

(10)

LEVEL III

AD-E 950 155

AD A10576

TECHNICAL REPORT RE-81-13

RADAR ANALYSIS AND TEST
OF A BULLET HIT INDICATOR

R. Russell, R. Garlough, F. Sedenquist, J. Cole
Advanced Sensors Directorate
US Army Missile Laboratory

June 1981

DTIC
ELECTE
S OCT 19 1981 D
B

Approved for public release; distribution unlimited.



U.S. ARMY MISSILE COMMAND

Redstone Arsenal, Alabama 35898

DMC FILE COPY

DISPOSITION INSTRUCTIONS

**DESTROY THIS REPORT WHEN IT IS NO LONGER NEEDED. DO NOT
RETURN IT TO THE ORIGINATOR.**

DISCLAIMER

**THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN
OFFICIAL DEPARTMENT OF THE ARMY POSITION UNLESS SO DESIGNATED
BY OTHER AUTHORIZED DOCUMENTS.**

TRADE NAMES

**USE OF TRADE NAMES OR MANUFACTURERS IN THIS REPORT DOES
NOT CONSTITUTE AN OFFICIAL INDORSEMENT OR APPROVAL OF
THE USE OF SUCH COMMERCIAL HARDWARE OR SOFTWARE.**

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER RE-81-13	2. GOVT ACCESSION NO. AD-A205776	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) RADAR ANALYSIS AND TEST OF A BULLET HIT INDICATOR		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. Russell, R. Garlough, F. Sedenquist, J. Cole		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander, US Army Missile Command ATTN: DRSMI-RD Redstone Arsenal, AL 35898		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Commander, US Army Missile Command ATTN: DRSMI-RPT Redstone Arsenal, AL 35898		12. REPORT DATE June 1981
		13. NUMBER OF PAGES 208
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Bullet hit indicator Radar system Bullet detection system		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents theoretical analysis and data analysis pertaining to tests performed by Cartwright Engineering Incorporated during the week of 17 November 1980 at Test Area 1, Redstone Arsenal, Alabama		

CONTENTS

	page
I. INTRODUCTION.	3
II. TEST DESCRIPTION.	3
III. RADAR SYSTEM ANALYSIS	5
IV. BULLET RADAR CROSS-SECTION ANALYSIS	8
V. DATA ACQUISITION AND PROCESSING	21
VI. DATA.	21
VII. DATA ANALYSIS	23
VIII. CONCLUSIONS AND RECOMMENDATIONS	27
APPENDIX.	31

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
PER. S.W. AMC	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

I. INTRODUCTION

The purpose of this document is to present theoretical analysis, and data analysis pertaining to tests performed by Cartwright Engineering Incorporated, 251 E. Palais Road, Anaheim, California 92805, during the week of 17 November 1980 at Test Area 1, Redstone Arsenal, Alabama. The unit under test was a brassboard Bullet Detection System (BDS). The BDS is intended to be used as a target scoring device for 20-millimeter projectiles. The tests were performed under the Phase II requirement of ESM 1653-3G Statement of Work, Attachment A, to Contract DAAH01-80-C-0012.

In this document, references to the contractor refer to Cartwright Engineering Incorporated.

Data reduction, data analysis, and theoretical analysis were performed by Mr. R. F. Russell, Group Leader, Mr. R. H. Garlough, Mr. F. W. Sedenquist, and Mr. J. S. Cole of the Land Combat Group, RF Guidance Technology, Advanced Sensors Directorate, US Army Missile Laboratory, US Army Missile Command, Redstone Arsenal, Alabama.

Compilation of this document was performed by Mr. Garlough. Data was recorded using US Army equipment located at Test Area 1 by Test and Evaluation Directorate personnel.

II. TEST DESCRIPTION

The following test description is excerpted from the contractor's final report, reference CEI-BDS-FTR, dated 18 December 1980. Those parts of the contractor's report which reference parts of that report are deleted.

"A CEI Model GRS-1L Ground Receiving Station was used to receive, process, display, and record the scoring data from the BDS. A 1515.5-MHz telemetry link was used between the BDS and receiving station. (Reference deleted.)

"The object of the BDS tests conducted at Redstone Arsenal was to demonstrate the feasibility of a scoring technique at 3.245 GHz during static firing tests. All test firings were conducted with the BDS suspended a minimum of 20 feet above ground level with the horn antenna pointed vertically. The 90° test shots were fired with ranges between 5 to 55 feet above the horn antenna. This test setup deviated from the Performance Test Plan (CEI-BS-PTP) because the 20-mm gun was more easily and accurately moved in elevation. Moving the gun in azimuth would have been considerably more difficult and time consuming.

"The test firings were conducted over a three-day period beginning on Tuesday, November 18, 1980 and ending Thursday, November 20, 1980. A total of 53 test rounds were fired at varying angles of 0°, 45°, 90°, 135° and 180°, and at varying ranges of 5 to 55 feet.

"On Tuesday, 11 test rounds were fired to check out the system. All rounds fired were at 90° (horn antenna pointed vertically)

and with ranges varying between 5 to 50 feet. The BDS exhibited a problem in that excessive noise was noted on the sensor output. The problem was corrected by realigning the timing between the transmitter and receiver pulses. (References deleted.)

"With the sensor readjusted, the tests were continued on Wednesday with 23 test rounds being fired (rounds 12 through 34)." (References deleted.) "Rounds 12 through 23 were conducted at 90° with ranges of 45, 50, 52, 55, 40, 35, 30, 25, 20, 15, 10, and 5 feet respectively. The ground receiving station counted all rounds correctly except for the round at the 55-foot range which was outside of the range of the system.

"Rounds 24 and 25 were fired with the antenna at 0° orientation (horn antenna pointed directly towards the gun) and at ranges of 5 feet and 10 feet above the antenna. The BDS started to exhibit excessive noise and deteriorating signal level again, and this problem persisted the remainder of the day. The round at 5 feet was counted; the round at 10 feet was not counted. The failure to score at 10 feet was primarily caused by the reduced radar cross-section at this orientation and the reduced response from the projectile passing through the edge of the scoring antenna pattern.

"Rounds 26, 27, and 28 were fired with an antenna orientation of 180° (horn antenna pointed directly away from the gun) at a range of 5 feet. These three rounds were not counted due to the recurring BDS noise problem.

"Rounds 29 through 34 were fired with antenna orientation of 45° (horn antenna pointed towards the gun and elevated at 45° at ranges of 5, 10, 20, 30, 40, and 25 feet respectively. All rounds were counted except for the rounds at 30 and 40 feet.

"On Thursday, 19 rounds were fired (rounds 35 through 53). (References deleted.) With the BDS operating properly, rounds 35 through 40 were fired with an antenna orientation of 0° (horn antenna pointed directly towards the gun). Rounds 35 through 38 were fired at a range of 3 feet under the antenna, round 39 at 5 feet under the antenna, and round 40 at 10 feet above the antenna. All rounds were counted on the ground station except round 40 at a range of 10 feet, which again was at the edge of the scoring patterns.

"Rounds 41 through 47 were fired with an antenna orientation of 45° (horn antenna pointed towards the gun and elevated at 45° at ranges of 5, 10, 20, 25, 30, 35, and 40 feet respectively). All rounds were counted except round 47 at 40 feet, which is the effective range limit for this reduced radar cross-section at a 45° aspect angle. In this orientation, the projectile passes the center of the scoring pattern at a distance of 57 feet ($40 \text{ ft} / \cos 45^\circ$), which is outside of the scoring range of the system.

"Rounds 48 through 51 were fired with an antenna orientation of 135° (horn antenna pointed away from the gun and elevated at 45° and ranges of 5, 10, and 20 feet respectively). Starting with round 48, the noise level from the BDS began to increase with a decrease of signal level. All rounds were counted except round 51 at 20 feet.

"Rounds 52 and 53 were fired with an antenna orientation of 180° (antenna pointed directly away from gun) at ranges of 3 feet and 5 feet under the BDS. Rounds 52 and 53 were not counted due to the degrading doppler signal-to-noise ratio from the BDS."

III. RADAR SYSTEM ANALYSIS

Radar performance can be evaluated from the simple form of the radar equation.

$$P_r = \frac{P_t G^2 \lambda^2}{(4\pi)^3 R^4 L_s}$$

where

P_r is power received

P_t is power transmitted

G is antenna gain

λ is radar wavelength

R is range to target

σ is radar cross section

L_s is system losses

Power received, P_r , can be expressed as a function of the signal-to-noise ratio (S/N).

$$P_r = KTB F (S/N)$$

where

K is Boltzmann's constant 1.38×10^{-23}

T is temperature degrees Kelvin 290°

B is receiver bandwidth

F is noise figure of the receiver

Substituting one equation into the other results in a more convenient form of the radar equation that evaluates signal-to-noise ratio of the receiver for given radar parameters.

$$S/N = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 KTBFL_s}$$

In analyzing radar performance, it is convenient to assume that the radar and target are both in free space. This case is allowed the freedom to do so because of the relative low frequency and the extremely short ranges involved.

The attenuation constant, α , at 3 GHz is less than 0.01 dB/km so over the fifty-foot range of this radar the attenuation constant is less than one thousandth of a dB.

The radar parameters of the Bullet Detection System Model BDS, as obtained from the contractor, are given in the following table.

TABLE 1. RADAR PARAMETERS

NAME	SYMBOL	VALUE	dB VALUE
Power Transmitted	P _t	3 Watts	4.77 dBw
Antenna Gain	G	6.31	8 dB
Wavelength	λ	0.0924 Meters	-10.34 dB
Radar Cross Section*	σ	0.02145 Meters square	-16.7 dB
Bandwidth	B	100 MHz	80 dB
Noise Figure	F	3.162	5 dB
System Losses	L _s	10.0	10 dB

*See Section IV. BULLET RADAR CROSS SECTION ANALYSIS

An example radar signal calculation for a 90° firing at 50 feet is shown compared to the signal received on round number 13 which was a 90° firing at 50 feet.

$$S/N = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 KTBFL_s} = 12.1 \text{ dB}$$

The ratio of the signal and noise voltages measured for Round 13 on Figure 1 is approximately 33:6. Therefore, the signal-to-noise ratio measured for Round 13 is

$$S/N \text{ measured} = 20 \log_{10} 33/6 = 14.8 \text{ dB}$$

which is very near the signal-to-noise from the radar parameters given.

FILE NAME: ROUND.013 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:35.359

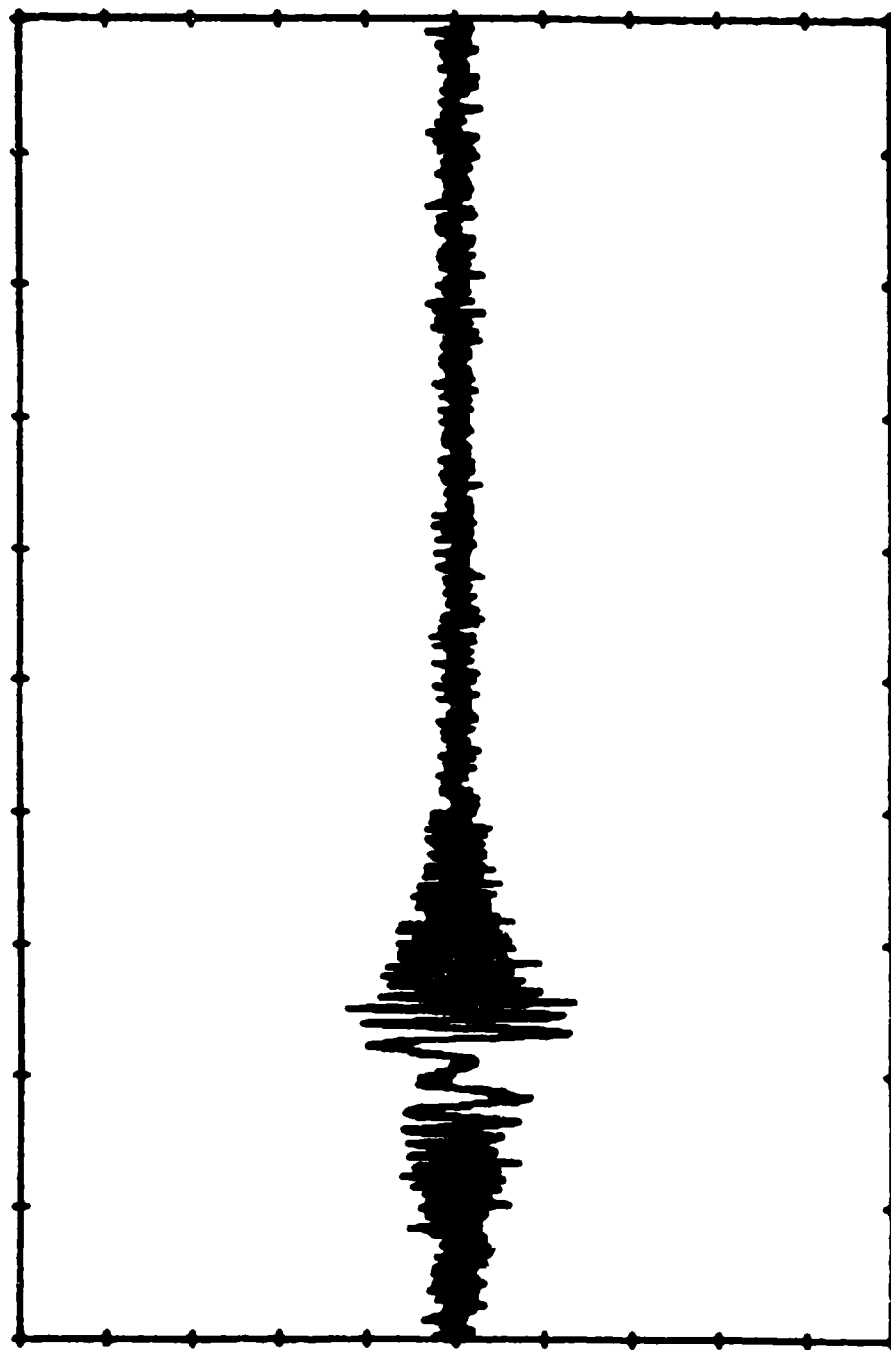


Figure 1. Signal received from round 13.

Another example is when the bullet is fired at an angle of zero degree relative to the radar (head-on). In this case the bullet cross section is reduced by 11 dB according to the contractor.

$$S/N = \frac{P_c G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 KTBFL_s} = 1.1 \text{ dB}$$

However, the radar cross-section of a head on bullet is in the so-called Rayleigh region or law, and has a radius-to-wavelength ratio of approximately 0.1. In this region, the radar cross-section is equal to the optical cross-section.

$$\sigma = \pi a^2 = 3.14 \times 10^{-4} \text{ meters square}$$

This converts to dB as

$$\sigma = -35.03 \text{ dB},$$

which is 18.33 dB down from the calculated and assumed radar cross-section at 90°. Therefore, assuming the end-on head-on radar cross-section to be -35.03 dB results in the following signal-to-noise calculation at 50 feet range.

$$S/N = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4 KTBFL_s} = -6.2 \text{ dB}$$

This level of signal-to-noise will make head-on and end-on detection very difficult even though the bullet may pass closer than fifty feet. Passing at 5 feet will increase the signal-to-noise by nearly 40 dB over the 50-foot case. However, the STC calculated would reduce this gain value to 10 dB, resulting in a S/N at 5 feet of + 4 dB which makes head-on automatic detection questionable. In this case, the zero doppler or zero crossing occurs outside the main beam of the antenna.

IV. BULLET RADAR CROSS-SECTION ANALYSIS

In order to predict the signal-to-noise ratio of the radar receiver, some means of determining the radar cross-section of the 20-mm projectile is needed. Figure 2 shows that the length L, of the projectile is 9.3 cm and the radius, r, is 1 cm. The radar wavelength is 9.24 cm. According to Kerr [1] (see Figure 3), for r/λ near 0.1 (Mie or resonance region), the higher order multiple moments fluctuate in phase and magnitude in a complicated way, causing the radar backscatter curve to oscillate. As r/λ becomes very large, the oscillations diminish much like $\sin X/X$ until the radar cross-section becomes the geometrical cross-section. Predicting the radar cross-section of simply shaped bodies in this region is very difficult at best, and for more complex shapes is beyond the scope of this effort. For this reason, three different methods have been used to develop a radar cross-section model of the 20-mm projectile.

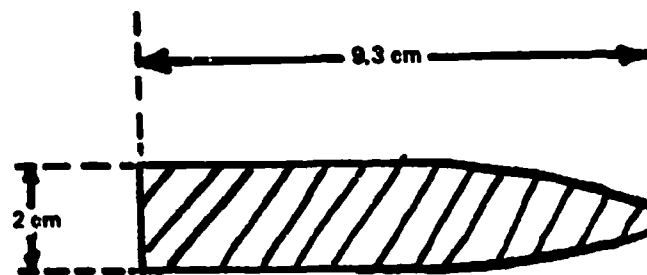


Figure 2. Outline drawing of 20-mm projectile.

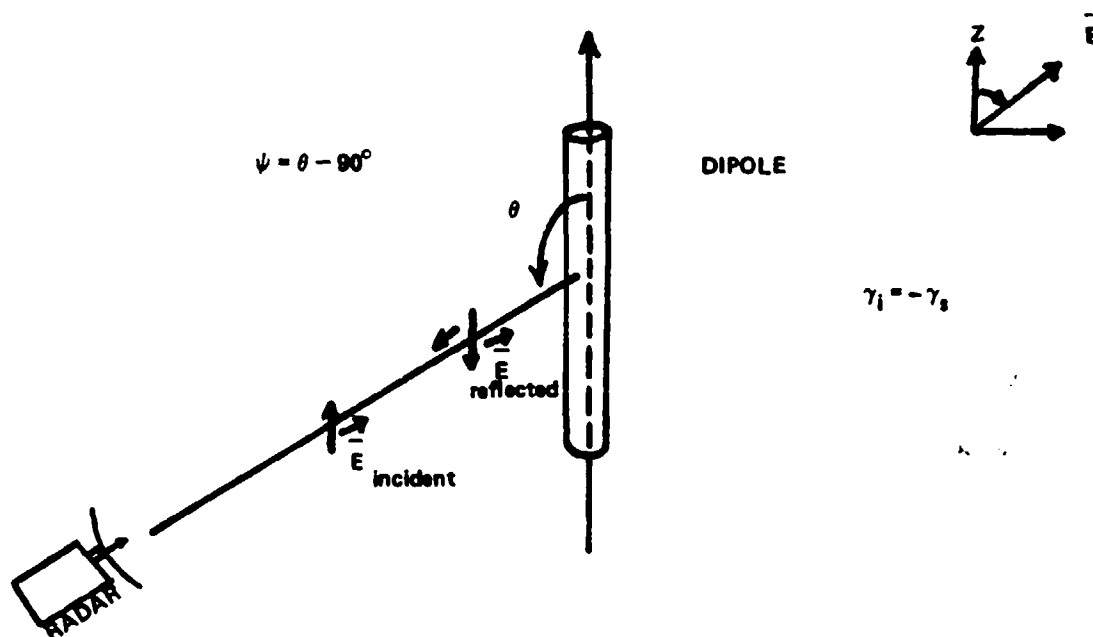


Figure 3. Scattering geometry for a full wave dipole.

The first method assumes the projectile acts as a full wave dipole. This assumption is based on $\lambda = 9.24$ and $L = 9.30$ cm. Figure 4 is a plot of the radar cross-section of a full wave dipole as a function of aspect angle. The null at broadside occurs because the model assumes an infinite thinness for the dipole.

The second method involves frequency scaling of radar cross-section data of an artillery shell which has approximately the same L/r ratio and general shape as the 20-mm projectile. Figure 5 shows the artillery shell and projectile. (The figures are not to the same scale).

The third method utilizes a computer program to decompose the projectile into a collection of evenly spaced concentric wire rings. The radar cross-section of the projectile is determined by summing each ring's contribution to the total backscatter using the method of modes.

A. The 20-mm projectile as a full wave dipole

The assumption is made that at $f = 3.245$ GHz, the projectile will act as a full wave dipole.

$$L = 9.3 \text{ cm (Length of projectile)}$$

$$f = 3.245 \text{ cm}$$

$$\lambda = \frac{c}{f} \quad c = \text{Propagation velocity}$$

$$\lambda = \frac{(3 \times 10^8 \text{ m/sec}) (100 \text{ cm/m})}{3.245 \times 10^9 \text{ Hz}}$$

$$\lambda = 9.14 \text{ cm}$$

$$L = \lambda$$

From Ruck the full wave dipole backscattering cross-section is given by:

$$\sigma = 0.93 \lambda^2 \cos^2 \delta_i \cos^2 \delta_s \left[\frac{\sin(\pi \sin \psi_i)}{\cos^2 \psi_i} \right]^2 \left[\frac{\sin(\pi \sin \psi_s)}{\cos^2 \psi_s} \right]^2$$

where

δ_i = Polarization angle, incident plane

δ_s = Polarization angle, scattering plane

ψ_i = Aspect angle, incident plane

ψ_s = Aspect angle, scattering plane

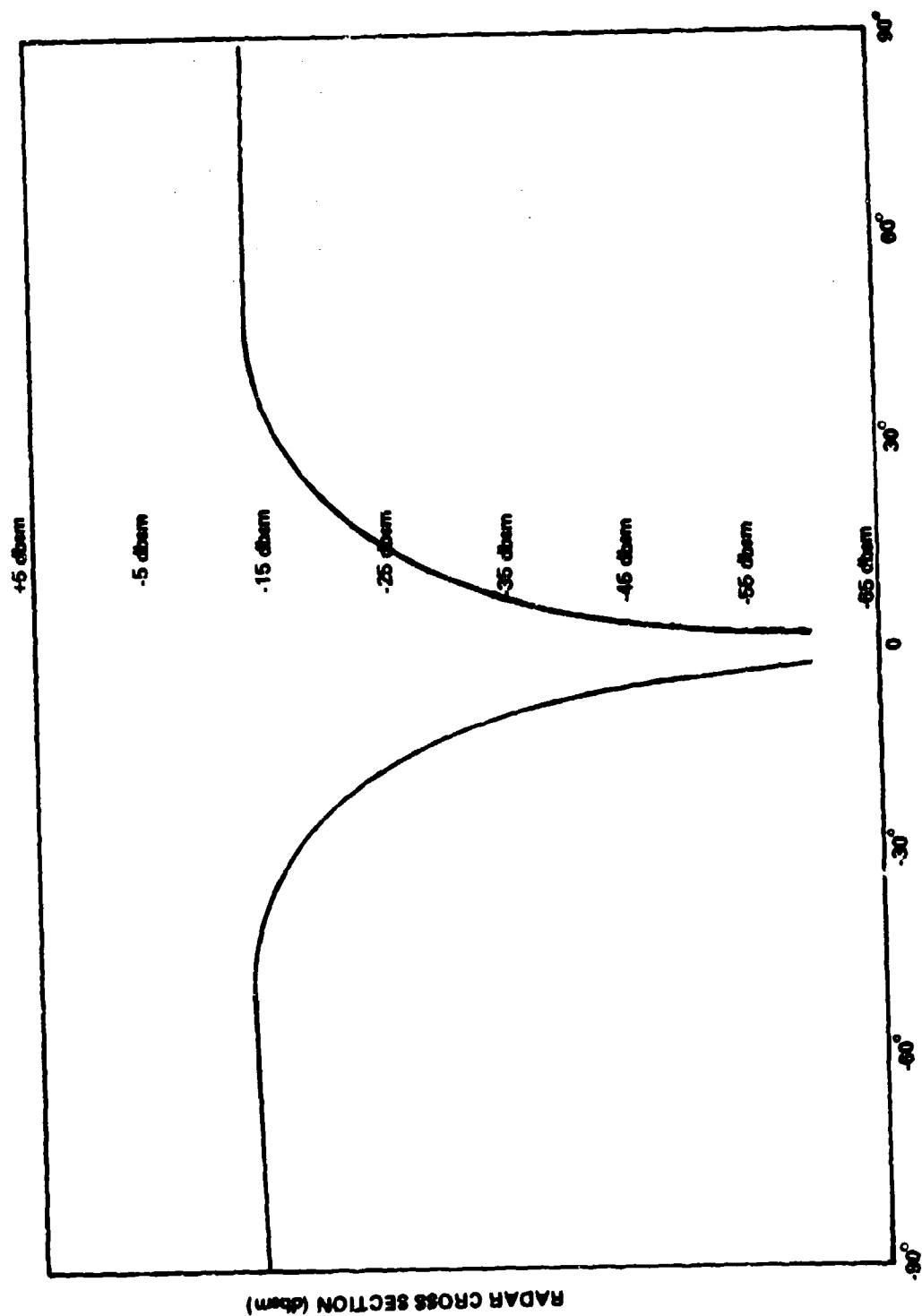
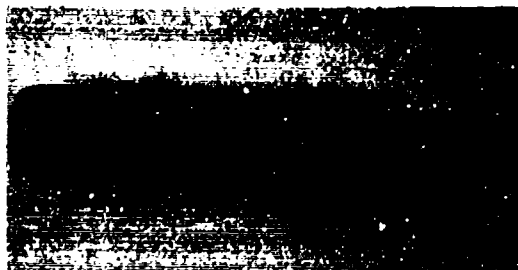
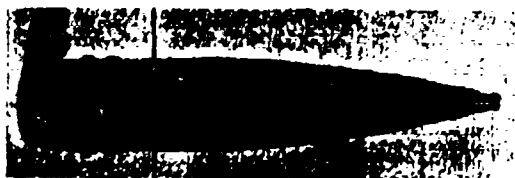


Figure 4. Radar cross-section of full wave dipole.



a.



b.

Figure 5. (a) 20-mm projectile and (b) artillery shell used for scale modelling.

For the backscattering only case:

$\psi_i = \psi_s = \psi$ = angle between a line normal to the dipole longitudinal axis and the radar.

ψ varies between -90° and 90° .

Rewriting (Equation 1) yields:

$$\sigma = 0.93\lambda^2 \cos^4 \delta \left[\frac{\sin(\pi \sin \psi)}{\cos^2 \psi} \right]^4$$

Figure 4 is a plot of this equation for $\lambda = 9.245$ cm. (Polarization parallel to the length of the dipole or $\psi = 0^\circ$.) Maxima radar cross-section occurs at $\psi = +55^\circ$. This equation models a thin dipole with a sinusoidal current distribution along the length and zero current at the ends. It assumes zero transverse cross-sectional area, hence the broadside return is zero. Singularities exist at $\psi = +90^\circ$ and $\psi = 0^\circ$ so the model is valid only in the region bounded by $\psi = +80^\circ$, $\psi = +5^\circ$.

B. Radar cross-section of 20-mm projectile from scale model

Using data taken on an artillery shell and standard scale modeling techniques, a plot of projectile radar cross-section versus aspect angle was developed. The raw data consisted of plots of the artillery shell RCS vs aspect angle for horizontal and vertical polarization. Pseudo circular polarization data was developed by vectorially adding the horizontal and vertical raw data. Frequency scaling techniques were applied to yield the radar cross-section of a 20-mm projectile at 3.245 GHz for circular polarization. Figures 6 and 7 are the artillery shell plots and Figure 8 is the 20-mm radar cross-section plot.

C. Radar cross-section of 20-mm projectile by computer modeling

Figures 9 and 10 are computer model plots of the projectile radar cross-section versus aspect angle for horizontal and vertical polarization. The horizontal plot corresponds to the $\vec{E}$ parallel to the longitudinal axis of the projectile. Nose-on occurs at 0 degrees and broadside at 90 degrees. Figure 11 is the result of vectorially adding the two plots to simulate circular polarization.

D. Figure 12 is a comparison of the results obtained by computer and scale modeling. The 5-dB difference at broadside can be attributed to resonance effects for which the computer model does not compensate. (See dipole plot, Figure 4, for resonance effect contribution to radar cross-section.) For ψ (aspect angle) = $+25^\circ$, the projectile cross-section approximates that of a half-wave dipole. The 16 dB drop (from scale model curve) between broadside and nose-on is in agreement with the data provided by the contractor. The contractor assumed the projectile acted like a half-wave dipole plus 4 dB at broadside with an 11-dB drop from broadside to end-on. The nulls at approximately $+30^\circ$ were not predicted by the contractors.

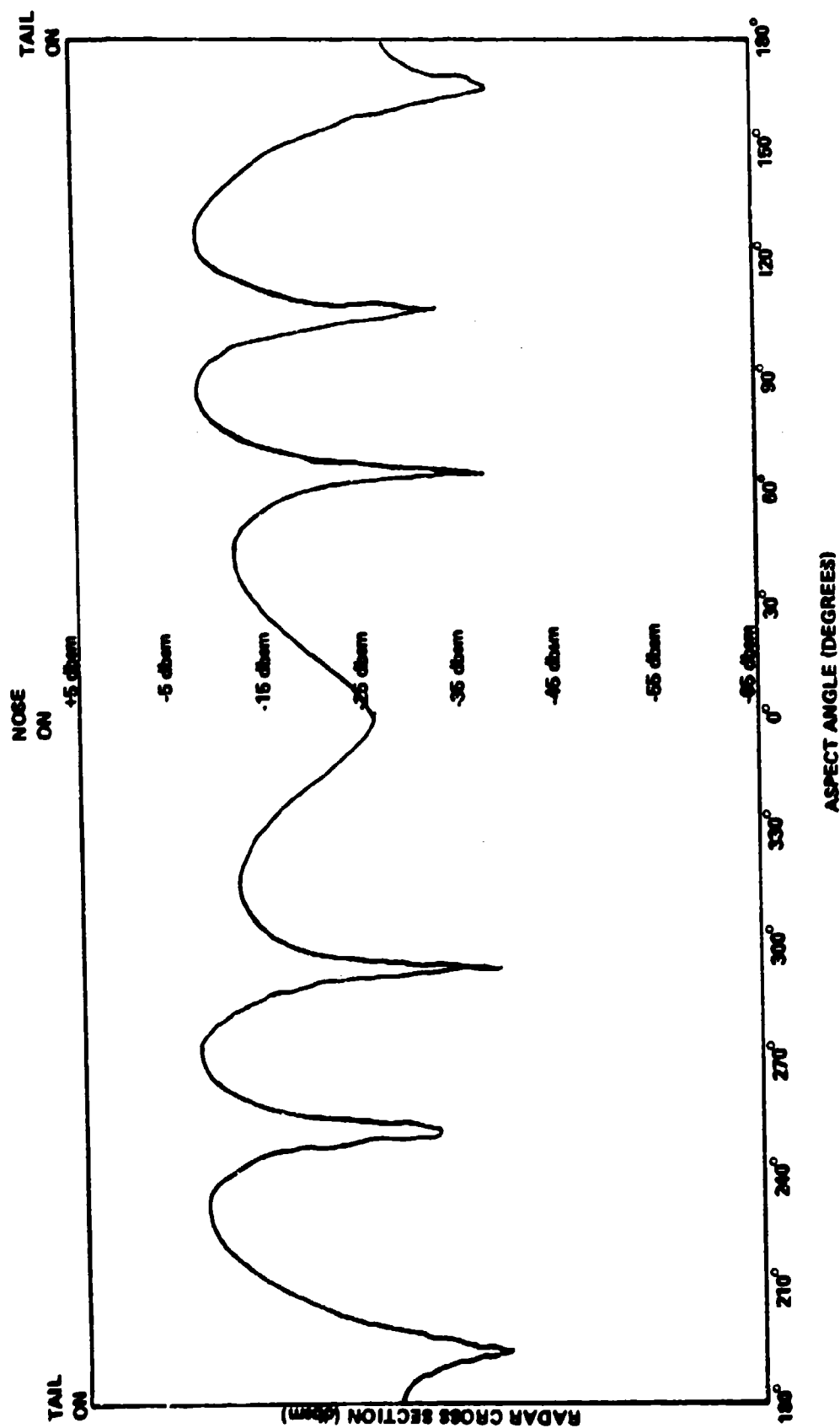


Figure 6. Radar cross-section of scale model vs aspect angle. Horizontal transmit, horizontal receive.

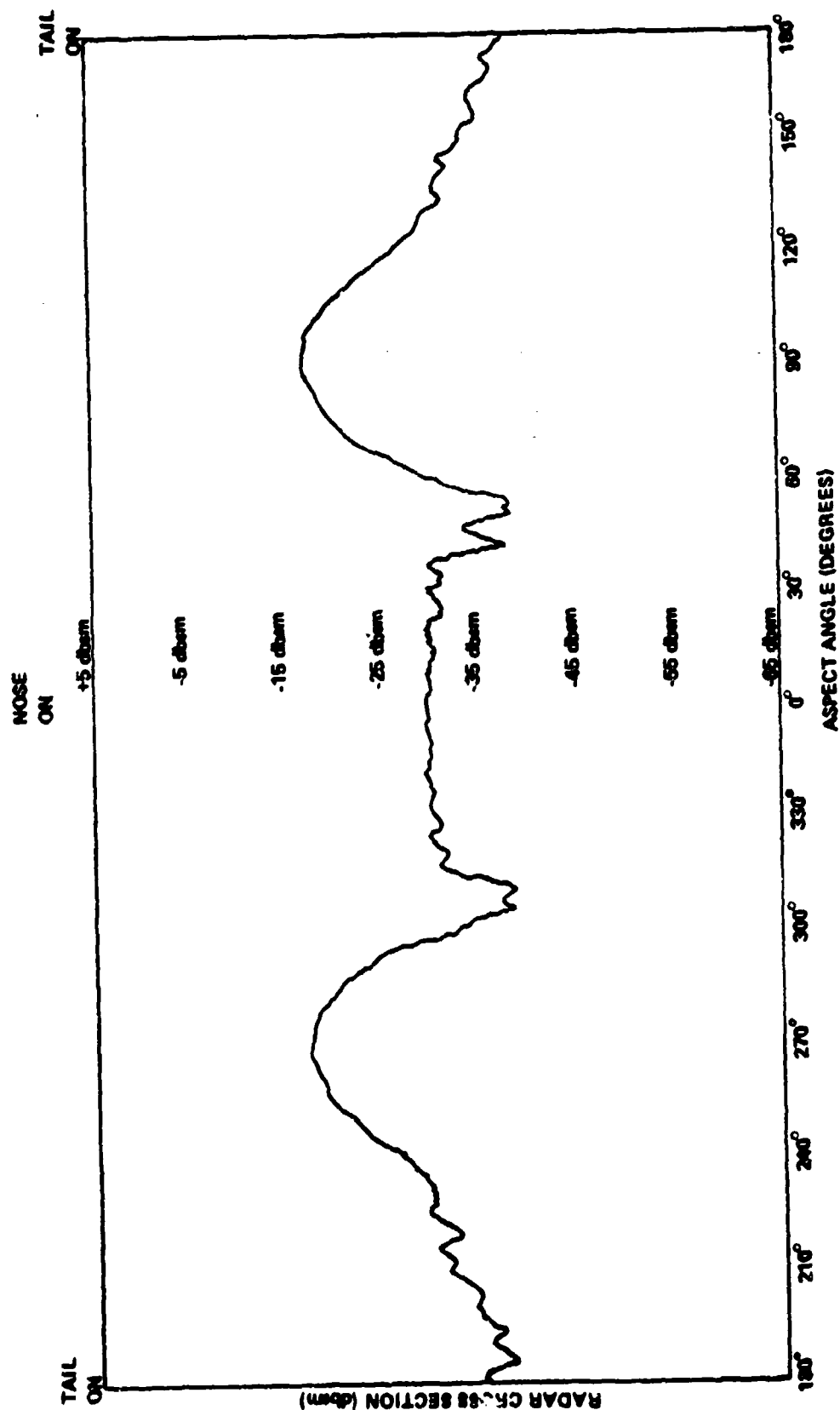


Figure 7. Radar cross-section of scale model vs aspect angle. Vertical transmit, vertical receive.

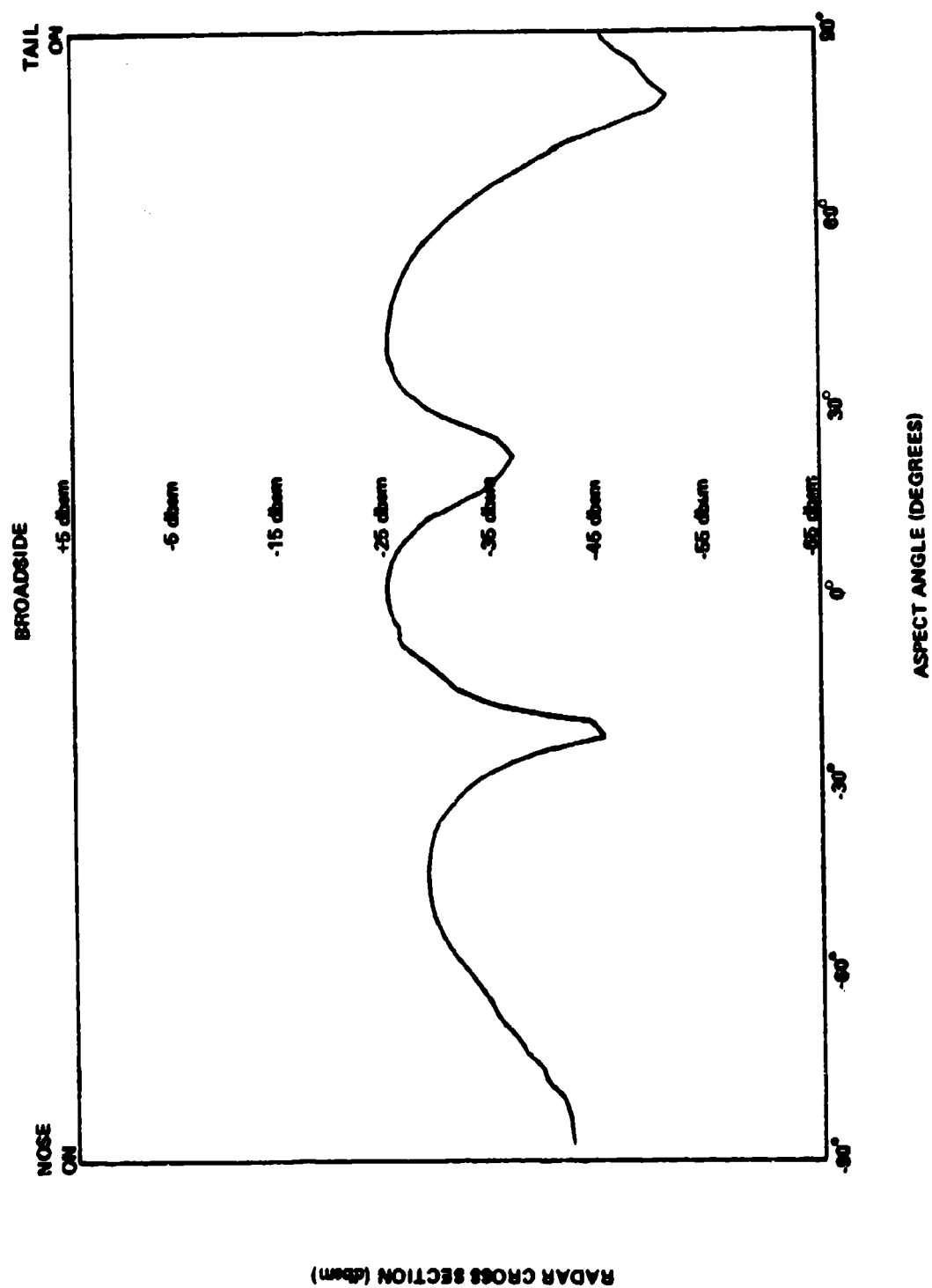


Figure 8. Radar cross-section of 20-mm projectile from scale model data. Circular polarization.

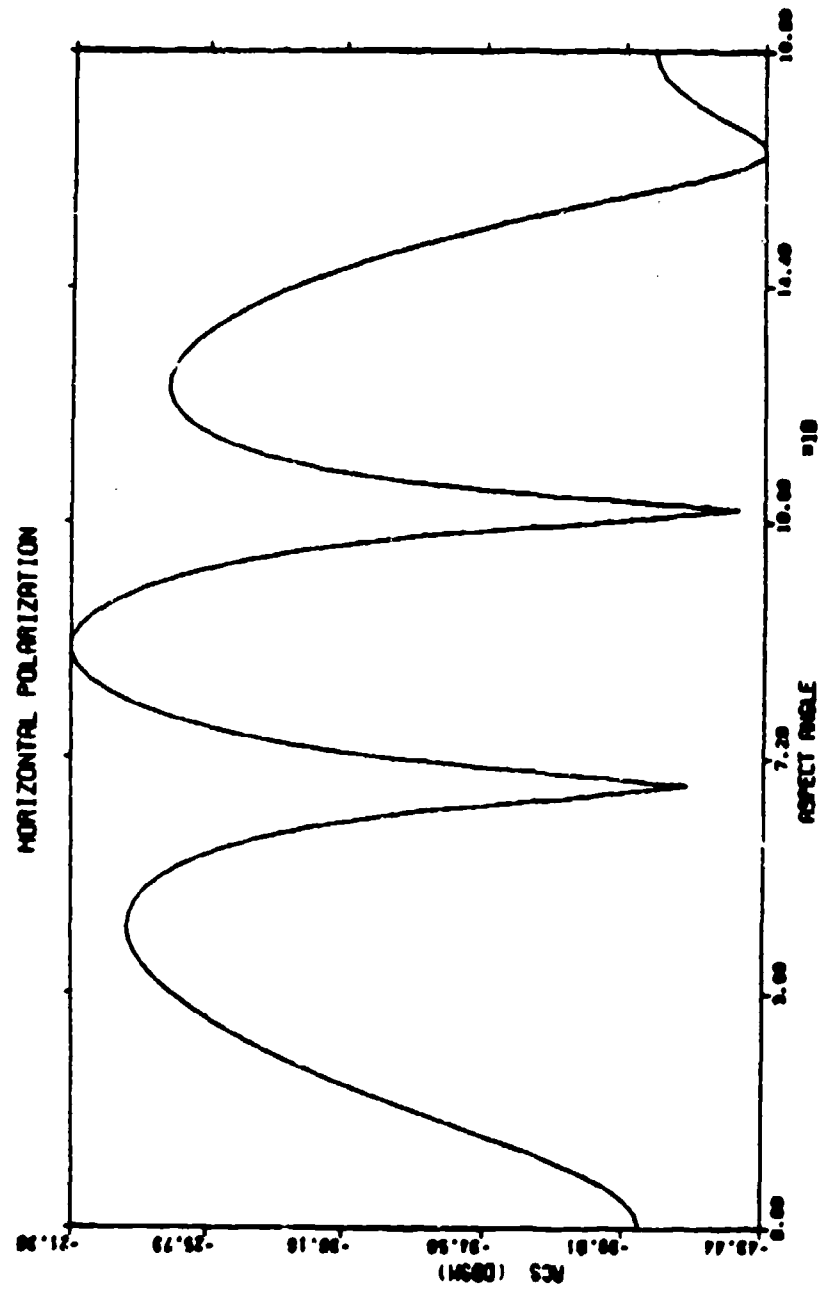


Figure 9. Computer model of 20-mm projectile, horizontal polarization.

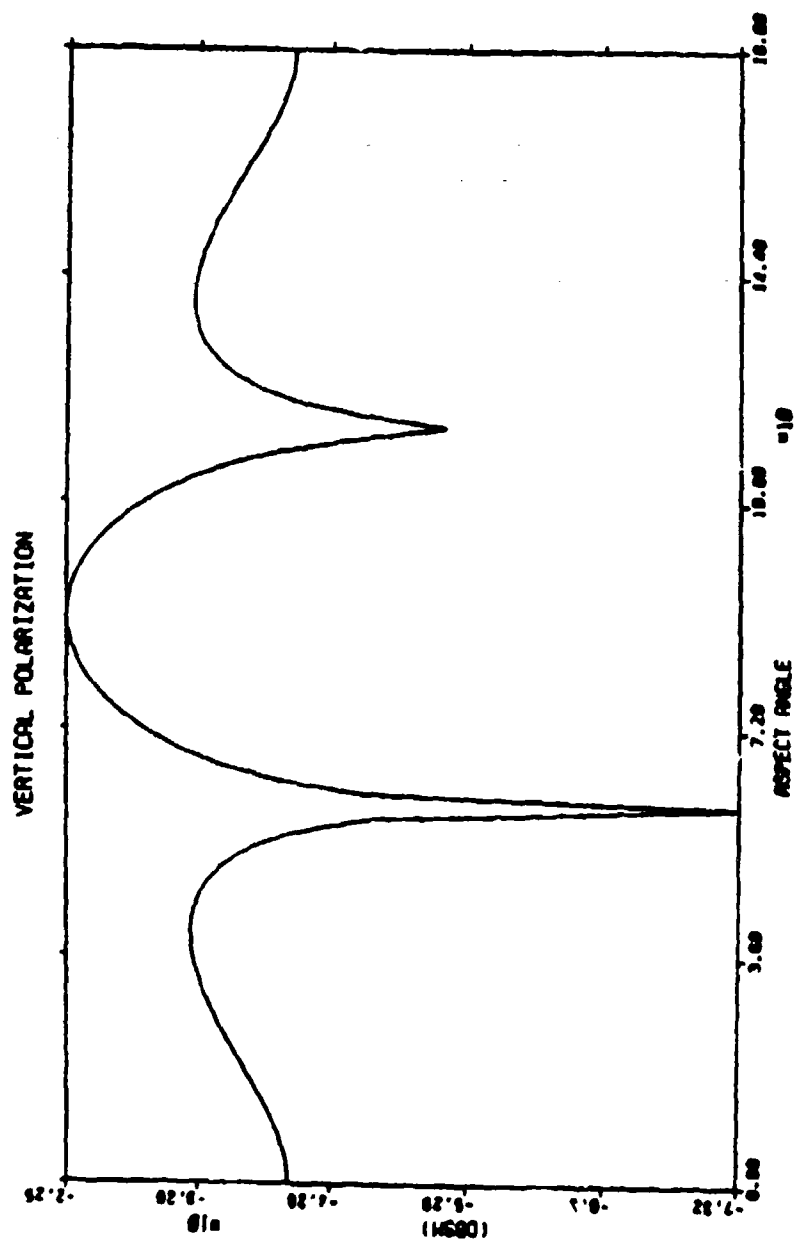


Figure 10. Computer model of 20-mm projectile, vertical polarization.

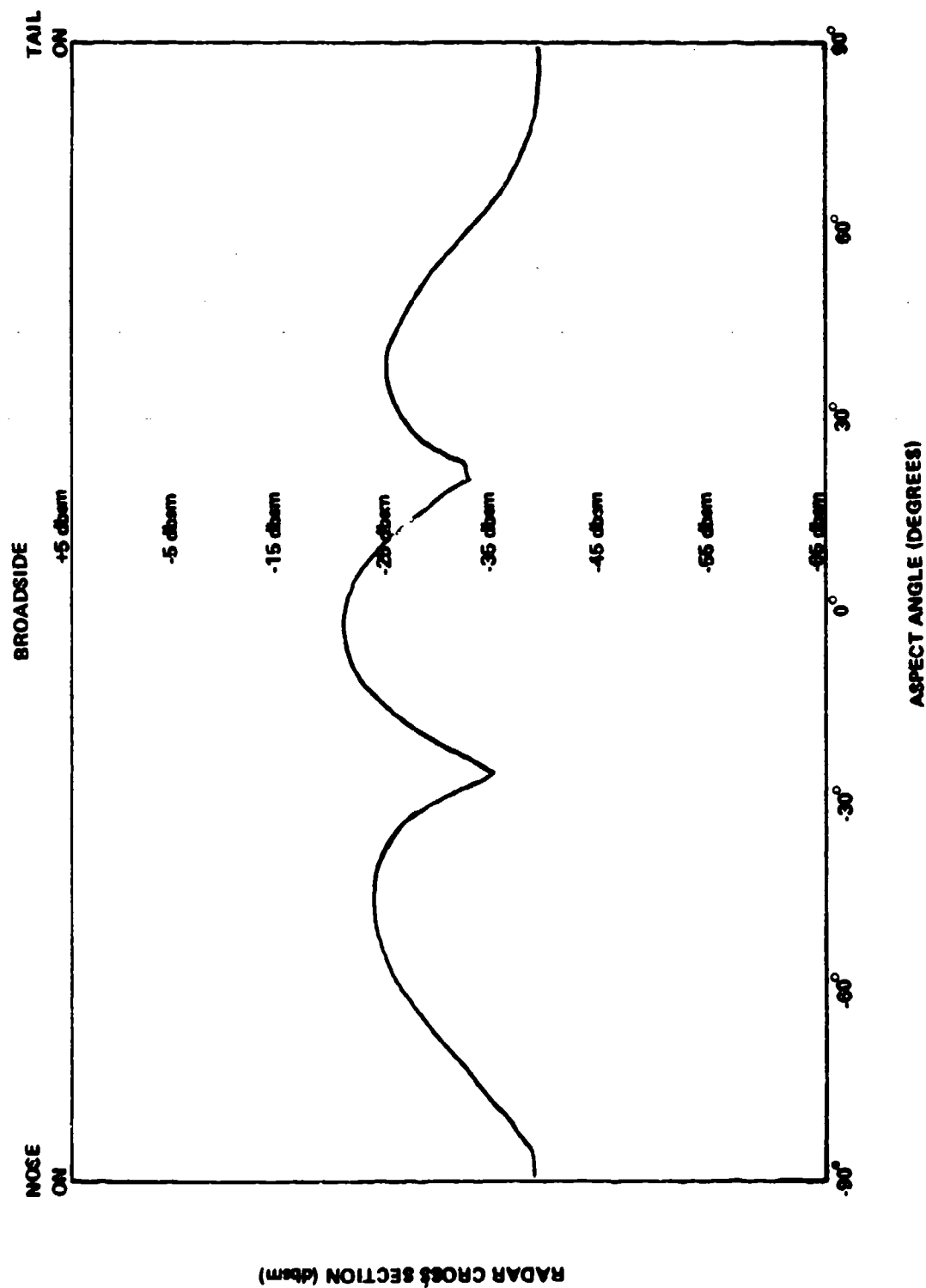


Figure 11. Computer model of a 20-mm projectile, circular polarization.

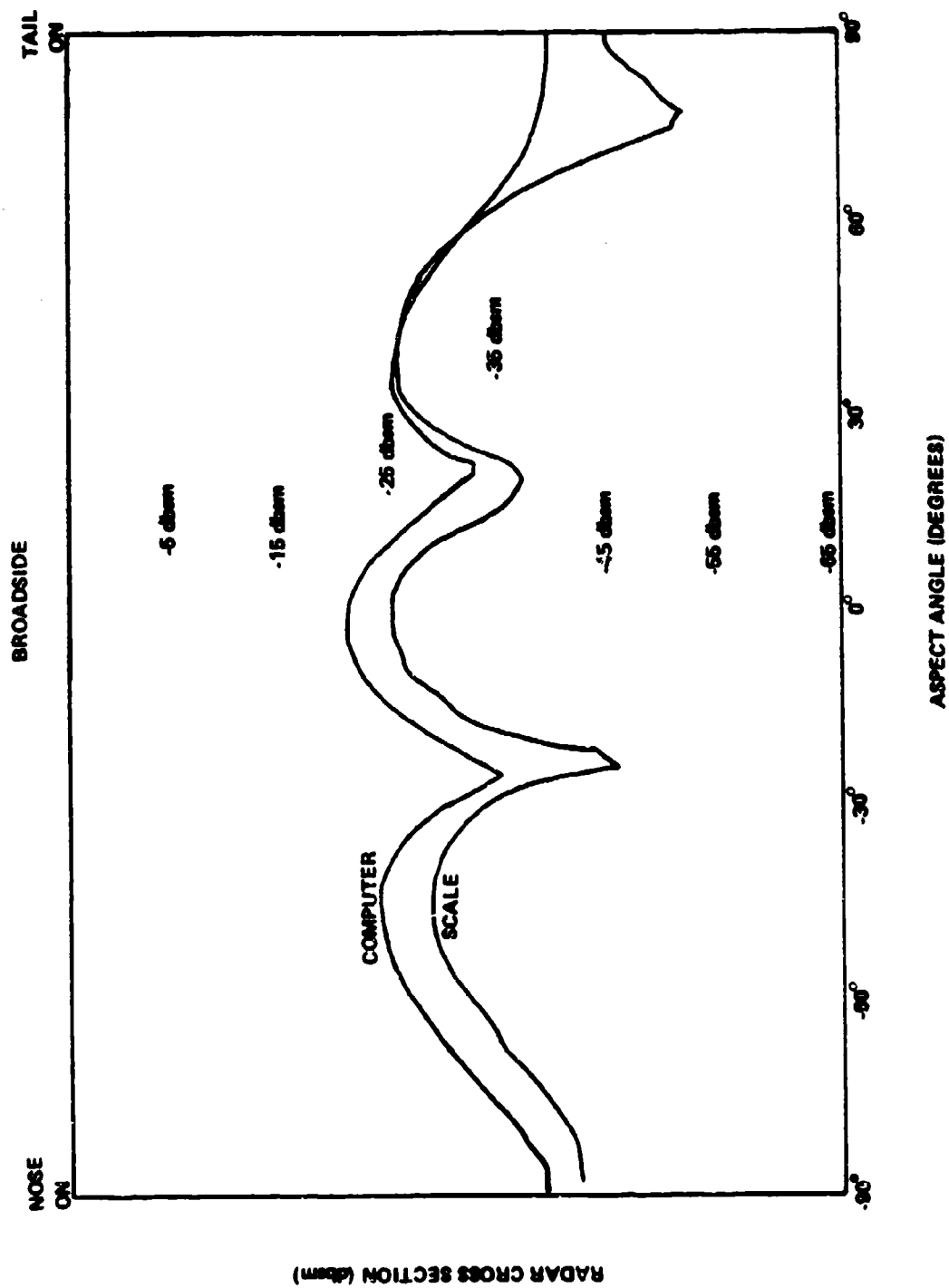


Figure 12. Comparison of computer model and scale mode.

V. DATA ACQUISITION AND PROCESSING

The data plots shown in this document were produced by the techniques described below.

Analog signals from the radar receiver of the system under test were transmitted via the system's telemetry transmitter to the telemetry receiver. The output signals from the telemetry receiver were recorded on magnetic tape.

The tape recorder was operated at 60 inches per second for recording. The tapes were played back at 15 inches per second. During playback, the signal from the tape recorder was sampled at 25 kilohertz, amplified and filtered through a 10-KHz low-pass filter. Since the playback speed of the recorder was reduced by a factor of 4, the equivalent sampling rate was 100 KHz and the equivalent bandwidth of the low pass filter was 40 KHz to real-time.

The signal samples were stored in a computer memory and then recorded on digital magnetic tape. The digital magnetic tape records were then read back into the computer. In the computer the records were sorted, expanded time wise, amplified, etc., to produce the most meaningful data. These data were then plotted on the computer display console and hard copies produced. Three plots (or more) of each round fired are presented in the Appendix. One plot with 4000 samples, 2000 samples, and one plot with 800 samples, for each round are shown.

Some of the deviations from smooth curve representation on the plots are due to sampling rate versus signal frequency. Figure 13 is an example of deviations from a smooth curve.

The three different numbers of samples plotted facilitate investigation of various parameters of the signals, e.g., the 4000-sample plots reveal the background noise before and after the doppler pattern and the expanded sample plots (fewer number of points) show the characteristics of the doppler pattern.

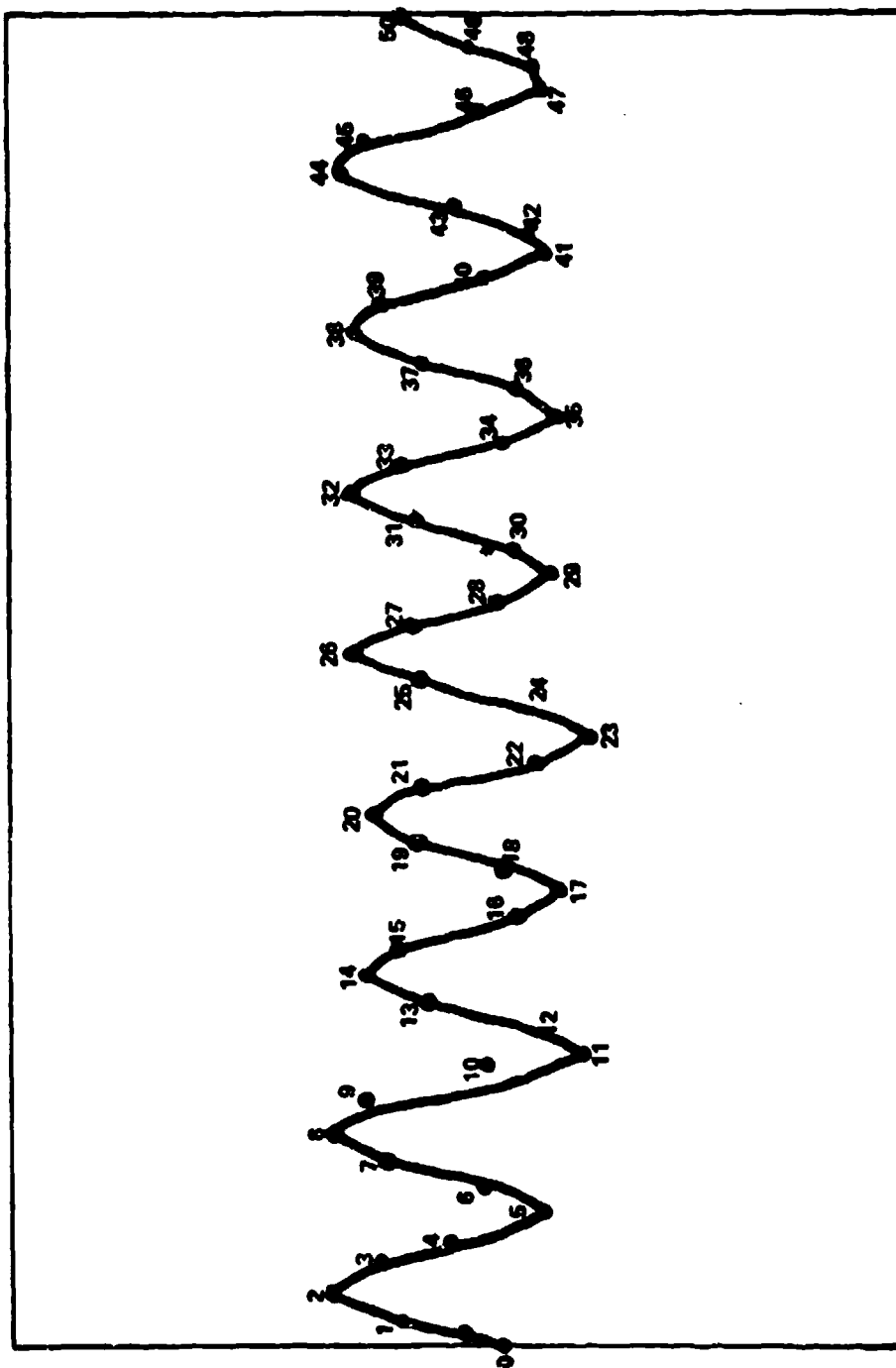
Processing of the data, from playback of the analog tapes to the hard copy plots, was performed by the RF Guidance Technology Data Analysis Facility, US Army Missile Command, Redstone Arsenal, Alabama.

VI. DATA

The data plots are presented in the Appendix. The data are plotted on three different scales, 4000, 2000, and 800 points per plot. The data were acquired at an equivalent rate of 100,000 points per second or 10 usec per point. Therefore, a 4000 point plot is 40 msec long, a 2000 point plot is 20 msec long and an 800 point plot is 8 msec long. The plots are conveniently tick marked both on X and Y axis at 10 percent points to facilitate easy interpolation. Since no calibration was provided, amplitudes are relative rather than absolute; however, all plots are the same amplitude scale. In some cases, the pertinent data straddles two digital tape records; in these cases there are presented more than 3 plots per round.

The round number is presented at the top of the plot along with the date-time group. The sample number limits are given at the bottom of the plot so that the number of points plotted can be easily identified.

FILE NAME: ROUND.013 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:35.459



SAMPLES 700 THRU 750

Figure 13. Example of deviations from smooth curve.

Excerpts from the contractors test logs are presented in the appendix. These excerpts contain the pertinent information about the specific round fired: round number, range, angle, and remarks.

VII. DATA ANALYSIS

A. Signal-to-Noise Ratio

The signal-to-noise ratio expected is presented in the Radar System Analysis section of this document. The data presented herein supports the theoretical S/N ratio calculated.

Refer to data plots and test logs. Measure the amplitudes of the signal and noise shown in the data plots. Compare the signal-to-noise ratios of count and no-count rounds. Compute $20 \times \log_{10} (S/N)$ for count and no-count rounds. All rounds which produced S/N ratios of 13 dB or more produced a count except round 32.

Round 32 data does not support a no-count condition. On this round, the background noise level is higher than normal but the S/N ratio is still greater than 15 dB.

Round 46 data indicates that a no-count should have occurred; however, count did occur. The S/N ratio on this round was approximately 8 dB.

Figure 14 shows a scenario of a projectile fired parallel to boresight as with round 39. Note that zero doppler occurs in the null 90 degrees from boresight in the antenna pattern. The entire radar return is weak due to poor aspect angle (minimum cross-section) as the projectile approaches the antenna. As the cross-section improves, the antenna pattern causes a null in signal strength. Hence, the zero doppler portion of the plot is obscured in noise.

B. Sensitivity Time Constant (STC) Curve

The STC curve, Figure 15 was plotted using the following technique. Since no calibration was provided, all values are normalized rather than using absolute values.

The theoretical signal strength decreases as the 4th power of range. See Figure 16. The relative signal strength as a function of range of 10 times $\log_{10}$ of the reciprocal of the 4th power of range (in meters). The signal strengths indicated are for ranges 5 through 55 feet in steps of 5 feet, all were broadside. Since an ideal STC curve would produce a straight line signal strength curve, an equation was generated to produce the line shown (labeled MEASURED) on the plot Figure 16. The STC attenuation curve was then produced by subtracting the straight line signal strength curve from the normalized theoretical signal strength curve. The relative STC curve as a function of range (or time) is shown in Figure 15.

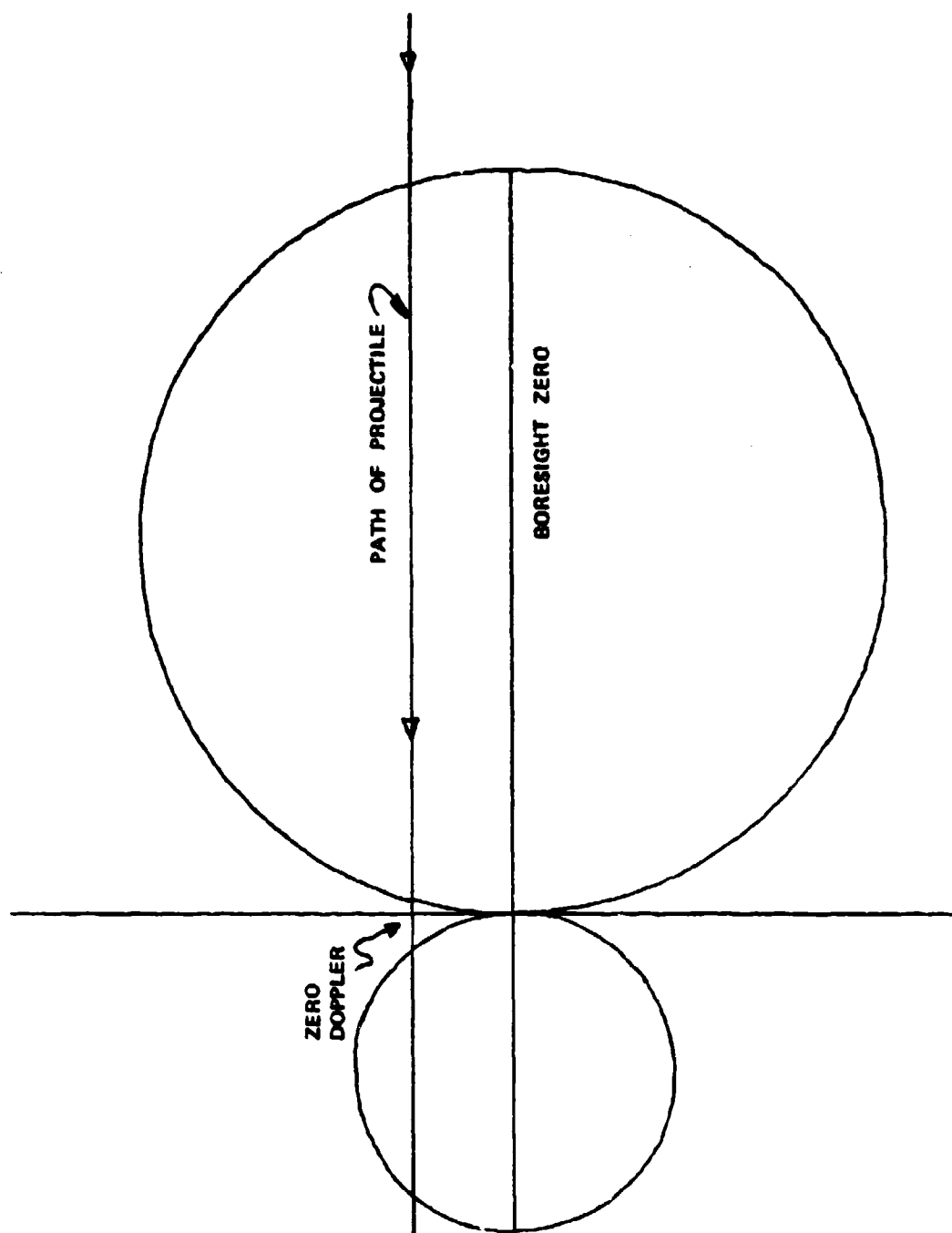


Figure 14. Scenario of a projectile fired parallel to boresight.

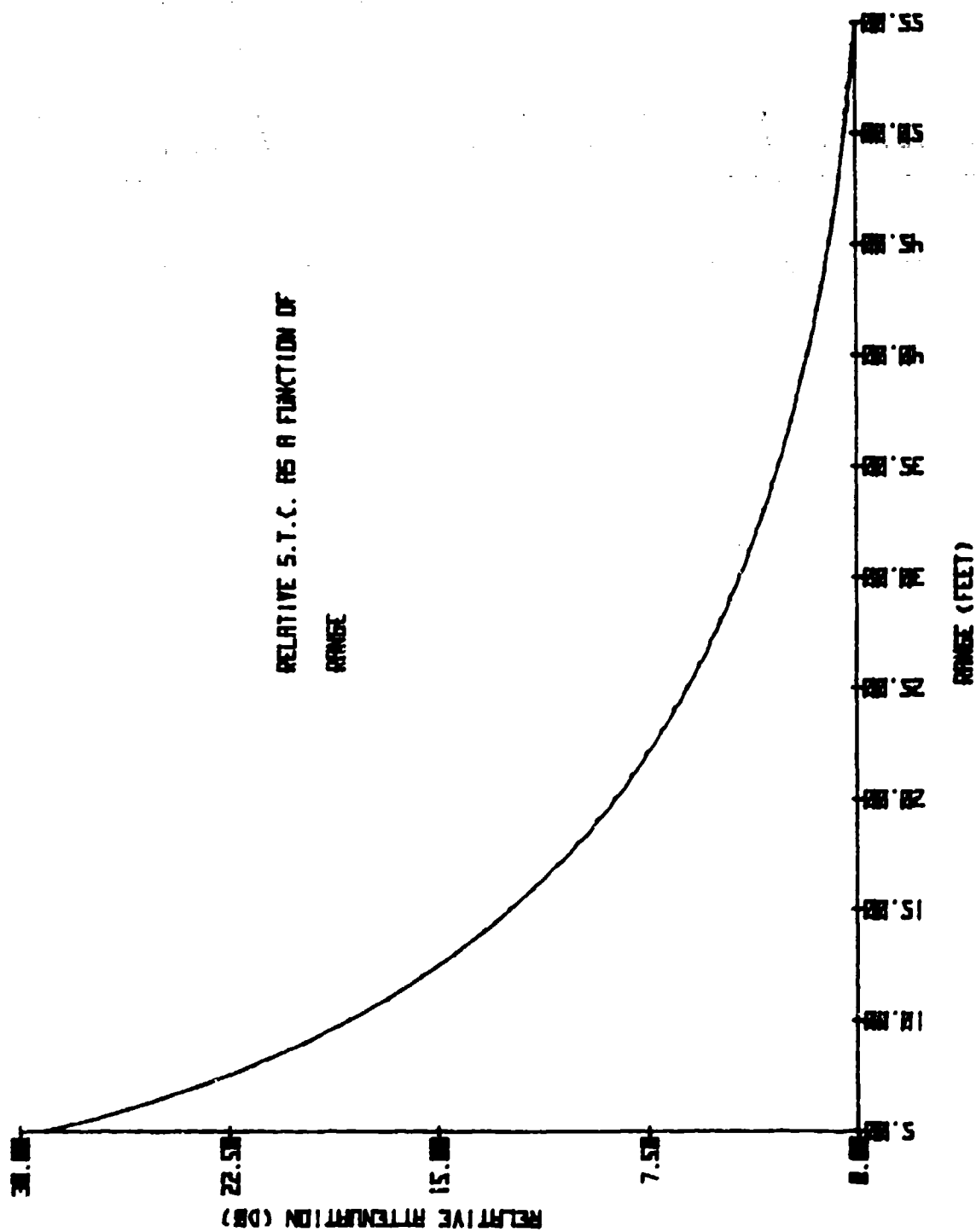


Figure 15. STC curve.

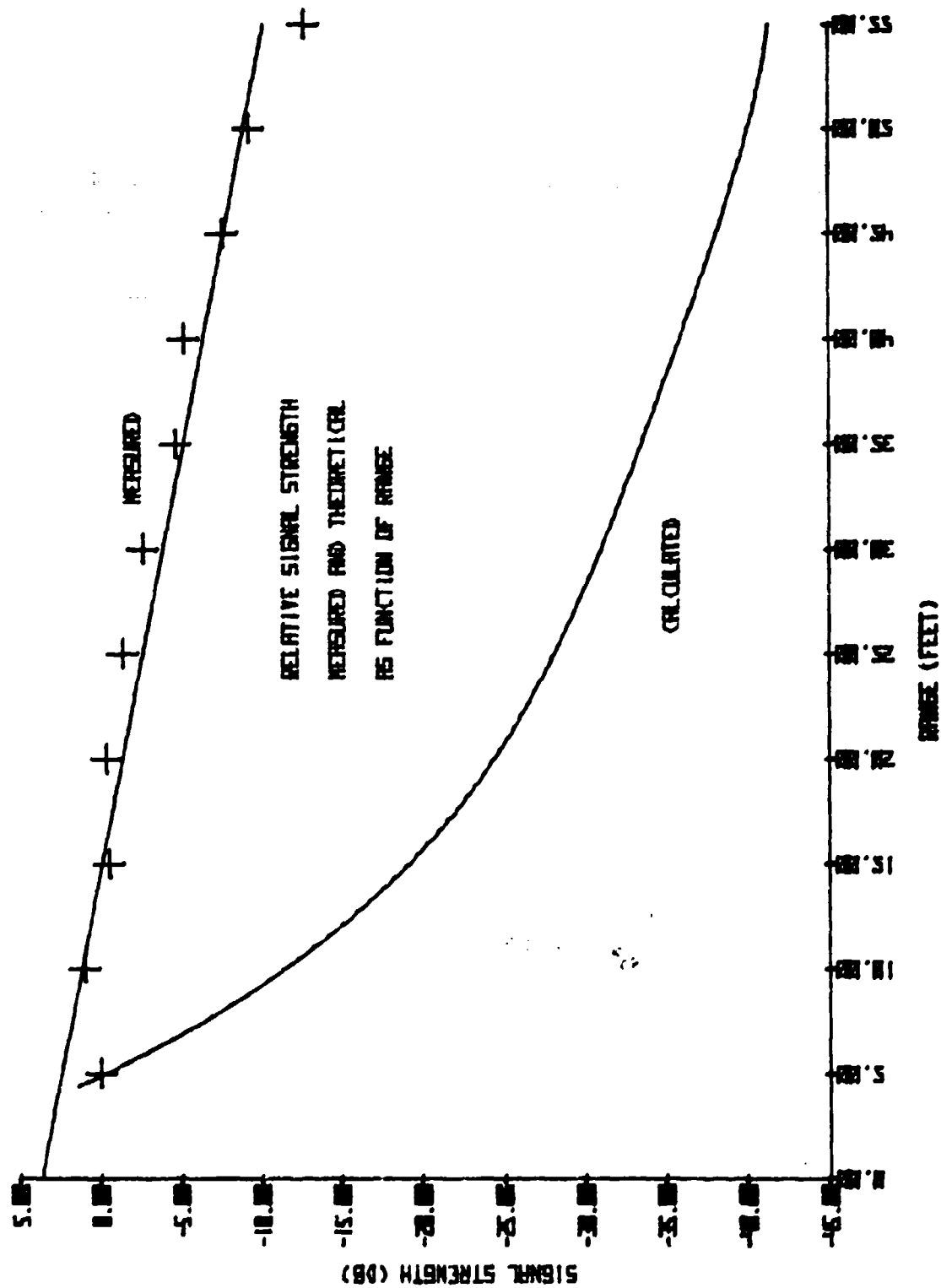


Figure 16. Relative signal strength.

C. Doppler Frequency

The doppler frequency can be calculated by counting the number of samples per doppler signal cycle. The number of samples is shown at the bottom of each plot. The effective sampling rate is 100K samples per second.

Refer to Figure 13. Approximately 49 samples were taken during 8 cycles of doppler. This is 6.13 samples per cycle; therefore, the doppler frequency is approximately 100K samples divided by 6.13 samples which equals to 16.31 KHz.

The calculations can be further extended to determine the velocity of the round relative to the antenna. Doppler frequency is equal to $2 \times \text{velocity}$ divided by wavelength of the radar frequency. The wavelength used in this system is 9.245 cm or 0.09245 meters. Wavelength is calculated by dividing the speed of propagation of radar, 300,000,000 meters per second, by the radar frequency 3.245 GHz. The velocity of the projectile is equal to one-half the frequency of the doppler multiplied by the wavelength of the radar signal which is in this case 754 meters per second (2473 feet per second).

D. Data Anomalies

During the tests, noise levels shown on the plots were not consistent. Some of these inconsistencies were explained by the contractor as caused by equipment malfunctions.

The 90-degree plots show asymmetrical amplitude responses, i.e., the amplitude of the doppler signal is greater after zero doppler than before zero doppler. This phenomenon and some reoccurring cyclic noise after some round passings appear to be caused by ringing in the system. These phenomena were not explained by the contractor.

The 45-degree plots show an amplitude build-up, an amplitude null, then another amplitude build-up prior to zero doppler. The null phenomenon cannot be explained as due to antenna pattern alone. One possible explanation is that as the aspect angle of the projectile changes, the amplitude of the radar return changes. See Section IV (BULLET RADAR CROSS SECTION). The only significant nulls in the antenna pattern occur at the 90-degree off boresight positions. Figure 17 shows the 45 degree scenario of rounds 30 and 42 as they pass through a theoretical antenna pattern. The antenna pattern provided by the contractor is shown in Figure 18.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The unit tested was capable of detecting projectiles passing at various angles. Best performance was when the projectile passed normal (90°) to antenna boresight. The range gate was adjusted to count projectiles passing within 5 to 50 feet and excluded counting projectiles passing outside these limits. Reliability of counting all projectiles passing within these limits is good but not excellent when the projectile passes normal to antenna boresight. For projectiles passing 45° to antenna boresight, no round passing at a distance greater than 35 feet was counted. At ranges of 35 feet and less, there was a tendency to register multiple counts for a single projectile. No projectile fired at 180° (from the rear) to antenna boresight was counted.

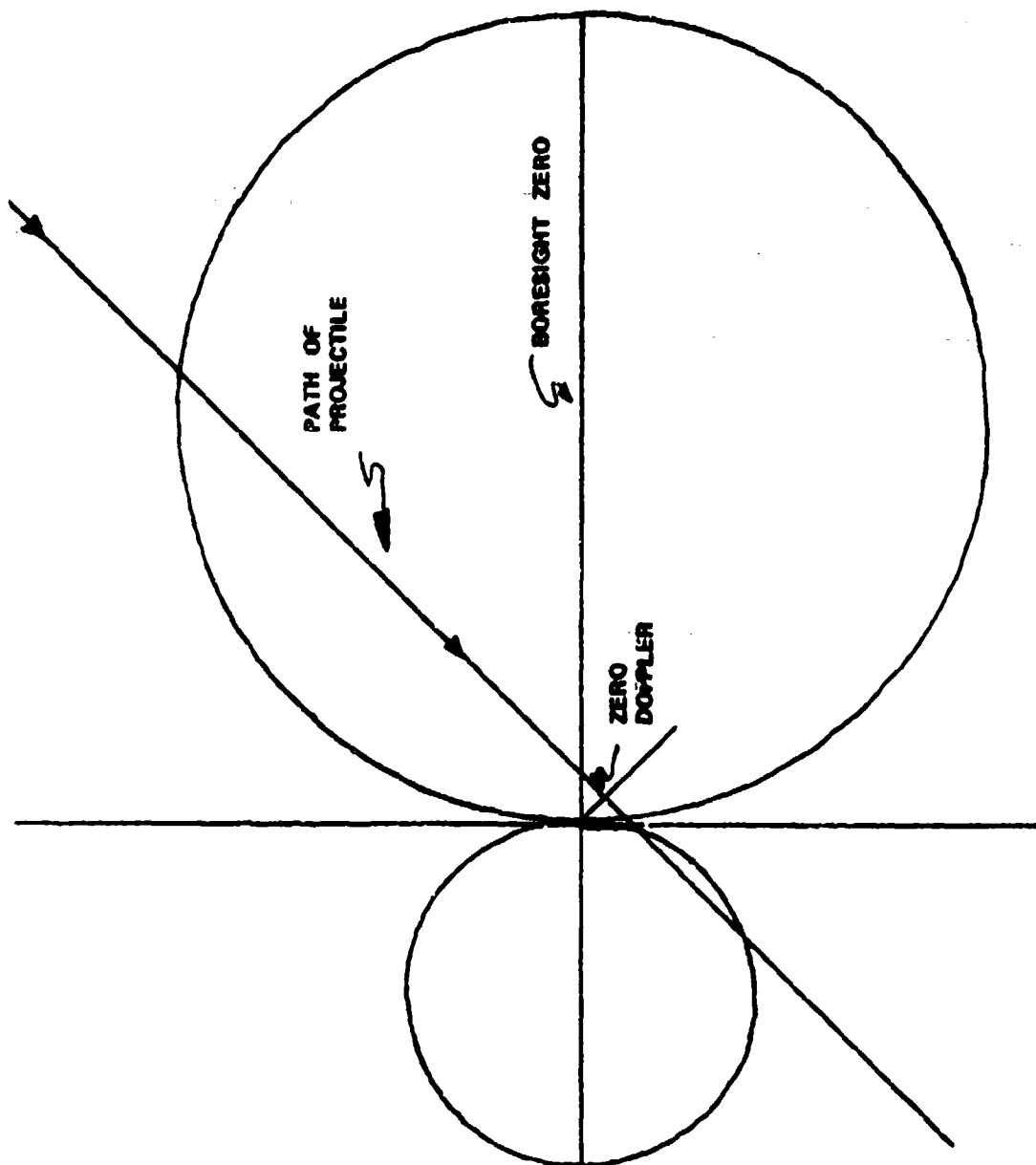
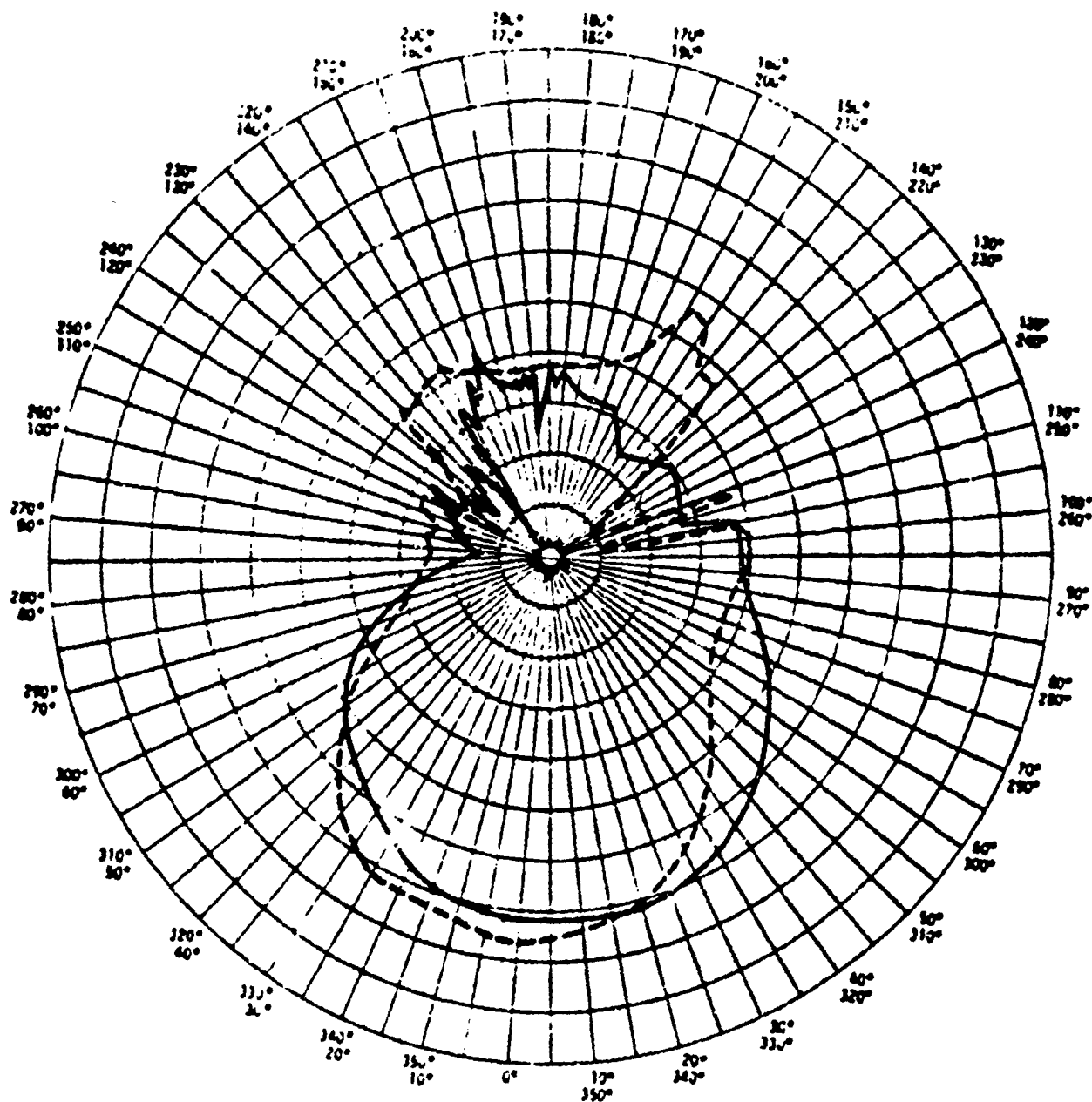


Figure 17. Scenario of a projectile fired 45° off bore sight.



AZUMITH CUT SOURCE VERTICAL
ELEVATION CUT SOURCE HORIZONTAL

Figure 18. Preliminary radiation pattern of 3.245 GHz scoring antenna.

Projectiles fired at 0° (head-on) passing at 3 and 5 feet were counted; however, multiple counts of a single projectile were registered at 3 feet. At 135°, projectiles at 5 and 10 feet were counted; none were counted at distances greater than 10 feet.

Analysis of data results in a conclusion that detection of a passing projectile is based on doppler amplitude and not doppler zero frequency. Detection criteria based on doppler amplitude would account for the multiple counts.

Information pertinent to detection criteria and processing technique was requested from the contractor, but this information was not received. Lack of this information precludes analysis of detection and processing methods. Recommend that this information be obtained from the contractor for analysis by Army personnel.

The ability to count multiple projectiles was not demonstrated. Recommend that the capability of counting multiple projectiles at 7200 rounds per minute be demonstrated.

Some data plots show asymmetrical data on projectiles passing normal (90°) to antenna boresight. The asymmetry is in the form of higher amplitude on the trailing pattern, after doppler zero, than on the leading pattern. This asymmetry and cyclic noise patterns following doppler pattern on some plots appear to be caused by circuit ringing. Whether or not the ringing phenomenon degrades to system should be investigated.

The apparent noise levels are different on some plots. Recommend that stability tests be run and verified for temperature, humidity, and vibration.

APPENDIX

This appendix presents excerpts from the contractor's test logs and plots of the data acquired during the Bullet Hit Indicator tests of November 1980.

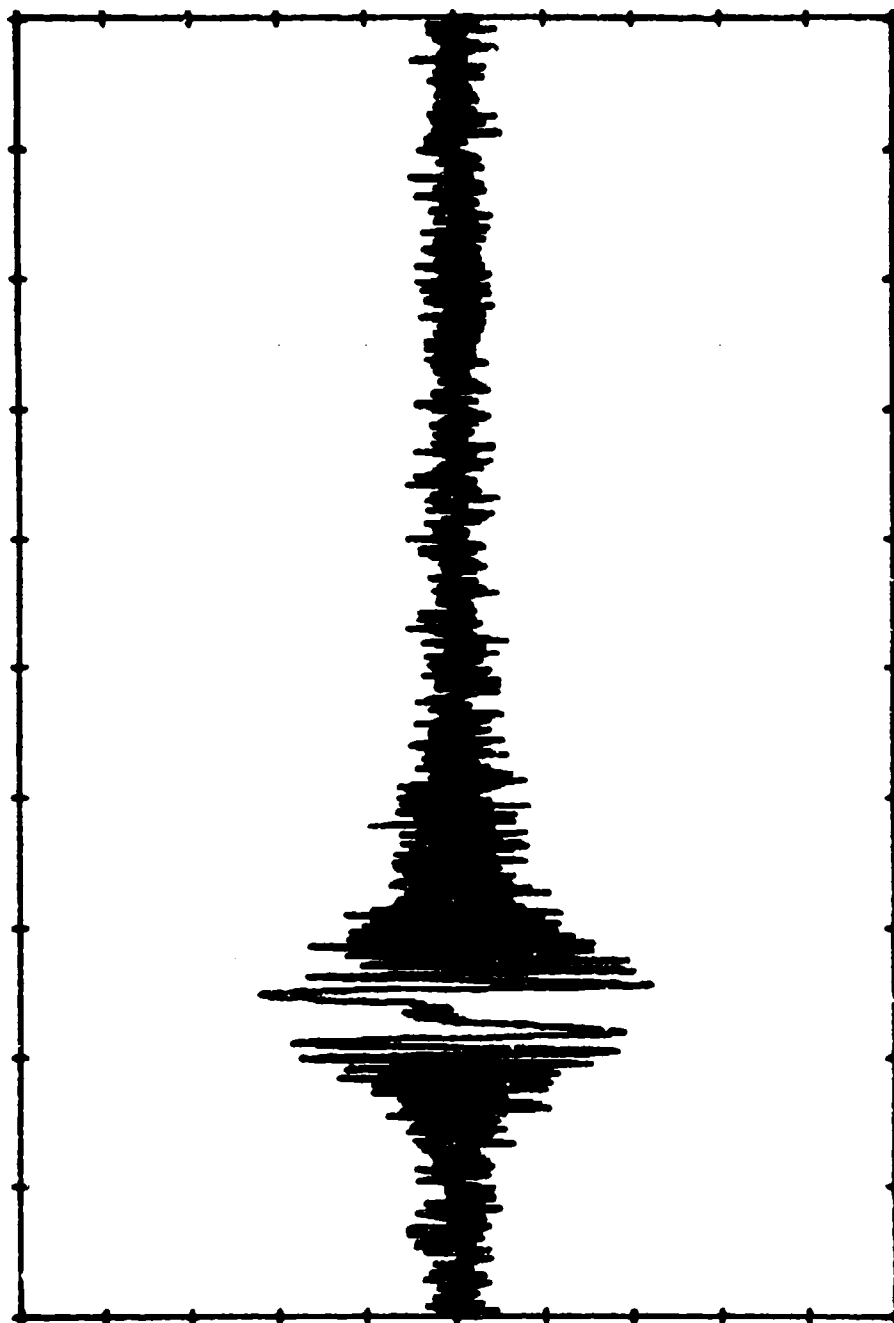
EXCERPTS FROM CONTRACTOR TEST LOGS

Round Number	Range (feet)	Angle (Degrees)	Remarks
1	30	90	Count 1
2	25	90	Count 1
3	20	90	Count 1
4	15	90	Count 1
5	10	90	Count 1
6	5	90	Count 1
7	35	90	Count 1
8	40	90	No Count
9	35	90	Count 1
10	45	90	No Count
11	50	90	No Count
12	45	90	Count 1
13	50	90	Count 1
14	52	90	Count 1
15	55	90	No Count
16	40	90	Count 1
17	35	90	Count 1
18	30	90	Count 1
19	25	90	Count 1

20	20	90	Count 1
21	15	90	Count 1
22	10	90	Count 1
23	5	90	Count 1
24	5	0	Count 2
25	10	0	No Count
26	5	180	No Count
27	5	180	No Count
28	5	180	No Count
29	5	45	Count 1
30	10	45	Count 1
31	20	45	Count 1
32	30	45	No Count
33	40	45	No Count
34	25	45	Count 1
35	3 under	0	GRS disabled (no detect)
36	3 under	0	Count 2
37	3 under	0	Count 2
38	3 under	0	Count 2
39	5 under	0	Count 1
40	10	0	No Count
41	5	45	Count 1
42	10	45	Count 3

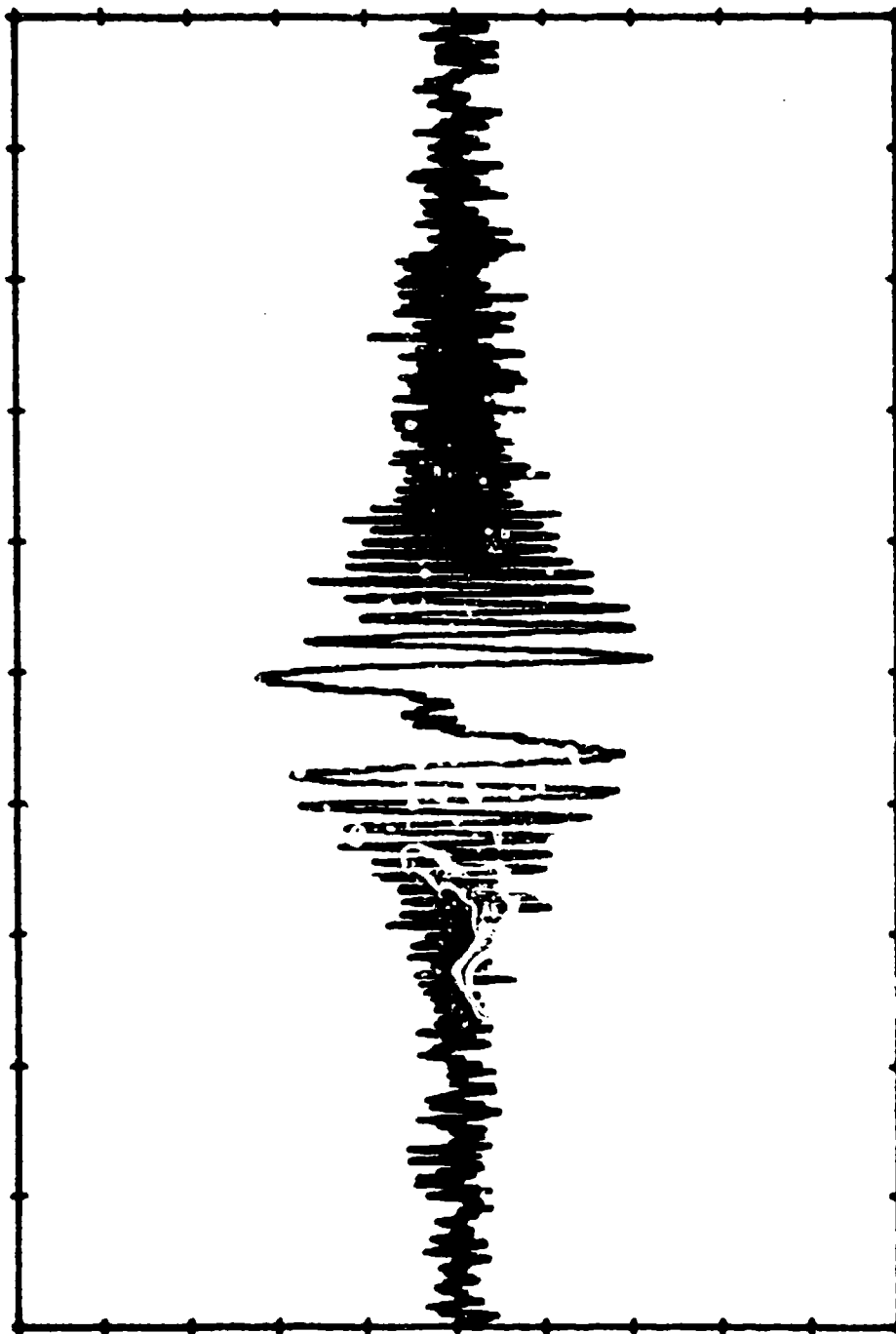
43	20	45	Count 3
44	25	45	Count 1
45	30	45	Count 1
46	35	45	Count 2
47	40	45	Count 2
48	5	135	Count 1 Noise Building
49	10	135	Count 1
50	10	135	Count 1
51	20	135	No Count
52	3 under	180	No Count
53	5 under	180	No Detect

FILE NAME: ROUND.001 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:32.11.224



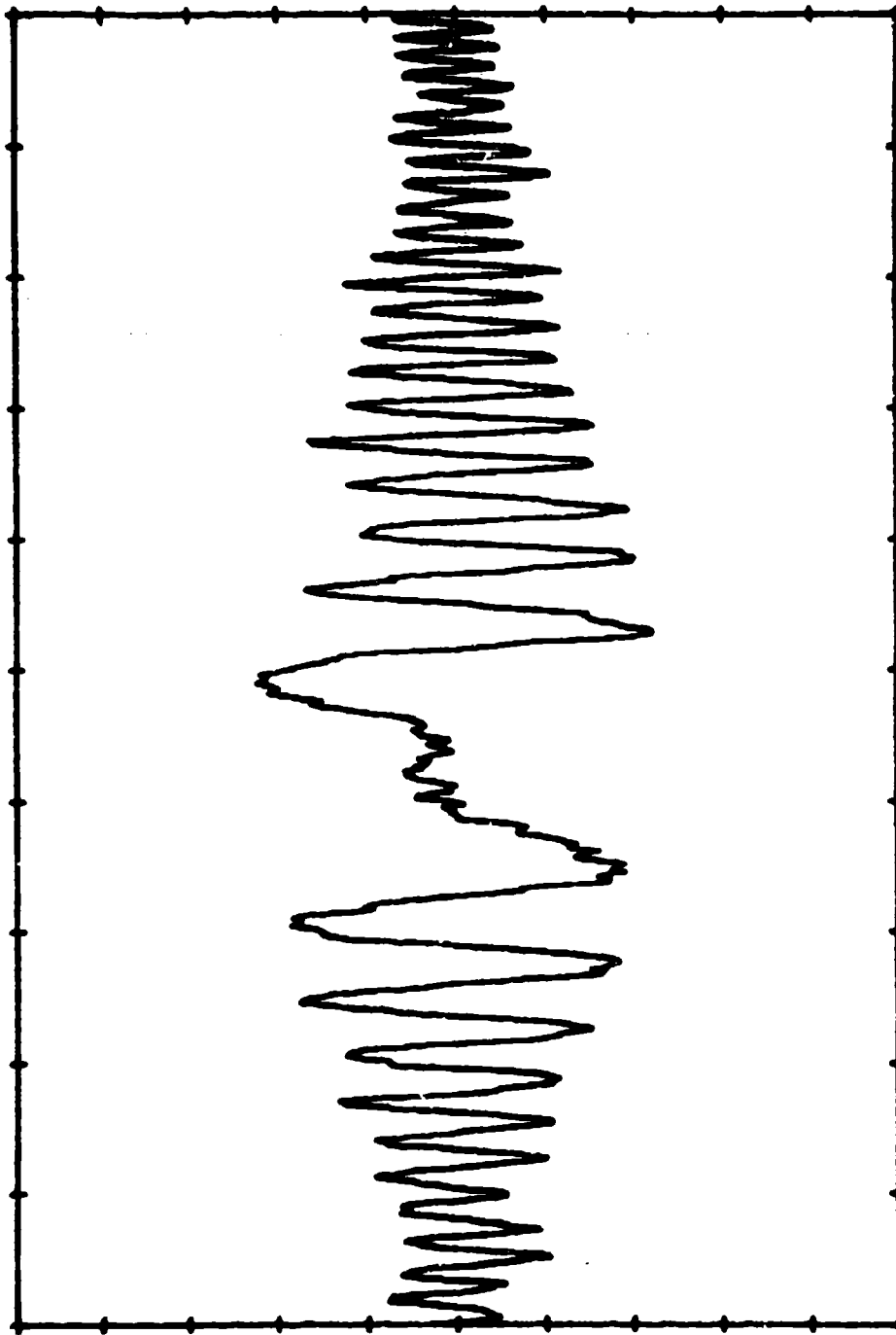
SAMPLES 1 THRU 4000

FILE NAME: ROUND.001 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323.22.32.11.224



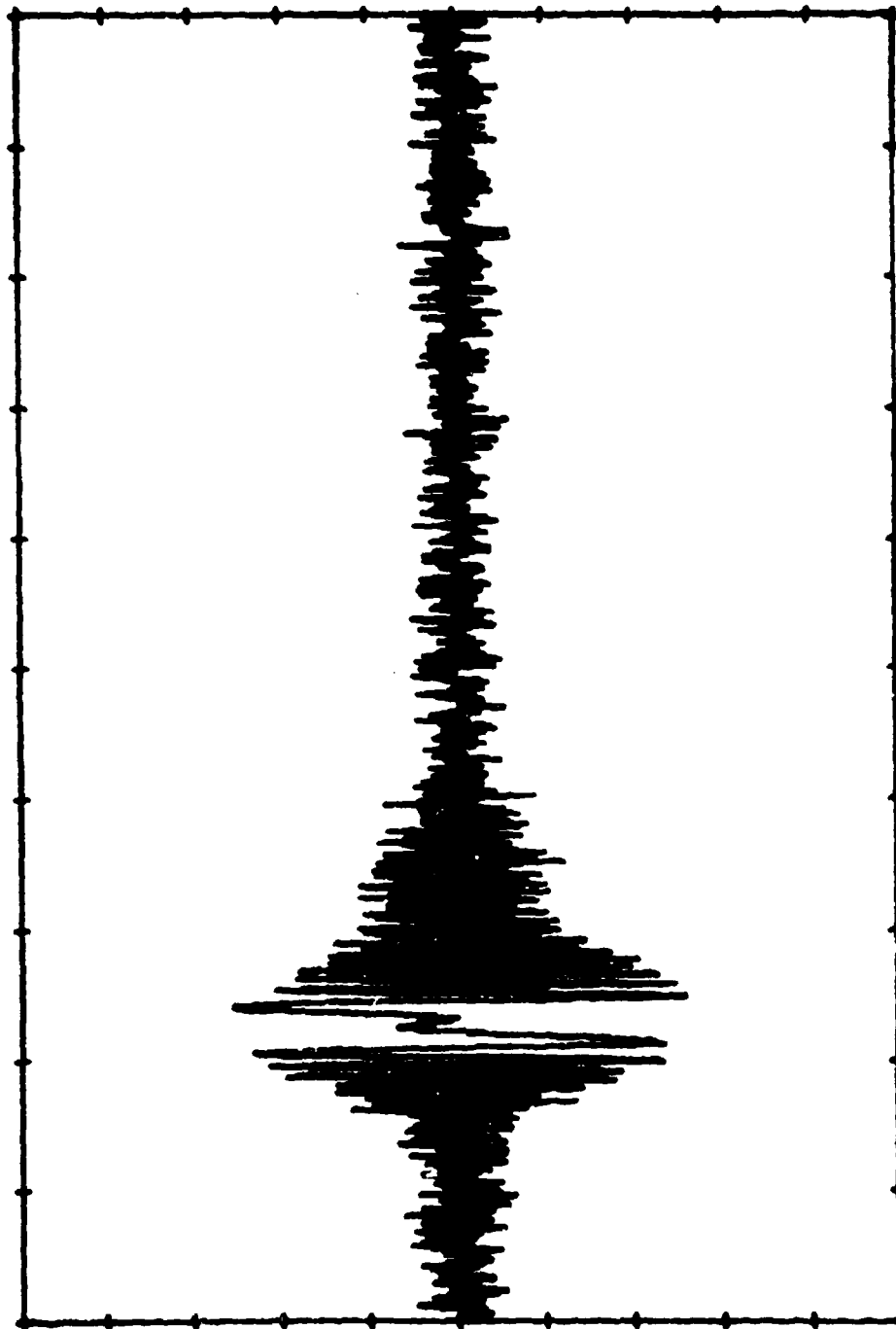
SAMPLES 1 THRU 2000

FILE NAME: ROUND.001 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:32.11.224



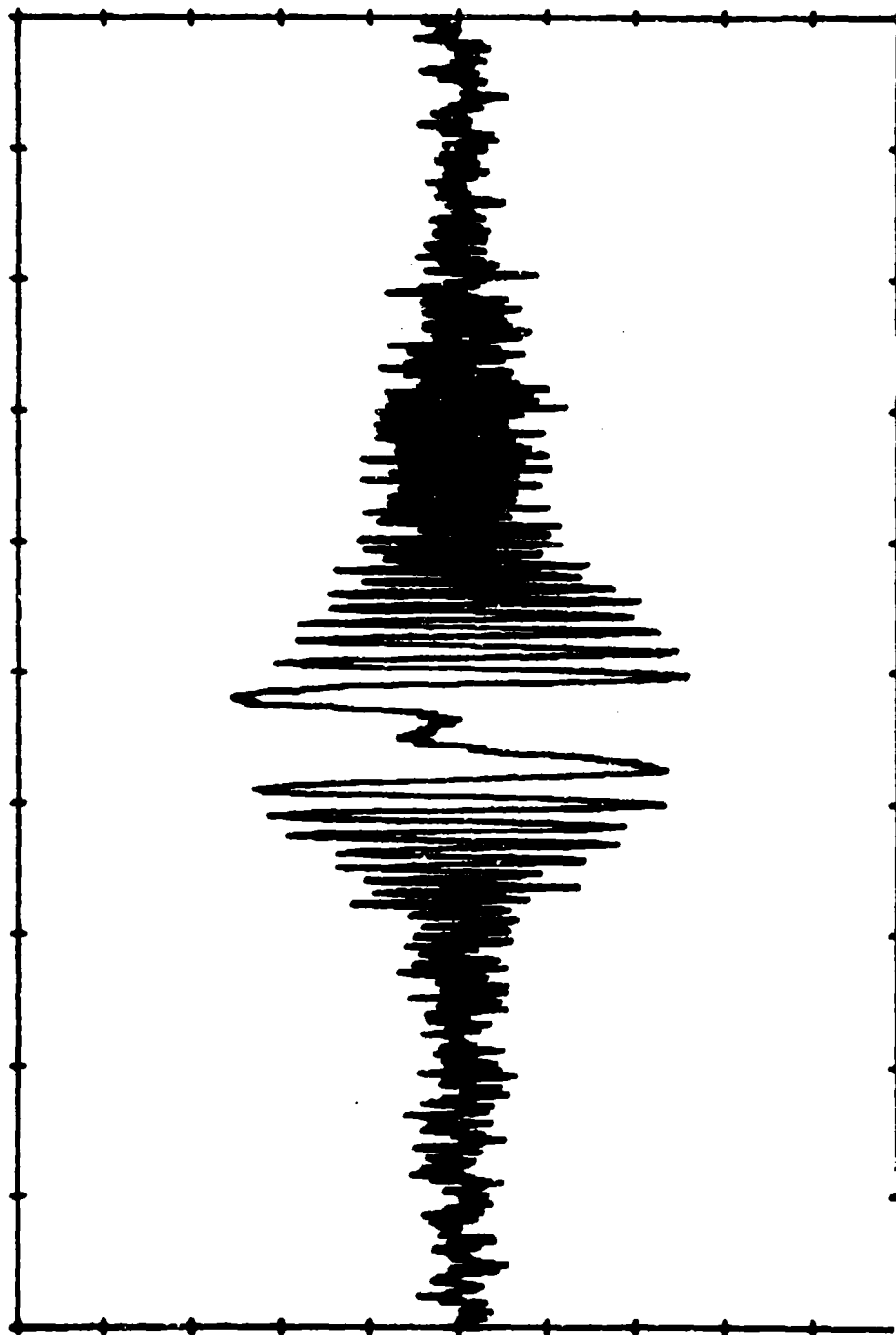
SAMPLES 600 THRU 1400

FILE NAME: ROUND.002 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:40:19.717



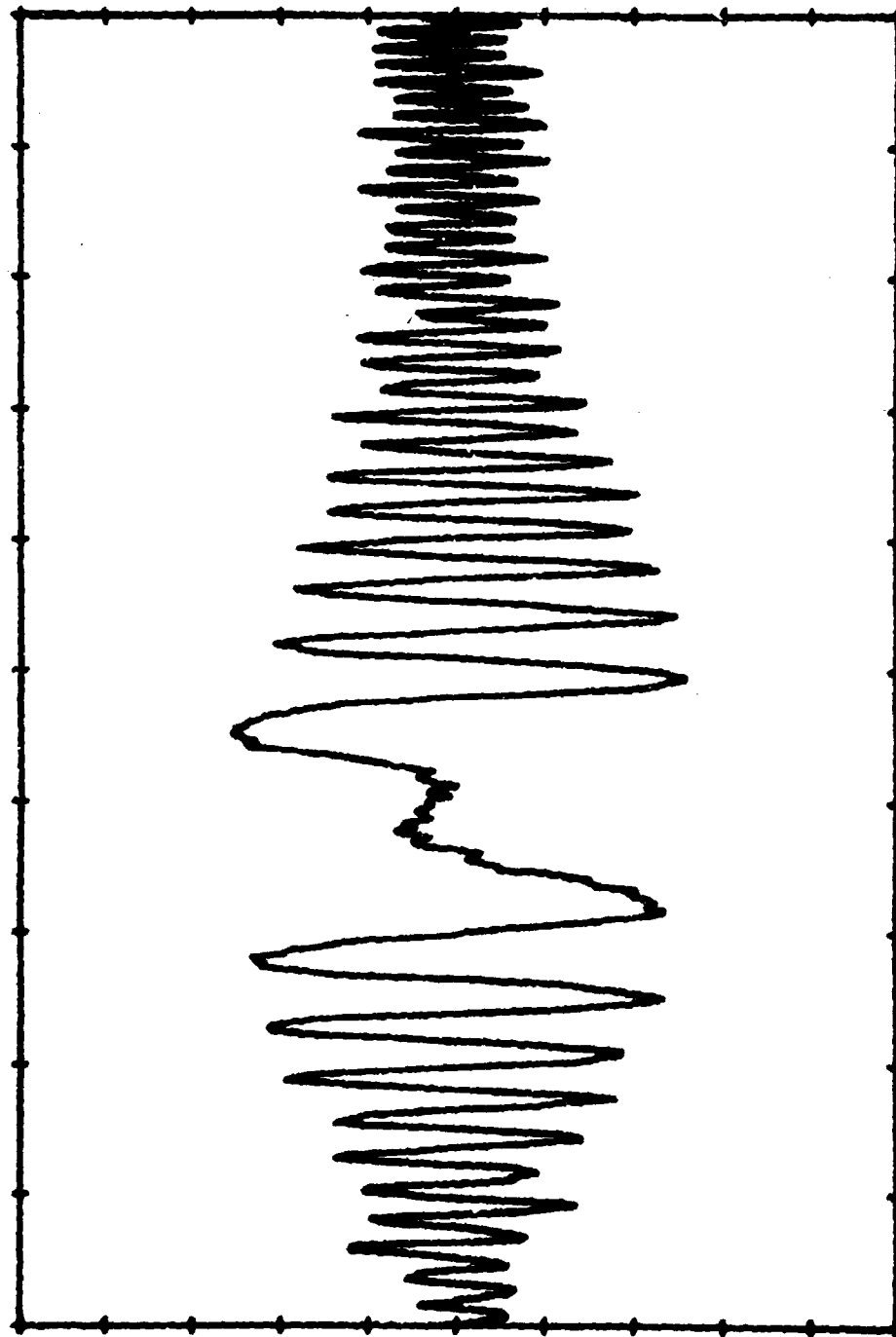
SAMPLES 1 THRU 4000

FILE NAME: ROUND.002 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:40:19.717



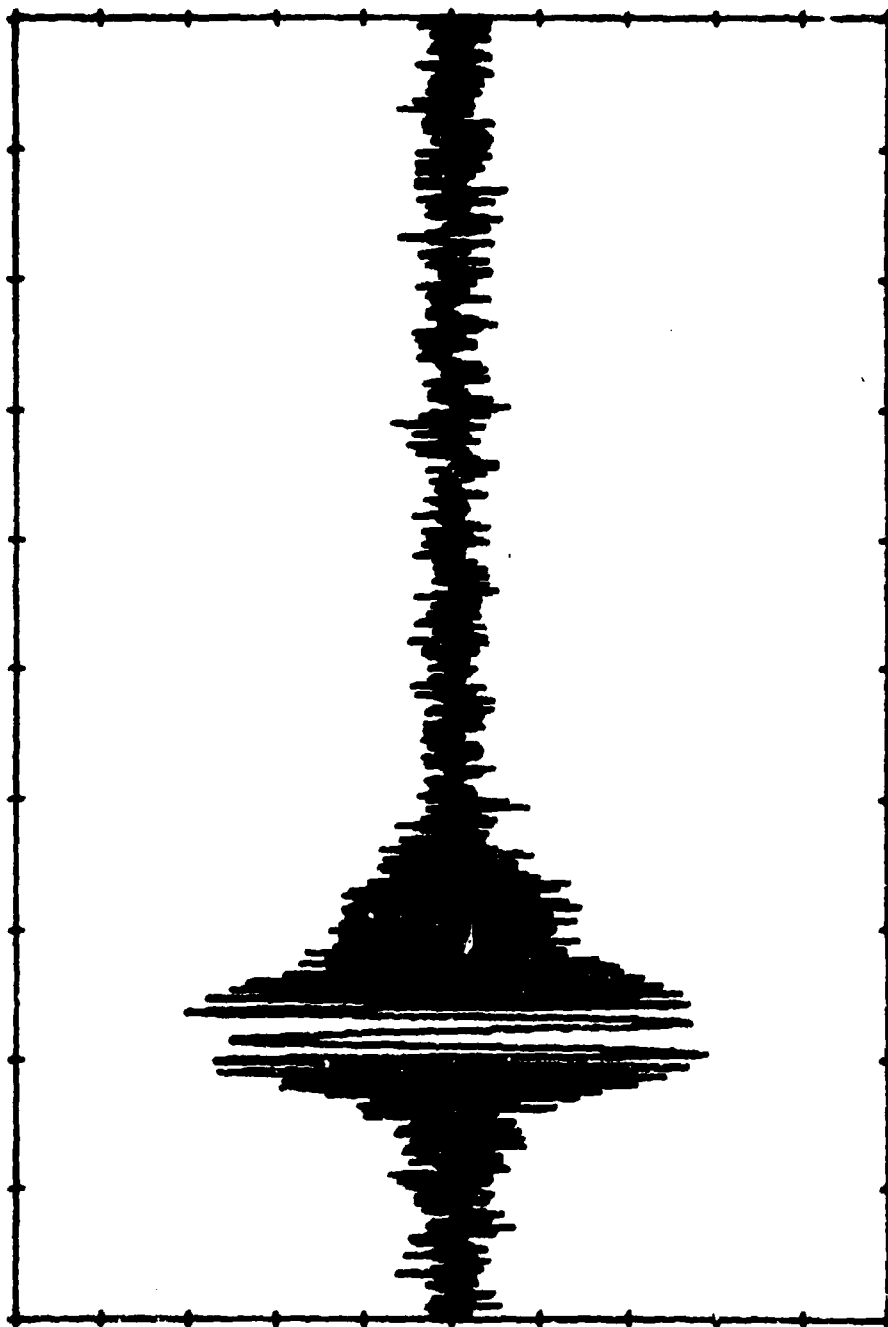
SAMPLES 1 THRU 2000

FILE NAME: ROUND.002 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:40:19.717



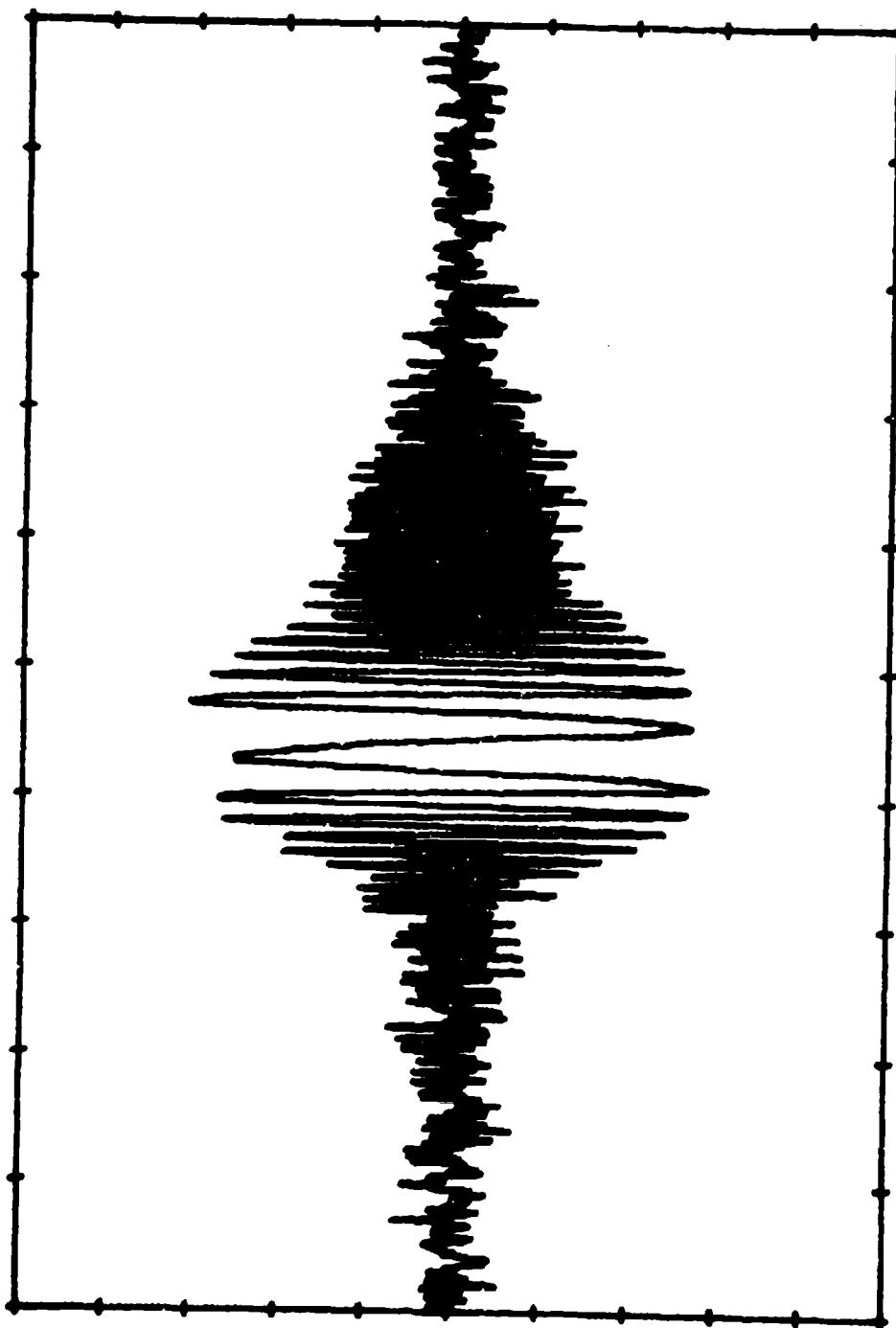
SAMPLES 600 THRU 1400

FILE NAME: ROUND 003 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:43:24.315



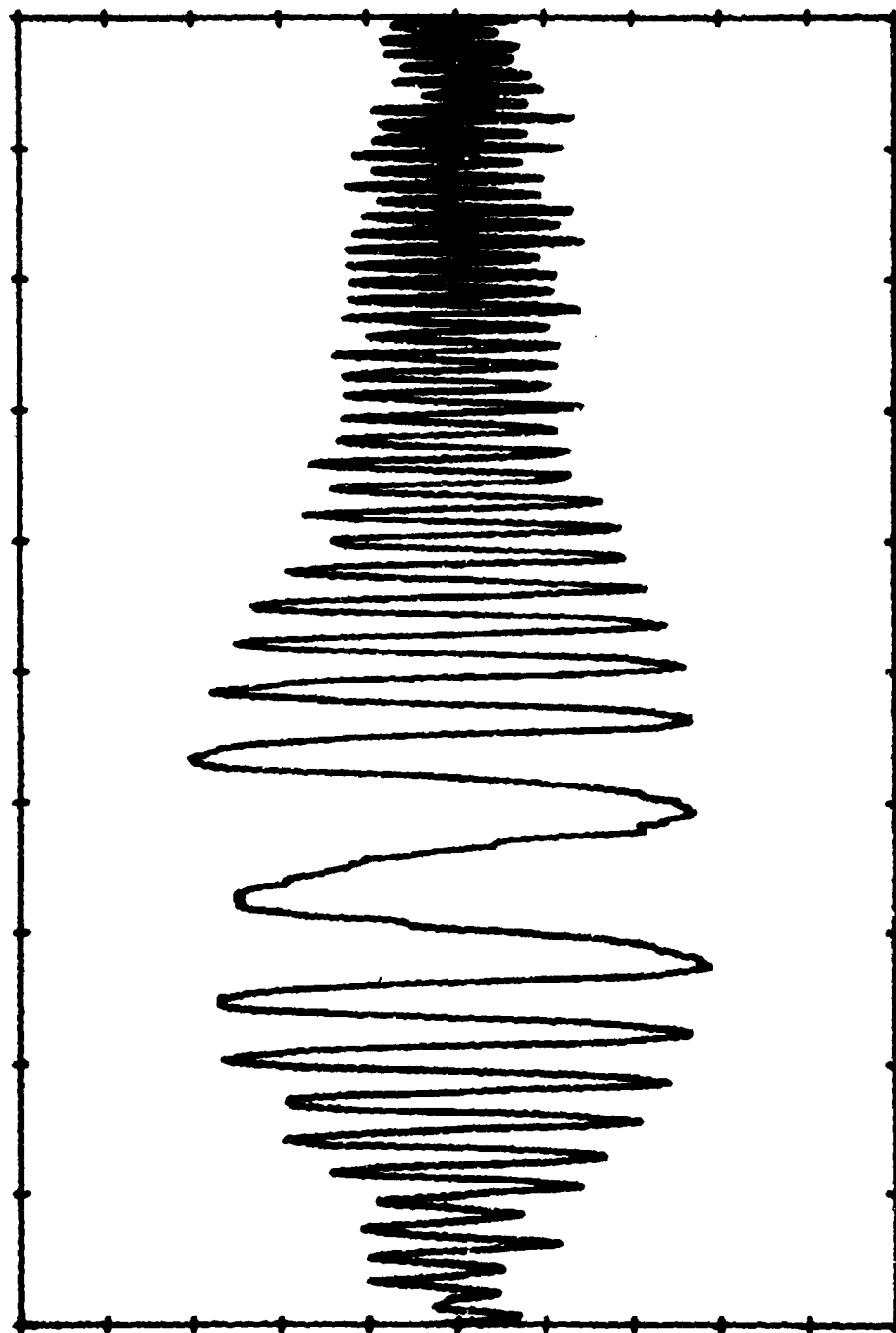
SAMPLES 1 THRU 4000

FILE NAME: ROUND.003 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323.22:43:24.315



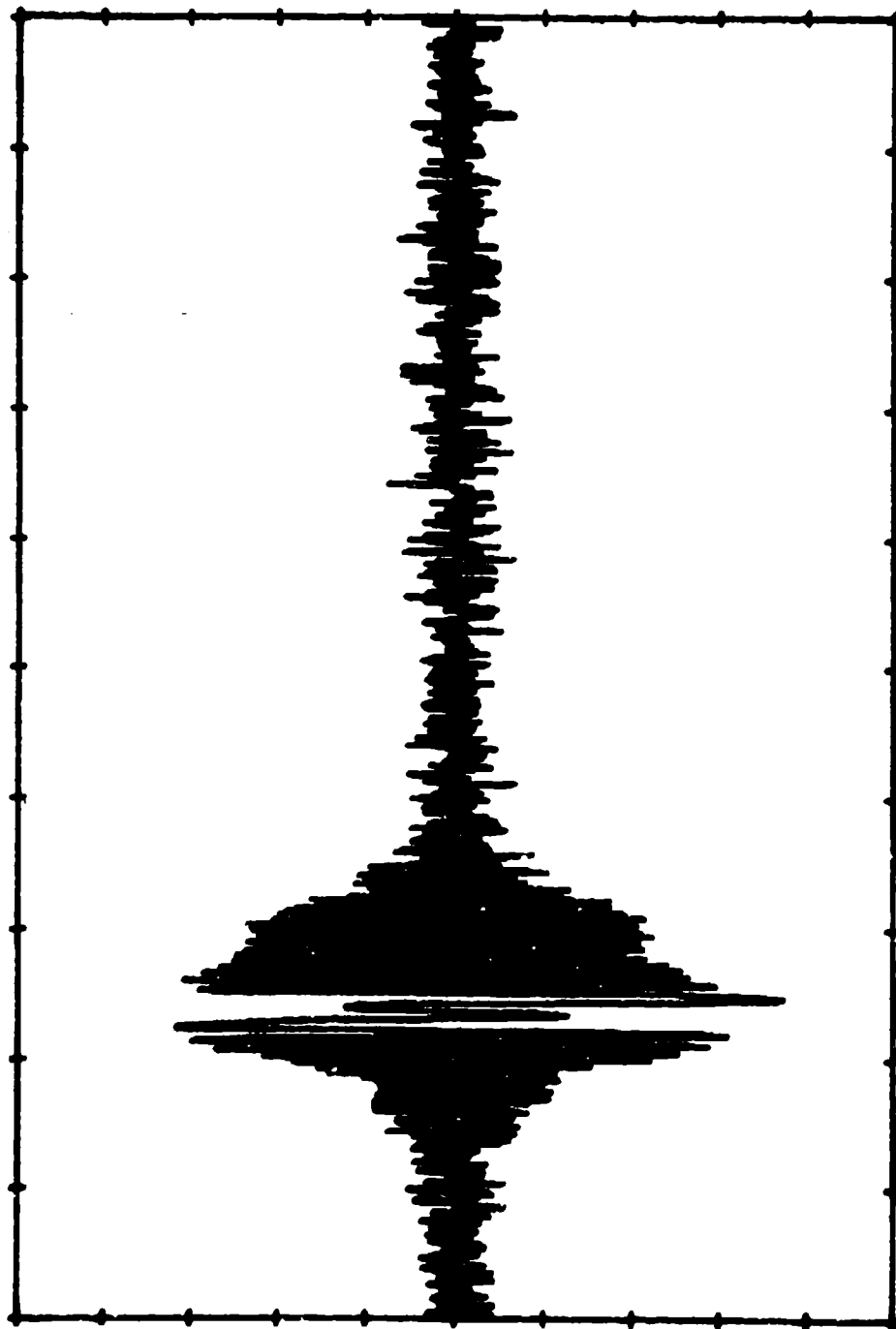
SAMPLES 1 THRU 2000

FILE NAME: ROUND.083 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:43:24.315



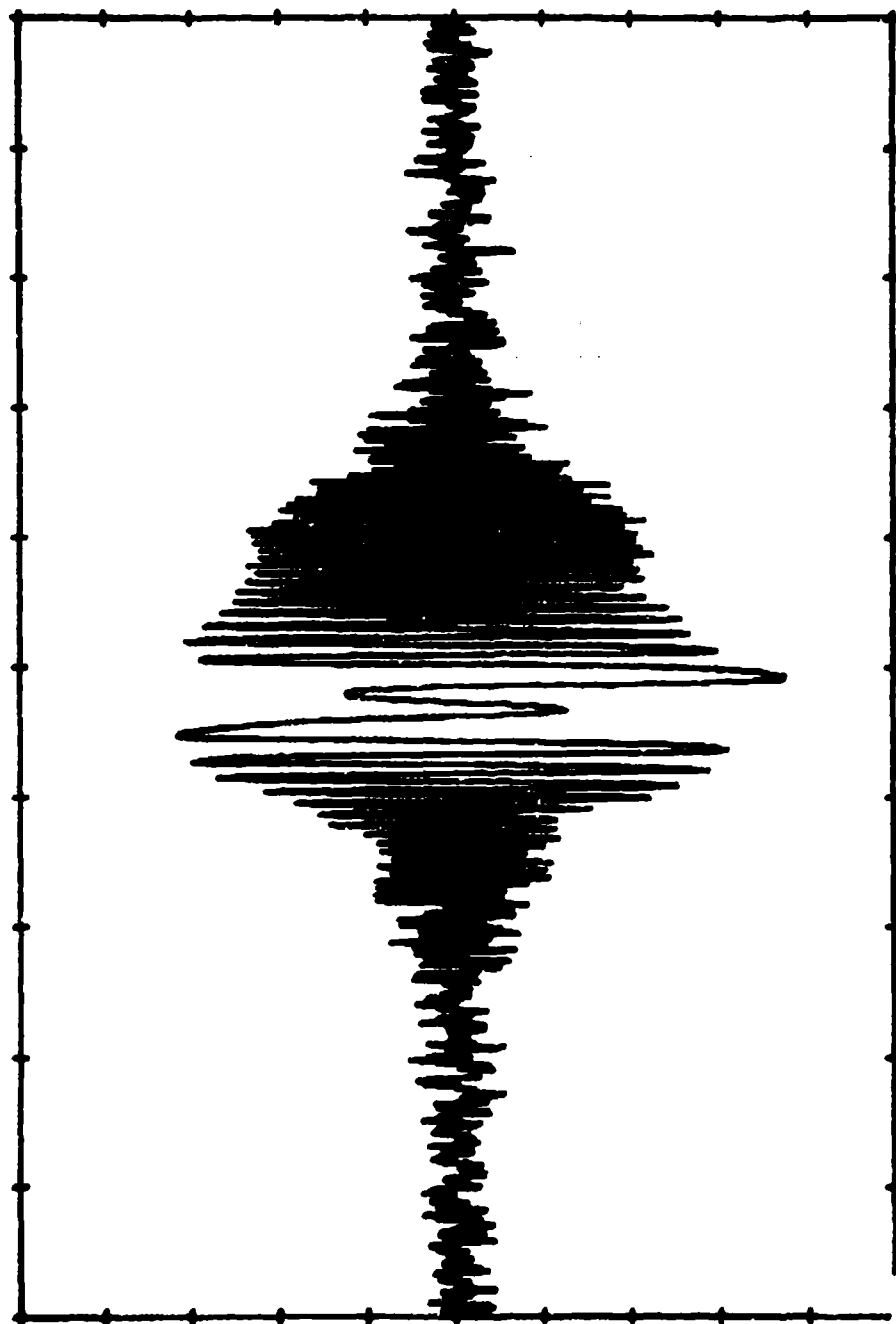
SAMPLES 600 THRU 1400

FILE NAME: ROUND.004 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:46:14.565



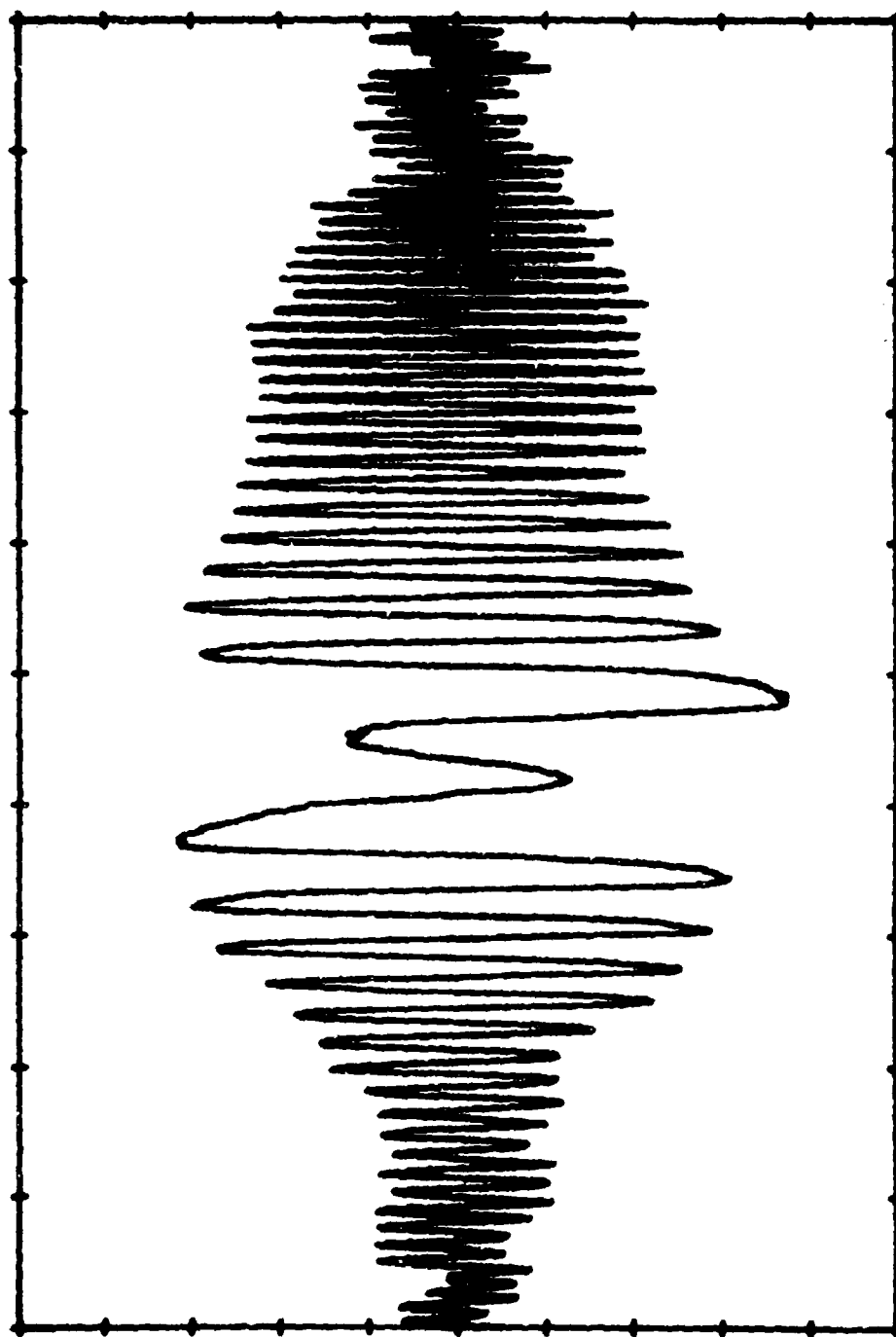
SAMPLES 1 THRU 4000

FILE NAME: ROUND.004 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:46:14.565



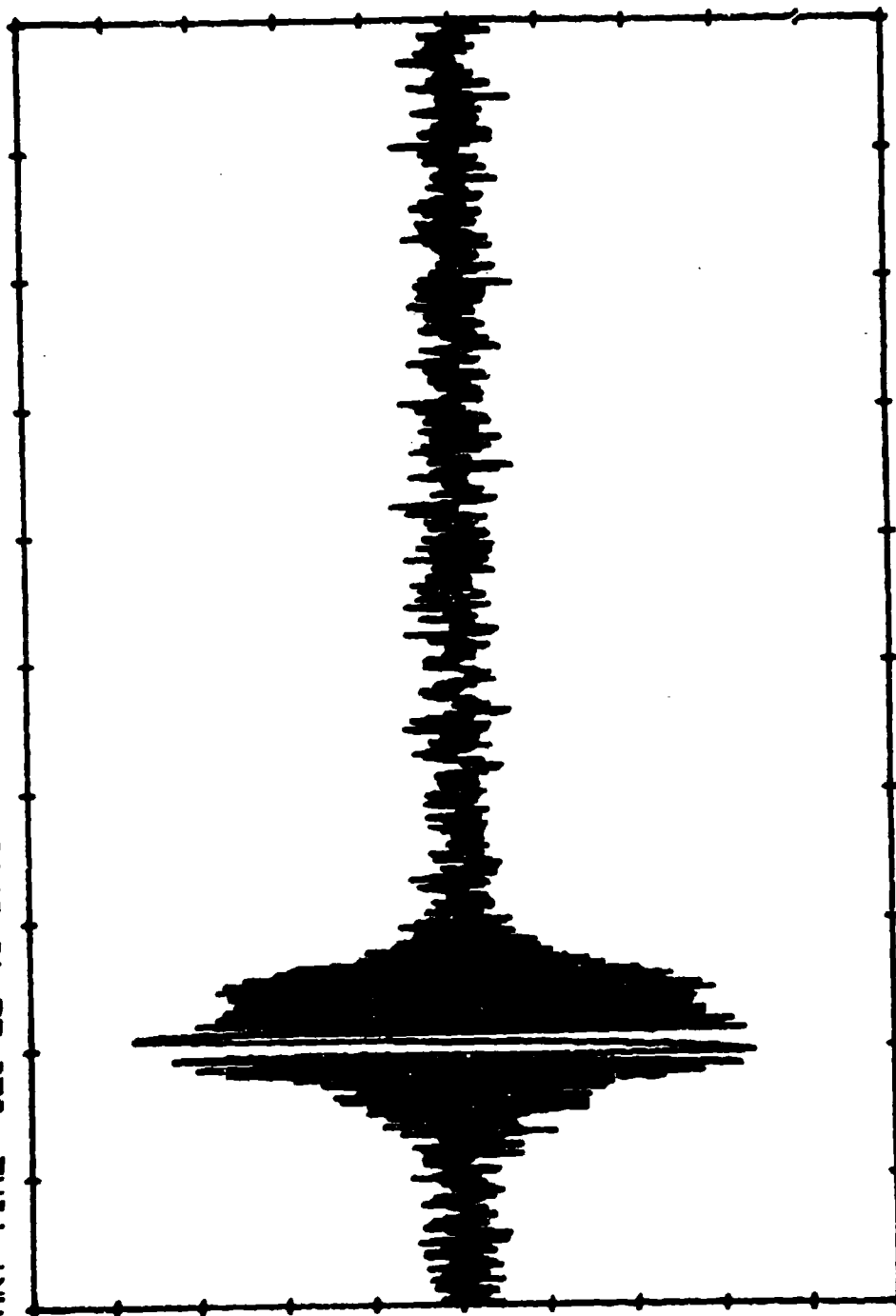
SAMPLES 1 THRU 2000

FILE NAME: ROUND.004 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:46.14.565



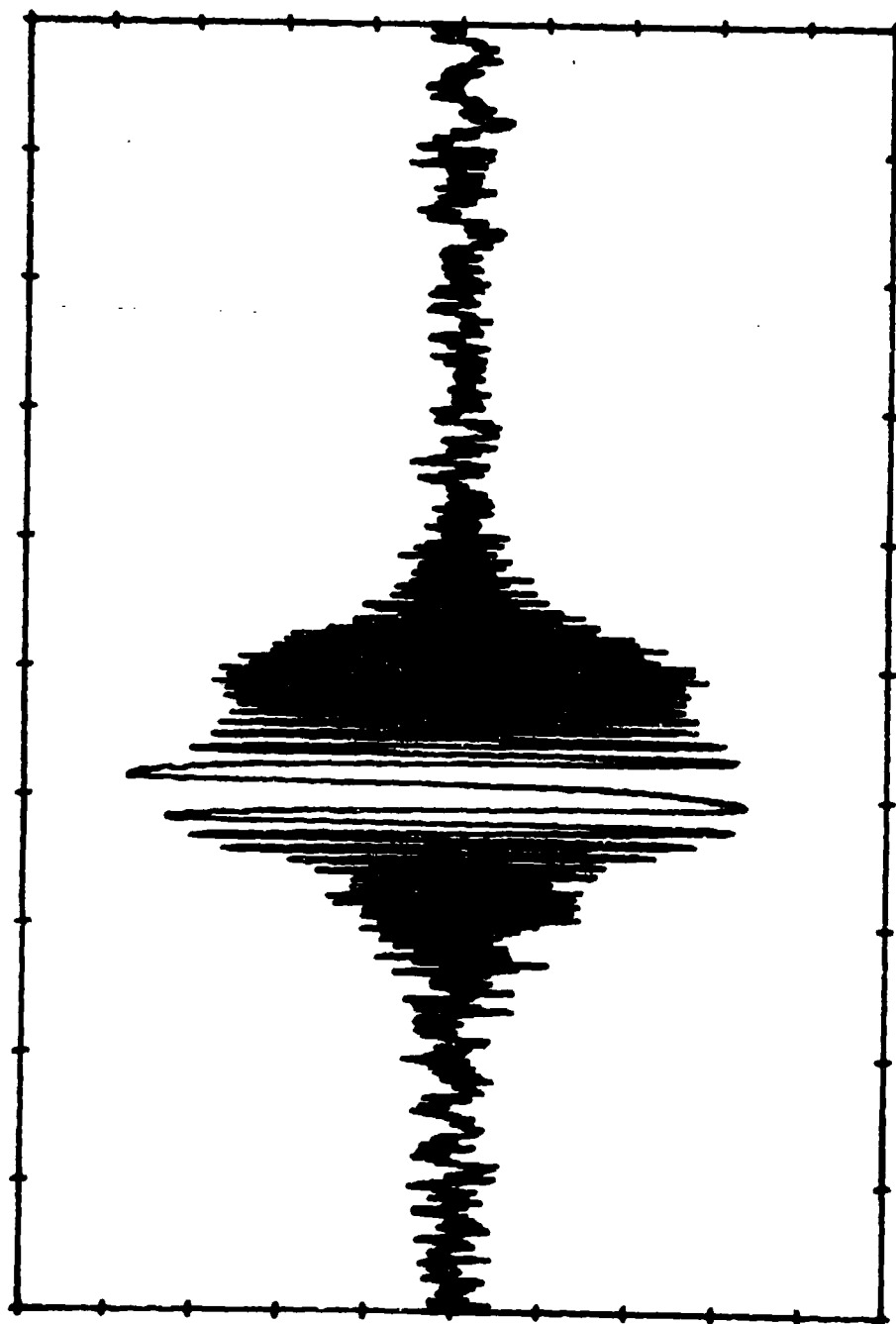
SAMPLES 600 THRU 1400

FILE NAME: ROUND.005 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:48:57.575



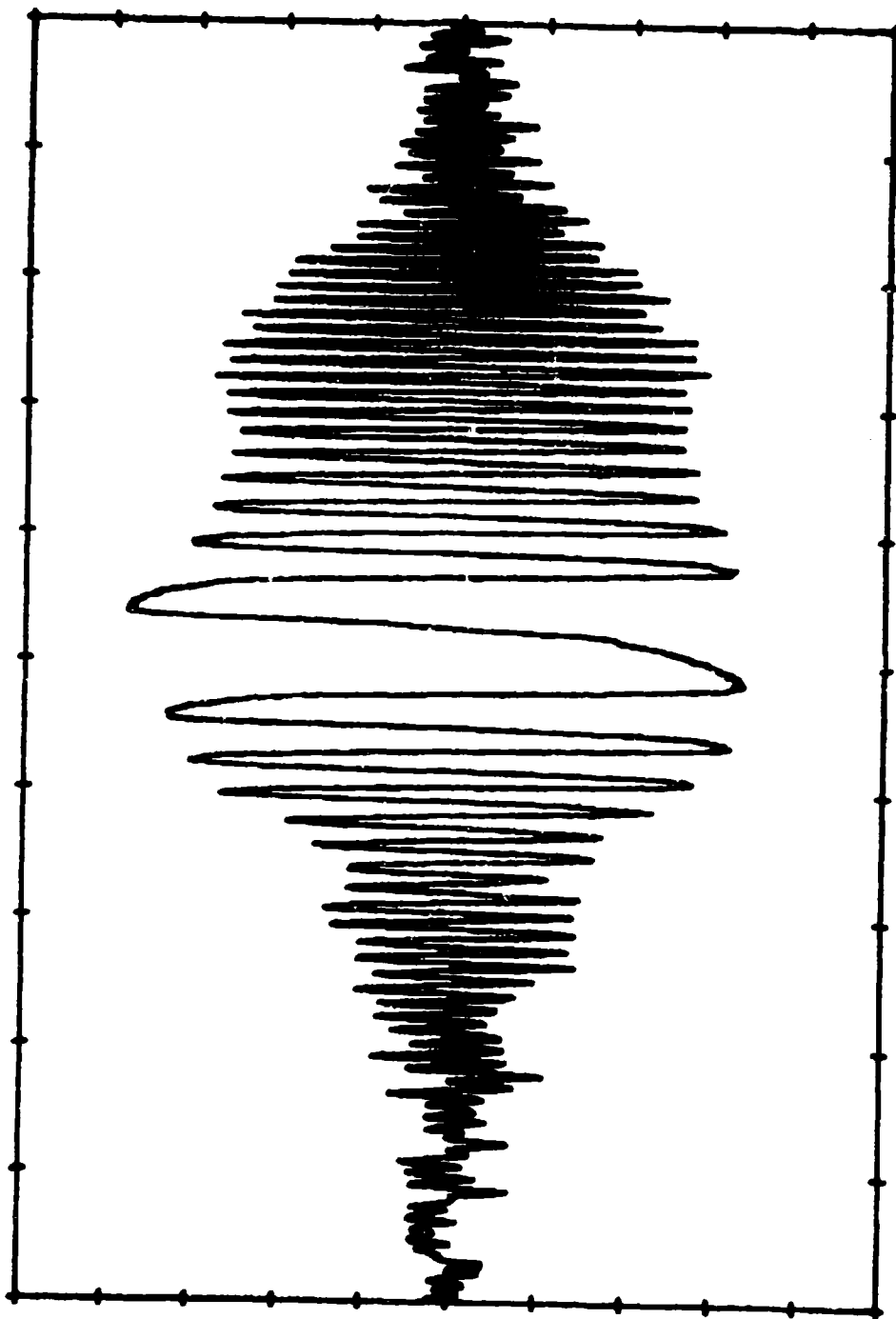
SAMPLES 1 THRU 4000

FILE NAME: ROUND.005 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:48:57.575



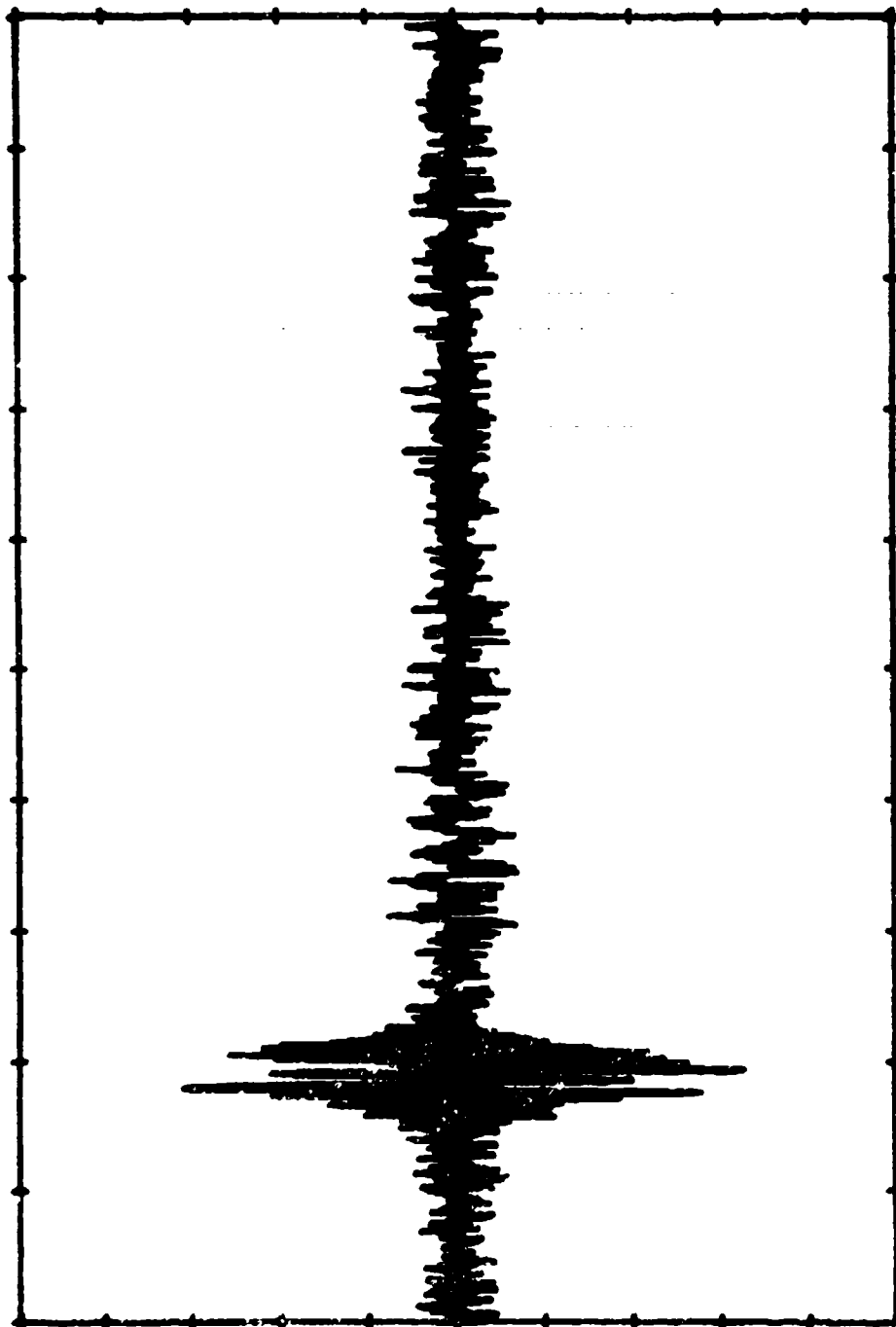
SAMPLES 1 THRU 2000

FILE NAME: ROUND.005 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:48.57575



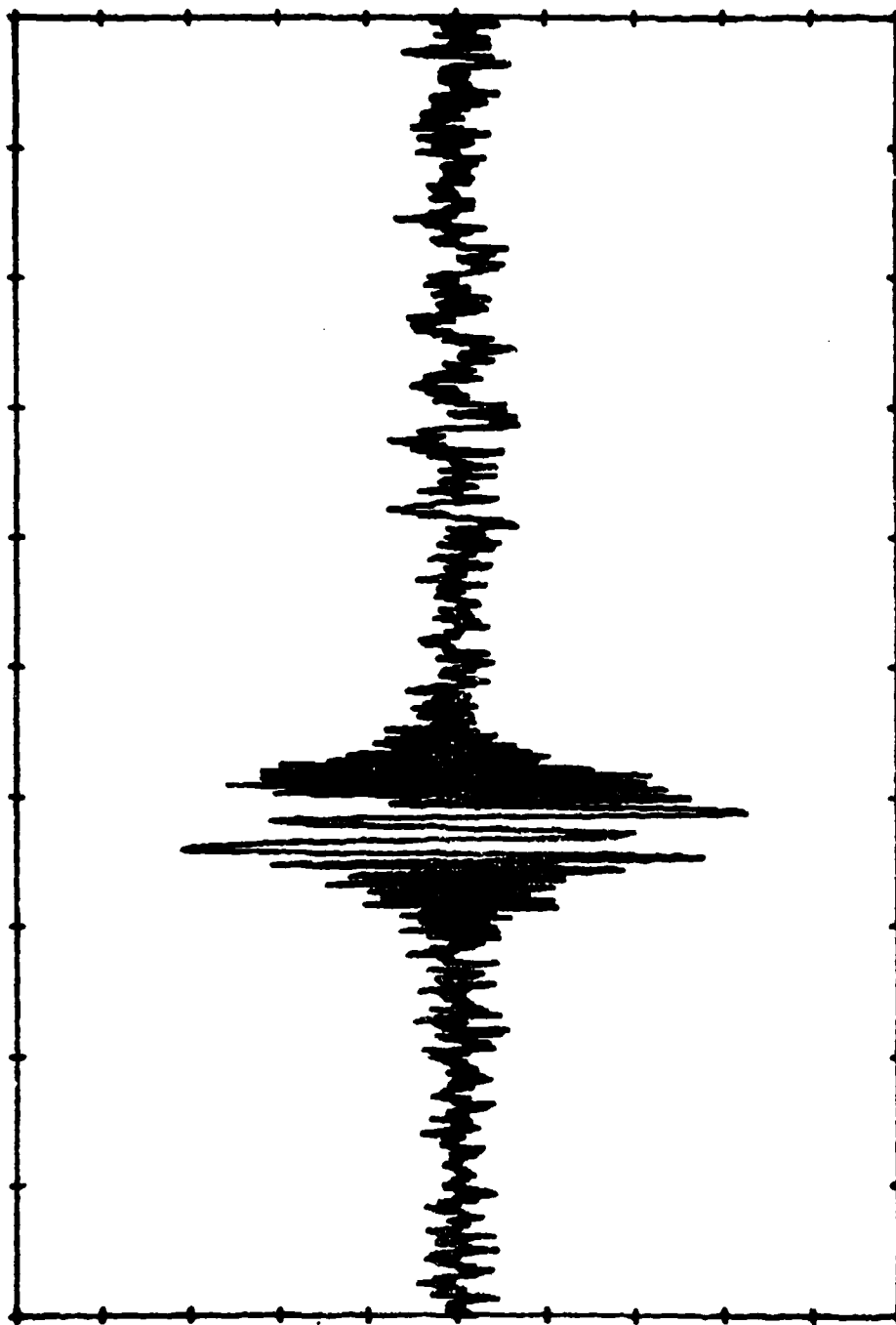
SAMPLES 400 THRU 1200

FILE NAME: ROUND 006 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:51:22.161



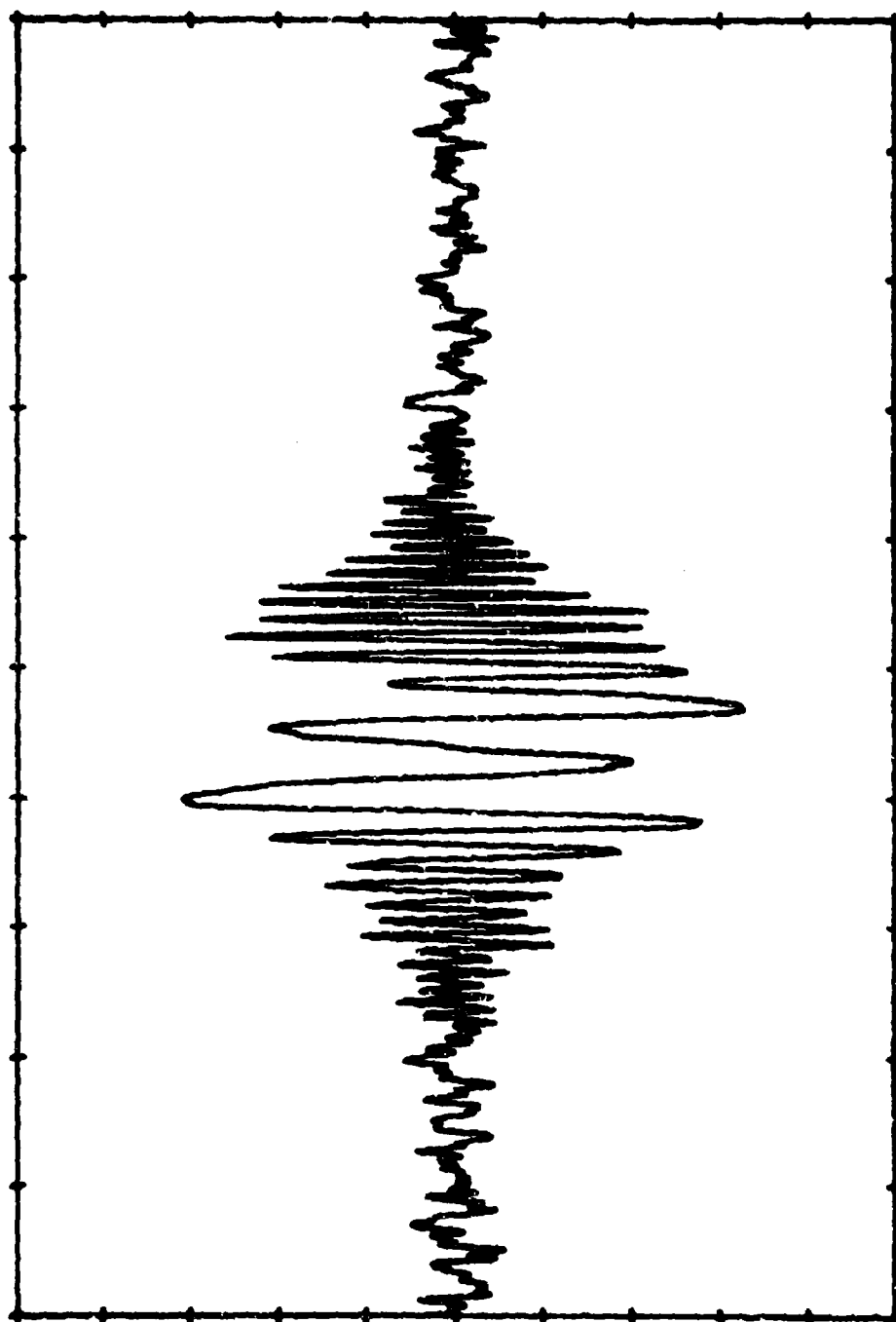
SAMPLES 1 THRU 4000

FILE NAME: ROUND.006 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:51.22.161



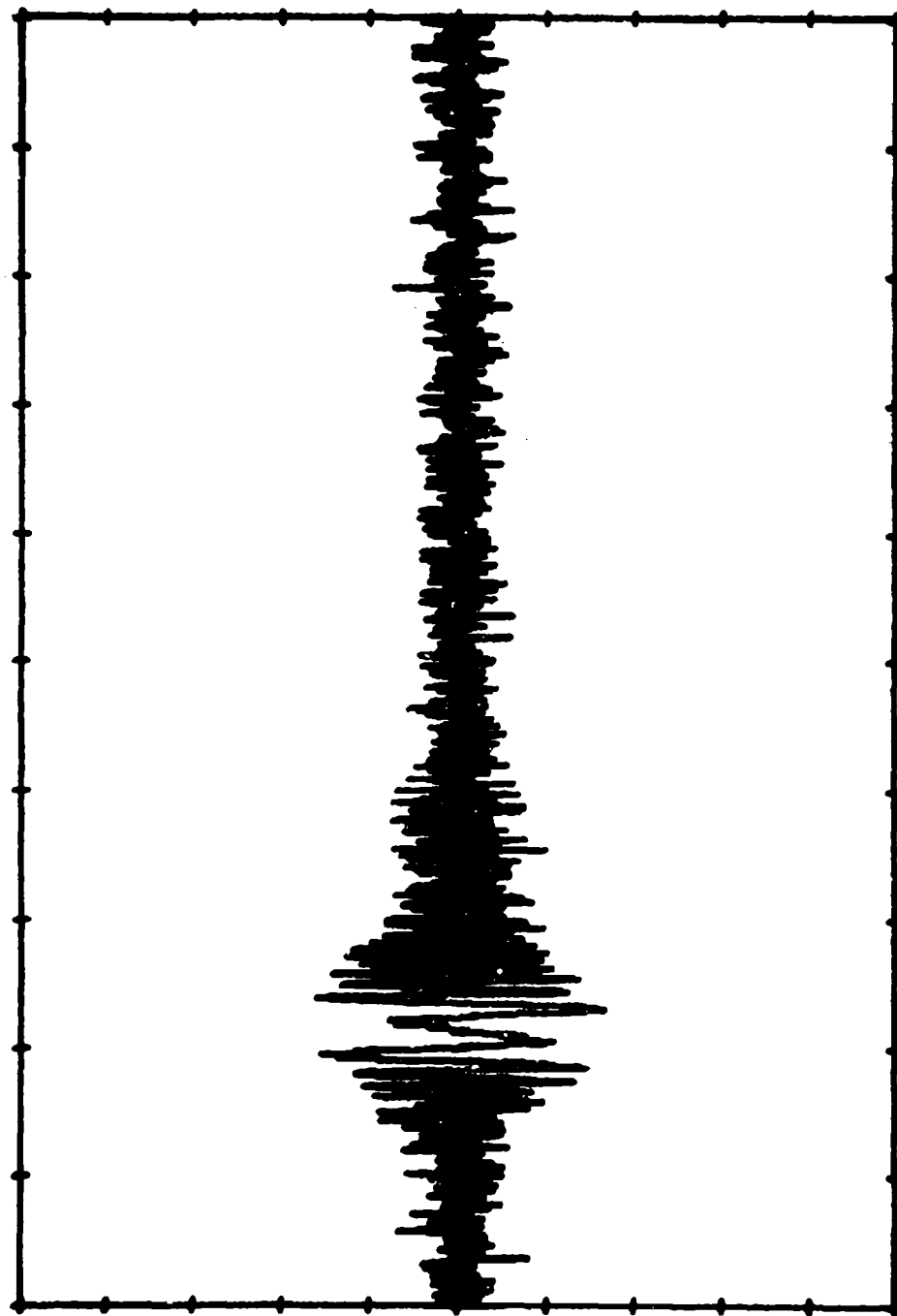
SAMPLES 1 THRU 2000

FILE NAME: ROUNO.006 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:51:22.161



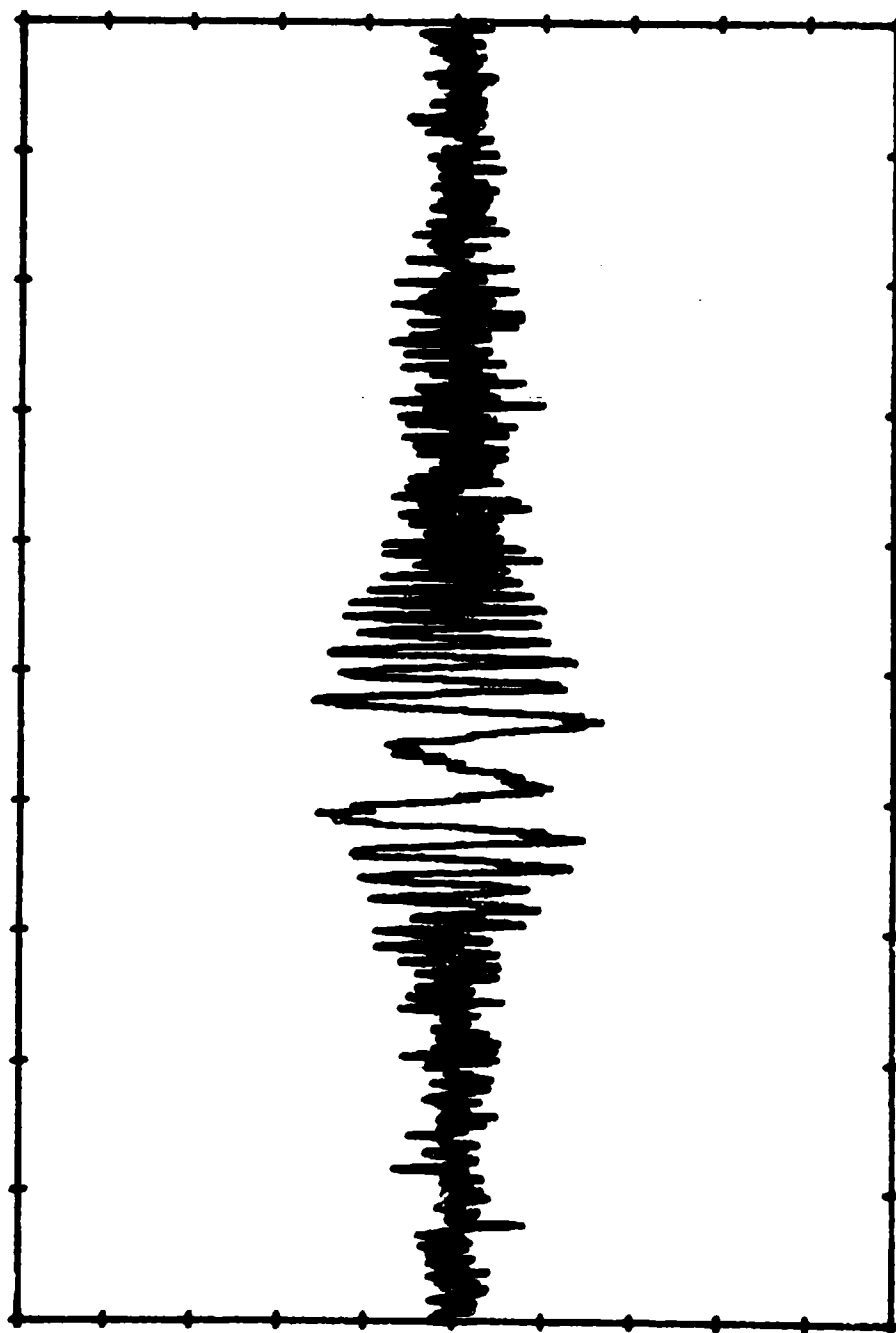
SAMPLES 400 THRU 1200

FILE NAME: ROUND.007 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:54:47.929



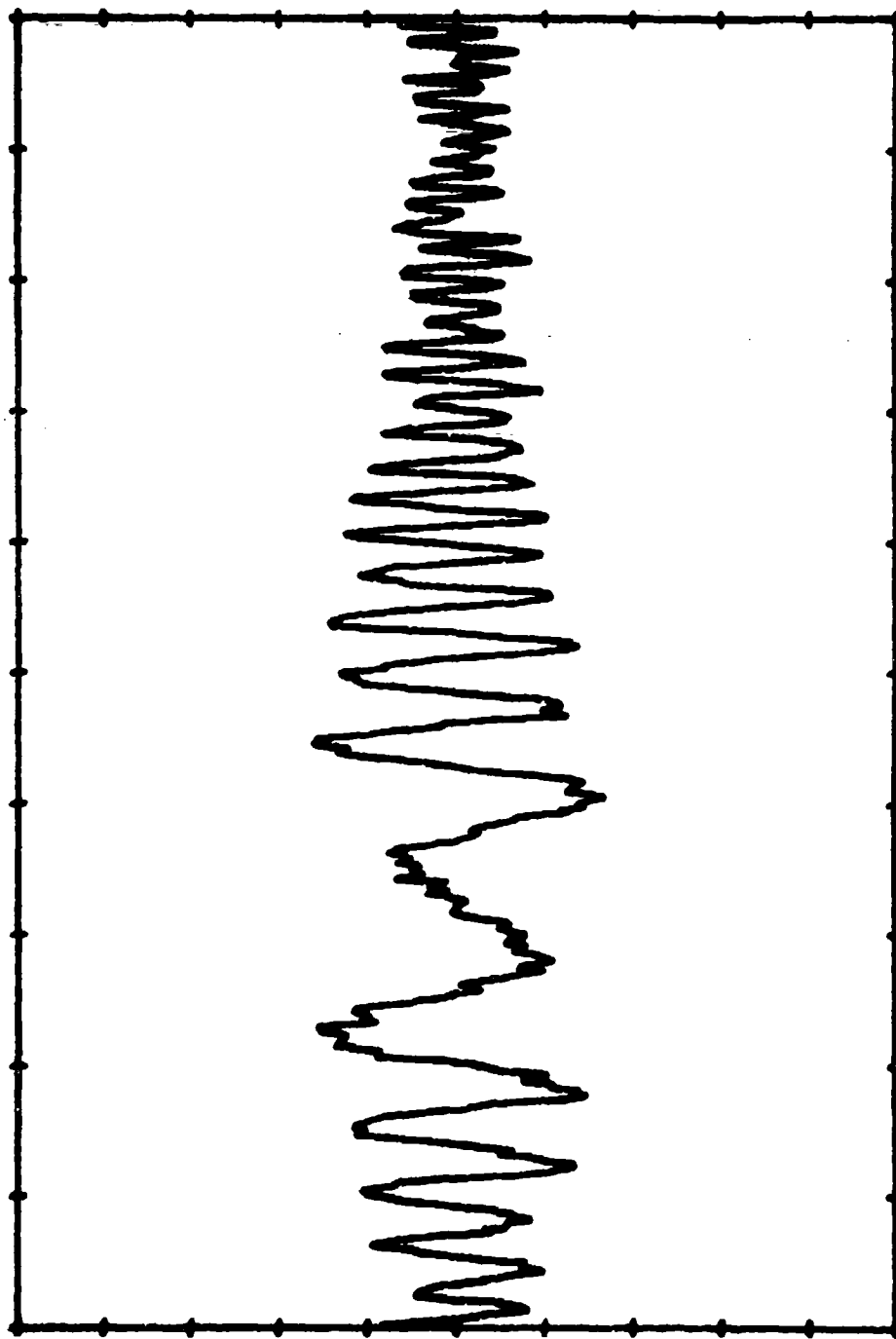
SAMPLES 1 THRU 4000

FILE NAME: ROUND.007 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323.22.54.47.929



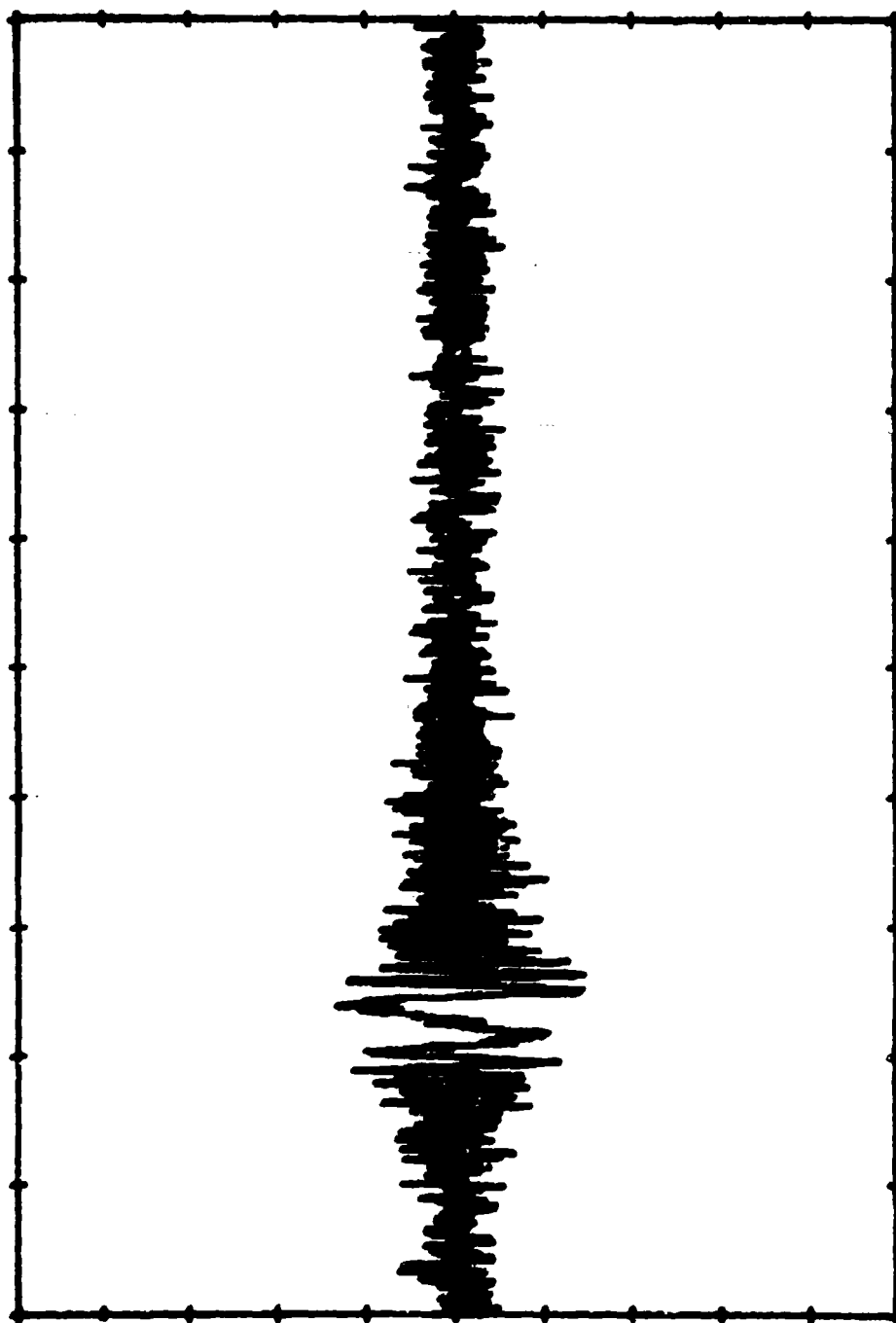
SAMPLES 1 THRU 2000

FILE NAME: ROUND.007 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:54.47.929



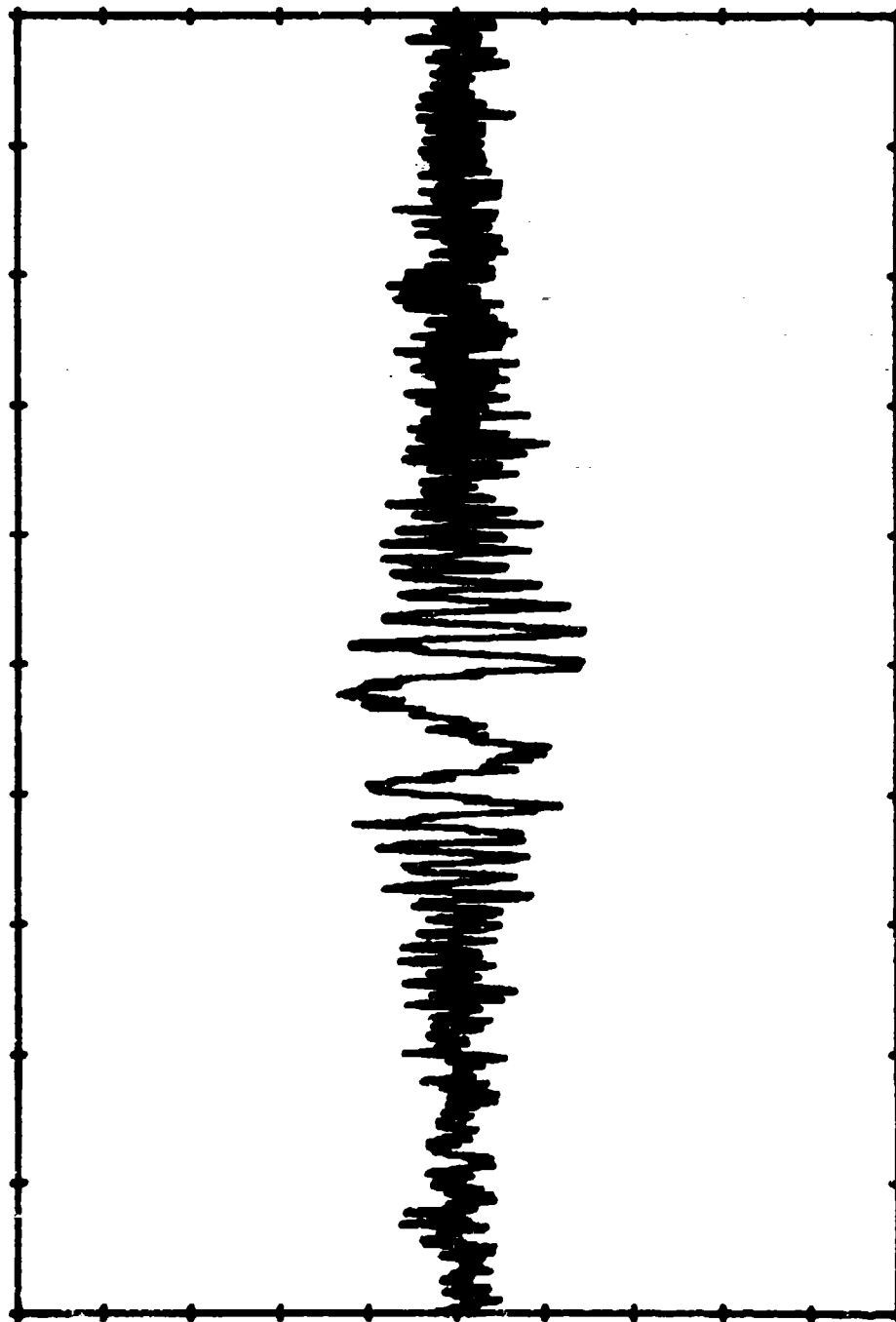
SAMPLES 600 THRU 1400

FILE NAME: ROUND.000 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:57.57.600



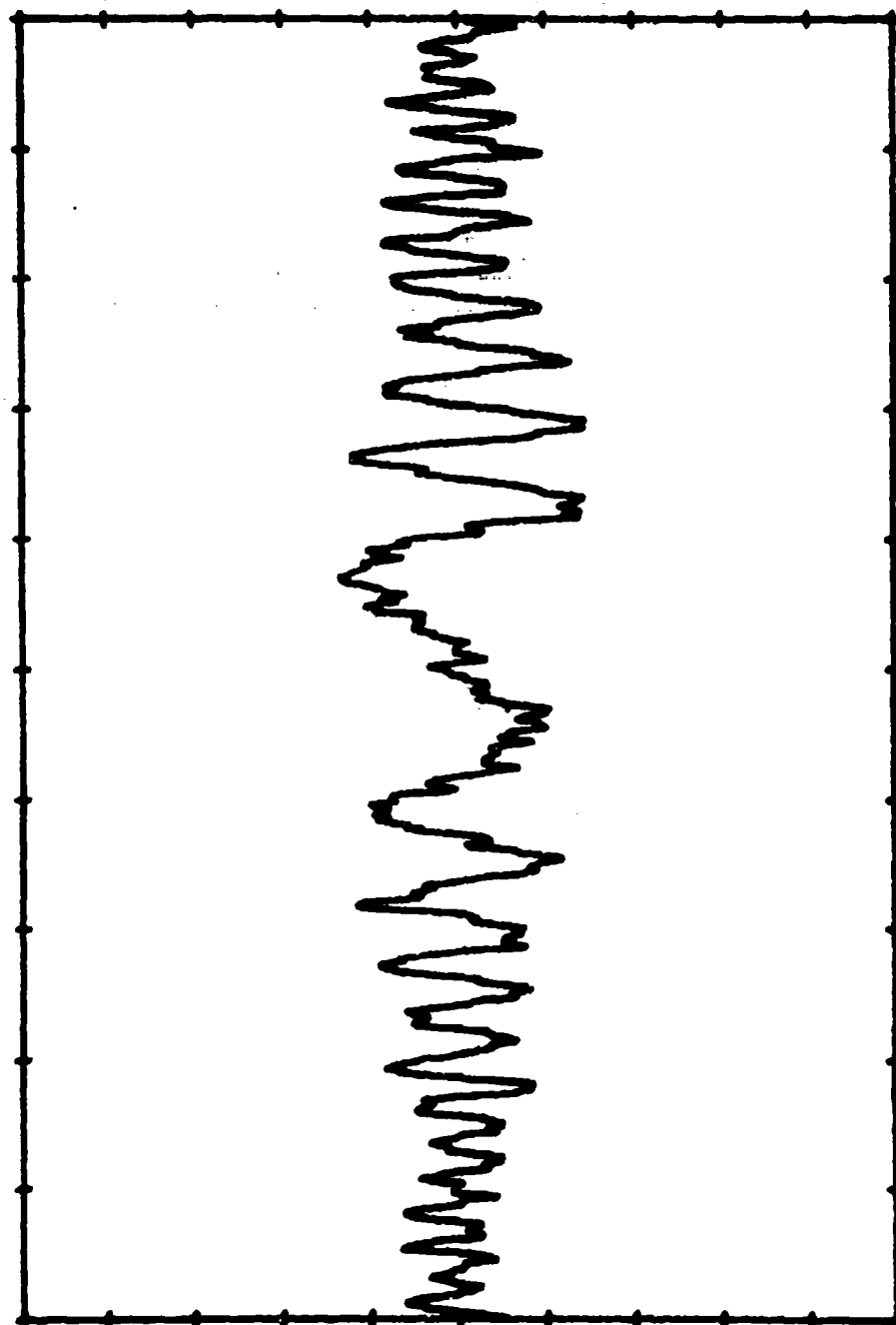
SAMPLES 1 THRU 4000

FILE NAME: ROUND.008 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323.22:57:57.600



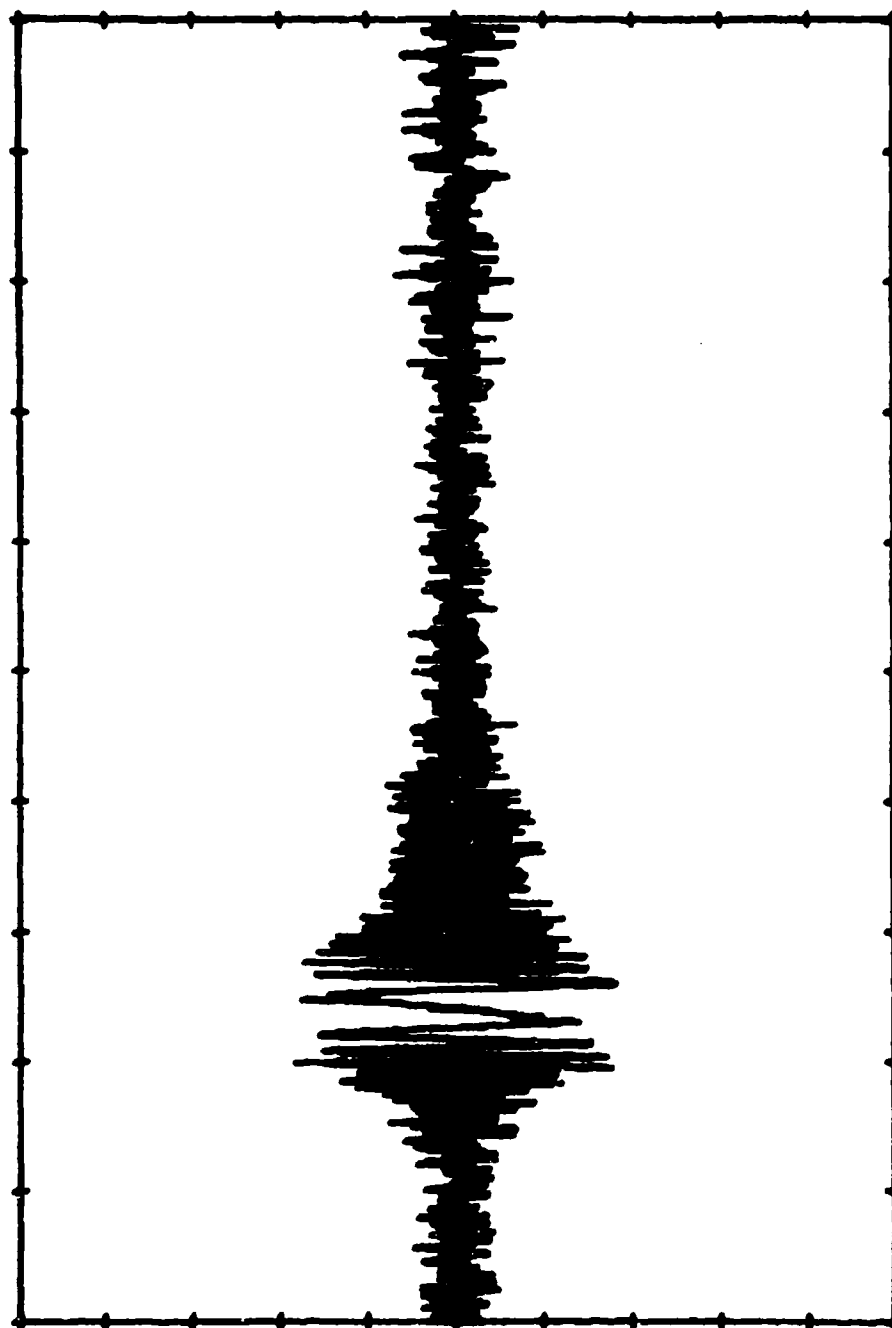
SAMPLES 1 THRU 2000

FILE NAME: ROUND.008 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:22:57.57.600



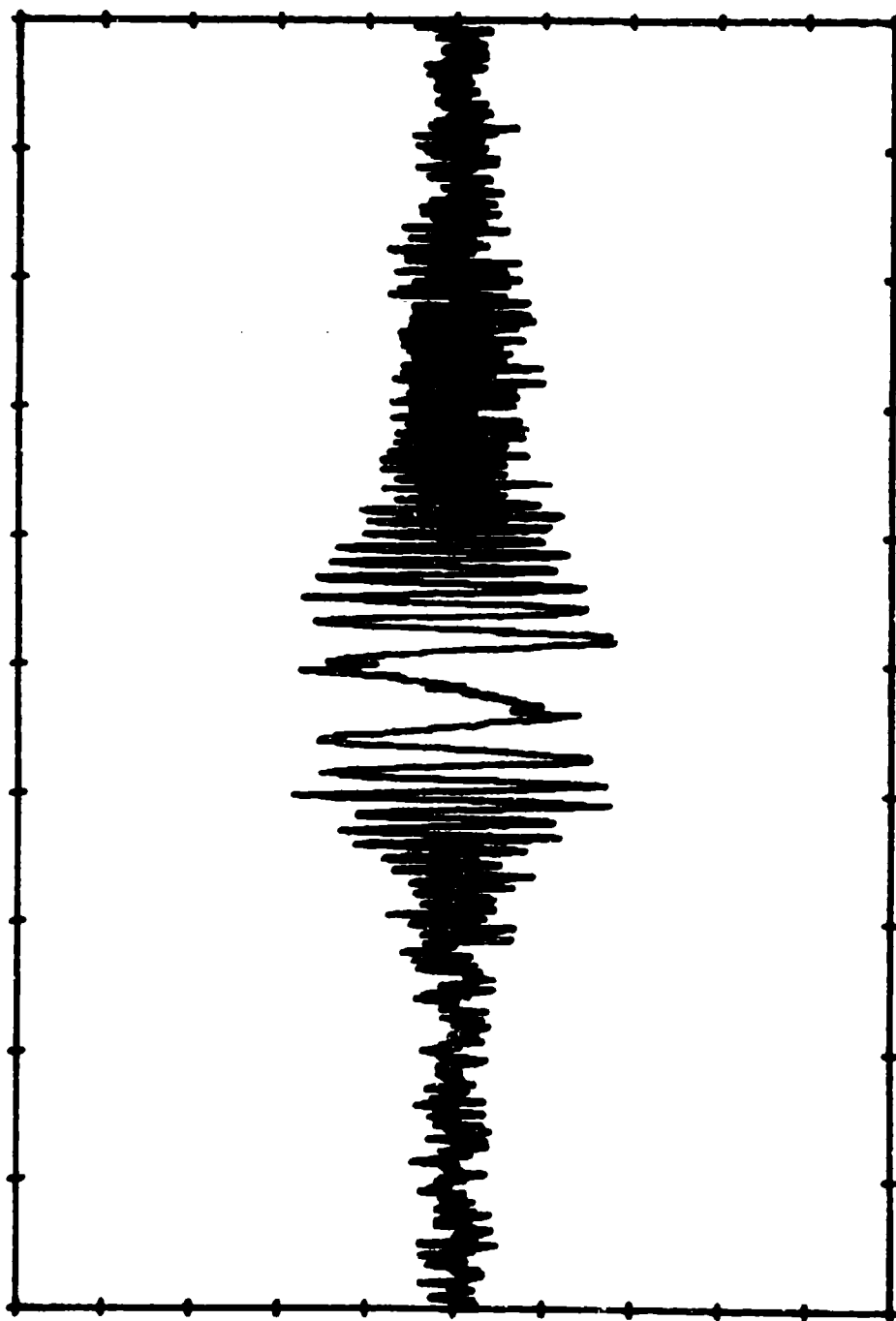
SAMPLES 500 THRU 1300

FILE NAME: ROUND.009 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:23: 2:15.265



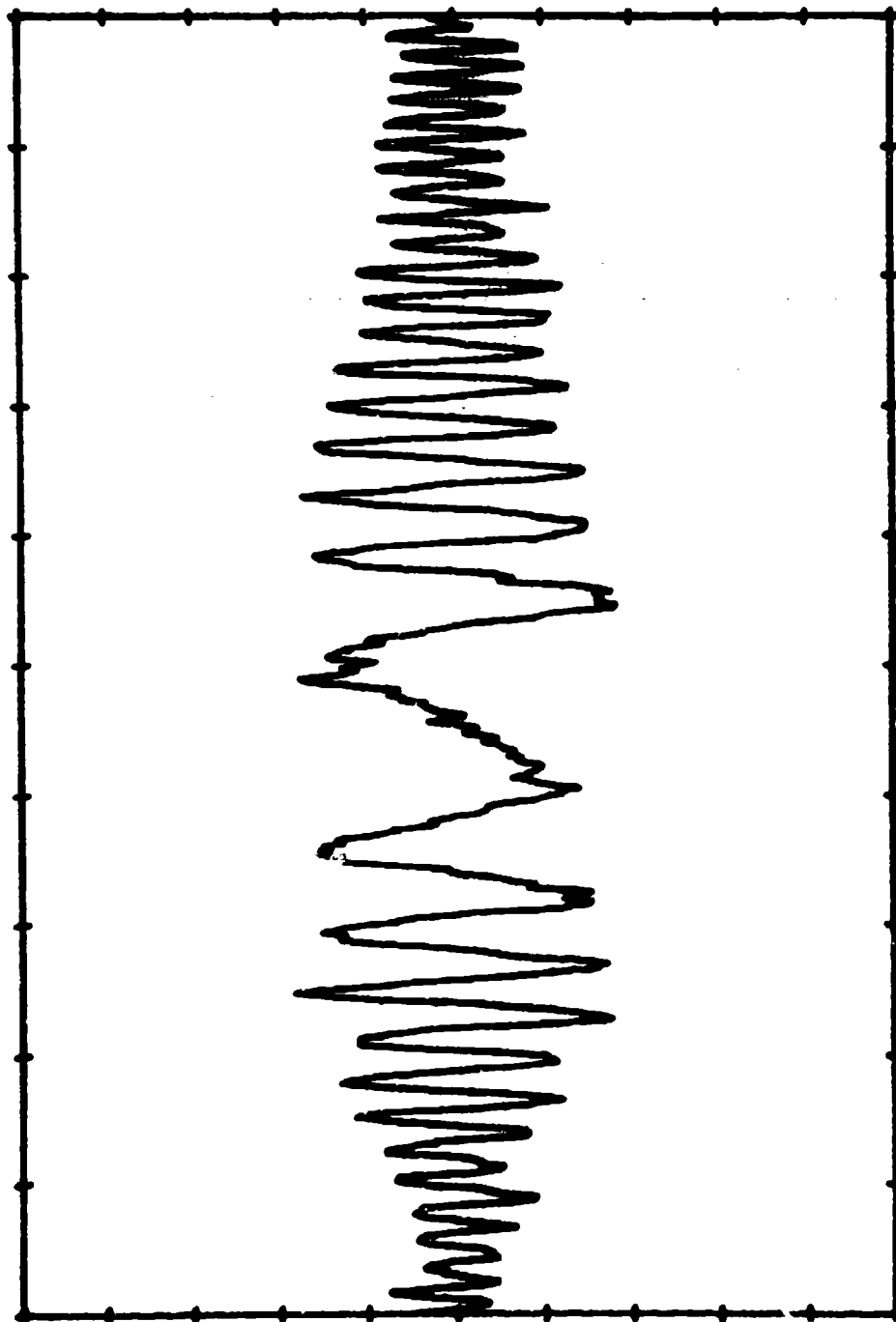
SAMPLES 1 THRU 4000

FILE NAME: ROUND.009 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:23: 2'15.265



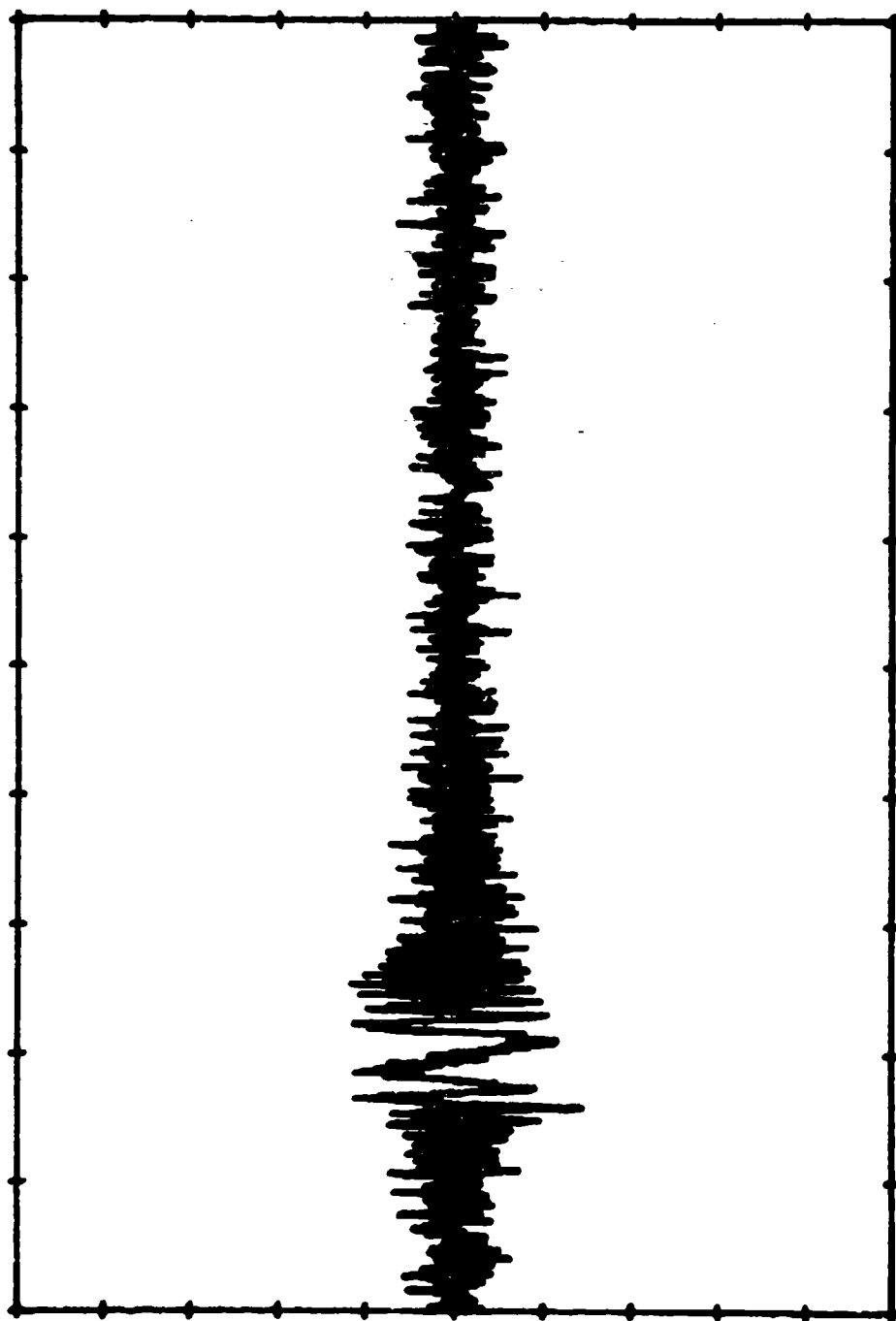
SAMPLES 1 THRU 2000

FILE NAME: ROUND.009 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323.23: 2:15.265



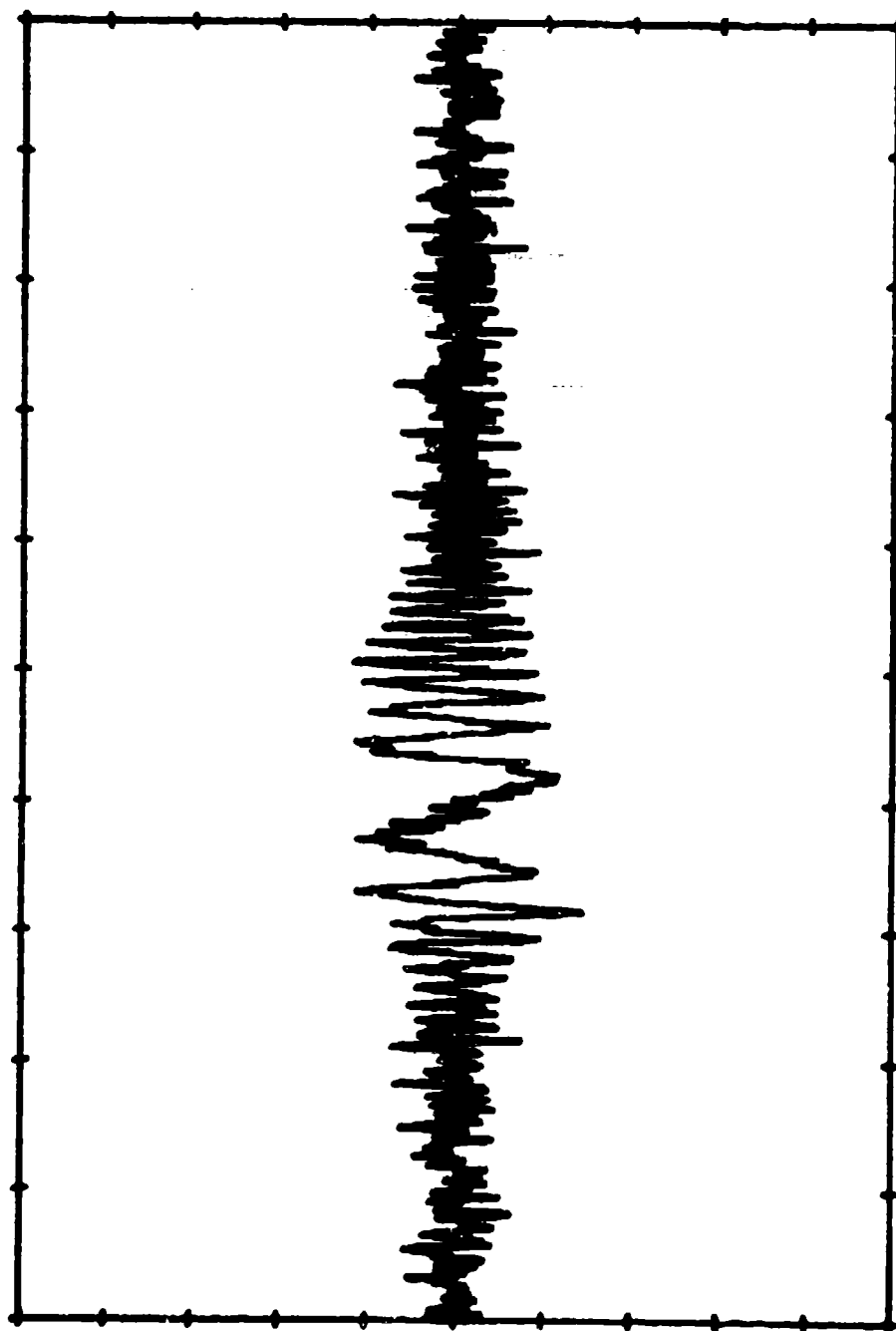
SAMPLES 600 THRU 1400

FILE NAME: ROUND.010 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:23: 6:49.033



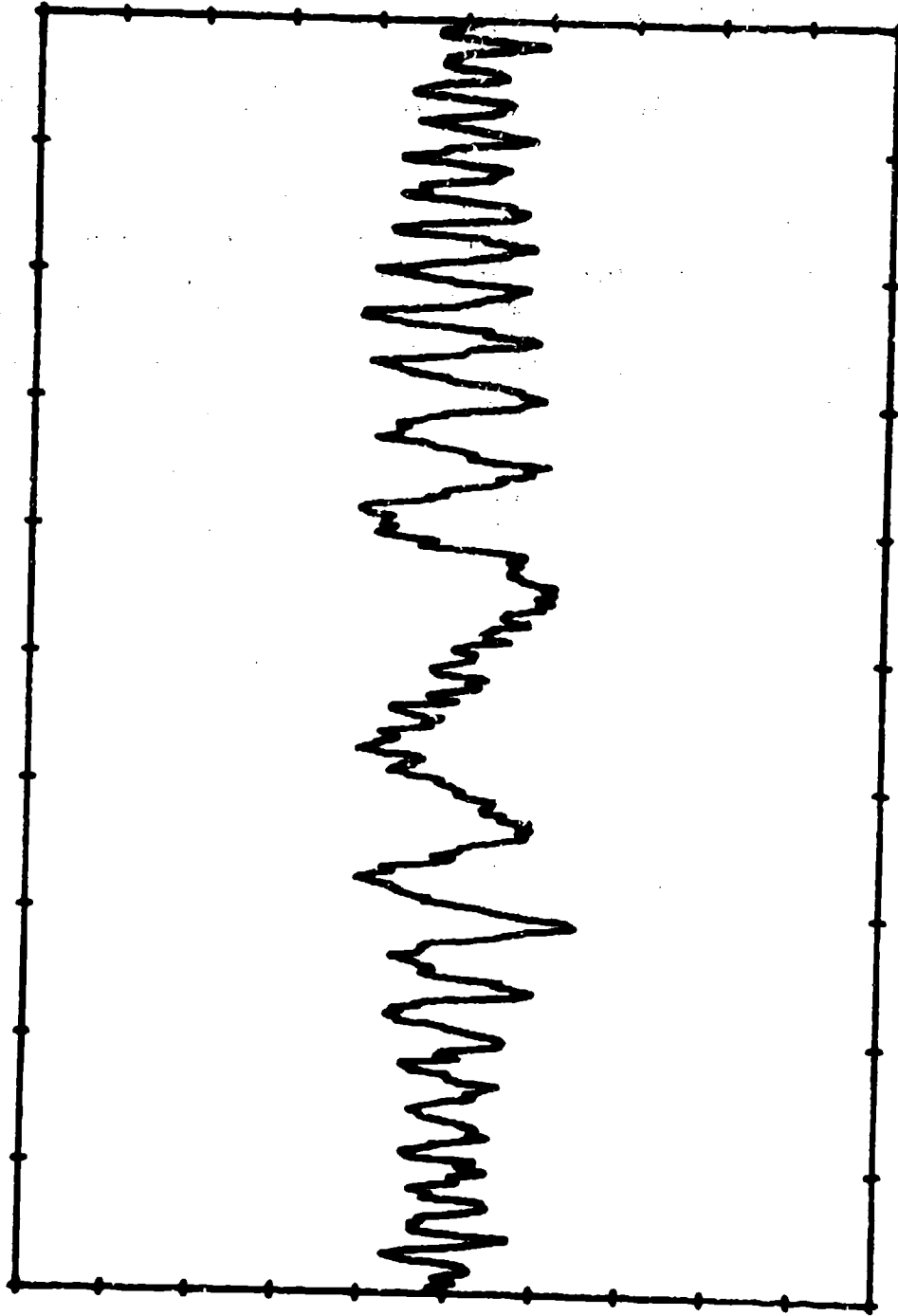
SAMPLES 1 THRU 4000

FILE NAME: ROUND.010 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323.23: 6:49.833



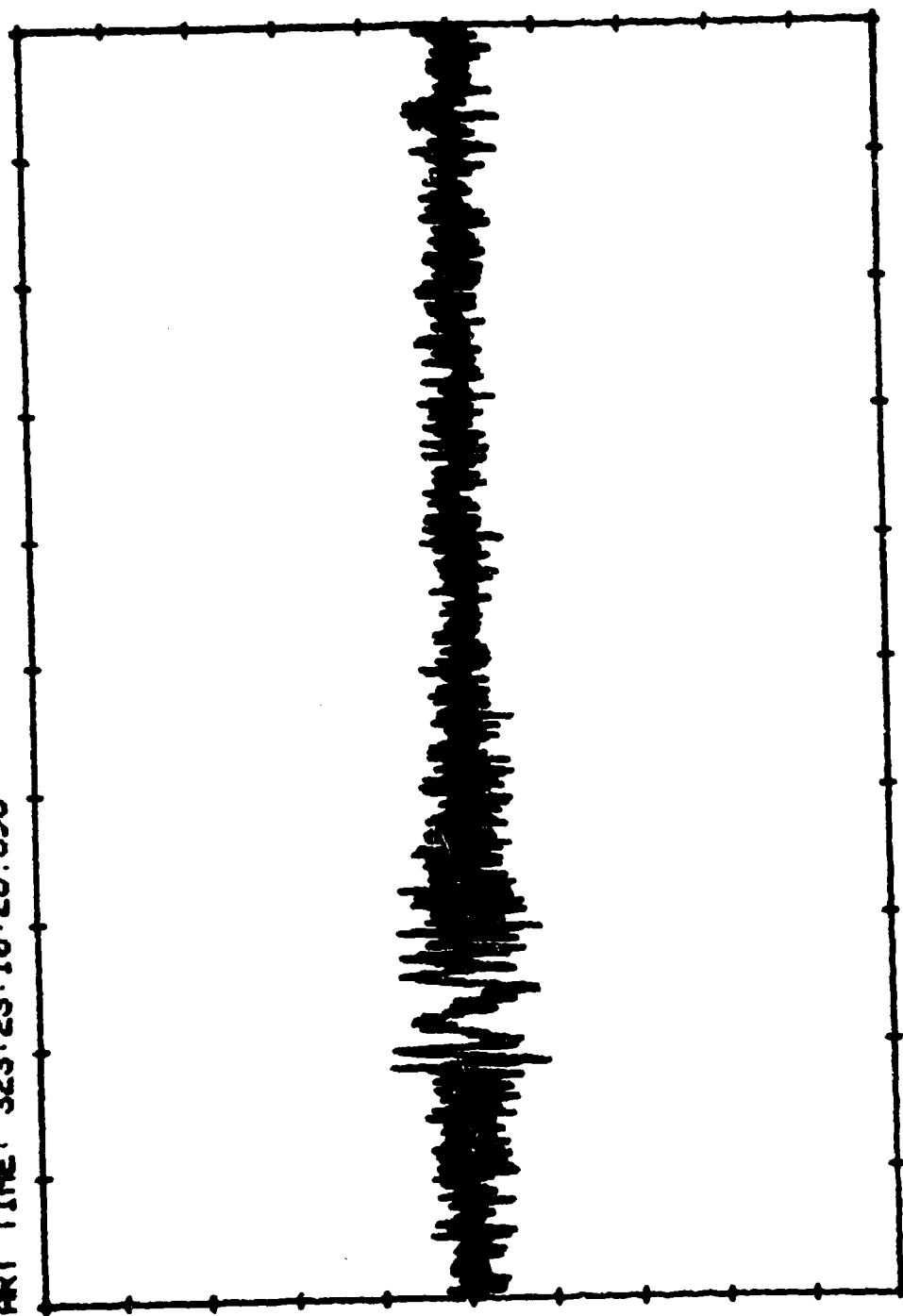
SAMPLES 1 THRU 2000

FILE NAME: ROUND.010 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:23: 6:49.833



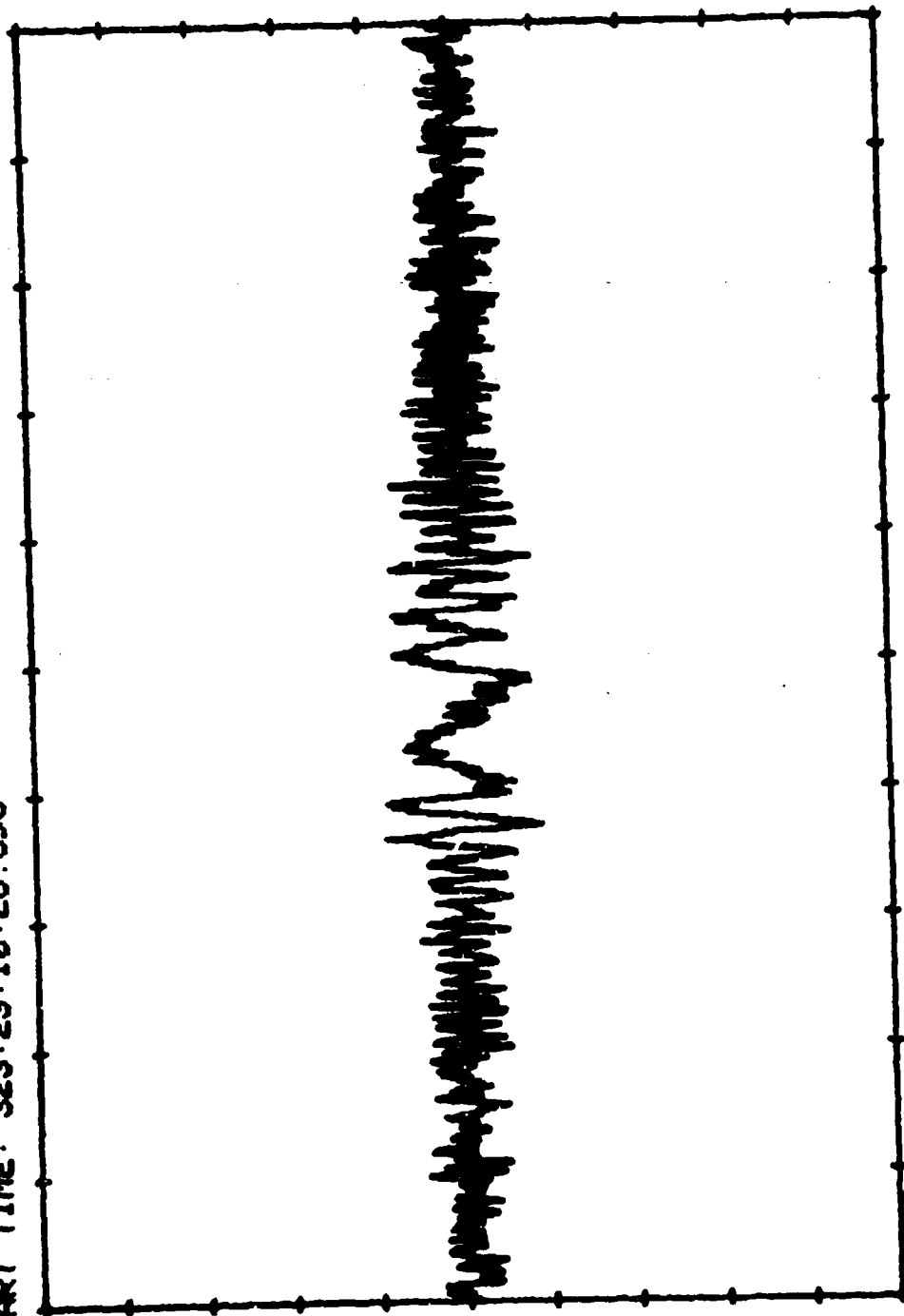
SAMPLES 400 THRU 1200

FILE NAME: ROUND.011 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323.23:10:28.698



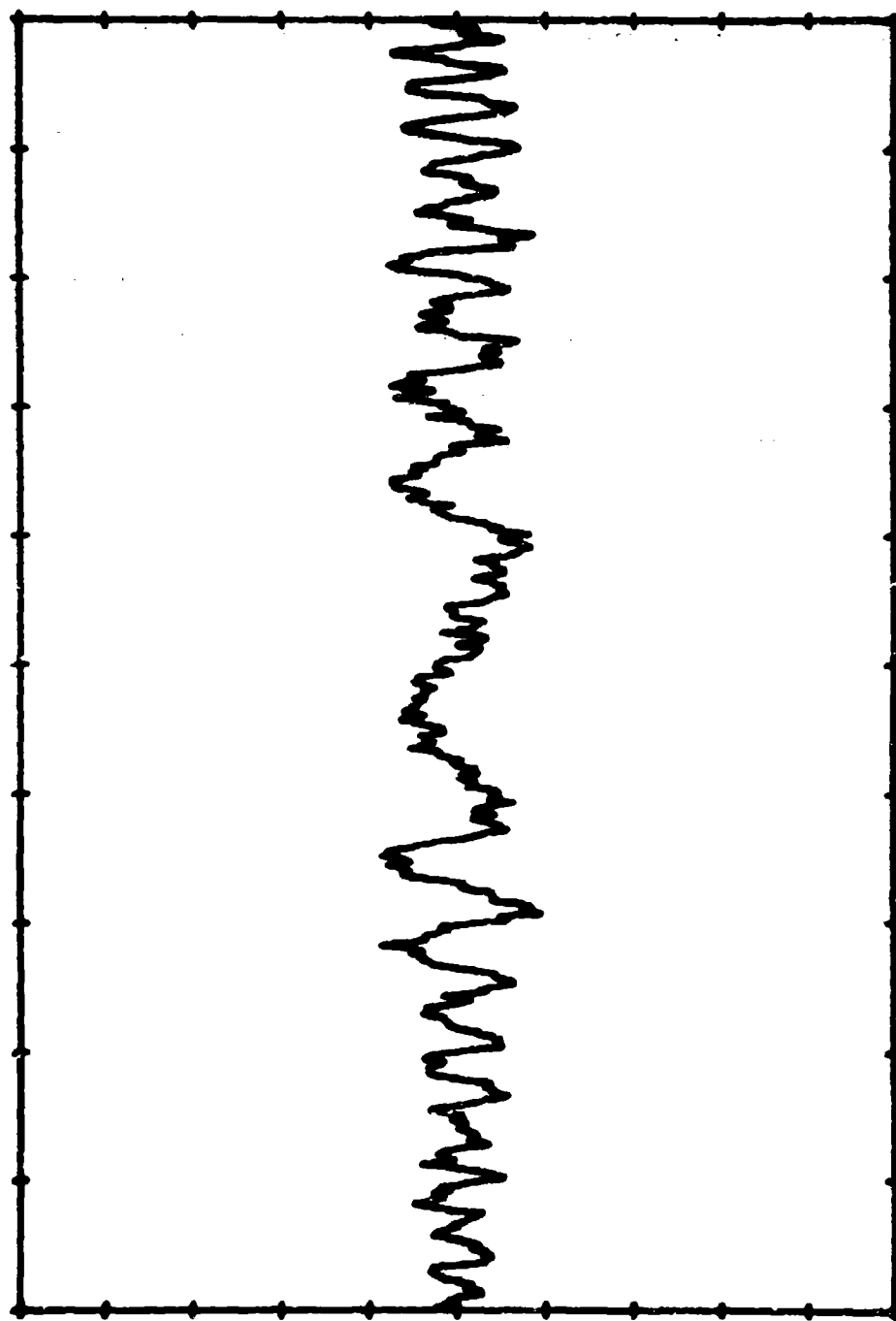
SAMPLES 1 THRU 4000

FILE NAME: ROUND.011 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:23:10.28.698



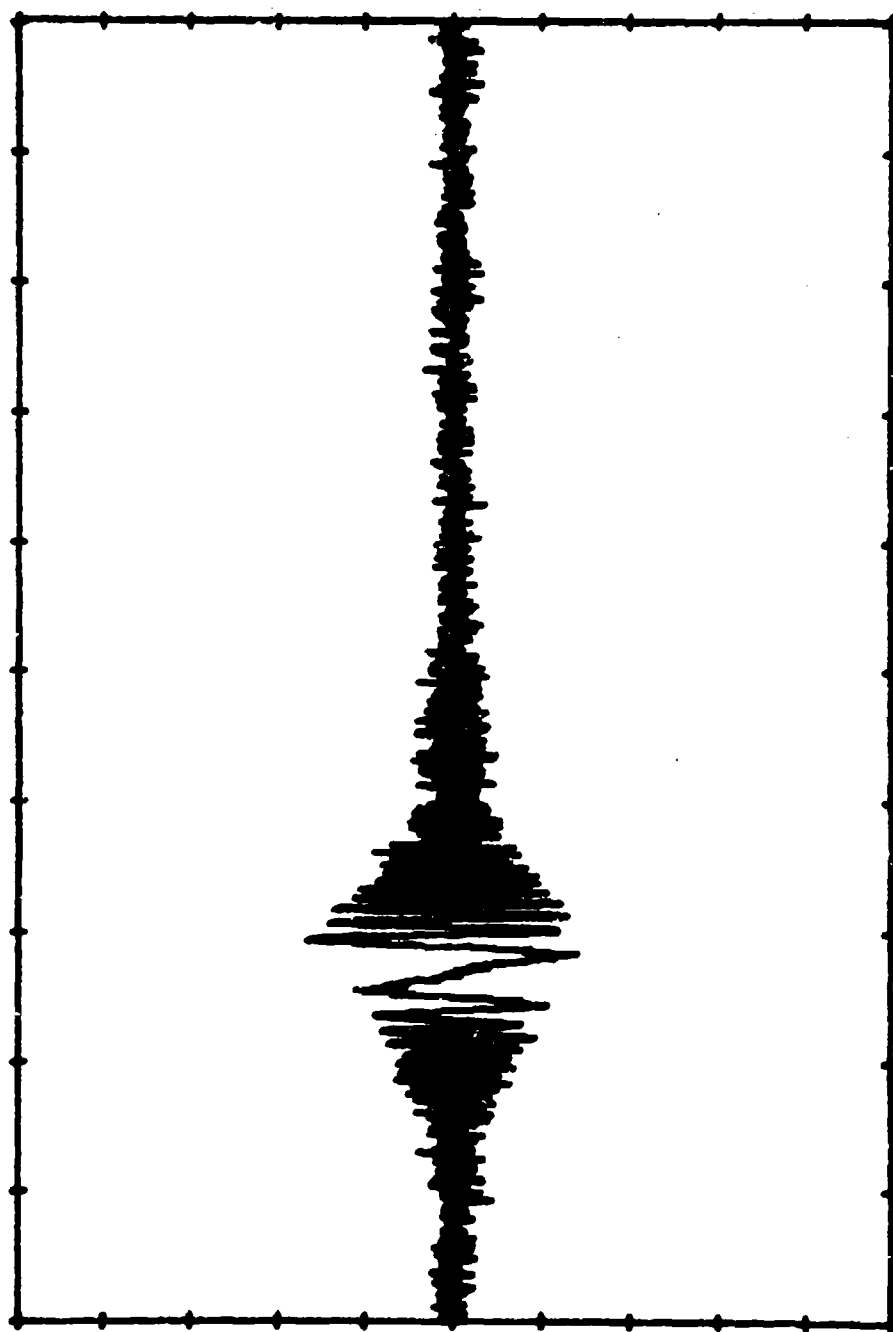
SAMPLES 1 THRU 2000

FILE NAME: ROUND.011 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:23:10.28.698



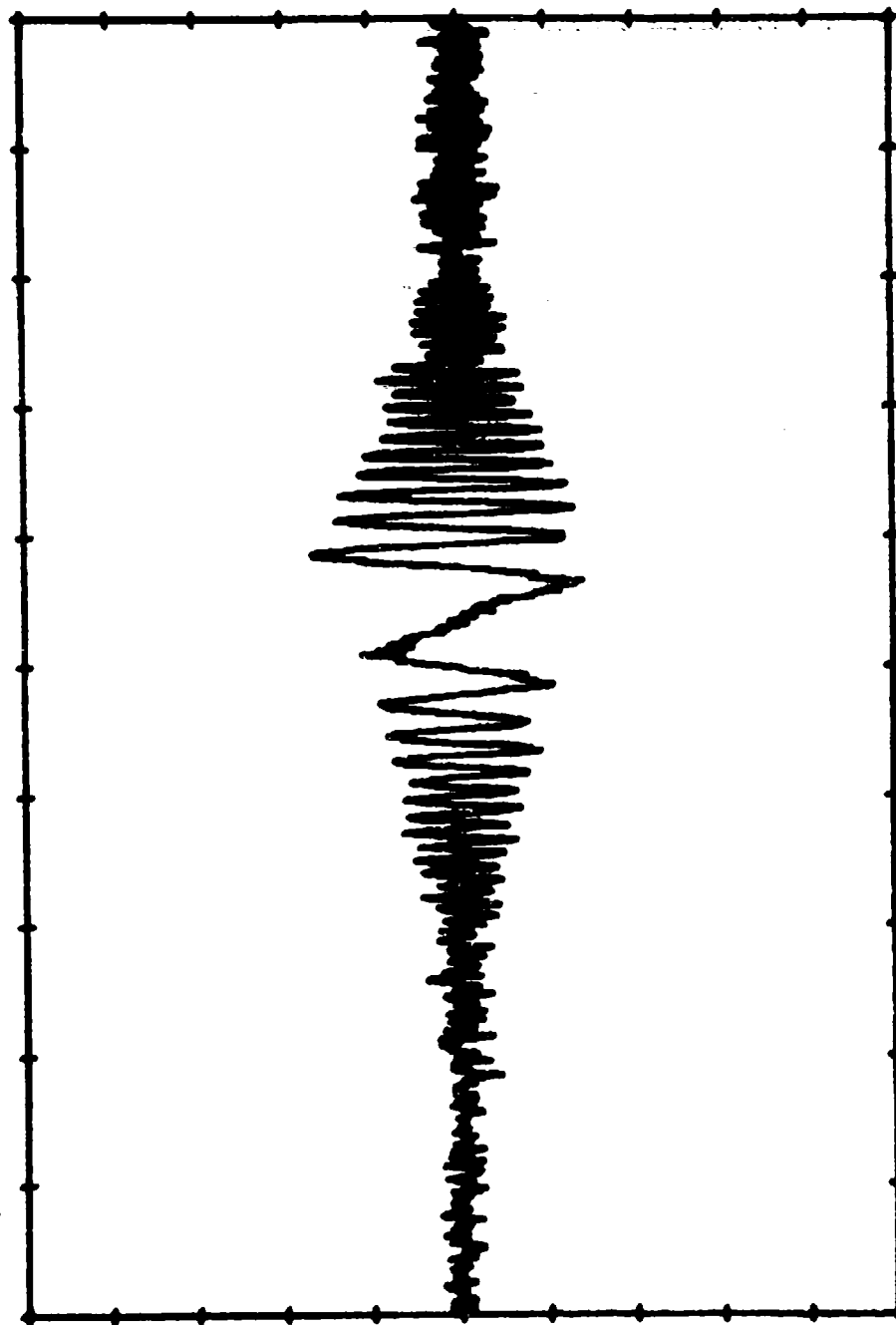
SAMPLES 500 THRU 1300

FILE NAME: ROUND.012 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:31.49.609



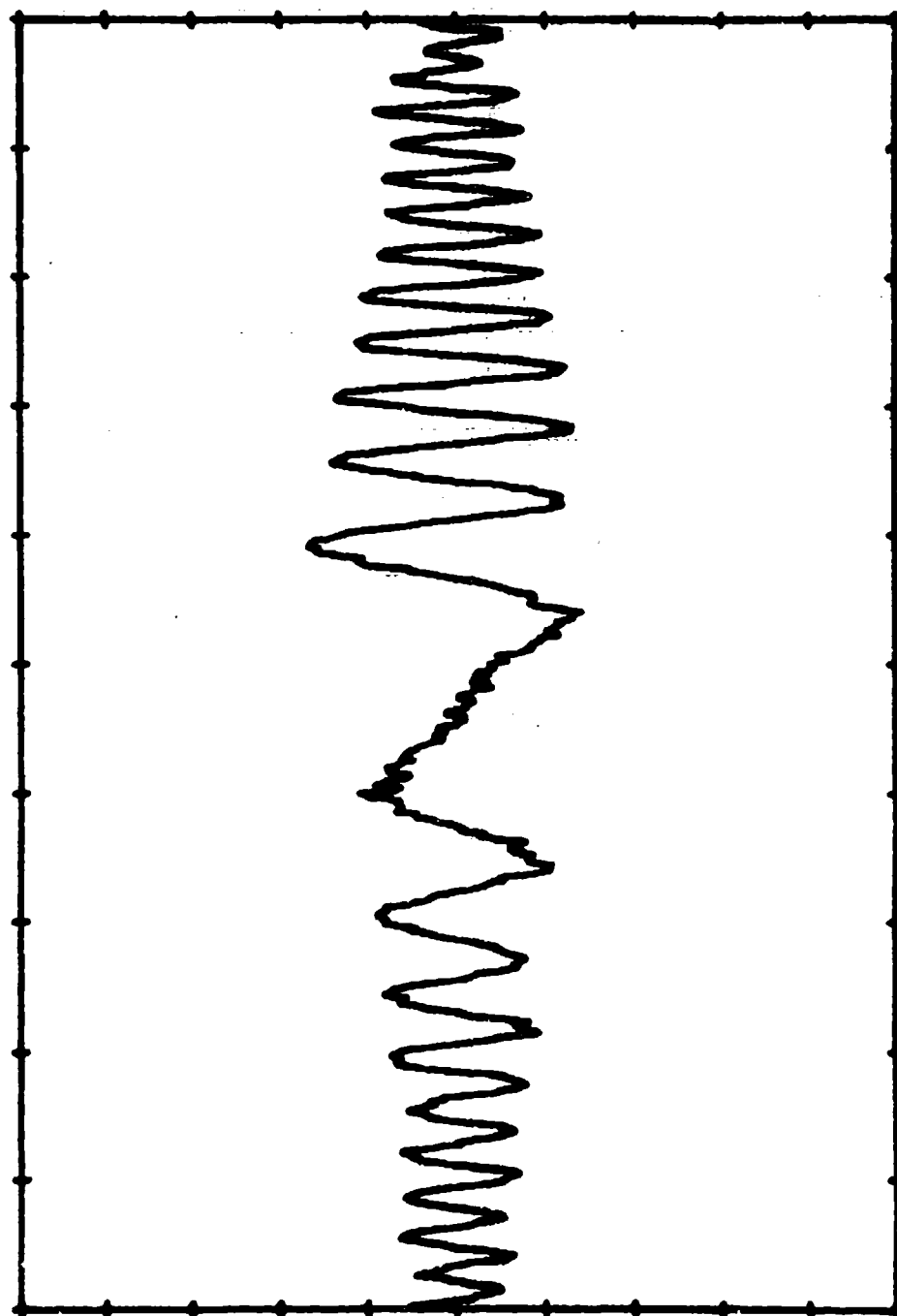
SAMPLES 1 THRU 4000

FILE NAME: ROUND.012 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:31.49.609



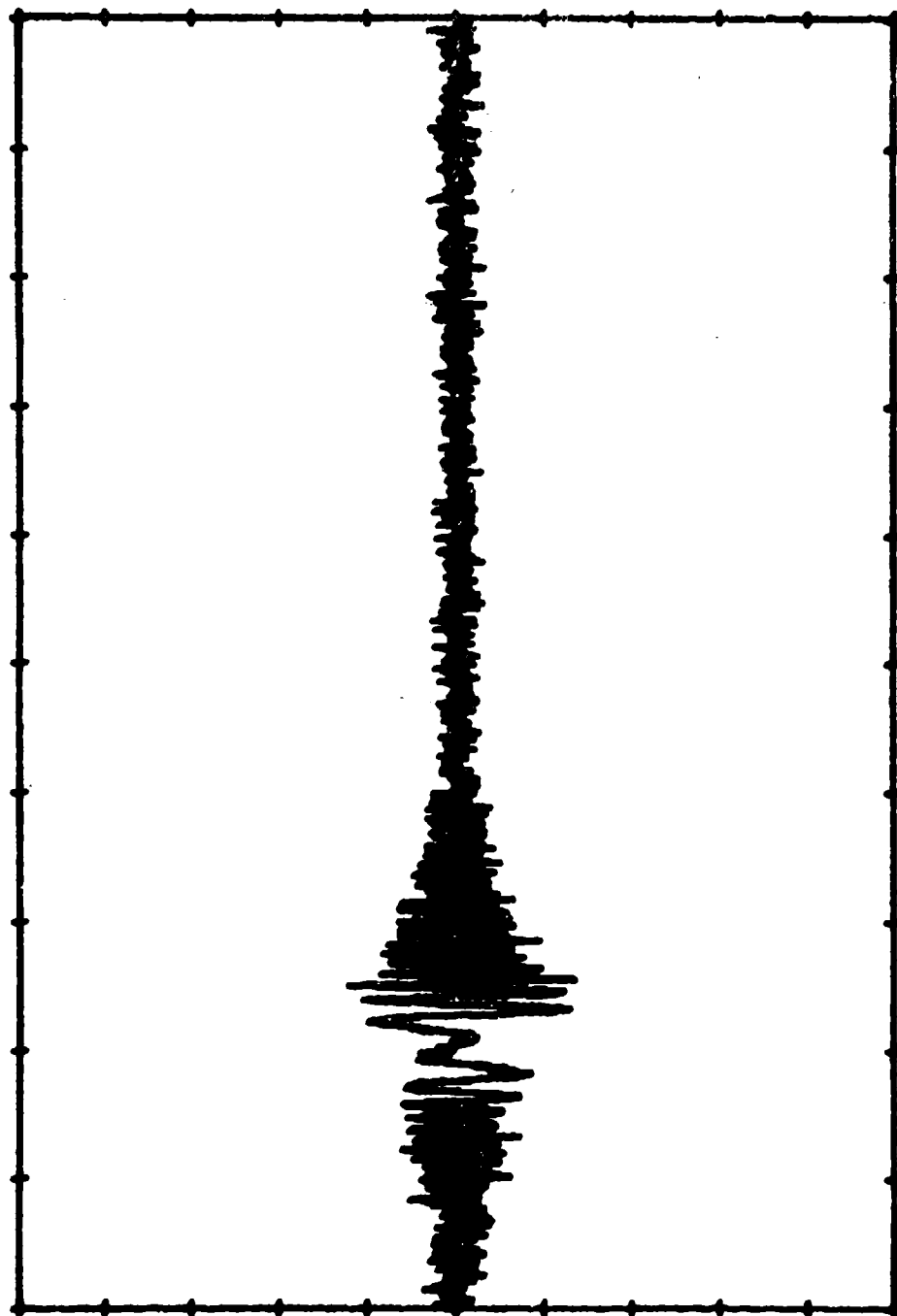
SAMPLES 1 THRU 2000

FILE NAME: ROUND.012 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:31:49.609



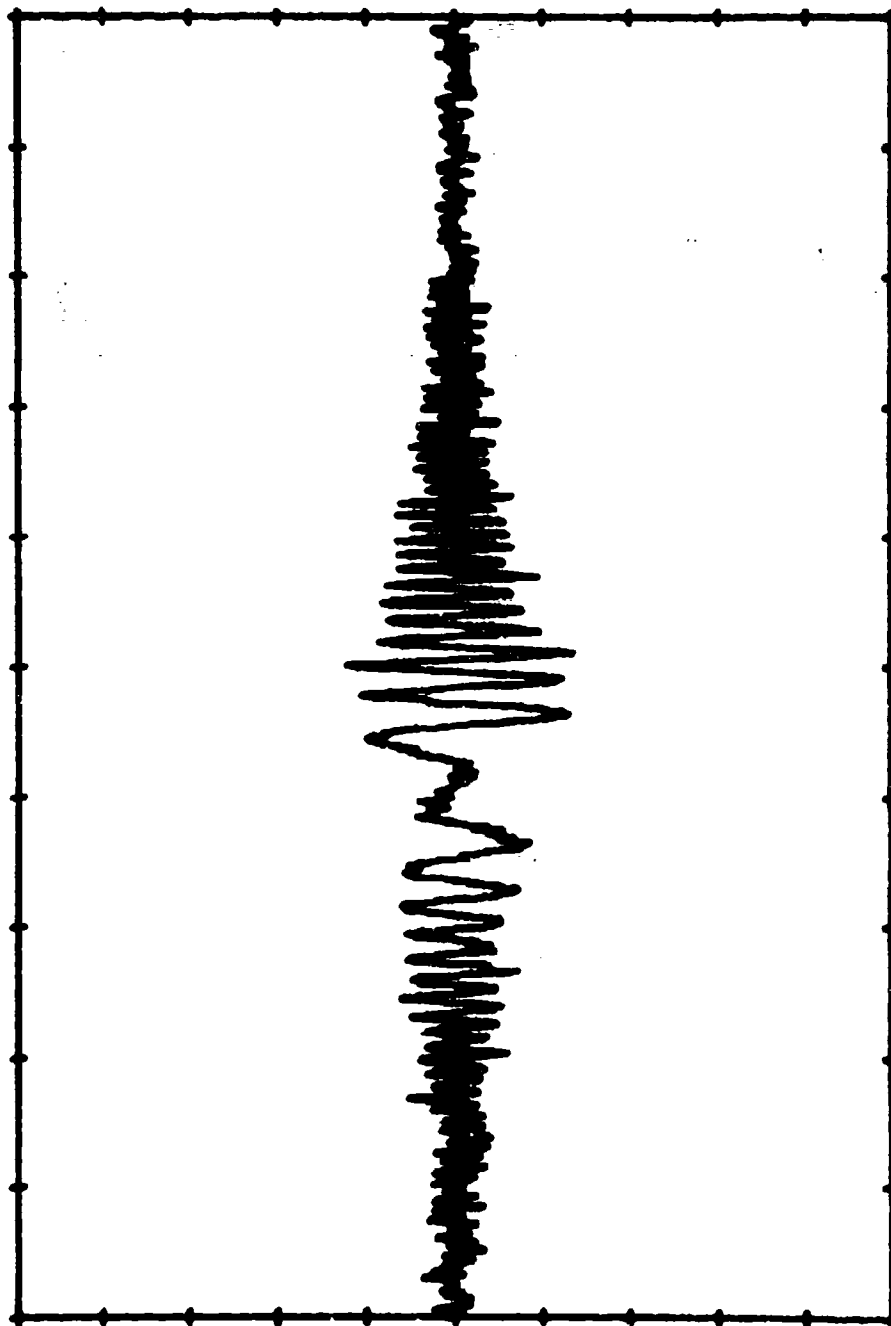
SAMPLES 700 THRU 1500

FILE NAME: ROUND.013 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:35.35.459



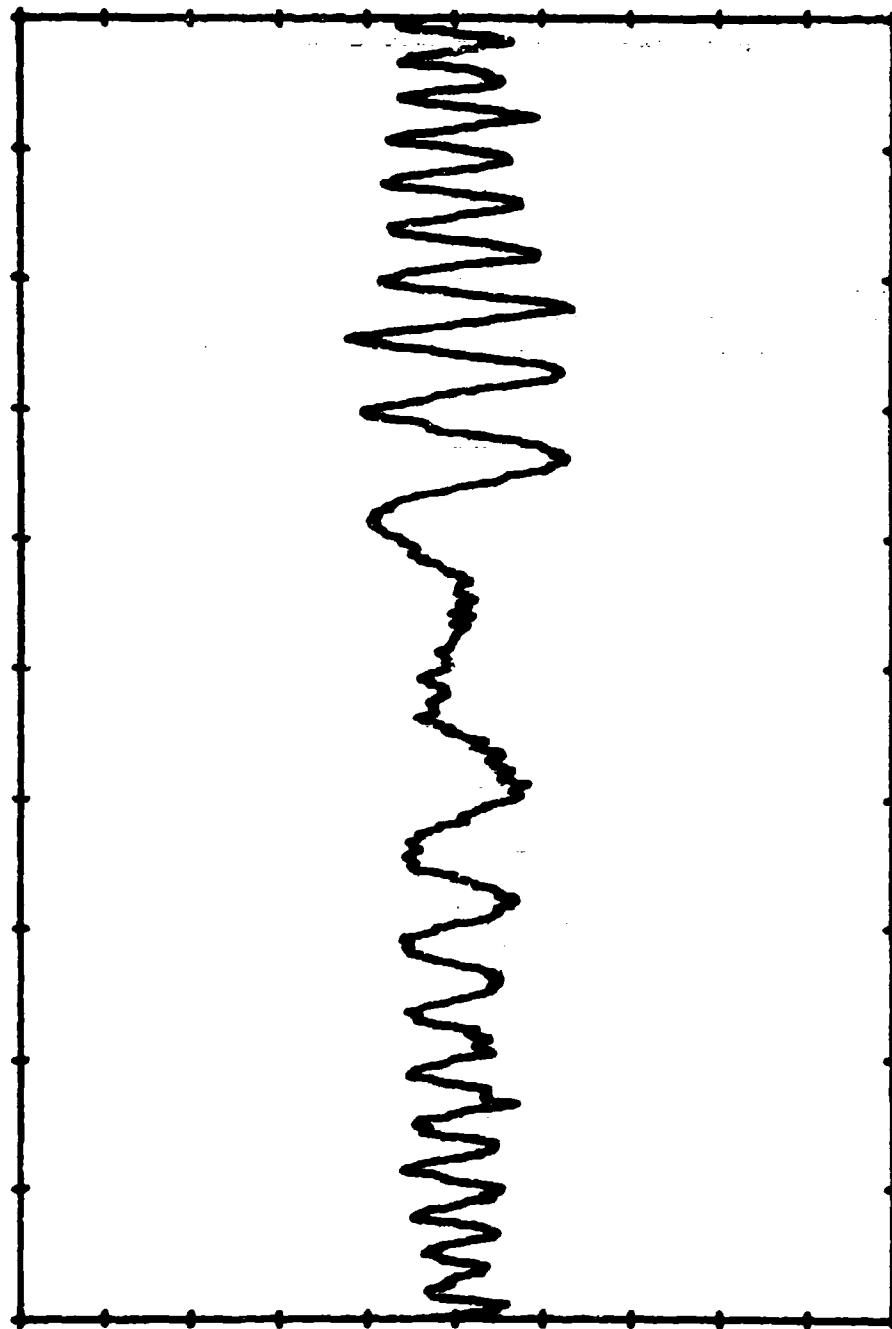
SAMPLES 1 THRU 4000

FILE NAME: ROUND.013 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:35.35.459



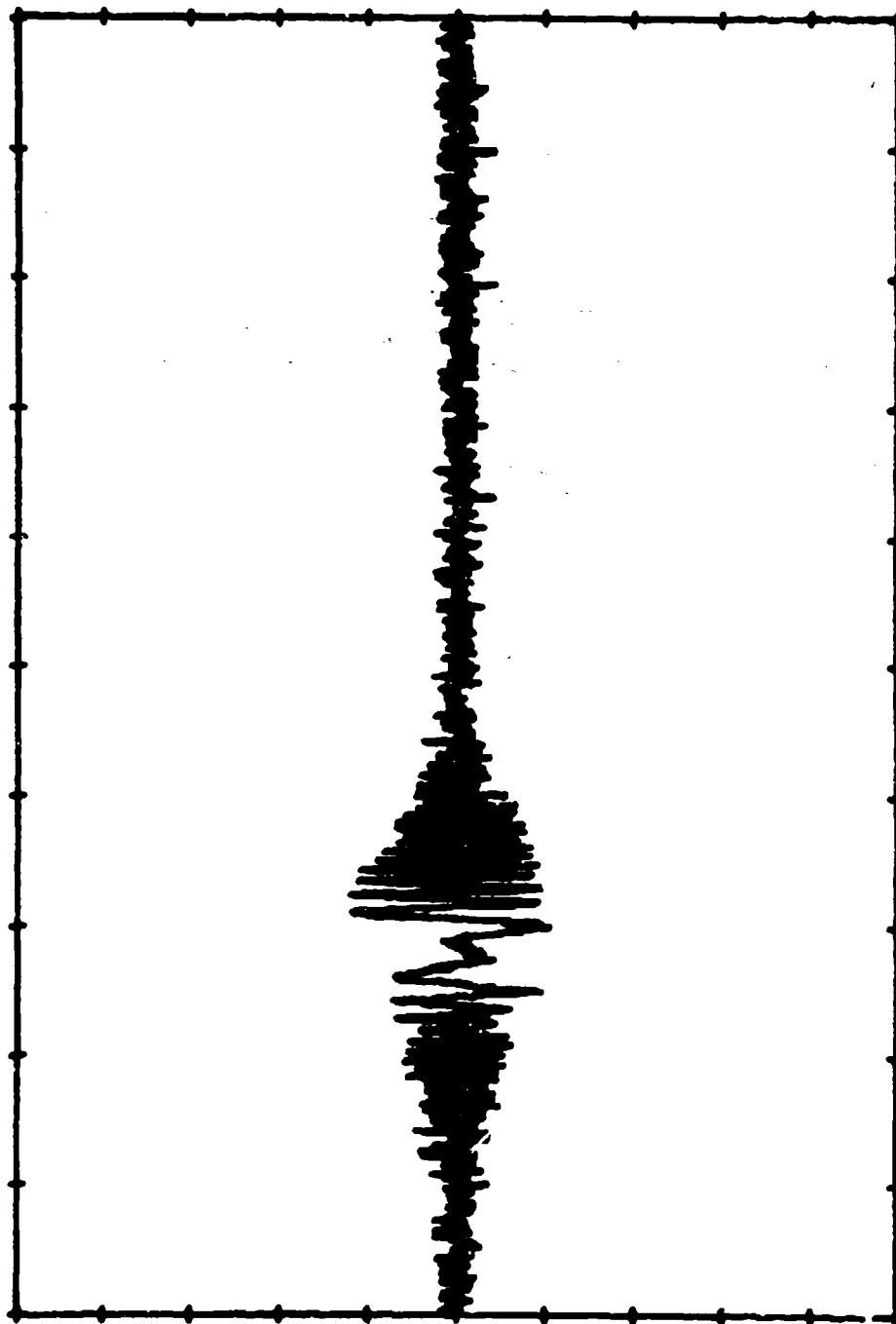
SAMPLES 1 THRU 2000

FILE NAME: ROUND.013 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:35.35.459



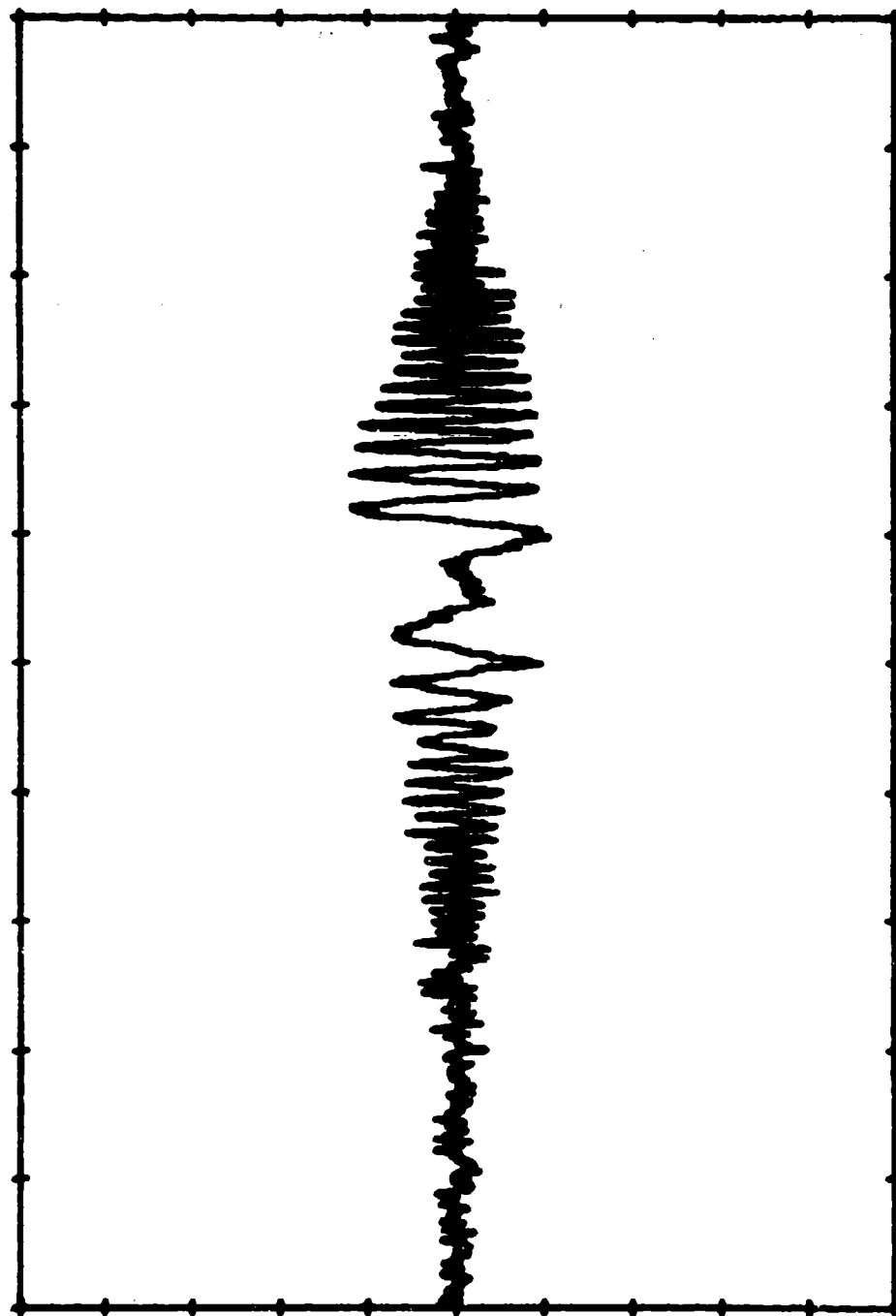
SAMPLES 400 THRU 1200

FILE NAME: ROUND.014 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:42.43. 76



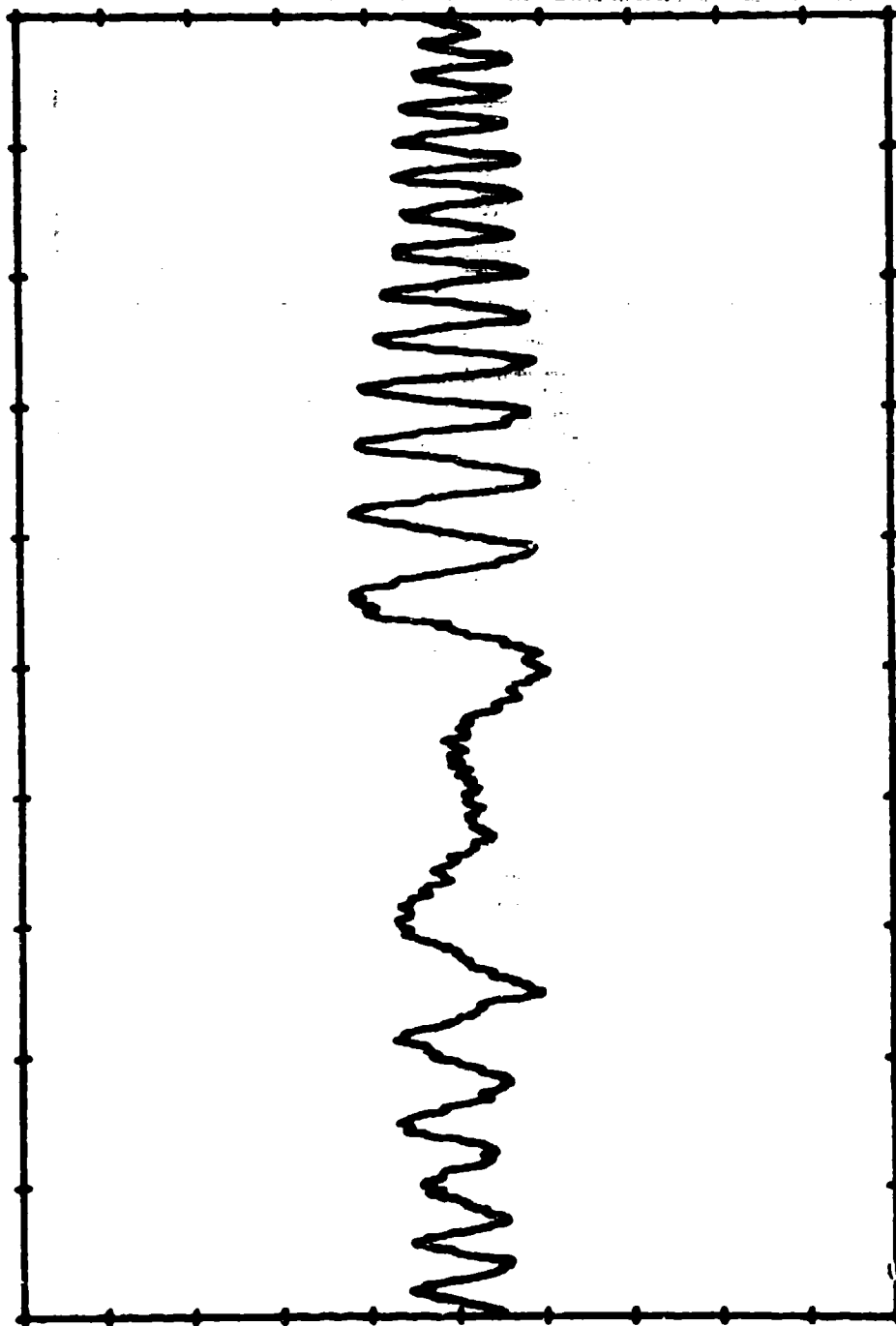
SAMPLES 1 THRU 4000

FILE NAME: ROUND.014 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:42:43. 76



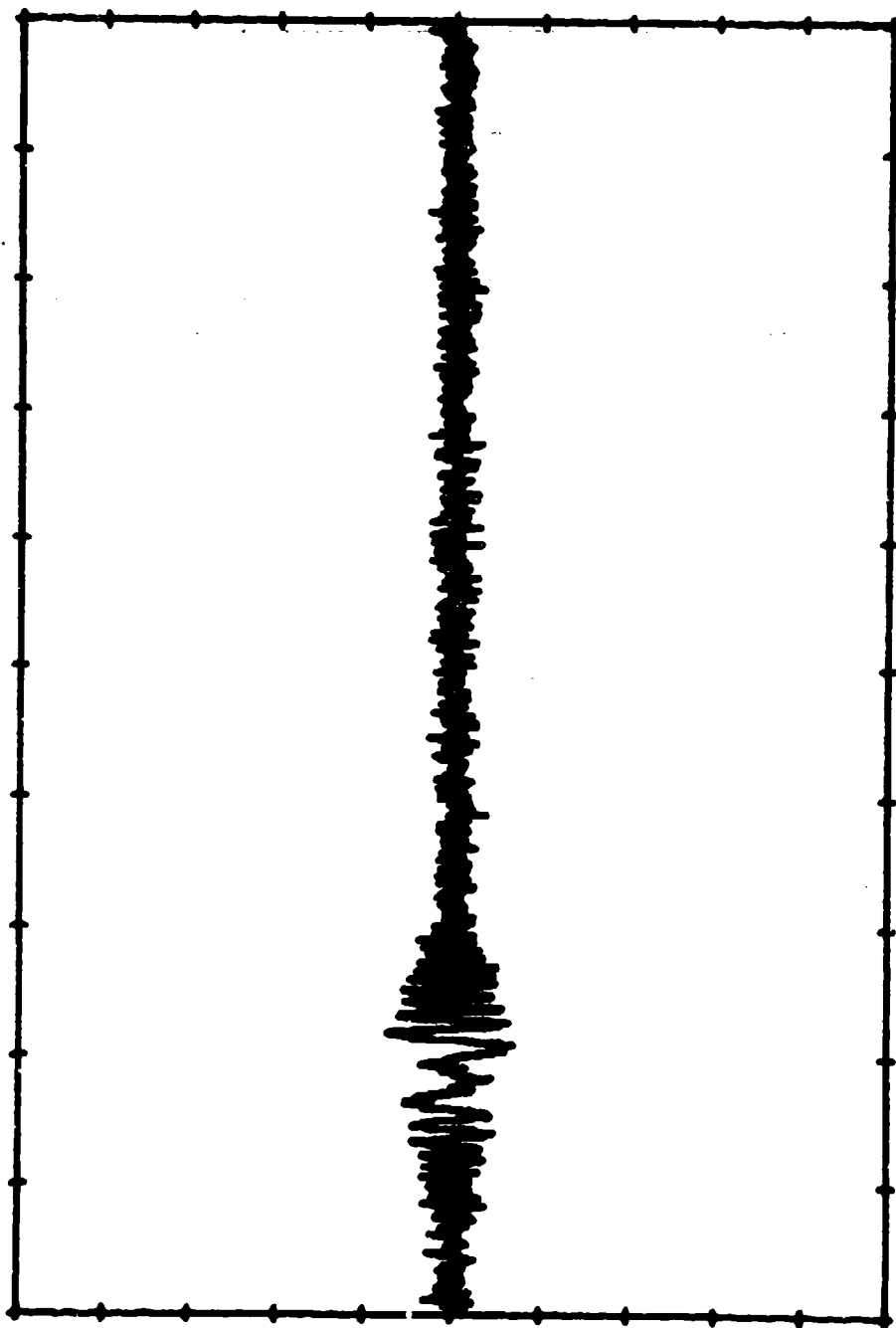
SAMPLES 1 THRU 2000

FILE NAME: ROUND.014 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:42.43.76



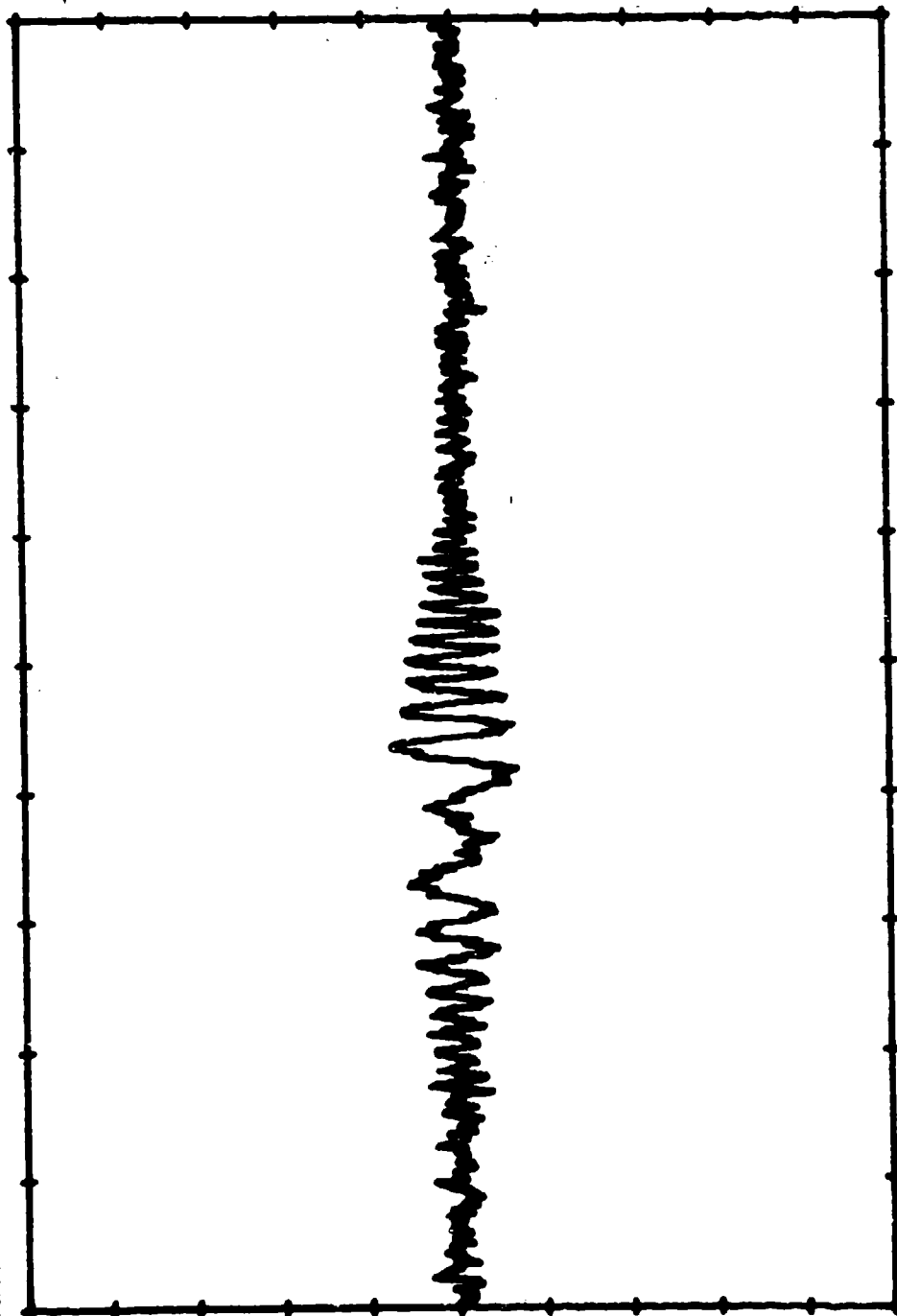
SAMPLES 900 THRU 1600

FILE NAME: ROUND.015 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:46.46.794



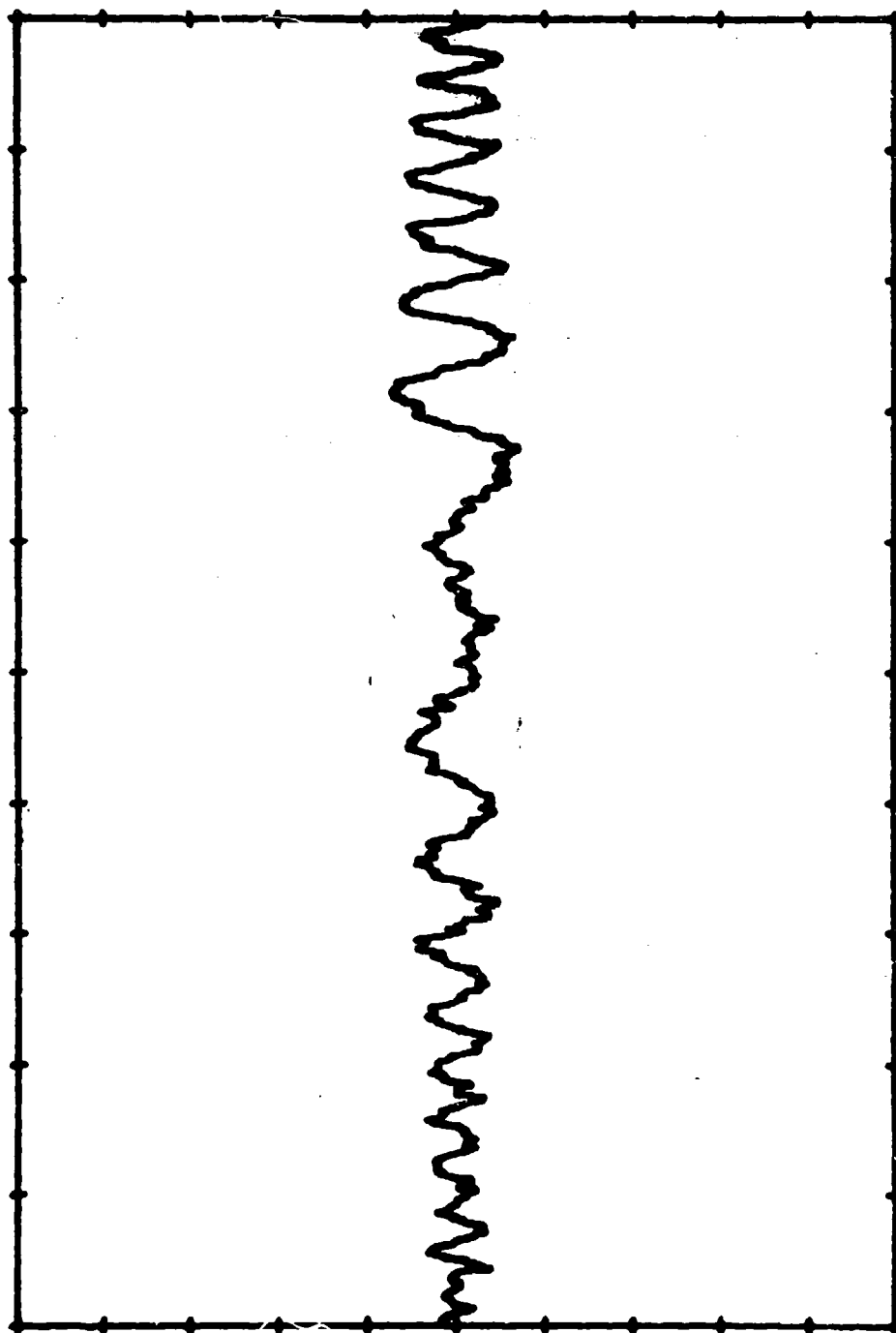
SAMPLES 1 THRU 4000

FILE NAME: ROUND.015 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:46.46.794



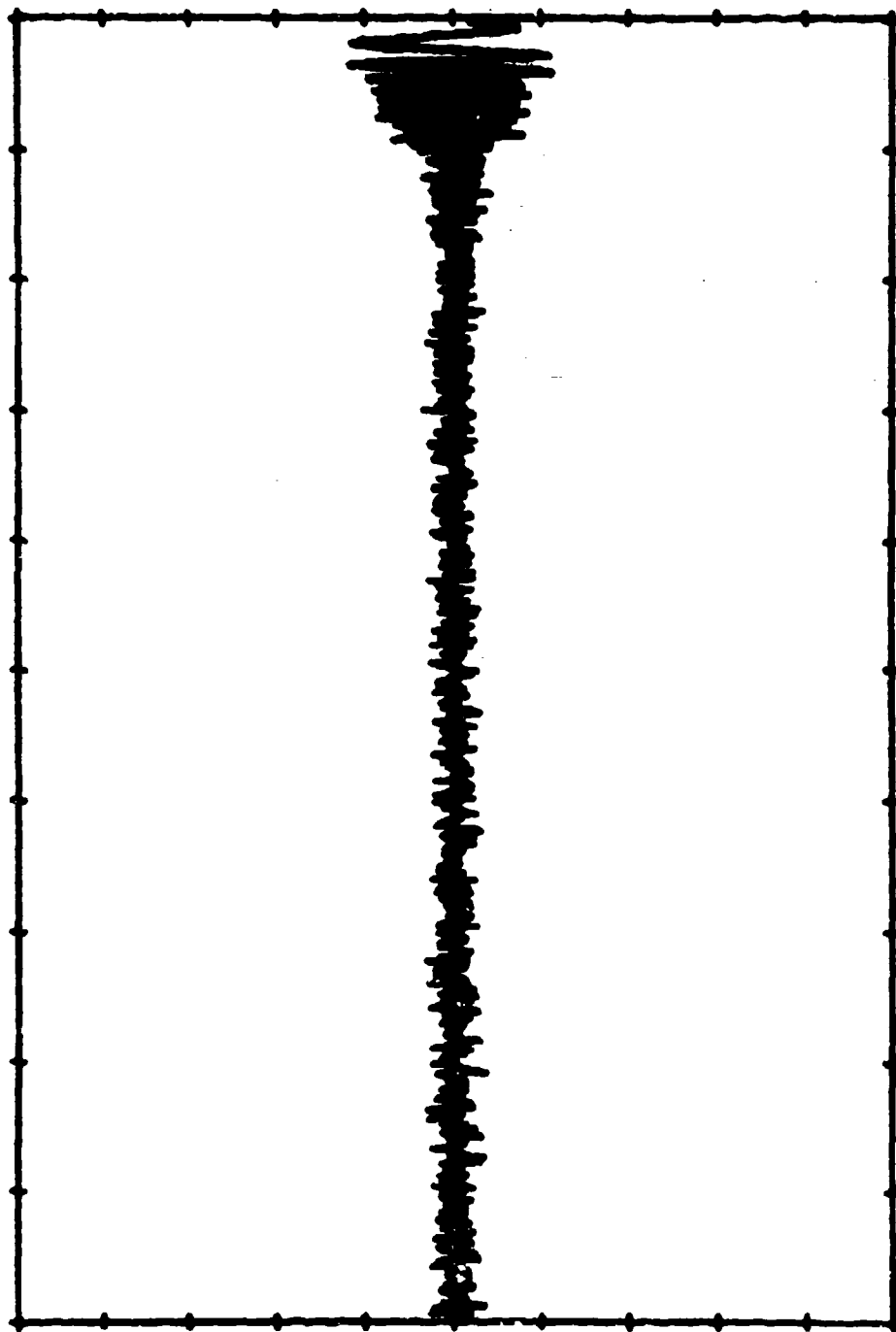
SAMPLES 1 THRU 2000

FILE NAME: ROUND.015 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:46.794



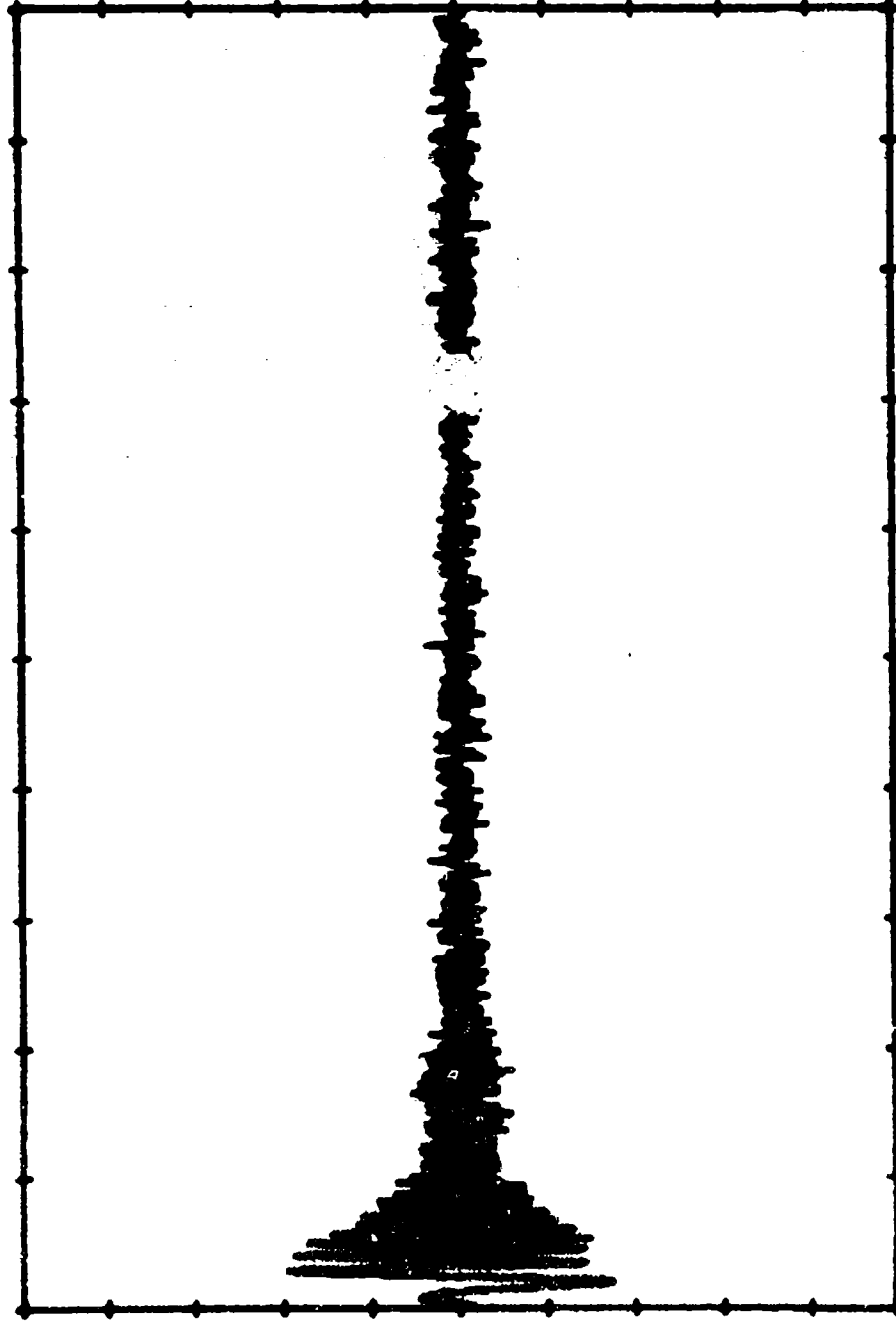
SAMPLES 300 THRU 1100

FILE NAME: ROUND.016 FILE DATA RECORD NUMBER: 1
FILE START TIME: 324.23:50.12.411



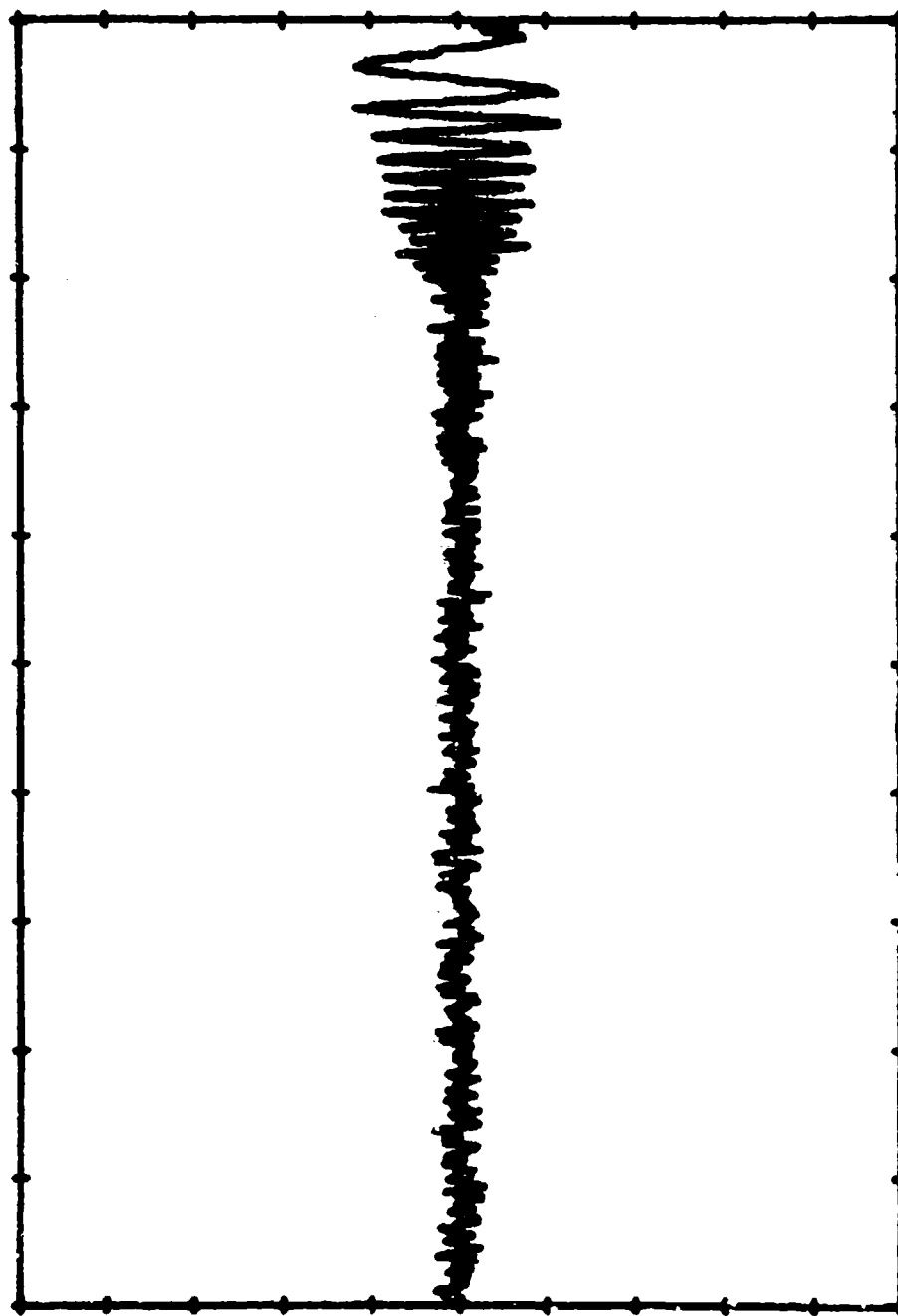
SAMPLES 97 THRU 4096

FILE NAME: ROUND.016 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:50:12.411



SAMPLES 1 THRU 4000

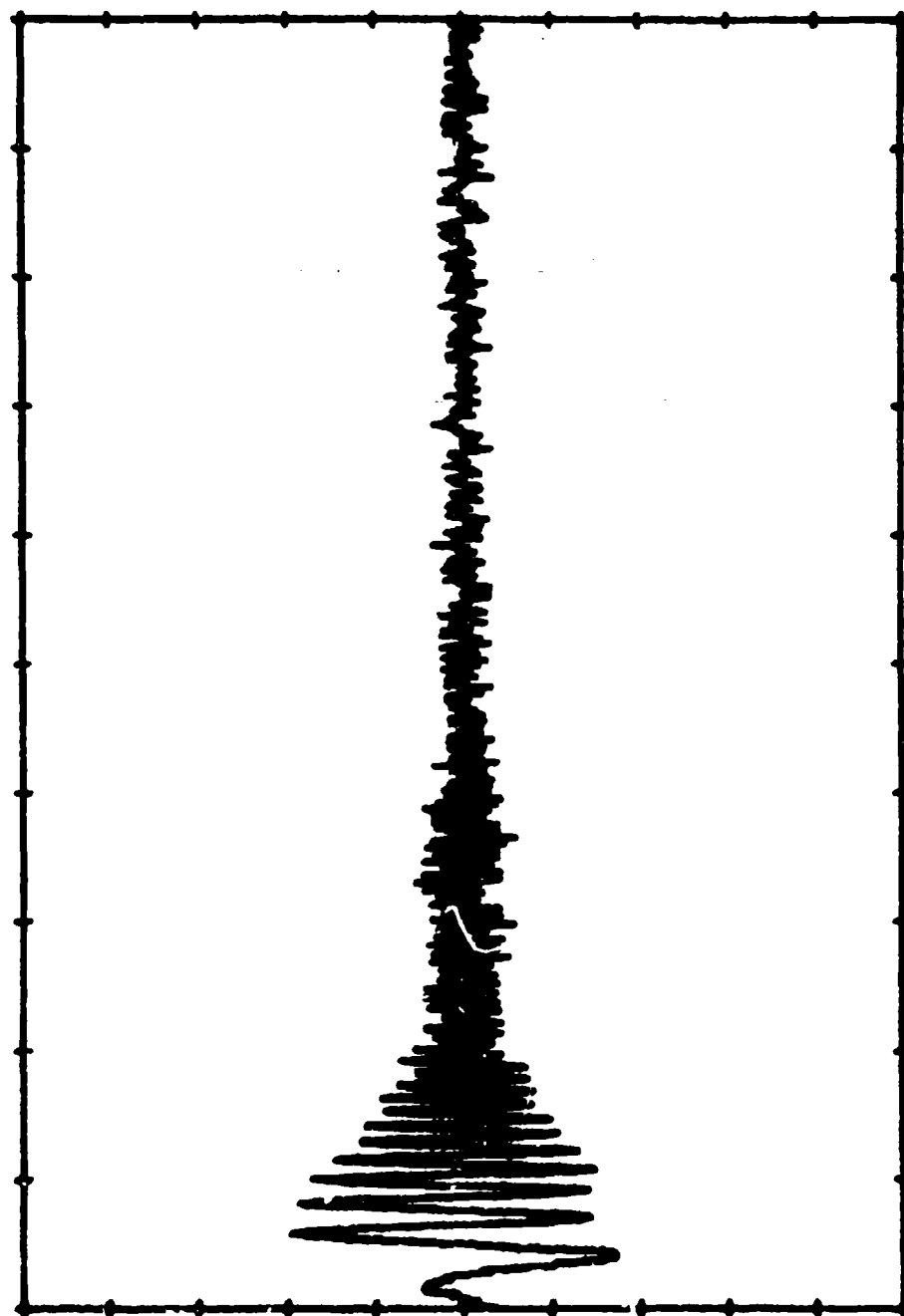
FILE NAME: ROUND.016 FILE DATA RECORD NUMBER: 1
FILE START TIME: 324:23:50:12.411



ENTER 10 TO ESCAPE XXX
SET TO OUTPUT TAPE

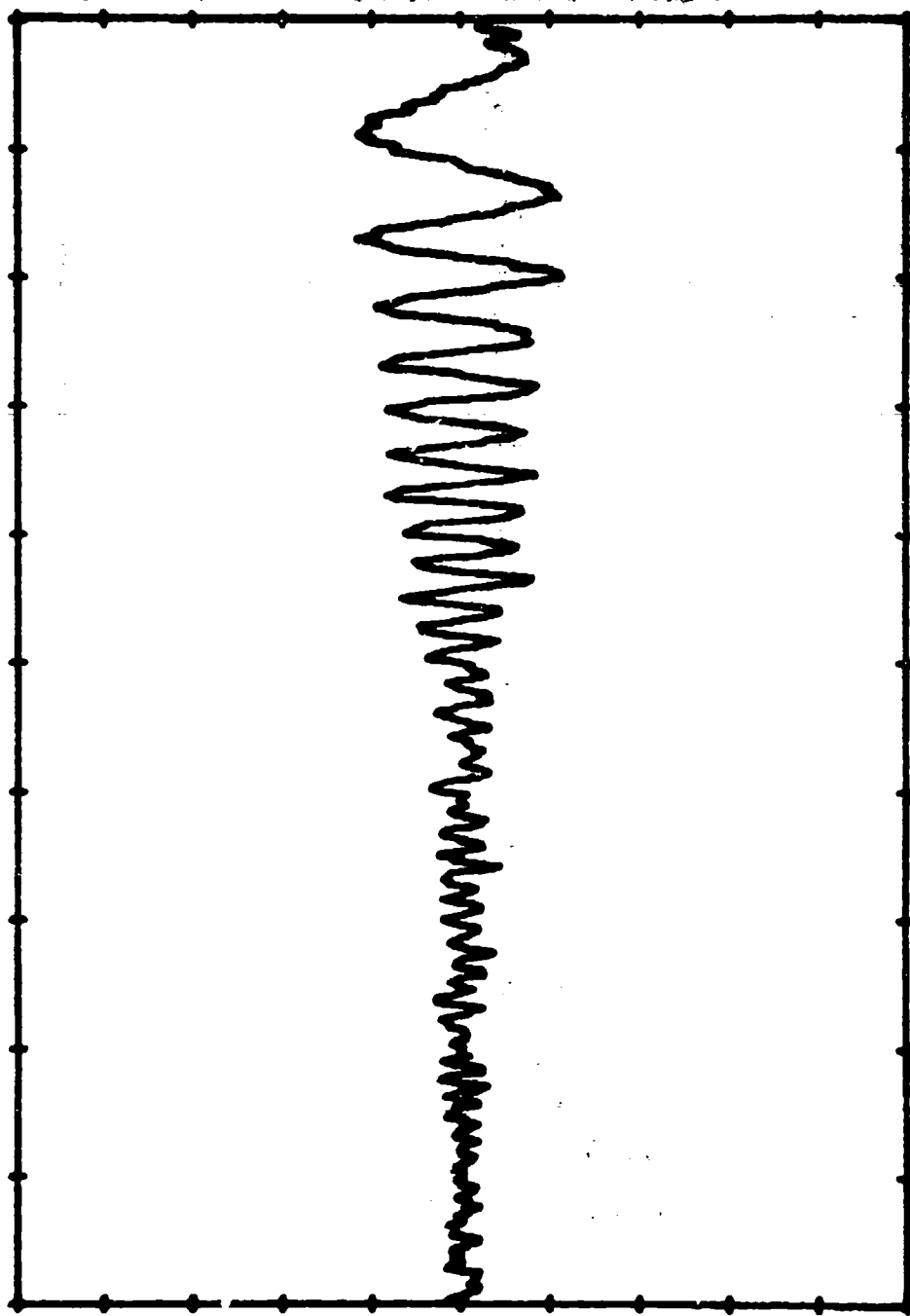
SAMPLES 2097 THRU 4096

FILE NAME: ROUND.016 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324.23:50.12.411



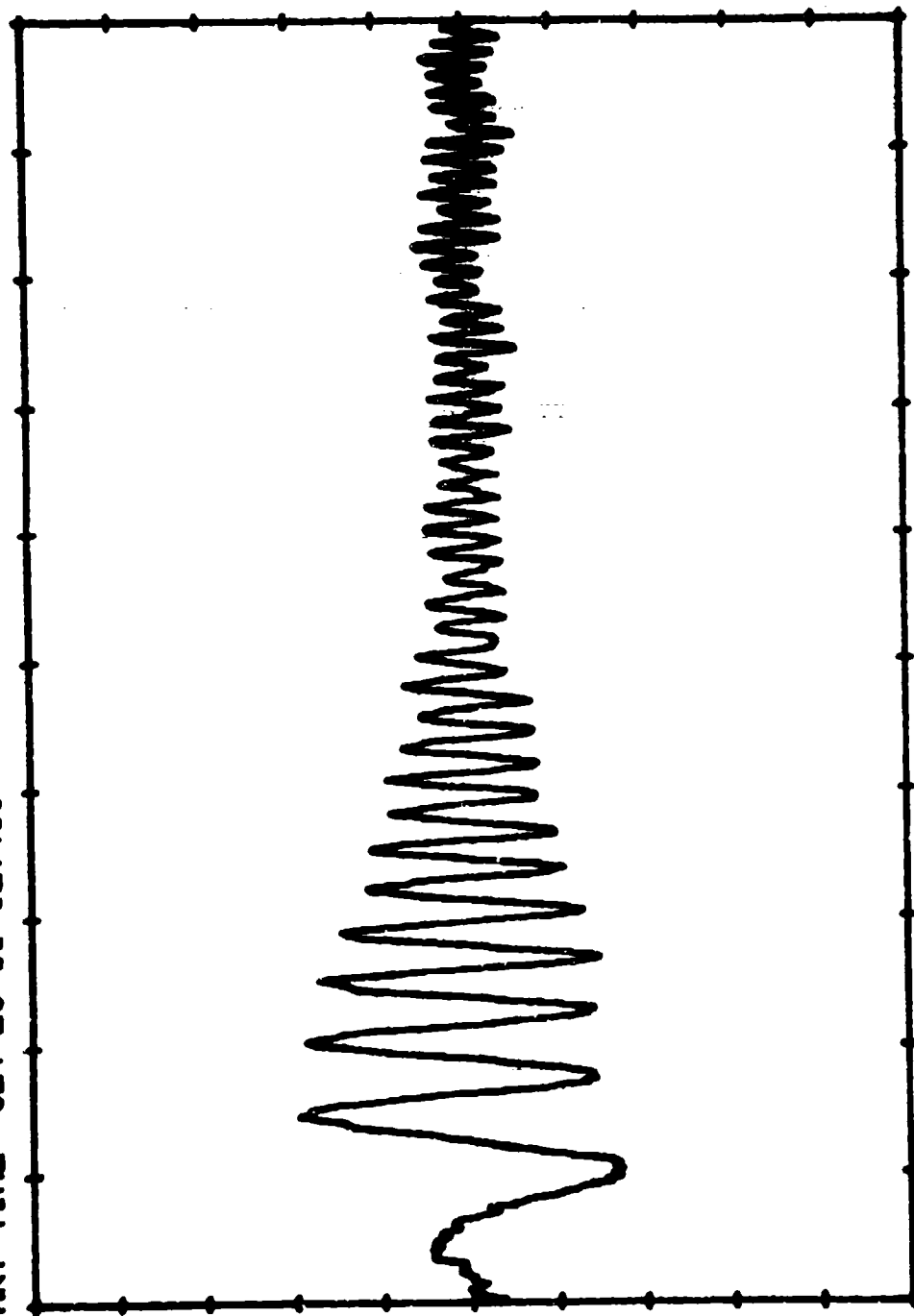
SAMPLES 1 THRU 2000

FILE NAME: ROUND.016 FILE DATA RECORD NUMBER: 1
FILE START TIME: 324.23.50.12.411



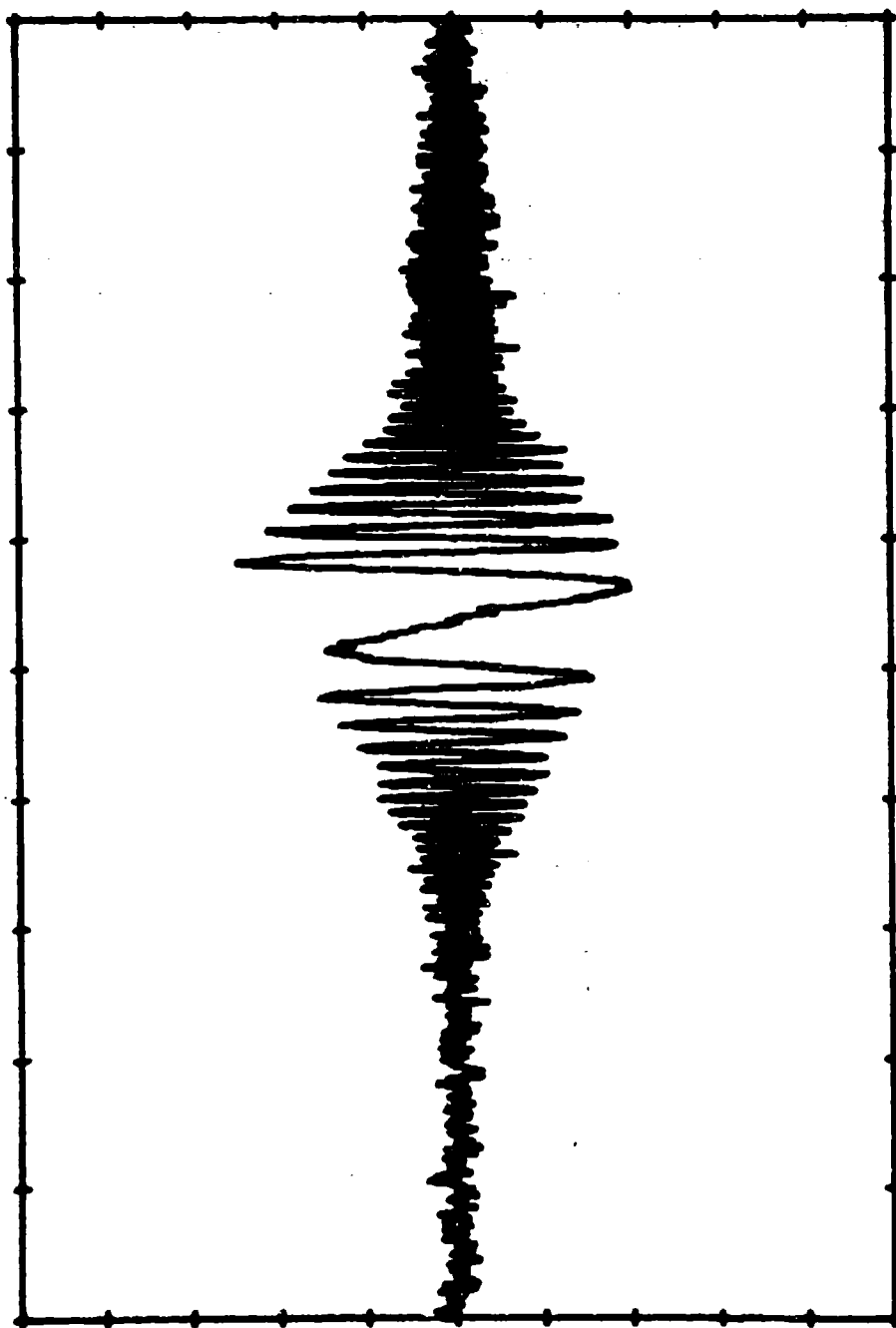
SAMPLES 3297 THRU 4896

FILE NAME: ROUND.016 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:50:12.411



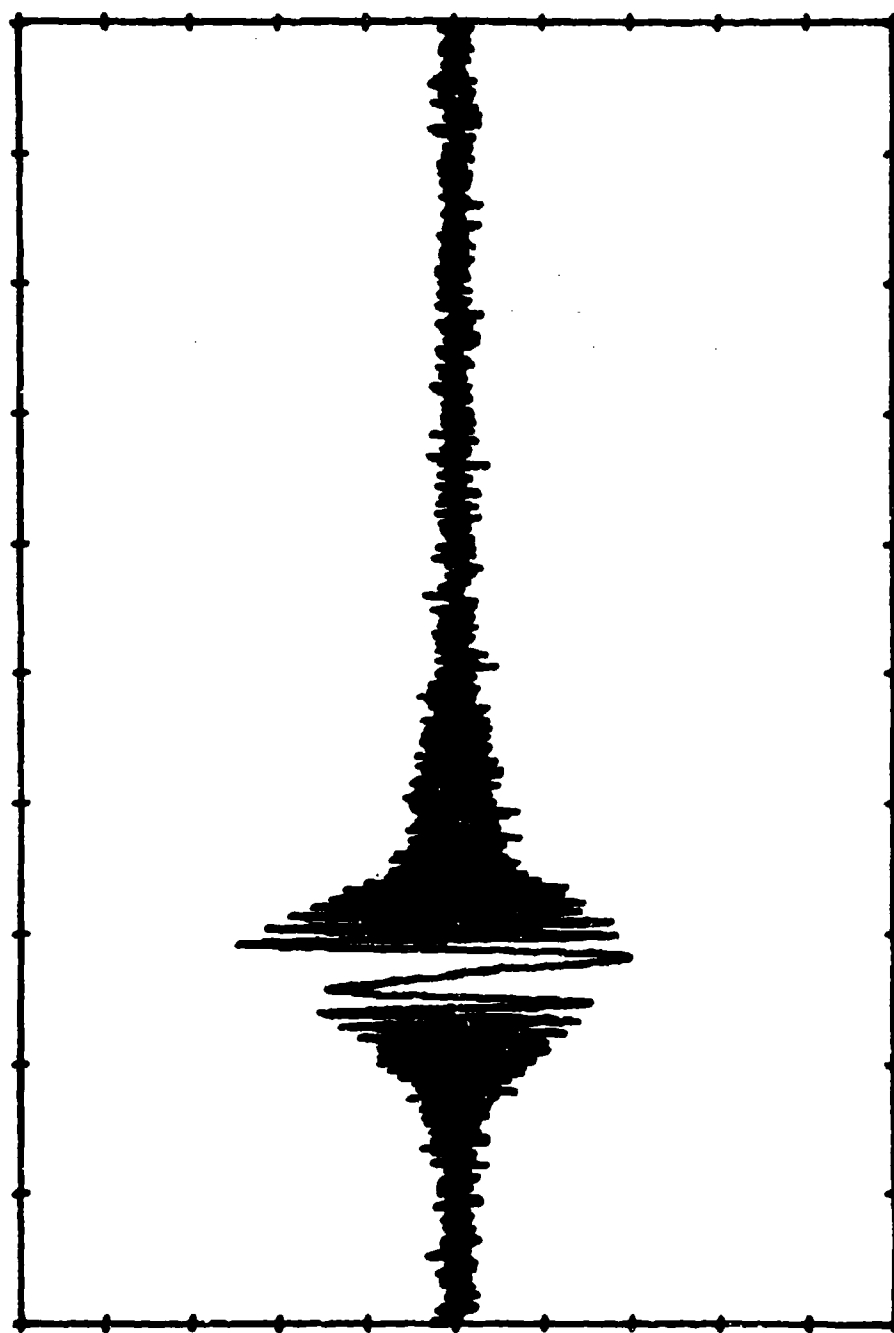
SAMPLES 1 THRU 500

FILE NAME: ROUND.017 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324.23.53.12.267



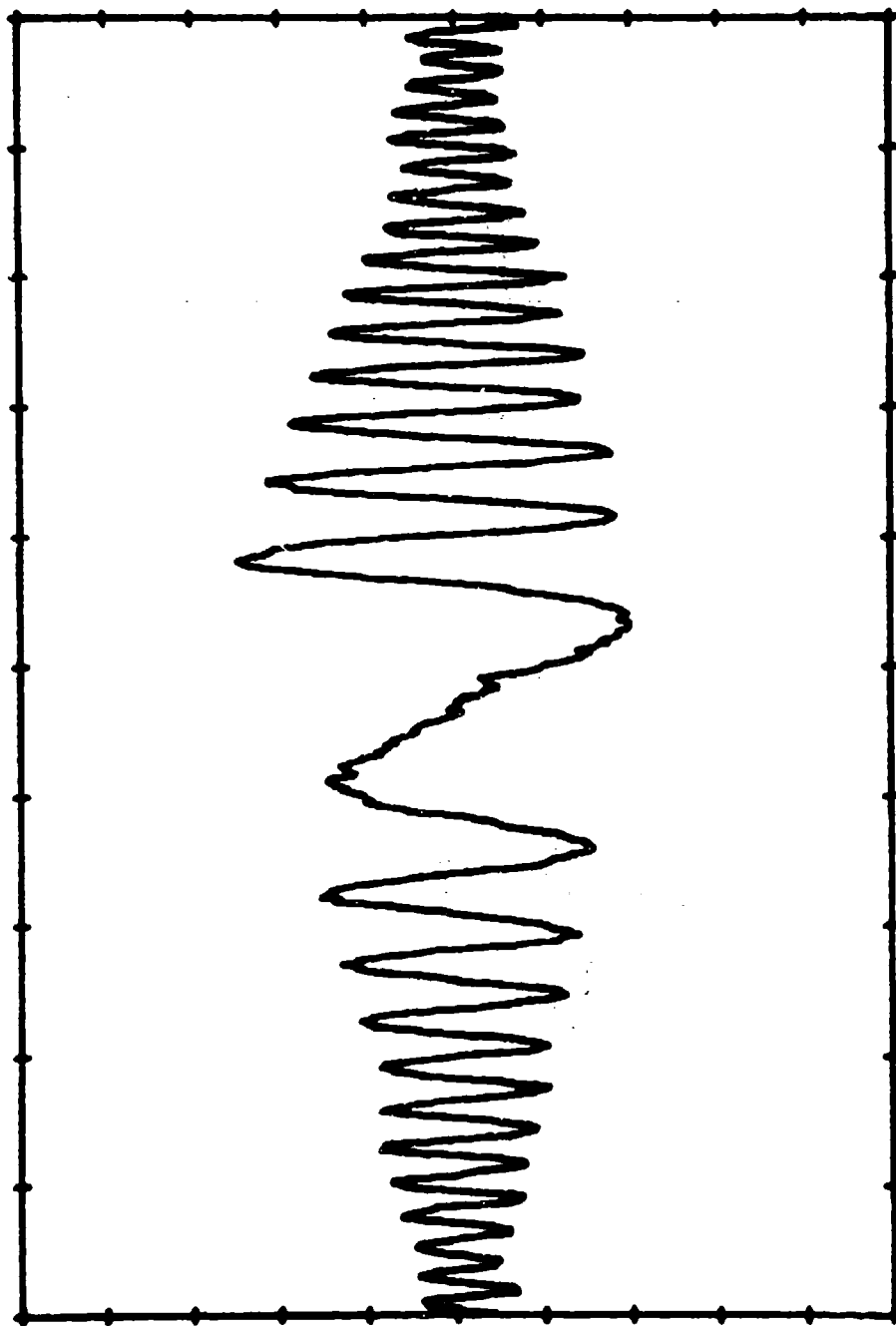
SAMPLES 1 THRU 2000

FILE NAME: ROUND.017 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:53.12.267



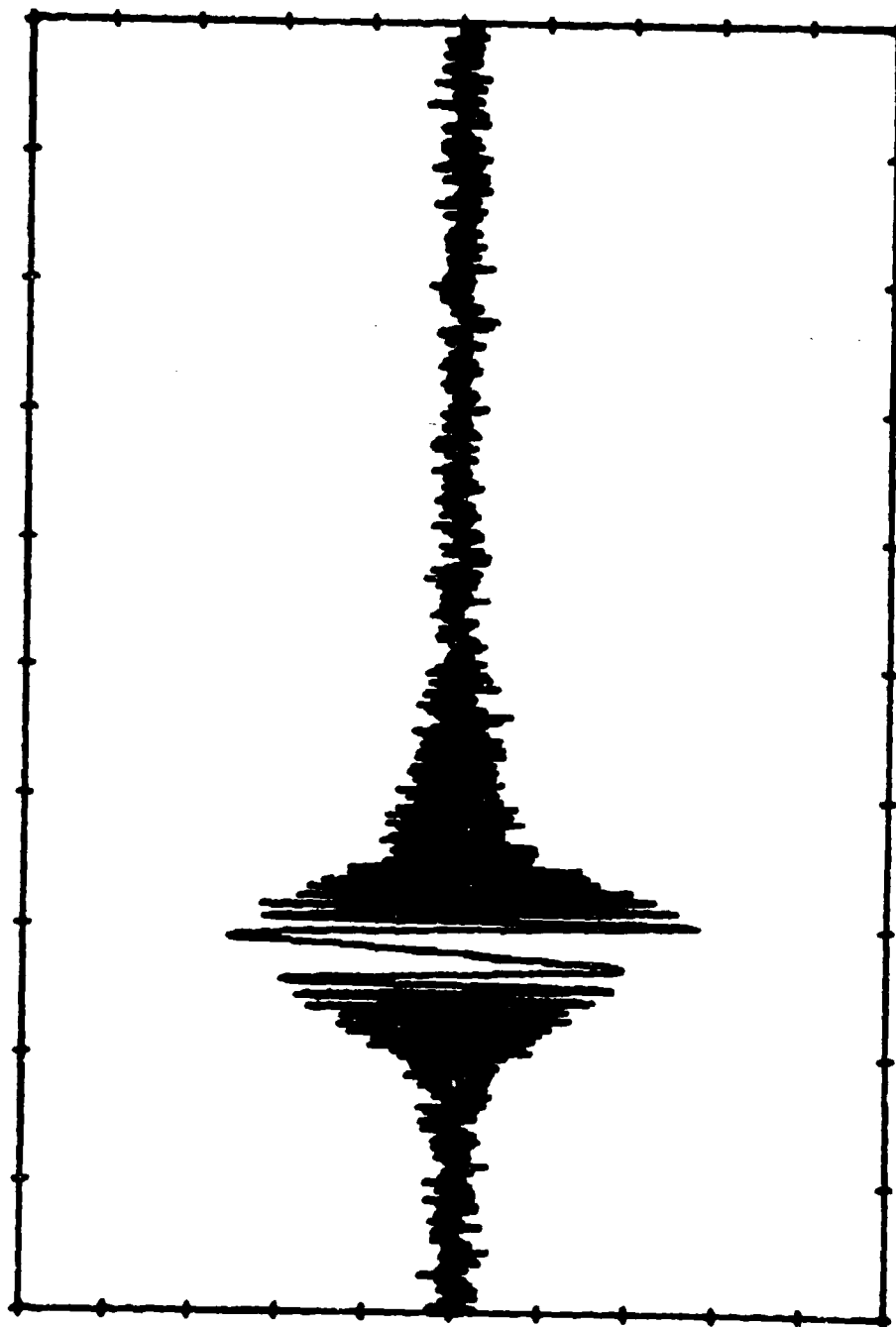
SAMPLES 1 THRU 4000

FILE NAME: ROUND.017 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324.23.53.12.267



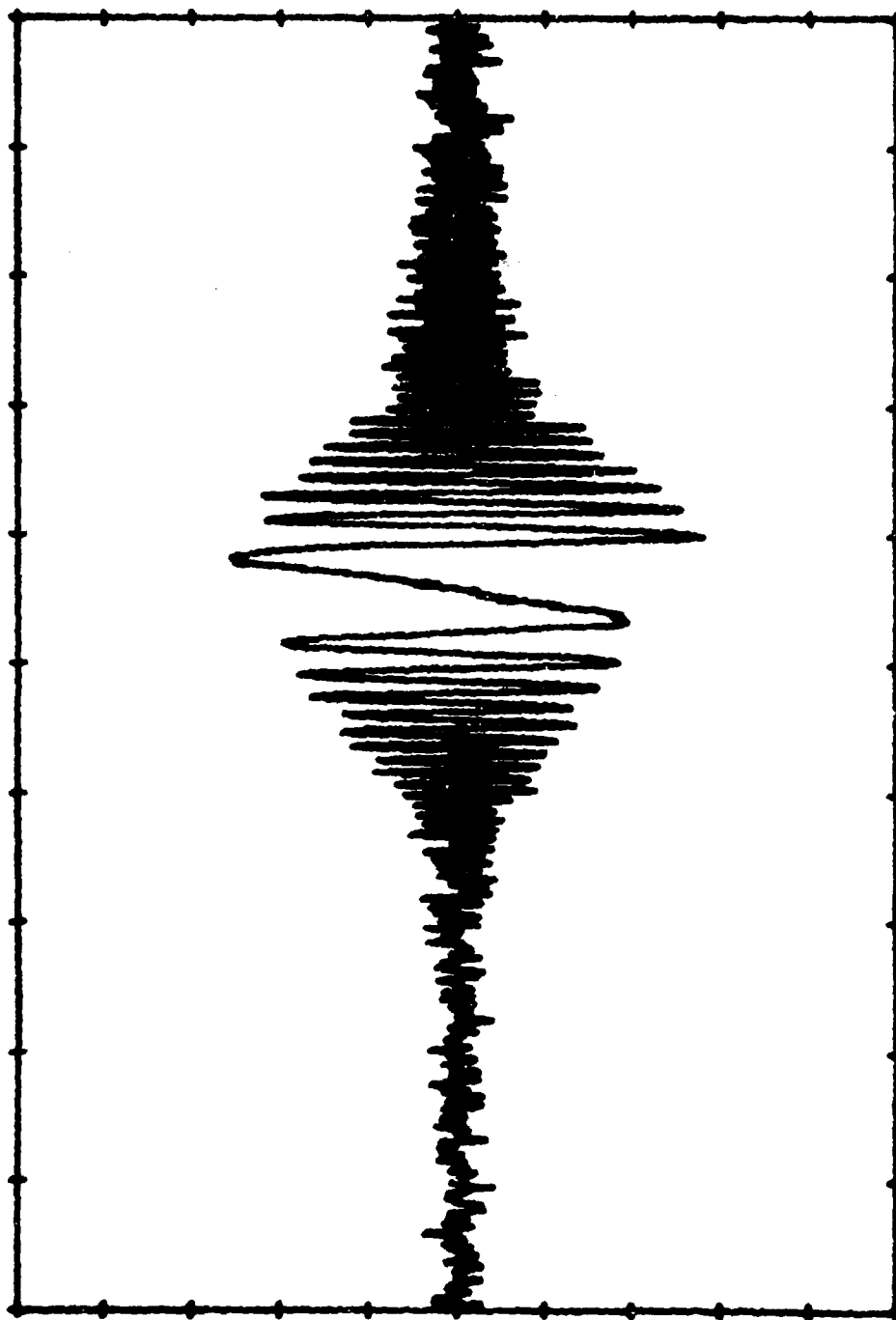
DEPRESS RETURN TO CONTINUE
ENTER -1 TO REPLOT POINTS
ENTER !00 TO WRITE THIS R
SAMPLES 700 THRU 1500

FILE NAME: ROUND.018 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:56:49.948



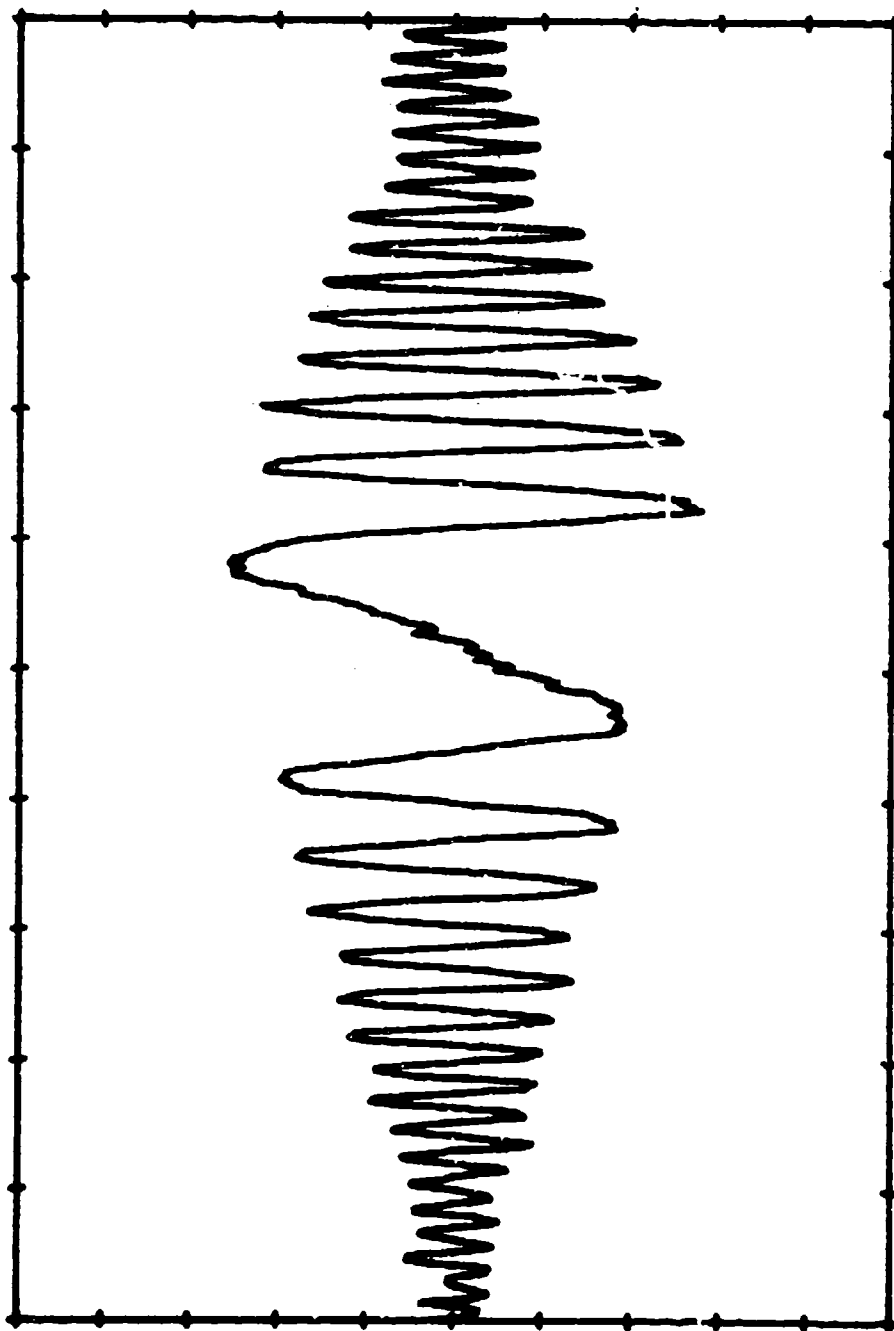
SAMPLES 1 THRU 4000

FILE NAME: ROUND.010 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:56:49.948



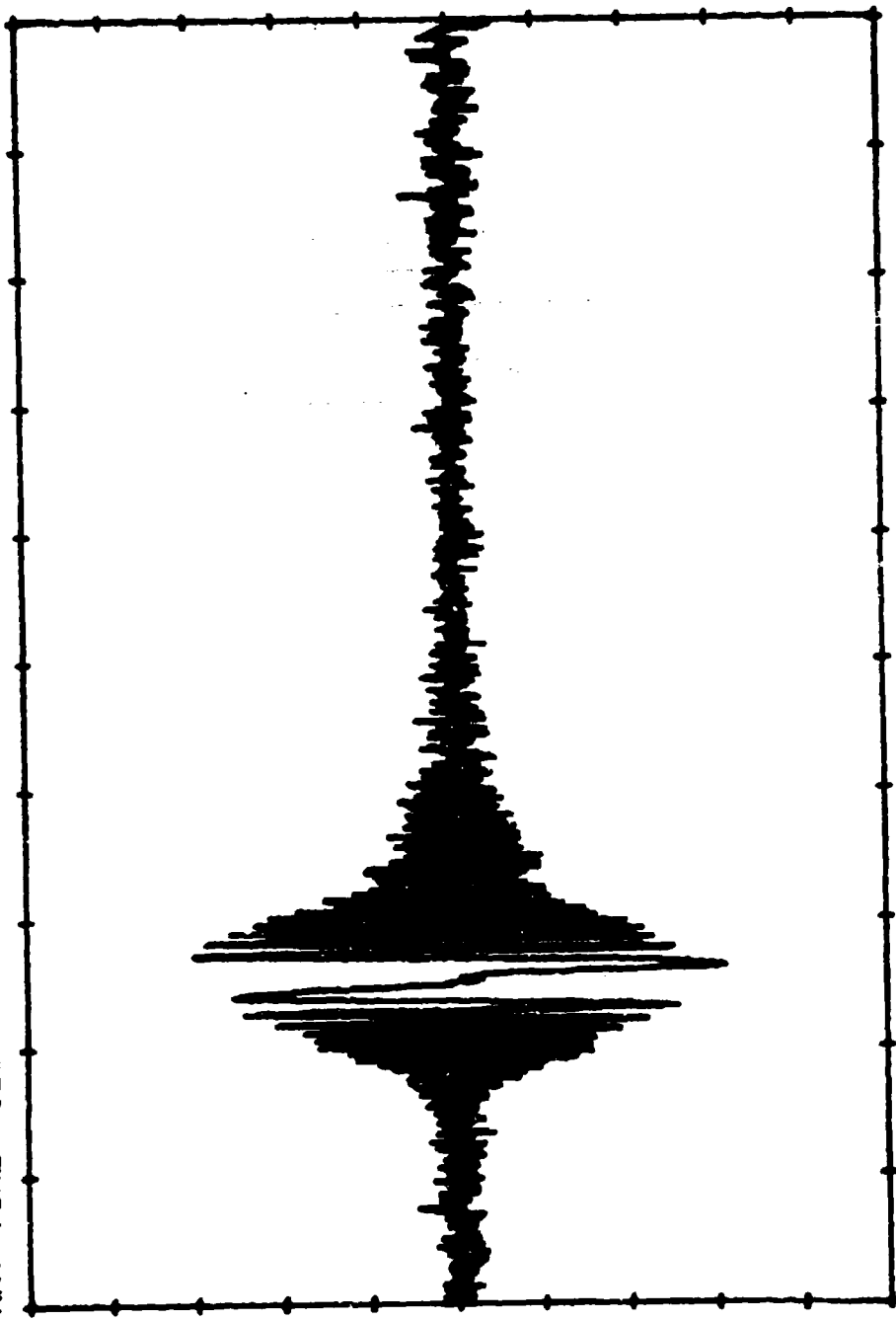
SAMPLES 1 THRU 2000

FILE NAME: ROUND.018 FILE DATA RECORD NUMBER: 2
FILE START TIME: 324:23:56.49.948



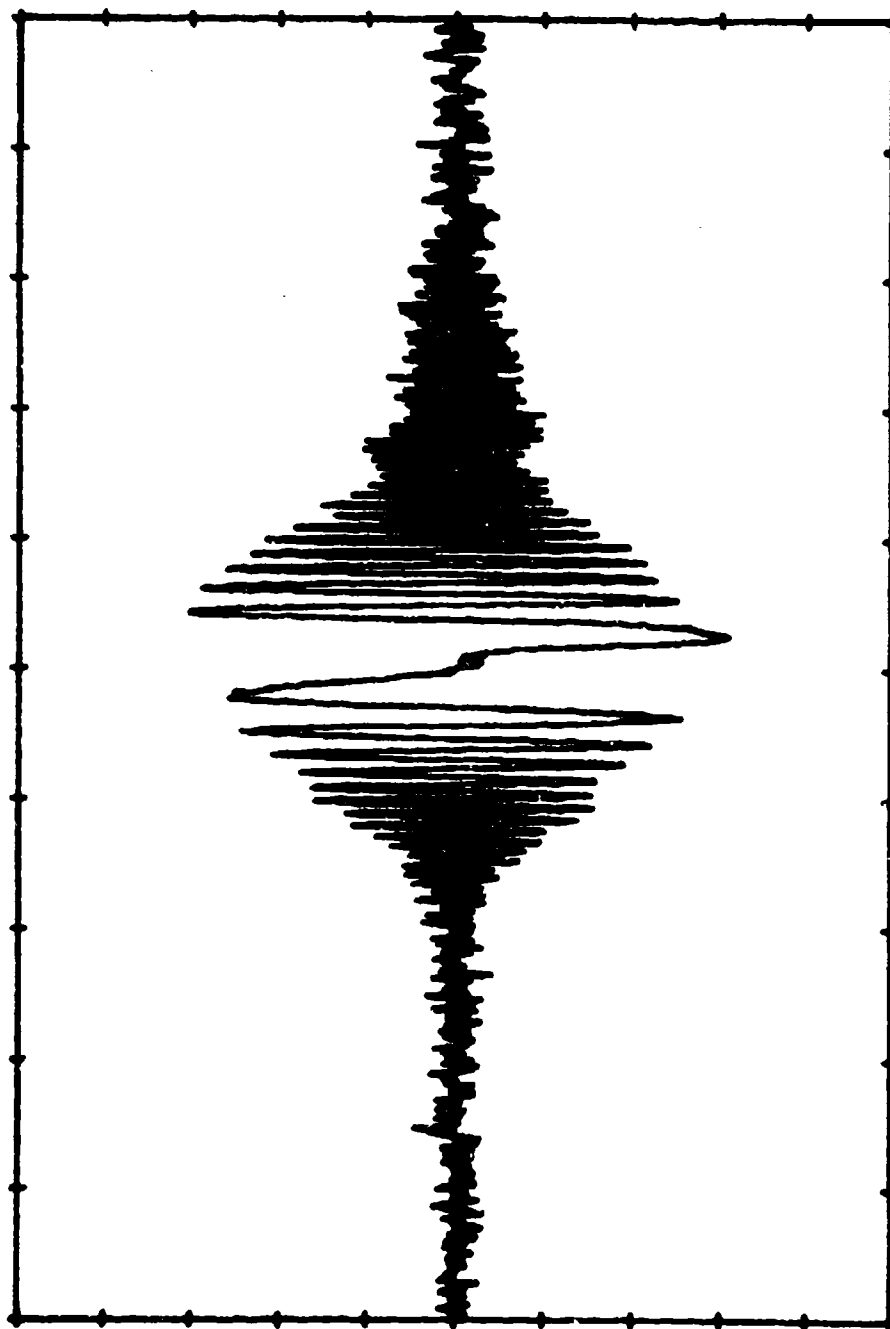
SAMPLES 700 THRU 1500

FILE NAME: ROUND.019 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325.0: 0: 2.280



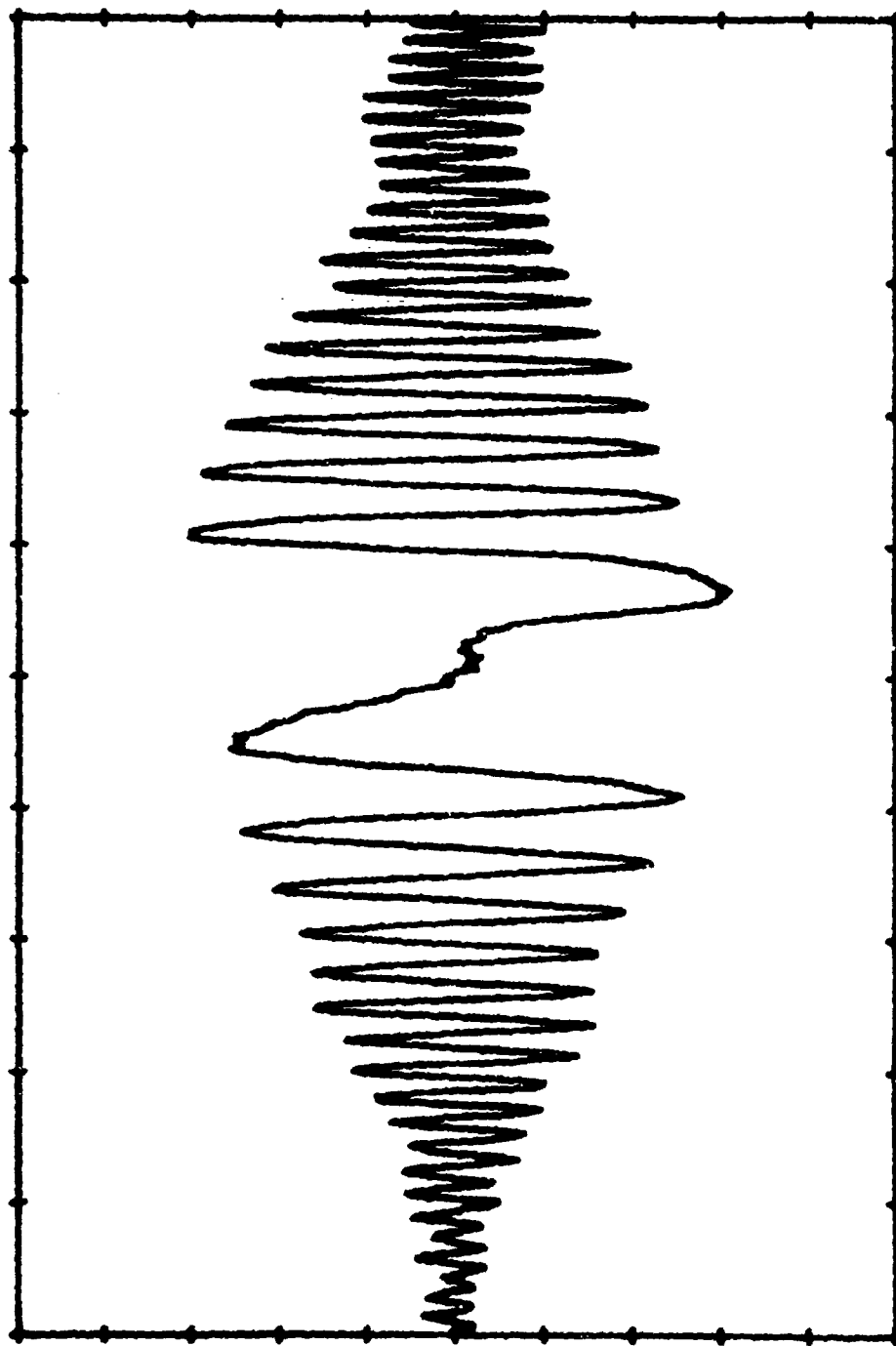
SAMPLES 1 THRU 4000

FILE NAME: ROUND.019 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325.0: 0: 2.280



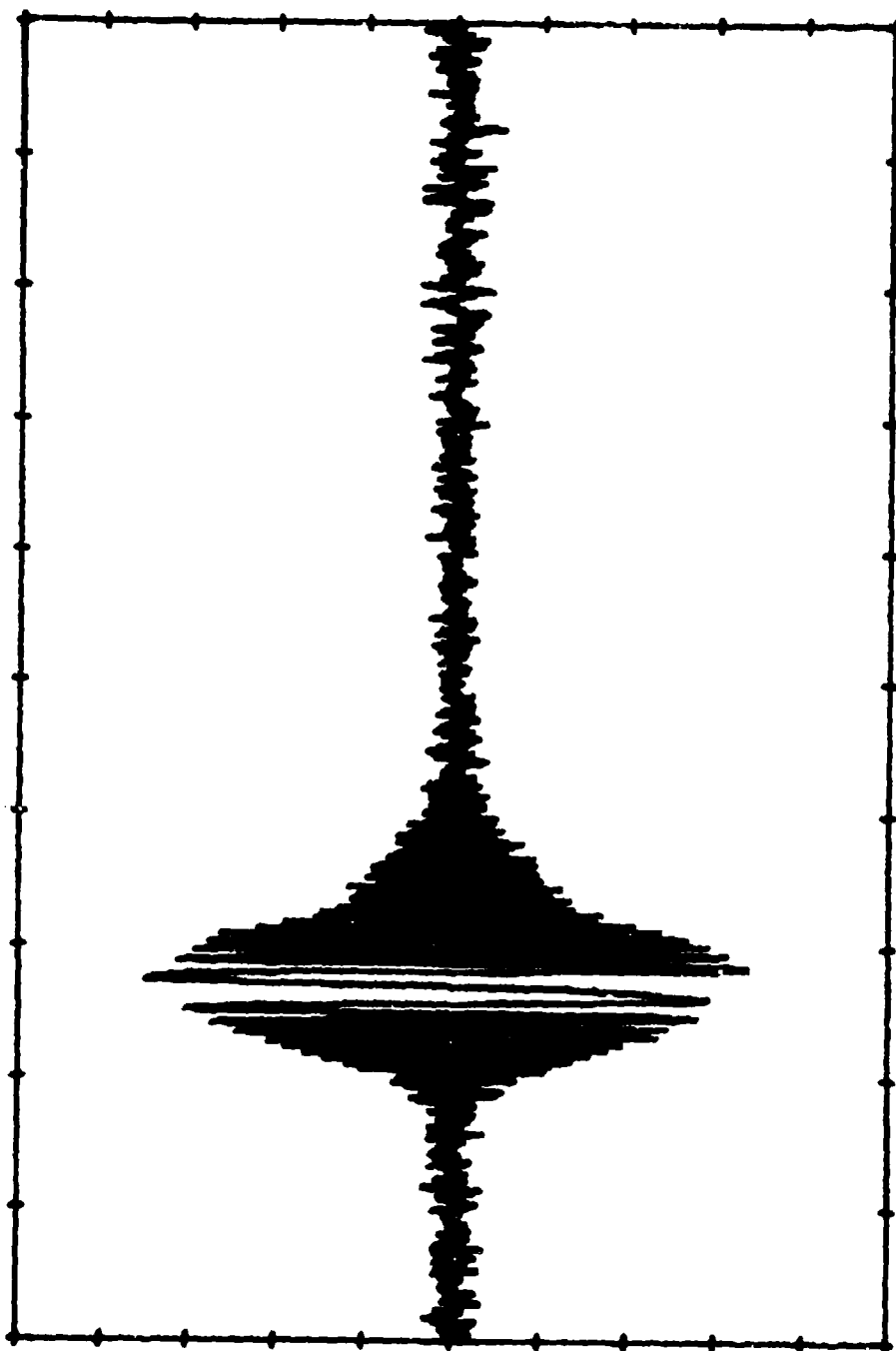
SAMPLES 1 THRU 2000

FILE NAME: ROUND.019 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325.0: 0: 2.280



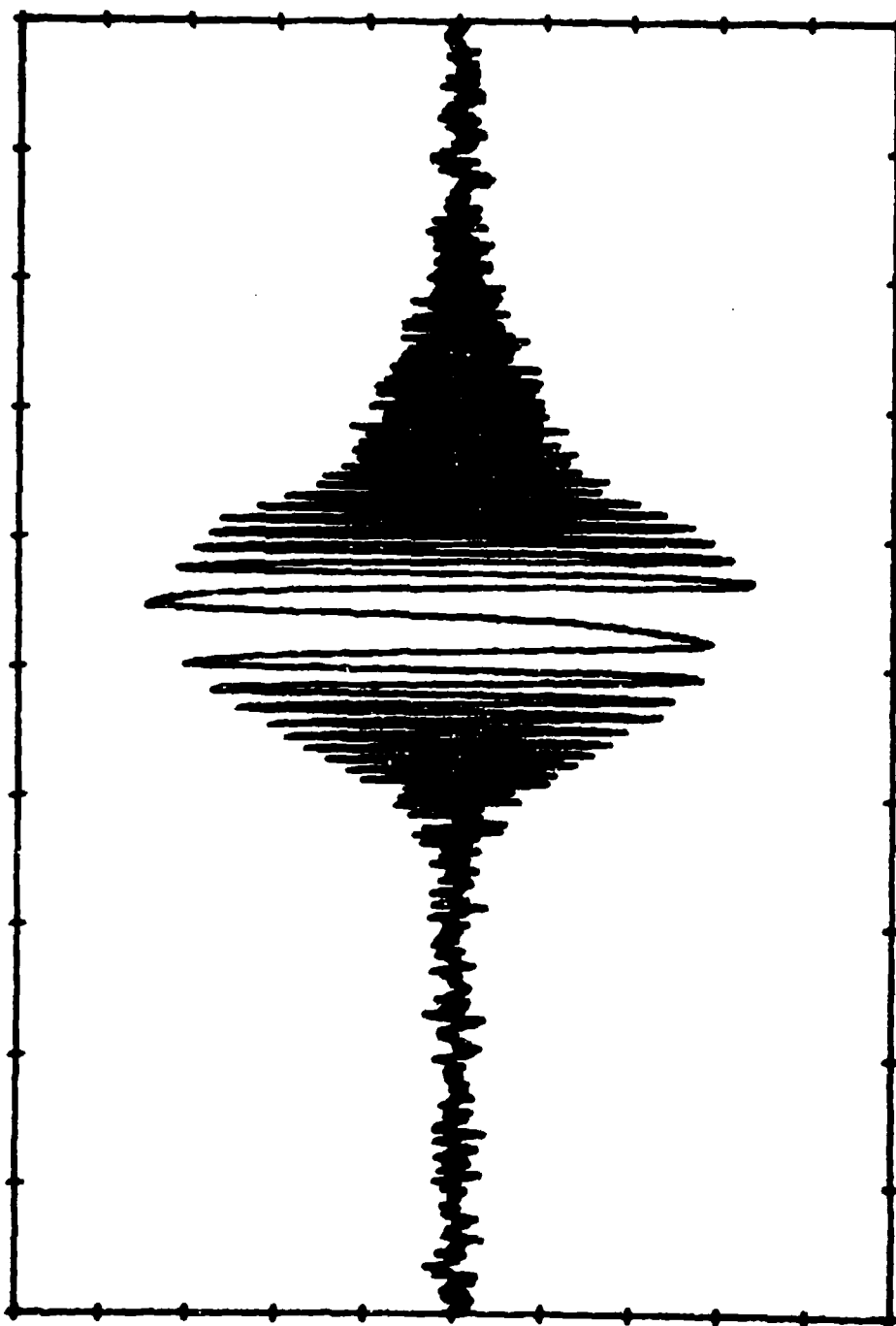
SAMPLES 600 THRU 1400

FILE NAME: ROUND.020 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0: 3:24.145



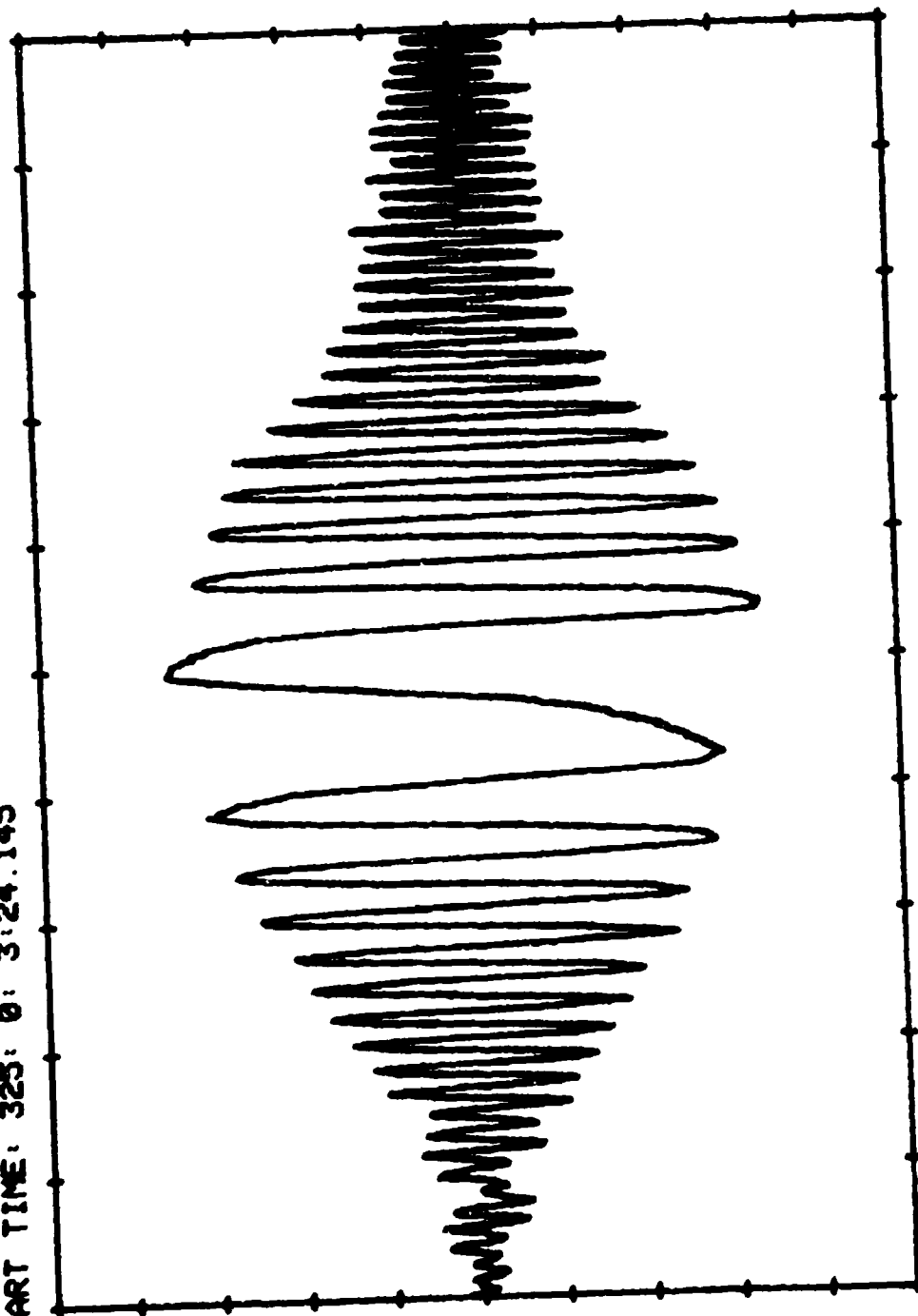
SAMPLES 1 THRU 4000

FILE NAME: ROUND.020 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0: 3:24.145



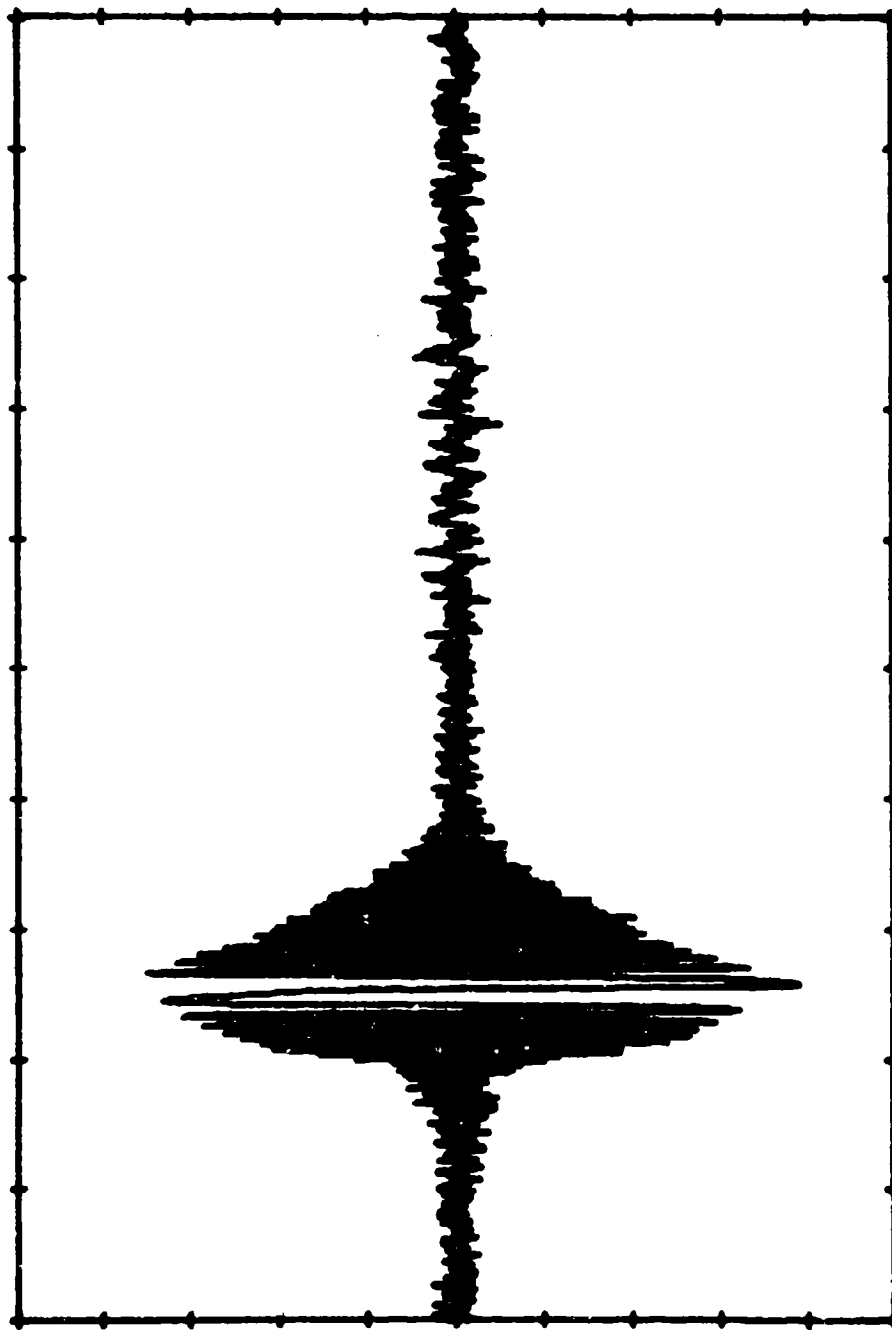
SAMPLES 1 THRU 2000

FILE NAME: ROUND.020 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0: 3:24.145



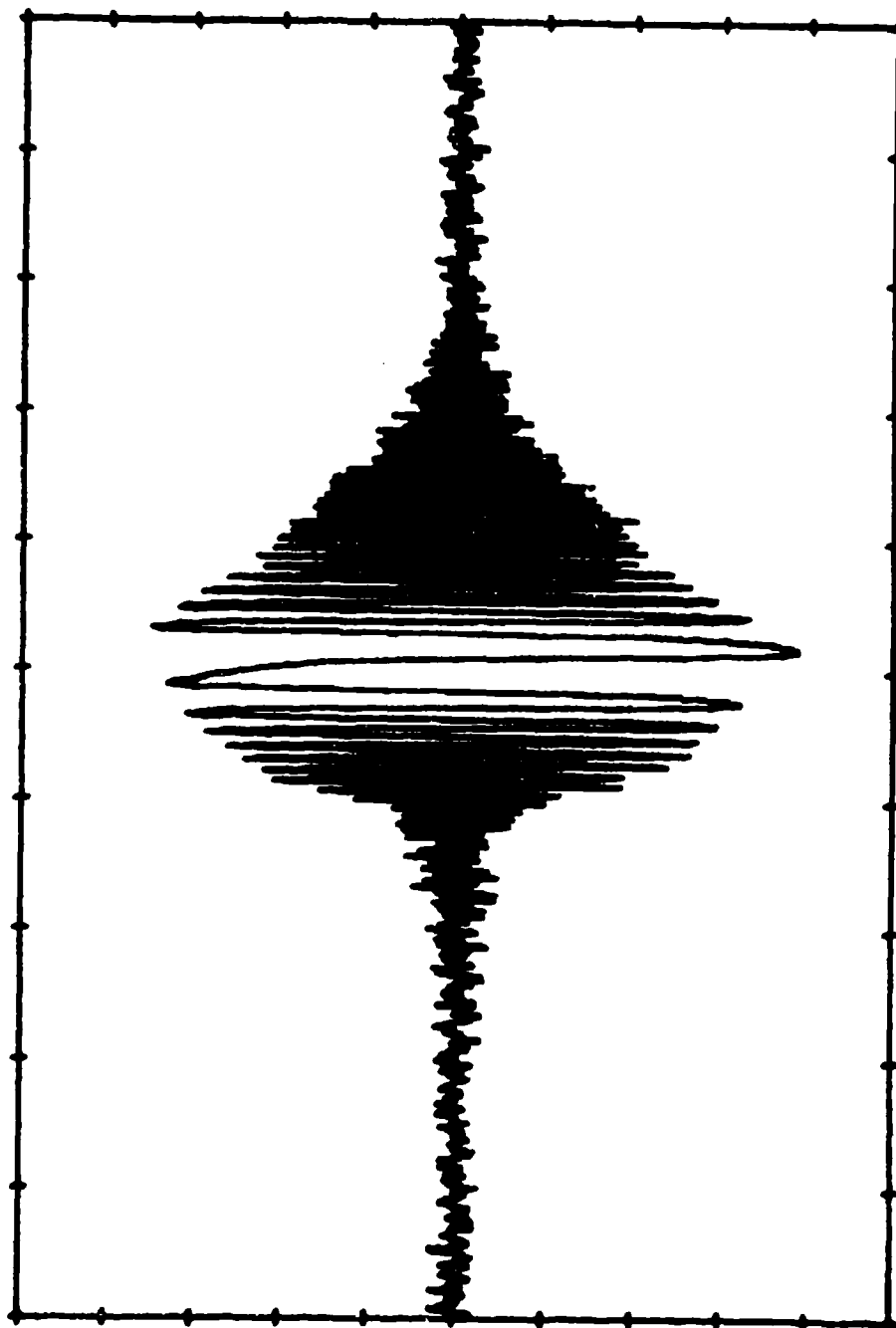
SAMPLES 700 THRU 1500

FILE NAME: ROUND.021 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0: 6:49.645



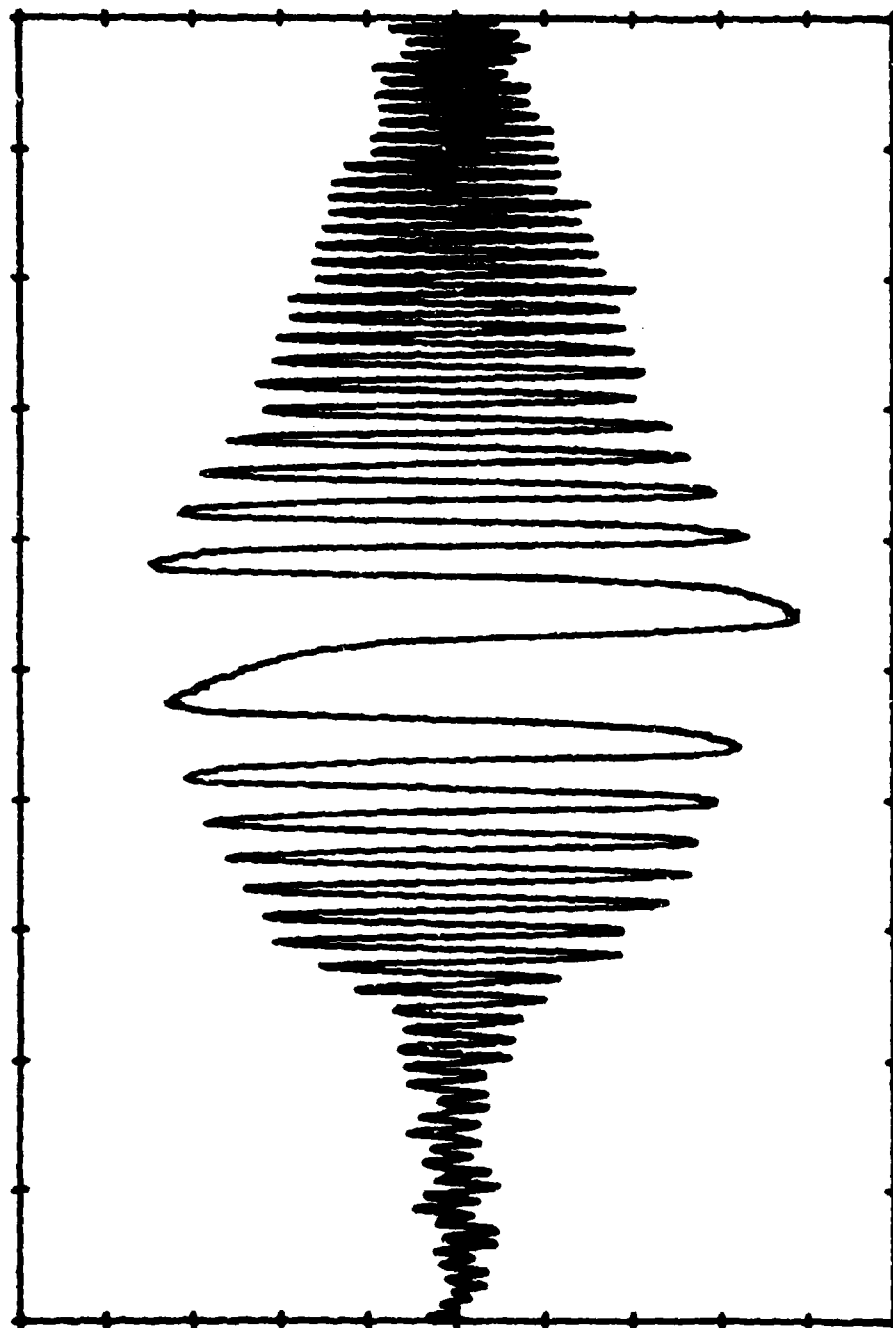
SAMPLES 1 THRU 4000

FILE NAME: ROUND.021 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0: 6:49.645



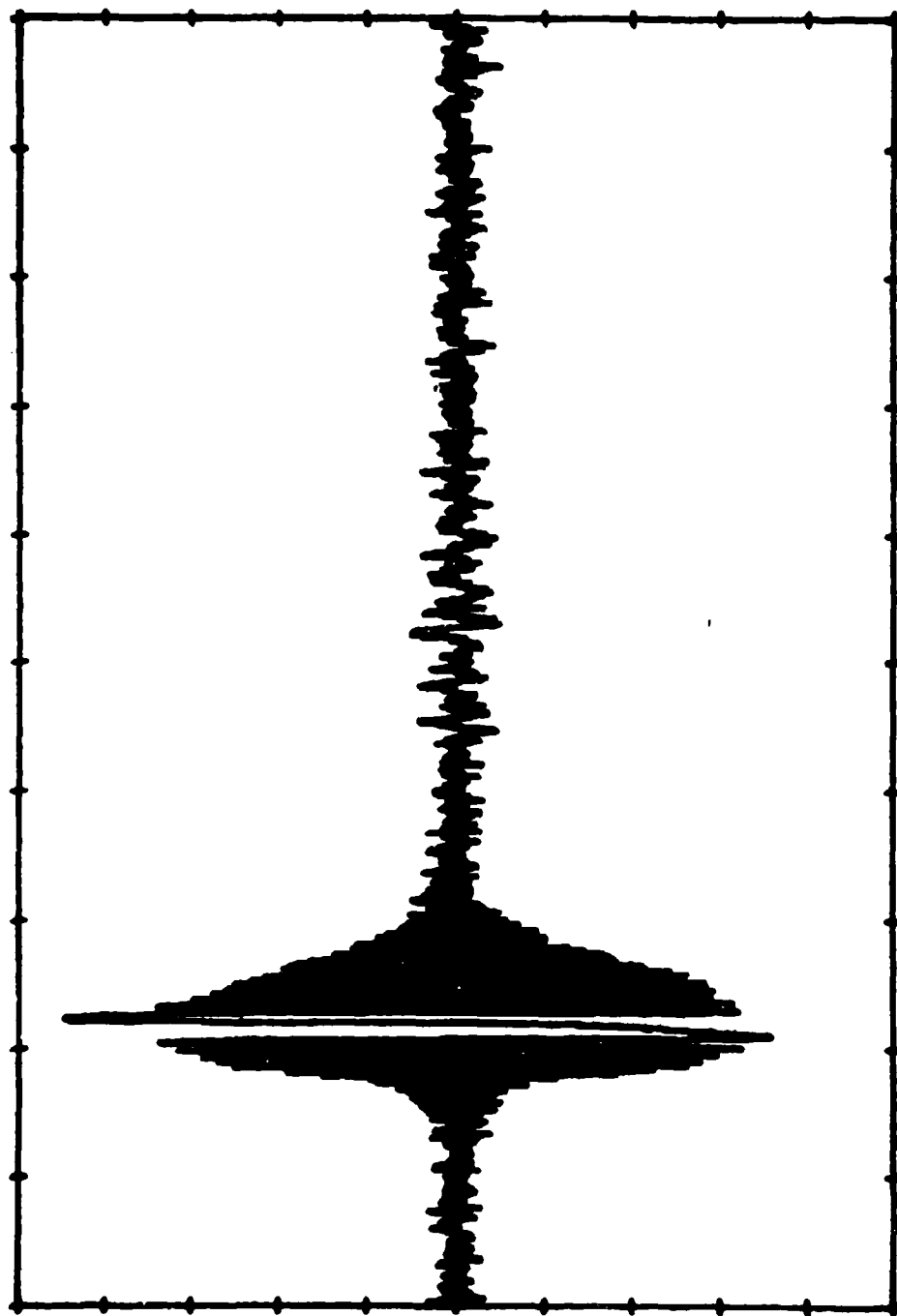
SAMPLES 1 THRU 2000

FILE NAME: ROUND.021 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0: 6:49.645



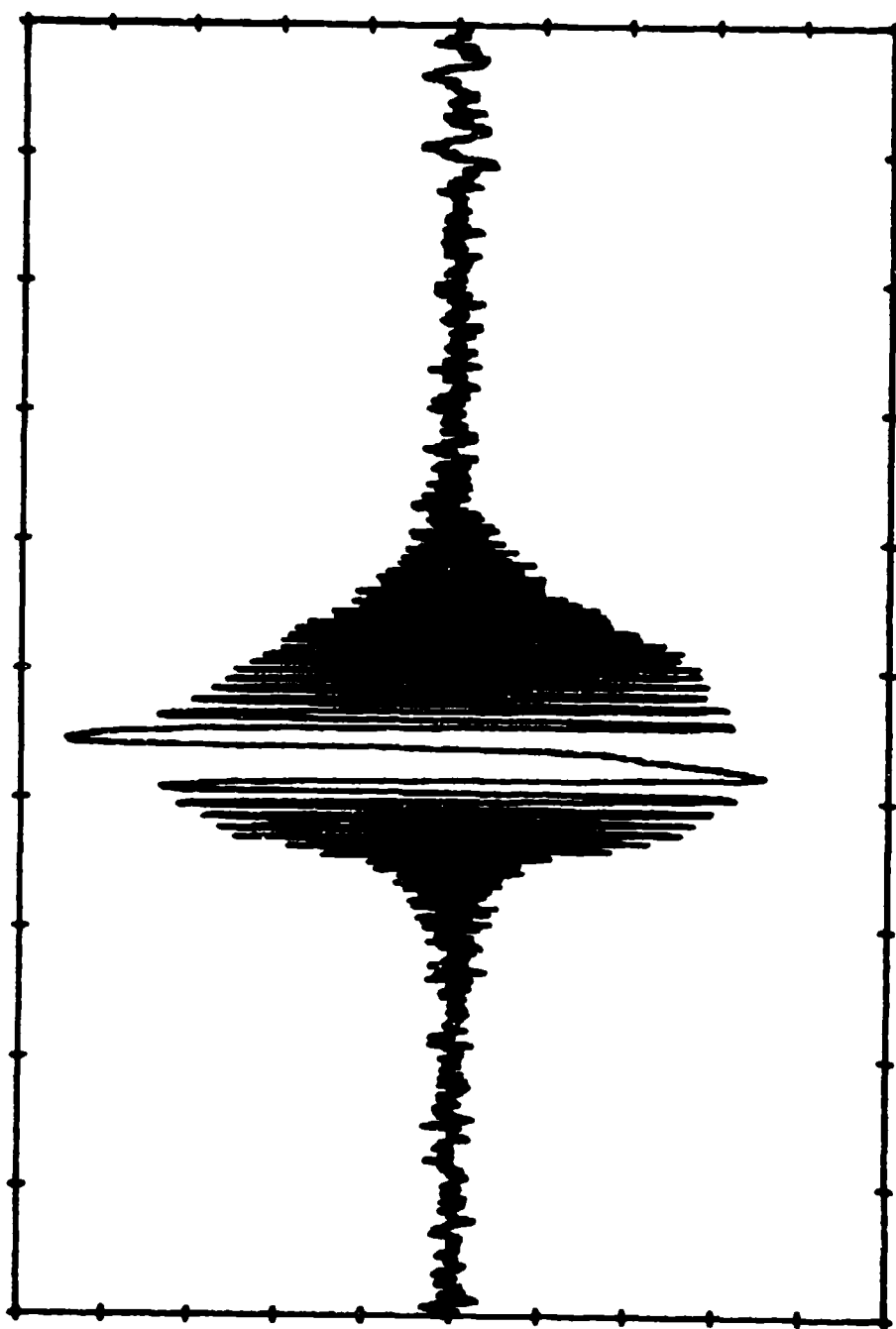
SAMPLES 600 THRU 1400

FILE NAME: ROUND.022 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0:17:33.664



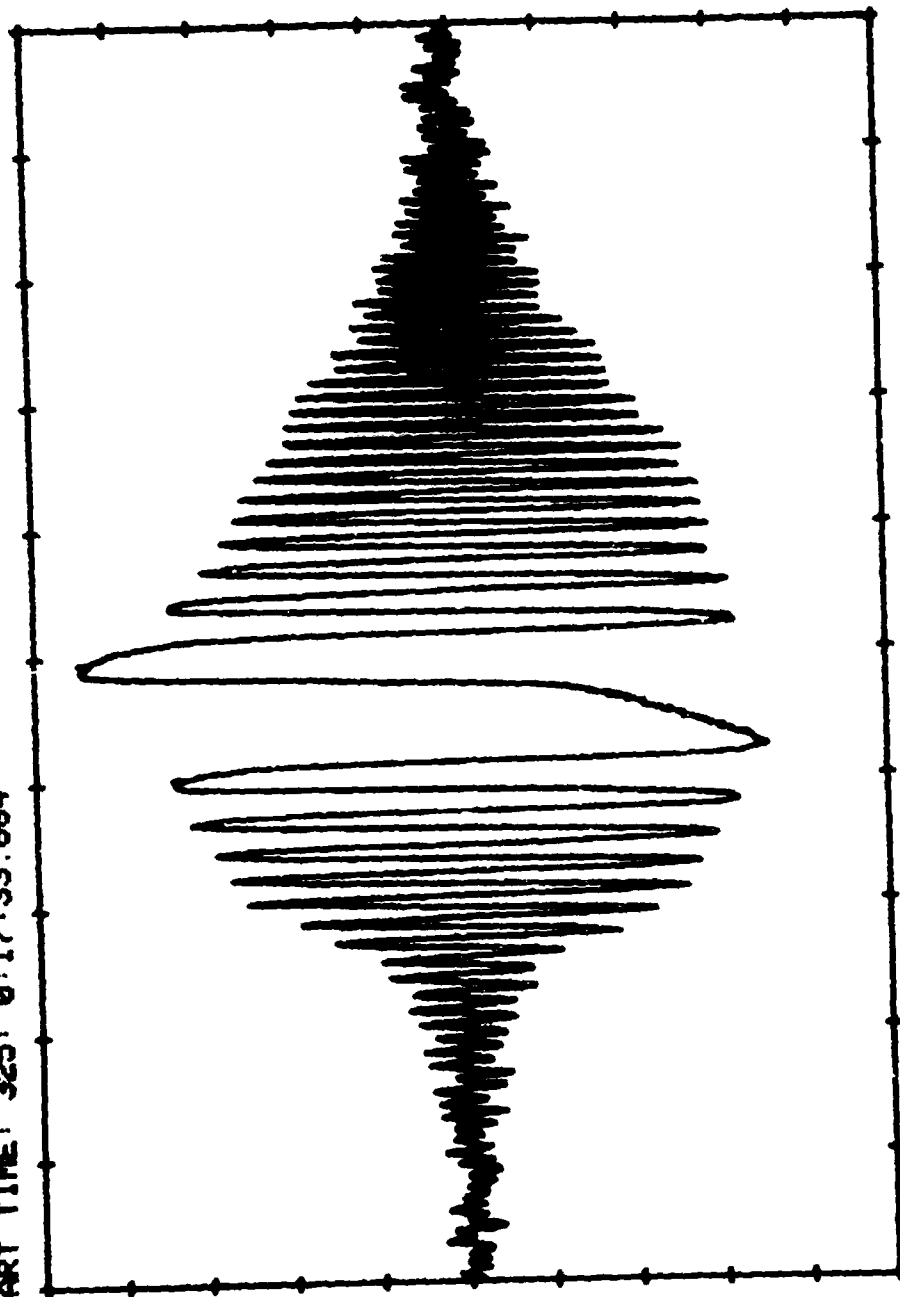
SAMPLES 1 THRU 4000

FILE NAME: ROUND 022 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0:17:33.664



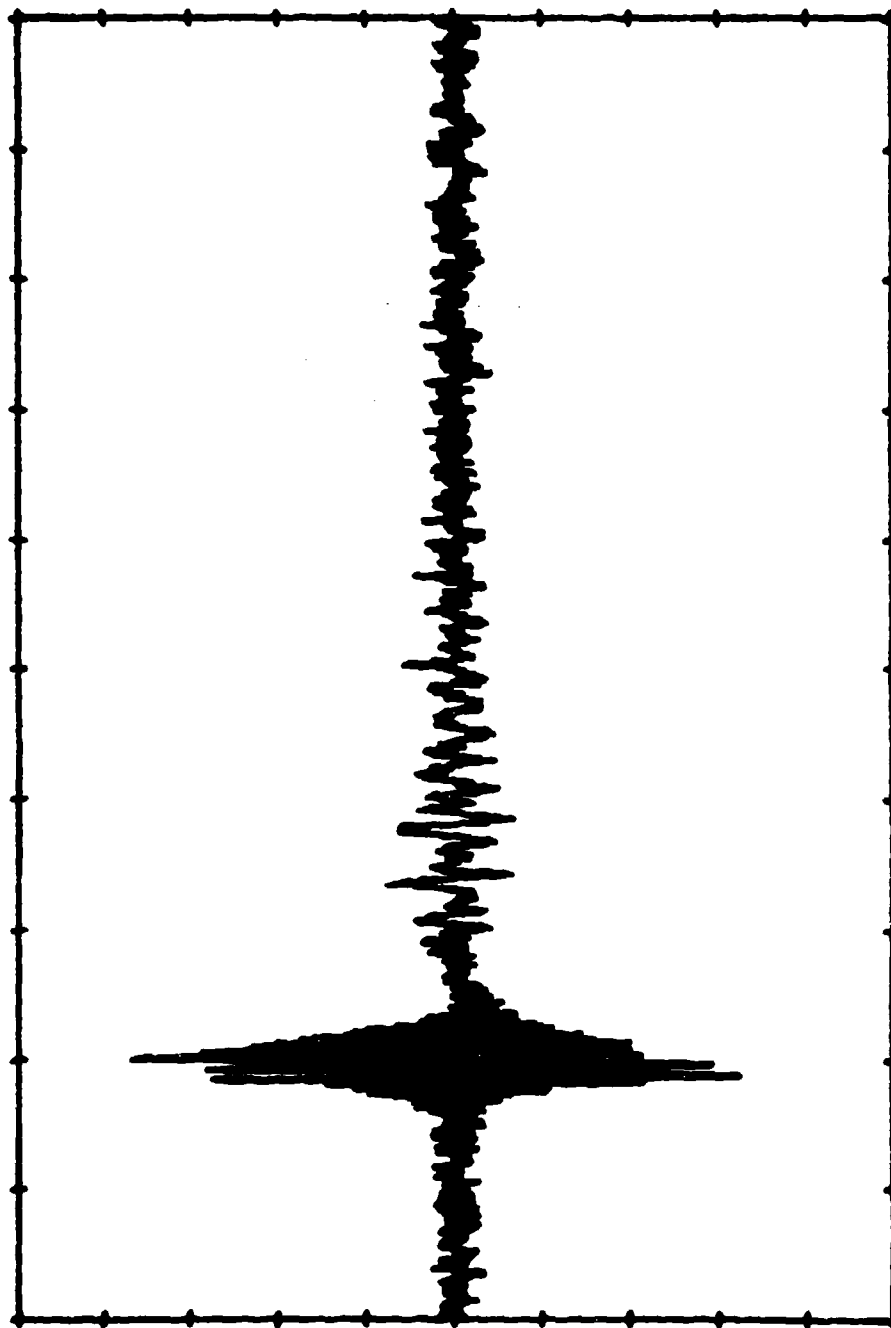
SAMPLES 1 THRU 2000

FILE NAME: ROUND.022 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0:17:33.664



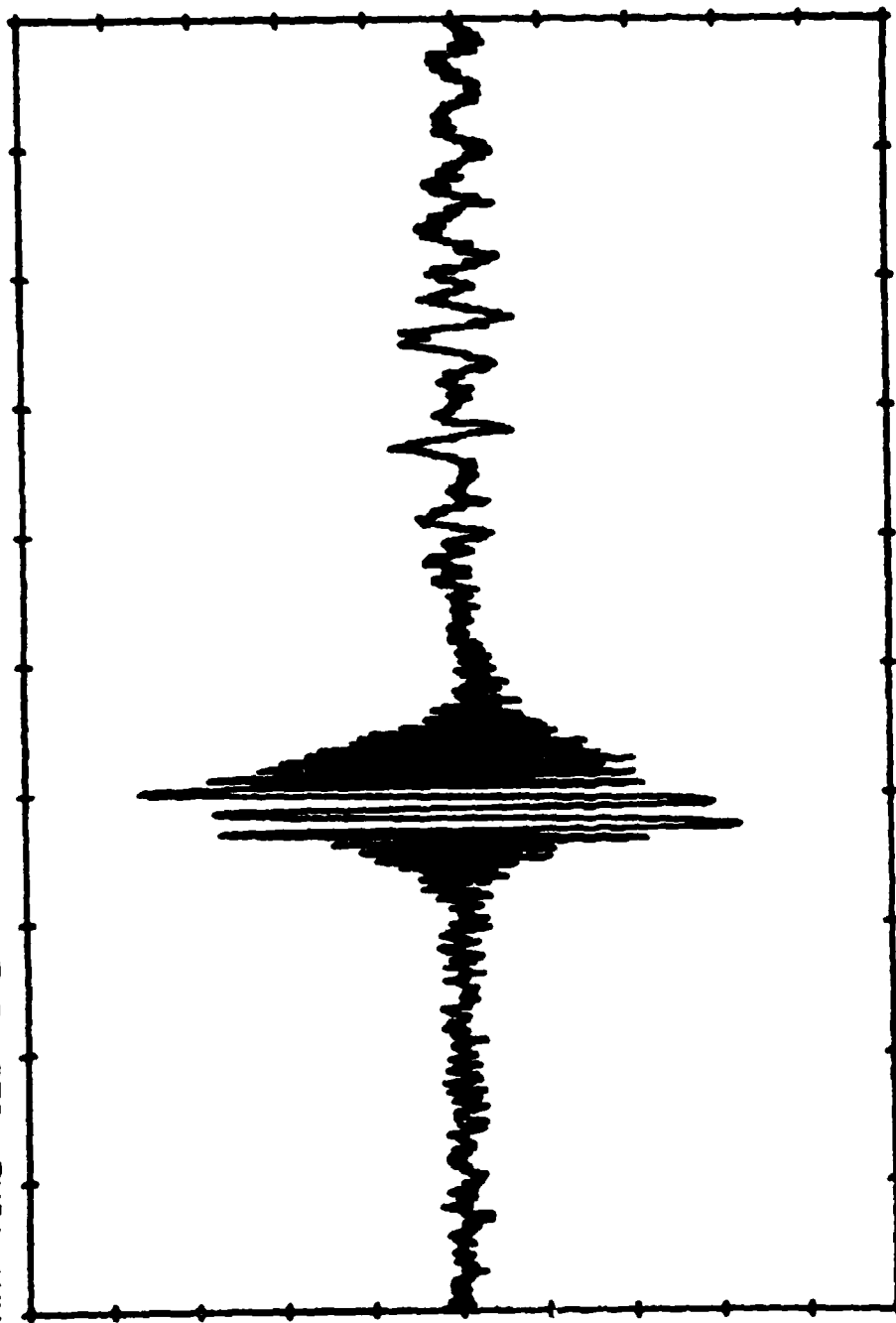
SAMPLES 500 THRU 1300

FILE NAME: ROUND.023 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0:20:35.199



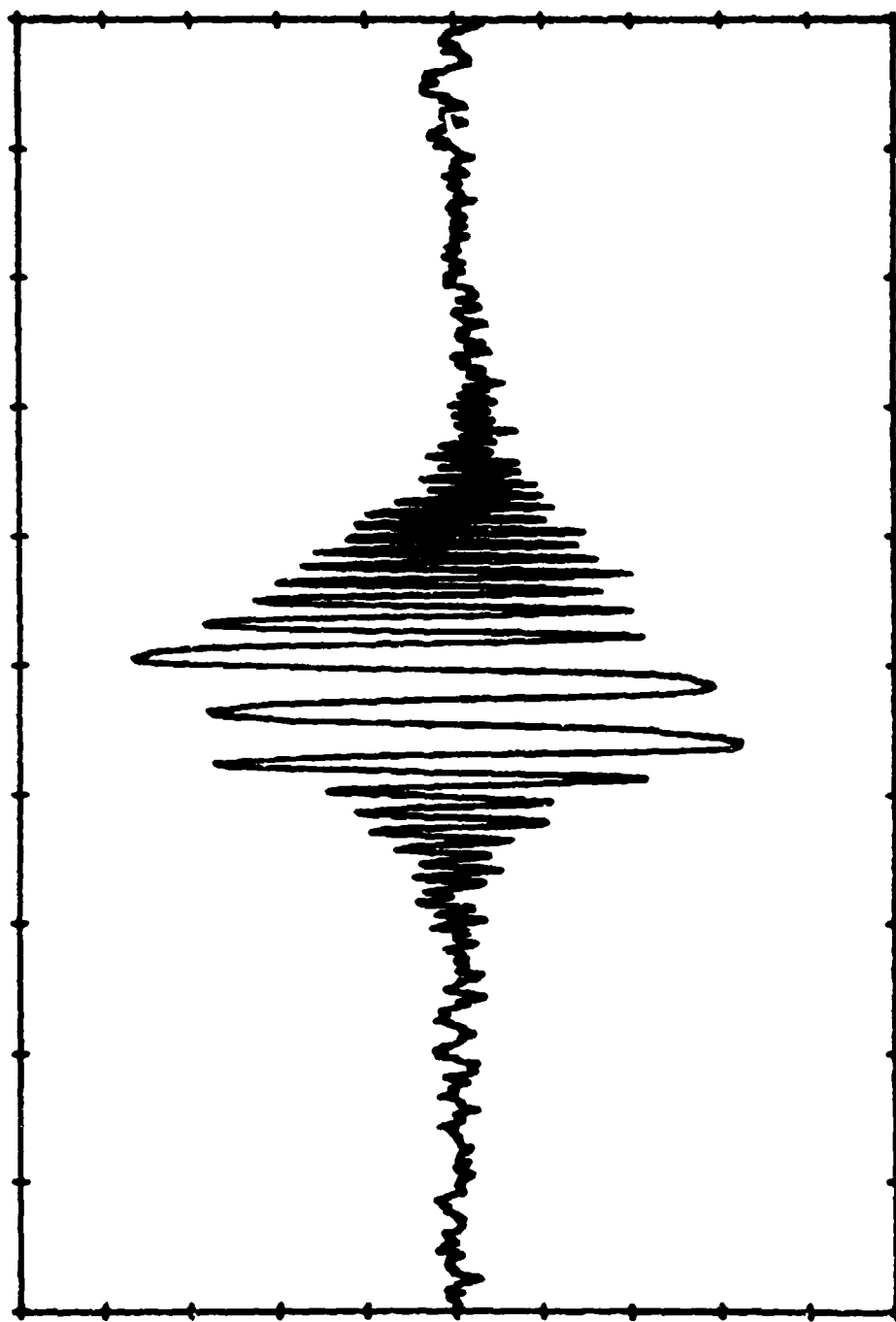
SAMPLES 1 THRU 4000

FILE NAME: ROUND.023 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0:20:35.199



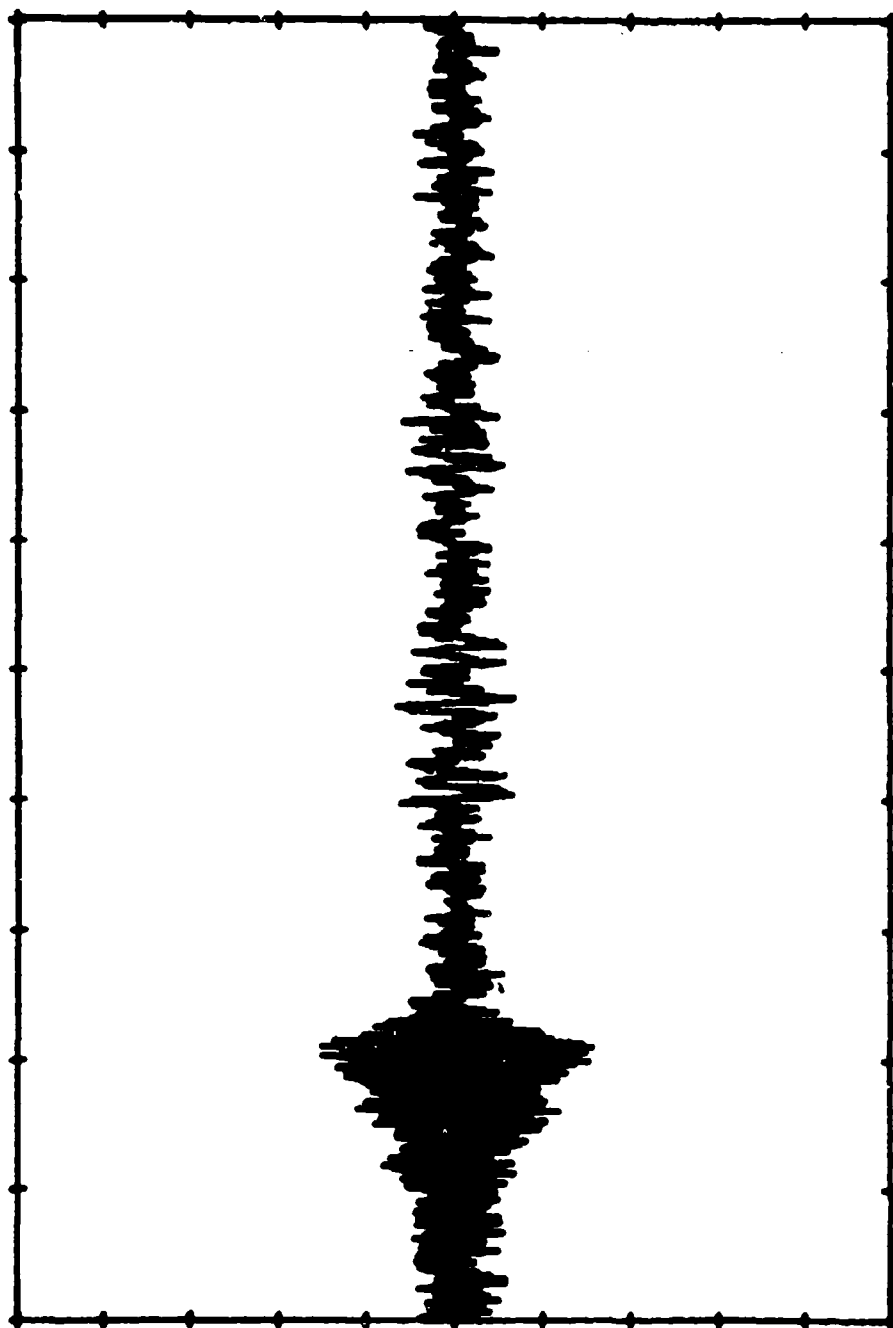
SAMPLES 1 THRU 2000

FILE NAME: ROUND.023 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 0:20:35.199



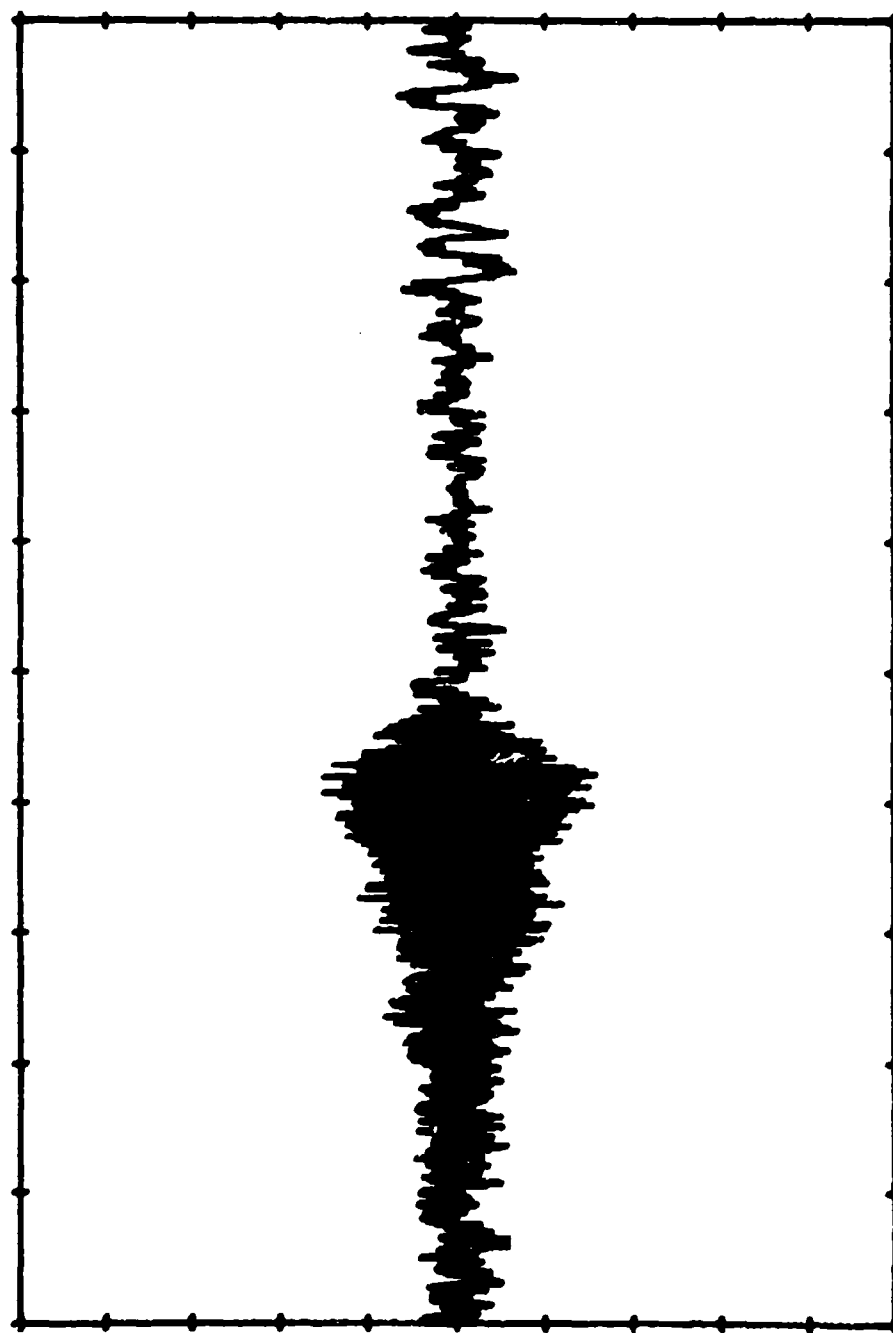
SAMPLES 400 THRU 1200

FILE NAME: ROUND.024 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:18:54.783



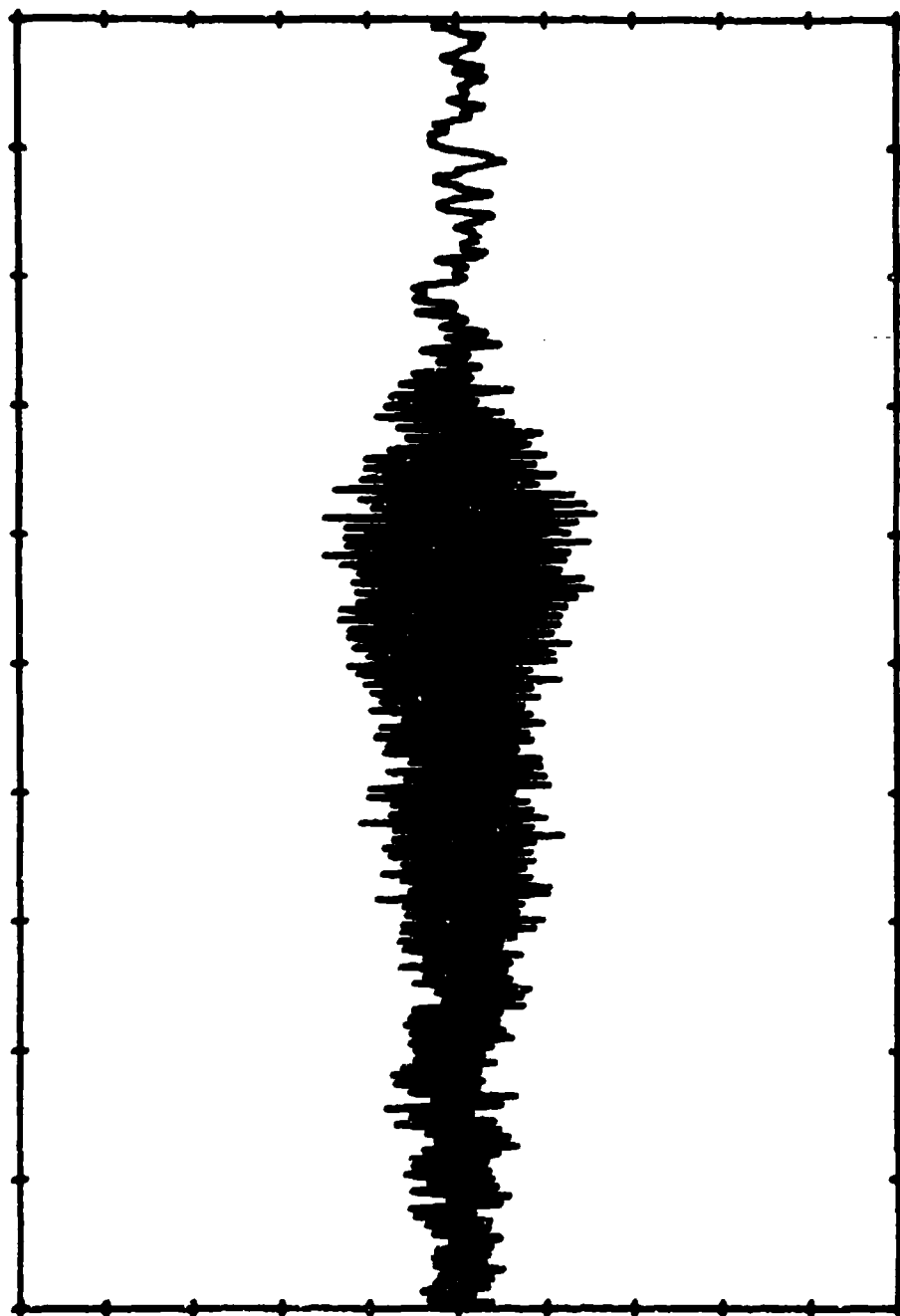
SAMPLES 1 THRU 4000

FILE NAME: ROUND.024 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:18:54.783



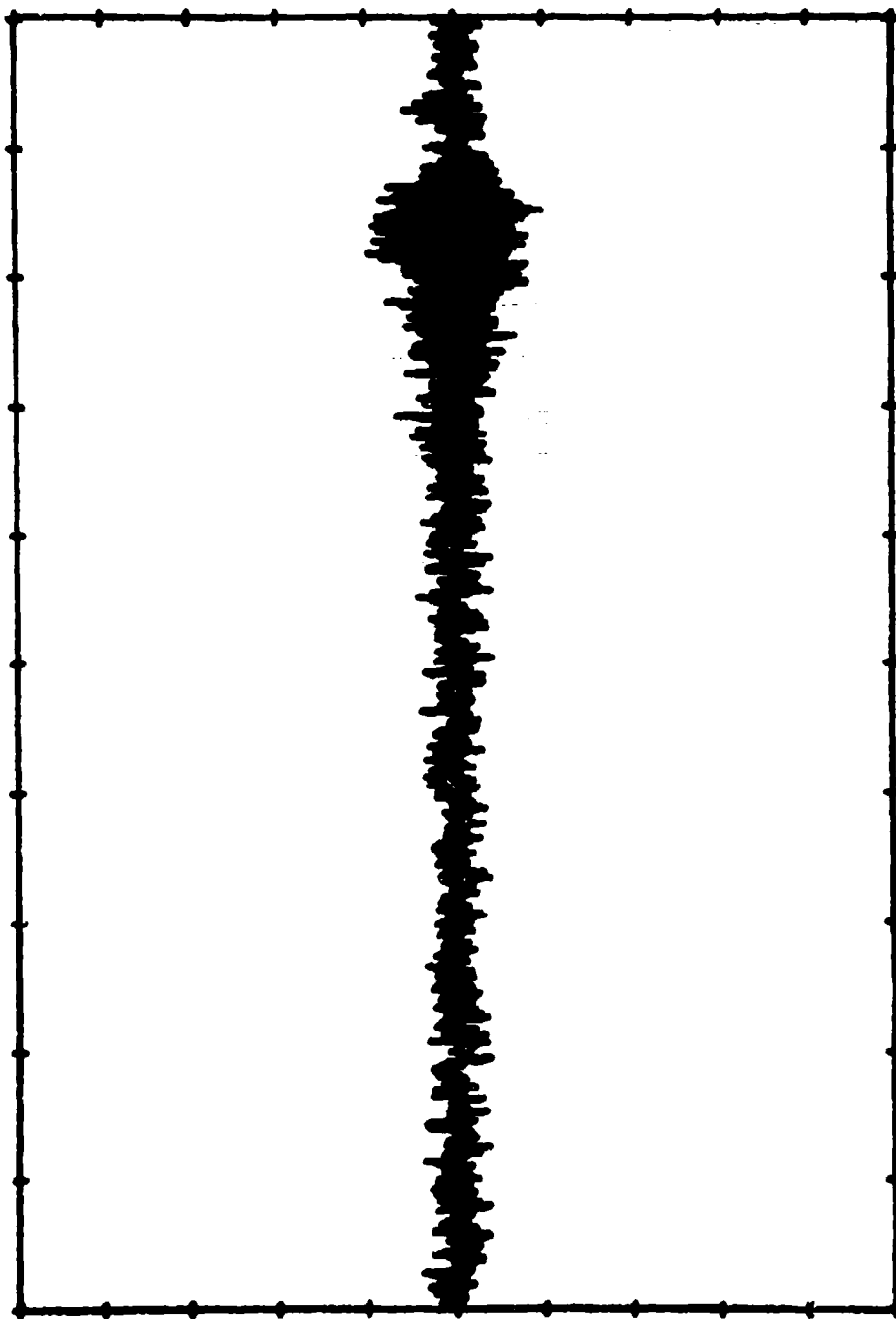
SAMPLES 1 THRU 2300

FILE NAME: ROUND.024 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325. 1:18:54.783



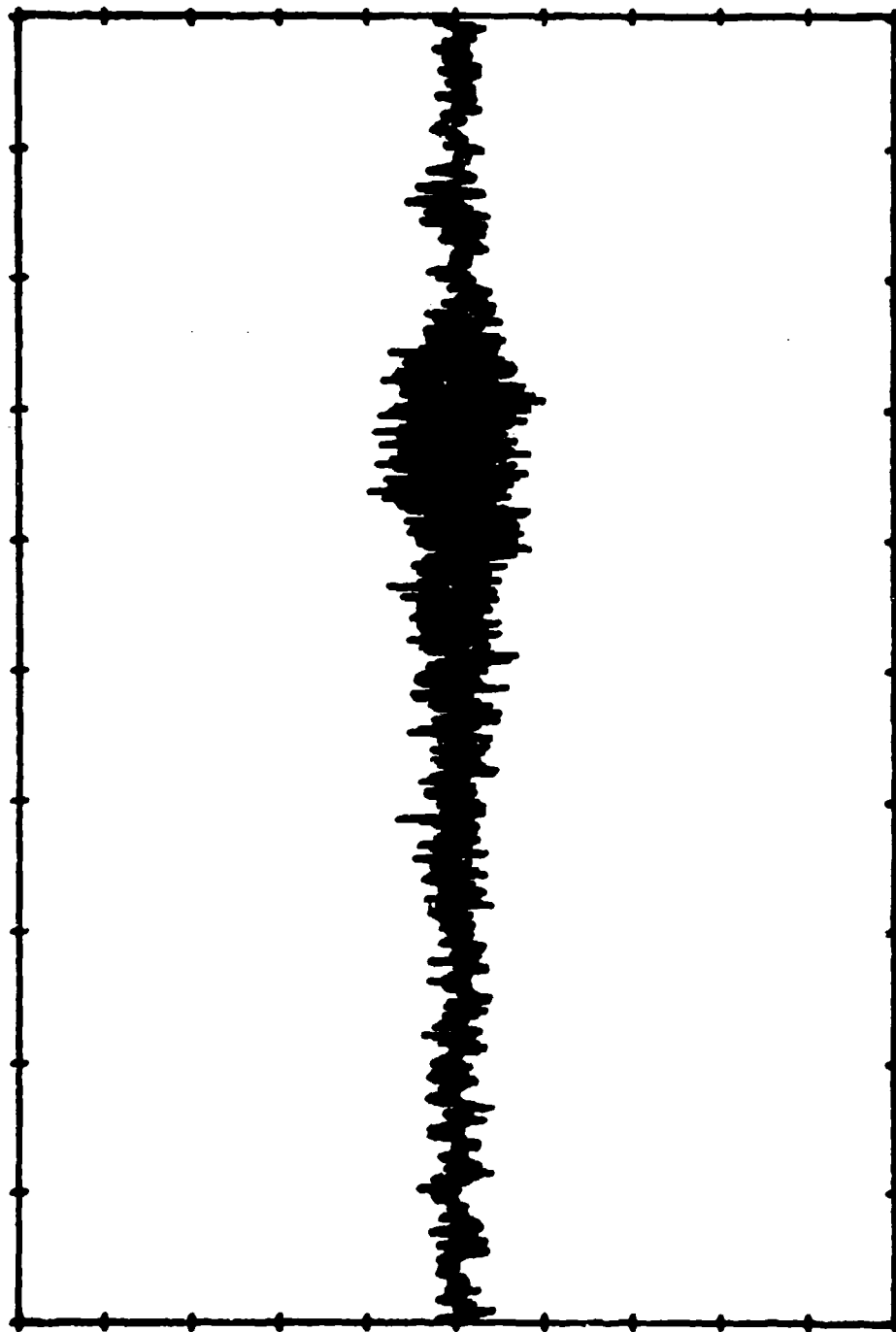
DEPRESS RETURN TO CONTINUE
ENTER -1 TO REPLOT POINTS *** ENTER 10 TO ESCAPE ***
ENTER 100 TO WRITE THIS RECORD SET TO OUTPUT TAPE
SAMPLES 350 THRU 1150

FILE NAME: ROUND 025 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325. 1:22:19.924



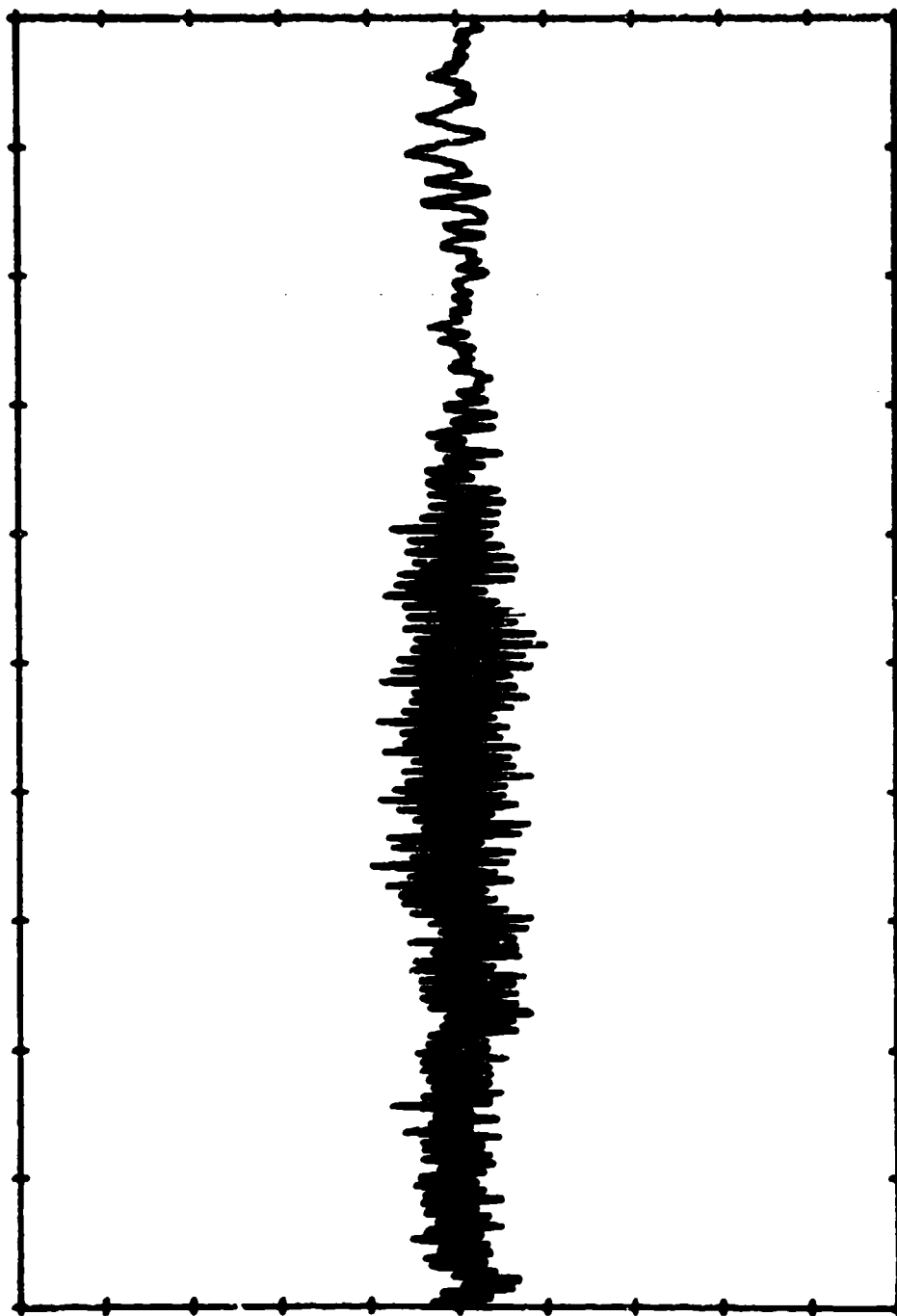
SAMPLES 97 THRU 4096

FILE NAME: ROUND.025 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:22:19.924



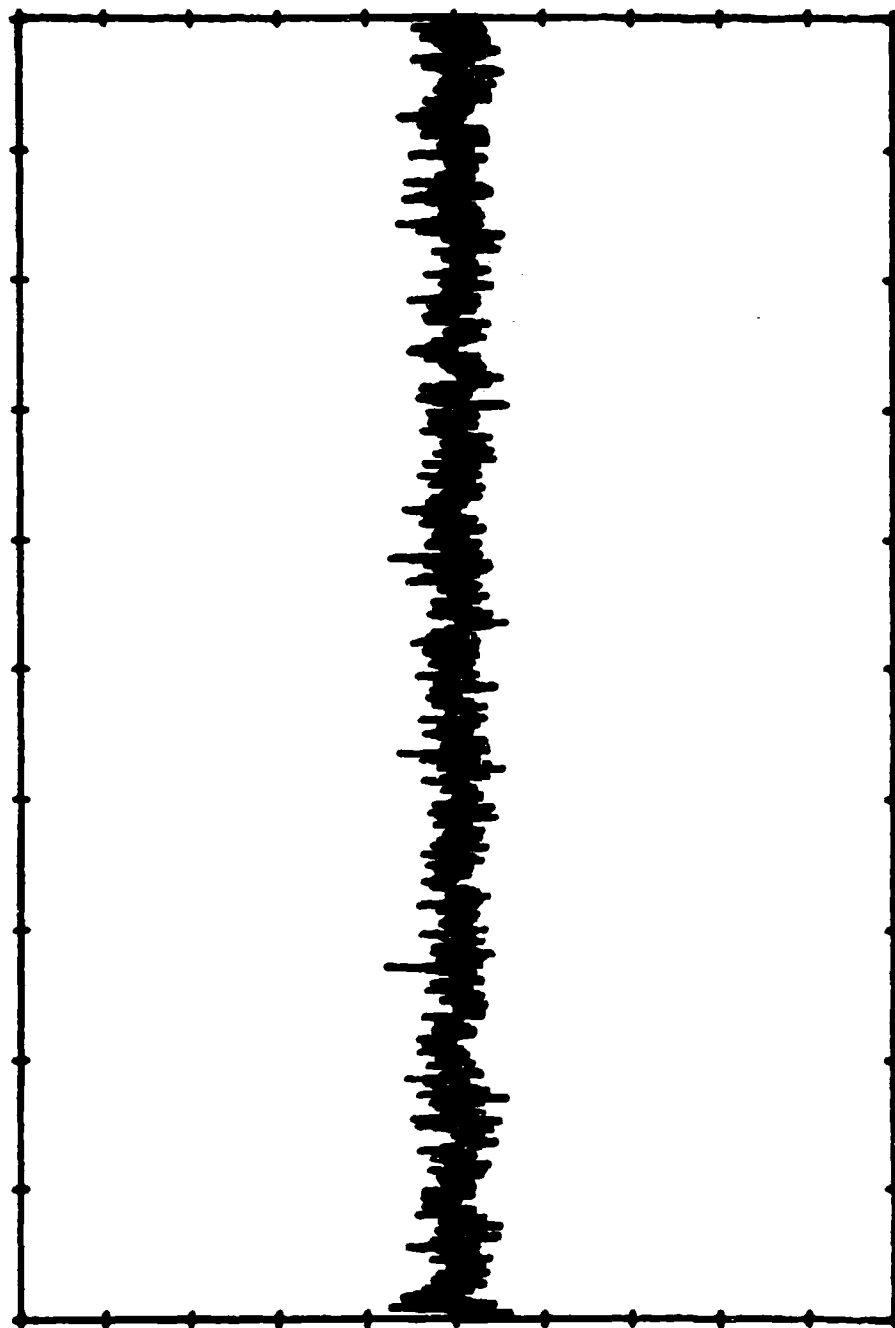
SAMPLES 2897 THRU 4896

FILE NAME: ROUND.025 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:22:19.924



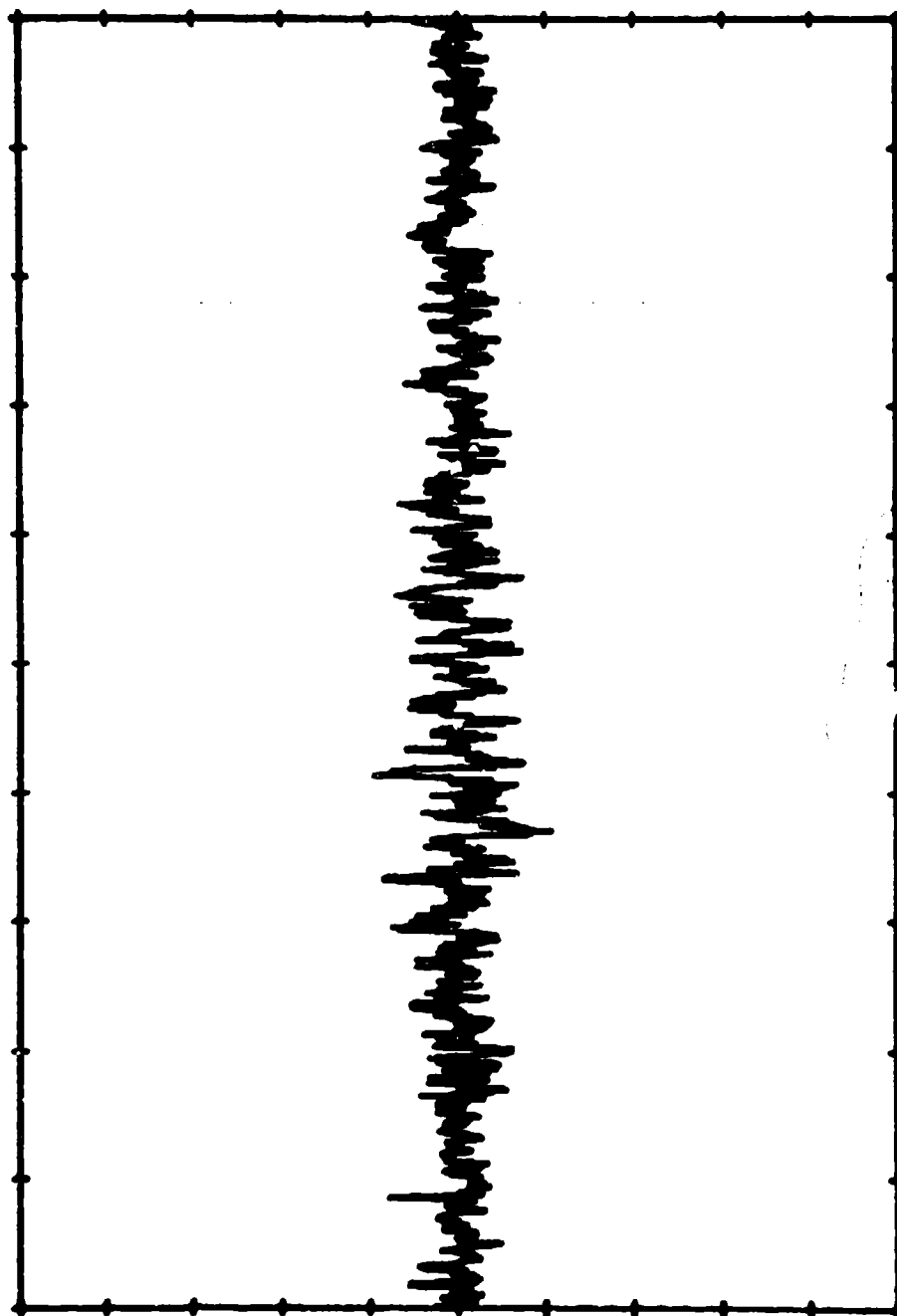
DEPRESS RETURN TO CONTINUE
ENTER -1 TO REPLOTT POINTS *** ENTER 10 TO ESCAPE ***
ENTER 100 TO WRITE THIS RECORD SET TO OUTPUT TAPE
SAMPLES 3100 THRU 3900

FILE NAME: ROUND.026 FILE DATA RECORD NUMBER: 3
FILE START TIME: 325: 1:39:19.144



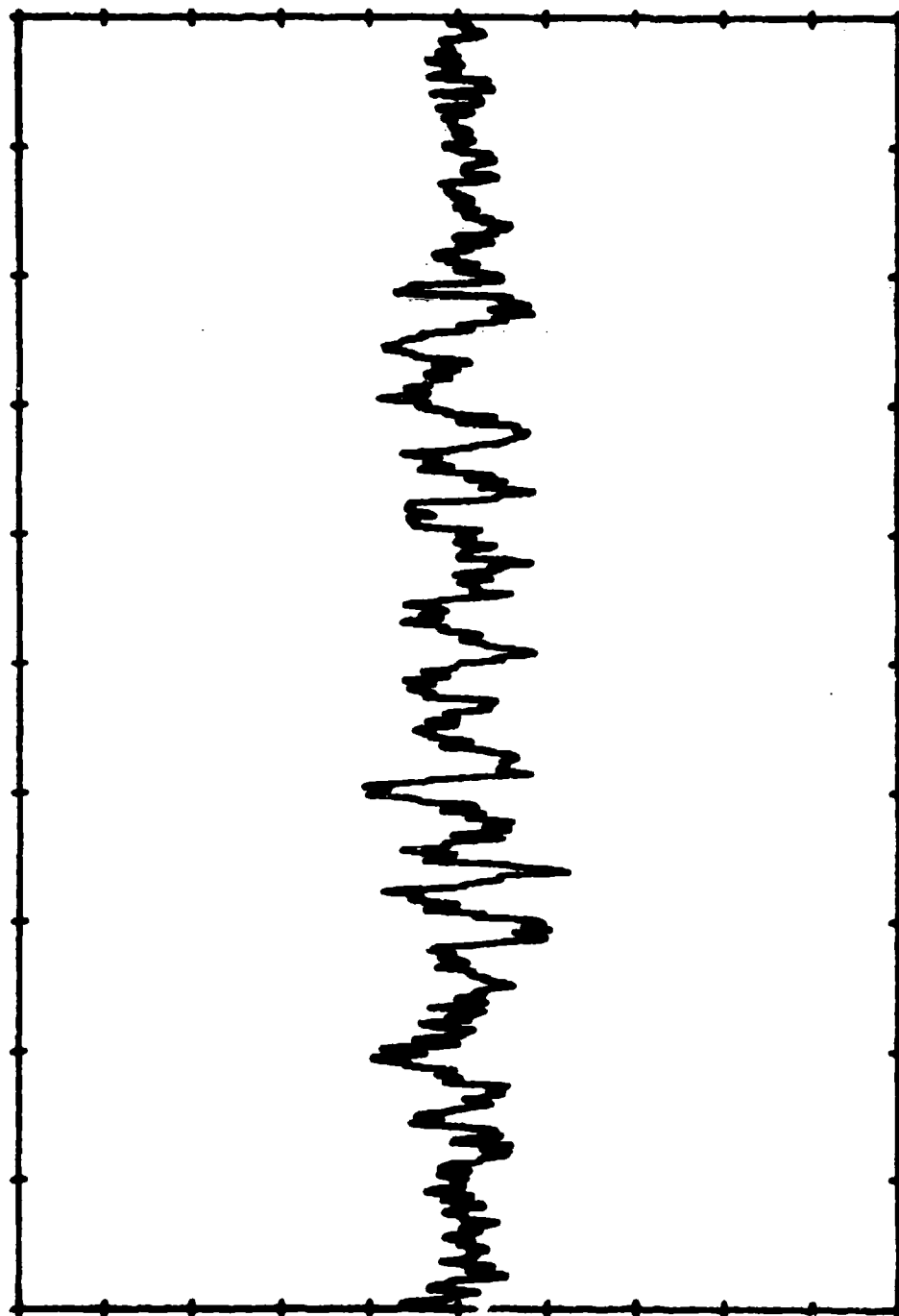
SAMPLES 1 THRU 4000

FILE NAME: ROUND.026 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:39:19.144



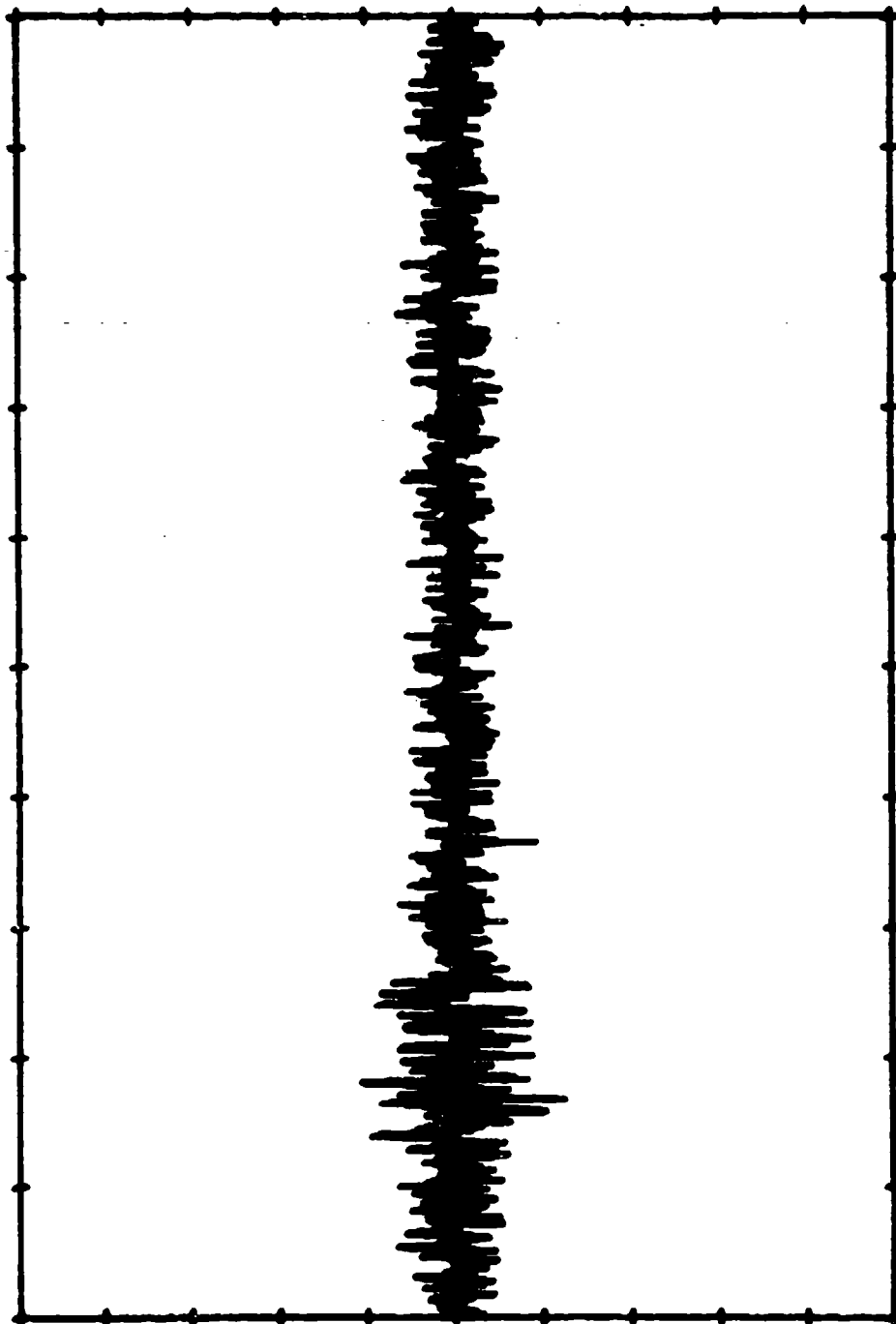
DEPRESS RETURN TO CONTINUE
ENTER -1 TO REPLOT POINTS *** ENTER 12 TO ESCAPE ***
ENTER 100 TO WRITE THIS RECORD SET TO OUTPUT. APE
SAMPLES 1600 THRU 3600

FILE NAME: ROUND.02? FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:41:57.695



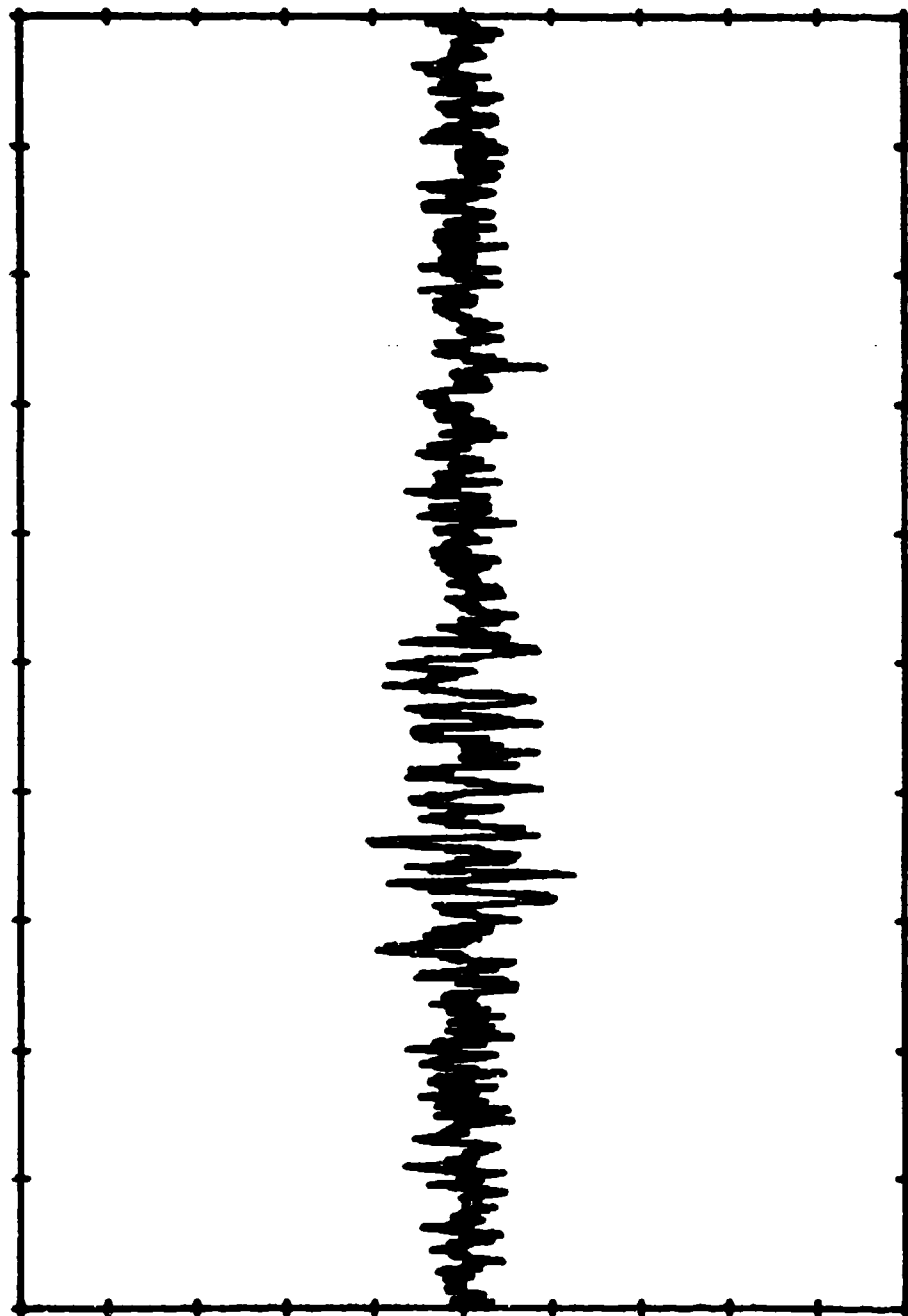
DEPRESS RETURN TO CONTINUE
ENTER -1 TO REPLOT POINTS *** ENTER 10 TO ESCAPE ***
ENTER 100 TO WRITE THIS RECORD SET TO OUTPUT TAPE
SAMPLES 400 THRU 1200

FILE NAME: ROUND.027 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:41:57.695



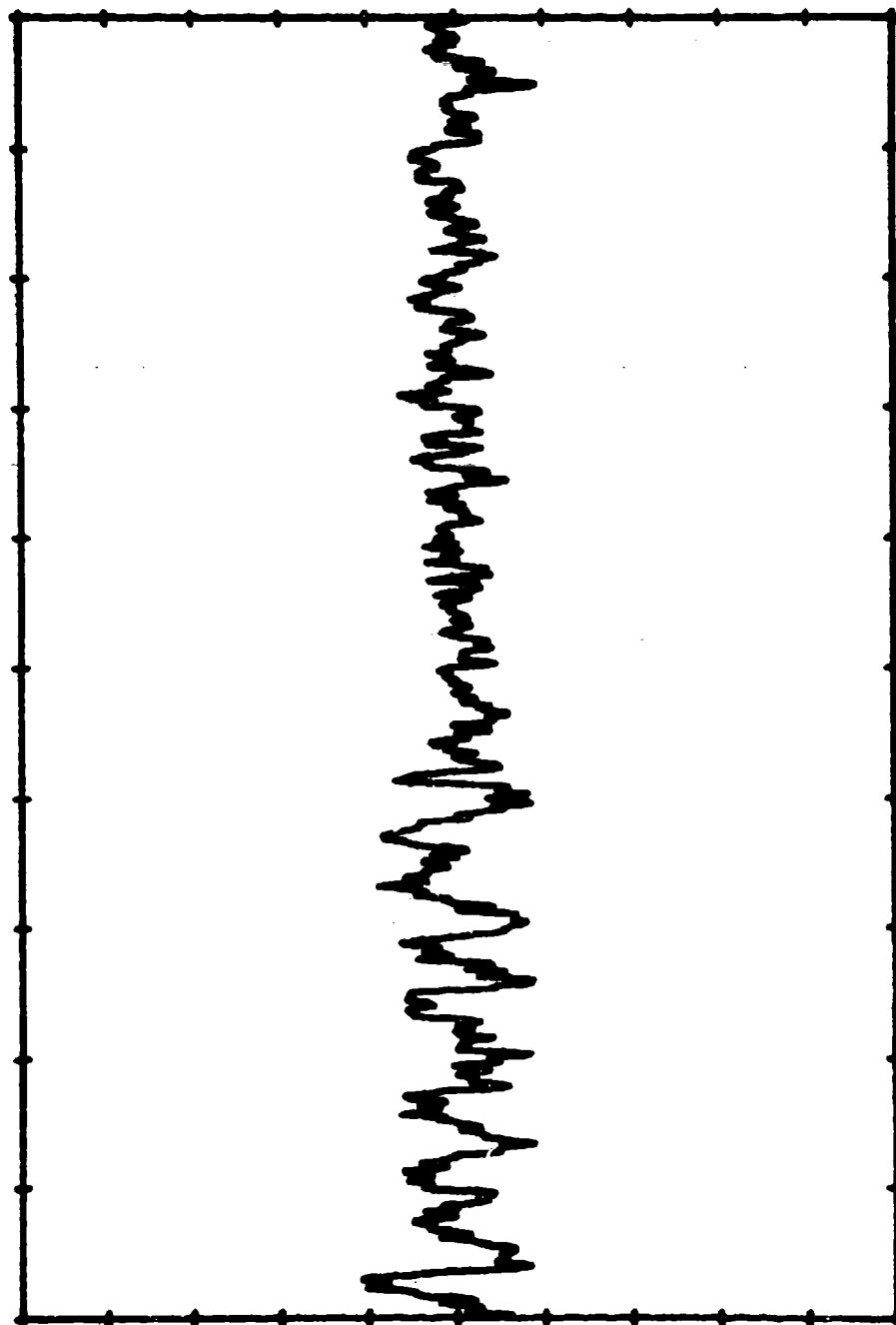
SAMPLES 1 THRU 4000

FILE NAME: ROUND.027 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:41:57.695



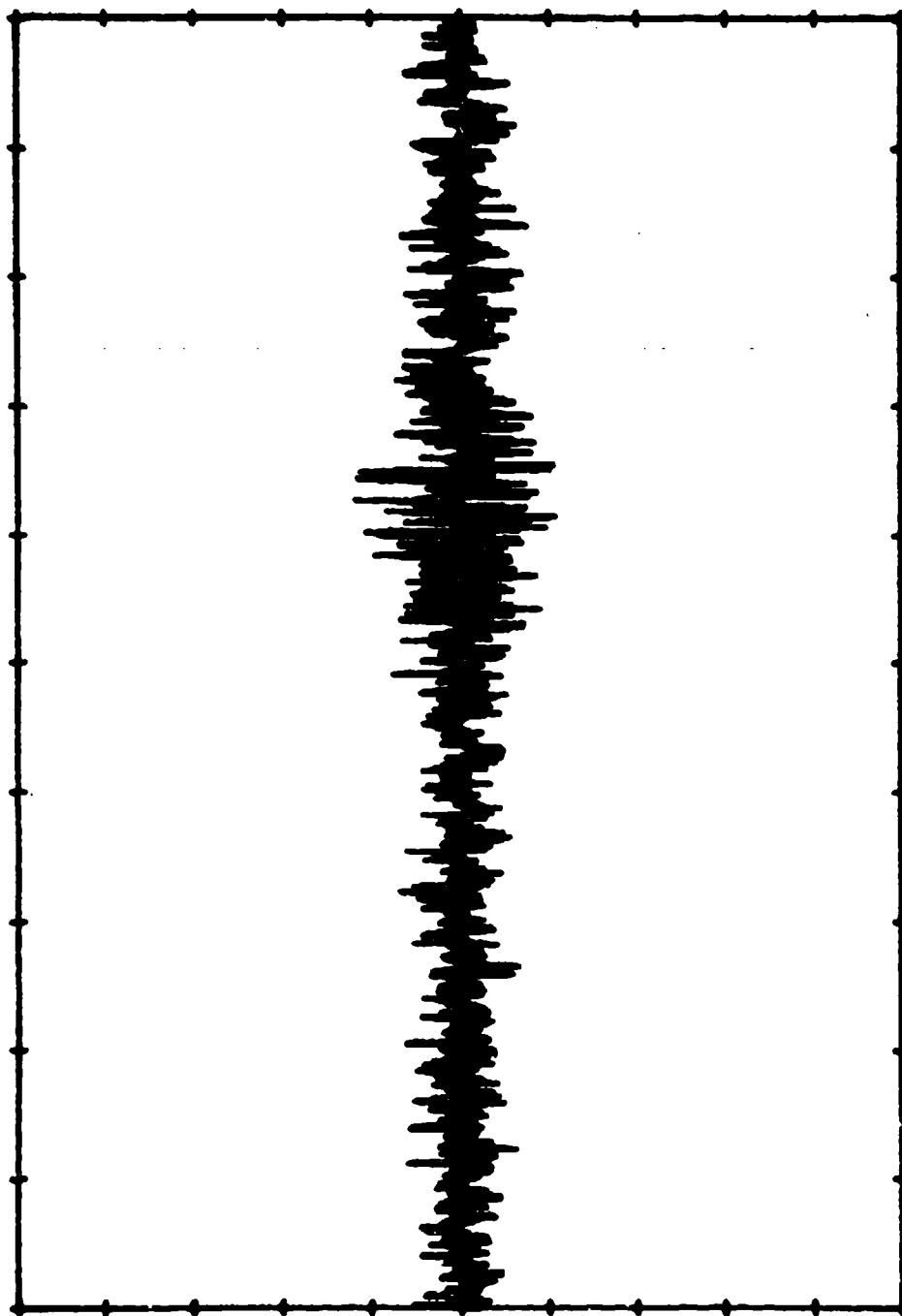
SAMPLES 1 THRU 2000

FILE NAME: ROUND.027 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:41:57.695



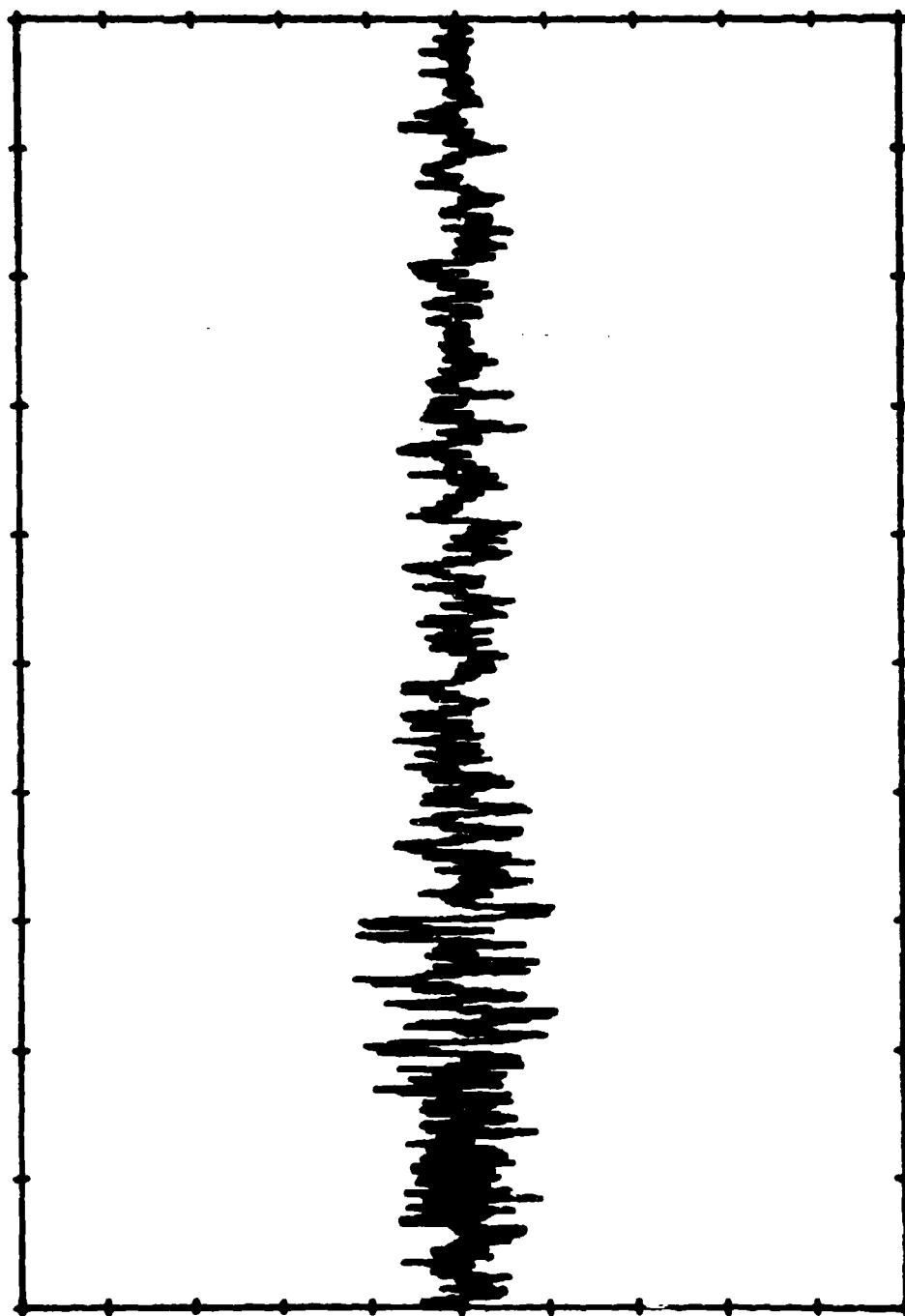
SAMPLES 700 THRU 1500

FILE NAME: ROUND.028 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:59:20.669



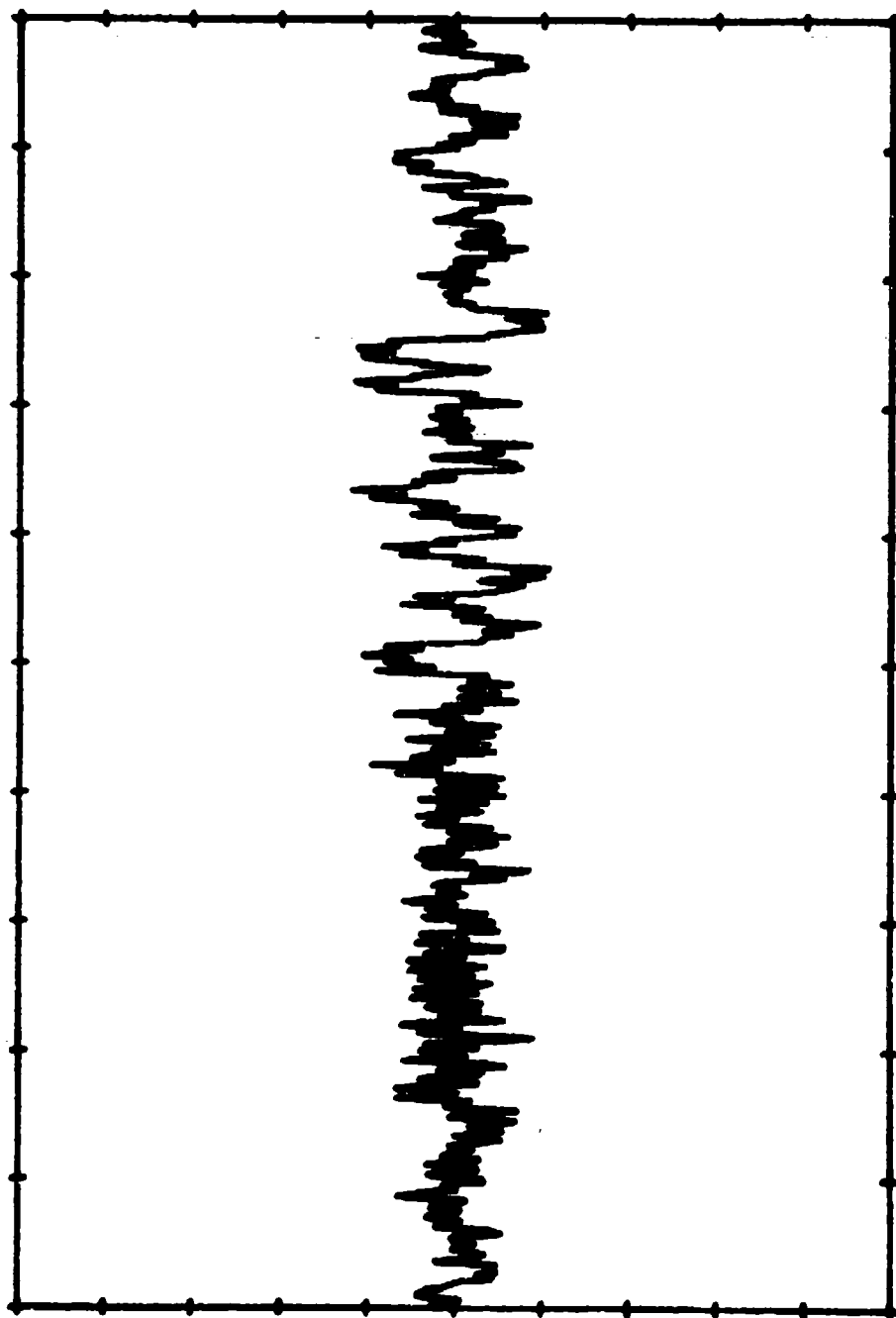
SAMPLES 1 THRU 4000

FILE NAME: ROUND.028 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:59:20.669



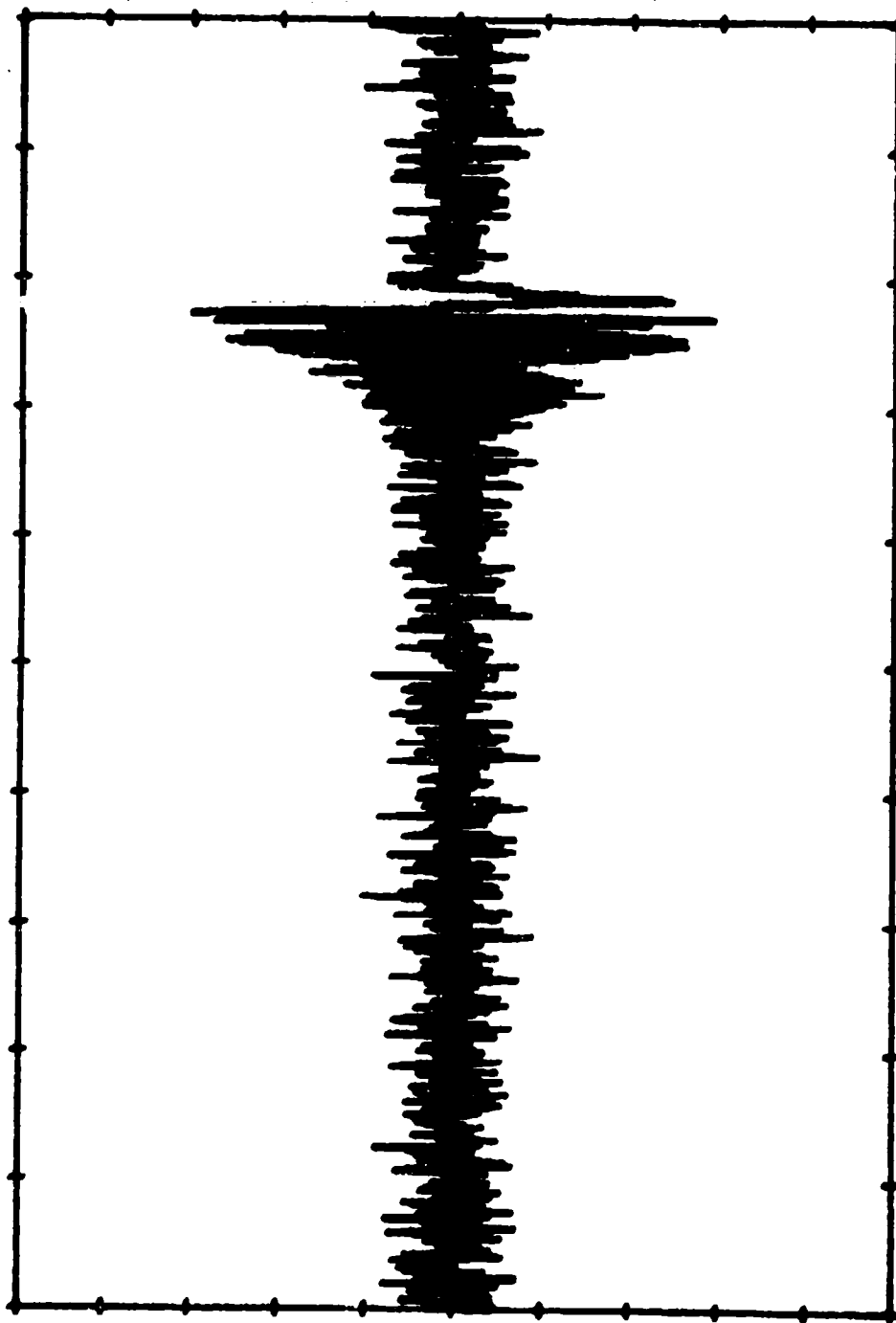
SAMPLES 2000 THRU 4000

FILE NAME: ROUND.028 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 1:59:20.669



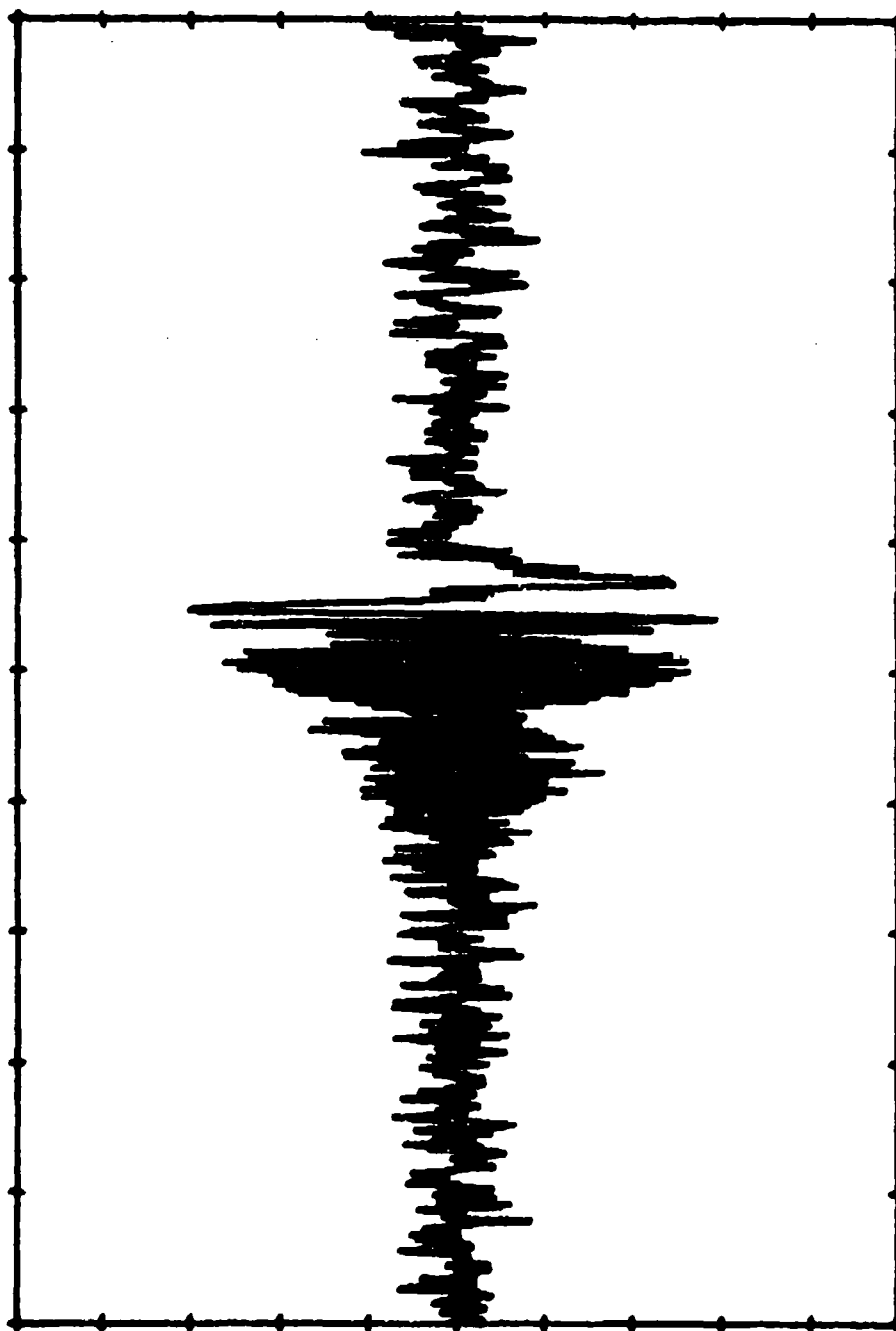
SAMPLES 2000 THRU 2800

FILE NAME: ROUND.029 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:18:44.650



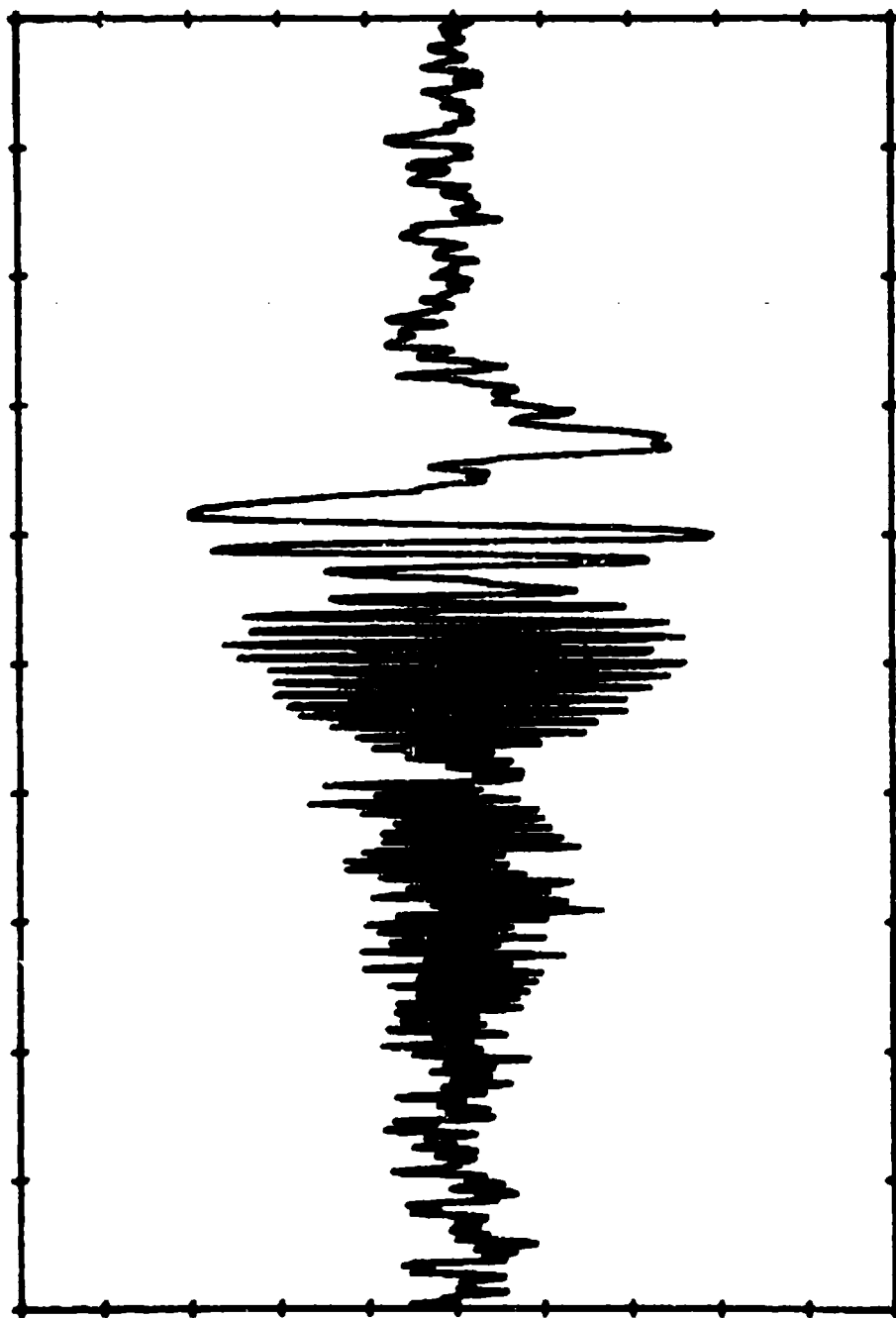
SAMPLES 1 THRU 4000

FILE NAME: ROUND.029 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325. 2:18:44.650



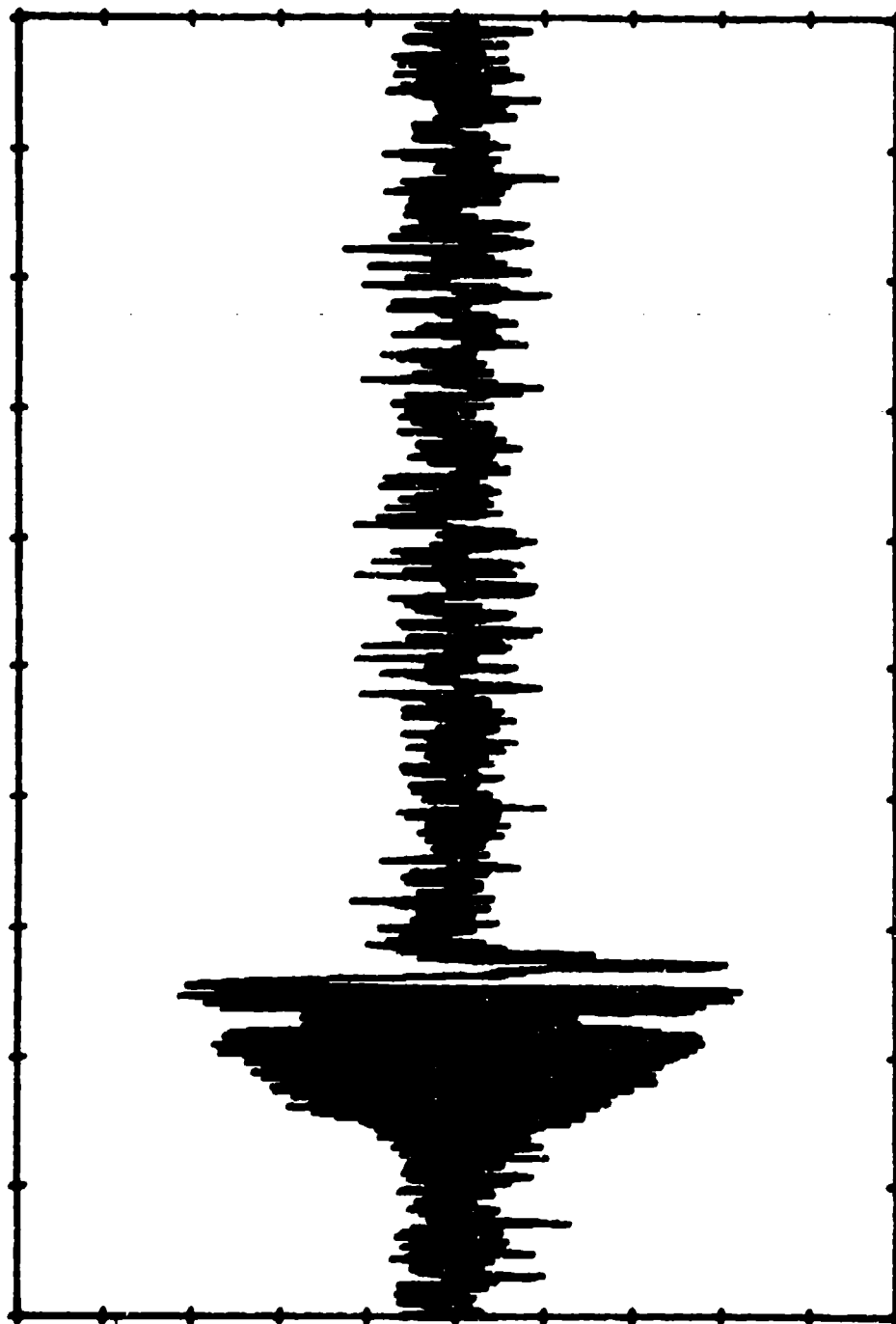
SAMPLES 2000 THRU 4000

FILE NAME: ROUND. 029 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:18:44.660



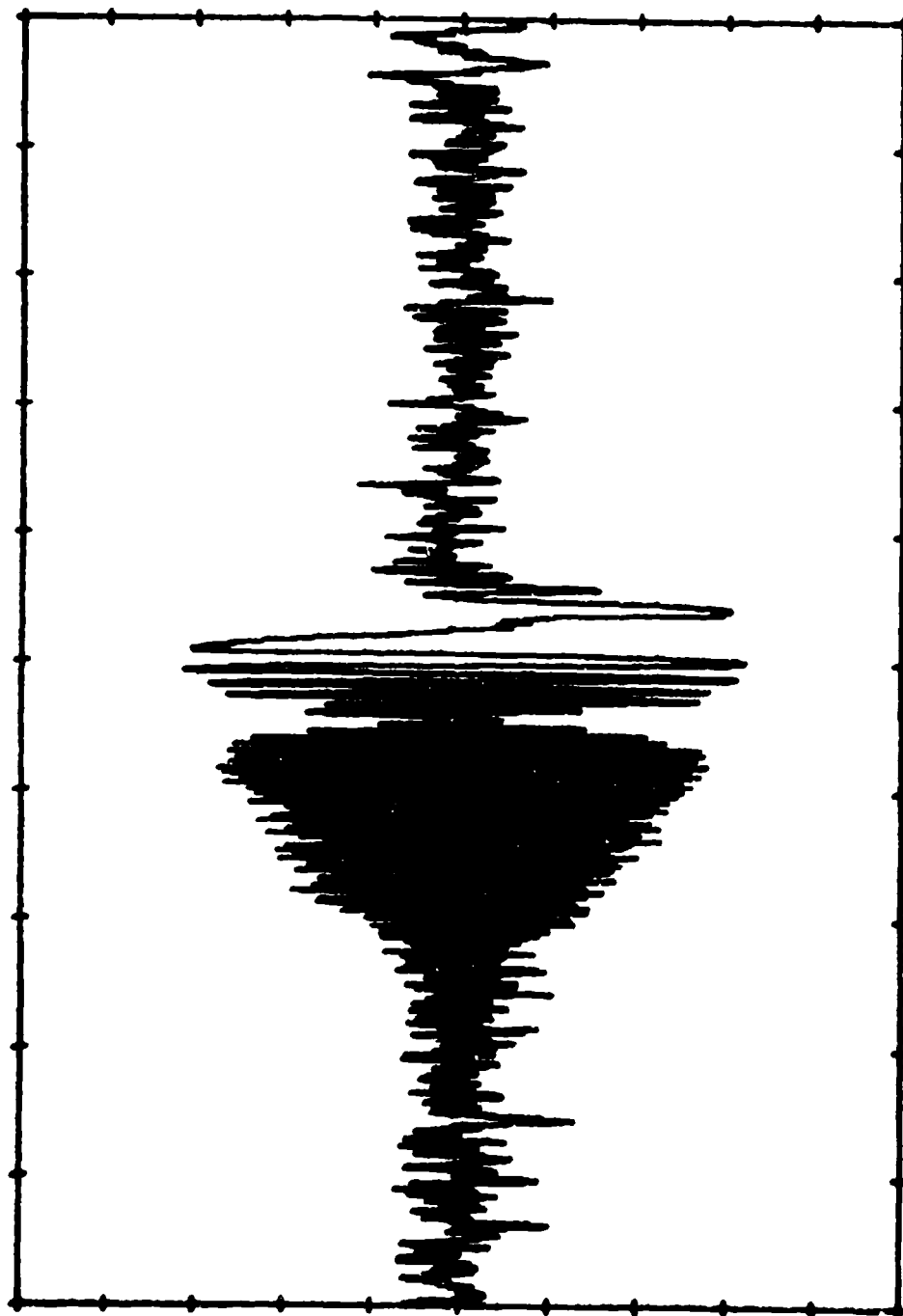
SAMPLES 2600 THRU 3400

FILE NAME: ROUND 030 FILE DATA RECORD NUMBER: 2
FILE START TIME: 3:25: 2:22: 3.608



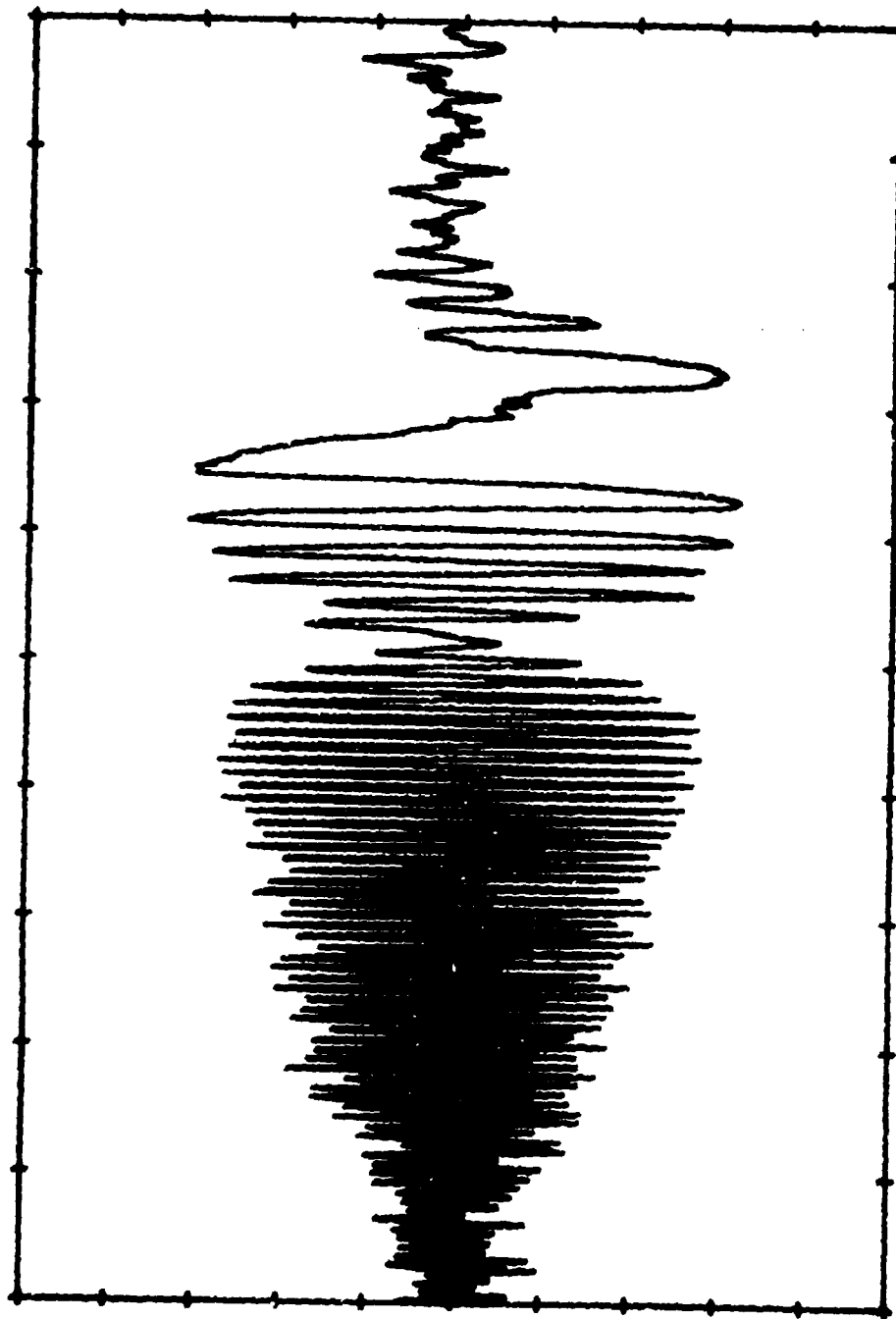
SAMPLES 1 THRU 4000

FILE NAME: ROUND.030 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:22: 3.608



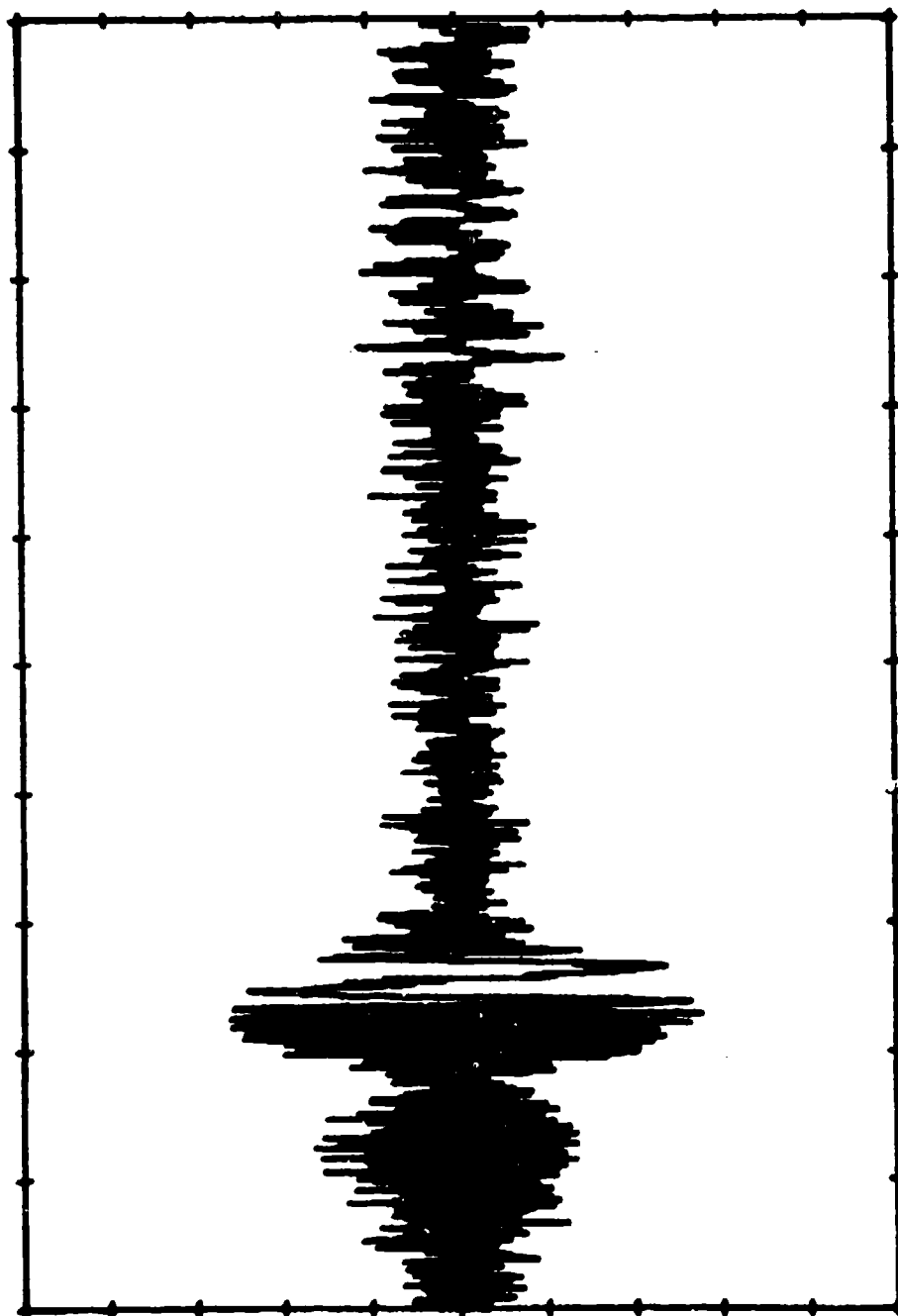
SAMPLES 1 THRU 2000

FILE NAME: ROUND.030 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325. 2:22: 3.608



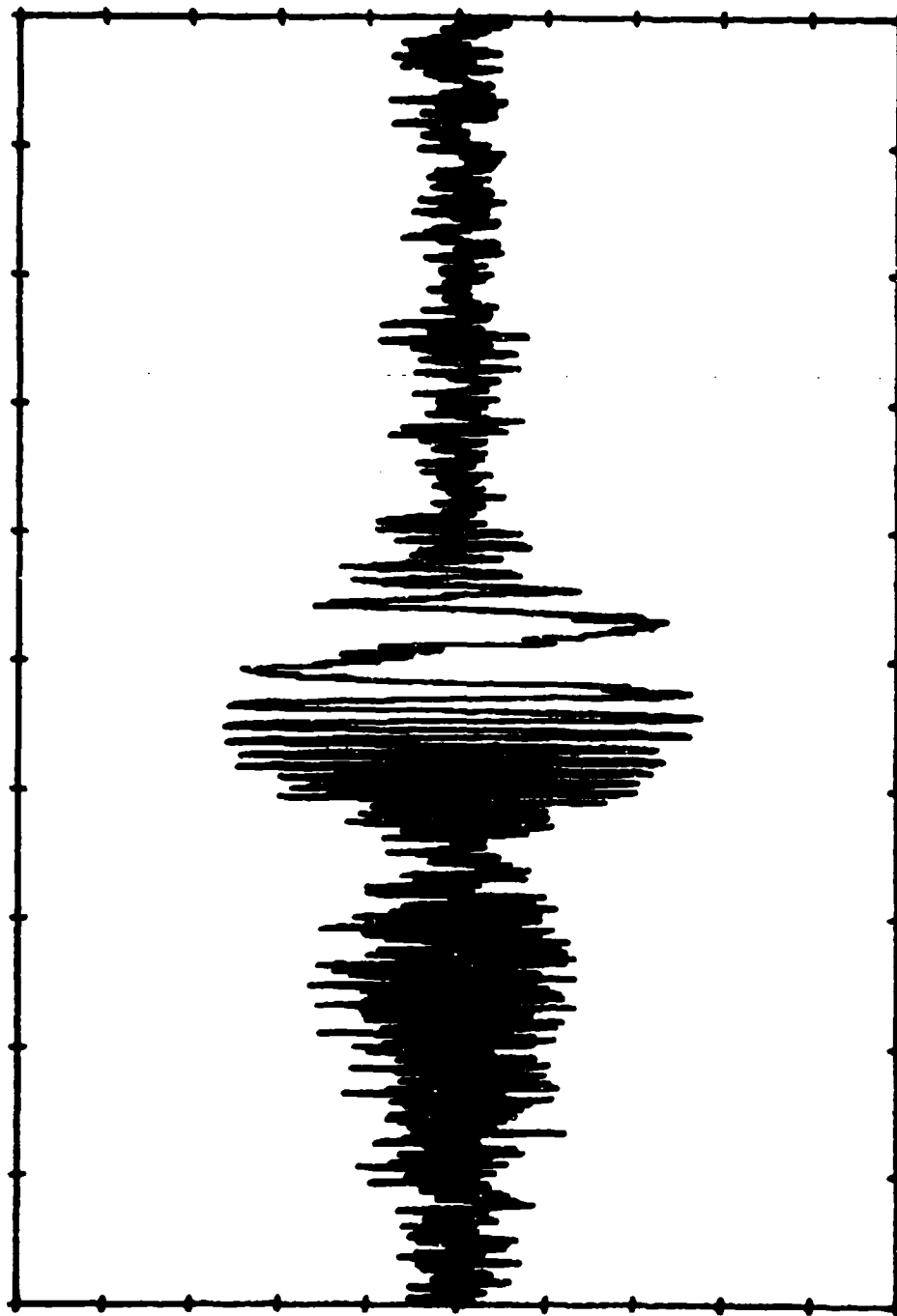
SAMPLES 500 THRU 1300

FILE NAME: ROUND.031 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:25:26.646



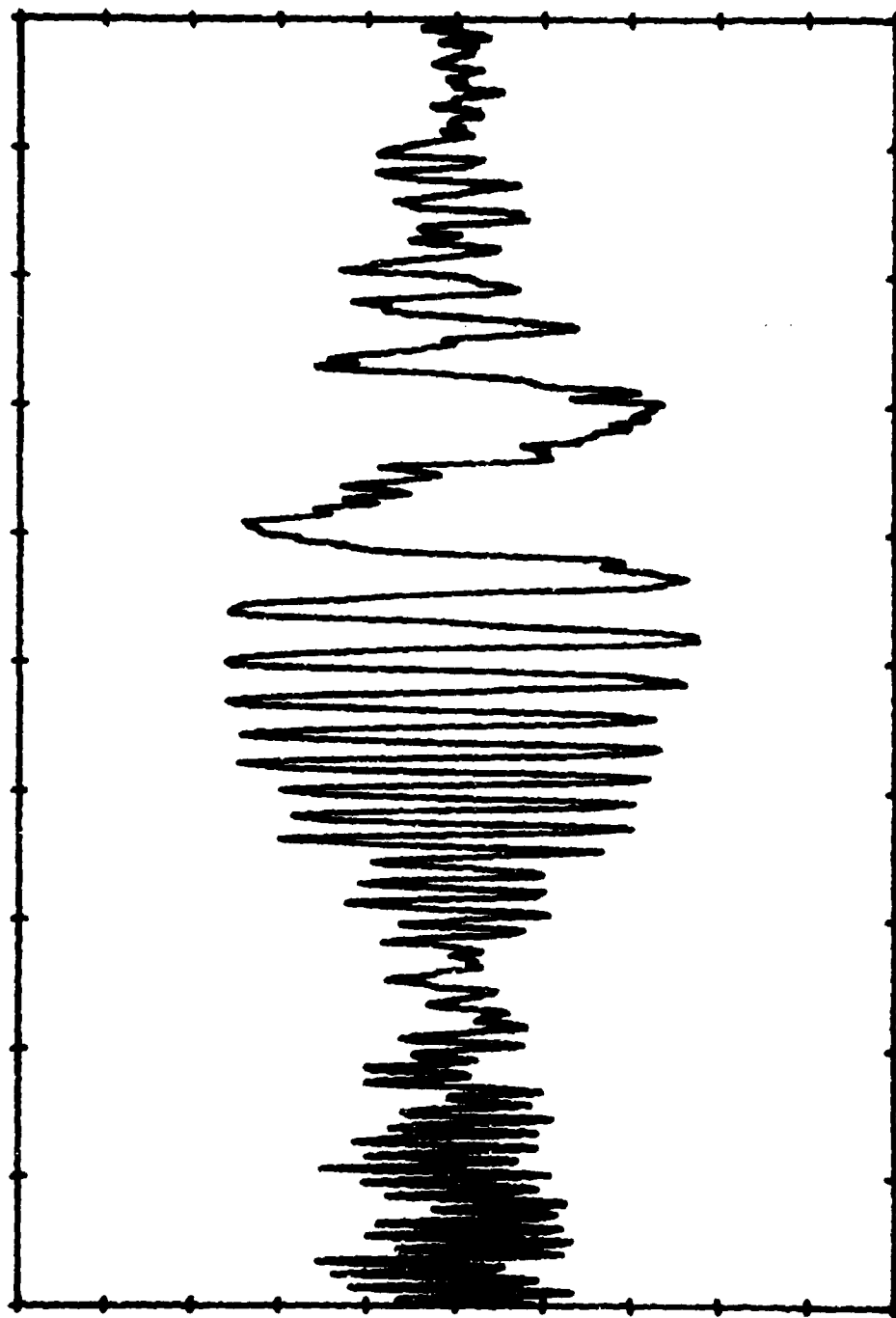
SAMPLES 1 THRU 4000

FILE NAME: ROUND.031 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:25:26.646



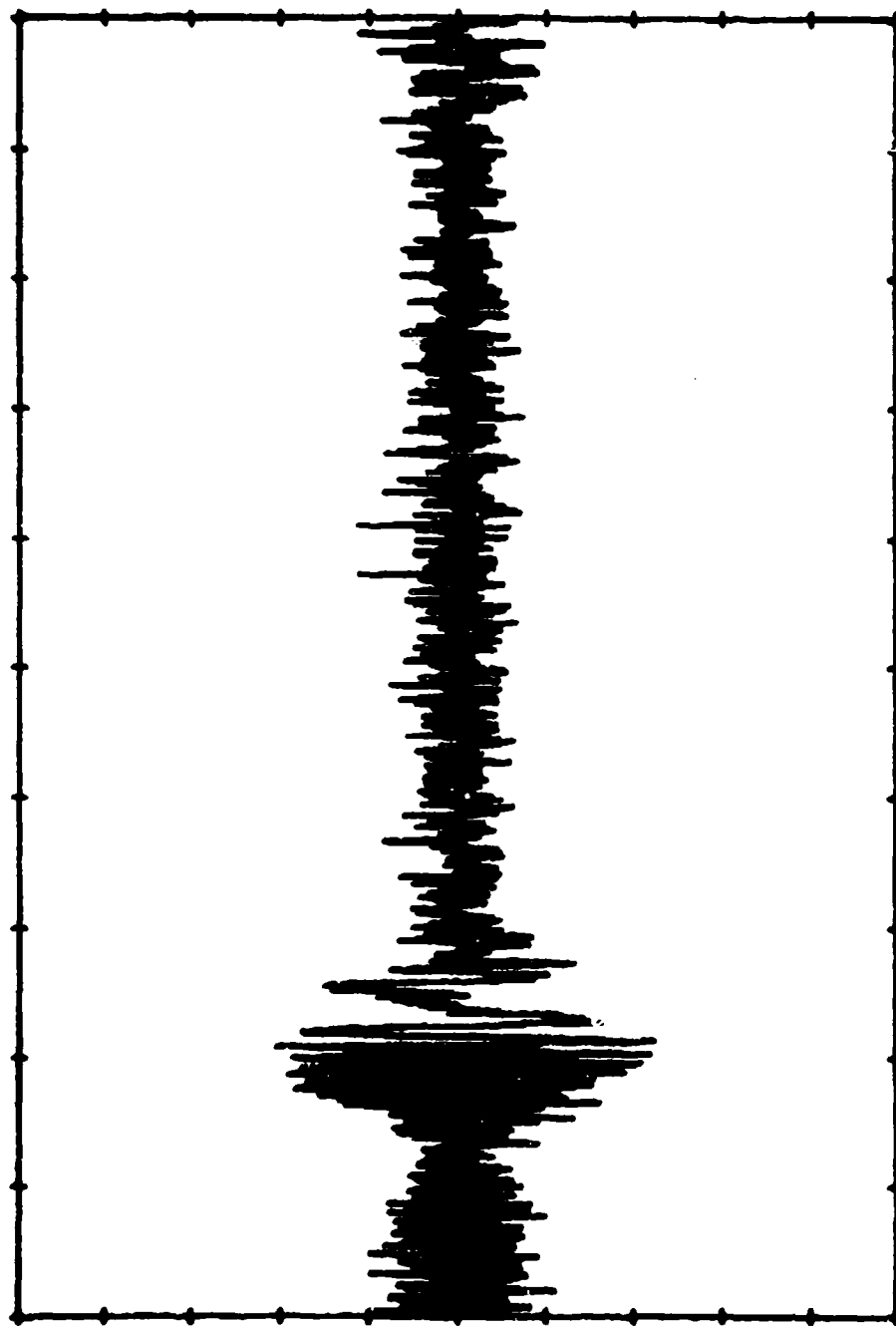
SAMPLES 1 THRU 2000

FILE NAME: ROUND.031 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325' 2:25:26.646



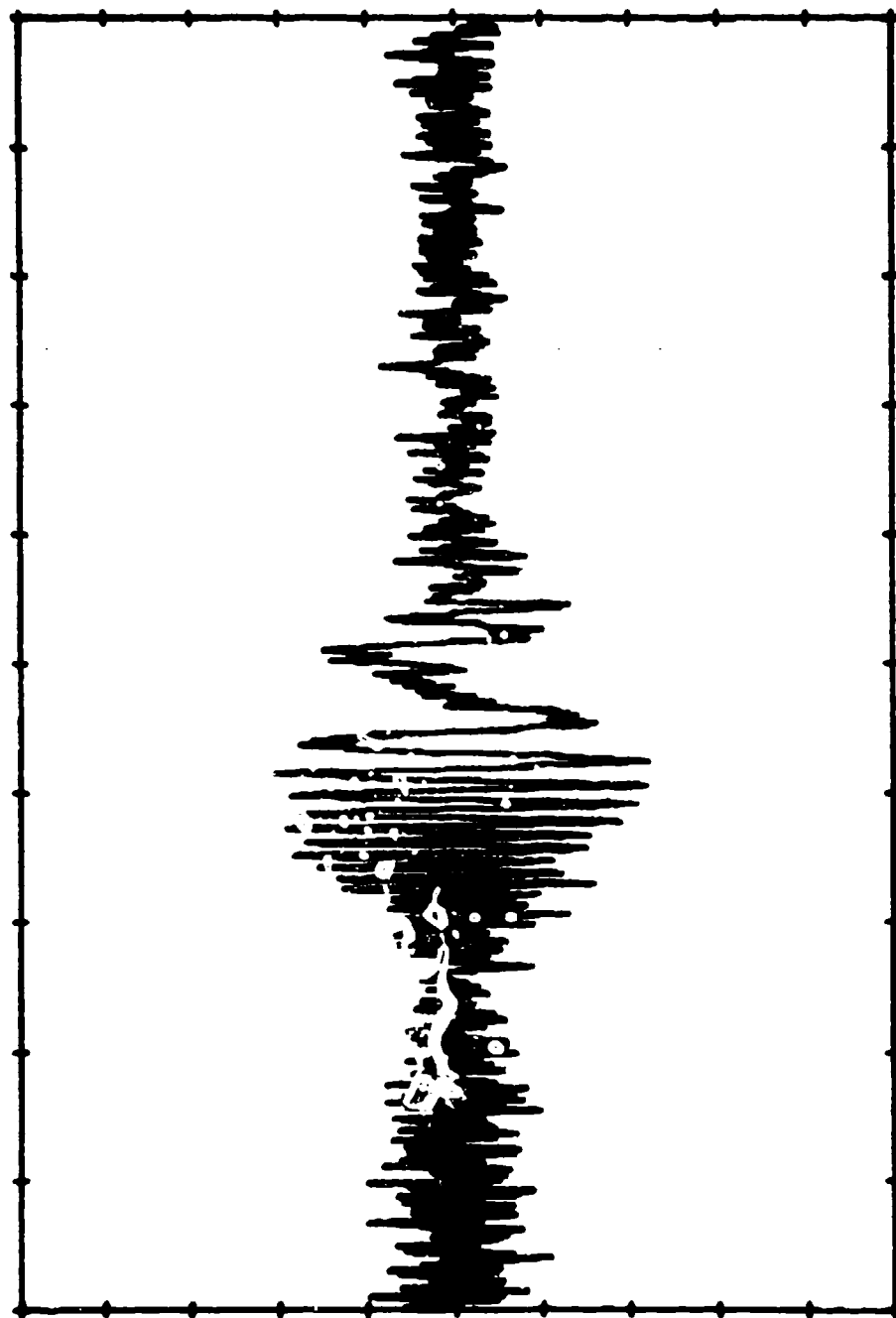
SAMPLES 500 THRU 1300

FILE NAME: ROUND.032 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:28:23.338



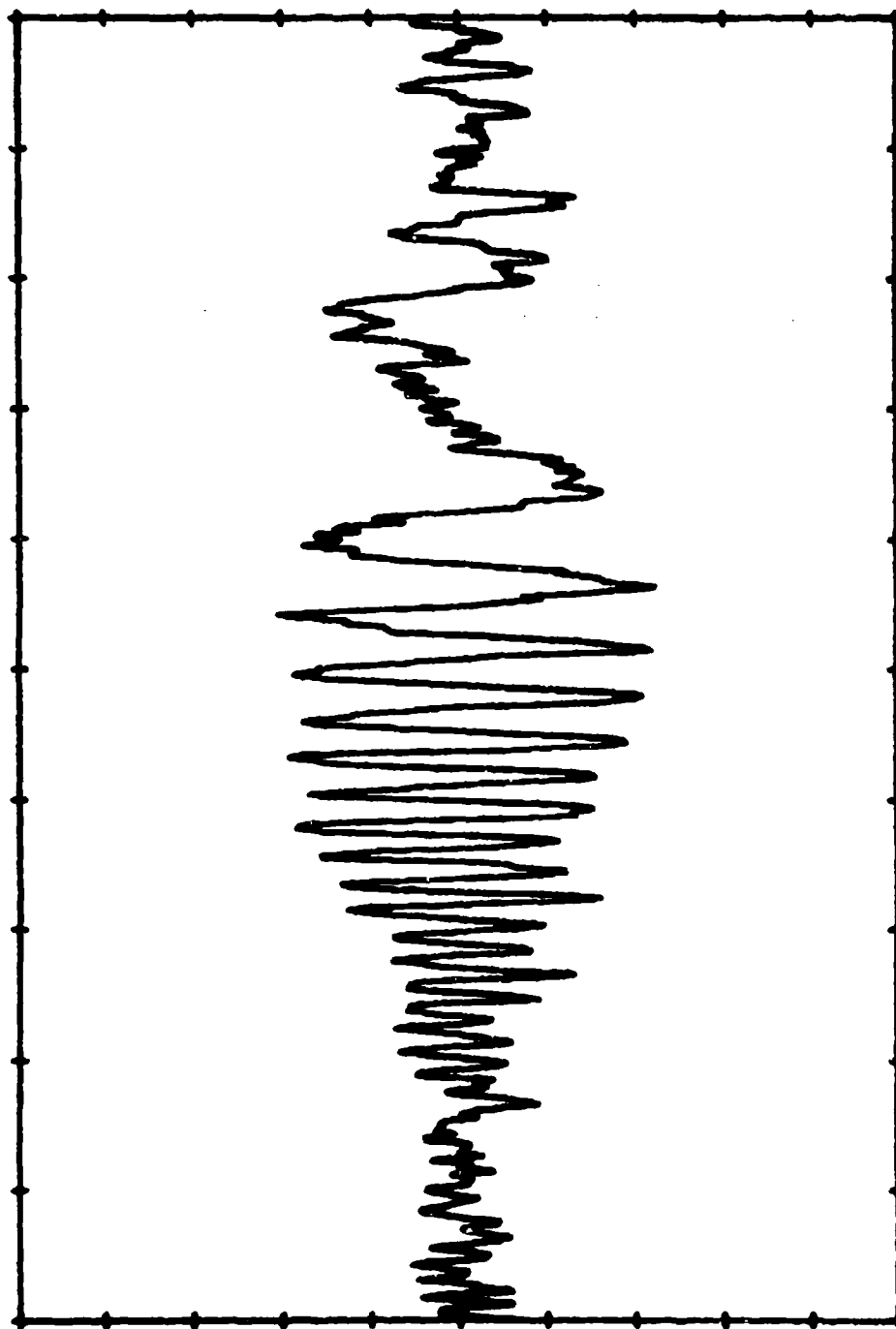
SAMPLES 1 THRU 4000

FILE NAME: ROUND.032 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:28:23.338



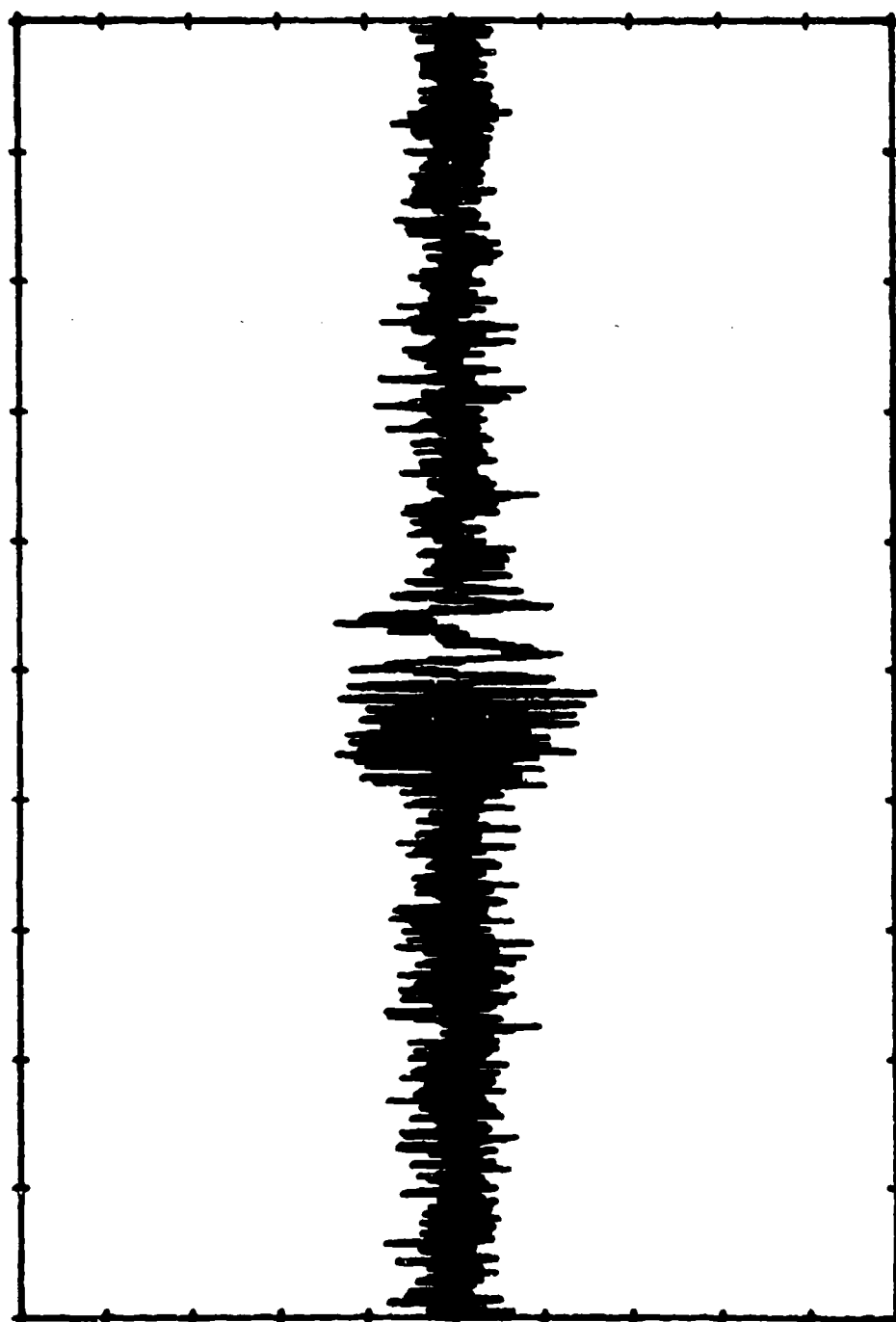
SAMPLES 1 THRU 2000

FILE NAME: ROUND.032 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:28:23.338



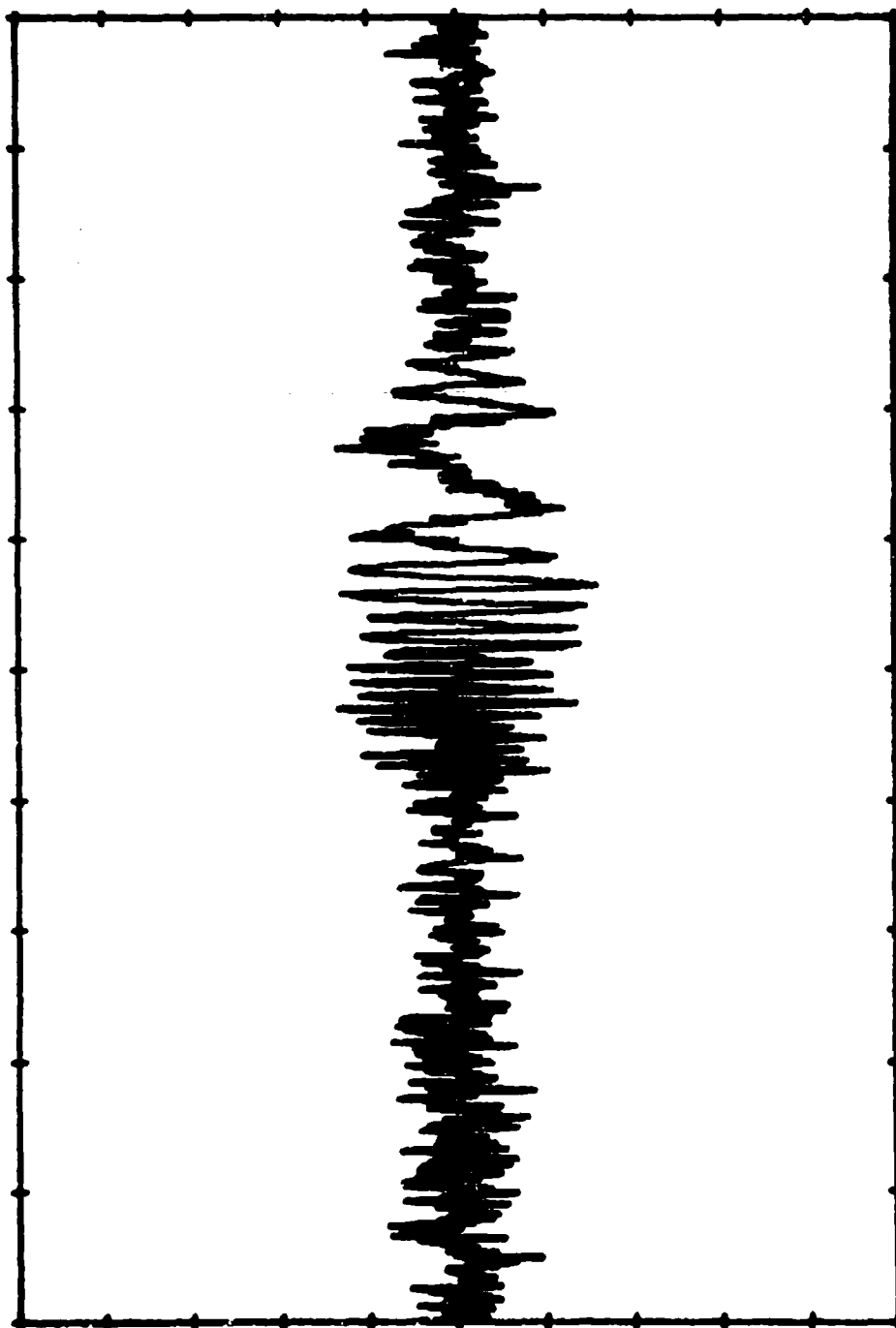
SAMPLES 400 THRU 1200

FILE NAME: ROUND.033 FILE DATA RECORD NUMBER: 3
FILE START TIME: 325: 2:31:14. 12



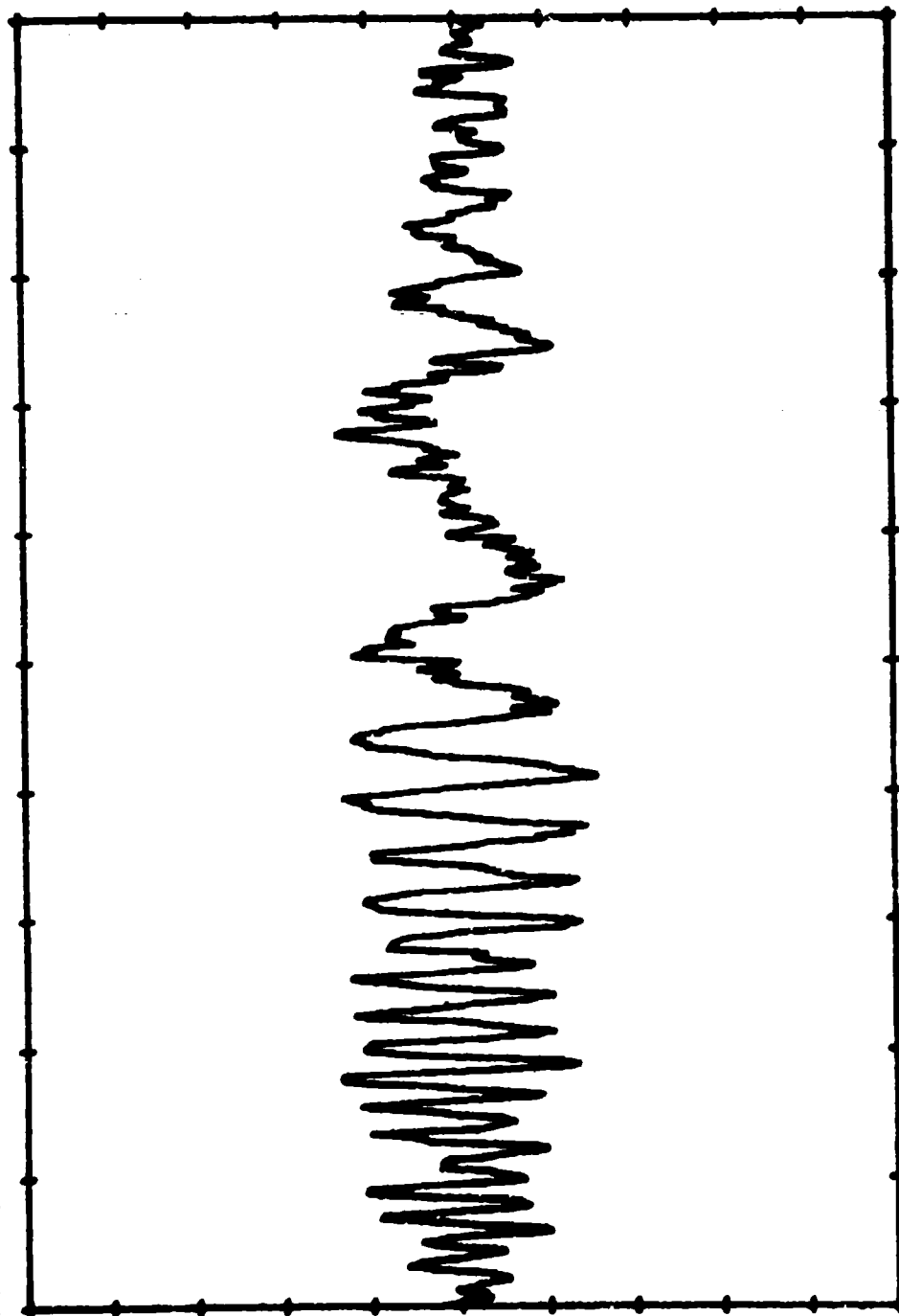
SAMPLES 1 THRU 4000

FILE NAME: ROUND.033 FILE DATA RECORD NUMBER: 3
FILE START TIME: 325: 2:31:14. 12



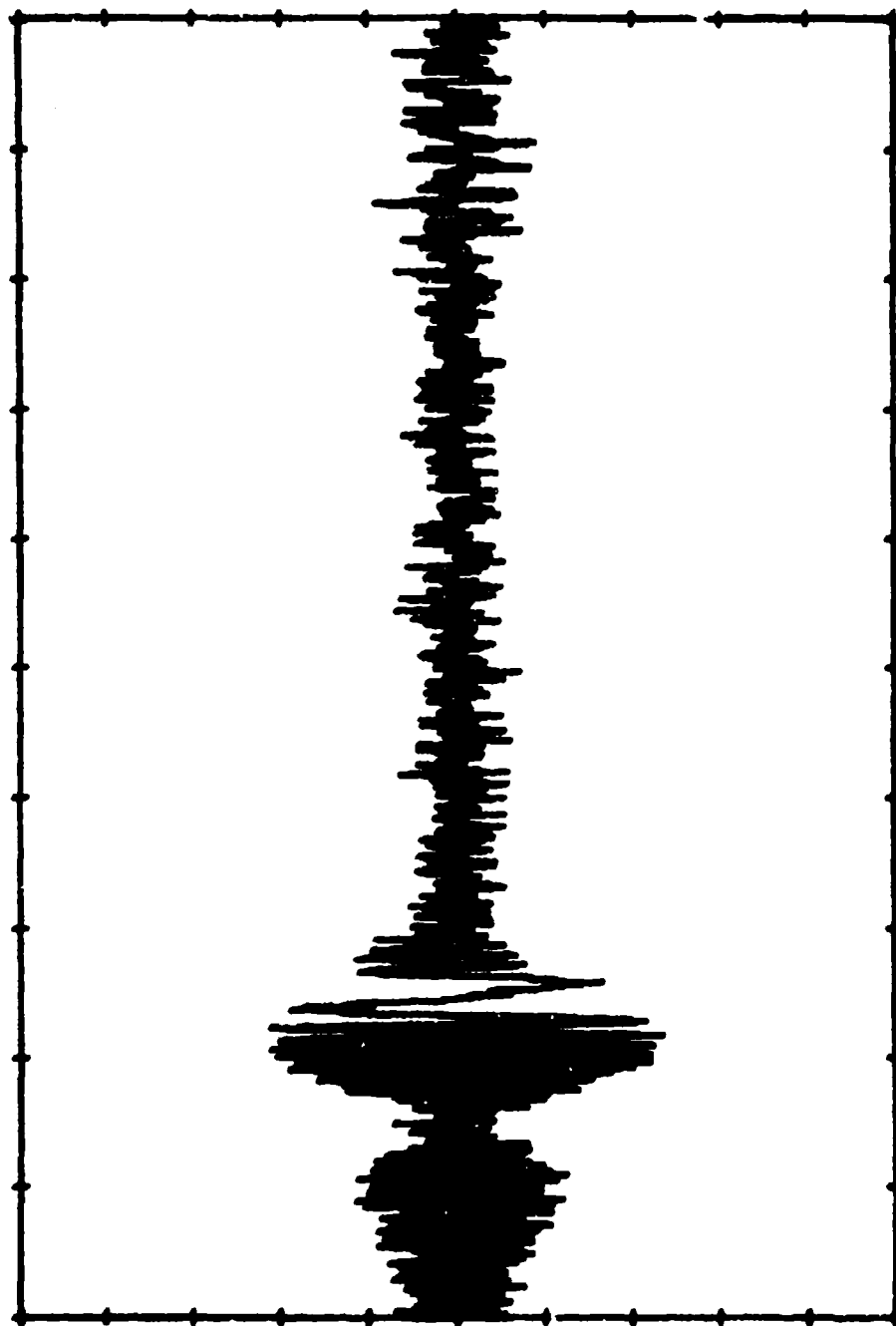
SAMPLES 800 THRU 2000

FILE NAME: ROUND.033 FILE DATA RECORD NUMBER: 3
FILE START TIME: 2:31:14. 12



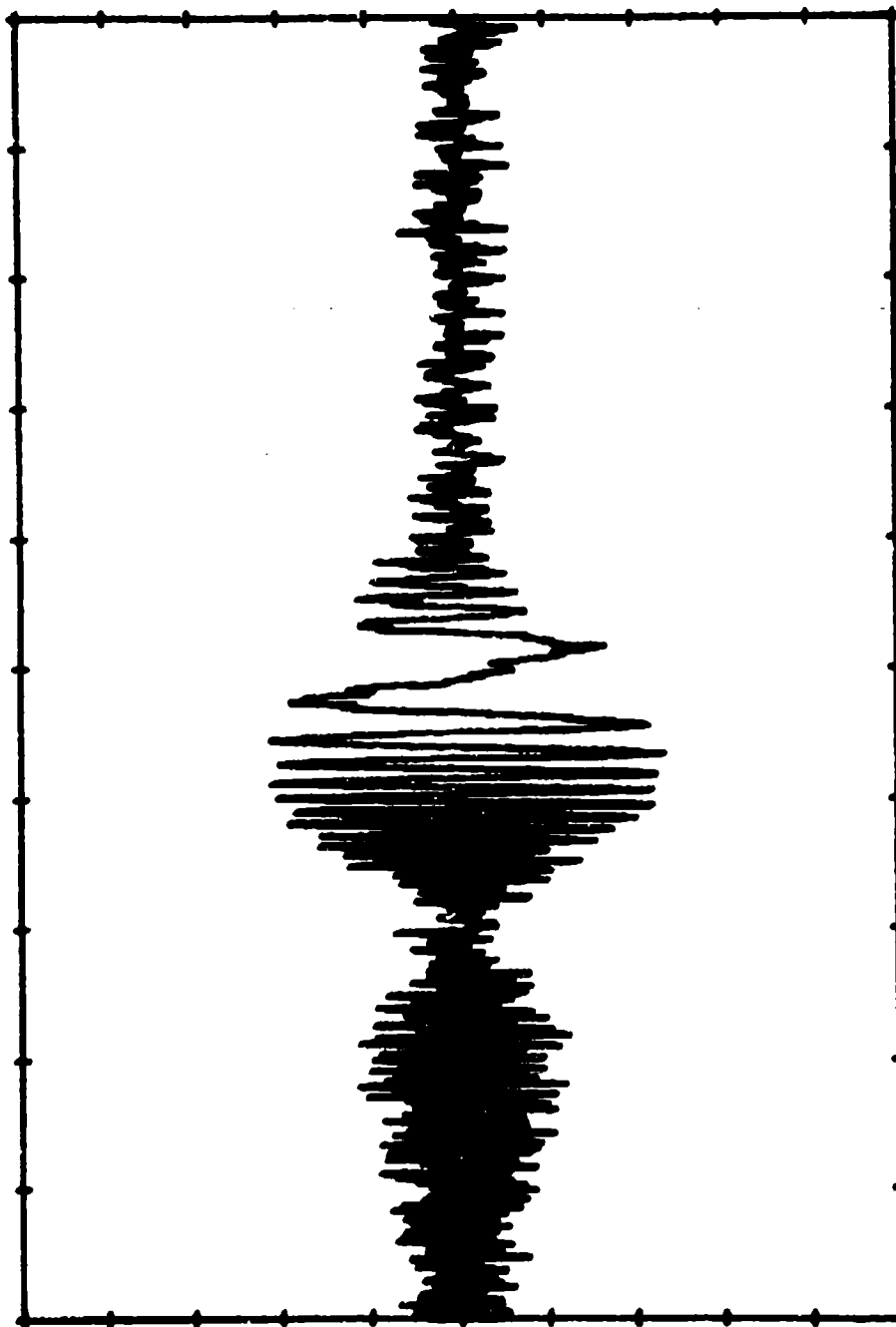
SAMPLES 1600 THRU 2400

FILE NAME: ROUND 034 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325.2:35:10.532



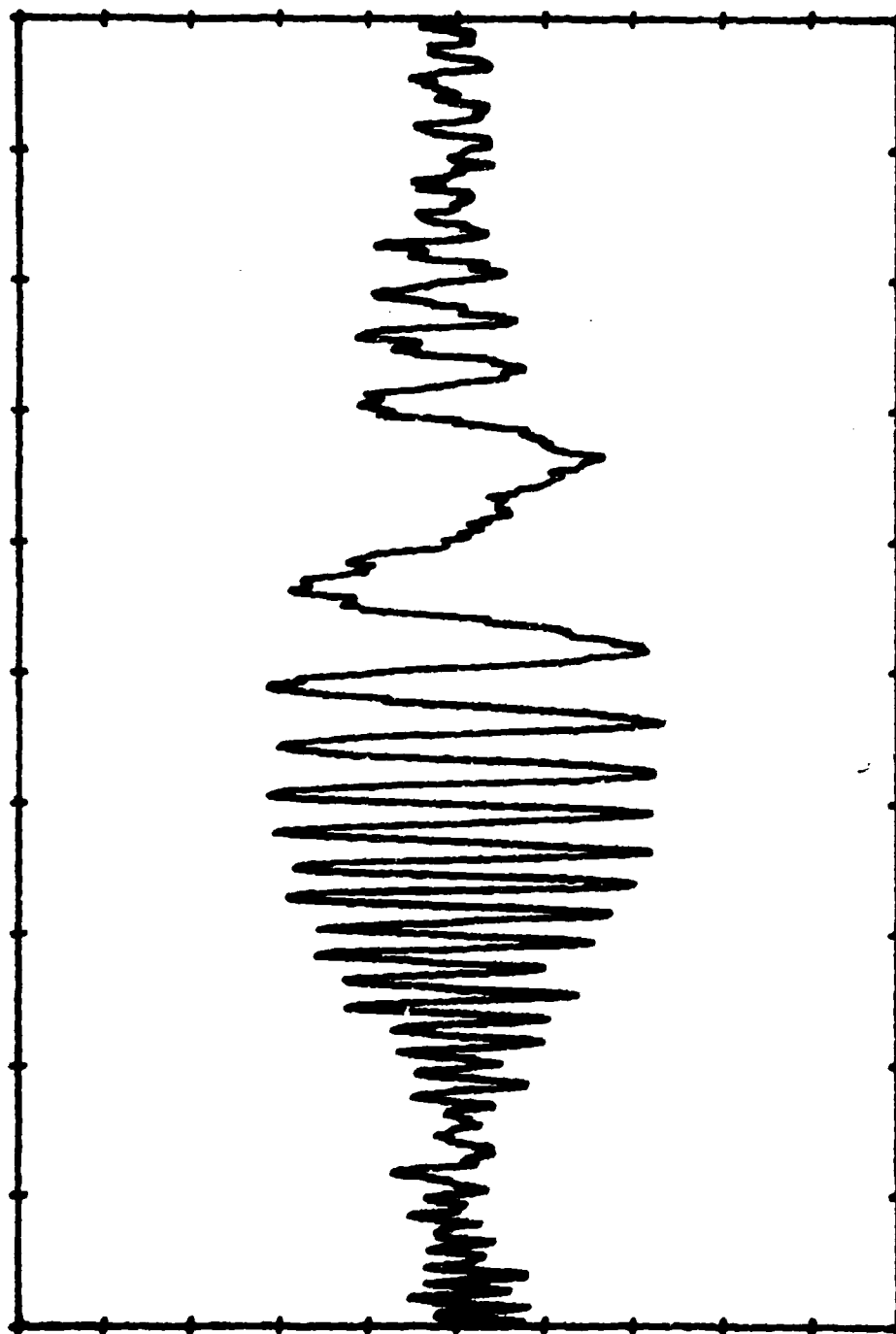
SAMPLES 1 THRU 4000

FILE NAME: ROUND.034 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:35:10.552



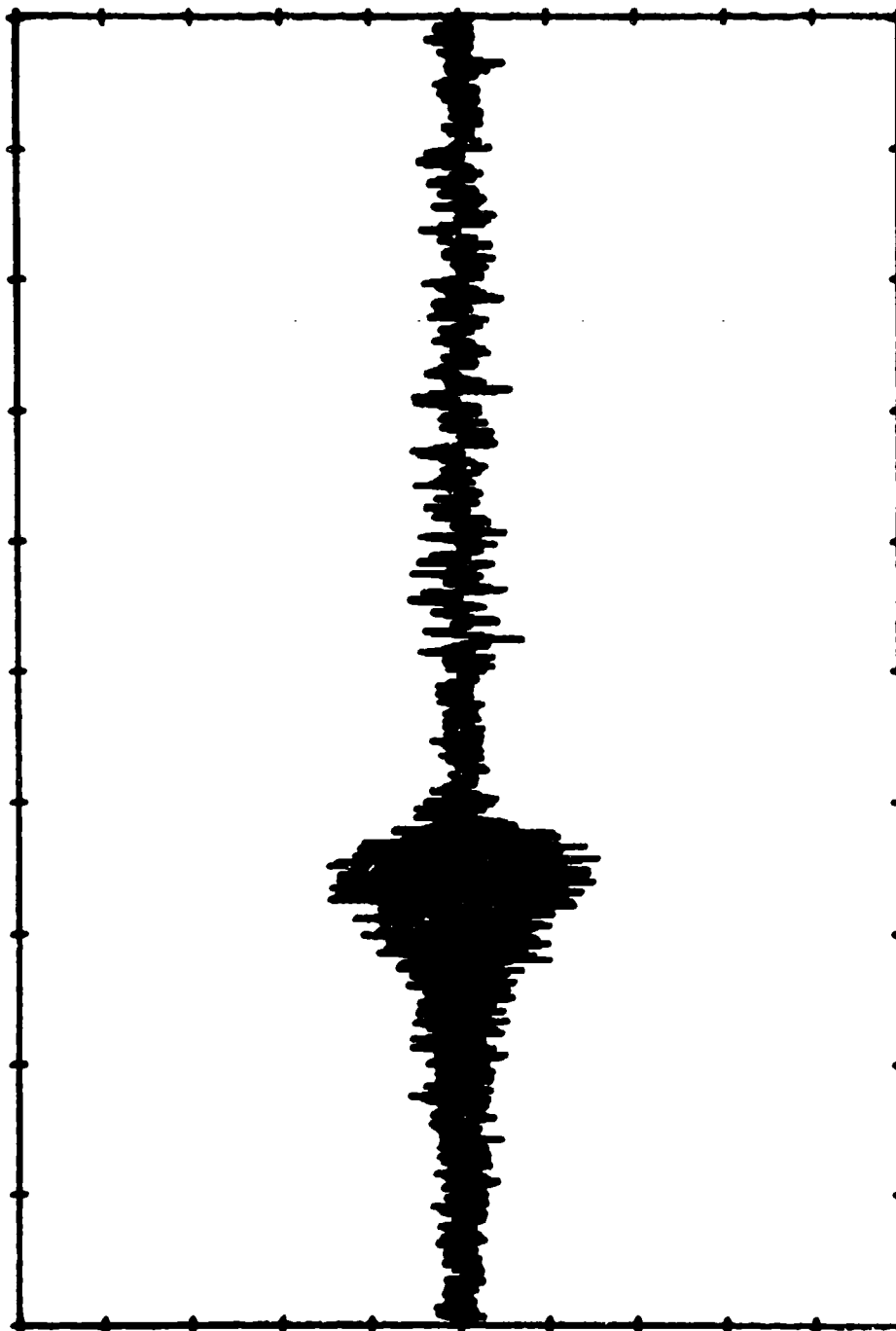
SAMPLES 1 THRU 2000

FILE NAME: ROUND.034 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325: 2:35:10.552



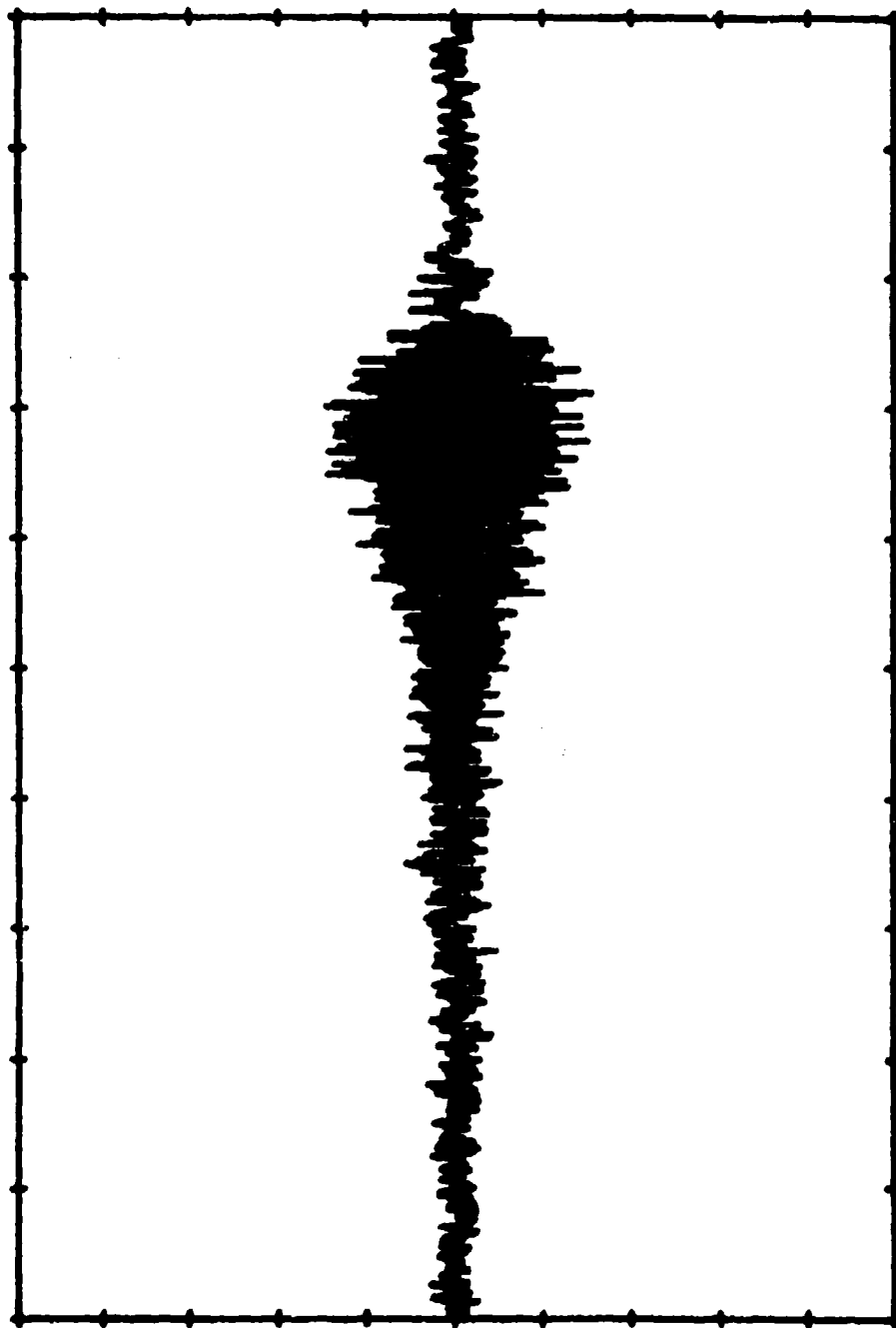
SAMPLES 500 THRU 1300

FILE NAME: ROUND.035 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:46:41.758



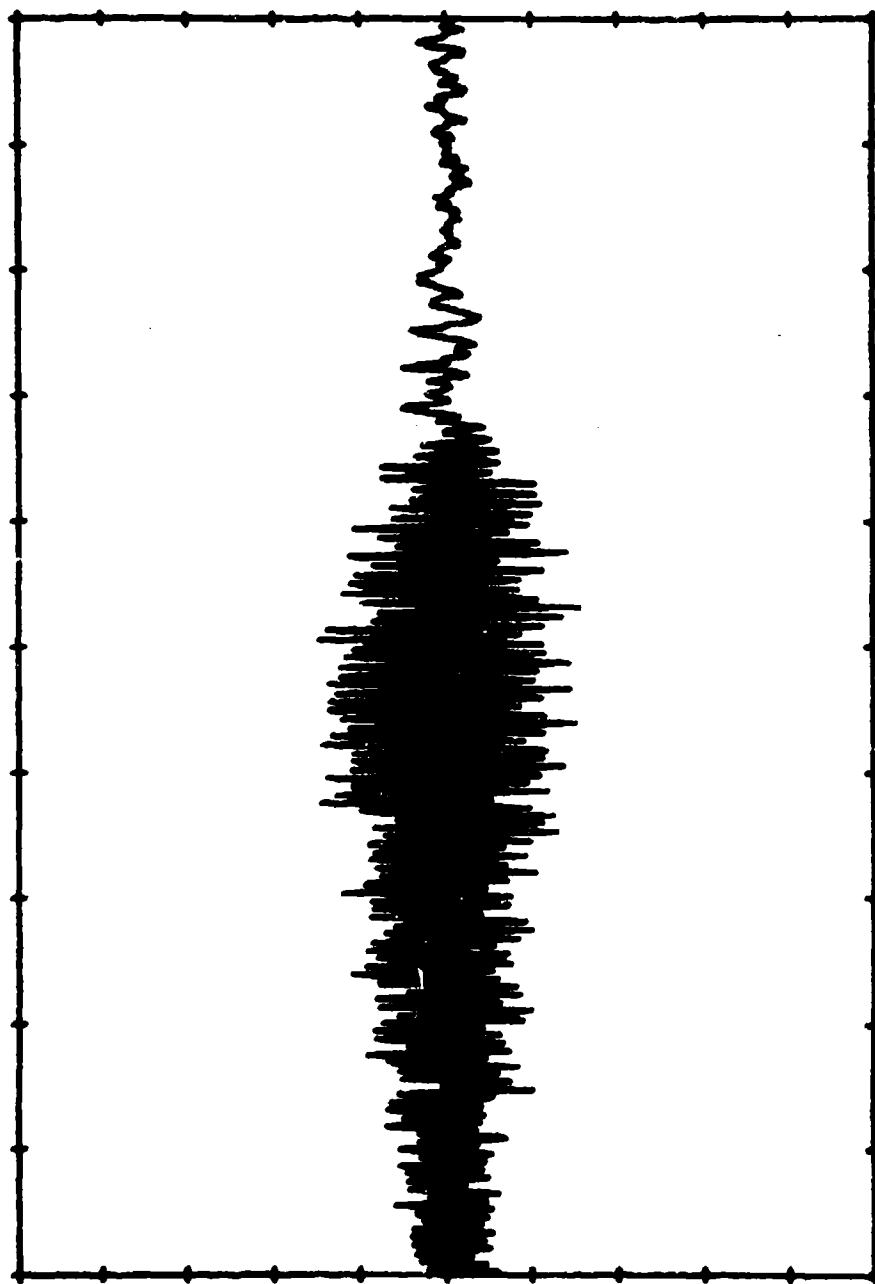
SAMPLES 1 THRU 4000

FILE NAME: ROUND.035 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325.23.46:41.758



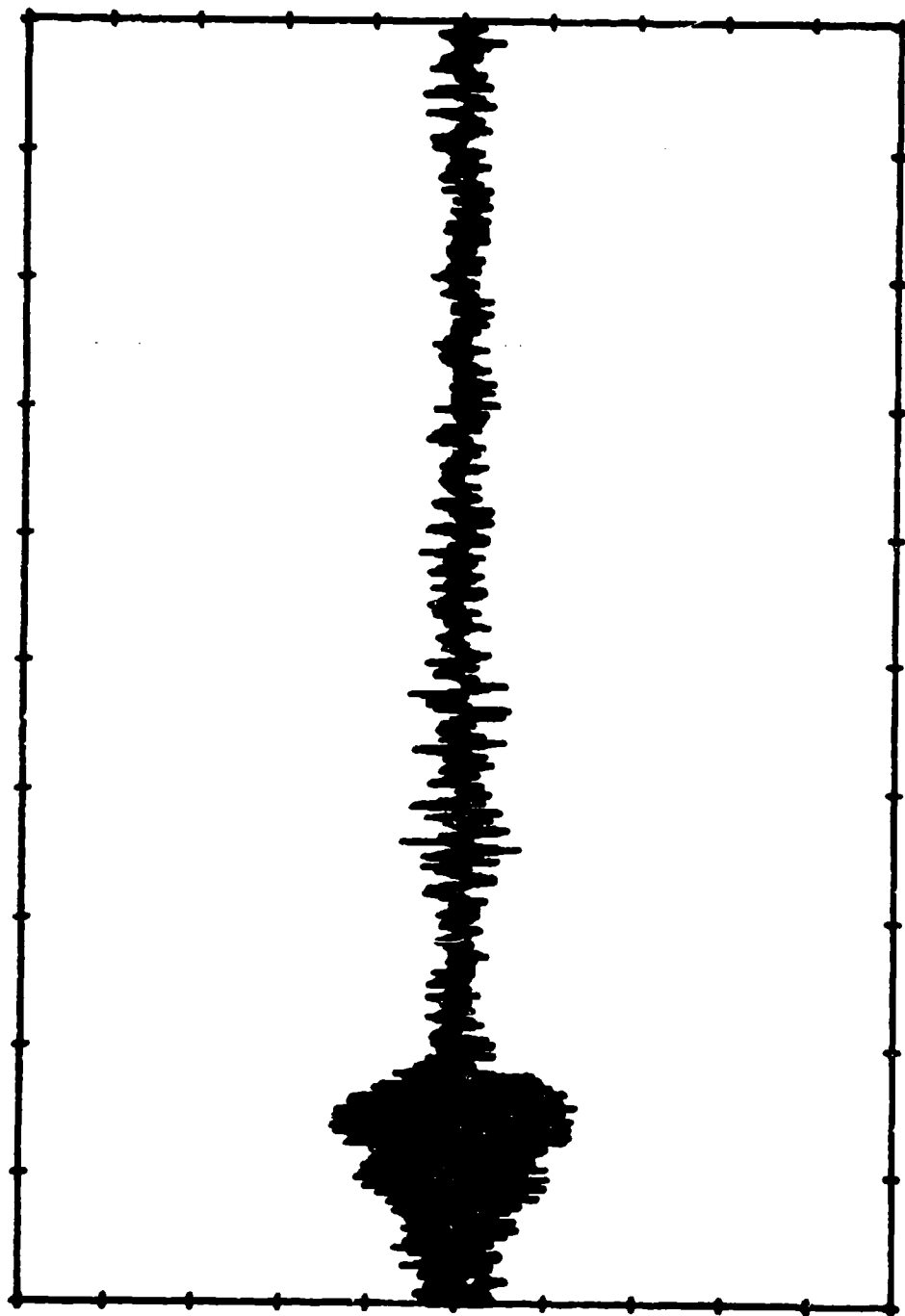
SAMPLES 1 THRU 2000

FILE NAME: ROUND.035 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325.23:46.41.758



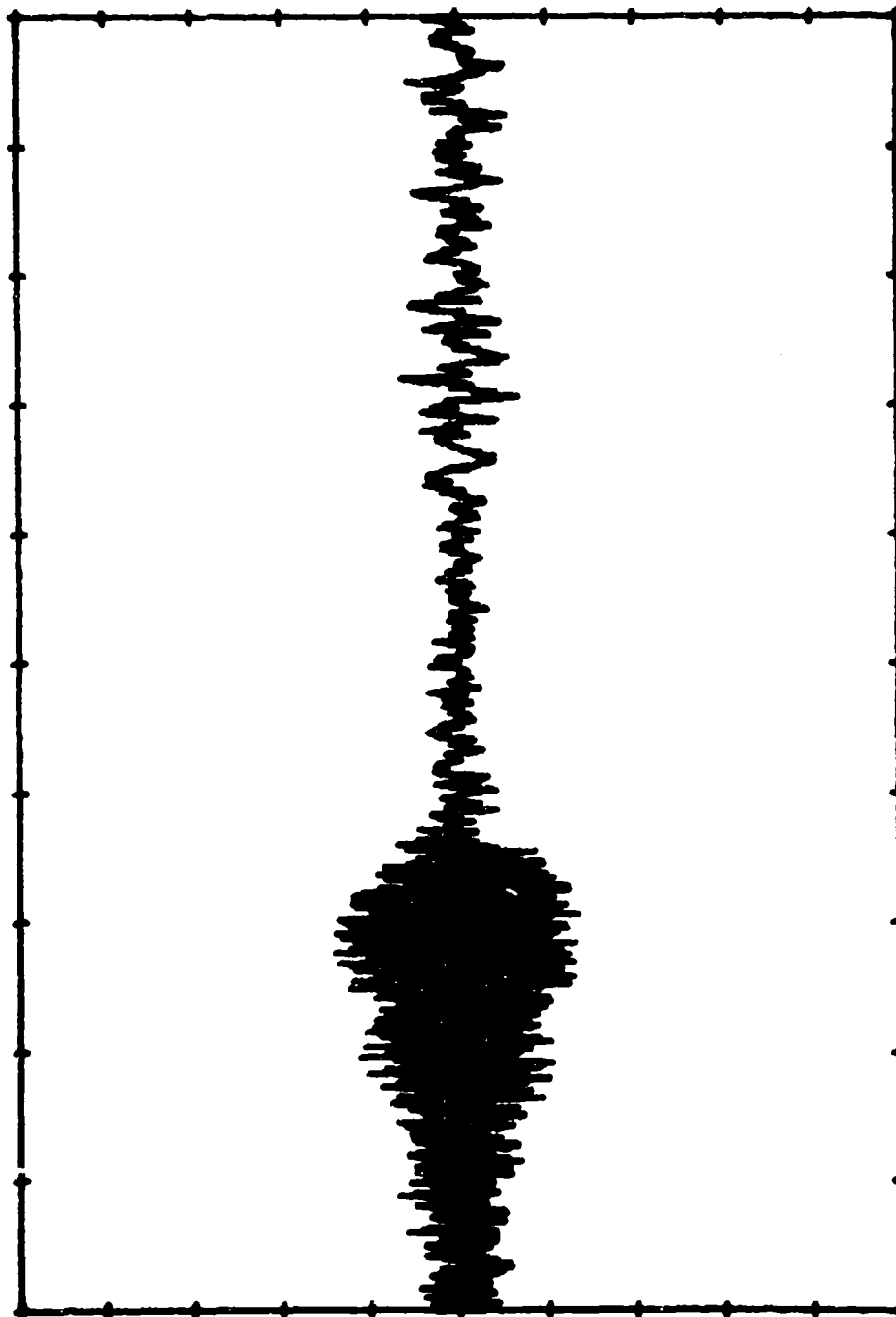
SAMPLES 1000 THRU 1800

FILE NAME: ROUND.036 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:50: 9.386



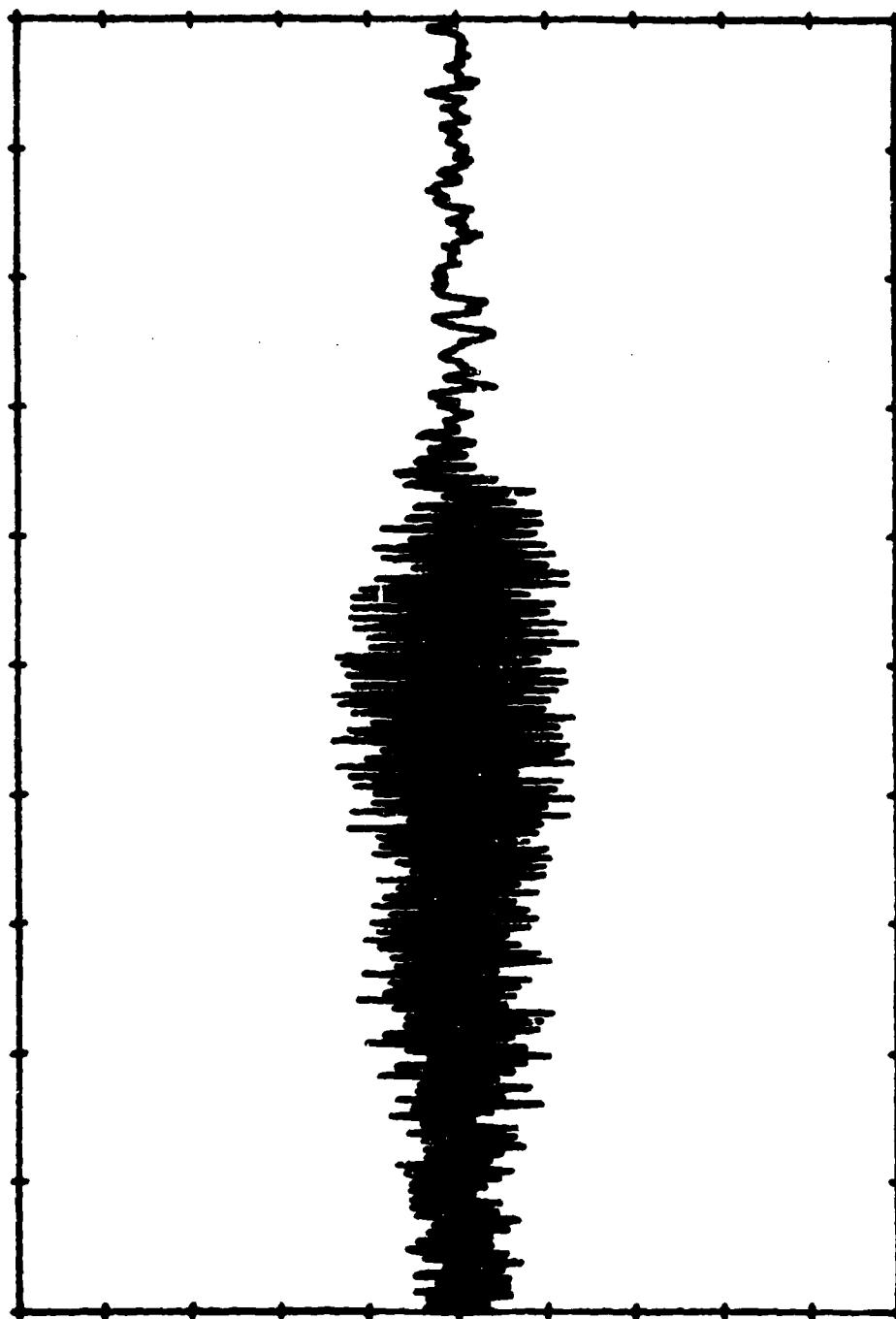
SAMPLES 1 THRU 4000

FILE NAME: ROUND.036 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:50: 9.386



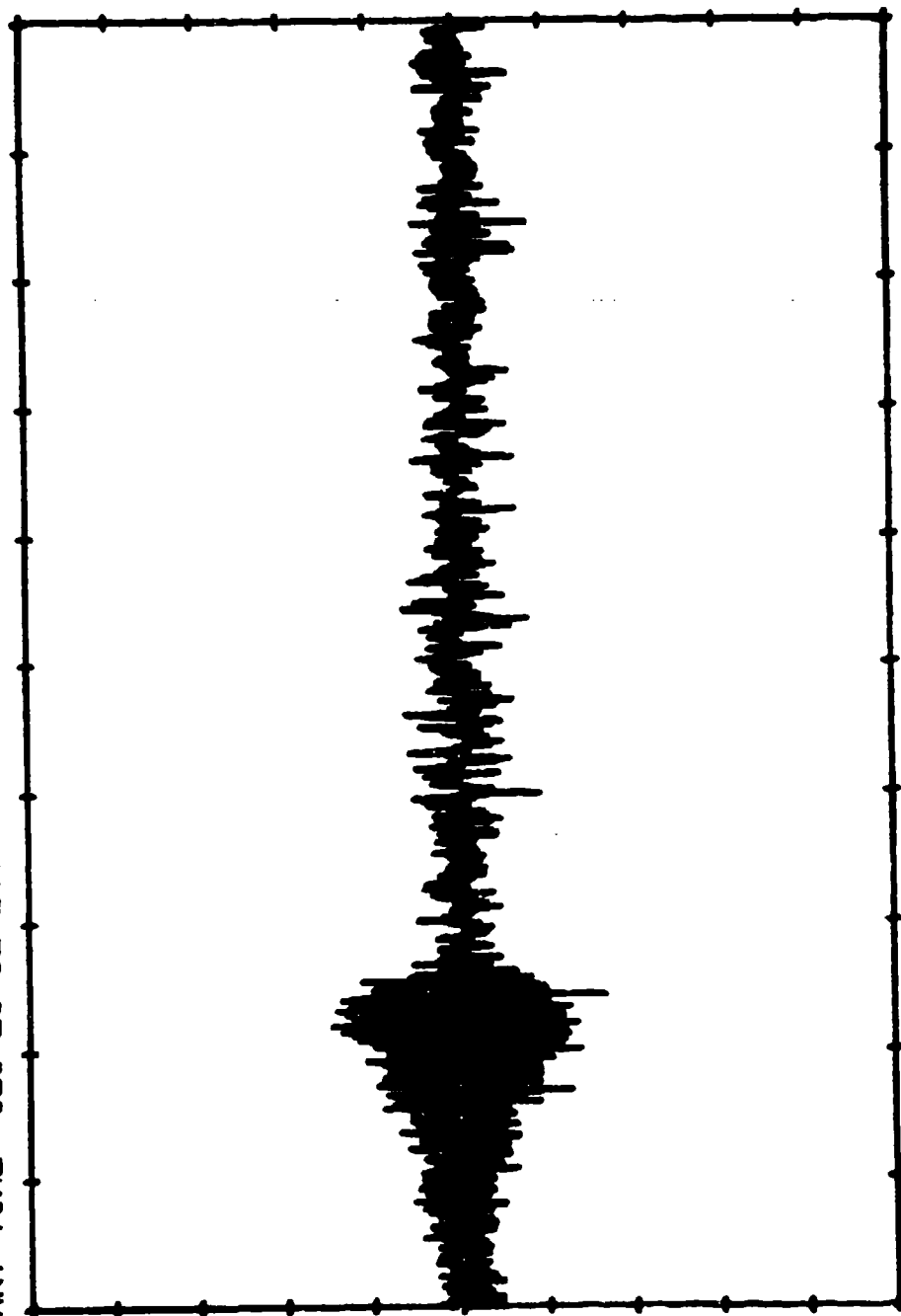
SAMPLES 1 THRU 2000

FILE NAME: ROUND.036 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:50: 9.386



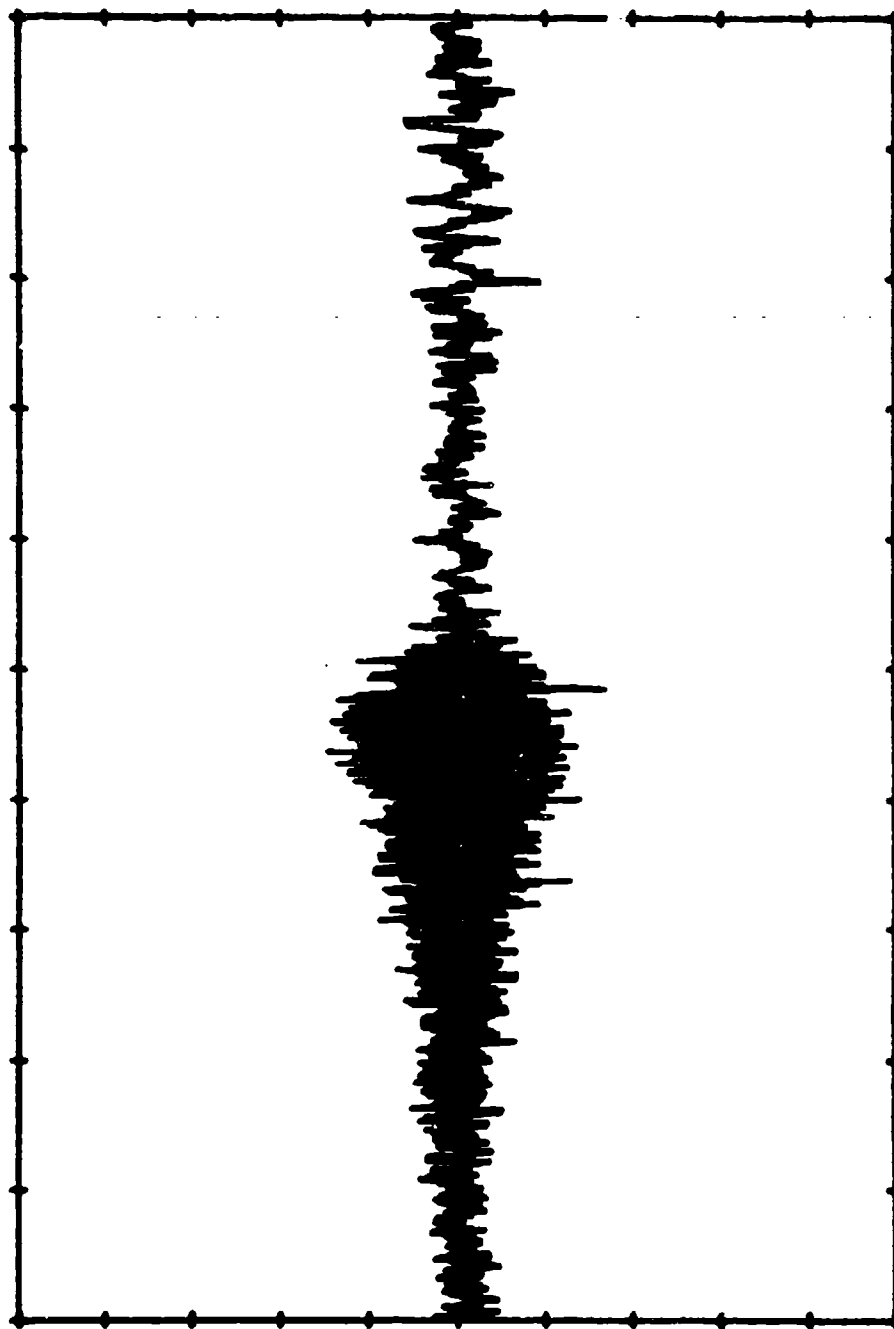
SAMPLES 200 THRU 1000

FILE NAME: ROUND.037 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:52.21.411



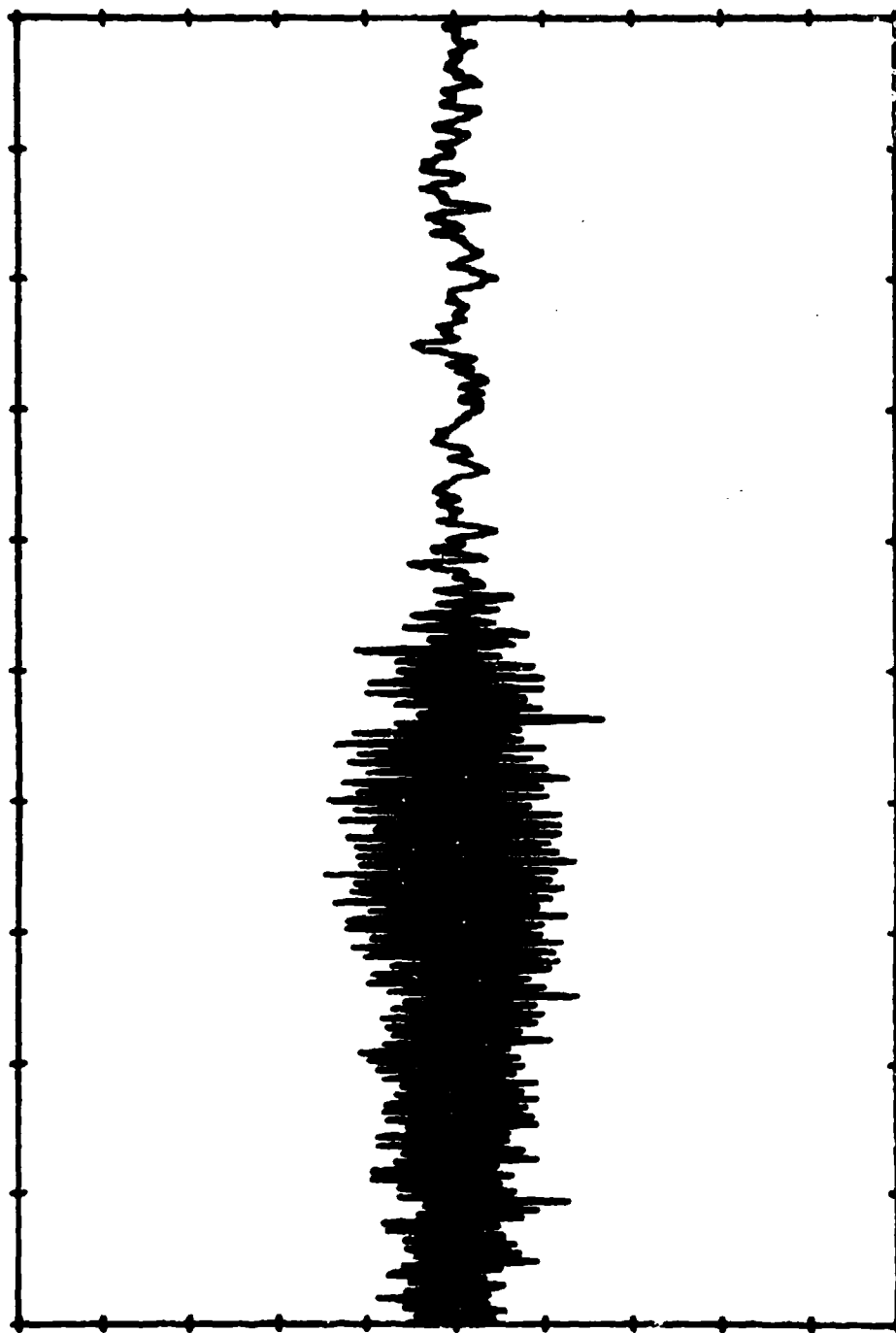
SAMPLES 1 THRU 4000

FILE NAME: ROUND.037 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:52:21.411



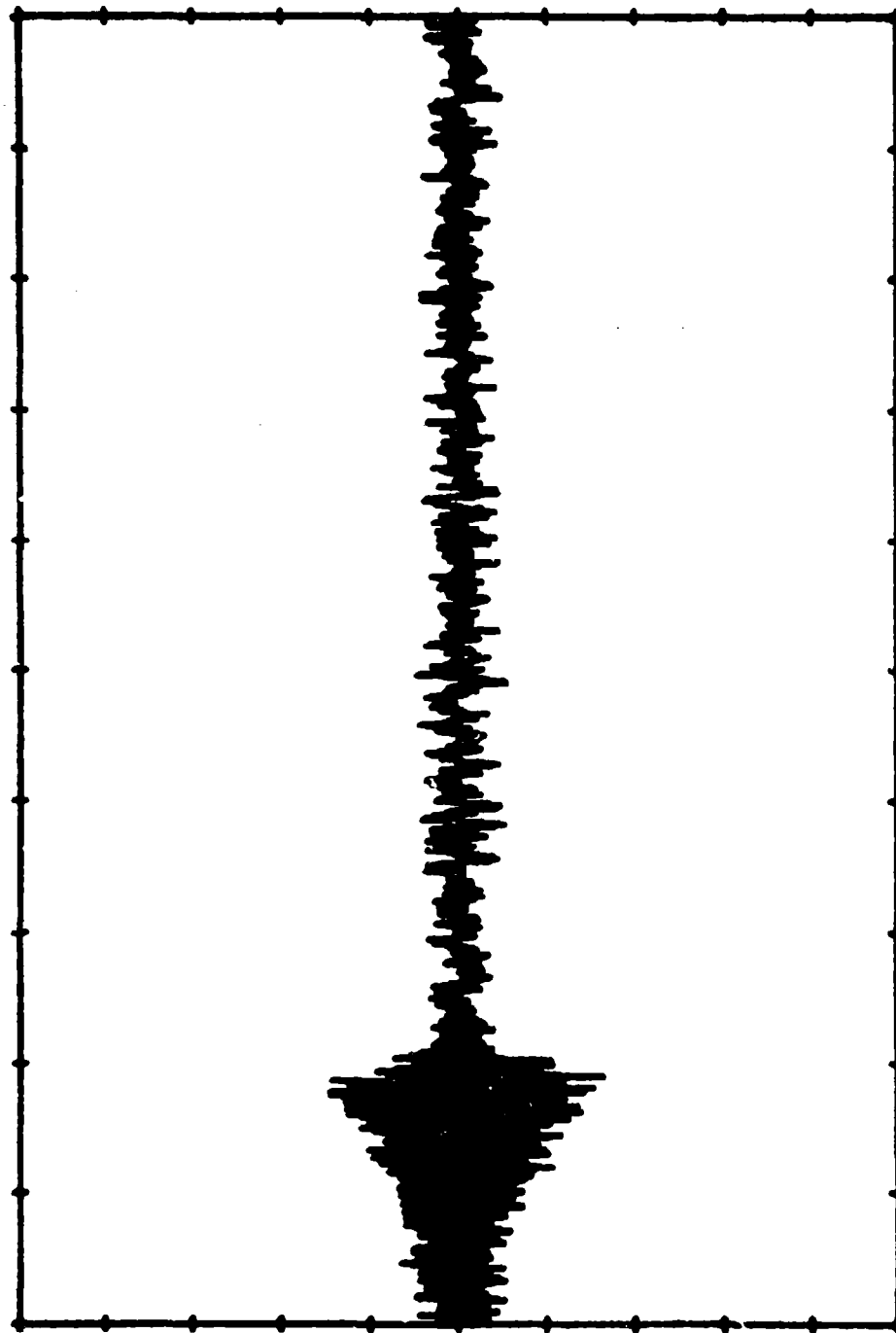
SAMPLES 1 THRU 2000

FILE NAME: ROUND.037 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:52:21.411



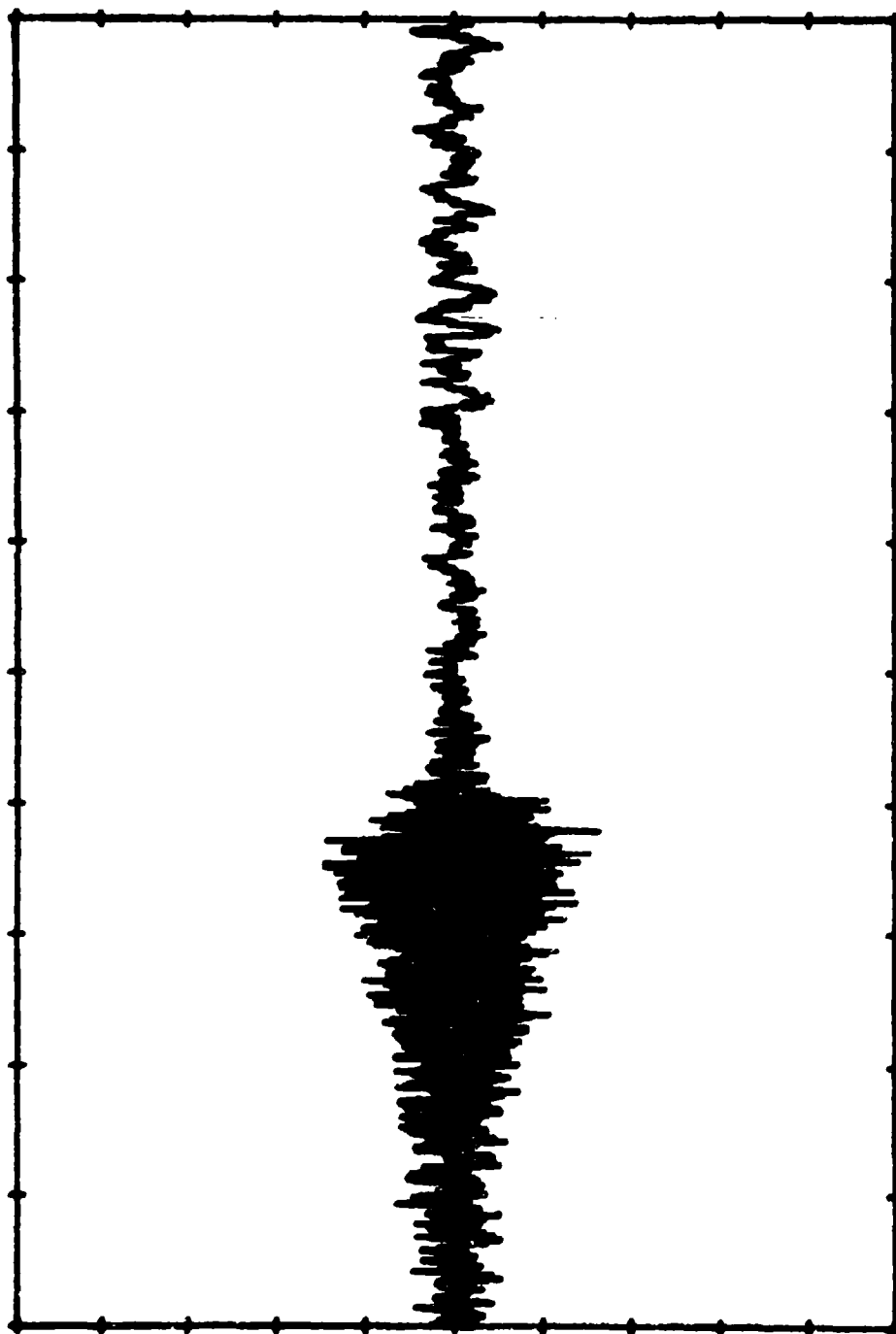
SAMPLES 600 THRU 1400

FILE NAME: ROUND.038 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:55.30. 87



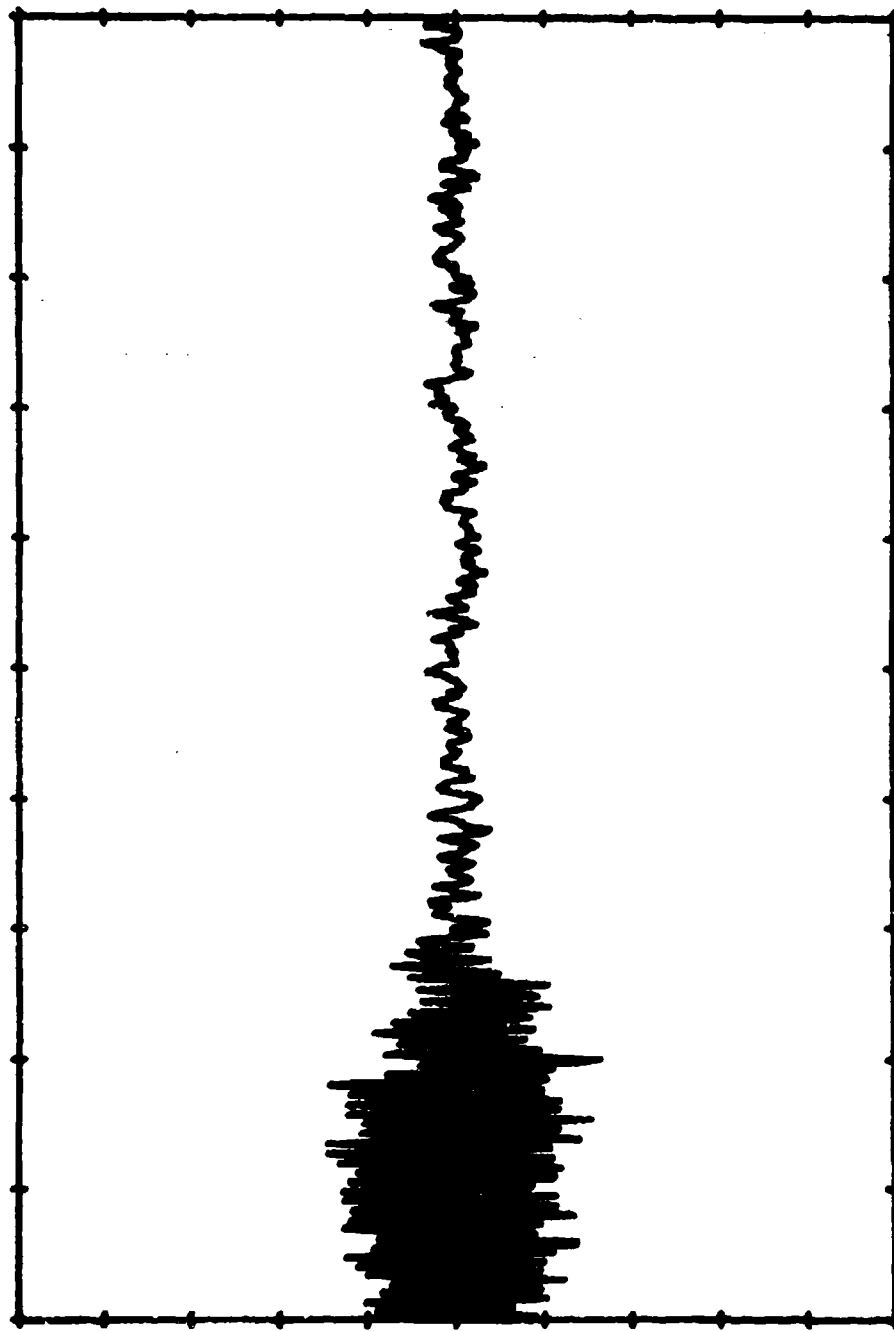
SAMPLES 1 THRU 4000

FILE NAME: ROUND.038 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:55:30. 87



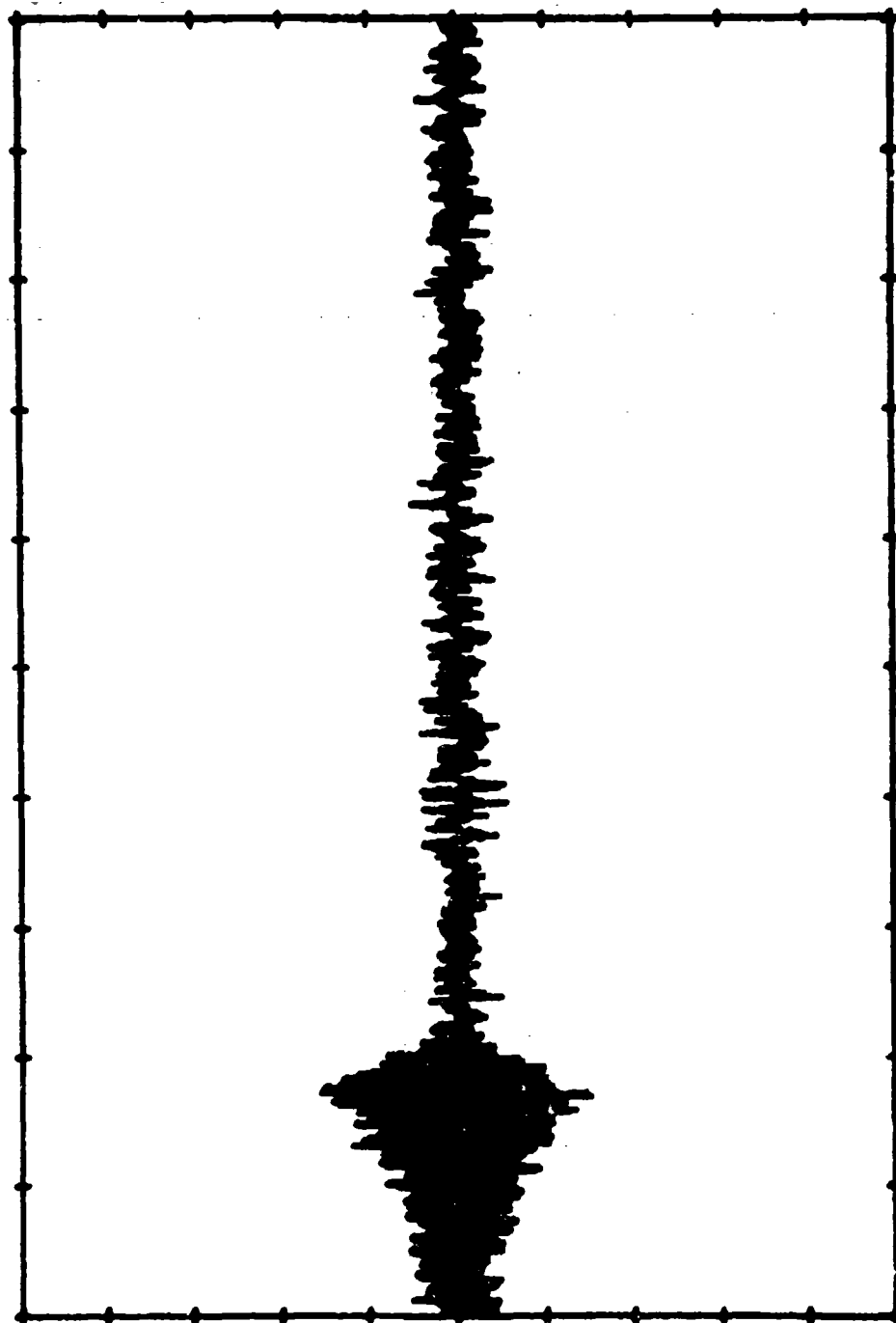
SAMPLES 1 THRU 2000

FILE NAME: ROUND.038 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:55:30.87



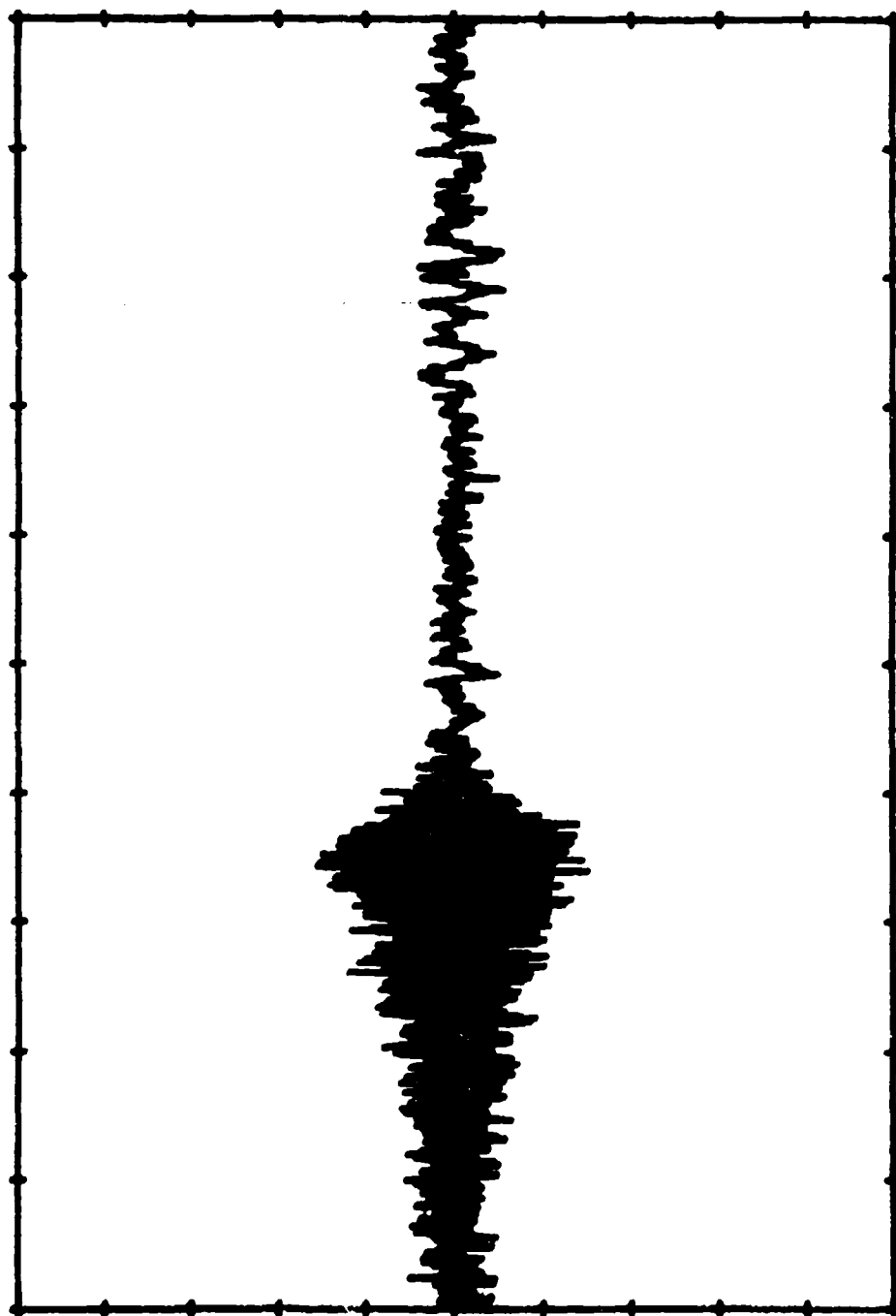
SAMPLES 600 THRU 1400

FILE NAME: ROUND.039 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:59:44.669



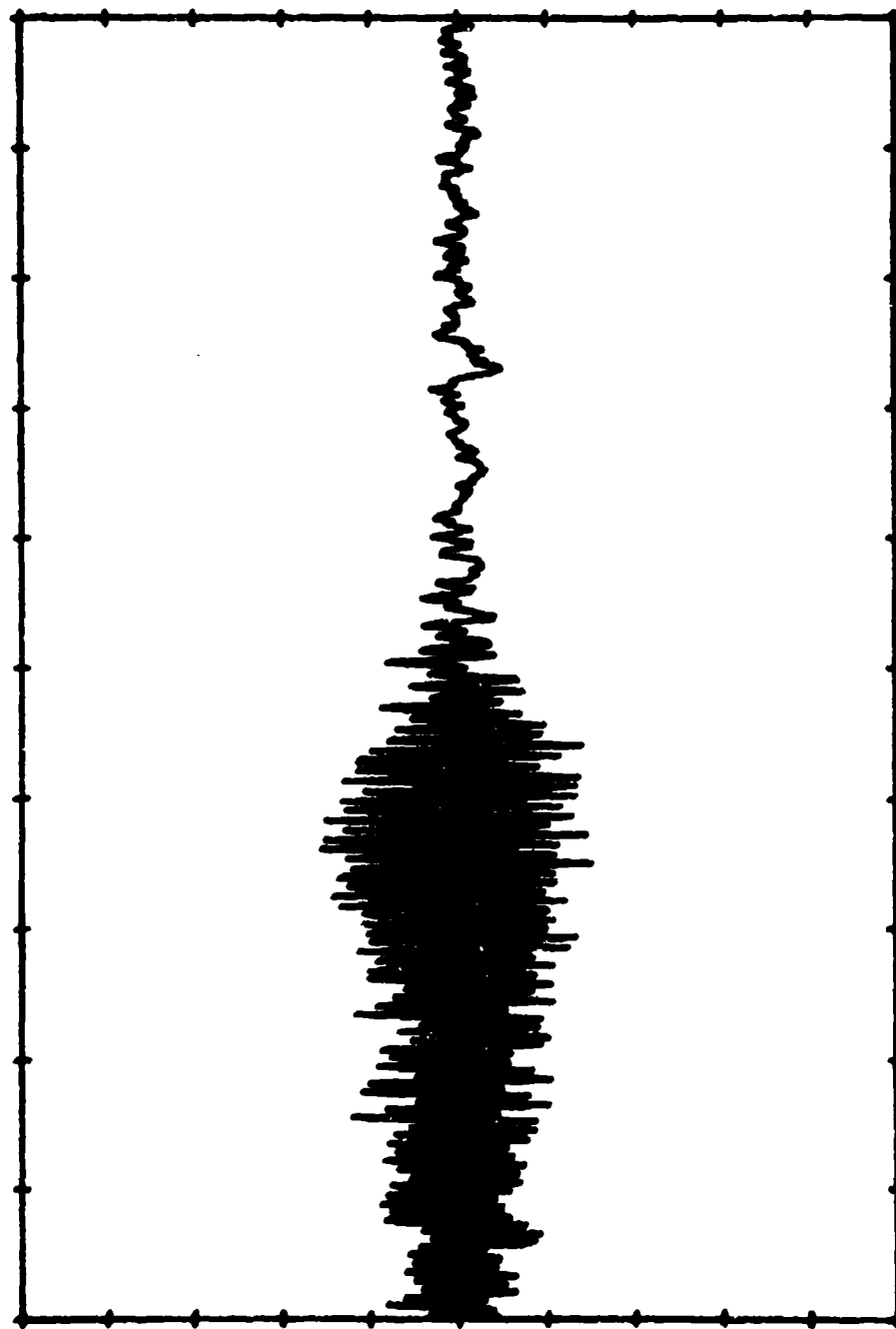
SAMPLES 1 THRU 4000

FILE NAME: ROUND 039 FILE DATA RECORD NUMBER: 2
FILE START TIME: 323:23:59:44.669



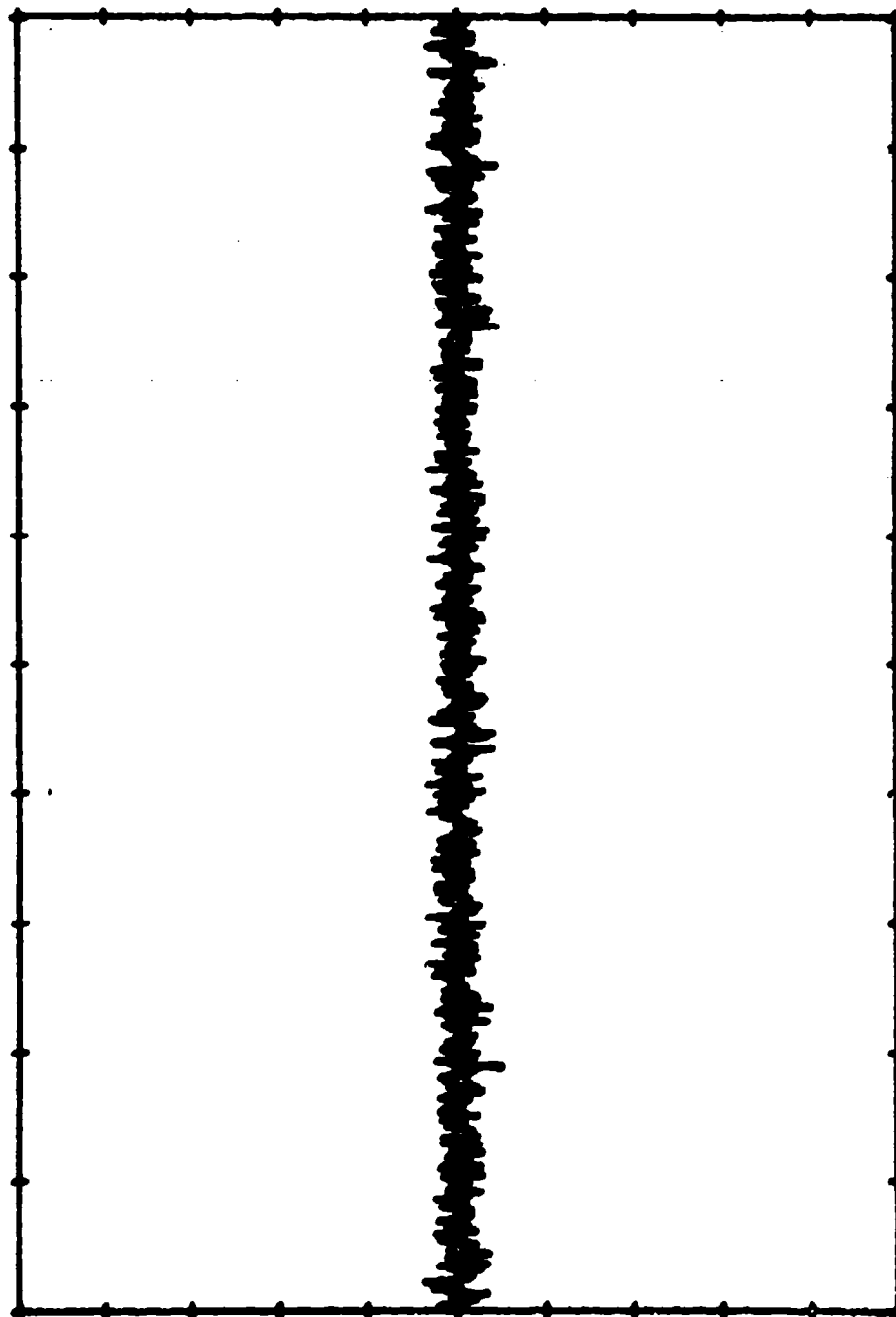
SAMPLES 1 THRU 2000

FILE NAME: ROUND.039 FILE DATA RECORD NUMBER: 2
FILE START TIME: 325:23:59:44.669



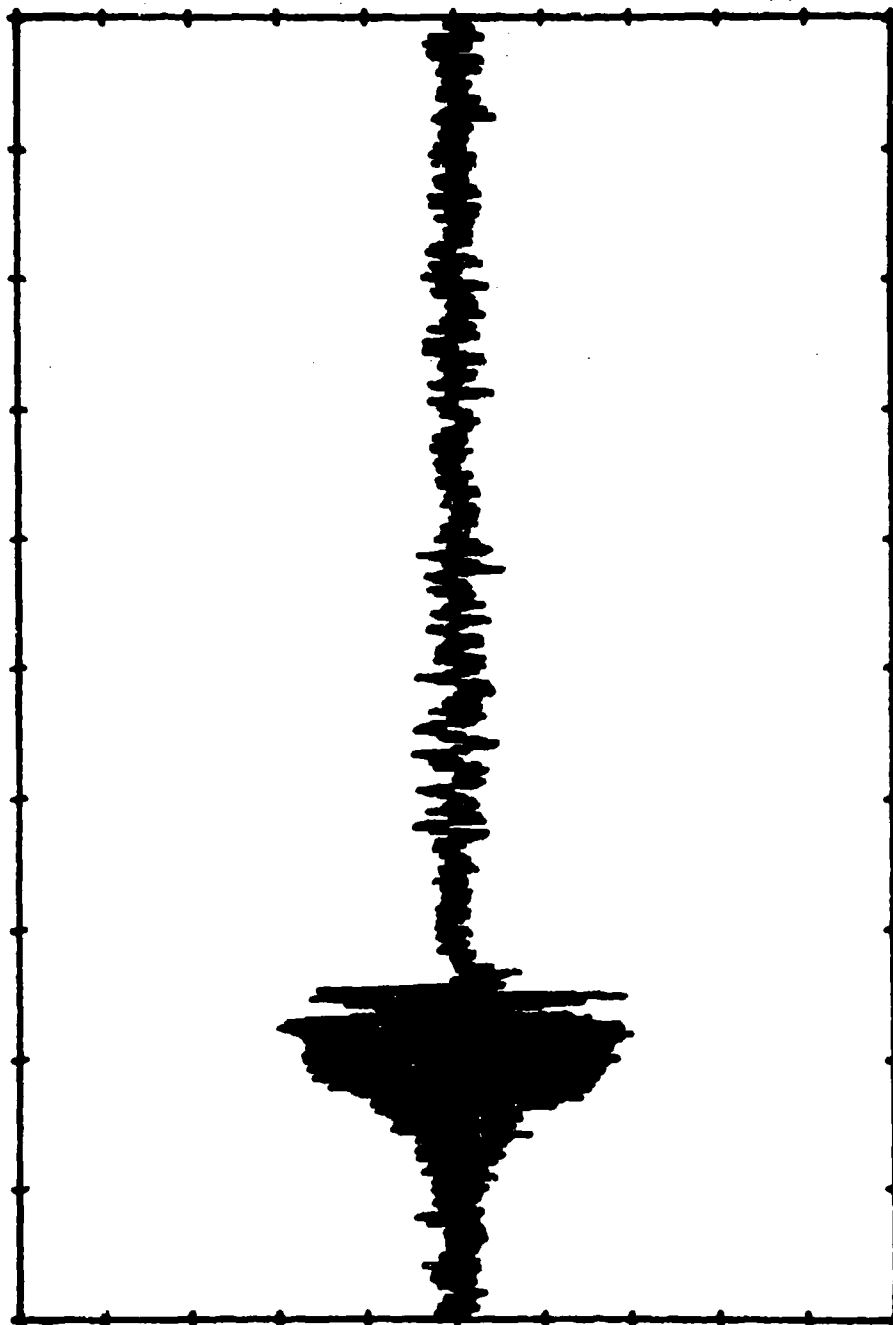
SAMPLES 400 THRU 1200

FILE NAME: ROUND.040 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326.0: 4:33.698



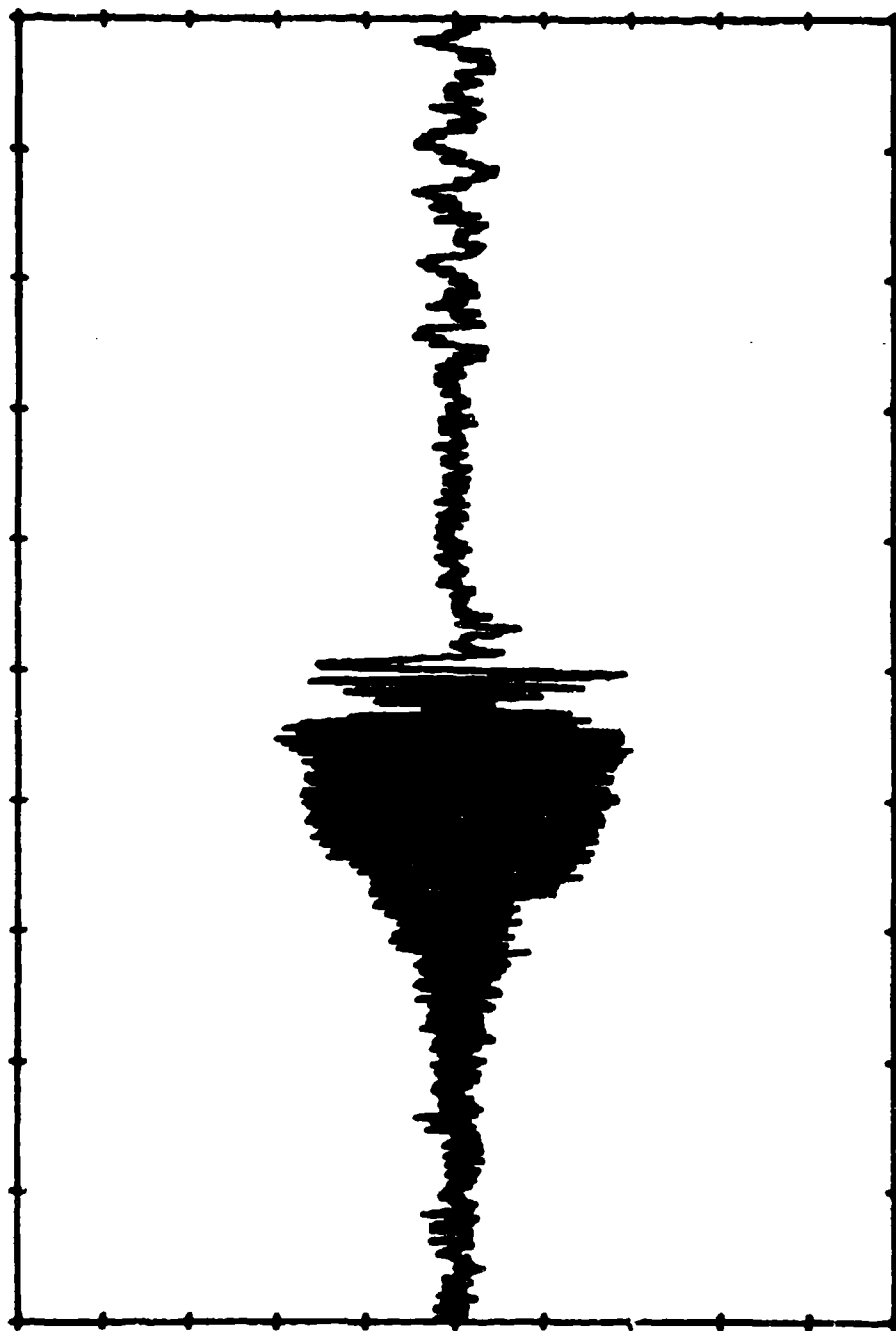
SAMPLES 1 THRU 4000

FILE NAME: ROUND 041 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:20: 3.931



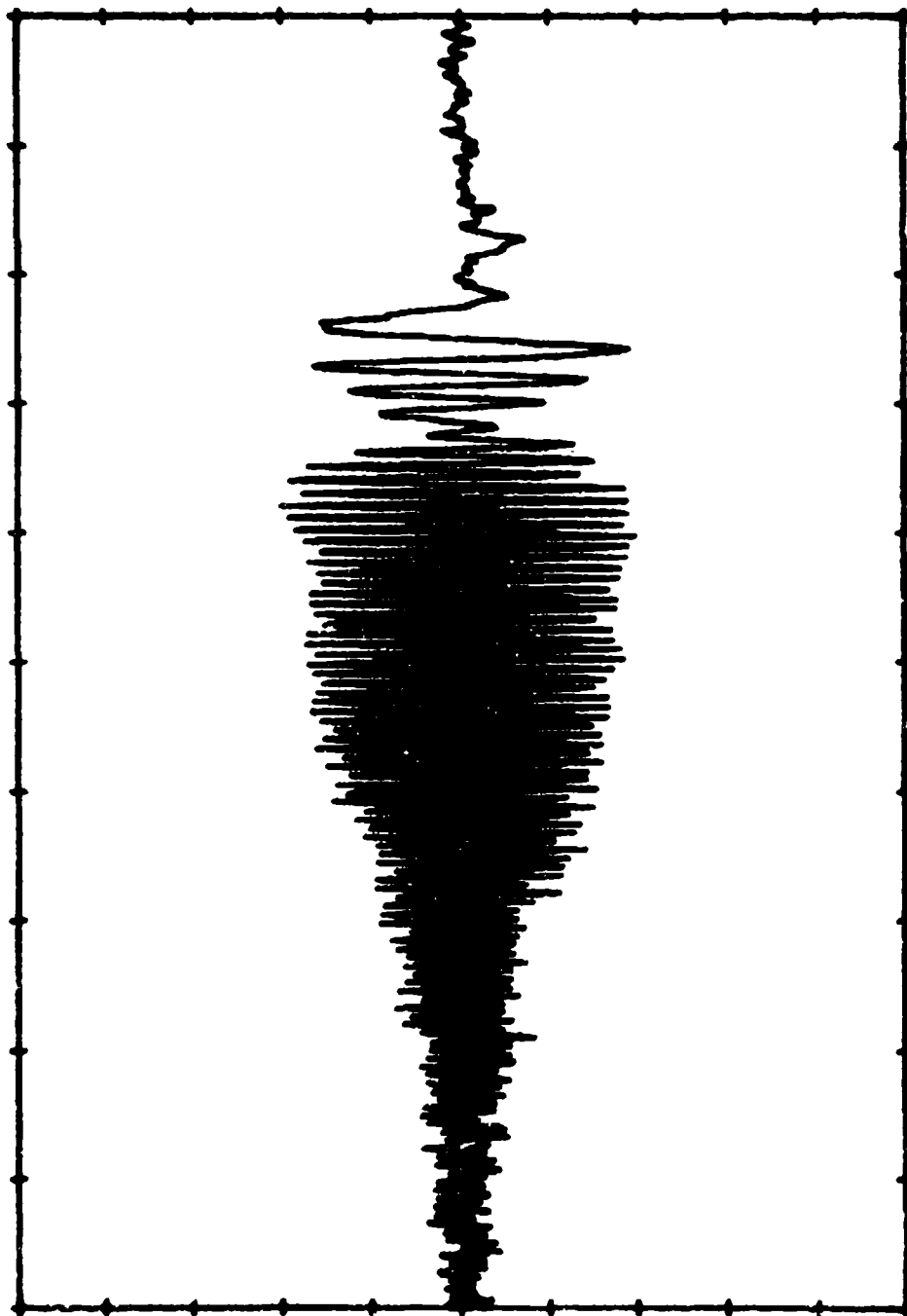
SAMPLES 1 THRU 4000

FILE NAME: ROUND.041 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:20: 3.931



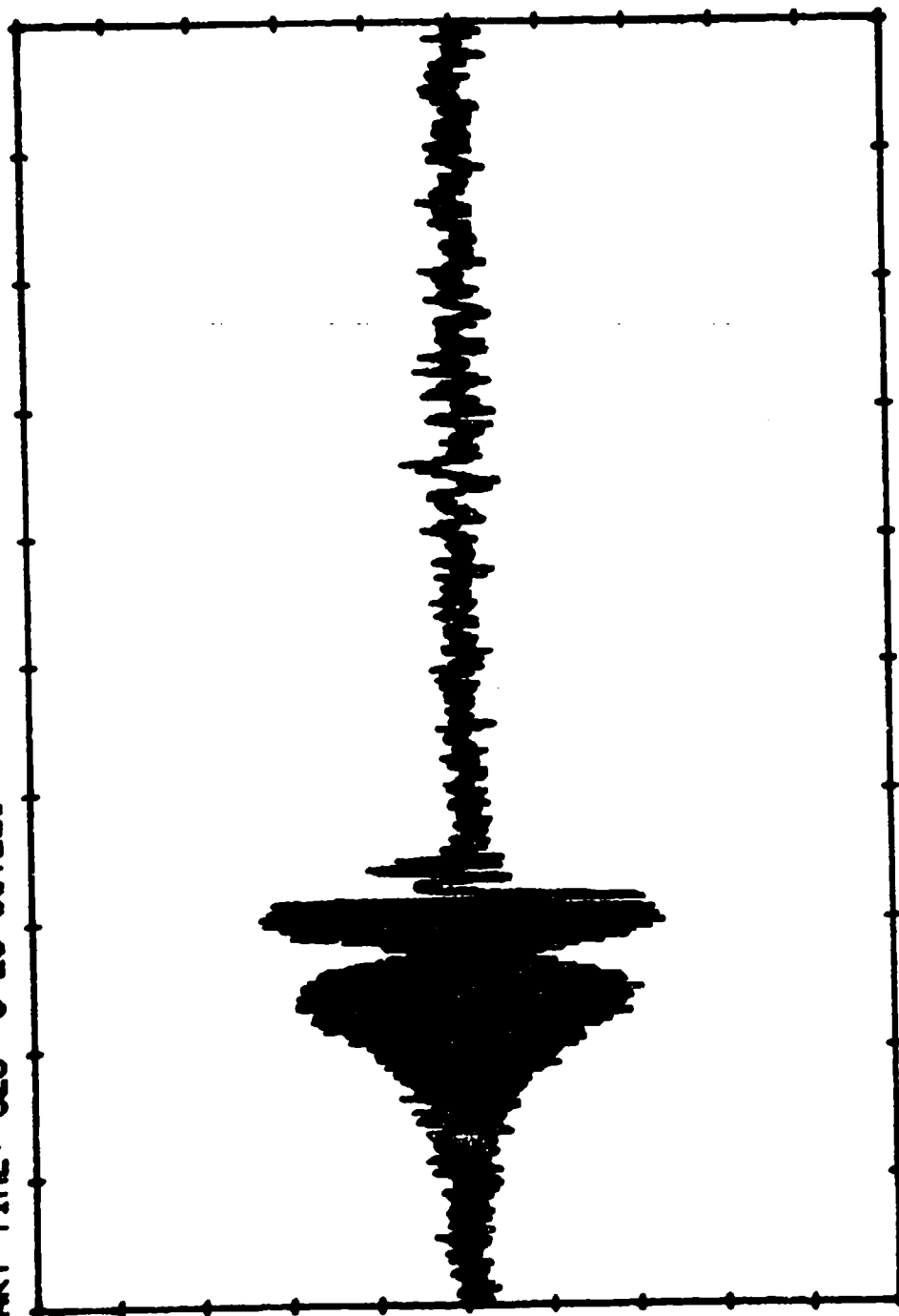
SAMPLES 1 THRU 2000

FILE NAME: ROUND.041 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0:20: 3.931



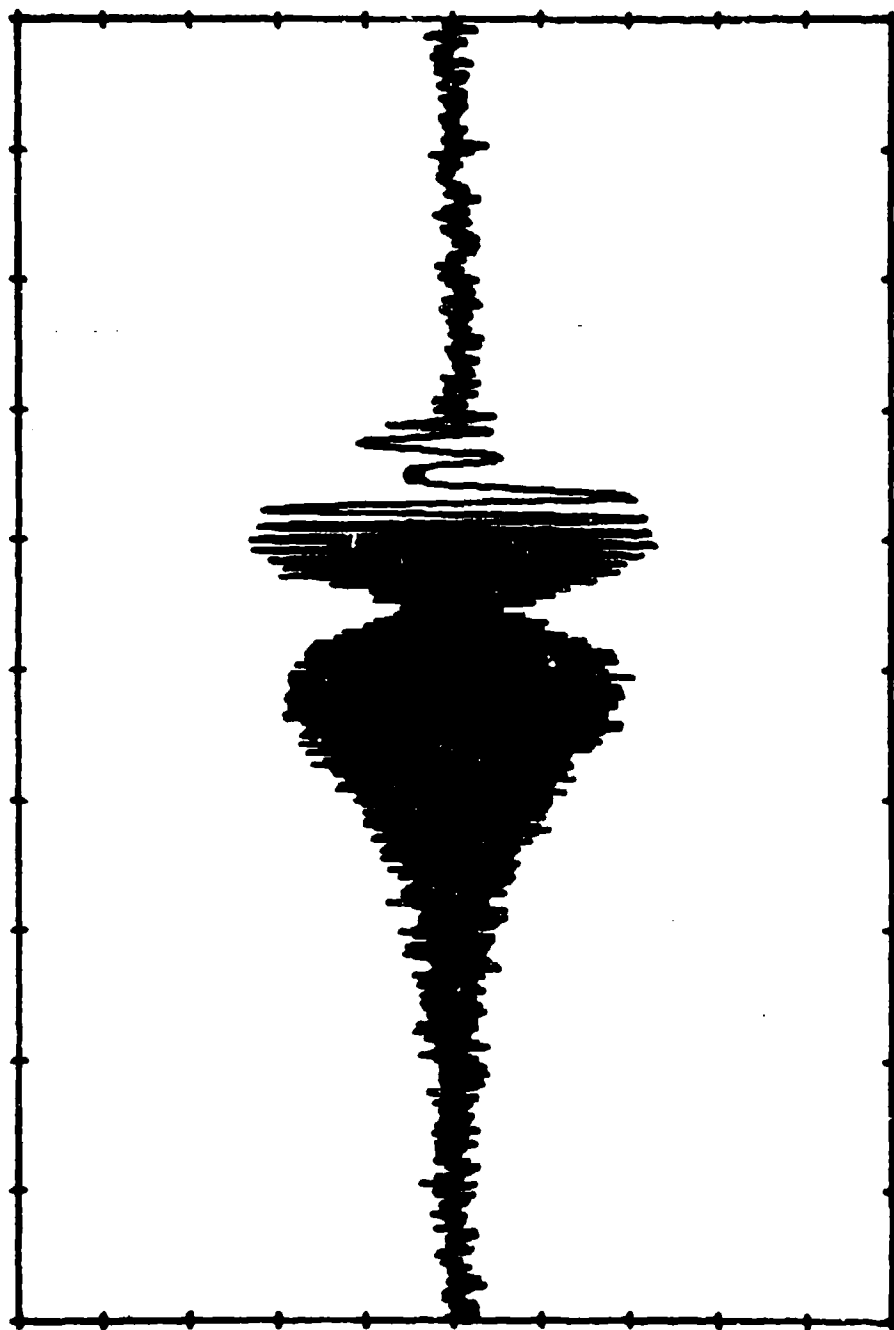
SAMPLES 400 THRU 1200

FILE NAME: ROUND.042 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326. 0:23:30.226



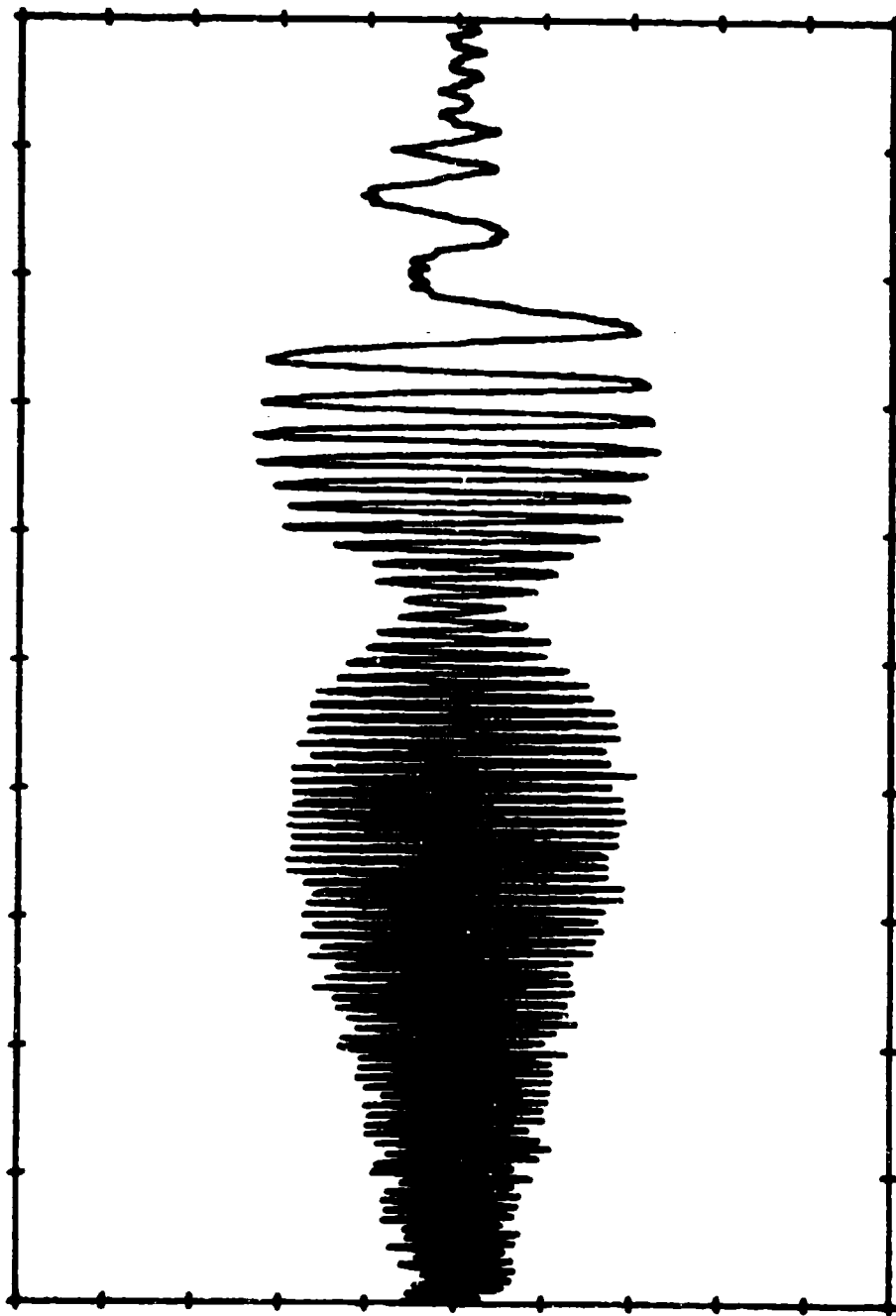
SAMPLES 1 THRU 4000

FILE NAME: ROUND.042 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326. 0:23:30.226



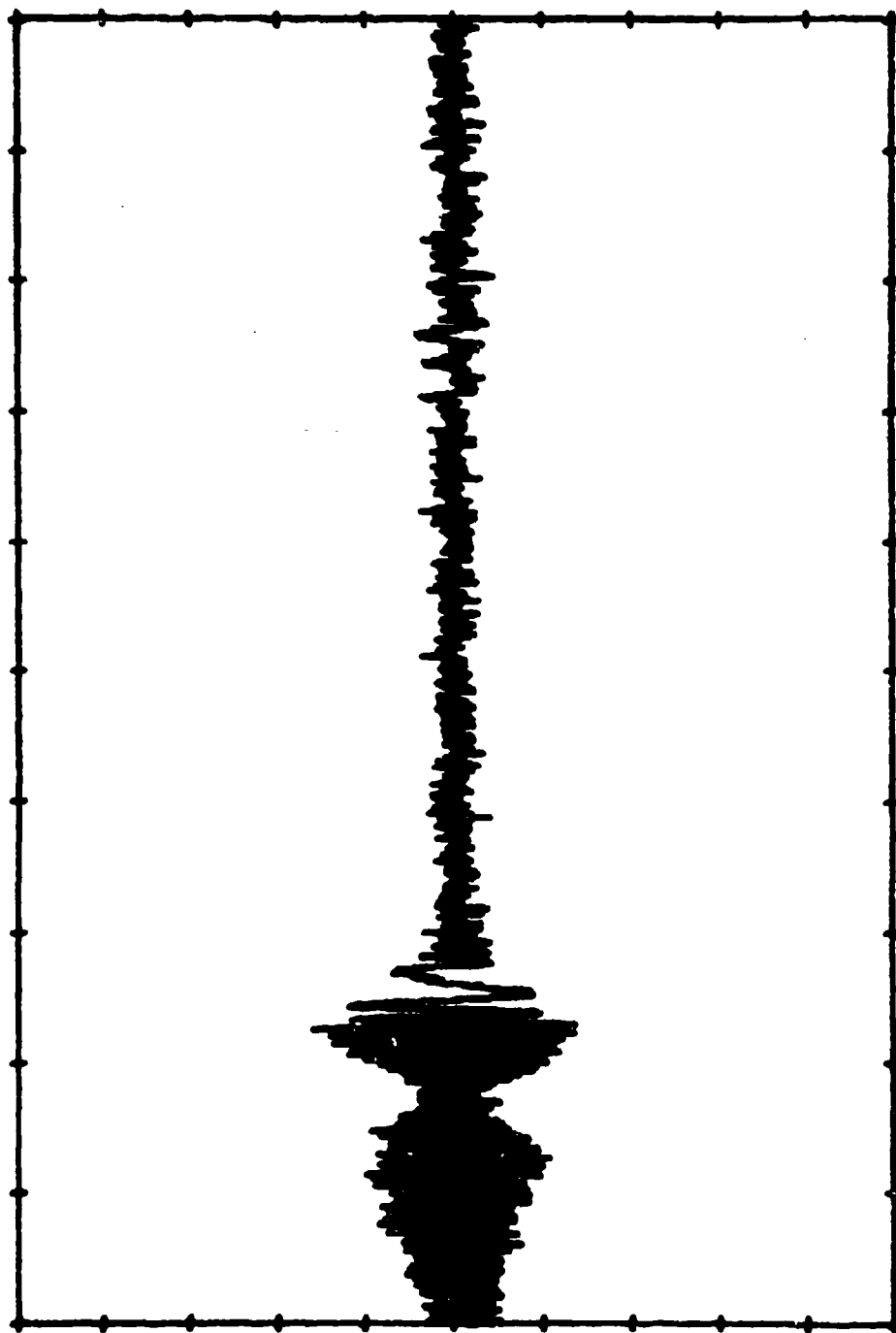
SAMPLES 1 THRU 2000

FILE NAME: ROUND.042 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:23:30.226



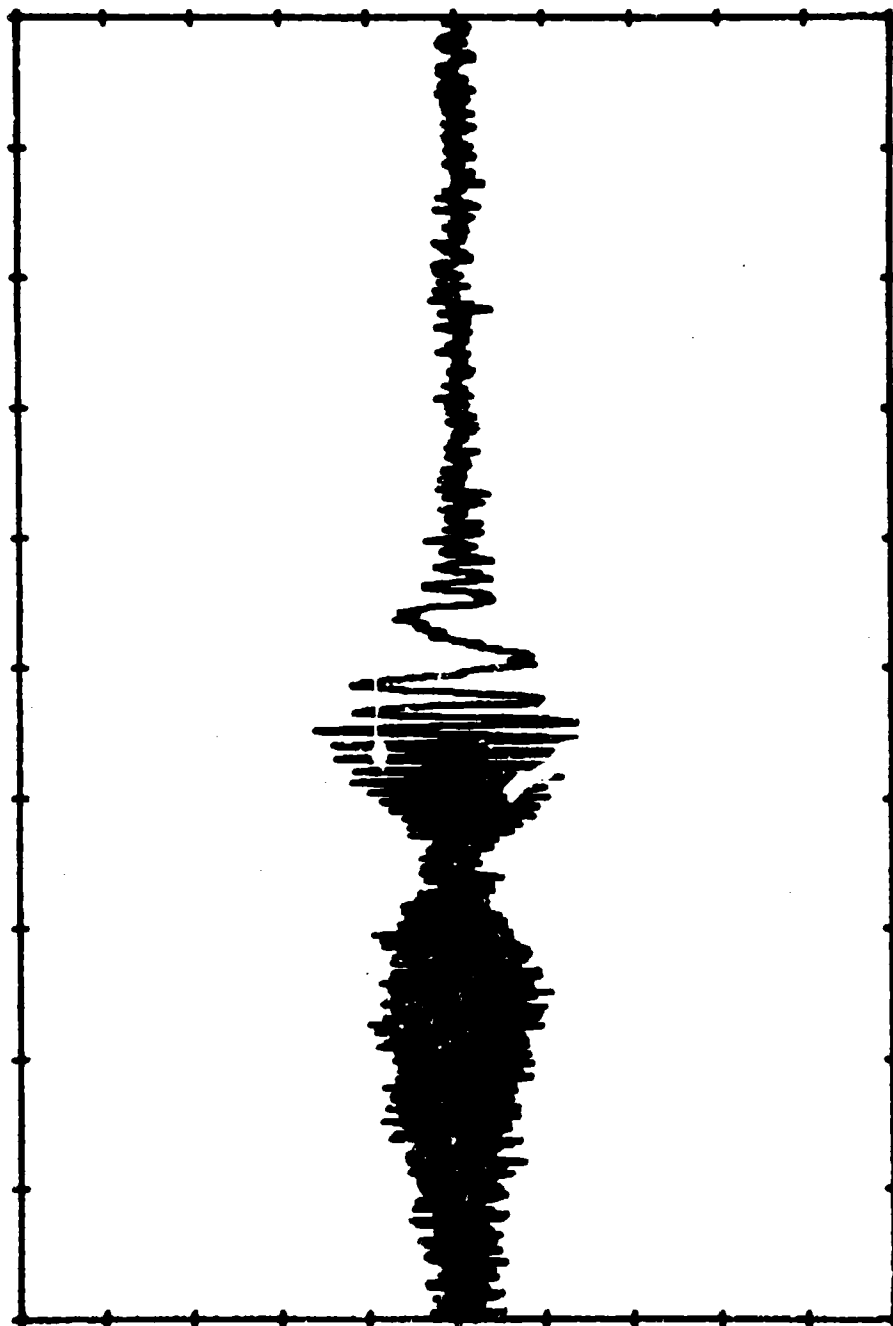
SAMPLES 660 THRU 1460

FILE NAME: ROUND.043 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0:26:45.839



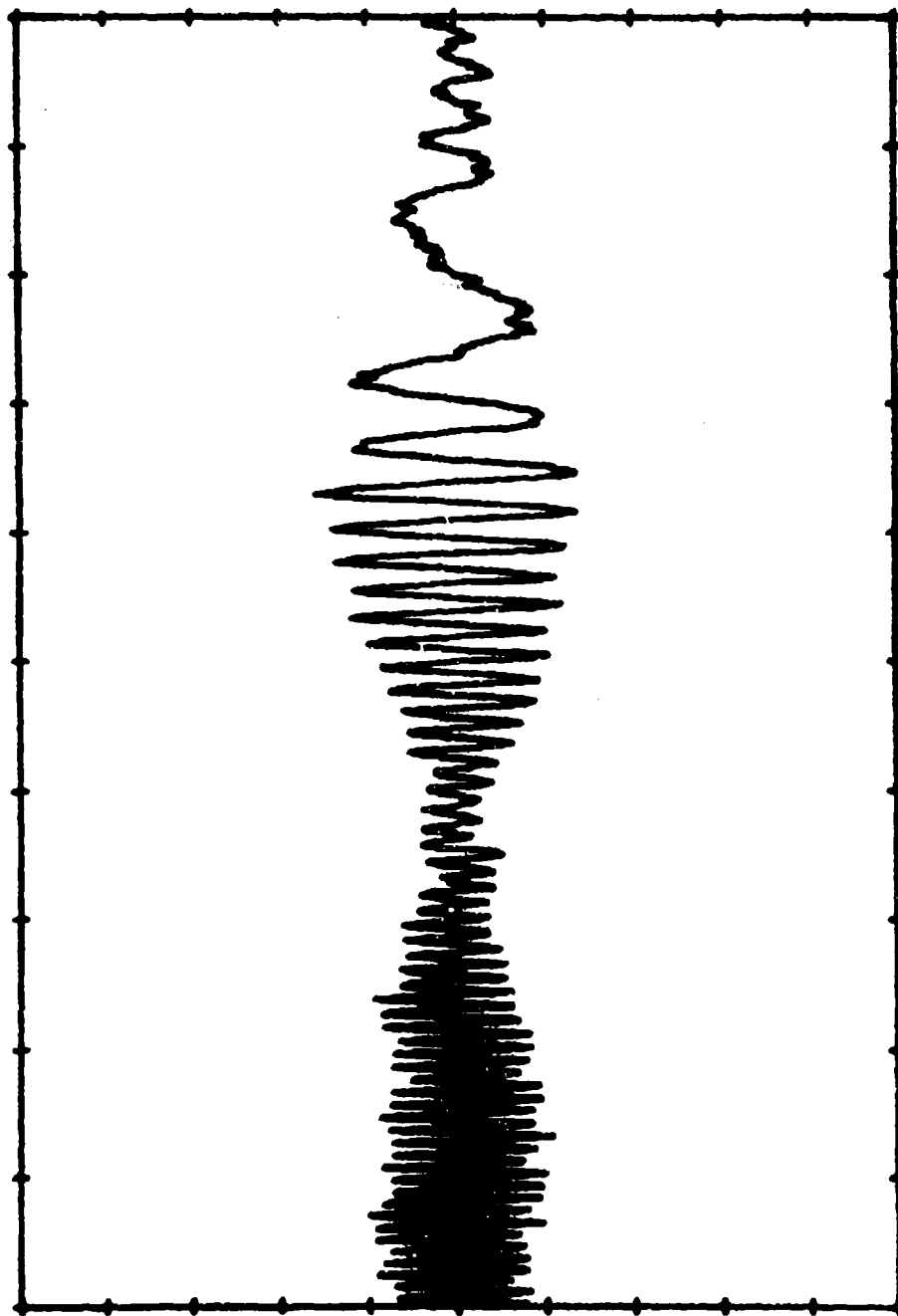
SAMPLES 1 THRU 4000

FILE NAME: ROUND.043 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:26:45.839



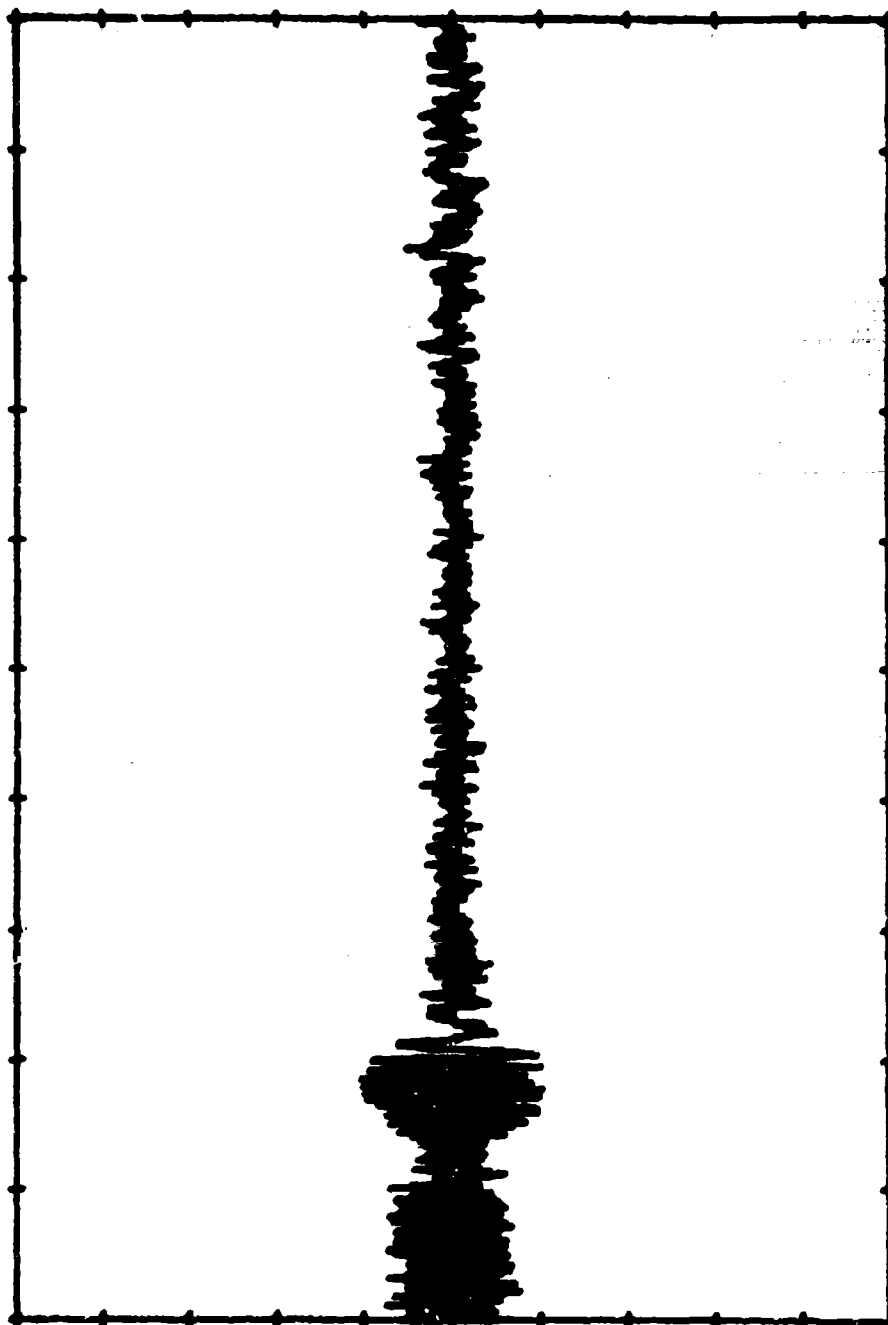
SAMPLES 1 THRU 2000

FILE NAME: ROUND.043 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:26:45.839



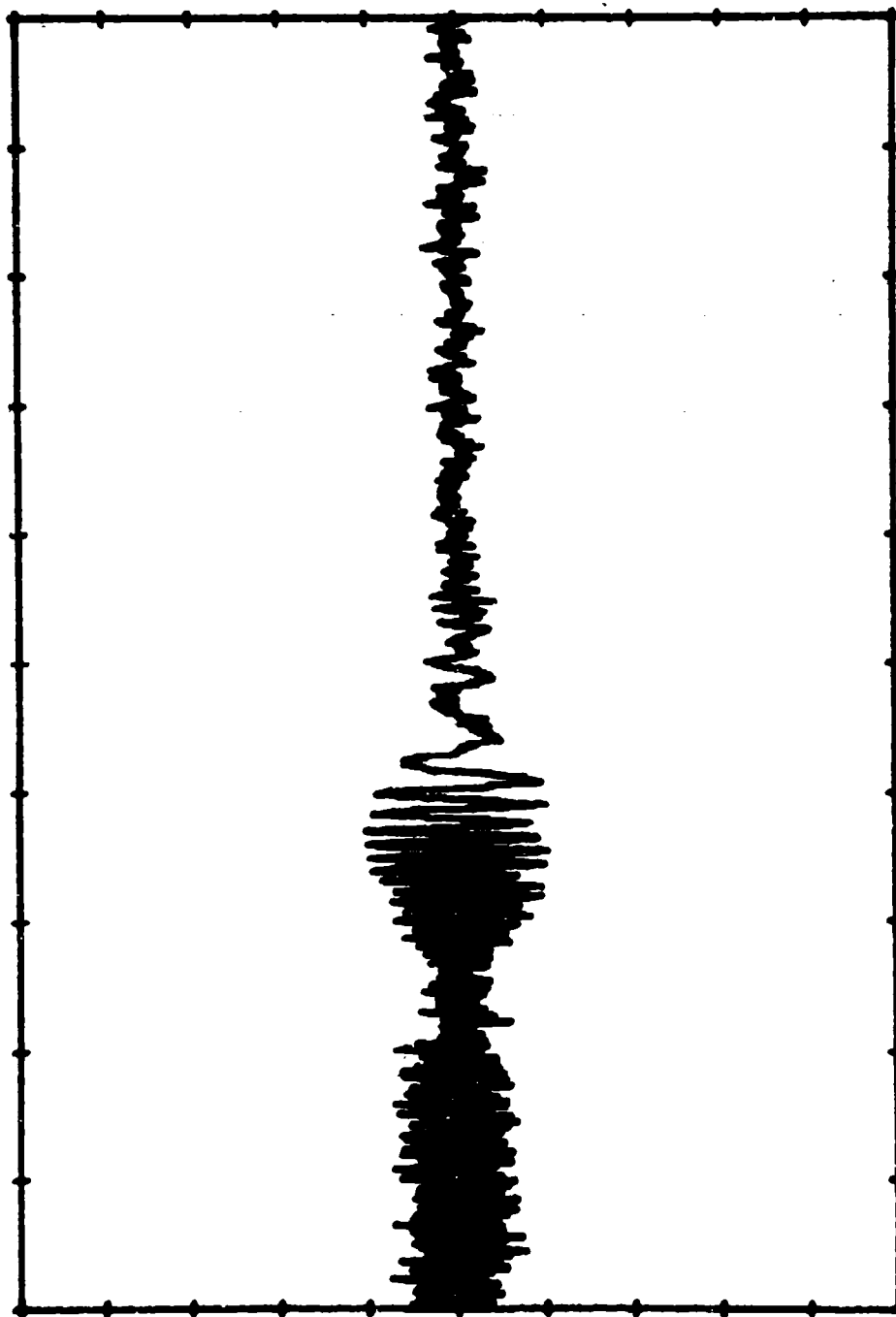
SAMPLES 400 THRU 1200

FILE NAME: ROUND 044 FILE DATA RECORD NUMBER: 2
FILE START TIME: 013047.539



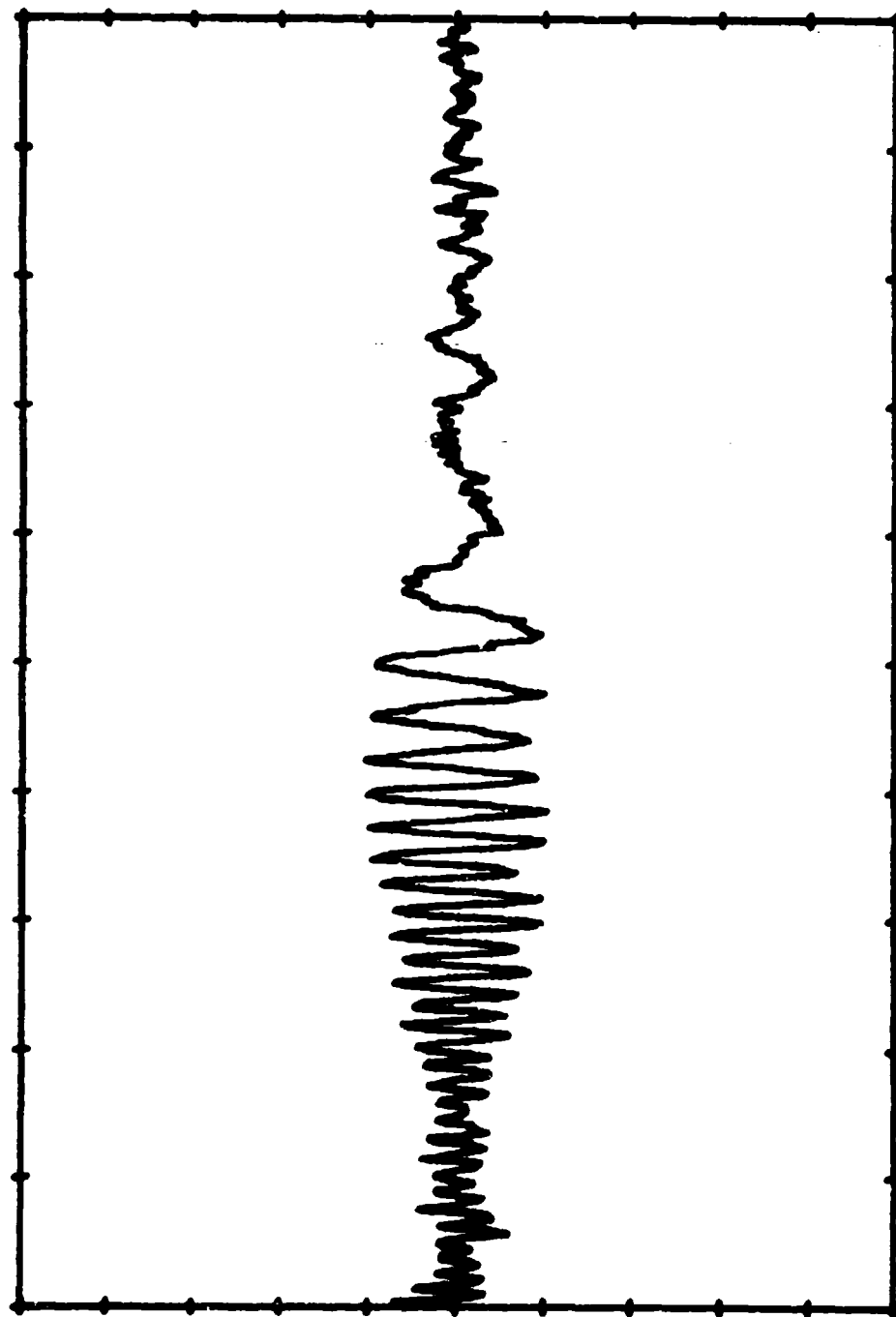
SAMPLES 1 THRU 4000

FILE NAME: ROUND.044 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:30:47.939



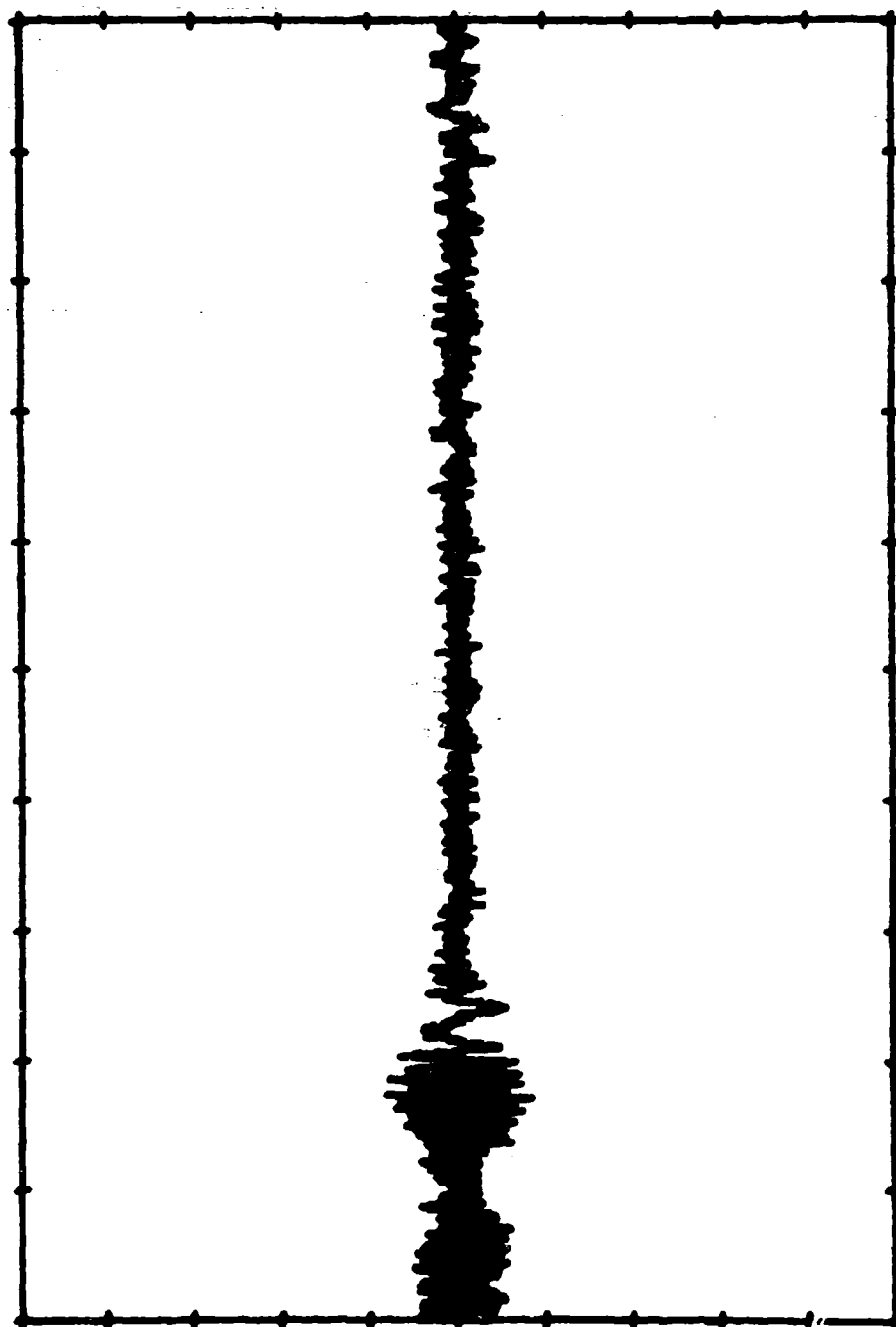
SAMPLES 1 THRU 2000

FILE NAME: ROUND.044 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:30:47.939



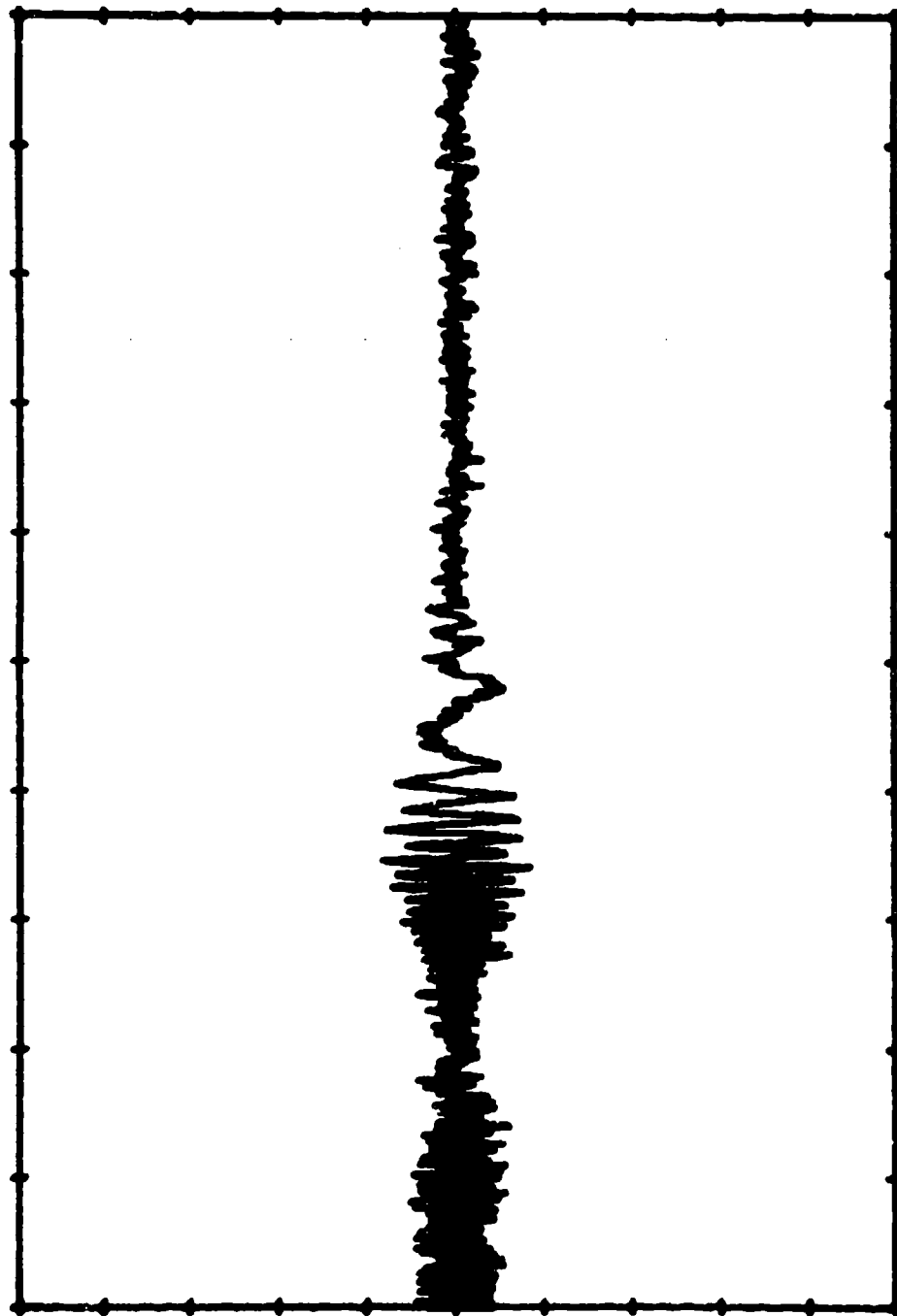
SAMPLES 400 THRU 1200

FILE NAME: ROUND.045 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0:34:42.442



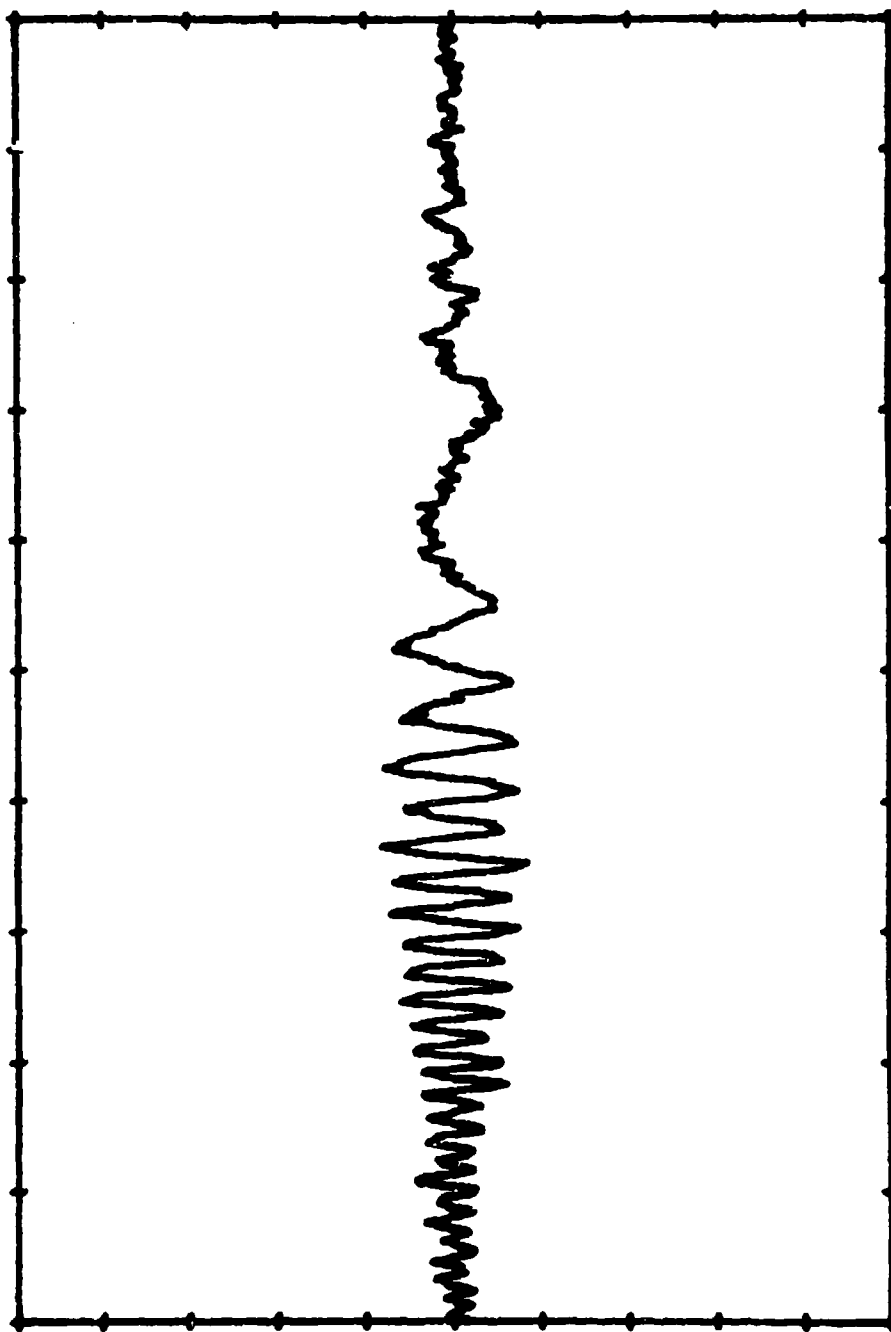
SAMPLES 1 THRU 4000

FILE NAME: ROUND.045 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:34:42.442



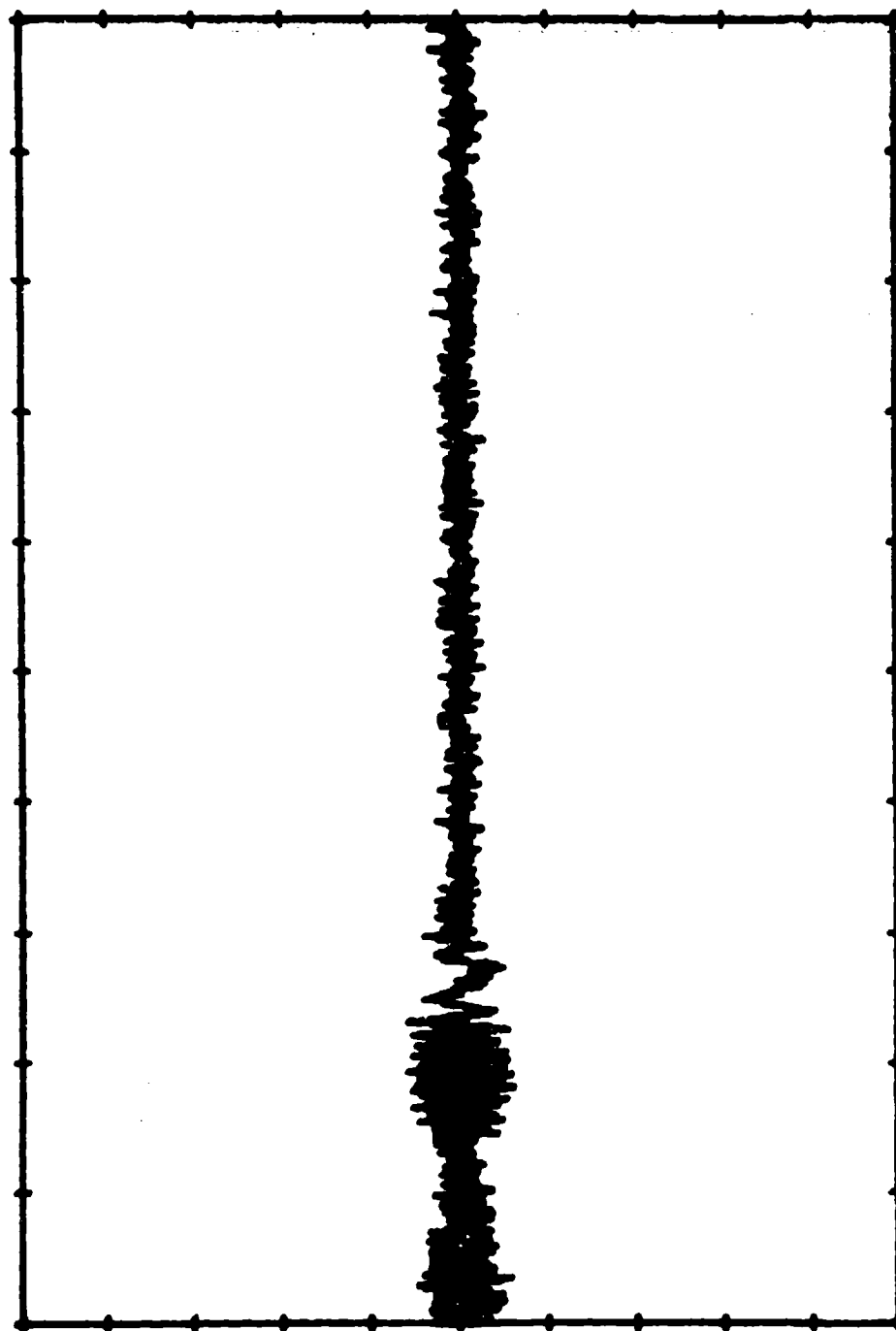
SAMPLES 1 THRU 2000

FILE NAME: ROUND.045 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:34:42.442



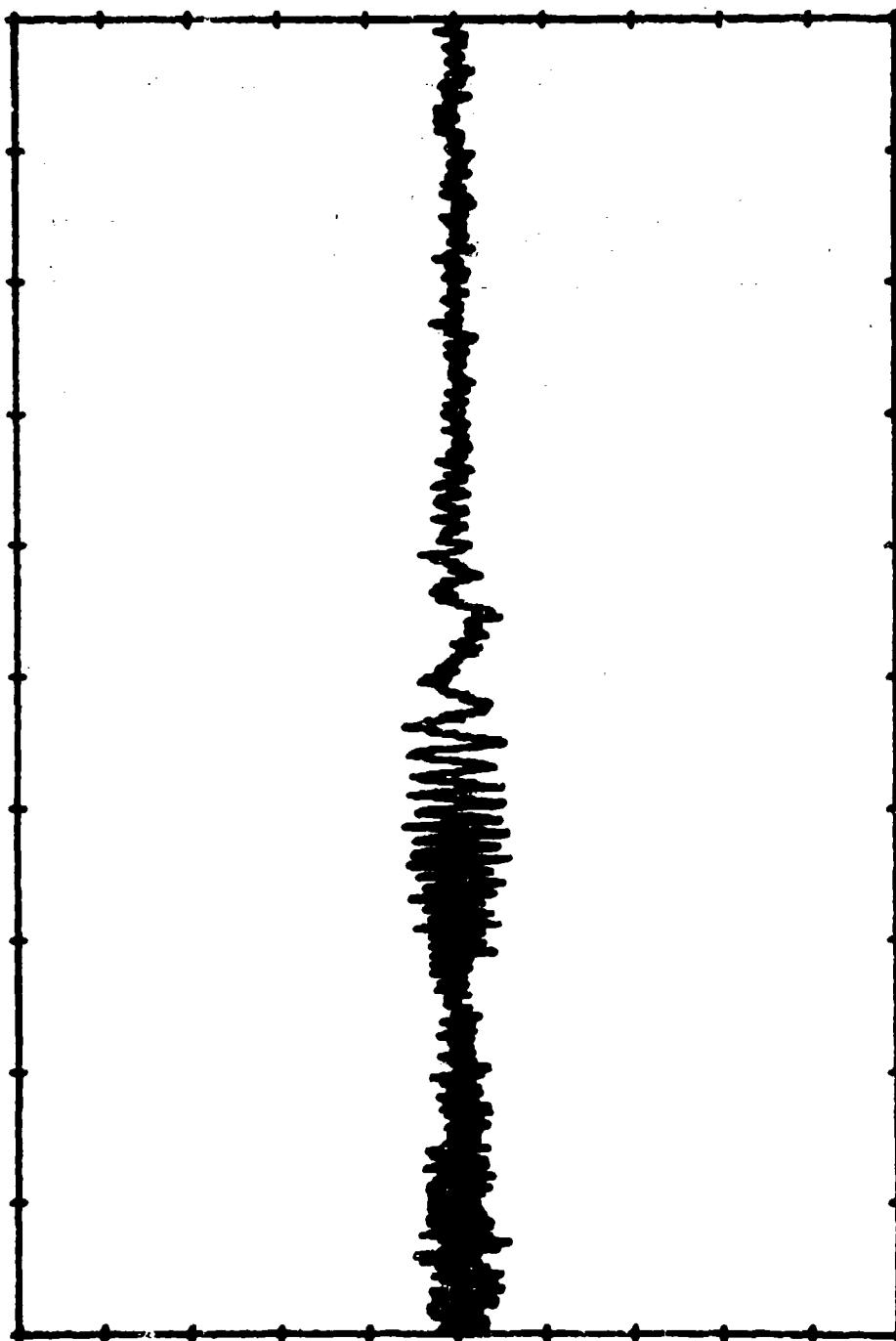
SAMPLES 400 THRU 1200

FILE NAME: ROUND.046 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0:37:42.133



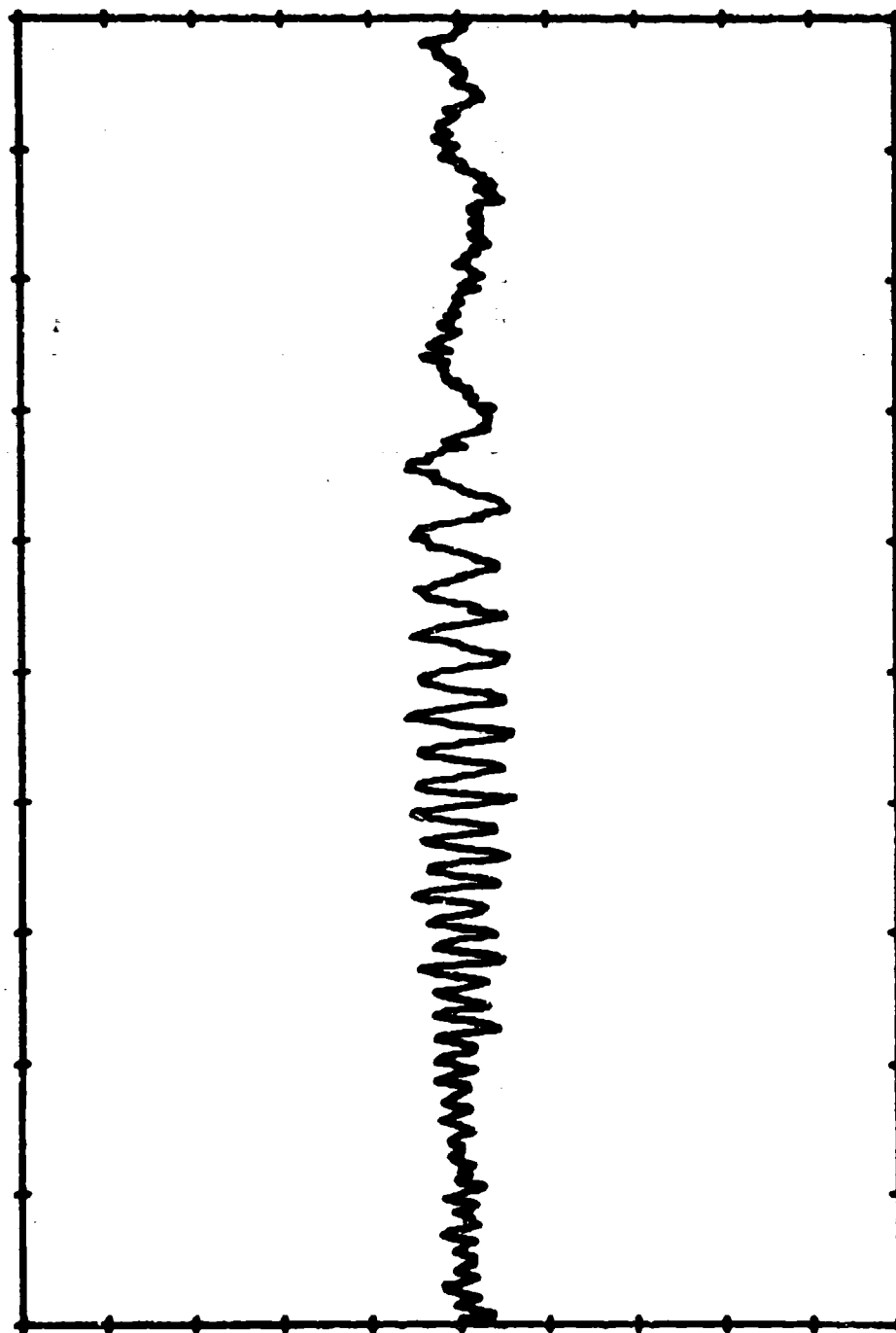
SAMPLES 1 THRU 4000

FILE NAME: ROUND.046 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:37:42.133



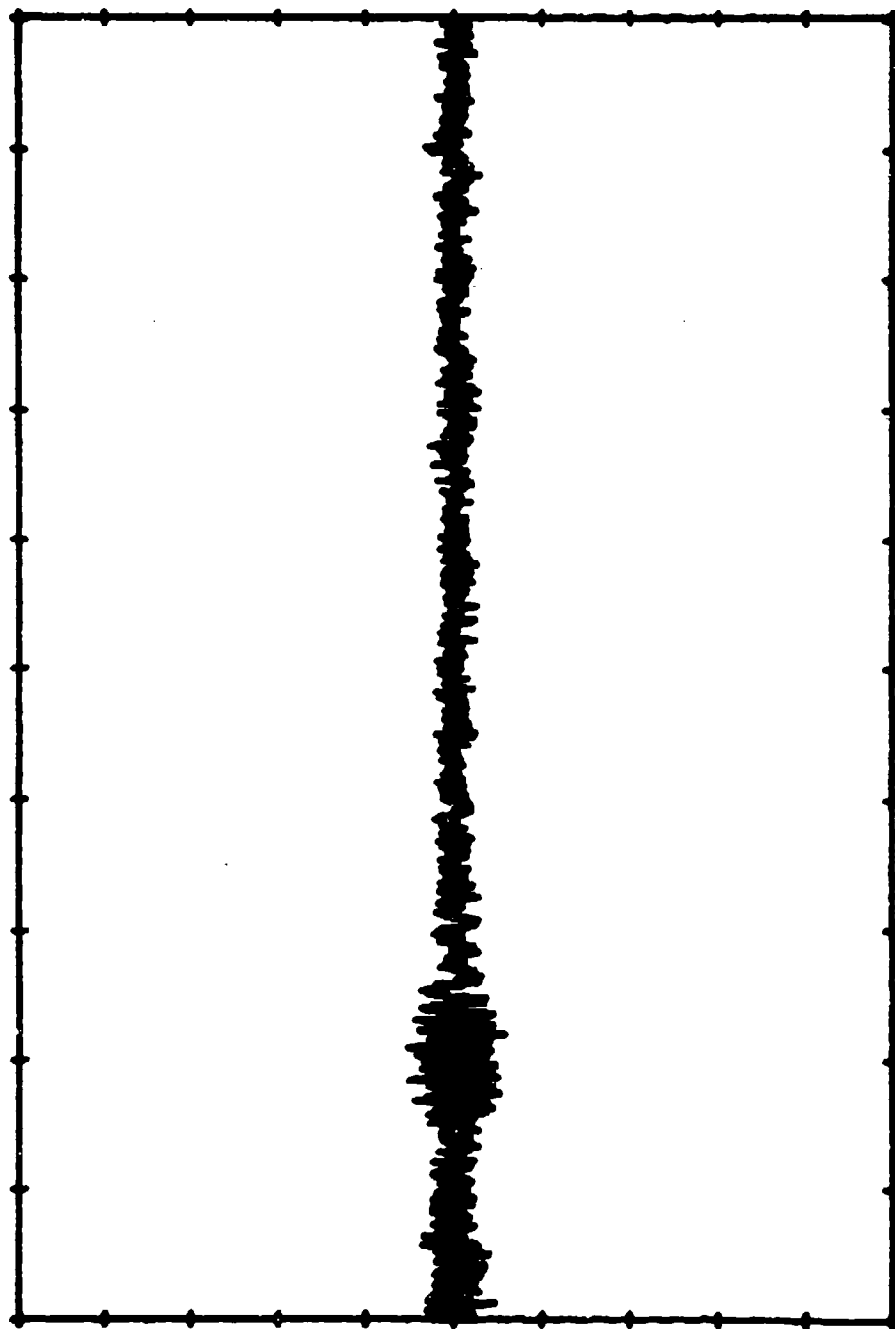
SAMPLES 1 THRU 2000

FILE NAME: ROUND.046 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:37:42.133



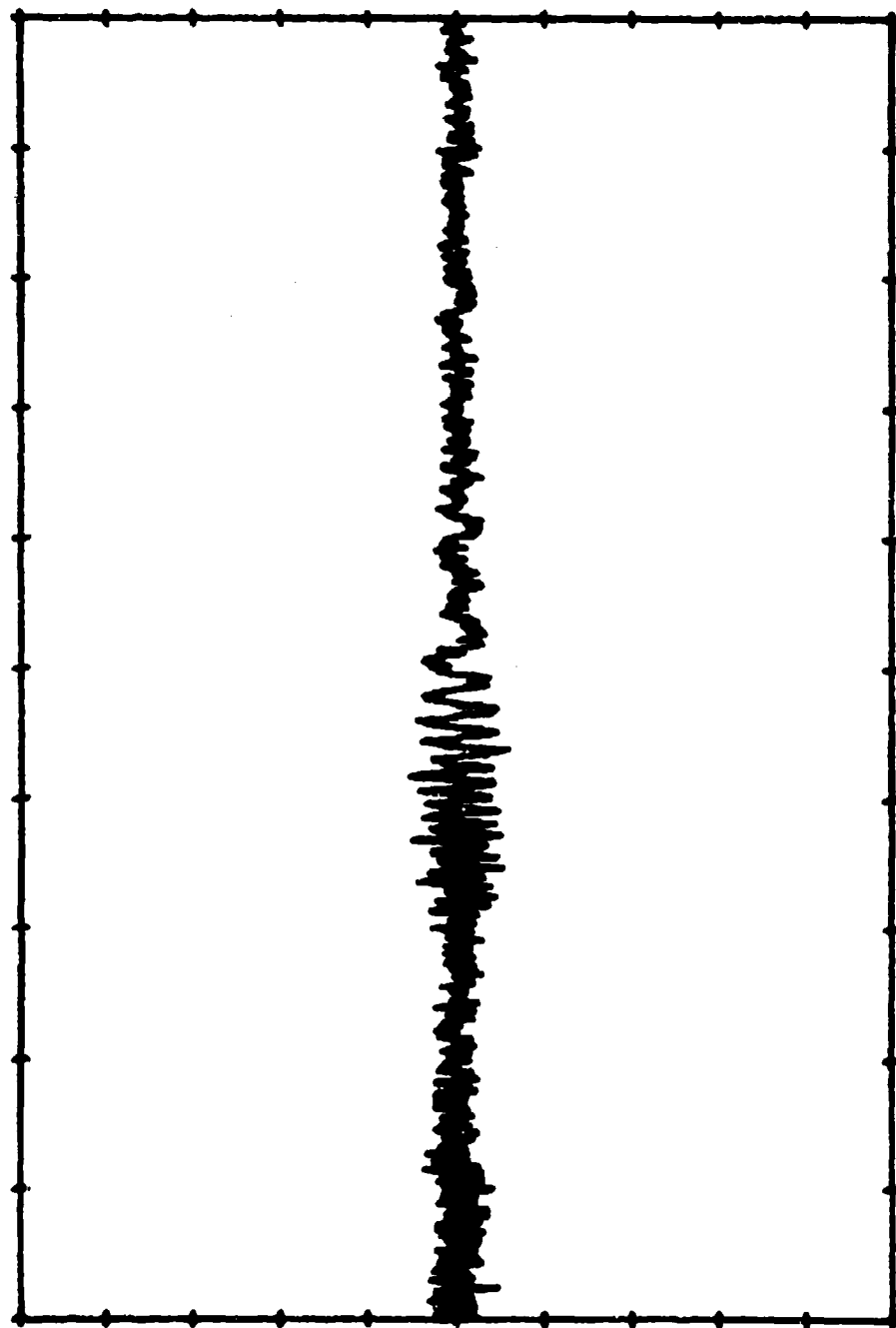
SAMPLES 400 THRU 1200

FILE NAME: ROUND.047 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 0:40:33.678



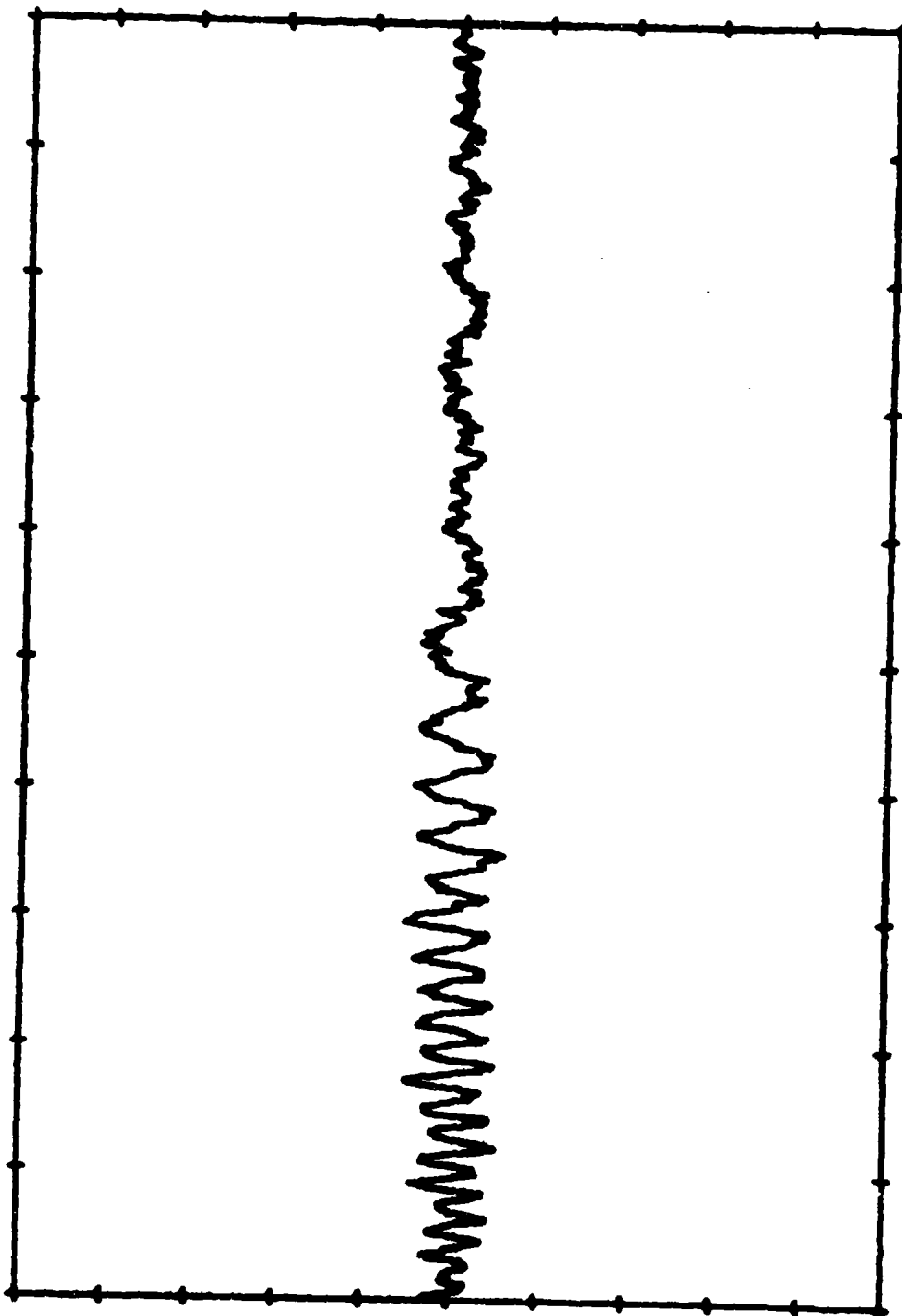
SAMPLES 1 THRU 4000

FILE NAME: ROUND.047 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0:40:33.678



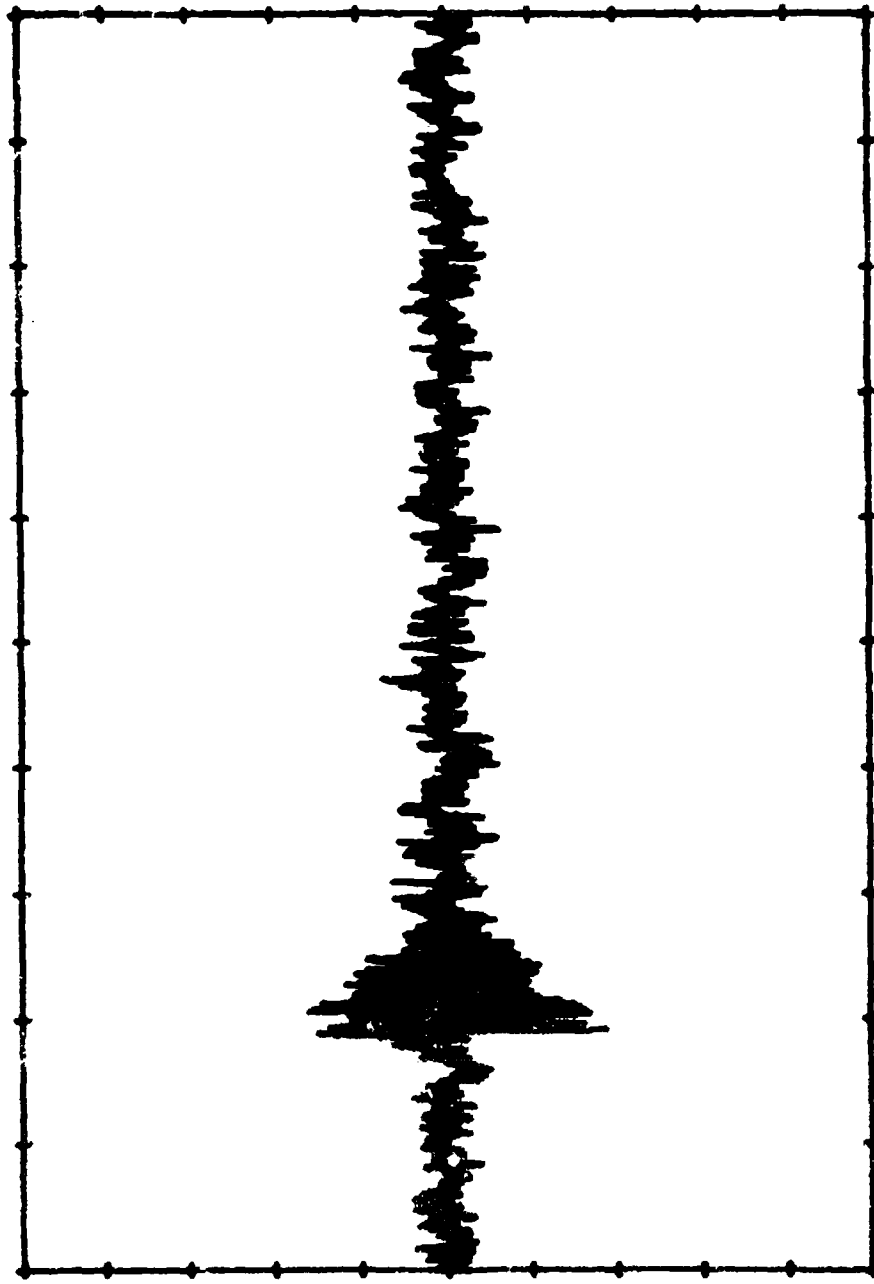
SAMPLES 1 THRU 2000

FILE NAME: ROUND.047 FILE DATA RECORD NUMBER: 2
FILE START TIME: 0:40:33.678



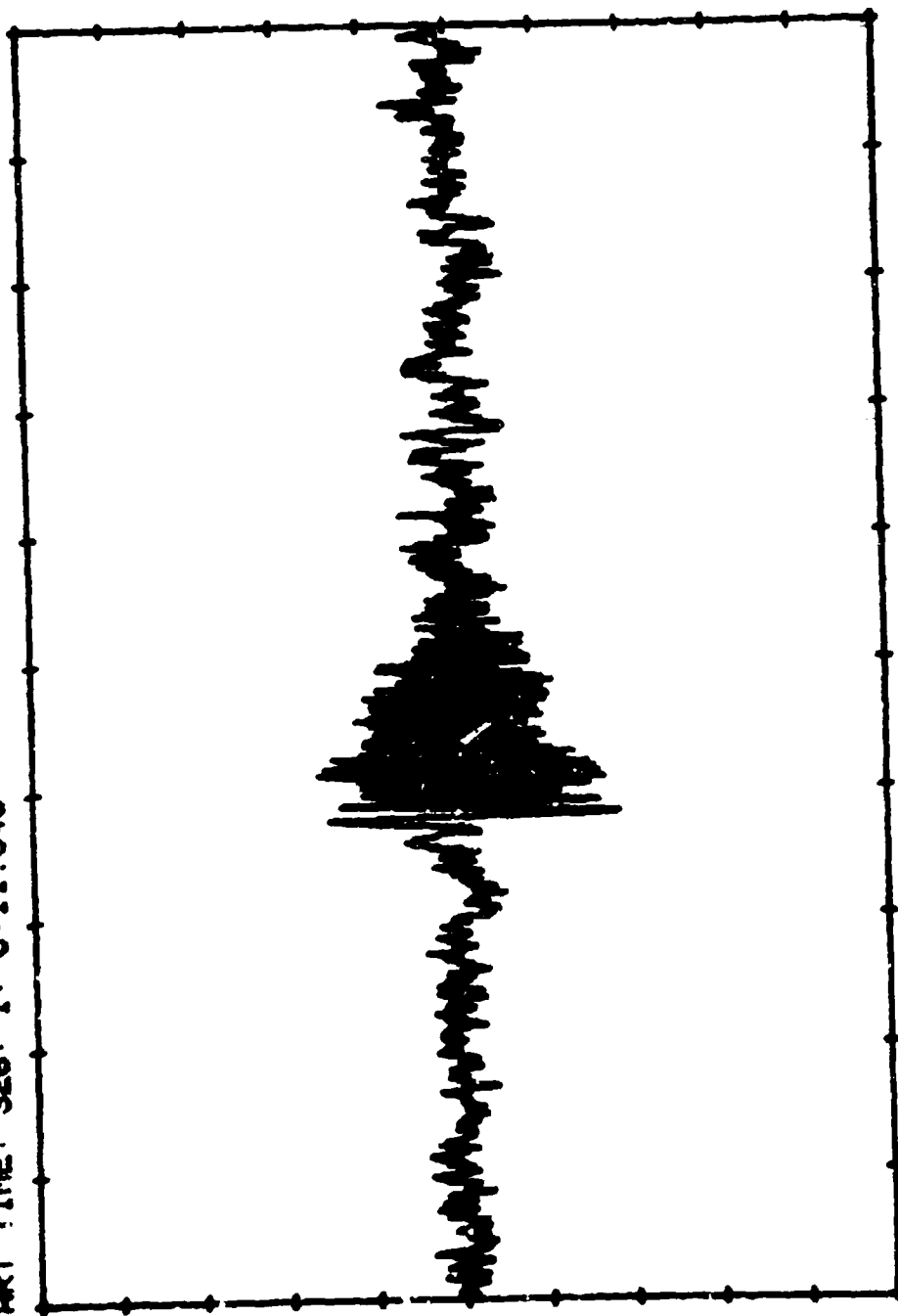
SAMPLES 600 THRU 1400

FILE NAME: ROUND.048 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326.1, 0:11.645



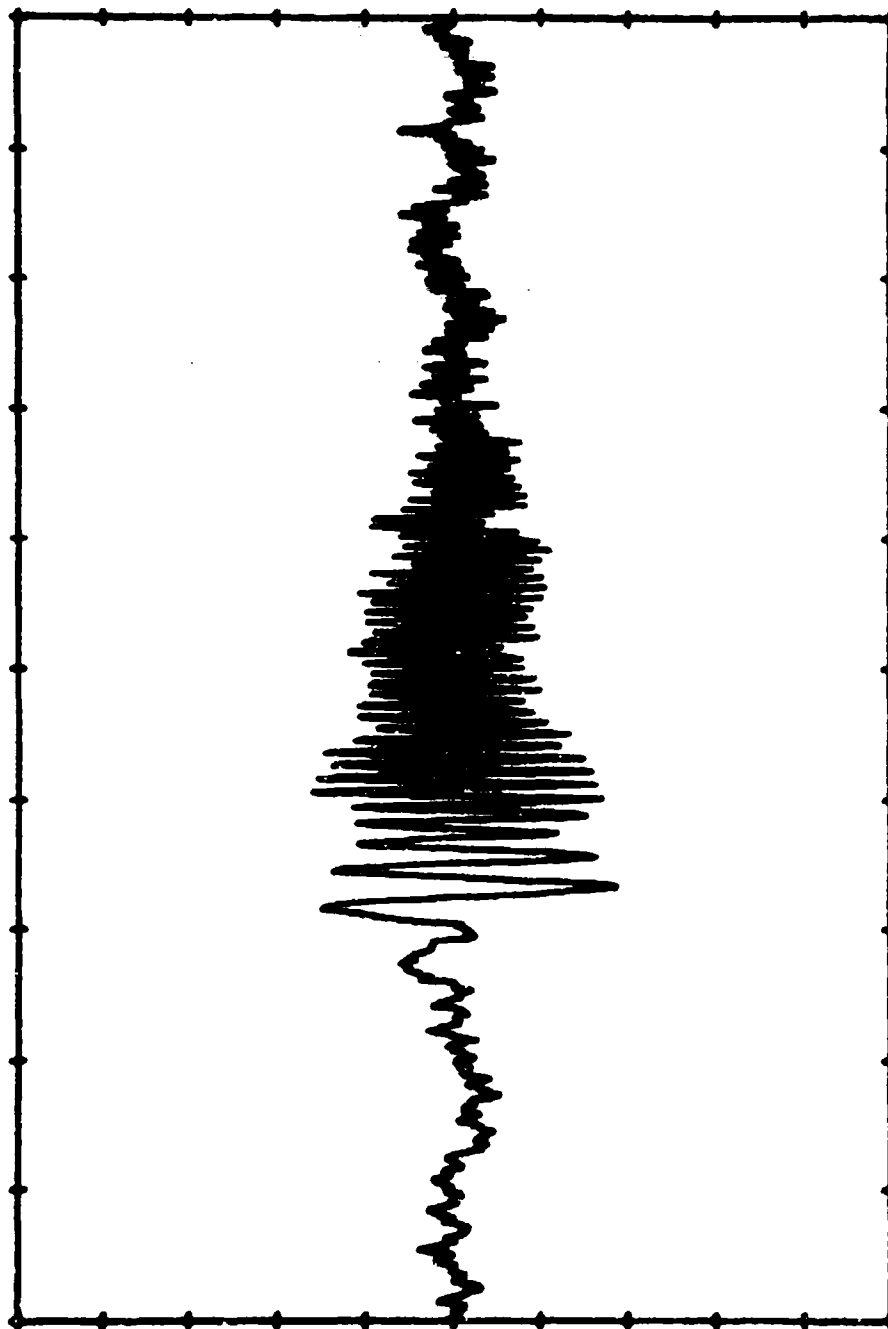
SAMPLES 1 THRU 4000

FILE NAME: ROUND.048 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326.1: 0:11.645



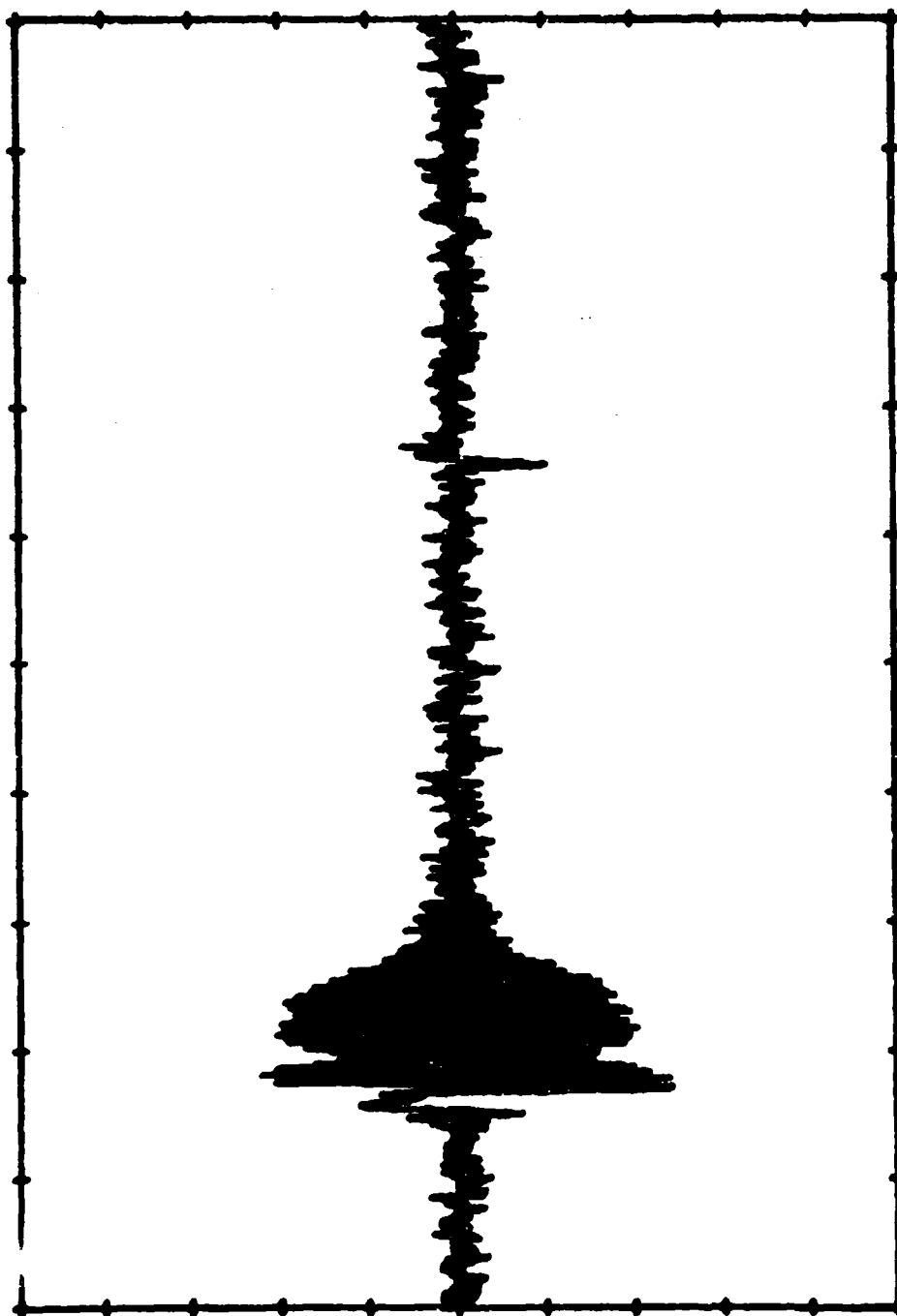
SAMPLES 1 THRU 2000

FILE NAME: ROUND.048 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326.1: 0:11.645



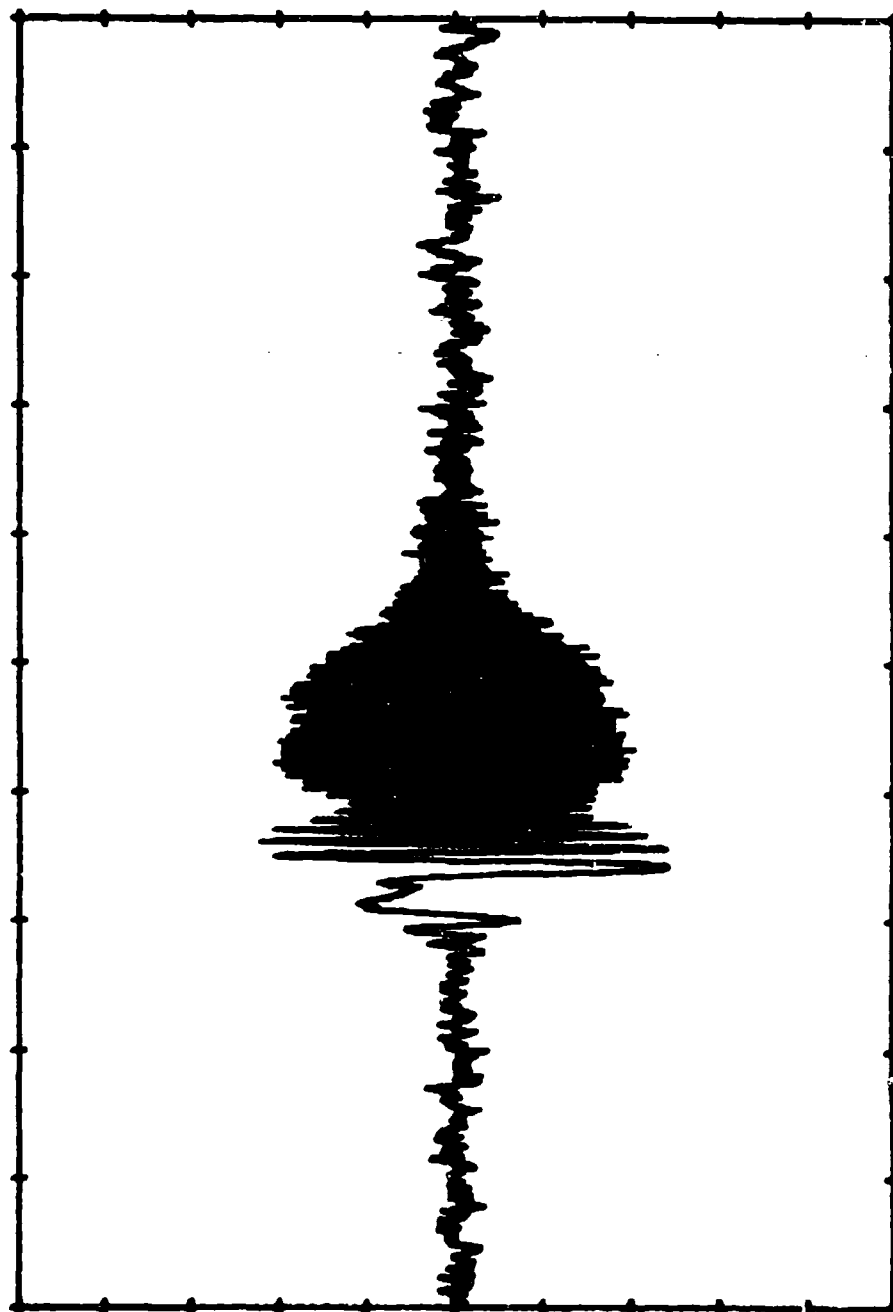
SAMPLES 500 THRU 1300

FILE NAME: ROUND.049 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1: 2:57.666



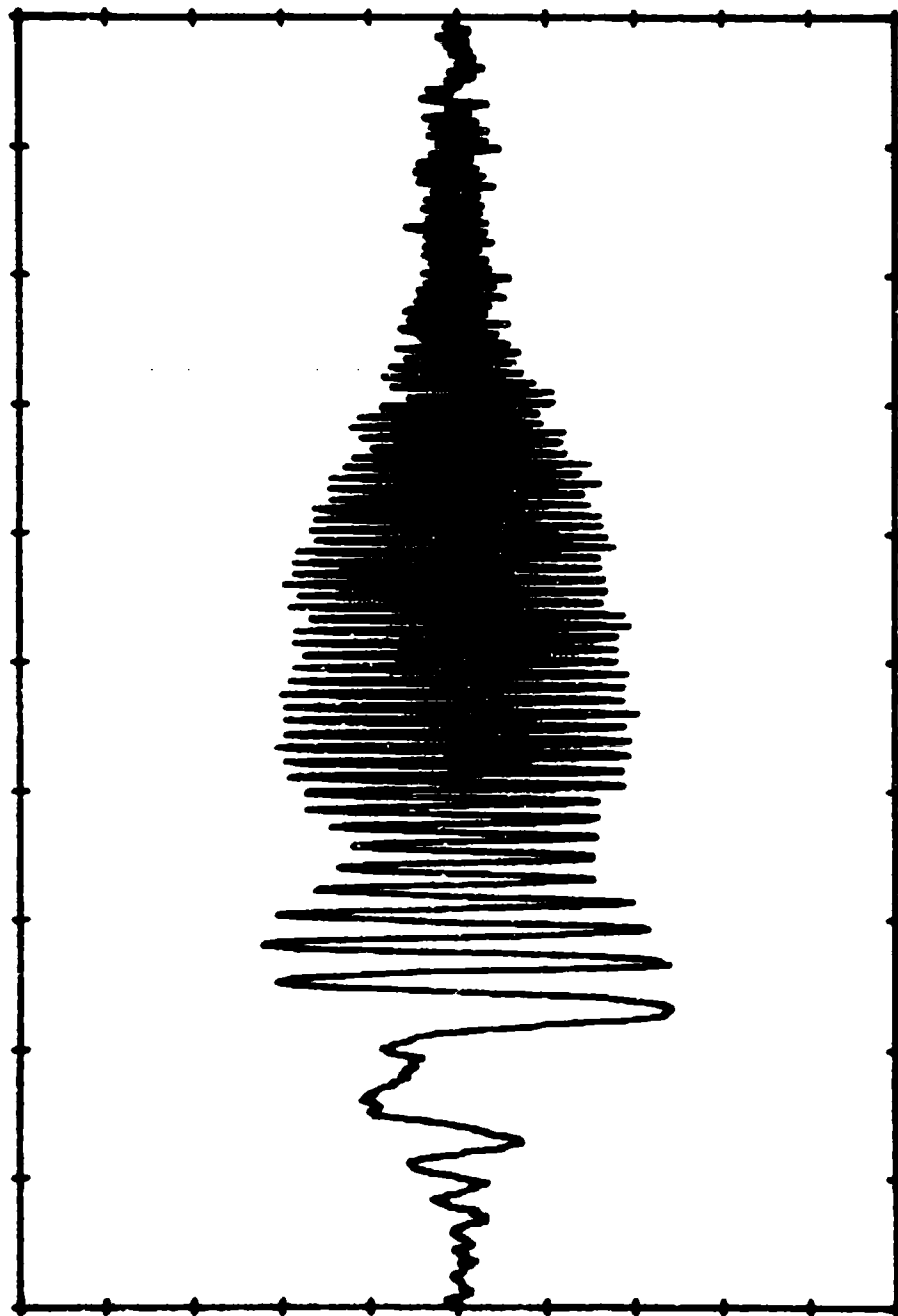
SAMPLES 1 THRU 4000

FILE NAME: ROUND.049 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326.1: 2:57.666



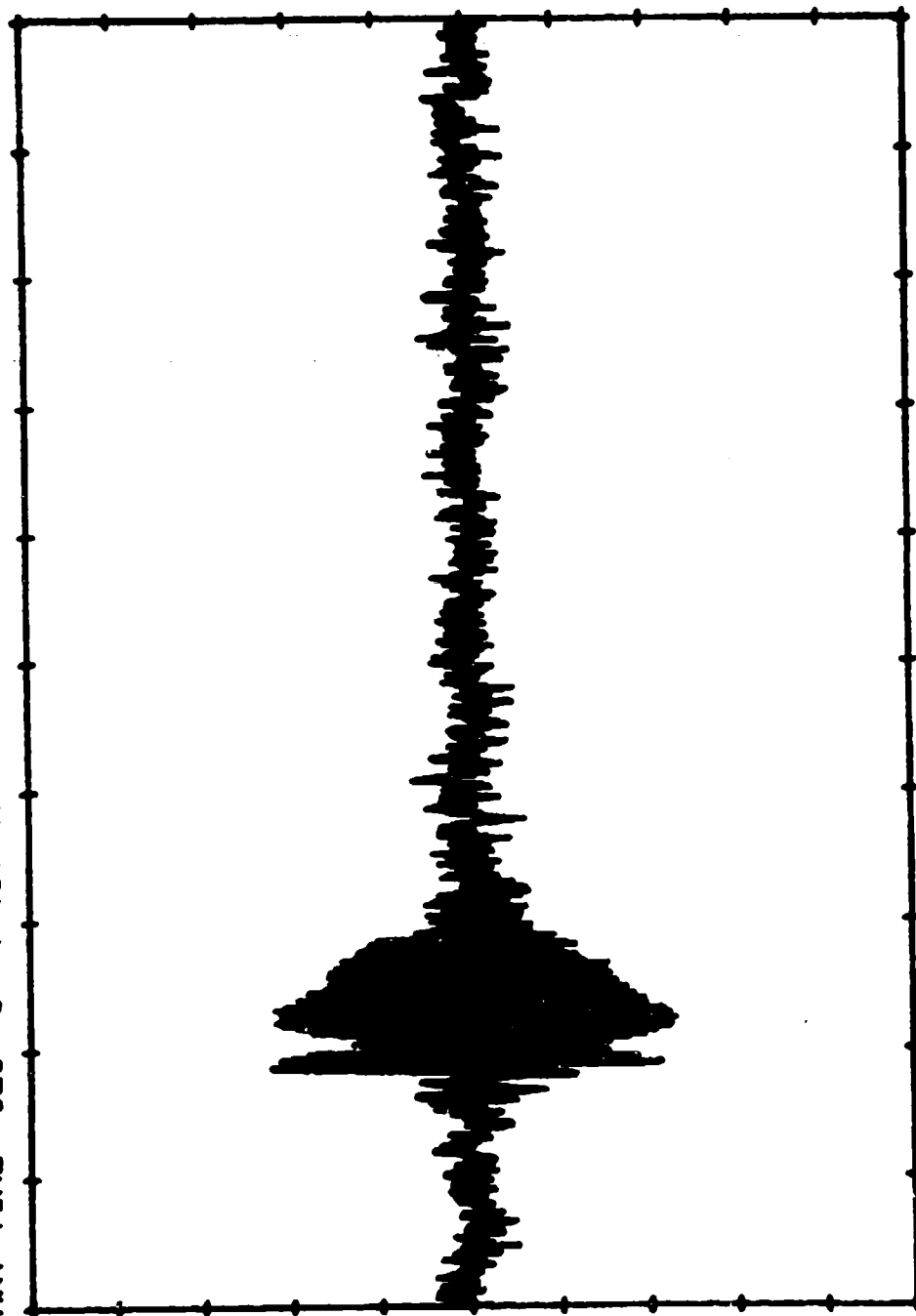
SAMPLES 1 THRU 2000

FILE NAME: ROUND.049 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326.1: 2:57.666



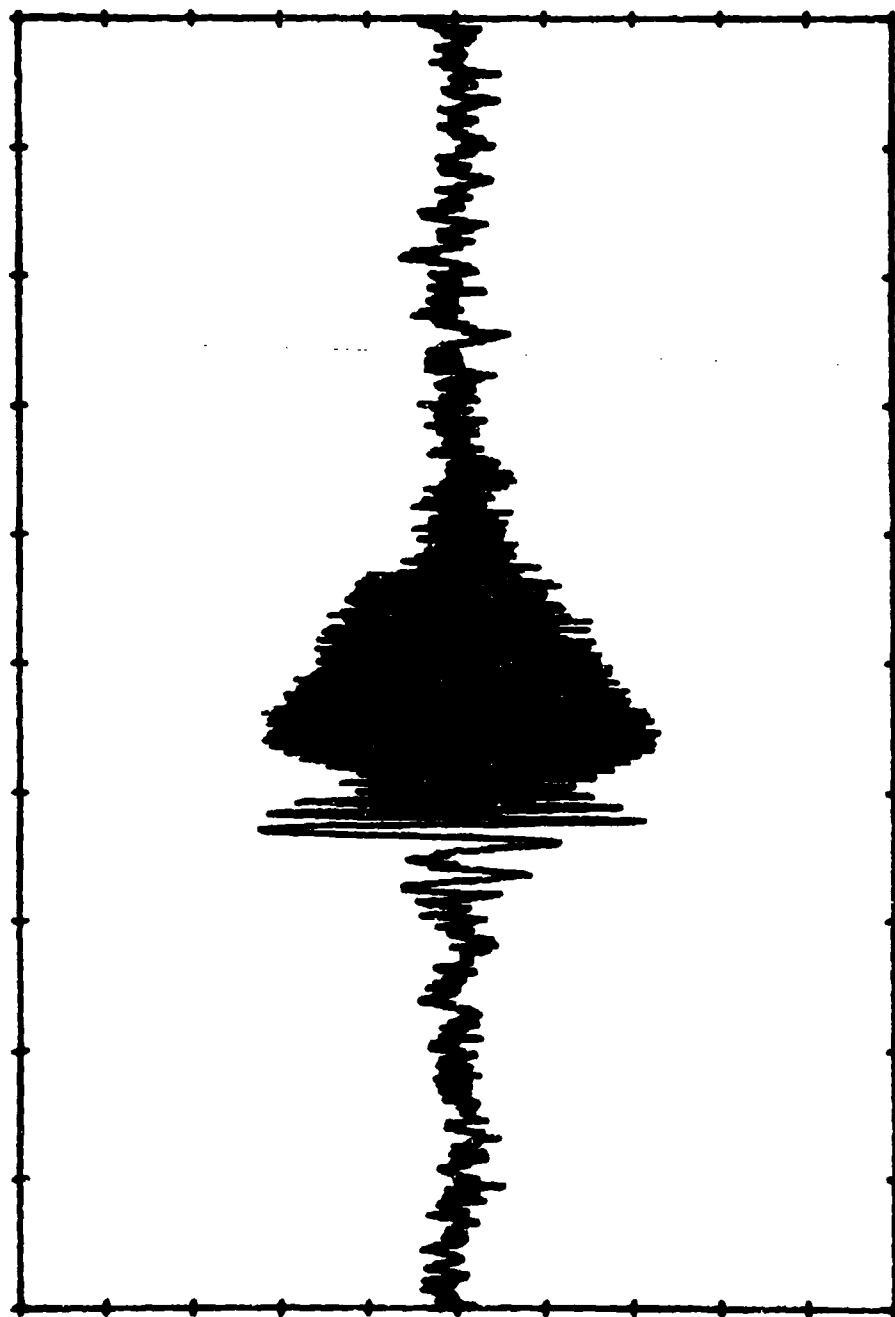
SAMPLES 500 THRU 1300

FILE NAME: ROUND.050 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326.1: 4:46.748



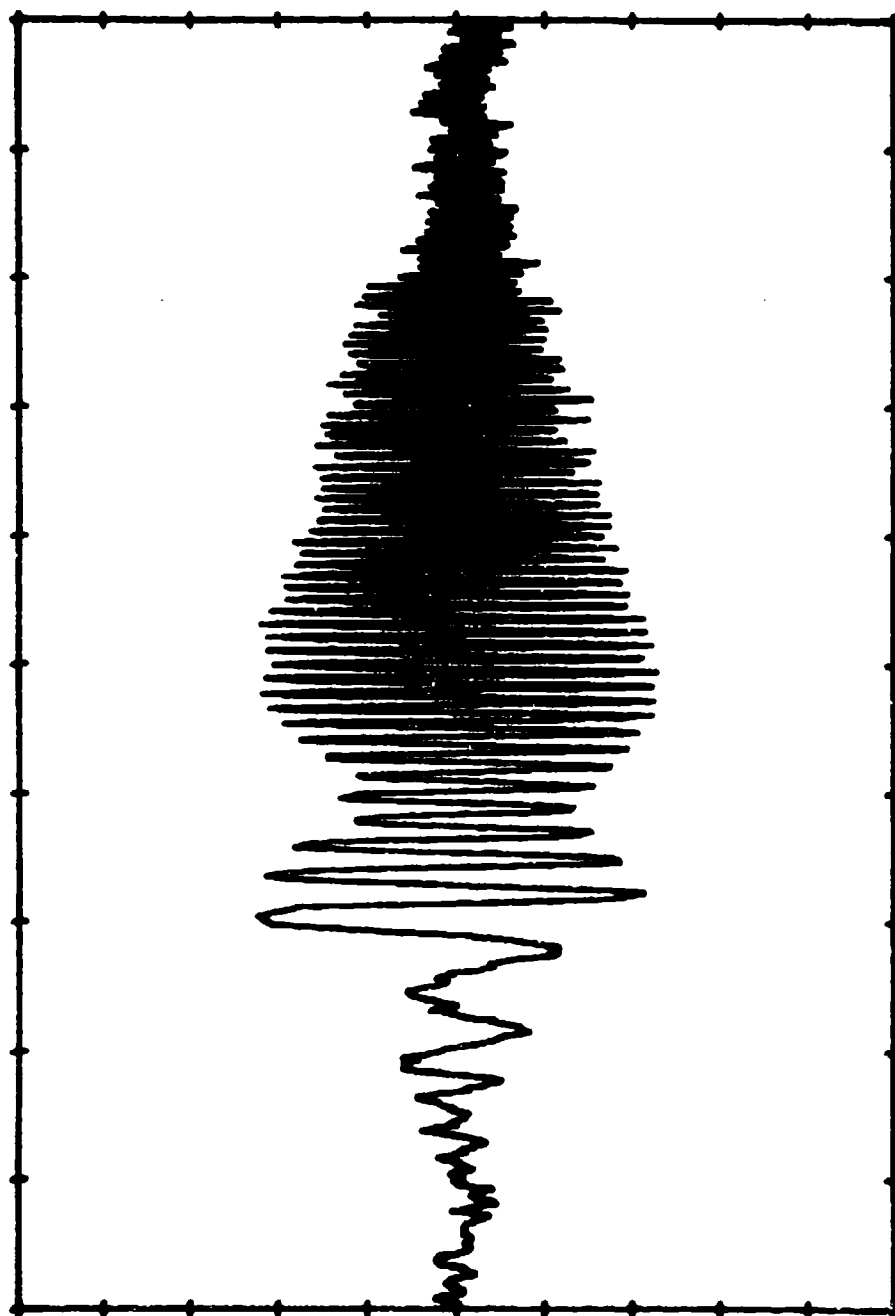
SAMPLES 1 THRU 4000

FILE NAME: ROUND.050 FILE DATA RECORD NUMBER: 2
FILE START TIME: 1: 4:46.748



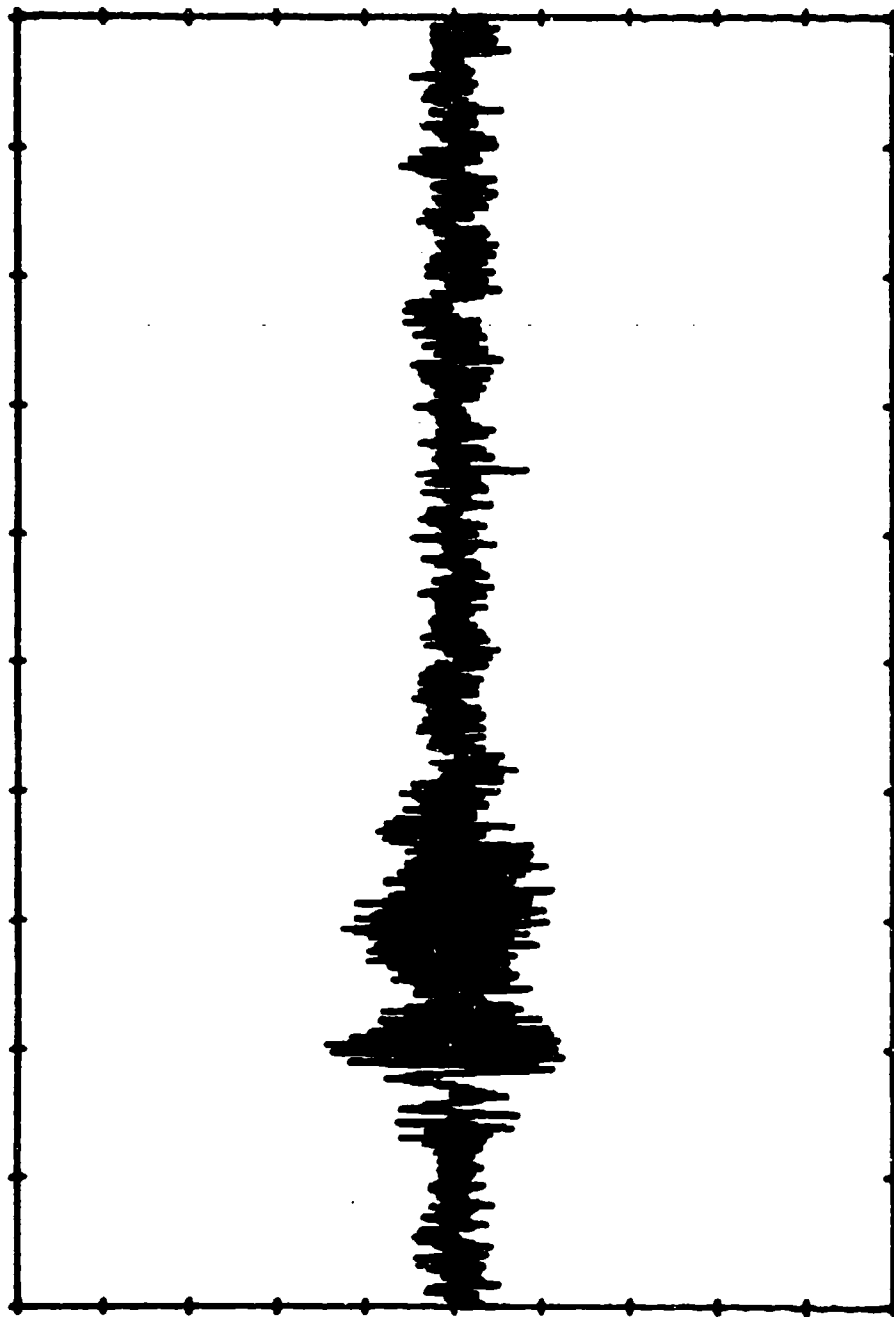
SAMPLES 1 THRU 2000

FILE NAME: ROUND.050 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1: 4:46.748



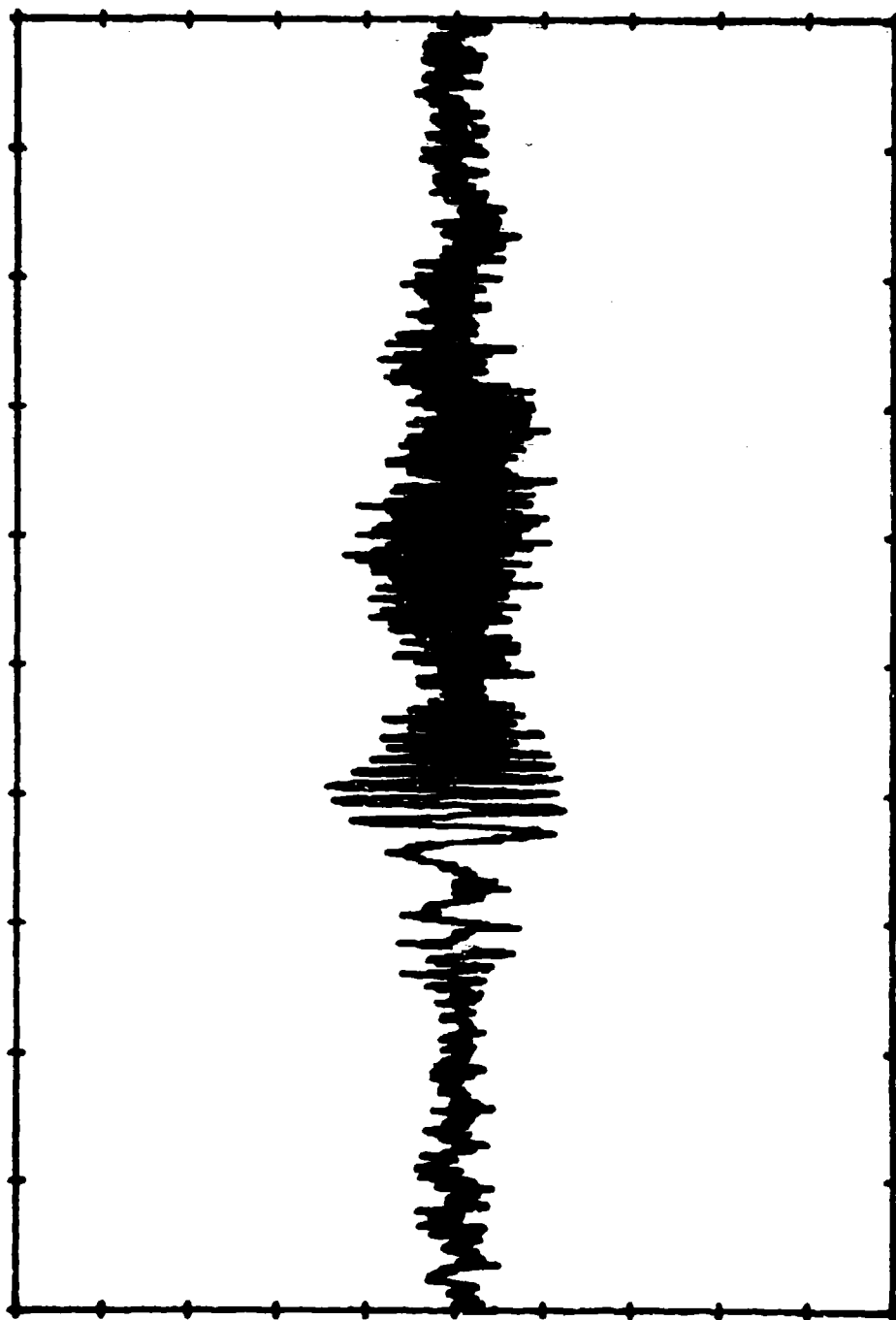
SAMPLES 500 THRU 1300

FILE NAME: ROUND 051 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1: 7:33.762



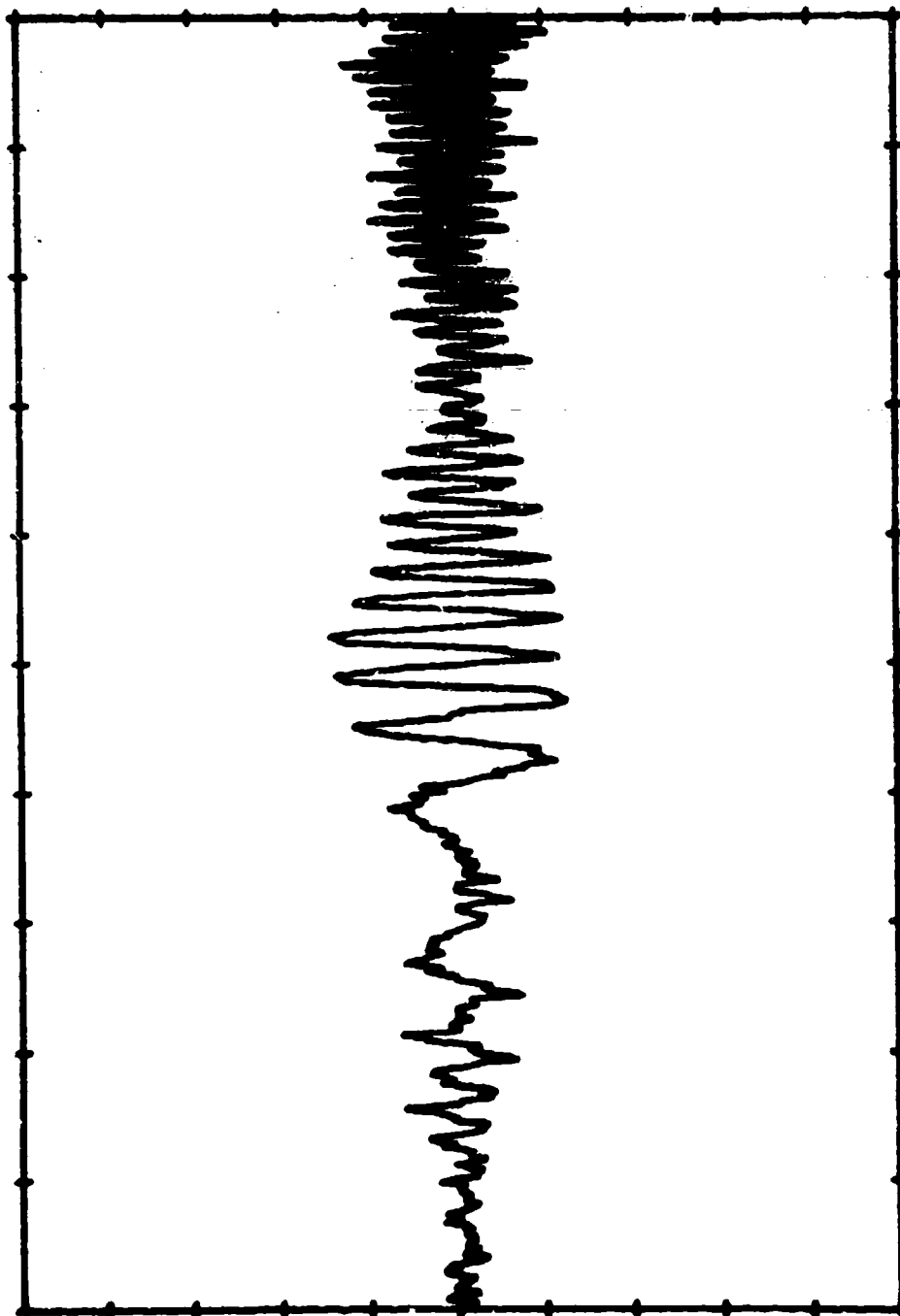
SAMPLES 1 THRU 4000

FILE NAME: ROUND.051 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1: 7:33.762



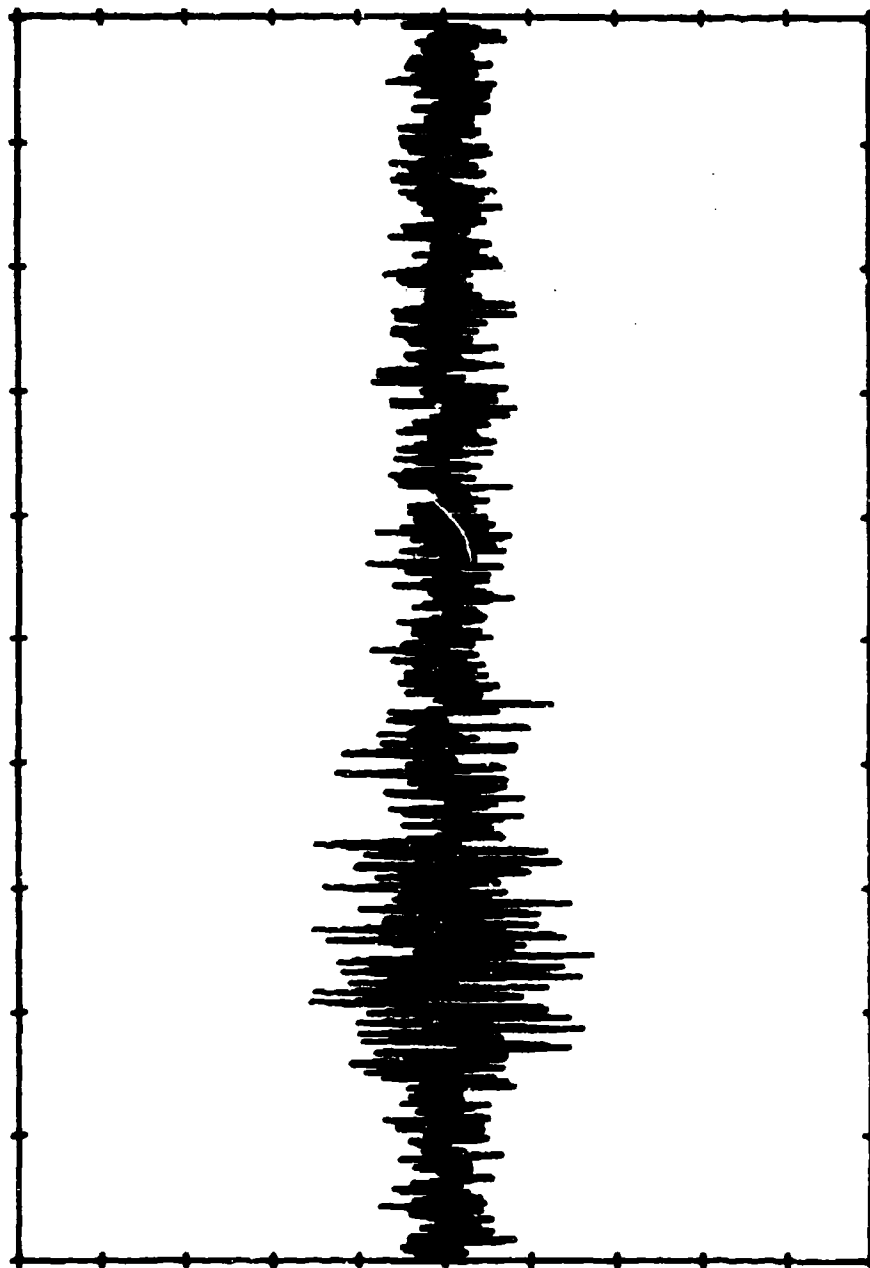
SAMPLES 1 THRU 2000

FILE NAME: ROUND.051 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1: 7:33.762



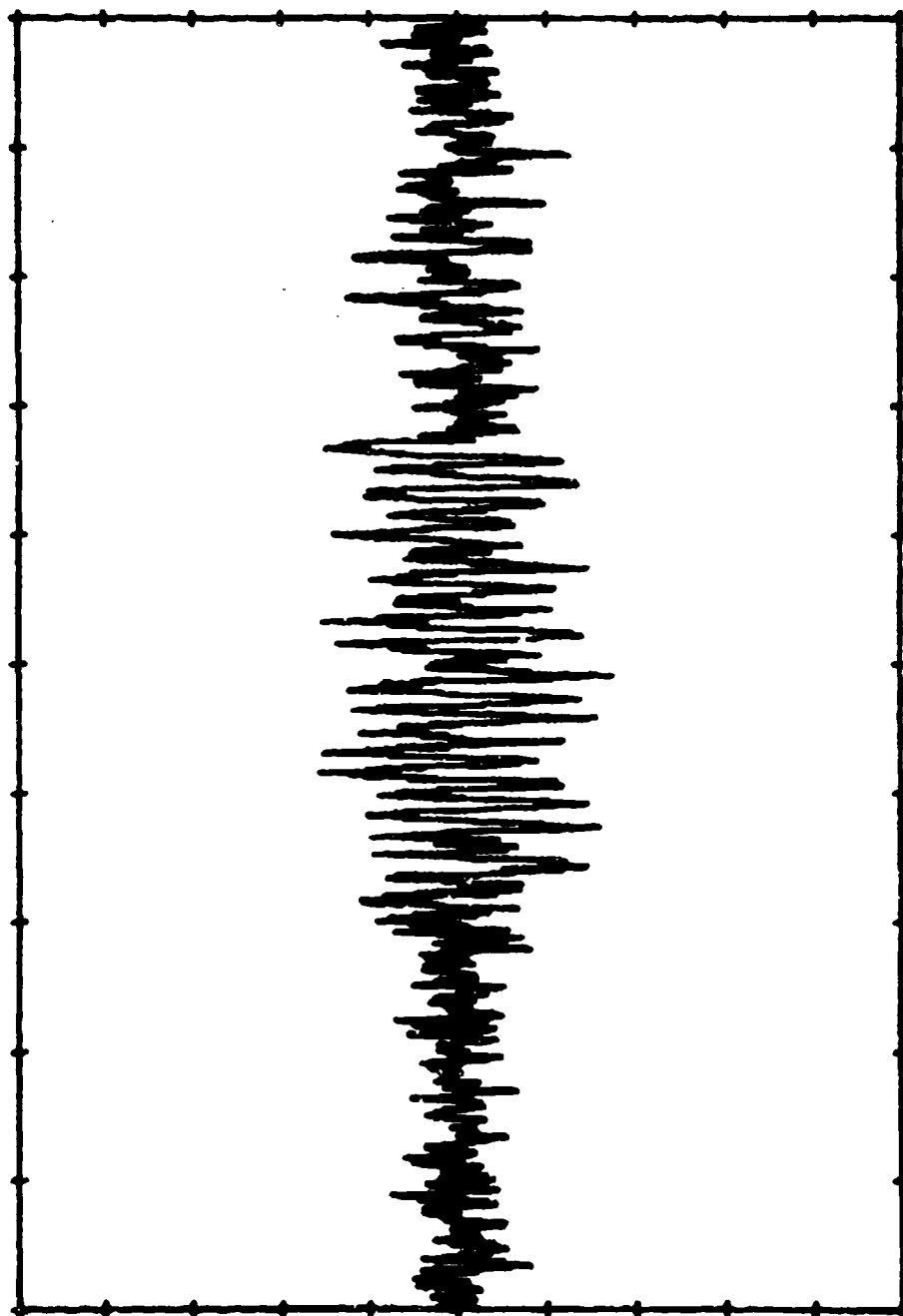
SAMPLES 400 THRU 1200

FILE NAME: ROUND.052 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1:30:51.711



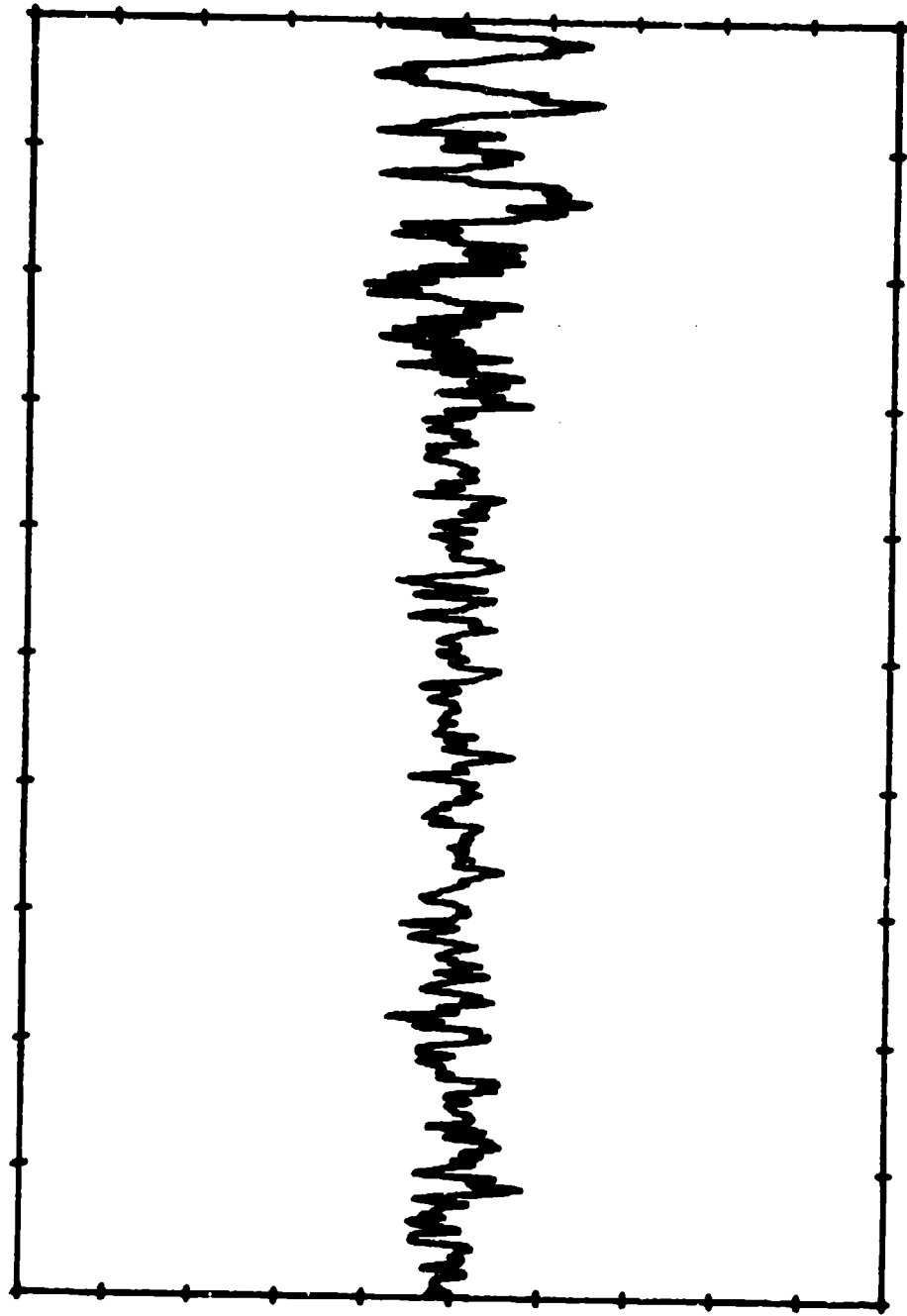
SAMPLES 1 THRU 4000

FILE NAME: ROUND.052 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1:30:51.711



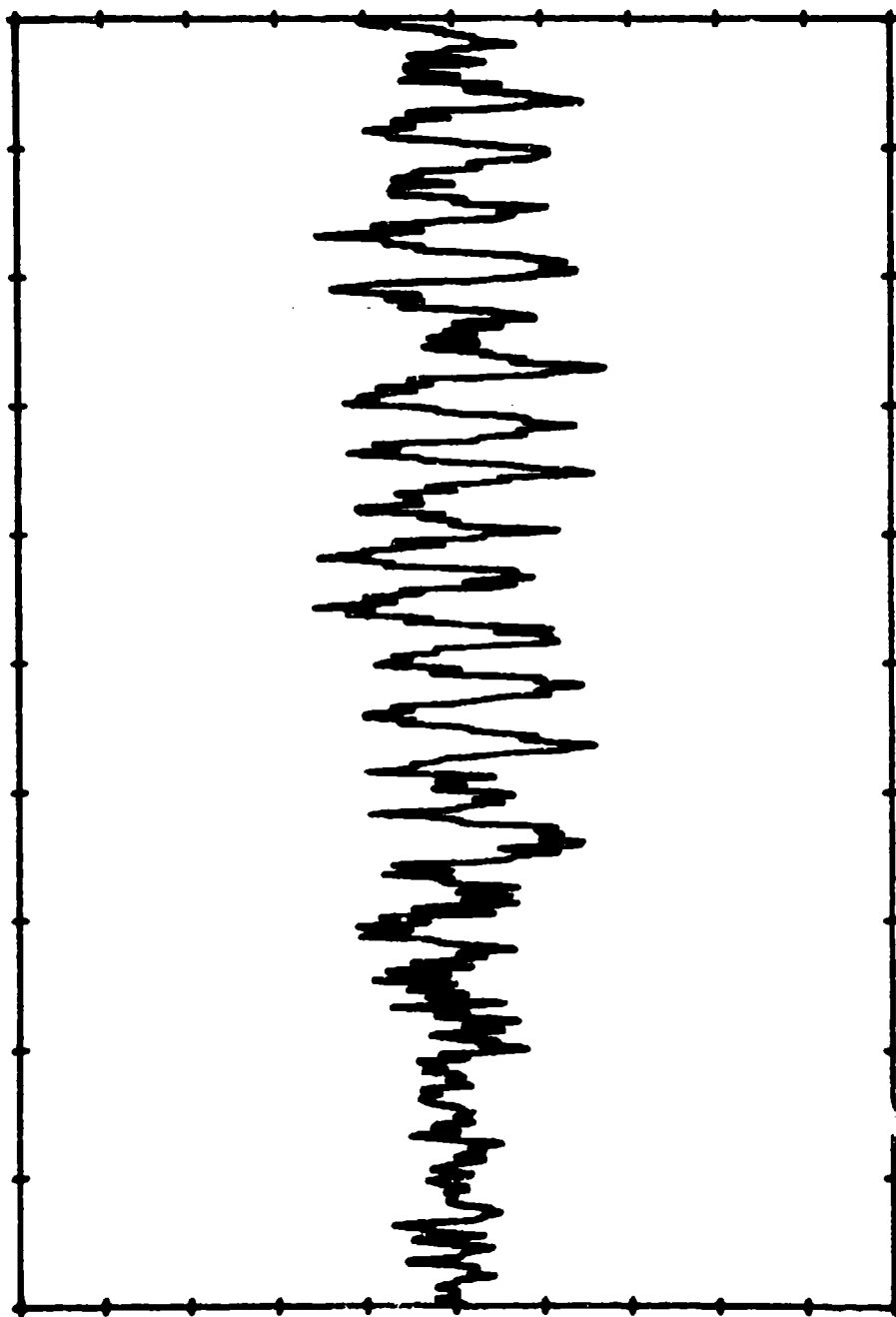
SAMPLES 1 THRU 2000

FILE NAME: ROUND.052 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1:30:51.711



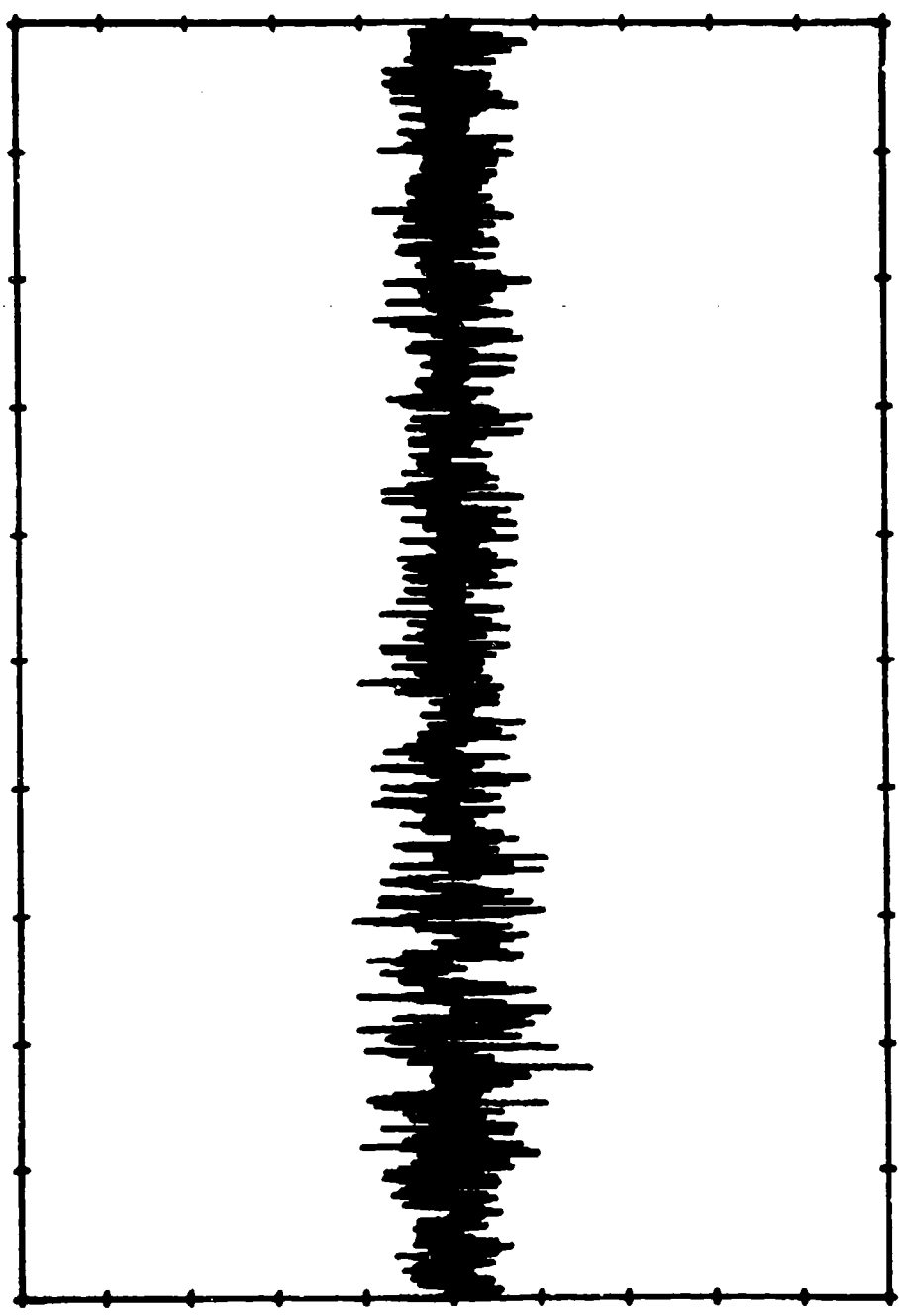
SAMPLES 1 THRU 800

FILE NAME: ROUND 052 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1:30:51.711



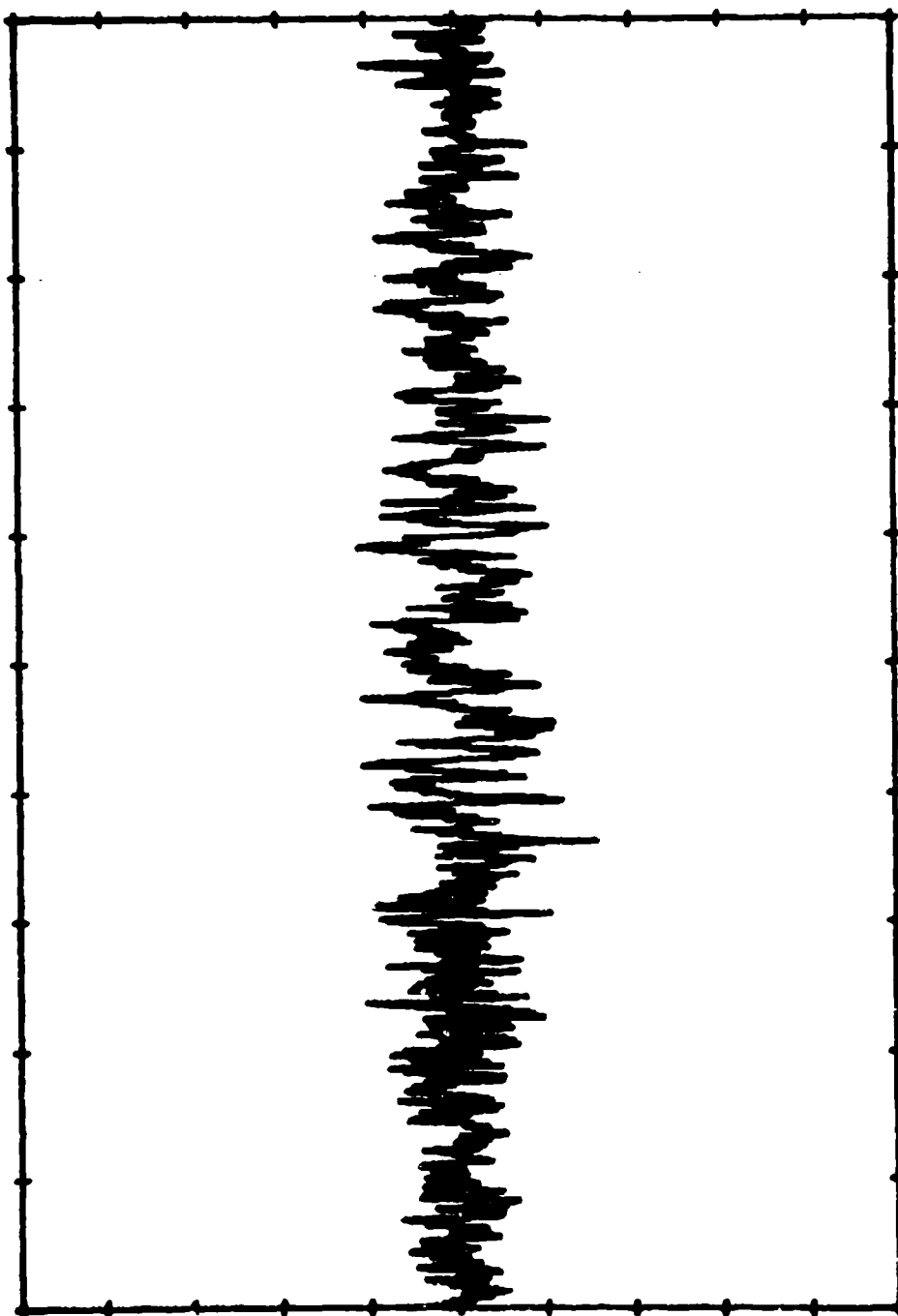
SAMPLES 400 THRU 1200

FILE NAME: ROUND.053 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1:34:46.853



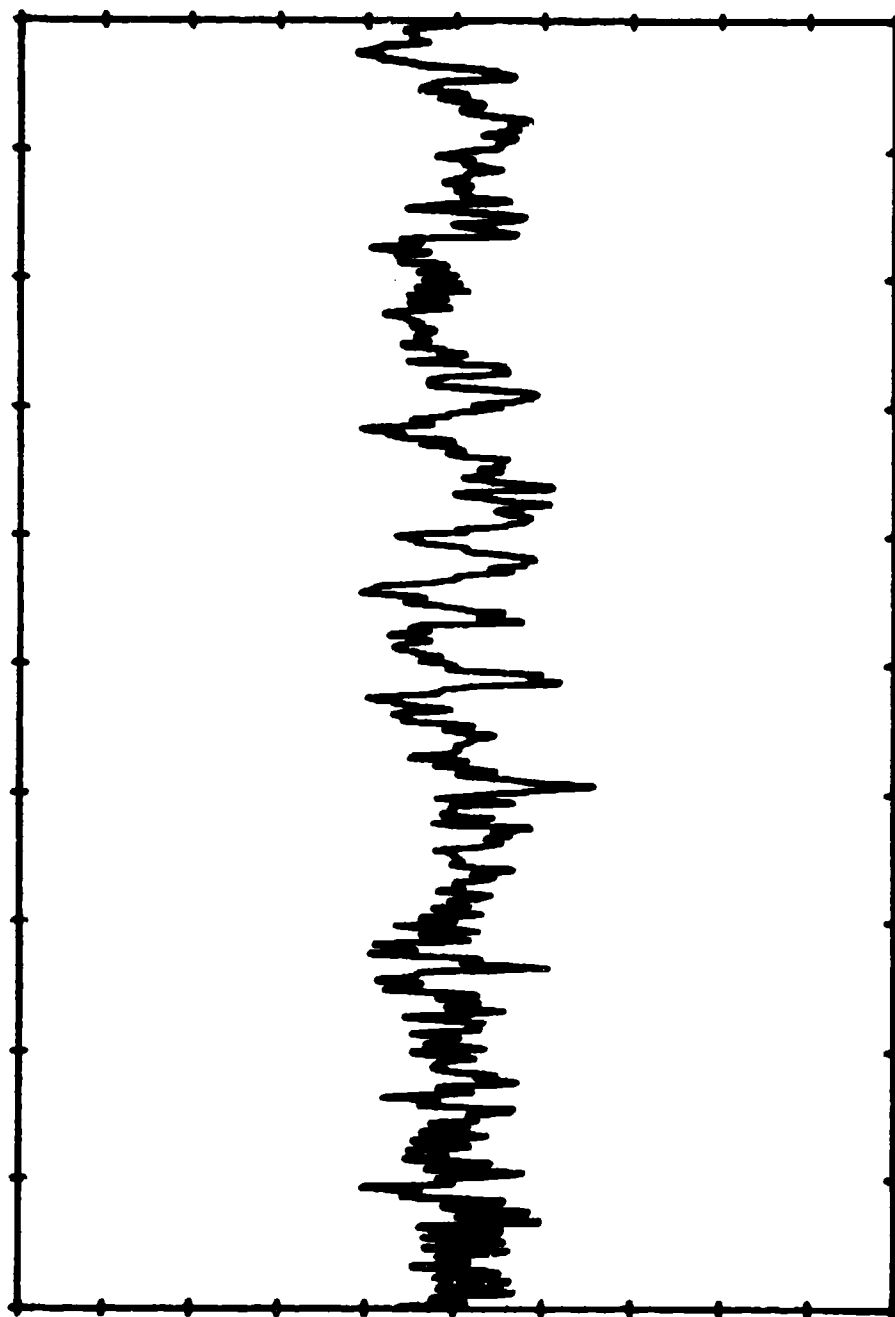
SAMPLES 1 THRU 4000

FILE NAME: ROUND.053 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1:34:46.853



SAMPLES 1 THRU 2000

FILE NAME: ROUND.053 FILE DATA RECORD NUMBER: 2
FILE START TIME: 326: 1:34:46.853



SAMPLES 400 THRU 1200

References

1. D. E. Kerr, "Propagation of Short Radio Waves," McGraw-Hill, New York, 1951, page 452.
2. Ruck, G. T., Barrick, D. E., Stuart, W. D., Krichbaum, C. K., "Radar Cross Section Handbook," Plenum Press, New York, 1970.

DISTRIBUTION

No. of Copies

Commander White Sands Missile Range ATTN: STEWS-AD-L White Sands Missile Range, NM 88002	1
Sandia Laboratories ATTN: W. H. Curry Div. 1336, Box 5800 Albuquerque, NM 87115	1
Commander US Army Armor Center and Fort Knox ATTN: ATZK-CD-MS Fort Knox, KY 40121	1
Jet Propulsion Laboratory California Institute of Technology ATTN: Library/Acquisitions 111-113 4800 Oak Grove Drive Pasadena, CA 91103	1
Commander (4253-3) Pacific Missile Test Center Point Mugu, CA 93042	1
Sandia Laboratories ATTN: Library P. O. Box 969 Livermore, CA 94550	1
Commandant US Army Air Defense School ATTN: ATSA-CD-MM Fort Bliss, TX 79916	1
Technical Library Naval Ordnance Station Indian Head, MD 20640	1
HQ SAC/NRI (Stinfo Library) Offutt Air Force Base, NE 68113	1
Commander Rock Island Arsenal ATTN: SARRI-RLPL-Technical Library Rock Island, IL 61201	1
Commander (Code 233) Naval Weapons Center ATTN: Library Division China Lake, CA 93555	1

Department of the Army US Army Research Office ATTN: Information Processing Office P. O. Box 12211 Research Triangle Park, NC 27709	1
ADTC (DLOSL) Eglin Air Force Base, FL 32542	1
US Army Command and General Staff College ATTN: ATSW-ET-L Fort Leavenworth, KS 66027	1
University of California Los Alamos Scientific Laboratory ATTN: Reports Library P. O. Box 1663 Los Alamos, NM 87545	1
Commander USACACDA ATTN: ATCA-CA Fort Leavenworth, KS 66027	1
Library US Army War College Carlisle Barracks, PA 17013	1
IIT Research Institute ATTN: GACIAC 10 West 35th Street Chicago, IL 60616	
Director US Army Ballistic Research Laboratory ATTN: DRDAR-TSB-S (STINFO) Aberdeen Proving Ground, MD 21005	1
US Army Materiel Systems Analysis Activity ATTN: DRXSY-MP Aberdeen Proving Ground, MD 21005	1
US Army Cold Region Research and Engineering Laboratory ATTN: CRREI-RT (Burger) P. O. Box 282 Hanover, NH 03755	1
Goodyear Aerospace Corporation 2112 Lewis Turner Blvd ATTN: Mr. McShera Fort Walton Beach, FL 32548	1

DRSMI-LP, Mr. Voigt	1
-EX, Mr. Owen	1
-R	1
-RPR	15
-REG, Mr. Russell	20
-RSL, Mr. Frank Case	2
-TE, Mr. Leeper	4
-RPT (Record Copy)	1
(Reference Copy)	1