PORTABLE SHORT-PERIOD SEISMOMETER MODEL S-13

OPERATION AND MAINTENANCE MANUAL

STOCK NO. 990-18300-9801

GEOTECH INSTRUMENTS, LLC

For information relating to other Geotech Instrument products and manuals, inquires may be addressed to:

GEOTECH INSTRUMENTS, LLC
10755 Sanden Drive
Dallas, Texas 75238-1336

Voice: 214 221-0000
Fax: 214 343-4400
Web: www.geoinstr.com

OPERATION AND MAINTENANCE MANUAL

PORTABLE SHORT-PERIOD SEISMOMETER, MODEL S-13

Stock Number 990-18300-9801

Geotech Instruments, LLC
10755 Sanden Drive
Dallas, TX 75238-1366

Phone: 214 221 0000
Fax: 214 343 4400
Web: www.geoinstr.com

18 May, 2000

Blank Page

CONTENTS

ILLUSTRATIONS

TABLES

OPERATION AND MAINTENANCE MANUAL
PORTABLE SHORT-PERIOD SEISMOMETER
MODEL S-13

1. GENERAL DESCRIPTION

1.1 PURPOSE OF THE EQUIPMENT

The Portable Short-Period Seismometer, Model S-13, is designed for use in field operations where a small, light-weight, short-period, moving-coil type seismometer is desired. The seismometer may be operated in either the horizontal or vertical position, and the period is adjustable from 1.33 to 0.91 second (0.75 to 1.1 Hz). Several main coil configurations are available. Refer to table 1 for the standard coil configuration. The seismometer is equipped with a calibration coil and has provisions for weight-lift calibrations.

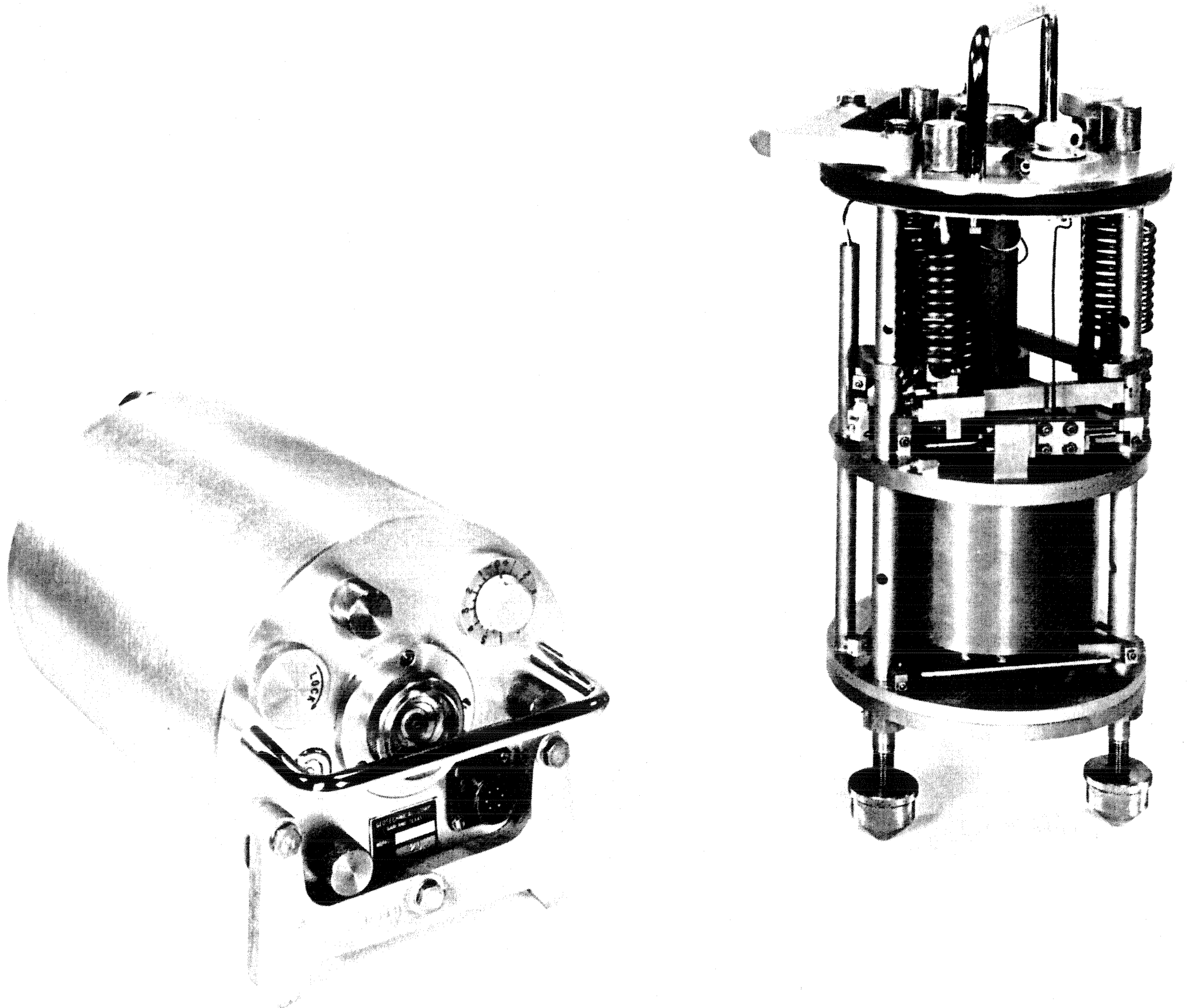
1.2 DESCRIPTION OF THE EQUIPMENT

The seismometer weighs less than 25 pounds and has a 5-kilogram mass. The cover and electrical connections are watertight so that the instrument may be submerged in up to 100 feet of water without leakage. All operational adjustments are external to the instrument. Included are adjustments for the period, mass position, and instrument leveling. A mass lock, a mass-position indicator, and a bubble level are also provided. The instrument is shown in figure 1.

1.3 SPECIFICATIONS

1.3.1 Operating Characteristics

Mode of Operation	Convertible, vertical to horizontal
Natural Period	Adjustable 1.33 sec/cycle to 0.91 sec/cycle
Natural Frequency	Adjustable 0.75 Hz to 1.1 Hz
Tilt (vertical mode)	Operates within 4° of vertical, at 0.8 Hz natural frequency
Weight of Inertial Mass	5 kg (11.0 lbs.) nominal
Spring Rate	(Approximately 10 to 1 lever) 3.82 newton/mm ±5% (21.8 lbs/in)
Temperature Range	-51° to +60°C (-60° to +140°F)



8495

Figure 1. Portable Short-Period Seismometer, Model S-13

Transducer	
Type	Moving coil (velocity)
Damping	Electromagnetic
Air gap flux density	4750 ±50 gauss, average over 22.224 mm coil length (0.875 in.); 4350 ±50 gauss, average over 25.4 mm coil length (1 in., standard coil); Flux density varies less than 2% over temperature range
Air gap length	3.81 mm (0.150 in.)
Area of smallest pole piece	0.00393 sq m (6.1 sq in.)
Coil volume	25.4 mm coil length - 15.1 x 10^3 cu mm 22.2 mm coil length - 13.2 x 10^3 cu mm
Coil to pole clearance	0.762 mm (min)
Generator constant	629 v-sec/m nominal when using the standard coil
Coil specifications	See table 1 (page 4)
Calibration coil	
Motor constant	0.1975 ±0.002 newton/ampere
Number of turns	50
Wire size	No. 42
Resistance	23 ±3 ohms at 25°C (77°F)

1.3.2 Physical Characteristics

Basic dimensions	
Height	0.381 m (15 in.)
Diameter	0.168 m (6.625 in.)
Net weight	10.4 kg (23 lbs.)
Shipping weight	13.6 kg (30 lbs.)
Shipping volume	0.036 cubic meters (1.3 cu ft.)
Seismometer bulk specific gravity	1.6 to 1.8

1.3.3 Connectors

Output	Receptacle MS3102C-14S-6P with mating plug MS-3108B-14S-6S and cable clamp AN3057-6

Table 1. Coil Specifications

Coil part no. 19936	Number of windings	Resistance per winding (ohms)	Total series resistance (ohms)	Resistance tolerance (percent)	Generator constant[c] volt-sec/m	CDR[d] (ohms) f_o = 0.8 Hz	CDR[d] (ohms) f_o = 1.0 Hz
-101	1	160	160	10	130.5	339	271
-102[a]	1	3,600	3,600	10	629	7,870	6,525 ±20%
-103[b]	2	25,000	50,000	10	2,285	104,000	83,100
-104[b]	4	395	1,520	10	406	3,028	2,630
-105	1	27,000	27,000	10	1,690	56,900	45,500
-106	1	63	62	10	82.1	134	107

[a]Standard coil

[b]All multiwinding coils have the same resistance in each winding. Unless otherwise specified, instrument is supplied with all windings connected in series.

[c]The design Generator constant is based on all windings connected in series. Actual generator constant value is measured and recorded to ±2% on customer data sheet.

[d]CDR is theoretical. See customer data sheet supplied for actual CDR.

1.4 EQUIPMENT SUPPLIED

1 Portable Short-Period Seismometer, Model S-13

1 Mating plug MS3108B-14S-6S and cable clamp AN3057-6

1 Operation and Maintenance Manual

1 Calibration Kit, No. 21323

1 Crate, shipping, No. 37949-01-01

Crate, special shipping, No. 20612-01-01 (available on request)

2. INSTALLATION

2.1 GENERAL

The Model S-13 Seismometer is a very stable instrument. When properly installed, it may be expected to operate without further adjustment for several years. General considerations in the use and placement of any seismometer are outlined below.

2.1.1 Normally, a seismometer is placed on bedrock, on a pier anchored to bedrock, or in a vault anchored to bedrock.

2.1.2 If the maximum possible magnification is to be realized, the location must be in a quiet zone away from cultural noise.

2.1.3 The instrument should not be exposed to direct sunlight and should be sheltered from wind.

2.1.4 The instrument location should have a thermally stable atmosphere.

2.1.5 If the instrument is to be placed where access will be difficult, all necessary tests can be performed before the seismometer is placed in its final location.

2.1.6 If the seismometer is used in a portable metal vault, at least 2 feet of earth should be placed on top of the vault for thermal stability and isolation from wind noise.

2.1.7 Cables and wiring should be installed with maximum separation between power and signal cables to minimize stray pickup. Belden shielded cable, No. 8422, has been used for indoor signal cables and spiral-four has been used for outdoor service. Shields of the signal cables should be grounded at both ends.

2.2 UNPACKING

The seismometer is packed in a reusable container and is shipped in the vertical position with the mass locked. It is assembled ready for vertical mode operation so that there is no need to remove the instrument cover unless it is to be inspected or changed for horizontal mode operation. If the cover is to be removed, see paragraph 3.3.1. Visually inspect the outside of the seismometer for any apparent damage. If damage is apparent and the instrument will not operate, return it to the manufacturer or an appropriate maintenance depot.

<u>NOTE</u>

> When moving the instrument, always be sure that the mass is locked.

2.3 SETTING UP THE SEISMOMETER

a. Place the instrument in its permanent position. If operated in the horizontal mode, the axis of the seismometer should be carefully aligned with a known bearing to determine direction of arriving signals. See paragraph 3.3.2 for conversion to horizontal mode operation.

b. Unlock the mass by turning the mass lock knob counterclockwise as far as it will go. Use the bubble level for leveling a vertical instrument and adjust mass position according to the procedure outlined in paragraph 3.2.3. Level a horizontal instrument by adjusting the movable foot until the mass is centered.

c. Make the electrical connections to the instrument using the connector furnished. A downward motion of the mass (away from the handle) should produce a positive voltage at pin A of the connector and a negative voltage at pin B, terminals of the main coil. A positive voltage applied to pin C of the cal coil should produce a downward motion of the mass (away from the handle). A schematic showing internal wiring connections is supplied with each instrument. Typical wiring schematics are shown in figure 17 of this manual.

3. OPERATION

3.1 PRINCIPLES OF OPERATION

For vertical mode installation, the seismometer mass is supported by three stiff springs attached to toggle action cantilevers. The cantilevers impart a relatively low spring rate to the mass due to a 9.4:1 lever ratio between the mass and spring attachments. The mass is constrained to move along the axis of the coil by stiffened wires called delta rods, three at each end of the mass. One end of a seventh delta rod is attached to the mass and is one part of the period adjust mechanism. The other end of this rod is axially pulled or pushed by means of a torsion rod imparting tangential loading in the delta-rod system. Varying the twist in the torsion rod varies the period of the mass.

The seismometer is equipped with an electromagnetic calibrator which consists of a calibration coil fixed to the instrument frame and a permanent magnet attached to the mass.

3.2 CONTROLS AND INDICATORS

Figure 2 locates the controls and indicators which are described in the following paragraphs.

3.2.1 Period Adjust

This control permits adjustment of the natural period of the instrument from 0.91 to 1.33 seconds. Clockwise rotation of the control will cause the period to decrease while counterclockwise rotation will increase the period. A socket-head cap screw in the dial body is used to clamp the control after adjustment.

3.2.2 Mass-Position Indicator

This indicator may be used to determine the mass position. Upon looking directly into the indicator, a red circle and three concentric black rings can be seen. The red circle changes diameter as the mass position changes. When the mass is against the upper stop (vertical operation), the red circle coincides with the largest black ring and when the mass is against the lower stop the red circle coincides with the smallest black ring. When the mass is centered the red circle coincides with the center black ring.

3.2.3 Mass-Position Adjustment (vertical operation)

The mass position of the vertical mode instrument may be adjusted by rotating the knurled knob shown in figure 2. Clockwise rotation of the knob moves the mass up.

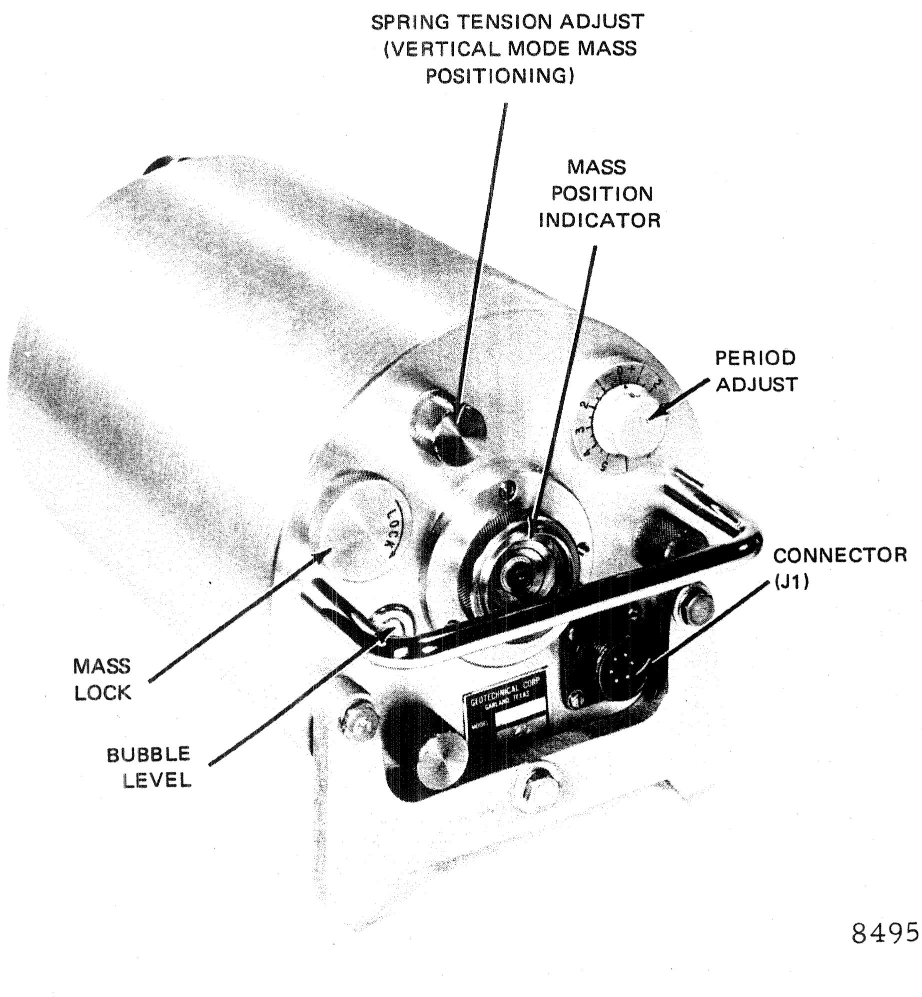


Figure 2. Controls and indicators

3.2.4 Bubble Level

This indicator is used to determine the vertical alignment of the instrument in the vertical mode.

3.2.5 Mass Lock

This control is used to lock the inertial mass. When the knob is rotated fully clockwise, the mass is locked firmly against the upper limit stop. It should be rotated fully counterclockwise to uncage the mass.

3.3 OPERATING PROCEDURES

The S-13 seismometer is a very sturdy instrument but is also very sensitive and should be handled accordingly. The following procedures apply to both horizontal and vertical operation:

a. The inertial mass should always be locked when the instrument is being moved or major adjustments are being made.

b. Cleanliness of the internal parts and O-rings is essential for proper operation.

c. All operational adjustments and indicators are externally located to minimize the need for removing the seismometer cover. The cover should not be removed in a dirty or dusty atmosphere or where small magnetic particles may be attracted to the magnet.

3.3.1 Removing the Instrument Cover

The cover may be removed from the instrument by removing the following items from the vertical legs, item 55, figure 16 (refer to figure 16 for numbers in parentheses in the following paragraphs):

a. Three seismometer feet (63);

b. Three lock rings (64);

c. Three hex jam nuts (40);

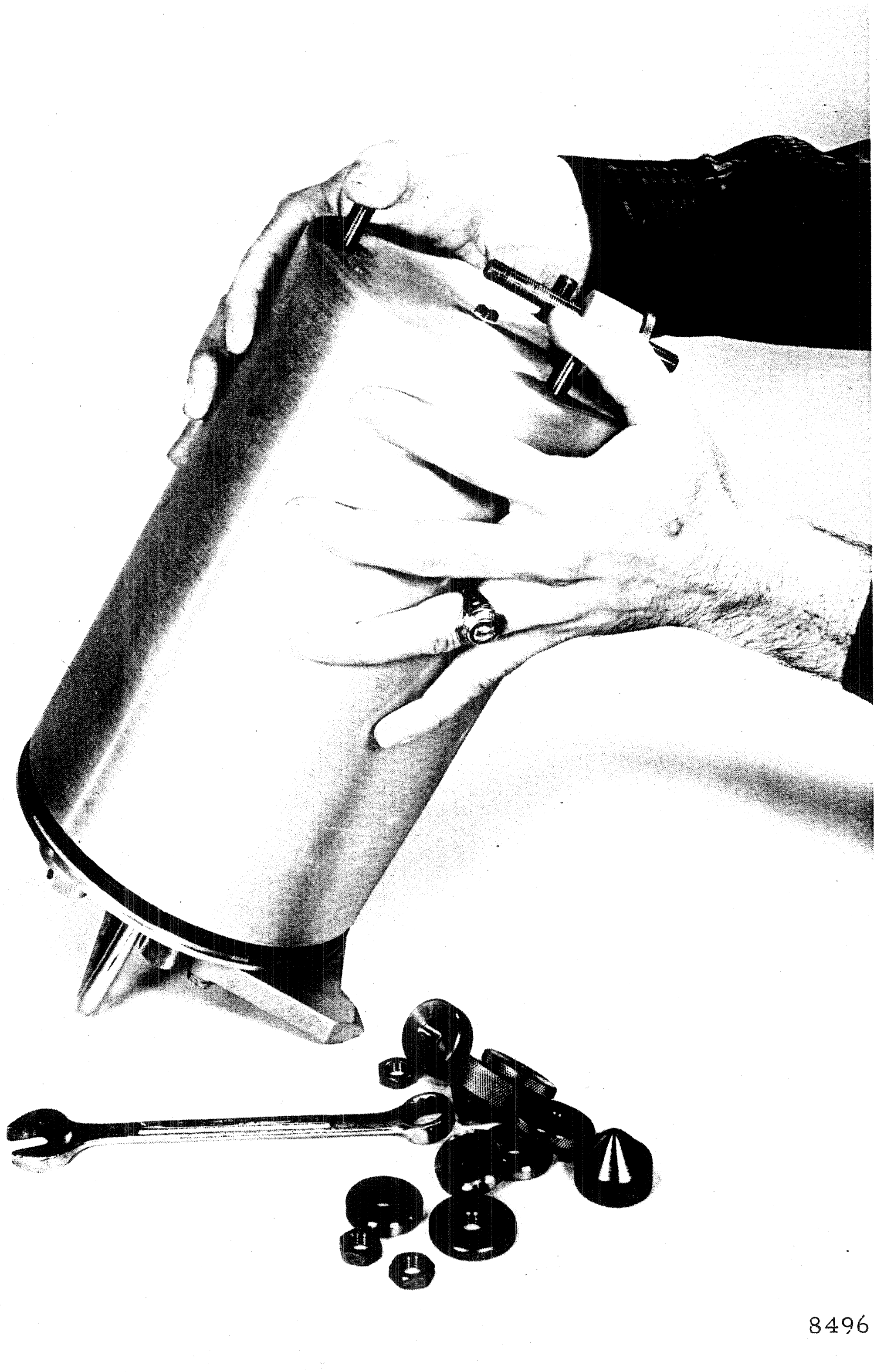
d. Three seal retainers (65) and three leg gaskets (66).

The cover may then be pulled off the seismometer as shown in figure 3. When replacing the cover, be sure that the three leg gaskets (66) are properly located against the cover and around the leg.

3.3.2 Horizontal Operation

As previously stated, the seismometer is assembled and shipped ready for vertical operation. If the instrument is to be used in the horizontal mode, convert it as follows:

a. Lock the mass and remove the instrument cover as directed in paragraph 3.3.1.



8496

Figure 3. Removing (or replacing) the cover

b. Set the seismometer in a vertical position.

c. Referring to figure 4, unfasten each of the three flexures (26) from the cantilever assembly (41) by removing the screw (79) and washer (85) and the flexure clamp (86). Press down on the mass end of the cantilever until all tension is removed from the flexure. Carefully work the flexure off the locating pin. Let each cantilever rise to rest against its cantilever stop (83). Store the flexure clamps and screws in the tapped hole provided in the top of each cantilever stop. The flexures, when free of the locating pin, should flex back, out of the way of the cantilevers. If any one of the three flexures touches any part of the cantilever assemblies, gently bend it back over a large radius until it will clear when released.

d. Replace the cover assembly being careful to clean and lubricate the large O-ring which seals the open end of the cover to the seismometer. Install the seal retainers (65) and hex nuts (40) to secure the cover.

e. Install one seismometer foot (63) and lock ring (64) on the horizontal adjust leg (59).

f. Install the remaining two feet on the vertical legs (55) to prevent damage to the leg threads.

g. Place the seismometer in its anticipated operating position. Maintain accessibility to the instrument controls and mass-position indicator.

h. Adjust the mass position by raising or lowering the seismometer foot on the horizontal adjust leg. Normally, the mass is centered between the stops. When the period is adjusted and the mass position attained, run one lock ring on the horizontal leg up tight against the horizontal foot support to lock the leg, and the other lock ring down tight against the foot. Angular tilt about the center axis of the seismometer is not critical.

NOTE

> Large scale period adjustments may affect the mass position setting. Therefore, it may be necessary to adjust both the mass position and natural period alternately until the desired period is attained at the desired mass position.

3.3.3 Vertical Operation

To change the seismometer from horizontal to vertical operation, reverse the steps given in paragraph 3.3.2. Level the seismometer using the vertical feet as adjustment devices. A bubble level is located in the top of the instrument to facilitate this adjustment. Center the mass between the limit stops by rotating the knurled mass-position knob (see paragraph 3.2.3) clockwise to raise the mass and counterclockwise to lower the mass. Determine the mass position using the mass-position indicator (see paragraph 3.2.2). Do not continue to turn the mass-position adjust knob after the mass has encountered a stop, or when the mass is locked.

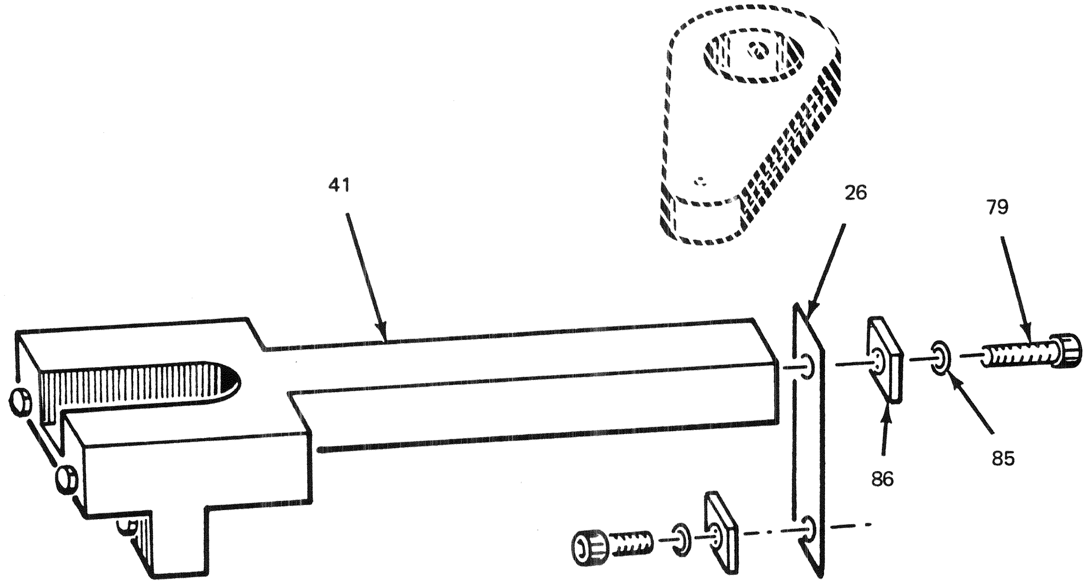
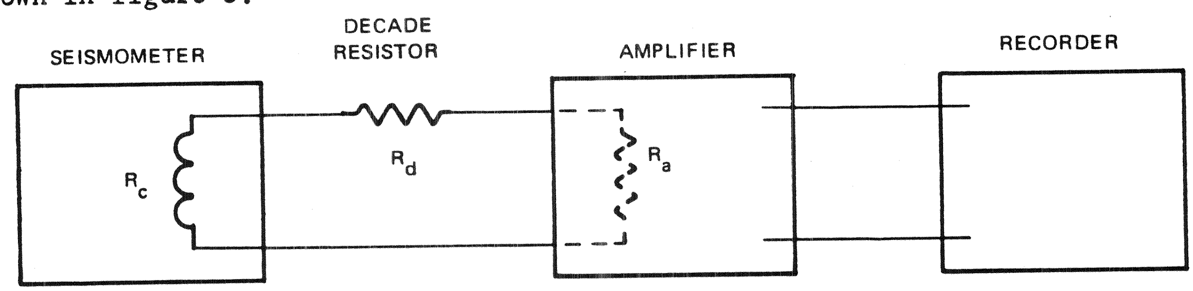


Figure 4. Flexure detachment for horizontal operation

4. OPERATING TESTS

4.1 NATURAL FREQUENCY

To determine the natural frequency of the seismometer, complete the test setup shown in figure 5.



$$R_d + R_a \geqq 2000 \times R_c$$

WHERE: R_c IS THE RESISTANCE OF THE SEISMOMETER COIL

R_d IS THE RESISTANCE OF THE DECADE RESISTOR

R_a IS THE RESISTANCE OF THE AMPLIFIER

Figure 5. Test setup for determining natural frequency

Excite the seismometer mass into oscillation with a weight lift (reference sections 4.3 and 4.4) or by a momentary dc pulse applied to the calibration coil. Record several cycles as the seismometer mass decays to rest at its free period. Determine the time required for any given number of cycles and calculate the natural frequency as follows:

$$\text{Natural frequency} = f_o = \frac{X \text{ number of cycles}}{\text{time for } X \text{ number of cycles}}$$

The natural frequency may be expressed in Hz (hertz).

An alternate method of determining natural frequency is given in section 4.9.

4.2 OPEN-CIRCUIT DAMPING

The internal losses of the S-13 with the standard 3600-ohm coil will impart a damping of less than 3% of critical damping when the seismometer is operated into an open circuit or looking at an external impedance which is at least 2000 times the internal impedance.

Usually this "open circuit" damping is neglected in determining CDR (critical damping resistance) or when computing the circuit resistance required for a desired seismometer damping.

Most high-impedance coils have higher internal losses, and result in open-circuit damping which may be significant in circuit calculations. (It should be noted that such losses are not necessarily detrimental in high-impedance coils which are used with high-impedance amplifiers, and may in some cases be desirable.)

To determine the open-circuit damping of the seismometer, proceed as follows:

a. Complete the test setup as shown in figure 5 for determining natural frequency, making certain that the circuit resistance external to the seismometer is equal to or greater than 2000 times the resistance of the seismometer coil.

b. Excite the mass into oscillation with a weight lift or by a momentary dc pulse applied to the calibration coil.

c. Record the output of the seismometer as the mass oscillation decays due to internal losses. The envelope of the decay curve should be logarithmic; if it is triangular (straight sides to the envelope) there may be frictional damping which must be corrected before proceeding. (Check for physical rubbing of parts in the mass-suspension system or dirt in the gap. Review section 5 on maintenance for additional information.)

d. Measure the positive zero-to-peak amplitudes of any two consecutive unclipped cycles, such as the fourth and fifth, and calculate their ratio as follows:

$$\frac{\text{Zero-to-peak amplitude of fourth cycle}}{\text{Zero-to-peak amplitude of fifth cycle}} = \frac{X_4}{X_5} = \underline{\hspace{4cm}}$$

e. The natural (base e) logarithm of the ratio of $\frac{X_4}{X_5}$ is related to the circuit damping, λ, as follows:

$$\ln \frac{X_4}{X_5} = \frac{2\pi\lambda}{\sqrt{1 - \lambda^2}}$$

wherein λ is defined as the fraction of or ratio to critical damping, and critical damping is equal to 1.0.

NOTE

Where λ is less than 0.1, the term $\sqrt{1 - \lambda^2}$ is between 1.0 and 0.995, and may be considered as 1.0 in the above equation to simplify calculations.

f. The fraction of critical damping, λ, corresponding to some values of $\frac{X_4}{X_5}$ are given in table 2.

Table 2. Fraction of critical damping, λ, corresponding to successive cycle zero-to-peak amplitude ratios, $\frac{X_4}{X_5}$

$\frac{X_4}{X_5}$	λ, fraction of critical damping
1.0	0
1.1	0.015
1.2	0.029
1.3	0.042
1.4	0.053
1.5	0.064
1.6	0.075

4.3 CRITICAL DAMPING RESISTANCE (CDR) FOR VERTICAL OPERATION

A spring-mass system is said to be critically damped when it approaches its final position at the greatest possible rate (least amount of time), without going beyond (without overshoot).

The S-13 seismometer employs an electromagnetic transducer consisting of a moving coil in a magnetic field. The seismometer is damped by an external load resistance placed across the coil terminals.

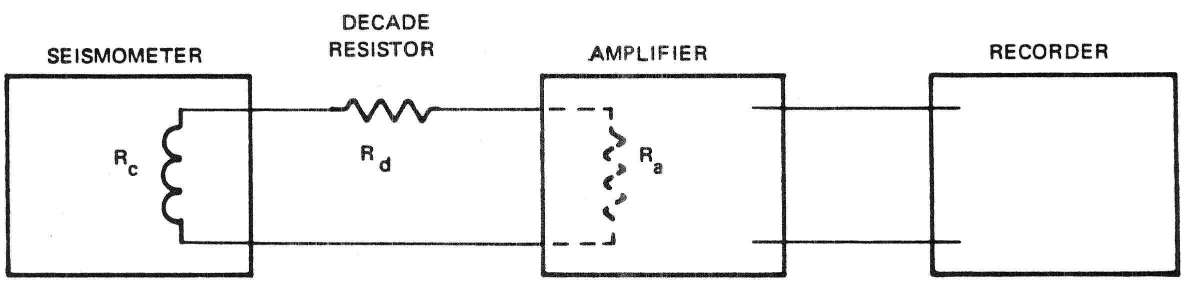
The total circuit resistance (R_t) which produces critical damping of the seismometer mass is known as the critical damping resistance (CDR). The CDR may be used to calculate the total circuit resistance required for any desired damping other than critical.

Where the open-circuit damping (section 4.2) is negligible, the CDR of the instrument may be determined by proceeding as follows:

a. Lock the mass and measure the resistance of the seismometer coil with a precision bridge.

b. Connect the seismometer as shown in figure 6.

c. Unlock the mass and center it if necessary. Adjust period as desired.



$R_t = R_c + R_d + R_a$

R_c IS THE RESISTANCE OF THE SEISMOMETER COIL

R_d IS THE RESISTANCE OF THE DECADE RESISTOR

R_a IS THE RESISTANCE OF THE AMPLIFIER

Figure 6. Test setup for determining CDR

d. Unscrew the mass-position indicator cap (2) so that weight lifts can be made from the table (6) located underneath.

e. Attach a length of nylon thread to one of the test weights supplied. Weights and nylon thread are supplied with the calibration kit No. 21323[1], which is stored in a plastic vial in the seismometer shipping crate.

f. Lower the weight onto the weight lift table. See figure 7. Allow the output to return to normal.

g. Lift the weight sharply. The movement must be as nearly vertical as possible. If the weight strikes any portion of the seismometer, repeat the lift.

h. The resultant record should be similar to that shown in figure 8.

i. Repeat the weight lifts and adjust R_d (figure 6) until the percent of overshoot is about 20 to 25%.

j. Enter table 3 with the percent overshoot and determine λ. The quantity λ is the ratio of actual damping to critical damping.

k. Calculate the CDR using the relation, CDR = $R_T \times \lambda$. This method is applicable to any velocity seismometer.

l. Once the CDR has been established for a seismometer having a given natural frequency, the total circuit resistance (R_t) required for any desired relative damping, λ, may be calculated as follows:

$$R_t = \frac{CDR}{\lambda}$$

Table 3. Ratio (λ) of actual damping to critical damping as a function of percent overshoot

% overshoot	λ	% overshoot	λ	% overshoot	λ
10.8	0.577	15.5	0.511	20.0	0.455
11.0	0.575	16.0	0.504	20.5	0.449
11.5	0.567	16.5	0.497	21.0	0.444
12.0	0.560	17.0	0.491	21.5	0.439
12.5	0.551	17.5	0.485	22.0	0.434
13.0	0.544	18.0	0.479	22.5	0.429
13.5	0.537	18.5	0.473	23.0	0.424
14.0	0.530	19.0	0.467	24.0	0.414
14.5	0.524	19.5	0.461	25.0	0.404
15.0	0.518				

[1]The weights supplied are 1g and 200 mg.

Figure 7. Vertical weight lift

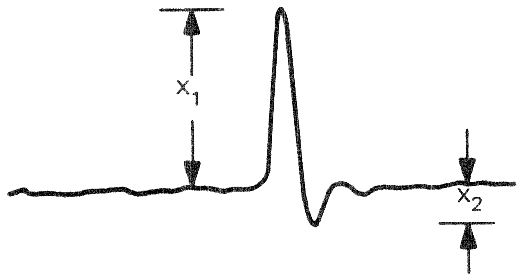


Figure 8. Determining percent overshoot

The foregoing calculations neglect damping due to internal losses, which may be appreciable for high-impedance coils. When it is required to consider these losses, proceed as follows.

m. Determine the open-circuit damping using the procedure outlined in section 4.2.

n. Determine the relative damping, λ_1, and note the total circuit resistance corresponding to λ_1 (not the CDR) as in steps a through j of this section.

o. Calculate the required total circuit resistance for any desired relative damping, λ_x, by using the following relation:

$$R_x = R_1 (\lambda_1 - \lambda_o) / (\lambda_x - \lambda_o)$$

wherein

R_x = total circuit resistance required to produce the desired relative damping λ_x.

R_1 = total circuit resistance required to produce the relative damping, λ (from step n)

λ_o = open circuit damping (from step m)

λ_1 = relative damping obtained with total circuit resistance, R_1 (from step n)

λ_x = relative damping desired of seismometer.

NOTE

When $\lambda_x = 1.0$, R_x is the CDR .

The CDR stated on the customer data sheet supplied with each instrument considers open circuit damping and is determined by the formulae given in step o.

4.4 CDR FOR HORIZONTAL OPERATION

To determine the CDR for horizontal operation, perform the following steps:

a. Repeat steps a, b, and c of paragraph 4.3.

b. Thread the hex nut onto the horizontal weight lift hook (both items are supplied in calibration kit No. 21323).

c. Unscrew the mass-position indicator cap.

d. Screw the horizontal weight-lift hook into the threaded hole in the calibration-coil support (96) a few turns and lock it with the jam nut so that the flat is in line with the center axis of the seismometer.

e. Tie the weight in the center of an 8-inch length of the nylon thread and run one loose end through the hole in the mass-position indicating post.

f. Run the other loose end over the edge of the flat and through the hole in the horizontal weight-lift hook as shown in figure 9.

g. Adjust each thread end so that a 90° angle is formed and the weight is the same distance from each end. A few turns around the hook and a simple overhand knot on the post will secure the thread.

h. When the seismometer output has settled to normal background noise, as seen on the recorder, lift the weight sharply with a small piece of cardboard or other stiff material. The weight should not strike the weight-lift hook; if it does, repeat the lift. The resulting record should be similar to that shown in figure 8.

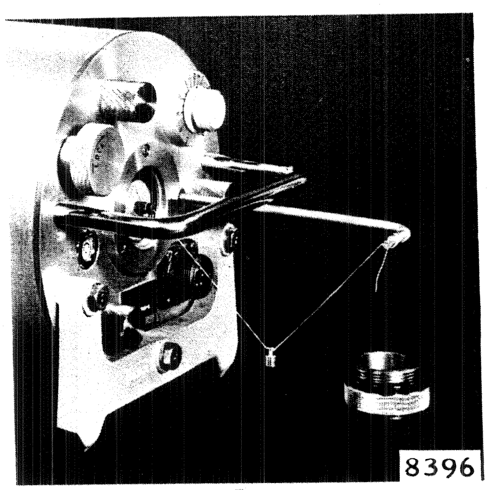


Figure 9. Horizontal weight lift

i. Continue weight lifts and adjust R_d until the percent overshoot is 20 to 25%. Repeat steps j and k of section 4.3 to determine the CDR. Where open-circuit damping must be considered, refer to steps m through o of section 4.3.

4.5 CDRX (CRITICAL DAMPING RESISTANCE, EXTERNAL)

Determine the CDRX from the relation: CDRX = CDR - R_c.

4.6 DETERMINING THE MAIN COIL GENERATOR CONSTANT, G

Determine the generator constant from the relation:

$$G = \sqrt{4\pi f_o M \text{ (CDR)}} \text{ V-sec/meter}$$

where

f_o = natural frequency of the seismometer in Hz.

M = mass of the inertial mass in kg (5 kg for 18300 seismometer)

CDR = critical damping resistance in ohms, corresponding to natural frequency, f_o.

This method can be used for any seismometer employing a velocity transducer, providing that open circuit damping is negligible.

4.7 DETERMINING MOTOR CONSTANT, G, OF THE CALIBRATION COIL

To determine the motor constant, G, of the calibration coil, proceed as follows:

a. Place the seismometer and recording systems in operation.

b. Make several weight lifts, and record the X_m (zero-to-peak amplitude) trace for each weight lift.

c. Apply dc pulses to the calibration coil and adjust the current, i_p, until the X_i (zero-to-peak) trace amplitude is within 10 percent of the X_m trace amplitude. Record X_i and note i_p.

d. Calculate the motor constant, G, of the calibration coil, using the average of three or more weight lifts:

$$G_{cal\ coil} = \frac{980 \times 10^{-5}\ Wt_{(eff)} X_i}{i_p\ X_m} \text{ newtons/ampere}$$

where:

G = motor constant of cal coil, newtons/ampere

X_i = zero-to-peak trace amplitude in millimeters due to current i_p

i_p = dc current in calibration coil, zero-to-peak, in amperes

X_m = zero-to-peak trace amplitude in millimeters due to weight lift, $Wt_{(eff)}$

$Wt_{(eff)}$ = effective weight lifted, in grams

For vertical seismometers, $Wt_{(eff)}$ = weight lifted, in grams

For horizontal seismometers, $Wt_{(eff)} = \frac{\text{weight lifted, in grams}}{2}$

NOTE

When calculating the calibration coil motor constant, G, care must be exercised to use only the traces made when the weight is lifted. Also, only dc pulse traces deflecting in the same direction as the lifted weight traces should be utilized. Reverse leads to the calibration coils if necessary to achieve this relation.

4.8 DETERMINING EQUIVALENT EARTH MOTION

When the motor constant of the calibration coil has been determined, the equivalent sinusoidal earth motion produced by a sinusoidal signal in the calibration coil can be determined by the following relation:

$$y = \frac{Gi \times 10^6}{4\pi^2 f^2\ M}$$

where:

y = equivalent earth motion in microns, peak-to-peak

G = calibration coil motor constant, newtons/ampere

i = current through the calibration coil, amperes, peak-to-peak

f = frequency of calibration signal

M = weight of mass in kilograms.

4.9 OBTAINING EQUIVALENT SHUNT RESISTANCE DUE TO INTERNAL LOSSES OF SEISMOMETER AND A SECOND METHOD OF CHECKING NATURAL FREQUENCY[2]

a. Connect a function generator, a dc-coupled oscilloscope, and the seismometer as shown in figure 10.

b. Adjust the output of the function generator to approximately 4 volts, peak-to-peak, and the tapped voltage to approximately 0.4 volt, peak-to-peak.

c. Unlock the seismometer mass.

d. Connect the vertical input of the oscilloscope to Y.

e. Adjust the frequency of the function generator output to the natural frequency of the seismometer. The oscilloscope figure will close and form a straight line at the natural frequency. This step requires patience, as the internal losses of the seismometer may be very slight.

f. Measure the voltage at Y.

g. Measure the voltage at Y'.

NOTE

> The ratio of Y and Y' are most conveniently measured as the ratio of the vertical deflections on the scope face if the scope gain is not changed when the switch is thrown.

h. Calculate the shunt resistance equivalent (R_m) of the mechanical losses from the relation:

$$R_m \text{ (ohms)} = \frac{V_y (R_1)}{V_{y'} - V_y}$$

where:

V_y = voltage at Y

R_1 = resistance in ohms

$V_{y'}$ = voltage measured at Y'.

[2]Mathematics and method for this section and sections 4.10 and 4.11 from a paper by Dr. Daniel P. Johnson and Mr. Harry Matheson of the National Bureau of Standards.

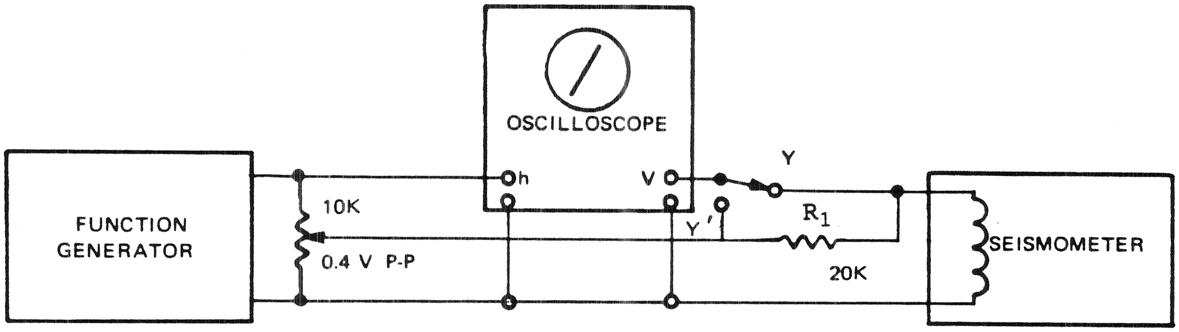


Figure 10. Test setup for determining the equivalent shunt resistance of the seismometer.

4.10 OBTAINING BEST FLAT VELOCITY RESPONSE

For the best flat response to velocity, the following equation holds:

$$\frac{\mathcal{R}}{R} = \frac{1}{\sqrt{2}} \left| \frac{\omega_o - \omega_g}{\omega_o + \omega_g} \right|$$

where:

$\mathcal{R}$ = $CDR_{(seis)} = CDR_{(galv)}$

R = total circuit resistance for best flat response

ω_o = natural angular frequency of seismometer in in rad/sec = 2π x freq in Hz.

ω_g = natural angular frequency of galvanometer in rad/sec = 2π x freq in Hz.

For example, with the circuit shown in figure 11, where the natural frequency of the galvanometer is 20.6 Hz,

$$R = R_S + R_L + R_G = \mathcal{R}\sqrt{2} \left| \frac{2\pi f_s + 2\pi f_g}{2\pi f_s - 2\pi f_g} \right|$$

$$= 160 \times 1.414 \times \frac{21.4}{19.8}$$

$$= 247$$

$$R_L = 247 - R_S - R_G$$

$$= 91 \text{ ohms.}$$

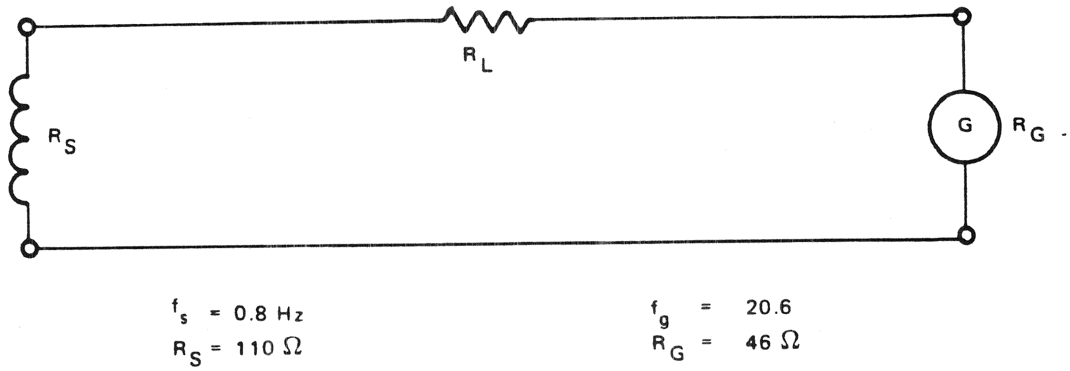


Figure 11. Typical seismometer-galvanometer circuit

4.11 CAPACITANCE METHOD OF DETERMINING CDR

If a capacitor is placed in parallel with the main coil of the seismometer, there is an angular frequency, ω_{pc}, at which the imaginary part of the impedance of the combination is zero. For this angular frequency, the following relation holds:

$$\mathcal{R} = \frac{\omega_o^2 - \omega_{pc}^2}{4\omega_o\omega_{pc}^2 C_e} \left(\frac{R_m}{R_o + R_m}\right)^2 \left(1 + \sqrt{1 - 4\omega_{pc}^2 C_e^2 R_o^2 \left[\frac{R_o + R_m}{R_m}\right]^2}\right)$$

Note that ω_{pc} is real provided that

$$\frac{R_m}{R_o + R_m} \geqq 2\omega_{pc} C_e R_o$$

where:

$\mathcal{R}$ = critical damping resistance in ohms (total circuit resistance)

ω_o = natural angular frequency = $2\pi f_s$ (natural frequency)

C_e = capacitance of parallel capacitor in farads

R_m = shunt resistance in ohms that is equivalent to internal losses

R_o = main coil resistance in ohms

ω_{pc} = natural angular frequency of the seismometer with the capacitor in parallel.

To use this method, determine ω_o and R_m (see paragraph 4.10). Place a capacitor (approximately 200 microfarad, nonpolarizing) across the main coil terminals and determine the apparent natural frequency in this condition. Substitute these values in the equation to determine the CDR ($\mathcal{R}$).

5. MAINTENANCE

5.1 GENERAL

The design of the S-13 seismometer is such that complete disassembly of the instrument should seldom be necessary and disassembly beyond the limits outlined in this section should be avoided. If it appears that further disassembly is needed, the instrument should be returned to the manufacturer for repair and readjustment. Each seismometer is carefully assembled with parts selected to give the best performance; therefore, parts removed should be replaced in their original locations. Figure 16 is an exploded view of the instrument which should be used as a reference for the item numbers which are given in the maintenance instructions. The following precautions should be observed when disassembling the seismometer as noted above:

a. Assembly area should be clean and free of dirt or metal chips, particularly magnetic metal chips.

b. The calibration magnet-to-mass assembly (97) should be handled carefully to avoid sharp blows. If the coil (49) is removed for any length of time, the gap of the magnet should be taped over to keep it clean.

c. The calibration magnet assembly (45) should never be removed from main magnet assembly (44), as their magnetic charges, which are set with close tolerances, are shunted in this assembled position.

d. The O-rings and O-ring grooves should be kept free of dirt, chips, and other foreign matter. On installation, the O-rings should be lubricated with a suitable O-ring lubricant.

e. Before attempting any maintenance on this seismometer the operations section, parts 3.1, 3.2, and 3.3 should be read and thoroughly understood.

5.2 REMOVING AND REPLACING THE COVER

Instructions for removing and replacing the cover are given in paragraph 3.3.1.

5.3 CHANGING THE CALIBRATION COIL

To remove the calibration coil proceed as follows:

a. Remove the mass indicator cap assembly (2).

b. Remove mass-position indicator cap (5) and weight-lift table (6).

c. Remove the three No. 6-32 x 1/2 socket head cap screws (4).

d. Remove calibration-coil support (96) and calibration-coil assembly (23). Note the orientation of the 10-32 tapped hole in calibration-coil support.

e. Unsolder the leads from the terminals.

f. Note the orientation of the terminals in relation to the 10-32 tapped hole in the calibration-coil support.

g. The calibration-coil assembly is cemented to the calibration-coil support with Pliobond cement and can be removed by twisting and pulling on the calibration-coil assembly.

h. Remove the Pliobond cement from the calibration-coil support with acetone.

i. Apply a small amount of Pliobond cement to the end of the new calibration-coil assembly. Wait until the cement is tacky and then insert it into the calibration-coil support until the calibration-coil assembly is butted against the shoulder in the calibration-coil support. Orientate the terminals 180° from the 10-32 tapped hole in the calibration-coil support.

j. Solder the green wire to terminal one and the green-white wire to terminal two.

k. Install the above assembly orientating the 10-32 tapped hole on the right hand side when looking at the end of the seismometer in a horizontal position.

l. Before reinstalling the mass indicator cap, lubricate the O-rings. Clean all dirt and foreign matter from the O-ring groove and inspect for any nicks, scratches, or burrs that would prevent O-rings from forming a seal.

5.4 CHANGING DELTA RODS

Delta rods which are distorted or broken should be replaced. If only the small diameter wire is bent, it can be straightened and replaced in the seismometer. To remove damaged delta rods, proceed as follows:

a. Lock the mass.

b. Remove the cover.

c. Remove the damaged delta rods by slackening the 4-40 x 3/16 socket head cap screws (34).

CAUTION

Do not remove all six delta rods at one time. At least 2 delta rods, 1 upper and 1 lower, should be left in place.

d. Fit the new delta rods so that:

(1) The wires rest in their grooves in the clamping blocks.

(2) The two ends of each delta rod lie in the same plane to form one straight line.

(3) The stiffened section is centrally disposed (0.250 each end) between the clamping blocks.

e. Ensure that all clamps (78) are straight and that all screws (34) are tight.

5.5 CHANGING SPRINGS

To change the springs (27), proceed as follows:

a. Lock the mass.

b. Remove the cover.

c. Release the springs until all tension is off the flexures (26, 80, and 87). To release the springs, turn the spring adjust nuts (13) counterclockwise.

d. Remove the 2-56 x 1/4 socket head screws (84) and flexure clamp (86) at the upper end of the cantilever-to-spring flexure (87).

e. Work the flexure off the flexure pin in the spring connector.

f. Pull up on the spring adjust nut and turn it counterclockwise until the nut comes off the spring assembly.

g. Carefully remove the spring assembly from the seismometer.

h. Before replacing the spring assemblies:

(1) Clean the O-ring grooves.

(2) Lubricate the O-rings (15) with light silicone oil or other suitable lubricant.

(3) Place the O-ring in the groove.

i. Extend the threaded end of the spring assembly through the hole in the upper frame plate (93). The flexure pin in the spring connector should be pointing to the left of the observer. Place the teflon washers (1) over the stud and screw the spring adjust nut onto the stud. Three to five turns will be sufficient. Push the spring adjust nut into the O-ring.

j. Lower or raise the spring assembly until the flexure pin will pass through the hole in the upper end of flexure (87).

k. Clamp the flexure to the spring assembly with the flexure clamp (86) and a 2-56 x 1/4 socket-head screw (84). Do not tighten the screw at this time.

l. Turn the spring adjust nut clockwise until a small amount of tension is on all flexures.

m. Make certain that the cantilever and flexures are straight. It may be necessary to slacken all screws holding the flexures. When the cantilevers and flexures are straight, tighten the screws making sure that the clamps are straight with their flexures. Take care not to misalign the cantilever and spring.

n. Tighten the spring adjust nuts until the springs will support the mass. Make sure that the springs line up with spring guides (24), when the spring assemblies are extended, until the dowel pins are approximately 1/8-inch from the bottom of the groove in spring guides. Unlock the mass.

o. Center the mass between the stops, taking care to keep the elongation in all springs equal.

CAUTION

Make sure no part of the spring assembly is rubbing against the cantilevers. The spring assembly should be centered in the yoke of the cantilever.

5.6 REPLACING DAMAGED FLEXURES

5.6.1 To replace a cantilever-to-spring flexure (87), proceed as follows:

a. Lock the mass.

b. Remove the cover.

c. Remove all tension from the flexures (see step 5.5 c).

d. Remove the 2-56 x 1/4 socket-head cap screws (84) and flexure clamp (86) at the upper and lower end of the flexure.

e. Remove the damaged flexure and replace it with a new one.

f. Clamp the flexure to the spring assembly and cantilever with the flexure clamps and 2-56 x 1/4 socket-head screws. Do not tighten the screws at this time.

g. Repeat steps 5.5 e through 5.5 o.

5.6.2 To replace a damaged cantilever-to-base flexure (80), proceed as follows:

a. Remove all tension from the flexures (see step 5.5 c).

b. Remove the 2-56 x 1/4 socket-head cap screw (84) and flexure clamp (86) from the bottom of the flexure.

c. Remove the 2-56 x 3/8 socket-head cap screw (79) and flexure clamp (86) from the top of the flexure.

d. Remove the damaged flexure and replace it with a new one.

e. Clamp the flexure to the cantilever with a 2-56 x 3/8 socket-head screw and the flexure clamp. Clamp the flexure to the middle frame plate assembly (77) with the 2-56 x 1/4 socket-head screw and flexure clamp. Do not tighten the screws at this time.

f. Repeat steps 5.5 e through 5.5 o.

5.6.3 To replace a damaged cantilever-to-mass flexure, proceed as follows:

a. Remove all tension from the flexures (see step 5.5 c).

b. Remove the 2-56 x 3/8 socket-head screw (79) from the top of the flexure (if the seismometer is in the vertical operation mode).

c. Remove the 2-56 x 1/4 socket-head screw (84) from the bottom of the flexure.

d. Remove the damaged flexure and replace it with a new one.

NOTE

The flexure should be installed with the bend away from the cantilever.

e. Clamp the flexure to the cantilever with a 2-56 x 3/8 socket-head screw and the flexure clamp. Clamp the flexure to the calibration magnet and mass assembly (97) with a 2-56 x 1/4 socket-head screw. Do not tighten either screw at this time.

f. Repeat steps 5.5 e through 5.5 o.

5.7 REPLACING THE MAIN COIL

To replace the main coil, proceed as follows:

a. Lock the mass.

b. Remove the handle and cover.

c. Place the seismometer upside down on a level working surface. A cloth on the surface will prevent scratches from occurring on the upper surfaces of the control knobs, etc. Unlock the mass.

d. Remove the three legs (55).

e. Unsolder the wires from the terminals on the coil.

f. Remove the mass-lock base assembly (54).

g. Unscrew the three 10-32 x 3/4 socket-head cap screws (56) and remove the main coil (49) from the base assembly (54).

h. Place the new coil assembly in position and secure it in place with the three 10-32 x 3/4 socket-head cap screws. Due to the way parts are designed, the coil assembly should be a tight slip fit or slight press fit into the recess of the base assembly. This design assures the centering of the coil in the gap of the magnet assembly.

i. Position the base assembly with the lower frame plate and drive gear. Thread the wires through the 7/16-inch hole provided in the base assembly and slip the base assembly onto the locating dowels.

j. Solder the leads to the new coil terminals (black wire to terminal 1 and white wire to terminal 2, 4, or 8, whichever is applicable).

k. Replace the legs and screw them down tightly.

l. Lock the mass.

m. Replace the case and handle.

5.8 CLEANING THE GAP

To clean the air gap, remove the main coil (see paragraph 5.7, omitting steps g and h). Clean out the dust, dirt, and nonmagnetic particles with a soft brush. Remove the magnetic particles with a nonmetallic rod tipped with masking tape. Take care at all times to avoid causing nicks or burrs in the gap or at its edges. When the gap is clean, replace the coil (see paragraph 5.7, omitting steps g and h).

6. INSTRUMENT CHARACTERISTICS

Typical instrument characteristics are shown in figures 12 through 15. Figure 12 shows a Model S-13 seismometer's terminal voltage versus frequency when a standard coil was used, the damping was 0.67 of critical, and the natural frequency was 0.8 Hz.

Figure 13 is a plot of observed data showing phase response for the Model S-13 when the damping was 0.67 of critical and the natural frequency was 0.8 Hz.

Figure 14 shows typical variations of mass position and natural frequency for this instrument.

Figure 15 shows typical variations of natural frequency as mass position changes.

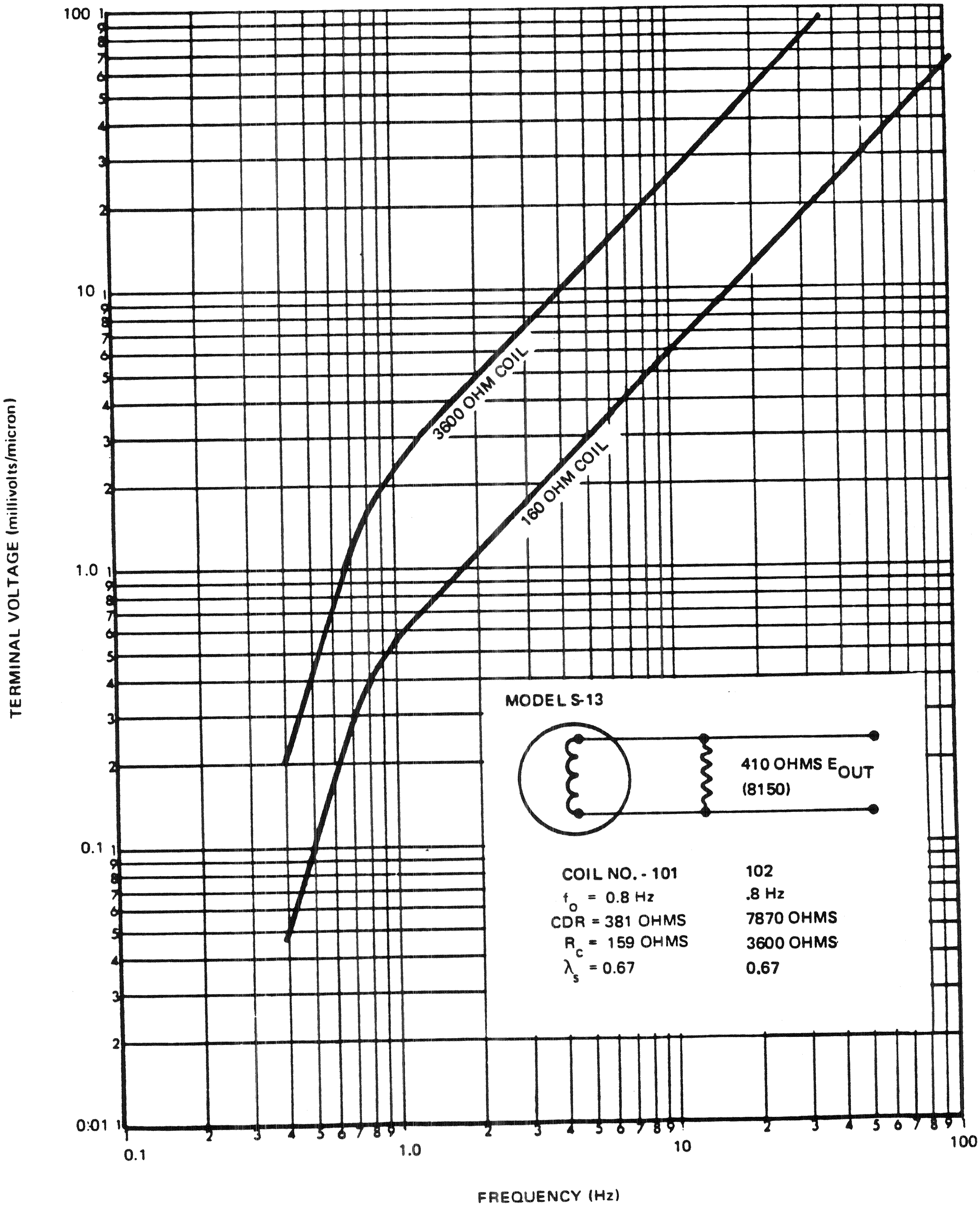


Figure 12. Terminal voltage of Portable Short-Period Seismometer, Model S-13, with standard 3600 ohm coil and 160 ohm coil

G 13993 A

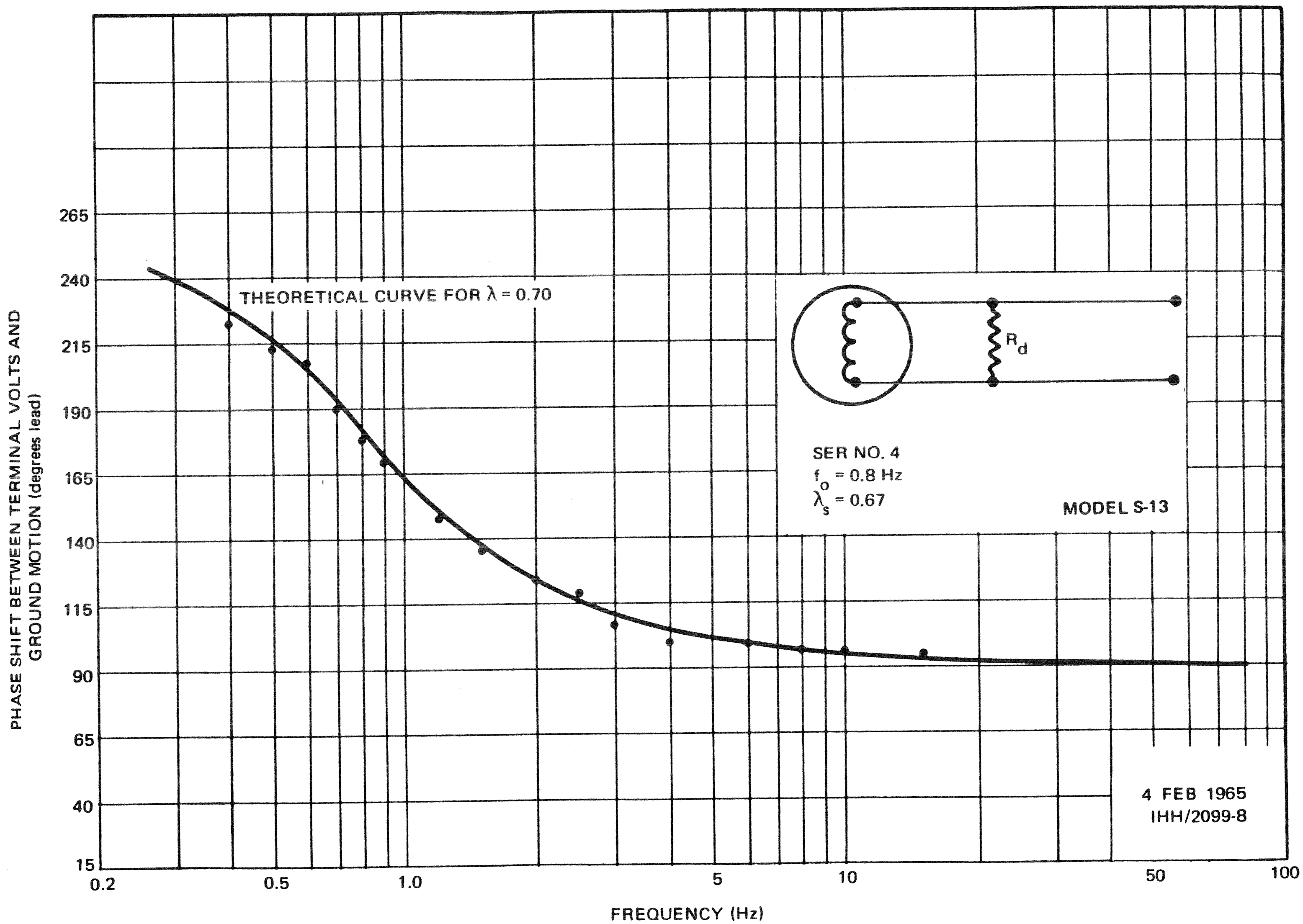


Figure 13. Phase response of Portable Short-Period Seismometer, Model S-13

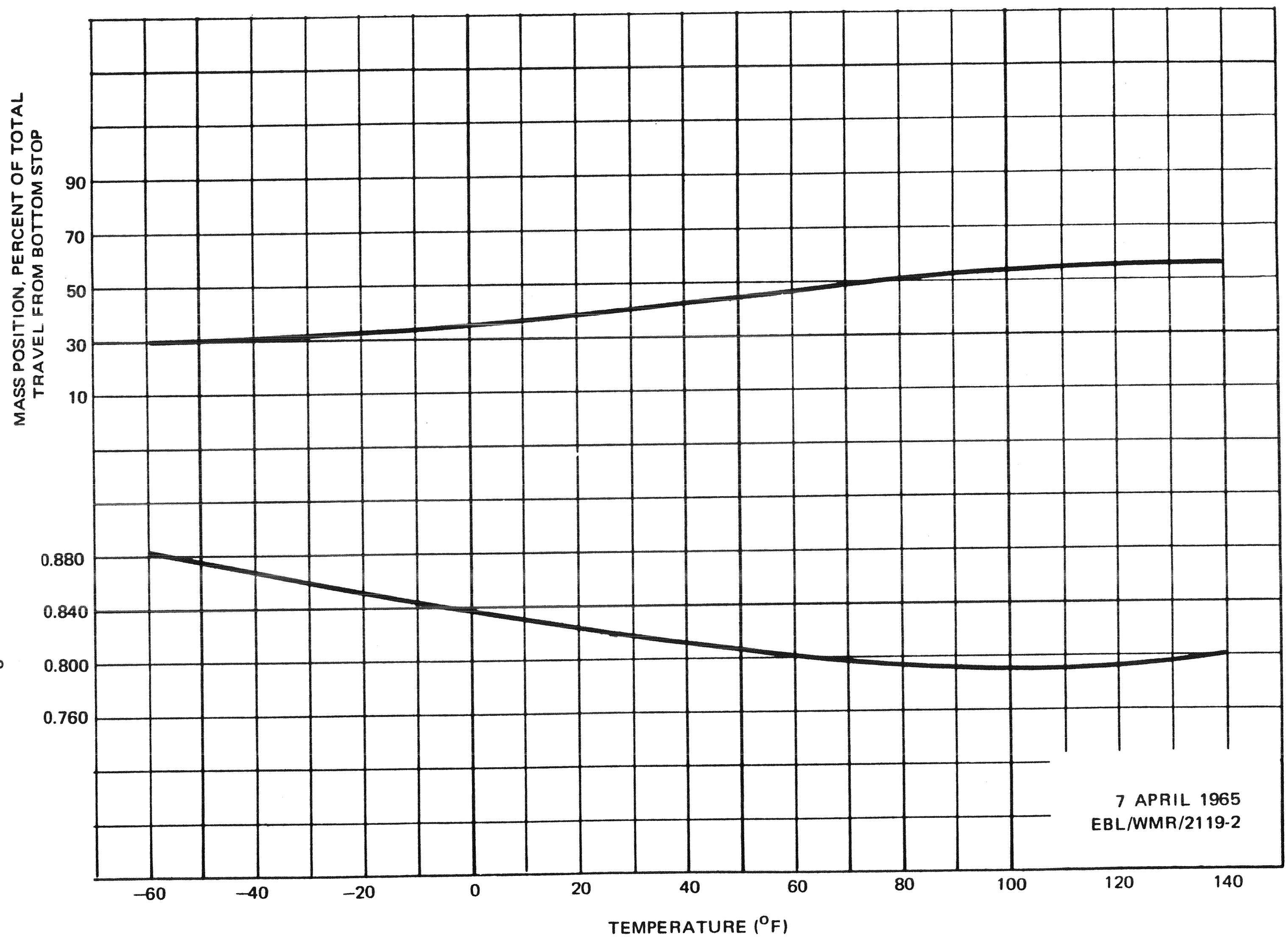


Figure 14. Typical variations of mass position and natural frequency with temperature, Portable Short-Period Seismometer, Model S-13

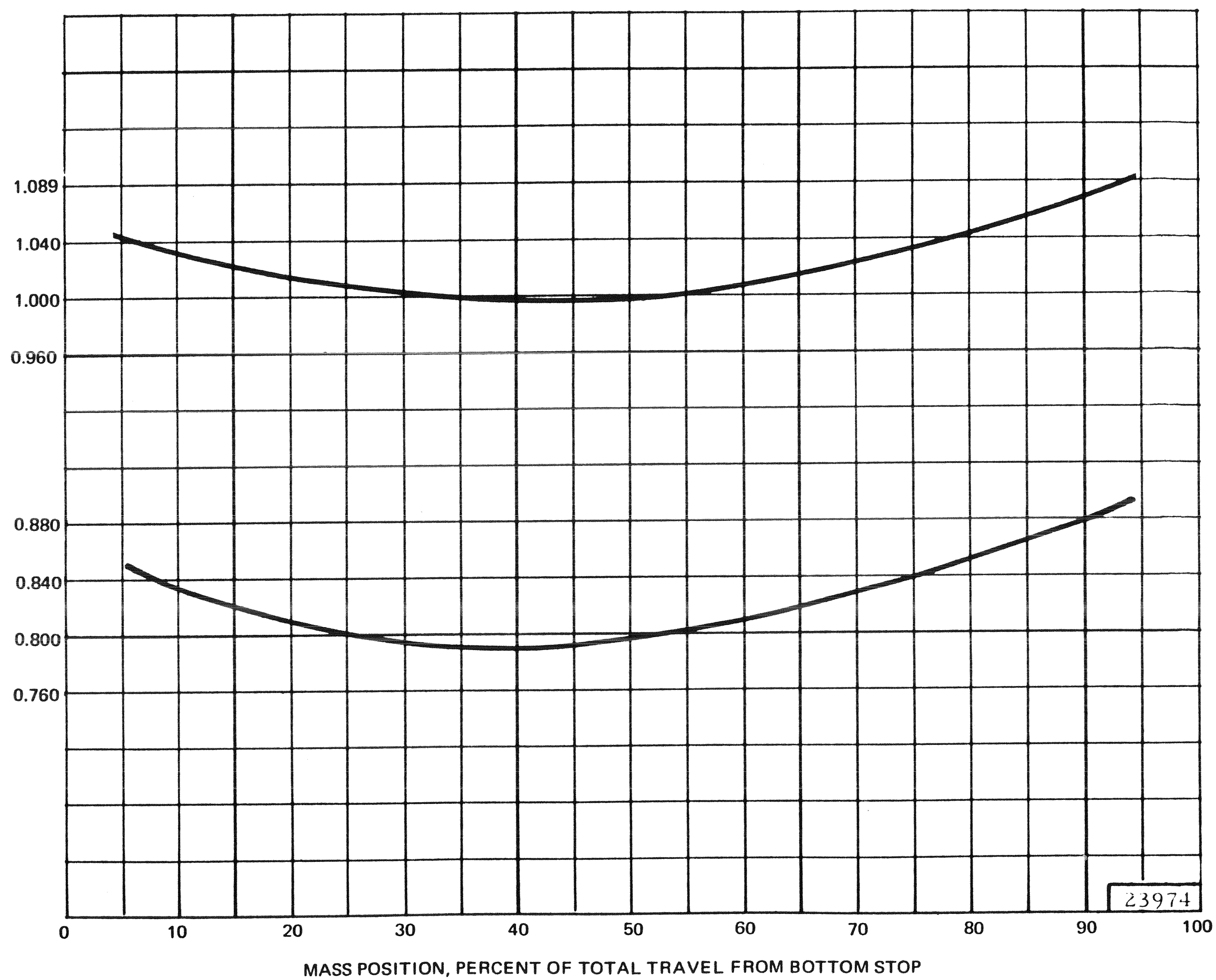


Figure 15. Typical natural frequency versus mass position, Portable Short-Period Seismometer, Model S-13

7. PARTS LIST

The nomenclature used in this section will aid in the identification of components of the seismometer. The item numbers correspond to the part numbers shown in the exploded view of the seismometer assembly in Figure 16. The quantities given are the total number of the parts used in the seismometer. Note that some parts are used at several different places in the assembly. The part numbers uniquely identify the parts in the Teledyne Brown Engineering Geotech Instruments inventory system, and should be used when ordering replacement parts.

Table of Replaceable Parts

Item	Part Number	Description	Quantity
1	990-20515-0101	Handle	1
2	990-20865-0101	Mass indicator cap assembly	1
3	042-11227-2300	O-ring	1
4	035-01018-0800	Socket head cap screw, sst., 6-32 x 1/2"	3
5	990-19984-0100	Mass position indicator	1
6	990-20141-0100	Weight lift table	1
7	035-47013-0300	Socket head setscrew, sst., 4-40 x 3/16"	1
8	990-21339-0102	Period adjust knob	1
9	042-11227-0500	O-ring	4
10	990-20857-0101	Washer	5
11	990-21337-0101	Period adjust dial	1
12	035-13013-0600	Fillister head screw, sst., 4-40 x 3/8"	2
13	990-19952-0101	Spring tension adjust nut	3
14	042-11230-0100	O-ring	1
15	042-11227-0800	O-ring	3
16	035-25013-0500	Pan head screw, sst., 4-40 x 5/16"	4
17	007-02142-6100	Connector (J1)	1
18	990-21328-0101	Torsion bar	1
19	035-01018-1000	Socket head cap screw, sst., 6-32 x 5/8"	1
20	042-11227-6200	O-ring	1
21	007-36675-1400	Neoprene rubber connector gasket	1
22	052-01280-1000	Bubble level	1
23	990-19981-0101	Calibration coil assembly	1
24	990-20571-0101	Spring guide	3
25	990-20142-0101	Mass indicator rod	1
26	990-19973-0101	Cantilever-to-mass flexure	3
27	990-20347-0101	Spring assembly	3
28	990-21327-0101	Period adjust delta rod assembly	1
29	990-21334-0101	Post clamp	1
30	990-21330-0102	Delta rod-to-torque tube clamp bar	1
31	035-01013-0800	Socket head cap screw, sst., 4-40 x 1/2"	16
32	990-21331-0101	Flexure anchor post	1
33	035-01013-1200	Socket head cap screw, sst., 4-40 x 3/4"	2
34	035-01013-0400	Socket head cap screw, sst., 4-40 x 1/4"	16
35	990-21333-0101	Flexure bar clamp	1

Table of Replaceable Parts, Continued

Item	Part Number	Description	Quantity
36	990-21329-0101	Period adjust flexure	1
37	990-21335-0101	Torque tube clamp bar	1
38	990-21332-0101	Period adjust-to-mass clamp	1
39	035-01021-0800	Socket head cap screw, sst., 8-32 x 1/2"	1
40	038-21053-0000	Jam nut, hexagon, 303, sst., 3/8-24	4
41	990-20572-0102	Cantilever assembly	3
42	990-20573-0101	Upper delta rod-to-mass clamp assembly	3
43	035-01013-1000	Socket head cap screw, sst., 4-40 x 5/8"	5
44	990-20346-0101	Mass assembly	1
45	990-20348-0101	Calibration magnet assembly	1
46	990-19967-0101	Lower delta rod-to-mass clamp	3
47	042-11227-0600	O-ring	1
48	990-19943-0101	Lower frame spacer	3
49	990-19936-0101	Main coil assembly	1
50	990-19940-0101	Lower frame plate	1
51	990-20350-0101	Mass lock assembly	1
52	990-20349-0101	Mass lock support	1
53	990-20569-0101	Wire tube	1
54	990-20866-0101	Mass lock base assembly	1
55	990-19949-0101	Leg	3
56	035-01025-1200	Socket head cap screw, sst., 10-32 x 3/4"	3
57	039-02606-1600	Berryllium copper roll pin, 3/32 x 1/2"	1
58	990-20201-0101	Drive gear	1
59	990-20576-0101	Horizontal leg adjust	1
60	038-50018-0000	Washer, sst., 1/4"	7
61	035-07041-2000	Hex head cap screw, sst., 1/4-20 x1-1/4"	2
62	990-19976-0101	Horizontal foot support	1
63	990-19989-0101	Seismometer foot	3
64	990-19950-0101	Lock ring	4
65	990-19951-0101	Seal retainer	3
66	990-21340-0101	Leg gasket	3
67	990-20200-0101	Idler spur gear	1
68	038-02021-0000	Hex nut, sst., 8-32	3
69	038-56111-0000	Internal lock washer, No. 8	3
70	038-68968-7200	Nylon washer	1

Table of Replaceable Parts, Continued

Item	Part Number	Description	Quantity
71	990-19959-0101	Delta rod assembly	6
72	990-19963-0101	Lower delta rod-to-base clamp	3
73	990-19934-0101	Mass lock shaft	1
74	038-61500-1400	Thread seal	2
75	038-25041-0001	Hex nut, self locking, 1/4-20	2
76	990-19947-0101	Case assembly	1
77	990-21085-0101	Middle frame plate assembly	1
78	990-19964-0101	Delta rod clamp	14
79	035-01007-0600	Socket head cap screw, sst., 2-56 x 3/8"	9
80	990-19971-0101	Cantilever-to-base flexure	6
81	990-19944-0101	Upper frame spacer assembly	3
82	035-47018-0400	Socket head setscrew, sst., 6-32 x 1/4"	3
83	990-20659-0101	Cantilever stop	3
84	035-01007-0400	Socket head setscrew, sst., 2-56 x 1/4"	15
85	038-56106-0000	No. 2 internal lock washer	24
86	990-19965-0101	Flexure clamp	24
87	990-19974-0101	Cantilever-to-spring flexure	3
88	035-01025-1600	Socket head cap screw, sst., 10-32 x 1"	2
89	038-50013-0000	Flat washer, sst., No. 10	2
90	038-61100-1000	Washer sealing	2
91	990-20532-0101	Stabilizing foot	1
92	035-07041-1600	Hex head cap screw, sst., 1/4-20 x 1"	3
93	990-19942-0101	Upper frame plate	1
94	035-47025-0300	Socket head setscrew, sst., 10-32 x 3/16"	2
95	990-19975-0101	Mass lock knob	1
96	990-19986-0101	Calibration coil support	1
97	990-19961-0101	Calibration magnet-to-mass assembly	1

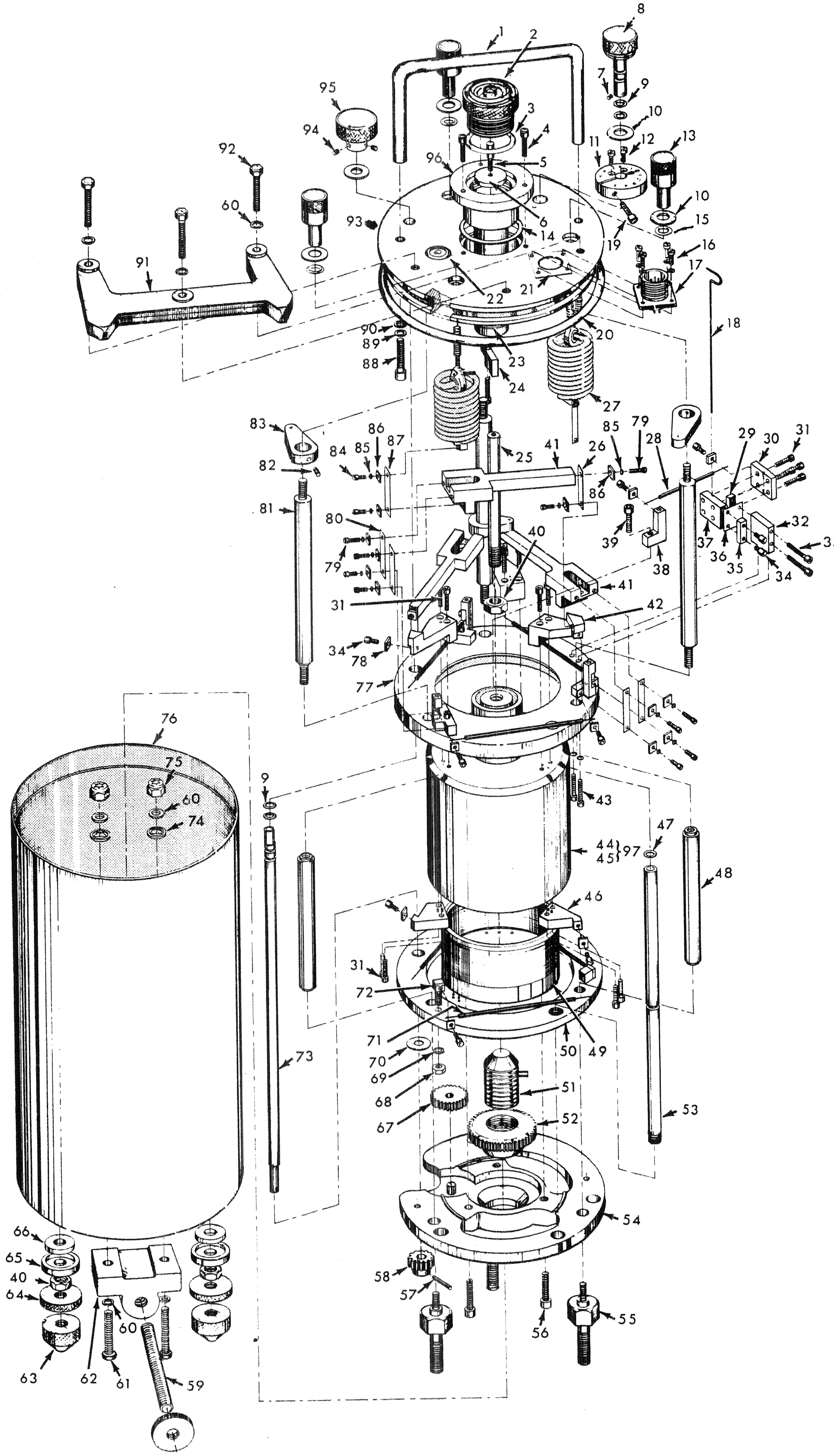
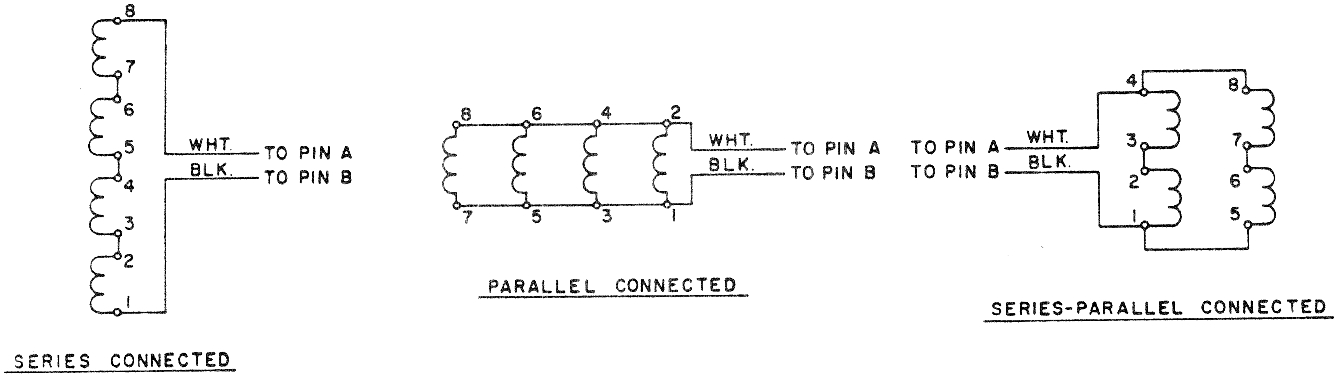
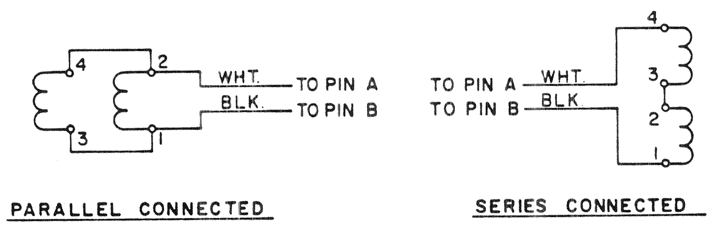


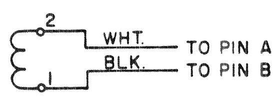
Figure 16. Exploded view of Portable Short-Period Seismometer, Model S-13



MAIN COIL CONNECTIONS FOR COILS HAVING FOUR EQUAL WINDINGS



MAIN COIL CONNECTIONS FOR COILS HAVING TWO EQUAL WINDINGS



MAIN COIL CONNECTIONS FOR SINGLE WINDING COIL

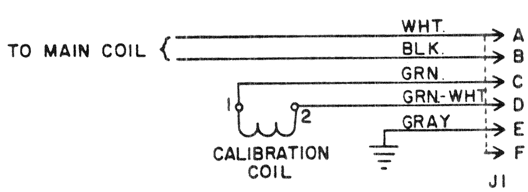


Figure 17. Typical wiring schematic, S-13 seismometer