of the detonation in the 1965 Mono Lake test.

Preparation of input data

56. In this example the profile depths have been read in through a batch terminal and are stored as a direct access permanent file. All the other data sets are entered into an interactive terminal by using the TEST mode and are stored as an indirect access permanent file.

Preparation of data file

57. Data of profile depths are stored in a direct access permanent file with a name MONODPT. The procedure of creating a direct access permanent file has been explained in the previous section.

58. All data except profile depths data are entered in as an indirect access permanent file MONODAT. The procedure of creating the data file MONODAT is shown in Table 2. Appendix B presents useful edit commands to modify a data file and Appendix C presents an example of using edit commands to modify a data file.

Actual computer run

```
 TRMDEF,PW=74
 TRMDEF COMPLETE.
/BATCH
RFL,0.
/OLD,REFRAC.
/GET,TAPE7=MONODAT.
/ATTACH(TAPE8=MONODPT/M=RA)
/ATTACH,DISSPLA/UN=APPLLIB.
/FTN,I=REFRAC,L=0.
      .543 CP SECONDS COMPILATION TIME
/ENTER.+LDSET(LIB=DISSPLA)+LGO.
  100  11290000   30  200.0000     1.0000      .0010     0.0000  130.0000
   0.00000    .08289 100.00000  0.00000   0.00000   0.00000
1WAVE REFRACTION PROGRAM
```

Note: The statements after the "/" mark are entered by the user.

PLOTTING COMMENCING

....

..... DISSPLA VERSION 8.2 .....
NO. OF FIRST PLOT 0

NOTATIONS USED IN THE OUTPUT:

- POINT = THE GRID POINT NUMBER.
- X = X COORDINATE FOR A RAY.
- Y = Y XOORDINATE FOR A RAY.
- ANG = AZIMUTH OF A RAY.
- DEPTH = WATER DEPTH AT EACH GRID POINT.
- LENGHT= WAVE LENGHT.
- CXY = WAVE CELERITY.
- RK = REFRACTION COEFFICIENT OF WAVE RAY AT STARTING LOCATION.
- SK = SHOALING COEFFICIENT FOR FIRST TIME STEP.
- H = WAVE HEIGHT.
- HH = (RK*SK)**2

1 MONOLAKE REFRACTION STUDY

MI=100 MJ=112 NPRINT= 30 GRID= 200.000 DCON=1.0
SET NO. 1, RAY NO. 1, PERIOD = 5.810 SECS.
GRINC= .086274, TIME STEP= .580 SECS.,
WAVE FRONT INCREMENT= 17.43 SECS.

POINT	X	Y	ANG	DEPTH	LENGTH	CXY	RK	SK	H	HH
1	23.00	12.00	205.00		172.84	29.75		1.0000		
30*	24.06	14.27	205.00	125.85	172.84	29.75	1.0000	1.0000	1.00	118.99
60*	25.15	16.61	205.00	124.77	172.84	29.75	1.0000	1.0000	1.00	118.99
90*	26.25	18.96	205.00	123.76	172.84	29.75	1.0000	1.0000	1.00	118.99
120*	27.34	21.30	205.00	122.83	172.84	29.75	1.0000	1.0000	1.00	118.99
150*	28.43	23.65	205.00	122.59	172.84	29.75	1.0000	1.0000	1.00	118.99
180*	29.53	26.00	205.00	121.49	172.84	29.75	1.0000	1.0000	1.00	118.99
210*	30.62	28.34	205.00	120.26	172.84	29.75	1.0000	1.0000	1.00	118.99
240*	31.71	30.69	205.00	117.88	172.84	29.75	1.0000	1.0000	1.00	118.99
270*	32.81	33.03	205.00	115.40	172.84	29.75	1.0000	1.0000	1.00	118.99
300*	33.90	35.38	205.00	113.06	172.84	29.75	1.0000	1.0000	1.00	118.99
330*	35.00	37.72	205.00	110.79	172.84	29.75	1.0000	1.0000	1.00	118.99
360*	36.09	40.07	205.00	108.40	172.84	29.75	1.0000	1.0000	1.00	118.99
390*	37.18	42.42	205.00	106.45	172.84	29.75	1.0000	1.0000	1.00	118.99
420*	38.28	44.76	205.00	105.01	172.84	29.75	1.0000	1.0000	1.00	118.99
450*	39.37	47.11	205.00	103.27	172.84	29.75	1.0000	1.0000	1.00	118.99
480*	40.46	49.45	205.00	101.24	172.84	29.75	1.0000	1.0000	1.00	118.99
510*	41.56	51.80	205.00	100.11	172.84	29.75	1.0000	1.0000	1.00	118.99
540*	42.65	54.14	205.00	96.48	172.84	29.75	1.0000	1.0000	1.00	118.99
570*	43.75	56.49	205.00	92.03	172.84	29.75	1.0000	1.0000	1.00	118.99
600*	44.84	58.84	205.00	87.79	172.84	29.75	1.0000	1.0000	1.00	118.99
630*	45.93	61.18	204.95	82.83	172.03	29.61	1.0000	.9884	.99	116.23
660*	47.01	63.51	204.85	77.55	171.67	29.55	.9997	.9845	.98	115.25
690*	48.09	65.84	204.68	70.62	170.93	29.42	.9990	.9777	.98	113.53
720*	49.15	68.16	204.40	62.31	169.47	29.17	.9981	.9669	.96	110.80
750*	50.18	70.45	203.74	50.26	165.42	28.47	.9959	.9459	.94	105.59
780*	51.13	72.68	202.75	40.02	158.86	27.34	.9930	.9265	.92	100.72
810*	52.03	74.86	201.92	35.56	154.64	26.62	.9915	.9194	.91	98.88

```
 840* 52.86 76.98 200.98  31.59 149.97 25.81  .9899  .9149  .91  97.59
 870* 53.64 79.06 200.15  28.53 145.66 25.07  .9889  .9131  .90  97.03
 900* 54.37 81.08 199.46  26.36 142.18 24.47  .9890  .9132  .90  97.04
 930* 55.06 83.07 198.97  24.75 139.34 23.98  .9899  .9141  .90  97.42
 960* 55.72 85.03 198.47  22.98 135.93 23.40  .9918  .9161  .91  98.22
 990* 56.35 86.93 198.10  20.94 131.61 22.65  .9931  .9200  .91  99.33
1020* 56.95 88.77 197.91  18.36 125.43 21.59  .9910  .9281  .92 100.66
1050* 57.50 90.49 197.52  15.19 116.56 20.06  .9846  .9446  .93 102.92
1080* 58.00 92.10 196.87  12.66 108.30 18.64  .9776  .9652  .94 105.93
1110* 58.45 93.62 196.31  11.38 103.47 17.81  .9716  .9796  .95 107.79
1140* 58.87 95.07 195.60  10.23  98.85 17.01  .9671  .9953  .96 110.24
1170* 59.25 96.48 194.86   9.43  95.39 16.42  .9638 1.0082  .97 112.36
1200* 59.61 97.84 194.36   8.95  93.21 16.04  .9614 1.0169  .98 113.75
1230* 59.94 99.18 193.97   8.61  91.64 15.77  .9598 1.0235  .98 114.82
1260* 60.26100.48 193.11   7.50  86.11 14.82  .9577 1.0486 1.00 120.01
1290* 60.52101.67 191.57   5.59  75.26 12.95  .9548 1.1087 1.06 133.34
1320* 60.71102.70 189.86   3.99  64.27 11.06  .9521 1.1881 1.13 152.27
1350* 60.85103.56 188.20   2.61  52.41  9.02  .9499 1.3047 1.24 182.78
1380* 60.95104.28 186.94   1.87  44.59  7.68  .9486 1.4080 1.34 212.28
1390  60.97104.47 186.64   1.69  42.45  7.31  .9483 1.4416 1.37 222.37

RAY STOPPED, WAVE BREAKS AT X=  60.97  Y= 104.47
ALL SETS COMPLETED, NO. OF SETS =    1


END OF DISSPLA 8.2 --      1162 VECTORS GENERATED IN      1 PLOT FRAMES.
-ISSCO-  4186 SORRENTO VALLEY BLVD.,SAN DIEGO CALIF. 92121

DISSPLA IS A CONFIDENTIAL PROPRIETARY PRODUCT OF ISSCO AND ITS USE
   IS SUBJECT TO A NONDISSEMINATION AND NONDISCLOSURE AGREEMENT.

*REVERT.CCL
/REWIND,PLFILE.
REWIND,PLFILE.
/SAVE(PLFILE=PLTREF)
/RETURN,PLFILE.
RETURN,PLFILE.
/
```

Note: The statement after the "/" mark is entered by the user.

Table 2

The Procedure for Creating an Indirect Access Permanent File

```
/trmdef,pw=74
 TRMDEF PROCESSING COMPLETE
/new,monodat
/text
ENTER TEXT MODE.

monolake refraction study                                                    ...Title
  100  11290000    30  200.0000    1.0000    0.0010    0.0000  130.0000 ...Parameter Set 1
   0.00000   0.08289 100.00000   0.00000   0.00000   0.00000   0.00000 ...Parameter Set 2
    1     0                                                             ...Parameter Set 3
   10     1        5.81      1.00      1.00      1.00      0.00    205.00 ...Parameter Set 4 (Card 1)
      0.58                                                              ...Parameter Set 4 (Card 2)
    0     0        3.00                                                 ...Parameter Set 5
  23.00000  12.00000                                                    ...Data Set 3

 PACK COMPLETE.

 EXIT TEXT MODE.
/save,monodat
```

Note: The statements after the "/" mark are entered by the user. All data are entered with the format stated in the Data Definition of Program REFRAC.

To plot the results on a Tektronix Terminal.

Step 1. Type in

GET,PLFILE = FILE NAME (File name should be the same as used in the SAVE command at the end of each run of the program REFRAC. In this case the file name PLTREF is used.)

Step 2. Type in

ATTACH,TKAPOP/UN=APPLLIB.

Step 3. Type in

TKAPOP.

DNA computer will respond with the TEKTRONIX POST PROCESSOR and then ENTER DIRECTIVES and the question (?) mark.

Step 4. If a Model 4014 Tektronix terminal is used, type in DRAW=n (where n is the number of plots to be plotted)

If a Model 4012 or 4051 Tektronix terminal is used, type in DRAW=1-n*MODI=1-n(SCAL=0.6) (where n is the number of plots to be plotted)

and the user should strike the carriage return key to answer the two question (?) marks.

DNA computer will respond with ENTER MODEL NUMBER.

Step 5. Type in

4051 (Model number of the Tektronix terminal)

Step 6. Enter line speed, 30 for the Baud Rate at 300 and 120 for a Baud Rate at 1200.

Step 7. Type in 0 (zero) for the Resolution Index and then answer the next question (?) mark by striking the carriage return key.

Step 8. Wait until the DNA computer responds with the CP seconds for the execution time then type in "REWIND,ZZZZOUT" and "COPY, ZZZZOUT,OUTPUT." Plot will start after this command.

Step 9. Type in "RETURN,PLFILE." and "RETURN,ZZZZOUT." at the end of the plot operation. This must be done to clear the local file.

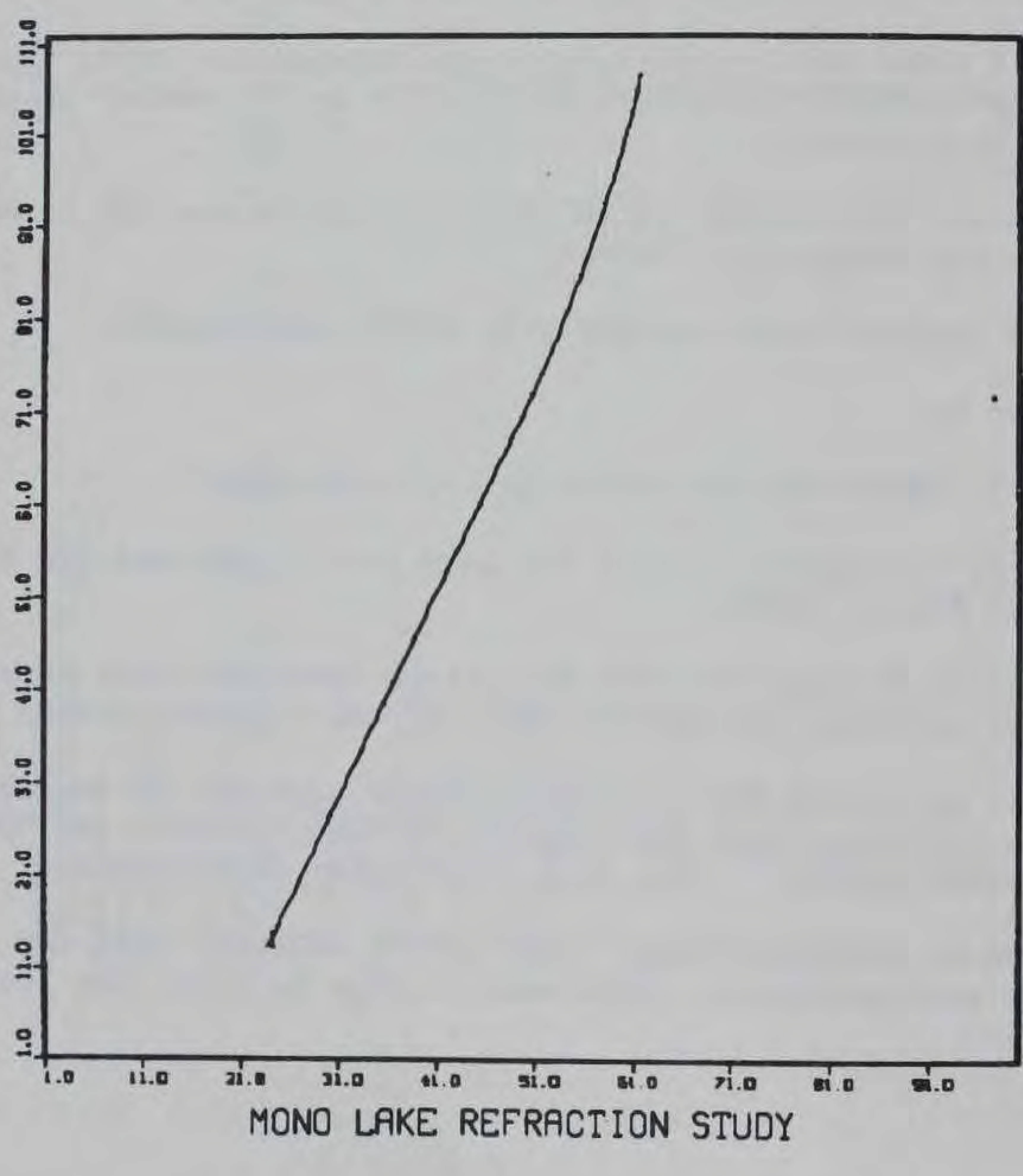
Actual Computer Run for Plot Operation.

```
GET,PLFILE=PLTREF.
/ATTACH,TKAPOP/UN=APPLLIB.
/TKAPOP.
      TEKTRONIX POST PROCESSOR
      ENTER DIRECTIVES
? DRAW=1 - 1*MODI=1 - 1(SCAL=0.6)
?
?


         PLOT FILE GENERATED BY USAE
     AT 15.16.16  ON 07/28/82
 ENTER MODEL NUMBER
? 4051
 ENTER LINE SPEED AS CHARS/SEC
? 30
 ENTER RESOLUTION INDEX: 0-1024, 1-4096
? 0
?


....................... END OF POSTPROCESSOR .........................

     0.072 CP SECONDS EXECUTION TIME.
/REWIND,ZZZZOUT.
REWIND,ZZZZOUT.
/COPY,ZZZZOUT,OUTPUT.
```



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* Classified reference. Bibliographic material for the classified reference will be furnished to qualified agencies upon request.

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APPENDIX A: THE PROCEDURE TO LOGIN A TEKTRONIX TERMINAL

a. Telephone line:

WES
1200 bpu (Baud rate): Dial direct 88-505-243-6782
300 bpu (Baud rate): Dial direct 88-505-242-0585

DNA
1200 bpu: Dial 57734 (direct line from DNA to AFWL)

b. Login:

1. Turn on the power. This will set the terminal in a local mode.

2. Check the current baud rate and parity by typing in the command:

   CALL "PRLIST"

   The terminal will respond by listing the following:

   CALL "PRLIST"

RATE	300	0	2
TSTRIN	/@/	/S/	/D/
.	.	.	.
.	.	.	.
.	.	.	.

   If the rate is correct, skip step 3. and go on to step 4.

3. Setting the correct baud rate, parity, and erract (error action, on received parity and framing errors) is done by typing in the following:

   CALL "RATE", 300, 0, 2 or

   CALL "RATE", 1200, , 2

4. CALL "TERMIN"

   This call statement causes the system to enter terminal mode.

5. Wait until the "BUSY" and "I/O" lights (at the right side of the screen) start to blink, then dial the correct phone number.

   A. Bell telephone:

      a. Press down the "talk" button
      b. Dial the correct number

c. Wait for the signal
d. Press down the "DATA" button once and return the receiver to the cradle.

B. Vadic phone:

a. Dial the correct number
b. Wait for the signal
c. Pull up the white button (lift side) and put the receiver on the table (do not return to the cradle).

6. DNA computer will respond as follows:

```
81/09/20. 08.54.29. T22               (T22 is the terminal ID)
DNA MULTIMODE SYSTEM - 81/07/15  NOS 1.5-519/528.
FAMILY:
```

Answer this question by pressing down the return key.

USER NAME:

Typing in USAEXLC or ...

PASSWORD:

Typing in PEANUTS or ...

T22 -APPLICATION:

Typing in IAF

TERMINAL: 14, NAMIAF
RECOVER/CHARGE

Typing in CHARGE

CHARGE NUMBER:

Typing in USAEWES

PROJECT NUMBER:

Typing in M8202

During the process of Login some times the system will respond with the statements such as "Improper Login, try again," "Illegal charge," or "Illegal User." In order to answer the statement "Improper Login," you have to reenter the answers for such questions as Family, User Name, or other questions. For the statement "Illegal Charge," you can answer it by typing in "Charge." For the statement "Illegal User," you can answer it by typing in "Hello," this will cause the system to restart the Login process all over again.

After you have successfully logged in, the system will respond by printing out the system bulletin. If you want to terminate the bulletin printout, you should first press down the BREAK button and then press down the Control key and the letter T at the same time.

Note:

1. To clear the screen: Press down the HOME PAGE button.

2. To back space: Use the BACK SPACE button.

3. To terminate the run: Press down the Control key and the letter T at the same time.

APPENDIX B: USEFUL XEDIT COMMANDS

TOP - Goes all the way to the beginning of the file.

LOCATE/ABC/ - To locate the statement in which contains character string ABC.

C/ABC/BCD/ - Change character A in the statement to B.

(Before you make any change, you have to locate the statement in which you would like to make some change)

Dn - Delete n line starting from the current line.

Pn - Print n line starting from the current line.

Nn - Go forward n line and print that line.

N-n - Go backward n line and print that line.

END - This command tells the computer to wait for a new name, and the up-to-date version is saved under the new name.

Q - This command will get you out of Xedit mode while editing an indirect access permanent file, but the up-to-date version is not saved.

Stop - To terminate the Xedit mode while editing a direct access permanent file.

APPENDIX C: EXAMPLE Of USING XEDIT TO CHANGE A DATA FILE

```
/OLD,MONODAT
/XEDIT
 XEDIT 3.1.00
?? P10
MONOLAKE REFRACTION STUDY
  100  11290000   30  200.0000    1.0000    0.0010    0.0000  130.0000
   0.00000   0.08289 100.00000  0.00000   0.00000   0.00000   0.00000
    1    0
   10    1       5.81      1.00      1.00      1.00      0.00    205.00
      0.58
    0    0       3.00
  23.00000  12.00000
END OF FILE
?? TOP
?? L/5.81/
   10    1       5.81      1.00      1.00      1.00      0.00    205.00
?? C/5.81/5.70/
   10    1       5.70      1.00      1.00      1.00      0.00    205.00
?? L/0.58/
      0.58
?? C/0.58/0.57/
      0.57
?? END
MONODAT IS A LOCAL FILE
/SAVE(MONODAT=MODAT)
/OLD,MODAT
/XEDIT
 XEDIT 3.1.00
?? P10
MONOLAKE REFRACTION STUDY
  100  11290000   30  200.0000    1.0000    0.0010    0.0000  130.0000
   0.00000   0.08289 100.00000  0.00000   0.00000   0.00000   0.00000
    1    0
   10    1       5.70      1.00      1.00      1.00      0.00    205.00
      0.57
    0    0       3.00
  23.00000  12.00000
END OF FILE
?? Q
MODAT   IS A LOCAL FILE
/
```

Note: The statements after the "/" and the "??" marks are entered by the user.