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

Manual Stock No. 990-60300-9800

GEOTECH INSTRUMENTS, LLC

Document History

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unkn	-	-	unkn	Initial Release
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Table of Contents

(Intentional Blank Page)

List of Figures

(Intentional Blank Page)

List of Tables

(Intentional Blank Page)

Typographic Conventions

When you see text like	This is what it means
`\dir\dir\filename.ext`	Data file name and extension with or without directory location included
`\dir\dir\FILENAME.EXT`	Executable file name and extension with or without the directory location included entered on the command line
`{auguement}` `{choice1 | choice2}`	Text inside braces is a **REQUIRED** command line argument, typed in as shown but with out braces. Vertical bar means a choice between two or more **REQUIRED** items in command line argument.
`[auguement]` `[choice1 | choice2]`	Text inside brackets are optional command line argument, typed in as shown but with out brackets. Vertical bar means a choice between two or more optional items in command line argument.
Italicized text	
CAPITALIZED TEXT	
Bold Text	**Stress** a word or words
<u>**Bold and Underlined text**</u>	<u>**Highly stress**</u> a word or words
<u>**CAPTITALIZED, BOLD, AND UNDERLINED TEXT**</u>	Use <u>**EXTREME CAUTION**</u> when executing the procedure and/or command
KEY NAMES	Small capitals letters are used for keyboard key strokes A plus (+) indicates a combination of keys. Example: CRTL+C means hold down the CTRL key while pressing the C key.

`Displayed Screen Text`
`Next Line`
`. . .`
`Next to last . . .`
`Last line`
	Text as displayed and the screen.
	If 3 dots (. . .) appear on a line then part of the example was intentional omitted
	If 3 dots (. . .) appear at end of a line then part of that line was intentional omitted

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1 INTRODUCTION

This manual describes the operation, installation, field maintenance and repair of the Horizontal S-13JH and Vertical S-13JV versions of the Short-Period Seismometer.

Section 2 contains a general description of the instrument and its specifications.

Section 3 contains the unpacking, preliminary checks, adjustments, and general installation instructions. This section should be read before placing the instrument in operation. It is generally a good idea to remove the cover (see Section 5.2, page5-1) of the seismometer and perform at least Sections 3.3.1, page 3-1 through 3.3.5, page 3-3of the Preliminary Checks and Adjustments contained in Section 3.3.

Section 4 describes in more detail the principles of operation of the Seismometer and additional operating tests that can be performed.

Section 5 describes the field repair and maintenance that can be performed by the user of this instrument.

Section 6 contains additional information on the operating characteristics of the S-13J Seismometer such as frequency and phase response, etc.

Section 7 contains a definition of symbols used in this manual, and Section 8 is the Index.

Sections and procedures that are specific to the S-13JV Vertical or S-13JH Horizontal versions are clearly marked throughout this manual.

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2 GENERAL DESCRIPTION

2.1 Purpose Of The Equipment

The S-13J Short-Period Seismometer is designed for use in field operations where a small, lightweight, short-period, a moving coil seismometer is desired.

2.2 Description Of The Equipment

The S-13J Seismometer weighs 3.0 kg (6.6 lbs) and has a 1 kg (2.2 lbs) inertial mass. It has an outside diameter of 102 mm (4.0 in) and an overall length of 152 mm (6.0 in). The case is pressure sealed with O-rings and designed for operating submerged in water at depths to 30 meters (100 ft). Operating temperature range is -51° to 60°C (-60° to 140°F). The natural frequency is internally adjustable from 0.9 to 1.1 Hz.
On request, a damping resistor corresponding to 0.7 of critical damping is soldered internally between pins A and F. In this case, the cable connector should have a short between pins B and F. Open circuit can still be tested between pins A and B.

The electrical connections are made at the top of the instrument. One external adjustment screw is located in the bottom for locking the Mass.

The instrument has a moving-coil transducer, with the Data Coil attached to the nonmagnetic Mass. The Magnet Assembly is designed as a fixed part of the Seismometer. Several Data Coil configurations with varying sensitivities and resistance are available.

Materials and finishes are selected for resistance to the corrosion and temperatures associated with surface vaults and shallow holes. The S-13JV Vertical instrument is shown in Figure 2-1, on page 2-2, and the S-13JH Horizontal version is shown in Figure 2-2, on page 2-3.

The model and serial numbers of the instrument are located on the top surface of the seismometer. The vertical model is designated S-13JV, and the horizontal version is designated as S-13JH.

Figure 2-1 - Model S-13JV, Vertical Seismometer, With and Without Cover

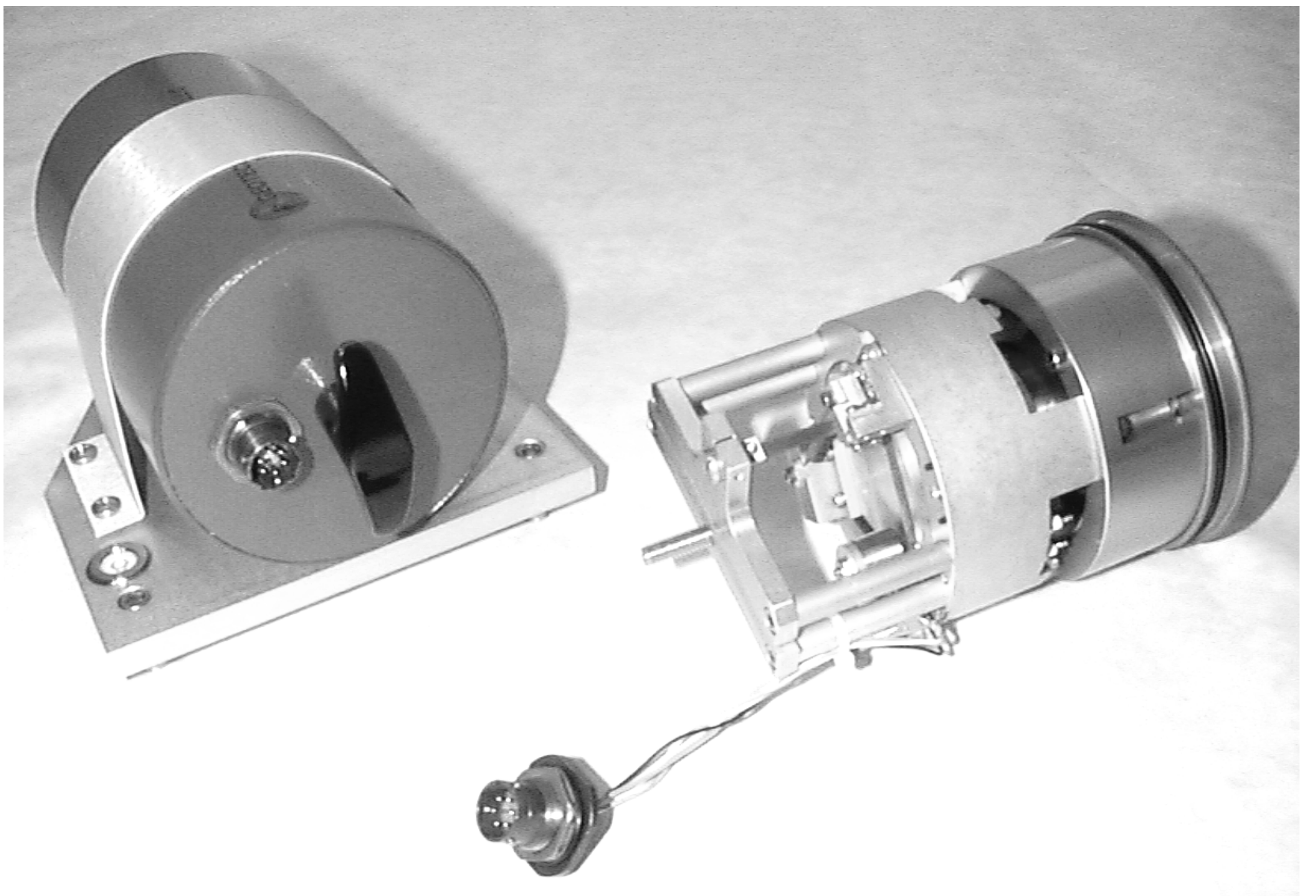

Figure 2-2 - Model S-13JH, Horizontal Seismometer With and Without Cover

2.3 Specifications

2.3.1 Operating Characteristics

Natural frequency	Adjustable from 0.9 to 1.0 Hz
Weight of inertial mass	1 kg (2.2 lb) ±1%
Operating temperature	-51° to 60°C (-60° to 140°F)
Storage temperature range	-51° to 60°C (-60° to 140°F)
Mode of operation	Vertical version or Horizontal version
First spurious mode	Above 500 Hz
Total vertical travel	1.5 mm (0.060 in) above center, 1.5 mm (0.060 in) below center

2.3.2 Transducer Specifications

Type	Moving coil (velocity) (magnet fixed to case)
Damping	Electromagnetic
Generator constant (G_{dc})	345 ±10% volts/(m/sec) when using 990-60093-0101 Data Coil (standard)

2.3.3 Data Coil Specifications

Data Coil Version No.	Resistance (R_c) ohms	Generator Constant[1] (G_{dc}) volts/(m/sec)	R_{CDR}[1] ohms
-0101[2]	6450 ±10%	343 ±10%	10000

2.3.4 Electromagnetic Calibrator

Type	Electromagnetic (moving coil, fixed magnet)
Motor constant (G_{em})	0.29 N/A
Coil resistance	29 ohm ± 2 ohm at 25°C (77°F)

2.3.5 Physical Characteristics

Diameter	102 mm (4.0 in)
Length	152 mm (6.0 in)
Net weight	3.0 kg (6.6 lb) approx.
Shipping weight	4.5 kg (10 lb)
Shipping volume	0.014 m^3 (.49 ft^3.)

[1] Generator Constant and R_{CDR} is theoretical. See data sheet supplied with instruments for actual values.
[2] Standard coil

2.3.6 Environmental Characteristics

2.3.6.1 Temperature/Humidity

Temperature range	(See operating characteristics)
Relative humidity	0% to 100%

2.3.6.2 Vibration

Operating	Not applicable
In transit	Packaged to withstand vibrations encountered in normal shipment by all modes of common carrier.

2.3.6.3 Shock

Operating	Designed to withstand shocks encountered during the performance of normal maintenance and installation with mass locked or unlocked.
In transit	Will withstand 1.3 m (4 ft) drop in shipping container.

2.3.6.4 Shock

Corrosion	Materials and finishes selected for corrosion resistance.

2.3.7 Connectors

All connections are made to the Seismometer through a six-pin mating connector Bendix PT06-A-10-6S or equal. See Figure 5-1, page 5-7 for wiring details.

2.4 Equipment Furnished

The following items are standard and are furnished with each Seismometer:

a. Short-Period Seismometer, Model S-13J Vertical or Horizontal version
b. Instruction Manual 990-60300-9800

Several transducer Data Coils, are available, covering a wide range of resistance and generator constants. Specifications for each coil are shown in Section 2.3.3, page 2-4. Instructions in this manual are applicable to any coil supplied.

The following accessories are available for the S-13J:

a. Horizontal Mounting Cradle, 990-60394-0101

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3 INSTALLATION

3.1 General

The Model S-13J Short-Period Seismometer is a sensitive yet rugged instrument designed for field use and handling. When properly adjusted and installed, it may be expected to operate for several years without attention or maintenance. General considerations in the use and installation of this Seismometer are outlined below. See Section 3.4, page 3-12 for more detailed installation instructions.

The Seismometer may be installed in a surface vault or any cased or uncased hole having sufficient diameter to allow entry and retrieval.

If the maximum possible system magnification is to be realized, the Seismometer must be operated in a quiet (low-seismic background) zone away from cultural noise.

3.2 Unpacking

The Seismometer is packed in a reusable container and is shipped with the Mass locked. Visually inspect the outside of the Seismometer for any apparent damage. If damage is apparent or the instrument cannot be adjusted to function properly, return it to the manufacturer. If the Cover is to be removed, see Section 5.2, page 5-1.

3.3 Preliminary Checks And Adjustments

3.3.1 Preparation for Checkout

After the Seismometer has been removed from the shipping crate and visually inspected, it should be placed on a pier and checked for satisfactory operation before being placed into operation. Horizontal should be mounted in the auxiliary Horizontal Mounting Cradle, 990-60394-0101, or other suitable mounting device so that it can be leveled. Figure 2-2, page 2-3 shows a Horizontal Seismometer correctly mounted in the cradle. Note that the connector should be oriented as shown.

CAUTION

The user should carefully study all instructions given in this manual before attempting to adjust, service, or operate this instrument.

The Customer Data Sheet and Packing List supplied with the Seismometer should be reviewed to determine the characteristics of the instrument as supplied by the factory.

When making preliminary checks and adjustments, the vertical instrument orientation should be vertical within 1°. The horizontal instrument should be level within 0.009°. Make electrical connections to the Seismometer (refer to Figure 5-1, page 5-7). Support the cable attached, to prevent it from tilting or tipping the Seismometer.

3.3.2 Outline of Preliminary Checks and Adjustments

This Section outlines the steps to be taken when making preliminary checks and adjustments. Each step is detailed in subsequent Sections. The basic steps are as follows:

a. Unlock the Mass and check for normal operation.
b. Center the Mass.
c. Determine the natural frequency (f_o).
d. Adjust the natural frequency, if necessary.
e. Determine the open circuit damping (λ_x).
f. Determine the critical damping resistance (R_{CDR}).
g. Determine the external resistance for critical damping (R_{CDRX}).
h. Check the motor constant, G_{em}, of the Electromagnetic Calibrator.

3.3.3 Checking for Normal Operation

The Mass of the Seismometer should be unlocked by turning the Mass-Lock Screw located on the bottom of the seismometer clockwise as far as possible (about 3 ½ turns). Connect the Data Coil output to an oscilloscope and observe the trace. A slight rocking of the Seismometer should set the instrument into oscillation and produce an easily observed signal. If normal operation is not evident, check the Data Coil for continuity or shorts. All leads and wires inside the Seismometer should be checked for more than 100M ohm resistance above ground and the instrument should be wired according to the schematic in Figure 5-7, page 5-19.

3.3.4 Determining Mass Position

The Seismometer is shipped with the Mass centered for normal operation in a vertical or horizontal position depending upon the version. The total travel of the Mass is 3mm (0.120 in), and the instrument is usually adjusted for the Mass to be within 0.5mm of its center position. The spring-supported Mass of the vertical version will generally rise to the upper stop with tilts in excess of 4°, so readjustment of the Mass may be necessary if such tilts occur. The horizontal version should be level within 0.009º. Vibration and shock encountered during shipment may cause the mass position adjustment to shift.

Before placing the instrument in operation, the mass position should be determined. If adjustment is necessary, the Cover must be removed (see Section 5.2, page 5-1) and the mass position must be adjusted as described in Section 4.2.2, page 4-1 for Vertical, or Section 4.2.3, page 4-1 for Horizontal. The mass position Horizontal version of the seismometer is very sensitive to tilt, therefore mass position adjustments can often be made by minor adjustments in tilt.

To determine the position of the Mass of the Seismometer without removing the cover, proceed as outlined in the following paragraphs:

Unlock the Mass with the external Mass Lock Screw (see Figure 5-2 Item 16, page 5-9) and note the number of turns required from full lock to full unlock (to the nearest ¼ turn, about 3½ turns).

Lock the Mass and connect an oscilloscope or highly attenuated recording system to the Data Coil (pins A and B of the mating connector).

For vertical instruments, hold the instrument vertical over the edge of workbench, and slowly unlock the Mass until the Mass just starts to oscillate or swing free of the locking mechanism. This should be easily observed on the oscilloscope or recorder if the gains are properly set and the instrument is undamped. Note the number of turns of the Mass Lock Screw when the desired motion of the Mass occurs.

For horizontal instruments, level the instrument to within 0.009°, and slowly unlock the Mass until the Mass just starts to oscillate or swing free of the locking mechanism. This should be easily observed on the oscilloscope or recorder if the gains are properly set and the instrument is undamped. Note the number of turns of the Mass Lock Screw when the desired motion of the Mass occurs.

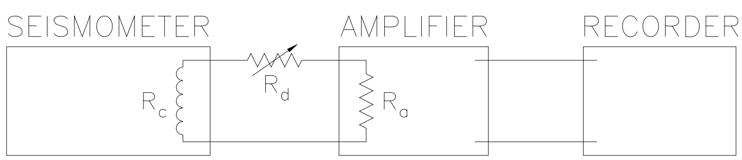
This number of turns divided by the total number of turns from the full lock to full unlock position is the ratio of the mass's position from the top stop to its total travel of 3 mm (0.120 in). Repeating this measurement several times and averaging the results will give a good estimate of the Mass position.

An alternate method of determining mass position of the Seismometer by putting current through the Data Coil is given in Section 4.3.4, and is useful when the Seismometer is located in a remote location.

3.3.5 Determining the Natural Frequency

To determine the natural frequency of the Seismometer, assemble the test setup shown in Figure 3-1.

Excite the Mass into oscillation by gently rocking the Seismometer, making a weight lift (vertical only) or otherwise displacing the Mass (if the Cover is removed), or pulsing the Electromagnetic Calibrator with a momentary dc pulse.



$$R_d + R_a \geq 1000 \times R_c$$

R_c = RESISTANCE OF SEISMOMETER COIL
R_d = RESISTANCE OF DECADE RESISTOR
R_a = RESISTANCE OF AMPLIFIER

Figure 3-1 - Test Setup for Determining Natural Frequency

Record several cycles as the seismometer’s mass motion decays to rest at its free period. Determine the time required for any given number of cycles and calculate the natural frequency as follows:

$$\text{Natural frequency } f_0 = \frac{\text{X number of cycles}}{\text{time for X number of cycles}}$$

A typical free-period record made by a Seismometer having low internal losses is shown in Figure 3-2, page 3-6.

3.3.6 Adjusting the Natural Frequency - Vertical

The natural frequency of the vertical Seismometer is adjustable from 0.9 to 1.0 Hz by the Frequency Adjust Screw located on the Lever Assembly, shown in

Figure 3-3, page 3-6. The Seismometer Cover must be removed to provide access to this adjustment. Refer to Section 5.2, page 5-1 for instructions regarding Cover removal.

CAUTION

The S13-J Seismometer contains a very strong magnet as part of the data transducer. Caution should be used as the magnet's stray field will "grab" magnetic tools and pull them into the Seismometer and possibly cause damage.

To adjust the natural frequency of the Seismometer, loosen the Lock Screw then turn Frequency Adjust Screw as shown in Figure 3-3, page 3-6. Clockwise rotation of the Frequency Adjust Screw decreases natural frequency. Tighten Lock Screw when the natural frequency is set.

When trimming or changing the Frequency Adjust Screw, the Mass should be positioned in the center of its travel. The Mass is centered when the top of the Mass is even with the top of the Delta Rod Frame. Visual alignment is adequate. The Mass may be positioned by turning the Mass Position Screw (Item 26) located at the top of the Spring Assembly (Item 7). See Figure 5-3-1, page 5-12.

CAUTION

When adjusting the mass position with the Mass Position Screw, lightly tap the Screw after each adjustment to stabilize the setting.

3.3.7 Adjusting the Natural Frequency - Horizontal

The natural frequency of the horizontal Seismometer is adjustable from 0.9 to 1.1 Hz by the Period Adjust Screw (Item 4) located on the Crossbar (Item 5), shown in Figure 5-5-1, page 5-16. The Seismometer Cover must be removed to provide access to this adjustment. Refer to Section 5.2 for instructions regarding Cover removal.

CAUTION

The S13-J Seismometer contains a very strong magnet as part of the data transducer. Caution should be used as the magnet's stray field will "grab" magnetic tools and pull them into the Seismometer and possibly cause damage.

To adjust the natural frequency of the Seismometer refer to Figure 5-5, page 5-16. Loosen the Lock Screw (Item 22) then turn Period Adjust Screw (Item 4) as shown in Figure 5-5. Clockwise rotation of the Period Adjust Screw decreases natural frequency. Hold the Period Adjust Screw (Item 5), and tighten Lock Screw (Item 22) after each adjustment. (Note: The Lock Screw can be made just tight enough to hold Period Adjust Screw after each adjustment. Tighten Lock Screw securely after the final adjustment.) Check the natural frequency after each adjustment and reset as required.

When trimming or changing the Period Adjust Screw, the Mass should be positioned in the center of its travel. The Mass is centered when the top of the Mass is even with the top of the Delta Rod Frame. Visual alignment is adequate. The Mass may be positioned by gently bending one or more of the Delta Rods (Item 3, Figure 5-12) at the Frame (Item 2) end to center the Mass. Gently bending the Period Adjust Delta Rod (Item 13), Figure 5-5 to adjust mass position is also permissible. Check Mass position after each natural frequency adjustment and reset Mass position as required.

If natural the frequency appears to be wrong after the Cover is installed, check that the instrument is level. Minor adjustments in the natural frequency can be made with minor adjustment of the instrument's level. Check mass position after each level adjustment.

3.3.8 Determining the Open Circuit Damping

The internal losses of this instrument with a standard Data Coil will typically impart a damping of less than 3 percent of critical damping when the Seismometer is operated into an open circuit or looking at an external impedance which is at least 1000 times the Data Coil resistance. The open circuit damping measured at the factory is listed on the Customer Data Sheet furnished with the instrument. Unless there is some evidence of damage or other reason to be suspect it should not be necessary to run this test on a new instrument.

The open circuit damping R_x, should be considered in determining R_{CDR} (critical damping resistance) or when computing the circuit resistance required for a desired Seismometer damping. This is particularly applicable to high-impedance Data Coils, which may 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. Assemble the test setup as shown in, Figure 3-1on page 3-3 for determining natural frequency, making certain that the circuit resistance external to the Seismometer is equal to or greater than 1000 times the resistance of the Seismometer Data Coil.

b. Excite the Mass into oscillation with a weight lift or by a momentary dc pulse applied to the Electromagnetic Calibrator. A weight lift or other manual means of displacing the mass can be made after the Cover has been removed. See Section 5.2 for Cover removal instructions.

c. Record the output of the Seismometer as the mass oscillation decays because of 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.) A typical free-period record is shown in Figure 3-2, page 3-6.

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:

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

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

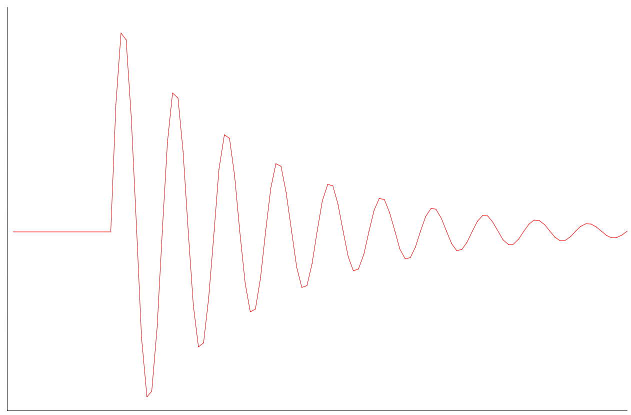


Figure 3-2 - Typical Record for Determining Seismometer Natural Frequency

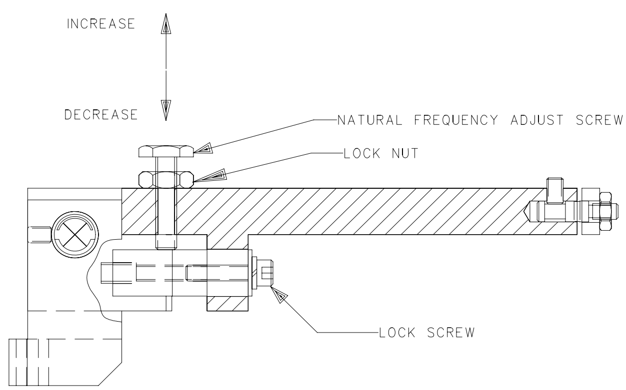


Figure 3-3 - Lever Assembly, Model S-13J Seismometer

$$\ell_n \frac{X_4}{X_5} = \frac{2\pi \lambda_x}{\sqrt{1 - \lambda_x^{\,2}}}$$

where;

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

NOTE

where; $\frac{X_4}{X_5}$ is less than 2.0, the term $\sqrt{1-\lambda_x^2}$ will be between 1.0 and .994, and may be considered as 1.0 in the above equation to simplify calculations.

3.3.9 Determining the Critical Damping Resistance (R_{CDR})

The S-13J 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. 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 the final position (without overshoot).

The total circuit resistance which produces critical damping of the Seismometer mass is known as the critical damping resistance (R_{CDR}). The R_{CDR} may be used to calculate the total circuit resistance required for any desired damping other than critical. The value of R_{CDR} measured during factory testing is listed on the Customer Data Sheet.

Where the open circuit damping R_X (Section 3.3.8) is considered negligible, the R_{CDR} of the instrument may be determined by proceeding as follows:

NOTE

These instructions assume that a weight lift or other manual means is used to apply a step function force to the Mass. A momentary dc pulse to the Electromagnetic Calibrator will produce equivalent results.

a. Lock the Mass and measure the resistance of the Seismometer Data Coil with a precision bridge.
b. Connect the Seismometer as shown in Figure 3-4, page 3-8.
c. Unlock the Mass and center it if necessary. Adjust the period as desired.
d. Attach a length of nylon thread to a small weight(approx. 2 gm).
e. Lower the weight onto the Mass. Allow the output to return to normal.
f. 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.
g. The resultant record should be similar to that shown in Figure 3-5, page 3-8.
h. Repeat the weight lifts and adjust $R_{L,}$, until the percent of overshoot ratio is about .20 to .25.
i. Enter Table 3-1, page 3-9 with the overshoot ratio and determine λ_o or compute λ_o from;

$$\lambda_o = \frac{1}{\sqrt{1 + \left(\frac{\pi}{\ln \rho}\right)^2}}$$

where;

$\rho = \frac{a}{b}$ and the quantity λ_o is the ratio of actual damping to critical damping, when internal losses are zero.

j. Calculate the critical damping resistance, (R_{CDR}) using the relation $R_{CDR} = R_t \times \lambda_o$ where R_t is the total circuit resistance (e.g. $R_t = R_C + R_L$) which produced the damping ratio λ_o. This method is applicable to any velocity Seismometer having negligible open circuit damping and where the amplifier impedance is much greater than R_L.

k. Once the critical damping resistance, (R_{CDR}) has been established for a Seismometer having a given natural frequency, the total circuit resistance (R_o) required for any desired relative damping, λ_o, may be calculated as follows:

$$R_o = \frac{R_{CDR}}{\lambda_o}$$

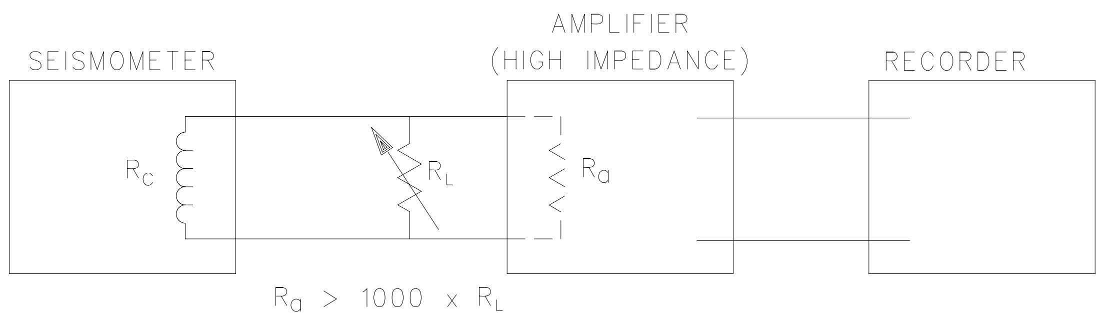


Figure 3-4 - Test Set-Up for Determining Critical Damping Resistance (R_{CDR})

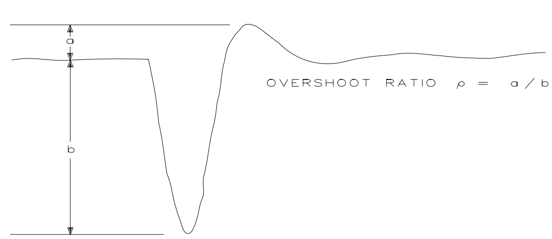


Figure 3-5 - Example of a Signal Produced by a Weight Lift

Table 3-1 - Ratio (λ_o) of actual damping to critical damping as a function of overshoot ratio.

overshoot a/b	λ_o	overshoot a/b	λ_o	overshoot a/b	λ_o
.108	0.577	.155	0.511	.200	0.455
.110	0.575	.160	0.504	.205	0.449
.115	0.567	.165	0.497	.210	0.444
.120	0.560	.170	0.491	.215	0.439
.125	0.551	.175	0.485	.220	0.434
.130	0.544	.180	0.479	.225	0.429
.135	0.537	.185	0.473	.230	0.424
.140	0.539	.190	0.467	.240	0.414
.145	0.524	.195	0.461	.250	0.404
.150	0.518				

The foregoing calculations neglect damping caused by internal losses, which may be appreciable for high impedance Data Coils. When it is necessary to consider these losses, proceed as follows.

l. Determine the open circuit damping using the procedure outlined in Section 3.3.8.

m. Determine the relative damping as outlined in steps (a) through (j) of this Section for some total circuit resistance, R_t. The damping measured will be the sum of the electromagnetic damping, λ_o, resulting from the current flowing through the total resistance, R_t, and the open circuit damping λ_x resulting from the internal losses of the instrument or:

$$\Lambda_o = \lambda_o + \lambda_x$$

n. Since the electromagnetic damping is λ_o,

$$\lambda_o = \Lambda_o - \lambda_x$$

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

$$R_t = R_o \frac{(\Lambda_o - \lambda_x)}{(\Lambda_t - \lambda_x)}$$

where;

R_t = total circuit resistance required to produce the desired damping λ_t

R_o = total circuit resistance required to produce the damping, λ_o (from step k)

λ_x = pen circuit damping (from step l)

Λ_o = relative damping obtained with total circuit resistance, R_o, and open circuit damping (from step m)

Λ_t = relative damping desired of Seismometer

The R_{CDR} stated on the customer data sheet supplied with each instrument considers open circuit damping and is determined by the formula given in step (o) above.

3.3.10 Determining the External Resistance for Desired Damping (R_{DRX})

The external resistance which, when connected directly across the Seismometer terminals that will set the desired damping, is known as the external damping resistance, (R_{CDRX}). It is obtained from the following relation:

$$R_{DRX} = R_t - R_c$$

The external resistance which, when connected directly across the Seismometer terminals will cause critical damping, is known as the external critical damping resistance, (R_{CDRX}). It is obtained from the following relation:

$$R_{CDRX} = R_{CDR} - R_c$$

3.3.11 Determining the Motor Constant, G_{em} of the Electromagnetic Calibrator - Vertical Instruments Only

The motor constant of the Electromagnetic Calibrator is determined by the magnetic flux density in the Electromagnetic Calibrator Magnet gap and the length of the wire on the Electromagnetic Calibrator Coil. The magnet material is Alnico 8 and is very stable with time and temperature. The reversible magnetic flux temperature coefficient is on the order 0.02 percent/°C. The loss of flux with time is less than .7 percent in 11.4 years. Therefore, the value of the Electromagnetic Calibrator Generator constant, G_{em}, listed on the Customer Data Sheet should be adequate for most applications.

To determine the motor constant, G_{em}, of the Electromagnetic Calibrator, proceed as follows:

a. Remove the Seismometer Cover, and 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 Electromagnetic Calibrator and adjust the current i_p, until the X_i (zero-to-peak) trace amplitude is within 10% of the X_m trace amplitude. Record X_i and note i_p. Maximum current into Electromagnetic Calibrator Coil should not exceed 150 mA.

d. Calculate the motor constant, G_{em}, of the Electromagnetic Calibrator, using the average of three or more weight lifts:

$$G_{em} = \frac{980 \times 10^{-5}\, m_w\, X_i}{i_p X_m}$$

where;

G_{em} = motor constant of Electromagnetic Calibrator, Newton/Ampere

X_i = zero-to-peak trace amplitude in millimeters caused by current ip

i_p = dc current in Electromagnetic Calibrator coil, zero-to-peak, in Amperes

X_m = zero-to-peak trace amplitude in millimeters caused by weight lift

m_w = weight lifted, in grams

NOTE

When calculating the Electromagnetic Calibrator motor constant, G_{em}, 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 used. Reverse leads to the Electromagnetic Calibrator's coil if necessary to achieve this relation.

3.3.12 Seals

When reassembling the instrument after making the preceding checks, inspect all O-ring seals and thread seals for cleanliness and for smooth surfaces, free of nicks or cuts. All O-rings, and thread seals should have a generous coating of a grease recommended for the application. Replace any questionable O-rings or seals. Never use a tool harder or sharper than a wooden stick in handling O-rings. Hand tighten Tee Handle that holds the Cover in place.

3.4 Installation Of The Seismometer

The S-13J 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 placement of any seismometer are outlined below.

a. Normally a seismometer is place on bedrock, on a pier anchored to bedrock, or in a vault anchored to bedrock.
b. If the maximum possible sensitivity is to be realized, the location must be in a quite zone away from cultural noise.
c. The instrument should not be exposed to direct sunlight and should be sheltered from wind.
d. The instrument should have a thermally stable environment.
e. If the instrument is to be placed where access will be difficult, all necessary tests can be performed before the seismometer is place in its final location.
f. If the seismometer is use in a metal vault, at least .6 to .7 meter (2 ft) of earth should be placed on top of the vault for thermal stability and isolation from wind noise.
g. Cables and wiring should be installed with maximum separation between power and signal cables to minimize stray pickup.
h. For a borehole installation, unlock the seismometer and apply a voltage of 6 to 12 Vdc to the Data Coil. Apply positive voltage to pin B and negative to pin A. This current will force the inertial mass of the seismometer against the top stop. Keep this voltage applied while the seismometer is being lowered into the hole. Lower the seismometer into the hole at a rate of not more than 9 meters per minute (30 feet per minute).

4 OPERATION

4.1 Principles Of Operation

The vertical S-13J Short-Period Seismometer has a .93 kg mass supported from a unique spring-cantilever suspension of which the effective spring rate may be varied to adjust the natural frequency of the instrument. The moving mass is nonmagnetic and has the Data Coil attached to its lower end.

The horizontal S-13J Short-Period Seismometer has a .93 kg mass that is supported by six Delta Rods.

For either version the Mass is guided axially by six Delta Rods, three of which are located near each end of the moving Mass. One end of each Delta Rod is attached to seismometer frame, and one end of each rod is attached to the mass.

The Magnet Assembly has a Neodymium Iron Boron permanent magnet located inside a heavy steel outer shell. The steel shell extends well beyond the Inner Pole Piece, and shields the Magnet Assembly from the shunting effect of external ferrous material, which a steel casing might produce. The result is a highly stable magnet structure, which is virtually independent of its physical environment.

The vertical instrument can be calibrated with weight lifts with the cover off, and both versions are equipped with an electromagnetic calibrator for remote calibrations. An external adjustment for locking the mass is located in the end opposite the connector end.

4.2 Controls

4.2.1 Mass-Lock Screw

A Mass-Lock Screw is located externally in the bottom of the seismometer and is used to adjust the mass locking mechanism to secure the Mass during handling and shipment. The screw is identified by the word LOCK and a counterclockwise arrowhead printed on the bottom of the seismometer. Turning the screw actuates the internal locking mechanism. To unlock the Mass, the screw is turned clockwise until a definite limit stop is reached. To lock the Mass, turn the screw counter clockwise until firm locking is achieved.

4.2.2 Mass Position Adjustment - Vertical

The Mass Position Screw is internally located and serves to adjust the position of the Mass. Turning the screw clockwise will raise the Mass. Counterclockwise rotation will lower the Mass. Changing direction of rotation for minor adjustments will cause irregular variations in the natural frequency, therefore, the Mass Position Adjust Screw should always approach its final position by turning clockwise for at least 1/8 turn. If the Mass is to be lowered, rotate the adjust screw counterclockwise until the Mass is below the desired position, then rotate the screw clockwise to raise the Mass to the desired position. Visually positioning the Mass level with the Delta Rod Frame within +/- 0.5 mm is adequate.

4.2.3 Mass Position Adjustment - Horizontal

The Mass position of the horizontal instrument can be adjusted by gently bending one or more of the Delta Rods. Visually positioning the top of the Mass even with the top of the Delta Rod Frame within ±0.5 mm is adequate.

4.2.4 Natural Frequency Adjustment -Vertical

The vertical instrument has a unique spring-lever suspension with a variable spring rate to adjust the natural frequency or period. The Frequency Adjust Screw is located on top of the Lever and positions the Lower Spring Flexure Connector of the assembly with respect to the Lever. The adjustment changes the angular relationship of the three flexures, which in turn changes the effective spring rate of the suspension while having little effect on the load-carrying capacity of the system. The Frequency Adjust Screw is accessible only with the Cover removed. Its adjustment is described in Section 3.3.6.

4.2.5 Natural Frequency Adjustment - Horizontal

The horizontal instrument uses a torsion spring and a seventh delta rod to bias the delta rod suspension and adjust the horizontal natural frequency. Turning the Frequency Adjust Screw counter clockwise will decrease the natural frequency and visa versa. The Frequency Adjust Screw is located on top of the Cross Bar of the horizontal unit and is accessible with the Cover removed.

4.2.6 Mass Position Adjust - Horizontal

The horizontal mass position is adjusted by carefully bending one or more of the delta rods at the frame-mounting end. Large mass position changes may require repositioning the Torsion Spring in the mass end clamp.

4.3 Operating Tests

4.3.1 General

Many of the important operating tests are given in the preliminary checks and adjustments of Section 2.3. These tests include determining mass position, checking and adjusting the natural frequency, determining the open circuit damping, the critical damping resistance and the CDRX, and determining the motor constant of the Electromagnetic Calibrator. The tests given in the following sections will provide additional data, which may be needed for optimum operation of the Seismometer in a system, as well as alternate methods for making some tests.

4.3.2 Determining the Data Coil Generator Constant, G_{dc}

The Data Coil generator constant, G_{dc}, in volts/meter/second (V-sec/m) may be derived from several methods, four of which are outlined in the following paragraphs. These are the:

a. R_{CDR} method;
b. Shake-table method;
c. Weight-current method;
d. Tilt-Current method;

A correlation of results within 5 percent using methods a, b, and c or d is considered satisfactory.

4.3.2.1 R_{CDR} Method for Determination of G_{dc}

The generator constant for the Data Coil may be determined from the following relation:

$$G = \sqrt{4\pi f_o M R_{CDR}(1-\lambda_x)}, \text{ V-sec/m}$$

where;

f_o = undamped natural frequency, in Hz

M_m = weight of inertial mass, in kilograms

R_{CDR} = critical damping resistance, in ohms (includes correction for λ_x)

λ_x = ratio of open circuit damping to critical damping

This method may be used for any Seismometer having a moving-coil (velocity) type transducer. For the
S-13J Seismometer with a 0.93 kg mass, the equation simplifies as follows to:

$$G_{dc} = 3.419\sqrt{R_{CDR}(1-\lambda_x)}, \text{ V-sec/meter}$$

when f_o = 1.0 Hz

4.3.2.2 Shake-Table Method for Determination of G_{dc}

The generator constant of a Seismometer may be determined from shake-table tests by driving the instrument with a sinusoidal signal at a known frequency and amplitude. The accuracy of this method depends upon the accuracy of measurement of the shake-table amplitude and frequency, the data coil and damping resistance, and the voltage at the data coil terminals.

The Seismometer should be connected as shown in Figure 4-1, page 4-4, and placed on a shake-table. The damping resistor, R_o, should provide a damping of 0.7 to 1.0 of critical. A high-impedance instrument such as an oscilloscope should be used to read the voltage, E_t, across the Data Coil terminals. The Seismometer Data Coil resistance, R_C, and the damping resistance R_o must be known accurately.

The Seismometer should be driven at a frequency at least 10 times its natural frequency, and at an amplitude which will produce a signal well above any background noise.

The generator constant may be calculated as follows:

$$G = \frac{E(R_c + R_o)}{y 2\pi f_1 R_o} \text{ V-sec/meter}$$

where;

E_t = terminal voltage of Seismometer across load resistor, R_o in volts, peak-to-peak

R_c = Data Coil resistance, in ohms

R_o = load resistance, in ohms

y_e = shake-table displacement in meters, peak-to-peak

f_1 = driving frequency of shake-table, in Hz. (This must be at least 10 times the natural frequency of the Seismometer).

Care must be taken that the driving frequency does not excite any spurious modes in the instrument. The averaging of results from drives of several different frequencies is suggested to obtain greater accuracy.

4.3.2.3 Weight-Current Method for Determination of G_{dc}

The generator constant in V-sec/meter is numerically equivalent to the motor constant in Newtons per Ampere (N/A). The motor constant can be determined by observing the floating mass position very accurately through a high-power magnifier with a scale reticule or through a microscope, or with an electronic capacitor type micrometer, adding known weights on the mass to displace it, then passing direct current through the Data Coil in such magnitude and direction as to exactly return the mass to its original position. In this manner, the force produced by the current in the coil is exactly equal to the weights added to the mass. This method of calibration using an electronic micrometer for measuring mass position is used for the factory calibration. The motor constant, and hence the generator constant, G_{dc}, is calculated as follows:

$$G = \frac{\text{Force in Newtons}}{\text{Current in Amperes}}, \text{ N/A or V-sec/m}$$

A one (1) pound force is equal to 4.4482 Newtons. A one (1) kilogram mass will produce a force of 9.806 Newton at sea level.

This method will produce more accurate results when the weights added are equal to or more than three grams per kilogram of mass. Calculations should be made for several weight applications, and those within five percent of each other averaged for the final result.

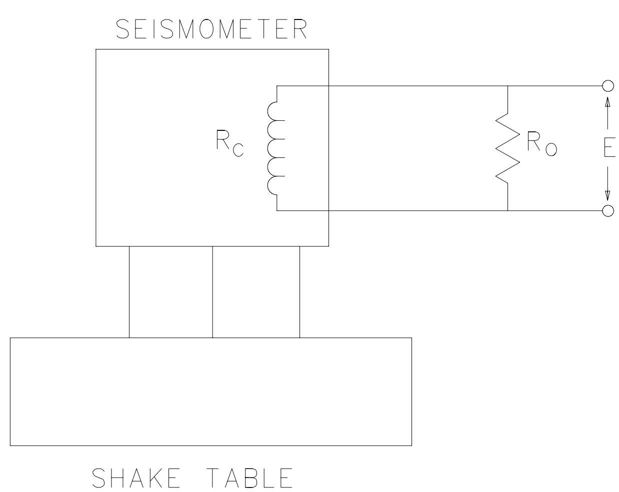


Figure 4-1 - Test Setup For Determining Generator Constant By Shake-Table Method

4.3.2.4 Tilt-Current Method for Determination of G_{dc}

The generator constant in V-sec/meter is numerically equivalent to the motor constant in Newtons per Ampere (N/A). The motor constant can be determined by observing the floating mass position very accurately through a high-power magnifier with a scale reticule or through a microscope, or with an electronic capacitor type micrometer, tilting the horizontal seismometer to displace it, then passing direct current through the Data Coil in such magnitude and direction as to exactly return the mass to its original position. In this manner, the force produced by the current in the coil is exactly equal to the force on the mass resulting from the tilt. This method of calibration using an electronic micrometer for measuring mass position is used for the factory calibration. The motor constant, and hence the generator constant, G_{dc}, is calculated as follows:

$$G = \frac{\text{Force in Newtons}}{\text{Current in Amperes}}, \text{ N/A or V-sec/m}$$

A one (1) pound force is equal to 4.4482 Newtons. A one (1) kilogram mass will produce a force of 9.806 Newtons at sea level.

This method will produce more accurate results when the tilts used are equal to or more than three grams per kilogram of mass. The applied force is equal to the mass times the sine of the tilt angle. Calculations should be made for several tilt applications, and those within five percent of each other averaged for the final result.

4.3.3 Determining Equivalent Earth Motion of Electromagnetic Calibrator Drive

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

$$y = \frac{G_{em} i x 10^6}{4\pi^2 \mathrm{f}_1{}^2 M_m}$$

where;

y_e =	equivalent earth motion in microns, peak-to-peak
G_{em} =	Electromagnetic Calibrator motor constant, Newtons/Ampere
i =	current through the Electromagnetic CalibratorCoil, Amperes, peak-to-peak
f_1 =	frequency of calibration signal
M_m =	weight of mass in kilograms

4.3.4 Alternate Method for Checking Mass Position

A method which permits accurate determination of mass position with the instrument cover on is presented here. This method also can be used to determine mass position when the instrument is in a remote operating location (in a hole).

Direct current fed through the main Data Coil will cause the transducer to act as a motor and displace the Mass a distance proportional to the current. Simple means for detecting when the Mass reaches the limit of its motion against either stop can be improvised. The mass position is then determined by the following ratio:

$$\text{Millimeters from top stop} = \frac{I_T}{I_T + I_L} \times 3\text{ mm}$$

where;

I_T = current required to force mass to top stop

I_L = current required to force mass to lower stop

The total mass travel is 3 mm, however, the operating center of the Mass is 1.5 mm from the top stop. Since centering is not critical, satisfactory operation may be expected when the mass is 1 to 2 mm from the top stop.

A typical circuit for supplying direct current to the Data Coil and detecting the Mass limiting against the stops is shown in Figure 4-2. In this circuit, a battery supplies the current, a variable resistor regulates the current, a dc millimeter measures the current, and a capacitor blocks dc from the detecting or indicating system. A reversing switch allows the current to move the mass down or up, and an on-off switch disconnects the battery. Two alternate detecting methods are shown.

The oscilloscope (a) allows a visual display of the Seismometer output. Motion of the mass caused by background vibration and variation of current in the Data Coil (observed as signals on the oscilloscope) will be seen to stop abruptly as the mass reaches the limit of its travel.

The Seismometer is internally wired to produce a downward motion of the mass relative to the frame when a positive voltage is applied to pin A and referenced to pin B of the connector.

The battery voltage and series variable resistor, R_B, should be selected to provide an adequate current through the Data Coil and still have reasonable adjustment. Coarse and fine variable resistors could be used if desired. Typical values for coils up to 1000 ohm would be a 12v battery and a 5000-ohm potentiometer for R_B.

NOTE

The sum of the currents required to force the Mass from one limit stop to the other depends upon the effective spring rate (related to natural frequency) and the generator constant of the Data Coil. The relationship is as follows:

$$\left(I_T + I_L\right) = \frac{k_{eff}}{G_{dc}} \text{ x (total mass travel, meters)}$$

where;

I_T = current required to force mass to top stop, in Amperes

I_L = current required to force mass to lower stop, in Amperes

k_{eff} = effective spring rate, in Newtons/meter

G_{dc} = Data Coil generator constant = motor constant in Newtons/Ampere

The effective spring rate, k_{eff}, is determined from the following relation:

$k_{eff} = (2\,\pi\, f_o)^2\, M_m$, in Newtons/meter

where;

f_o = natural frequency in Hz

M_m = mass of Seismometer (1 kg)

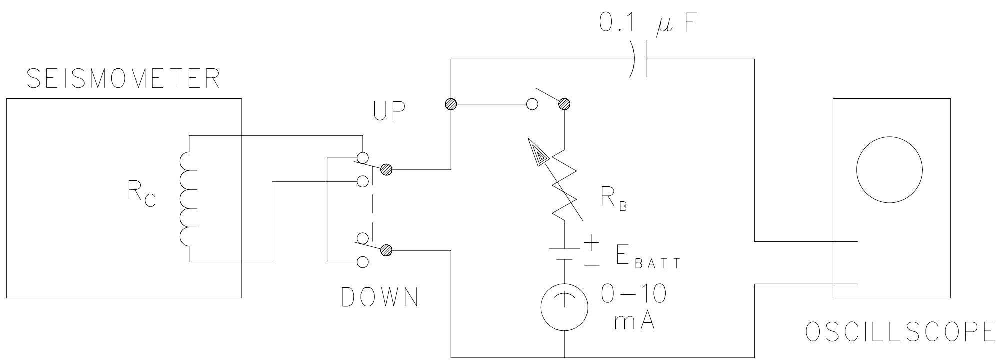


Figure 4-2 - Circuit For Determining Mass Position of Seismometer

4.3.5 Determining Seismometer Output at Various Frequencies

When considering the use of the Seismometer with an amplifier, the response of the Seismometer at various frequencies must be known in order to predict the system characteristics. The Seismometer response is usually plotted as the terminal voltage (across a load resistor) per meter/sec of earth motion versus frequency. A typical curve is shown in Figure 4-3, page 4-9.

Data for the Seismometer response curve may be taken from shake-table tests, a Electromagnetic Calibrator driven by a sinusoidal signal, or may be predicted when the natural frequency, relative damping, Data Coil resistance, R_c, and generator constant, G_{dc}, and the external load resistance are known. These methods are outlined in the following Sections.

4.3.5.1 Shake-Table Method for Determining Seismometer Response

The Seismometer response from a shake-table test may be made using a test set up identical to that shown in Figure 4-1, page4-4 for determining the generator constant of the Data Coil. A high-impedance instrument should be used to indicate or record the output voltage of the Seismometer. The load resistor should damp the Seismometer for the desired response.

The shake-table frequency is varied over the frequency range of interest, with the amplitude and frequency of the table motion carefully measured and recorded with the corresponding Seismometer output voltage. The Seismometer output voltage is then divided by the shake-table amplitude in microns and the results plotted against frequency.

Shake-table response curves are the accepted standard means of determining the Seismometer response because shake tables produce the actual equivalent of earth motion. When performed carefully, shake-table tests will disclose non-linearity caused by spurious modes and will help to locate sources of spurious vibration within the instrument.

The special low-frequency, low-amplitude shake tables required for Seismometer testing are found in only a few special seismological research laboratories. Techniques in the following Sections can be used satisfactorily in the field.

4.3.5.2 Electromagnetic Calibrator Method for Determining Seismometer Response

The Seismometer response to varying frequency may be determined by driving an electromagnetic calibrator mounted on the instrument with a sinusoidal signal, which can be varied in amplitude. The equipment should be connected as shown in Figure 4-4, page 4-9. A high-impedance instrument should be used to indicate or record the output voltage of the Seismometer. The load resistor should damp the Seismometer for the desired response.

The motor constant of the Electromagnetic Calibrator must be known (refer to Section 3.3.11), and provisions must be made for carefully measuring the peak-to-peak current through the coil. The equivalent earth motion produced by the signal through the Electromagnetic Calibrator may be calculated as outlined in Section 4.3.3. The Seismometer output voltage is then divided by the equivalent earth motion for each data point and the result plotted against frequency.

This method is satisfactory for low-frequency response data, but it is usually difficult to obtain data at frequencies above 100 Hz, because the motor constant and hence the driving force of the Electromagnetic Calibrator is usually small. Data can usually be obtained over the frequency range of interest in seismology.

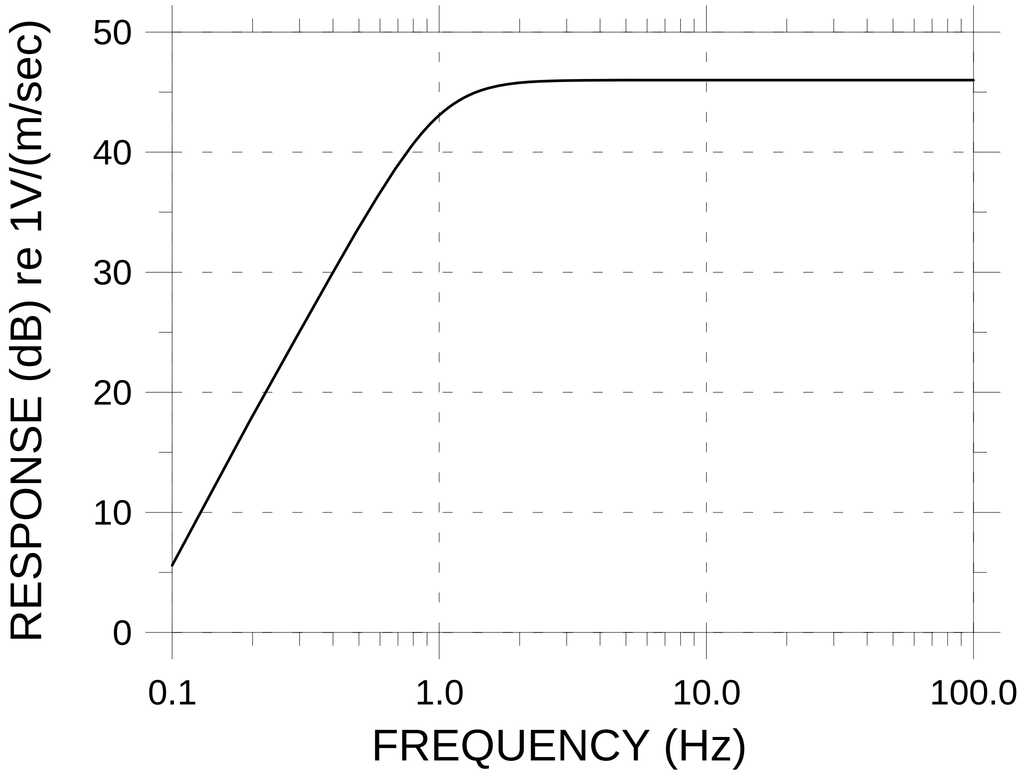


Figure 4-3 - Short-Period Seismometer, Terminal Voltage as a Function of Frequency

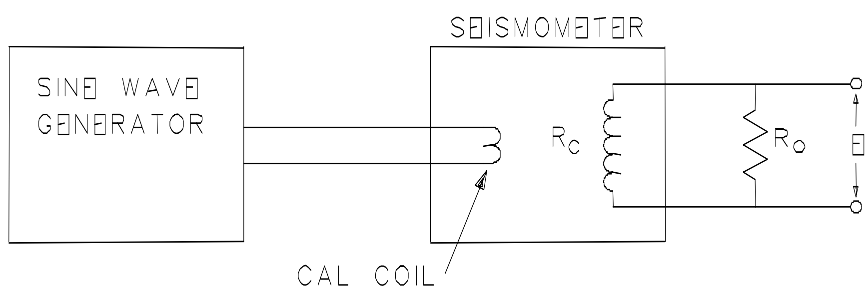


Figure 4-4 - Test Setup For Determining Seismometer Response From Electromagnetic Calibrator Drive

4.3.5.3 Prediction of Seismometer Response from the Instrument Specifications

Where the complete instrument specifications are known, it is possible to calculate and construct a theoretical seismometer response curve which will closely approximate those obtained from shake-table and Electromagnetic Calibrator tests.

From the instrument specifications the generator constant, the natural frequency, the Data Coil resistance, and the critical damping resistance should be obtained. The desired damping for the Seismometer should be established and the external load resistance calculated which would provide this damping. Information for making these calculations is included in Section 3.3.9. (The external load resistance is that which remains after the Data Coil resistance is subtracted from the total circuit resistance required to produce the desired damping.) If open circuit damping is to be considered in the calculations, these data should be obtained as outlined in Section 3.3.8.

From the above data, the theoretical terminal voltage across the load resistor for 1 x 10^{-6} meter/sec ($\dot{\mu}$) of sinusoidal earth motion velocity for any frequency may be calculated as follows:

$$\frac{E}{\dot{\mu}} = \left(\frac{G_{dc}\,\mathrm{R_o}}{(\mathrm{R_c} + R_o)x10^6}\right)\left(\frac{f_1^{\ 2}}{\sqrt{\left[1-\left(\frac{\mathrm{f_o}}{\mathrm{f_1}}\right)^2\right]^2 + \left(2\lambda_o\,\frac{\mathrm{f_o}}{\mathrm{f_1}}\right)^2}}\right)$$

where;

G_{dc} = Data Coil generator constant, V-sec/meter

f_1 = frequency of desired data point, in Hz

f_o = natural frequency of the Seismometer in Hz

R_o = load resistance, in ohms

R_c = Data Coil resistance, in ohms

λ_o = ratio of Seismometer damping to critical damping

The voltage per micron of earth motion should be plotted as data points on log paper with frequency increasing from left to right and the vertical scale indicating increasing terminal volts per micron. A curve drawn through the points obtained by plotting the above data will be the theoretical response of the Seismometer.

4.3.5.4 Seismometer Poles and Zeros

The response equation given in Section 4.3.5.3 in terms of poles and zeros is given by;

$$\frac{E}{\dot{\mu}} = \left(\frac{G_{dc} R_o}{(R_c + R_o) x 10^6}\right)\left(\frac{(s+z_1)(s+z_2)}{(s+p_1)(s+p_2)}\right)$$

where;

$$z_1, z_2 = 0$$

$$p_1 = \omega_o\left(\lambda_o + j\sqrt{1-\lambda_o^2}\right)$$

$$p_2 = \omega_o\left(\lambda_o - j\sqrt{1-\lambda_o^2}\right)$$

where;

$\omega_o = 2\pi f_o$

$s = 2\pi f_1$

G_{dc} = Data Coil generator constant, V-sec/meter

f_1 = frequency of desired data point, in Hz

f_o = natural frequency of the Seismometer in Hz

R_o = load resistance, in ohms

R_c = Data Coil resistance, in ohms

λ_o = ratio of Seismometer damping to critical damping

4.3.5.5 System Sensitivity from Electromagnetic Calibrator Drive

The magnification of the system at any frequency may be determined by driving the Electromagnetic Calibrator with a sinusoidal signal of known frequency and amplitude. The equivalent earth motion of the driving signal is calculated by the formula given in Section 4.3.3. For example, for the Model S-13J Seismometer, which has a Mass of 0.93 kg and a nominal Electromagnetic Calibrator motor constant of .285 N/A, when the driving frequency is 1.0 Hz, the equation for earth motion simplifies to:

$$y_e = 7790(i)$$

or 1.0 mA, peak-to-peak, produces the equivalent of 7.79 x 10^{-6} meter (μ) of earth motion, peak-to-peak. The equivalent earth motion divided into the record amplitude, as given in Section 3.3.9, gives the system magnification at the test frequency.

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5 MAINTENANCE

5.1 General

The design of the S-13J Seismometer is such that complete disassembly of the instrument should seldom be necessary. Disassembly beyond the limits outlined in this Section should be avoided. If damage is such that further disassembly appears necessary, the instrument should be returned to the manufacturer for repair and readjustment. The illustrations

Figure 5-1, page 5-7 to Figure 5-12, page 5-30 in the rear of the manual should be used as a guide to the general construction and assembly of the Seismometer. Item numbers given in parentheses ( ) following part descriptions refer to those given in these figures and their corresponding Parts List. The following precautions should be observed when servicing or repairing the instrument:

a. The assembly area should be clean and free of dirt, lint, or metal chips.
b. The instrument and its parts should be kept covered whenever actual service work is not in progress. A plastic bag or sheet will make a satisfactory temporary cover.

5.2 Cover Removal And Replacement

5.2.1 Cover Removal

Refer to Figure 5-2 thru Figure 5-6 for Item No.'s used in this section. Make sure Seismometer mass is locked. To remove Cover, Item 5, unscrew Connector Nut. Remove Tee Handle, item 17, and Seal Washer, Item 28. Turn Seismometer upside down and press Tee Handle Screw, Item 27, against a hard surface and pull down on Cover until it slides off of O-ring, Item 31. Turn Seismometer over and remove Cover.

CAUTION

Be sure to always remove Connector Nut before attempting to remove Cover.
Failure to do so may result in damage to the internal wiring of the Seismometer.

5.2.2 O-Ring and Seal Washer Care

Keep O-ring, (Item 31), and Seal Washer, (Item 28), clean. If Cover is to be removed for an extended period of time, the O-Ring Seal Washer should be removed and stored. Do not use sharp tools to remove O-ring or Seal Washer. Check O-ring and Seal Washer for nicks and cuts before reusing.

5.2.3 Cover Replacement

Lubricate O-ring with a suitable lubricant and install in groove of base. Clean and lubricate O-ring mating surface of Cover, item 5. Be sure Connector O-ring is in place. Pull connector and wires upright and slide Cover into place while threading connector through hole in the top of the Cover. Rotate Connector until if fits into its recessed pocket on the underside of the Cover top. Orientation of Cover is not critical, but wires must not touch spring or other moving parts of the Seismometer. Note that the arc shaped pocket in the under side of the Cover top should be centered approximately over the Mass Position Adjust Screw, Item 26. Press Cover down over O-ring. Lubricate Seal Washer, Item 28, with a suitable O-ring lubricant and install over Tee Handle stud. Install Tee Handle, Item 17, and hand tighten. If Tee Handle ends up over connector when tight, remover Cover and reposition Screw, Item 27 approximately 1/4 turn. Loosen Set Screw, Item 36, before turning Screw, Item 27, then tighten Set Screw. Install connector nut and tighten.

5.3 Removing/Replacing The Magnet Assembly

5.3.1 Removing Magnet Assembly

Remove the Cover as described in Section 5.2.1. Unlock Seismometer as described in Section 3.3.3**.** Loosen the three screws marked Magnet Attachment Screws in Figure 5-2, page 5-9. Turn Seismometer upside down and remove the Magnet Attachment Screws(A Ball-Point hex key wrench is very handy for removing and installing these screws.). Slowly and carefully remove Magnet Assembly, and **DO NOT** turn seismometer right side up because Seismometer Mass is now unlocked. Seismometer may be laid on its side tilted so that the Mass rests against the upper stop. Cover Magnet gap to keep it clean and free of magnetic particles. See 5.3.2 for instructions on cleaning the gap.

5.3.2 Cleaning Magnet Assembly Gap

Check magnet gap for any signs of trash. Magnetic particles may be removed by wrapping a piece of tape, sticky side out, around a wooden stick, and wiping the inside of the gap to remove the particles.

5.3.3 Replacing Magnet Assembly

Reverse the procedure describe in 5.3.1 to install the Magnet Assembly. Remember to not turn Seismometer upright until Magnet Assembly is in place. Be careful to not damage the Data Coil when replacing Magnet Assembly. Tighten Magnet Assembly Screws.

5.4 Removing/Replacing The Data Coil

5.4.1 Removing Data Coil

Remove Magnet Assembly as described in Section 5.3.1. Refer to Figure 5-12, page 5-25. Unsolder Pigtail Leads from the Data Coil terminals or the terminals on the frame of the Seismometer. Remove the three Screws, Item 7, that mount the Data Coil to the Mass.

5.4.2 Replacing Data Coil

Reverse the procedure of 5.4.1 to install a Data Coil. Check continuity of Data Coil circuit, and install Magnet Assembly per Section 5.3.3.

5.5 Replacing Delta Rods

Delta Rods that are slightly bent may be removed, straightened, and replaced. To replace a single Delta Rod, lock the Mass, and refer to Figure 5-12 Sheet 2 of 2. Remove the two Screws and Clamps, Items 4 and 6, and remove the Delta Rod. Leave the Screws loose. Unlock the Mass until the Mass is at its center position, then tighten the Delta Rod Screws.

5.6 Replacing The Spring Connector Flexure - Vertical

5.6.1 Replacing Broken Flexure

If the Spring Connector Flexure, Item 2, Figure 5-11, is broken, the Spring, Item 1, will be curled up against the Crossbar, Item 13, Figure 5-4. Remove the broken flexure by removing the two Screws, Item 2, shown in Figure 5-11. Also remove the broken end from the Lever Assembly, Item 2, by removing the Screw and Clamp, Items 14 and 19, of Figure 5-4. When reattaching the new Flexure to the Spring, note the correct position of the Nut Plate, Item 3, Figure 5-11. The bevel on the Nut Plate must be positioned as shown. Inspect the edge of the of the Nut Plate, over which the flexure bends, for nicks or burrs. Polish with very fine sand paper if necessary.

To reattach the Flexure to the Lever Assembly, the Spring must be forced into its operating position. To do this, Loosen the Set Screw, Item 36, Figure 5-4. Place a piece of metal under Set Screw, Item 27, to protect the Spring (a coin can be used), and turn Screw, Item 27, clockwise to force Spring into position. Slip the Flexure over the locating pin in the end of the Lever Assembly. Pliers may be used to gently twist Spring end to help with the lateral positioning of the Flexure hole onto the pin. Install Clamp and Screw, Items 14 and 19. The Clamp is a stamped part and has slightly rounded edges on one side and sharper edges on the other. Place the Sharper edges toward the Flexure and tighten the Screw securely. Hold the Clamp square with the side of the Lever as required. Note that this Flexure has approximately 11 kgf (25 lbf) on it when the Spring is released. **Never loosen Screw, Item 19, with tension on the Flexure as the hole in the Flexure cannot support this tension.**

When all Flexure Screws are tight, slowly turn Screw, Item 27, counterclockwise to release Spring. Turn Screw until it is flush with the bottom of the Clamp, Item 13. Tighten Set Screw, Item 36, to lock Screw, Item 27, in place.

5.6.2 Replacing Damaged but not Broken Flexure

If the Flexure is not broken, but is damaged and in need of replacement, proceed as follows. Loosen the Set Screw, Item 36, Figure 5-4. Place a piece of metal under Set Screw, Item 27, to protect the Spring (a coin can be used), and turn Screw, Item 27, clockwise to release Spring tension. This will be achieved when the Flexure has some slack and is not under tension. Leave Spring in this position. Remove the Screws holding the Flexure to the Spring and the Lever Assembly and reattach Flexure to Spring as described above. Slip the Flexure over the locating pin in the end of the Lever Assembly. Pliers may be used to gently twist Spring end to help with the lateral positioning of the Flexure hole onto the pin. Install Clamp and Screw, Items 14 and 19. The Clamp is a stamped part and has slightly rounded edges on one side and sharper edges on the other. Place the Sharper edges toward the Flexure and tighten the Screw securely. Hold the Clamp square with the side of the Lever as required. Note that this Flexure has approximately 11 kgf (25 lbf) on it when the Spring is released. **Never loosen Screw, Item 19, with tension on the Flexure as the hole in the Flexure cannot support this tension**

When all Flexure Screws are tight, slowly turn Screw, Item 27, counterclockwise to release Spring. Turn Screw until it is flush with the bottom of the Clamp, Item 13. Tighten Set Screw, Item 36, to lock Screw, Item 27, in place.

5.7 Replacing Wire Flexure - Vertical

The Wire Flexure, Item 9, Figure 5-4, that attaches the Lever to the Mass is a piece of 0.18 mm (.007 inch) diameter phosphorous bronze wire. In an emergency it can be replaced with a piece of music wire. This Wire Flexure is only under a tension of approximately 1 kgf (2.2 lbf). If is broken, the Lever will be pulled up against the Spring Support, Item 10. The Lever can easily be held in place with a finger.

To remove the Wire Flexure, hold the tip of the Lever with a finger, and loosen either of the Nuts, Item 12, Figure 5-9 or Item 4, Figure 5-10 and slowly release the Lever until it comes to rest against the Spring Support.

To replace the Wire Flexure, adjust the Locking Screw until the Mass is in its center position. Place a 9.53 mm (.375 inch) gage block between the Lever and the Flexure Connector , Item 6. Thread one end of the Wire Flexure through the cross hole in the Stud, Item 2, Figure 5-10. Install the Clamp, Item 3, and Nut Item 4. Turn Nut moderately tight. **Do Not** over tighten as Stud is easy to twist off and Wire Flexure can be cut. Thread Wire flexure through cross hole in Stud in tip of Lever. Install Clamp and Nut. Hold Lever down against 9.53 mm spacer and tighten Nut on end of Lever. Remove gage block.

5.8 Replacing The Spring Assembly - Vertical

It should rarely be necessary to replace the Spring, Item 1, Figure 5-11. Should it be necessary to replace the Spring, proceed as follows. Do **NOT** remove Screws, Items 21 or 26, Figure 5-4 until told to do so.

CAUTION

Spring is under high tension and can cause injury if improperly handled. Force on the end of the Spring in its operating position is approximately 11 kgf (25 lbf).

Remove Spring Connector Flexure as described in Section 5.6.2. Refer to Figure 5-4. Back off Screw, Item 27, until Spring rests against Crossbar, Item 13. Loosen but do not remove Screws, Item 24, at each end of the Crossbar. Press down on end of Spring just behind the Flexure attachment holes with thumb, and rapidly remove one of the Screws, Item 24, in the end of the Crossbar.(It may be helpful to have an assistant press on the Spring while removing the Screw). **DO NOT press on the tip of the Spring as it may break and cause injury.** Swing Crossbar out of the way and, and release Spring slowly.

Remove Mass Position Adjust Screw and Swivel Washers, Items 26,29, and 30. Remove Screws, Item 21, and Spring Clamp, Item 11, and remove Spring.

To replace Spring, reverse the above procedure. Apply a small amount of lubricating grease between mating surfaces of the Swivel Washers, Items 29 and 30, and on the threads of the Mass Position Adjust Screw, Item 26. **BE SURE Mass Position Adjust Screw, Item 26 is in place finger tight, and that Screws, item 21, are tightened securely before compressing Spring**. Reattach Spring Connector Flexure as described in Section 5.6.1.

5.9 Repairing Lever Assembly -Vertical

In the event that one of the Crossed Flexures in the Lever Assembly is damaged, the assembly should be removed for repair. To remove, repair, and replace the Lever Assembly, follow the procedures outlined in the following Subsections. The Lever Assembly is shown in Figure 5-9, and as Item 2 in Figure 5-4.

5.9.1 Removing the Lever Assembly

Disconnect the Spring Connector Flexure as described in Section 5.6.2. Disconnect Wire Flexure as described in Section 5.7. Remove Screw, Item 24, Figure 5-4. Gently pry Lever Support(Item 6, Figure 5-9) off of locating Dowel Pins(See Item 10, Figure 5-12).

5.9.2 Replacing Crossed Flexures in the Lever Assembly

Refer to Figure 5-9. Replace Cross Flexures, Item 14, one at a time. To replace a Cross Flexure, loosen Set Screws, Item 8, and gently push Cross flexure out of its mounting hole. To replace a Cross Flexure, support Mount, Item 6. and Lever, Item 1, so that Lever is horizontal as shown in Figure 5-9. Slip Cross Flexure in place and rotate it until it is in the position shown in Figure 5-9. Orientation of the Cross flexure is IMPORTANT. If Cross Flexure is mounted upside it WILL be damaged when the Spring load is applied. Position Cross Flexure so that gap in flexure is in center of gap between the Mount and the Lever. Tighten set screws only tight enough to keep Cross Flexure from moving in mounting hole. When Cross Flexures are properly mounted, the Lever should move freely without dragging on Mount

5.9.3 Replacing the Lever Assembly

Place Lever assembly in place and press Lever Mount down over locating Dowel pins on frame. DO NOT put pressure on Lever as Cross Flexures will be damaged. Once Mount starts onto Dowel pins, Install Screw, Item 24, Figure 5-4. Tighten Screw until Mount pulls down over Dowel pins and is flush with frame.

Reconnect Spring Connector Flexure per Section 5.6.2 , and Wire Flexure per Section 5.7

5.10 Complete Field Disassembly Of The Seismometer

Complete field disassembly of the Seismometer beyond the limits described in the preceding Sections should not be necessary. Minor parts can be replaced by referring to the assembly drawing, Figure 18. For maintenance or repairs beyond those described, the instrument should be returned to the manufacturer.

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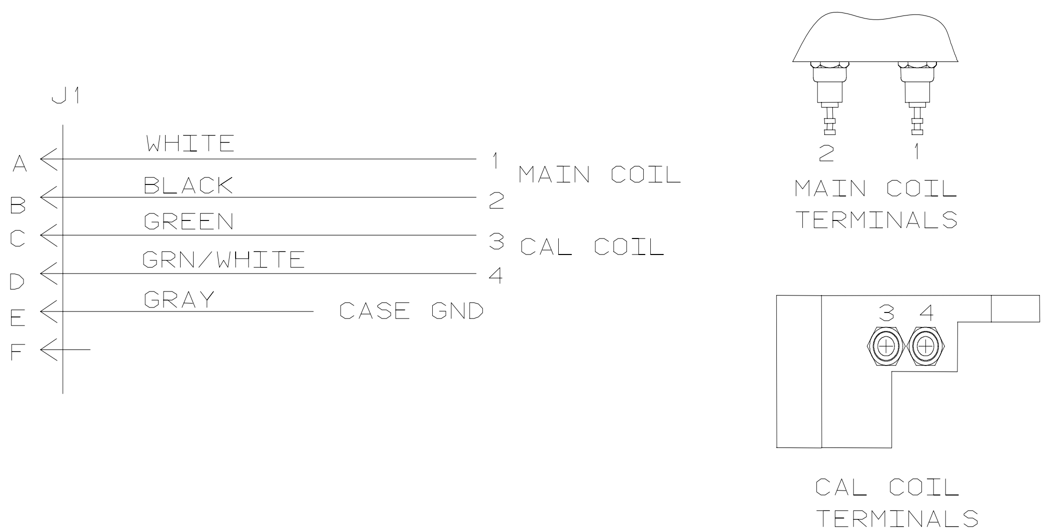

Figure 5-1 - S-13J Short-Period Seismometer, Schematic Diagram

On request, a damping resistor corresponding to 0.7 of critical damping is soldered internally between pins A and F.
In this case, the cable connector should have a short between pins B and F.
Open circuit can still be tested between pins A and B.

5.11 S-13J Short-Period Seismometer, Interim Assembly - 990-60300-1201

Table 5-1 - S-13J Short-Period Seismometer, Interim Assembly - Parts List

Item	NO.	Qty	U/M	Description
990603360101	1	1	EA	MASS TO MAGNET ASSEMBLY
990603310101	3	1	EA	CALIBRATION MAGNET ASSEMBLY
990600780101	4	1	EA	CALIBRATION COIL ASSEMBLY
990603320101	5	1	EA	COVER ASSEMBLY
990600850102	12	1	EA	MOUNT, CAL MAGNET
990600940101	13	1	EA	CROSSBAR
990600980101	15	2	EA	PIGTAIL, LEAD
015870113328	16	2	EA	STANDOFF, .312 DIA., 8-32 THD EA END, 1.750 LG, GOLD IRIDITE
044102293300	17	1	EA	KNOB, PLASTIC, T-HANDLE, 1/420 BRASS INSERT
008220148037	18	2	EA	TERMINAL, 4-40 THD
035170070300	20	1	EA	SCREW, MACH, FLAT HD(82),CROSS RECESSED, 300 SER SST, 2-56x3/16
035010181400	23	1	EA	SCREW, MACH(CAP),SOCKET HD, 18-8 SST, 6-32 x 7/8 LG
035010210800	24	1	EA	SCREW, MACH(CAP),SOCKET HEAD, 18 T,8-32 X 1/2 LG -8 SST, 8-32 X ½
035470210800	25	2	EA	SETSCREW, SOCKET, CUP PT, 18-8 SS
035470411600	27	1	EA	SETSCREW, SOCKET, CUP PT, 18-8 SS T,1/4-20 X 1 LG
038020130000	32	1	EA	NUT, PLAIN, HEXAGON, 4-40 UNC-2B 300 SER SST,
070040005500	33	0	EA	GREASE, SILICONE (5.3 OZ TUBE) DOW CORNING #55
070070063000	34	0	EA	GREASE (10 1/2 OZ TUBE)
035600130156	36	1	EA	SETSCREW, SOCKET, NYLON PT, SST, 4-40 X 5/32 LG (ALLIED DEVICES CORP #DCS9 OR EQUAL)

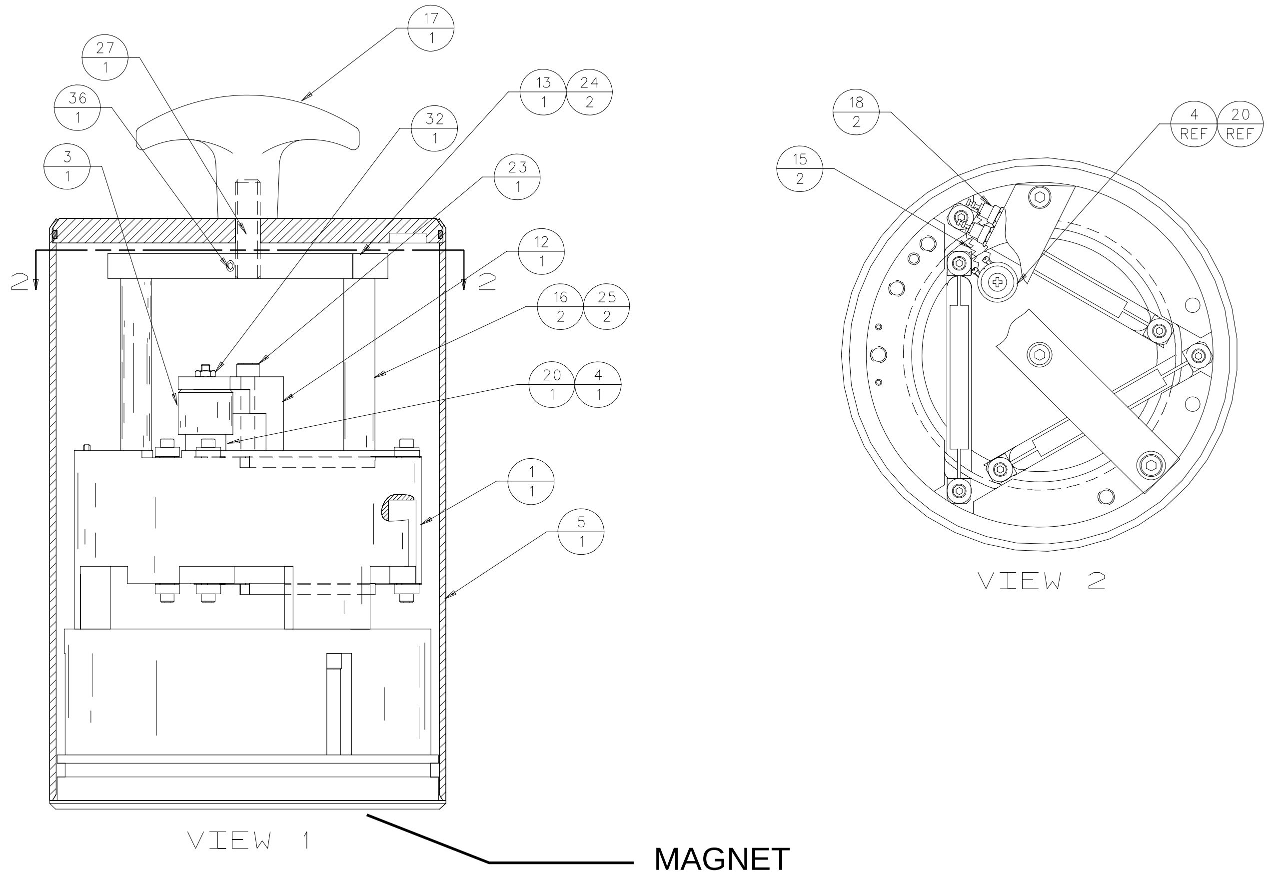

Figure 5-2 – S-13J Short-Period Seismometer, Interim Assembly

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5.12 S-13JV Short-Period Seismometer, Vertical - 990-60300-0101

Table 5-2 - S-13JV Short Period Seismometer, Vertical - Parts List

Item	NO.	Qty	U/M	Description
990603360101	1	1	EA	MASS TO MAGNET ASSEMBLY
990603290101	2	1	EA	LEVER ASSEMBLY
990603340102	6	1	EA	FLEXURE CONNECTOR SUBASSY MASS TO LEVER
990603350101	7	1	EA	SPRING ASSEMBLY
990603370101	8	1	EA	INTERNAL CABLE ASSEMBLY
990600760103	9	1	EA	FLEXURE, WIRE
990600620101	10	1	EA	SUPPORT, SPRING
990600720101	11	1	EA	CLAMP, SPRING SUPPORT
990199650101	14	1	EA	CLAMP, FLEXURE
990604210101	15	1	EA	SPACER,COVER,HORIZONTAL
044102293300	17	1	EA	KNOB, PLASTIC, T-HANDLE, 1/420 BRASS INSERT
008220148037	18	2	EA	TERMINAL, 4-40 THD
035010070600	19	1	EA	SCREW, MACH(CAP),SOCKET HD, 18-8 SST, 2-56 X 3/8 LG
035010130500	21	4	EA	SCREW, MACH(CAP),SOCKET HEAD, 18-8 SST, 4-40 X 5/16 L
035010181200	22	2	EA	SCREW, MACH(CAP),SOCKET HEAD, 18-8 SST, 6-32 X 3/4 LG
035010211200	26	1	EA	SCREW, MACH(CAP),SOCKET HEAD, 18-8 SST, 8-32 X 3/4 LG
038615410000	28	1	EA	WASHER, BOLT SEALING, 1/4".505 OD x .050 THK, CAD PL STL
038570110001	29	1	EA	WASHER, SWIVEL, FEMALE, 300 SER SST
038570110002	30	1	EA	WASHER, MALE, SWIVEL, 300 SER SST
042111536747	31	1	EA	O-RING, 3 1/2 ID X 3/32 CROSS SECTION
990049500103	35	1	EA	NAMEPLATE
007361605055	36	1	EA	CONN, CIRC, PLUG, 6 PIN, FEMALE, WITH STRAIN RELIEF: PACKING LIST ITEM
990603009800	37	1	EA	O & M MANUAL (S13J): PACKING LIST ITEM
990603009600	38	1	EA	CUSTOMER DATA SHEET

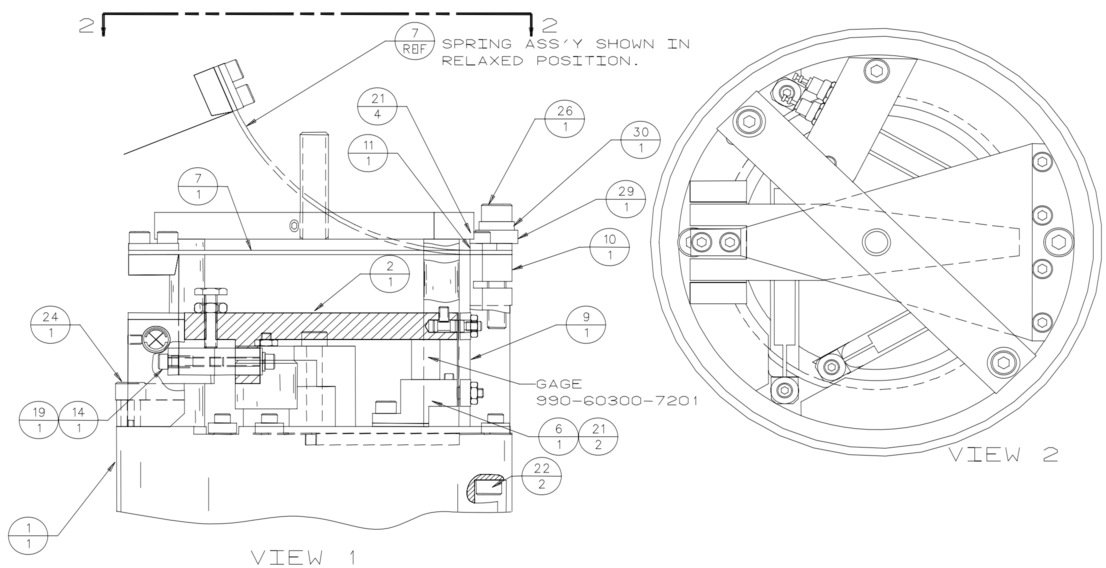

Figure 5-3 - S-13JV Short-Period Seismometer, Assembly - Vertical (Sheet 1 of 2)

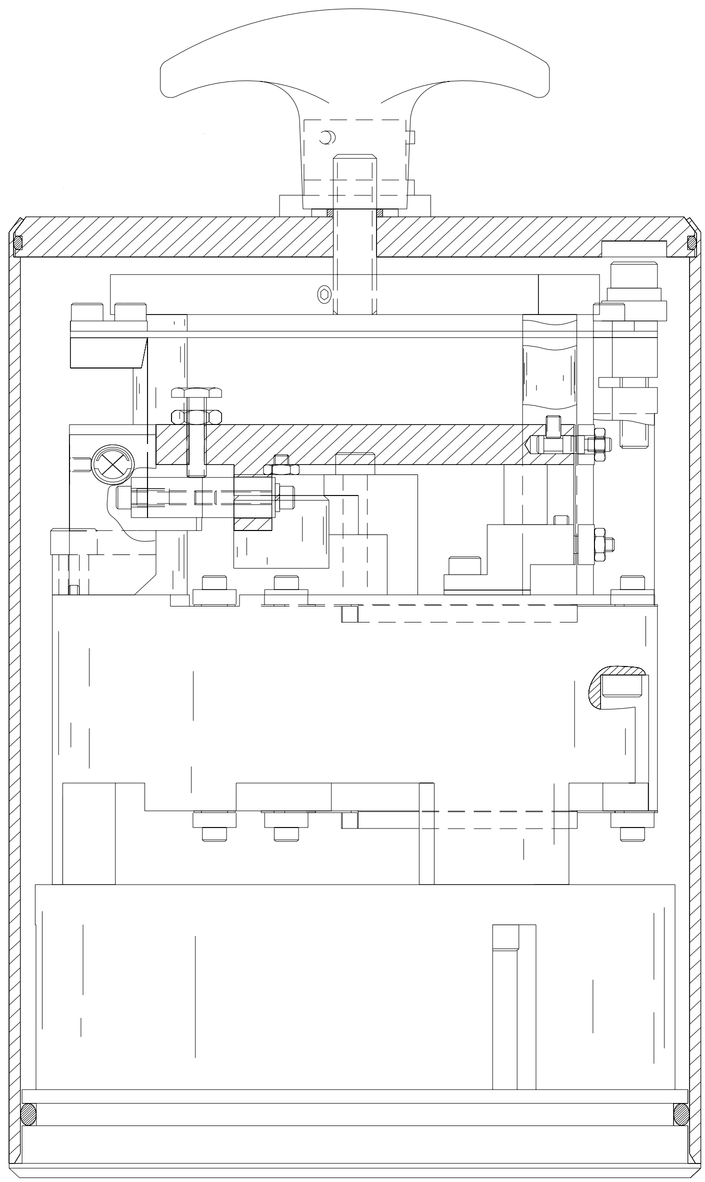

Figure 5-4 - S-13JV Short-Period Seismometer, Assembly - Vertical (Sheet 2 of 2)

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5.13 S-13JH Short-Period Seismometer, Horizontal - 990-60300-0102

Table 5-3 - S-13JH Short-Period Seismometer, Assembly - Part List

Item	NO.	Qty	U/M	Description
990603000201	1	1	EA	INTERIM ASSEMBLY, S-13J
990600920101	2	1	EA	POST, PERIOD ADJUST, HORIZONTAL
990603740101	3	1	EA	LEVER, PERIOD ADJUST, HORIZONTAL
990603750101	4	1	EA	KNOB, PERIOD ADJUST
990603760102	5	1	EA	CROSSBAR, HORIZONTAL
990600670103	6	1	EA	FLEXURE CONNECTOR, MASS TO
990600770101	7	2	EA	CLAMP, FLEXURE, HORSE, PERIOD
990603370101	8	1	EA	INTERNAL CABLE ASSEMBLY
990603770101	9	1	EA	CLAMP, PERIOD ADJUST, SPRING
990603790101	10	1	EA	FLEXURE, PERIOD ADJUST
990600790101	11	1	EA	SPRING, PERIOD ADJUST
990199650101	12	1	EA	CLAMP, FLEXURE
990600810101	13	1	EA	DELTA ROD, PERIOD ADJUST
990600580104	14	2	EA	CLAMP, DELTA ROD
990604210101	15	1	EA	SPACER,COVER,HORIZONTAL
035010070500	20	10	EA	SCREW, MACH(CAP)SOCKET HD 18-8 SST, 2-56 X 5/16 LG
035010130500	21	2	EA	SCREW, MACH(CAP),SOCKET HEAD, 18-8 SST, 4-40 X 5/16L
035010131000	22	1	EA	SCREW, MACH(CAP),SOCKET HD, 18-8 SST, 4-40 X 5/8 LG
038610163250	28	1	EA	WASHER, SEAL, .240 ID x .505 OD x .050 THK, CAD PLATED STEEL
035470210800	30	2	EA	SETSCREW, SOCKET, CUP PT, 18-8 SST, 8-32 X 1/2 LG
042111536747	31	1	EA	O-RING, 3 1/2 ID X 3/32 CROSS x SECTION
035010210800	32	2	EA	SCREW, MACH, CAP,, SOCKET HD, 18-8 SST, 8-32 X ½
070040005500	33	0	EA	GREASE, SILICONE (5.3 OZ TUBE)
990049500103	34	1	EA	NAMEPLATE
007361605055	35	1	EA	CONN, CIRC, PLUG, 6 PIN, FEMALE, WITH STRAIN RELIEF
015870113328	36	1	EA	STANDOFF, .312 DIA., 8-32 THD EA END, 1.750 LG, GOLD IRIDITE
990603009800	37	1	EA	O & M MANUAL (S13J)
990603008602	38	1	EA	PACKING LIST, HORIZONTAL SEISMOMETER S-13J
990603009602	39	1	EA	CUSTOMER DATA SHEET, HORIZONTAL SEISMOMETER, S-13J

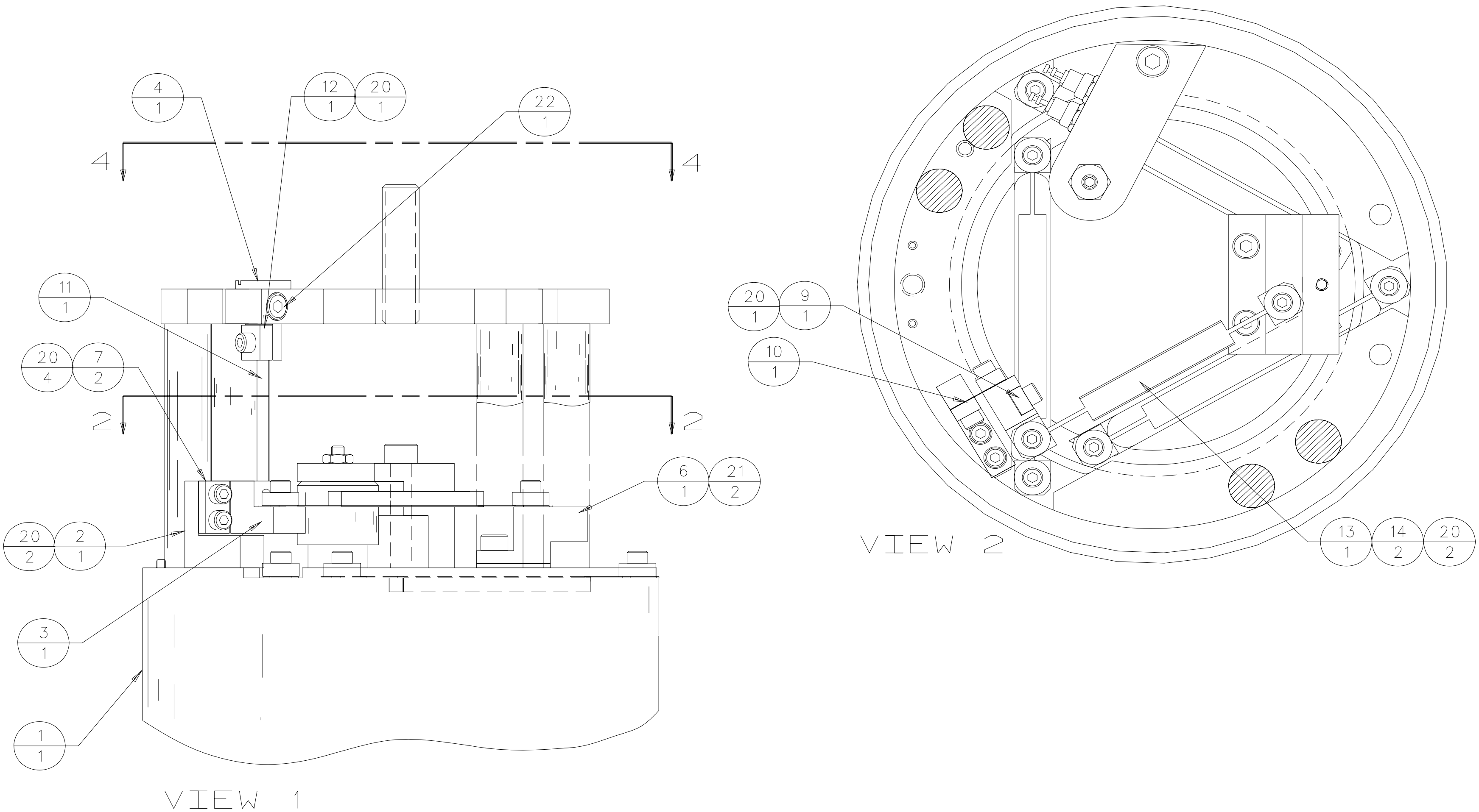

Figure 5-5 - S-13JH Short-Period Seismometer, Assembly (Sheet 1 of 2)

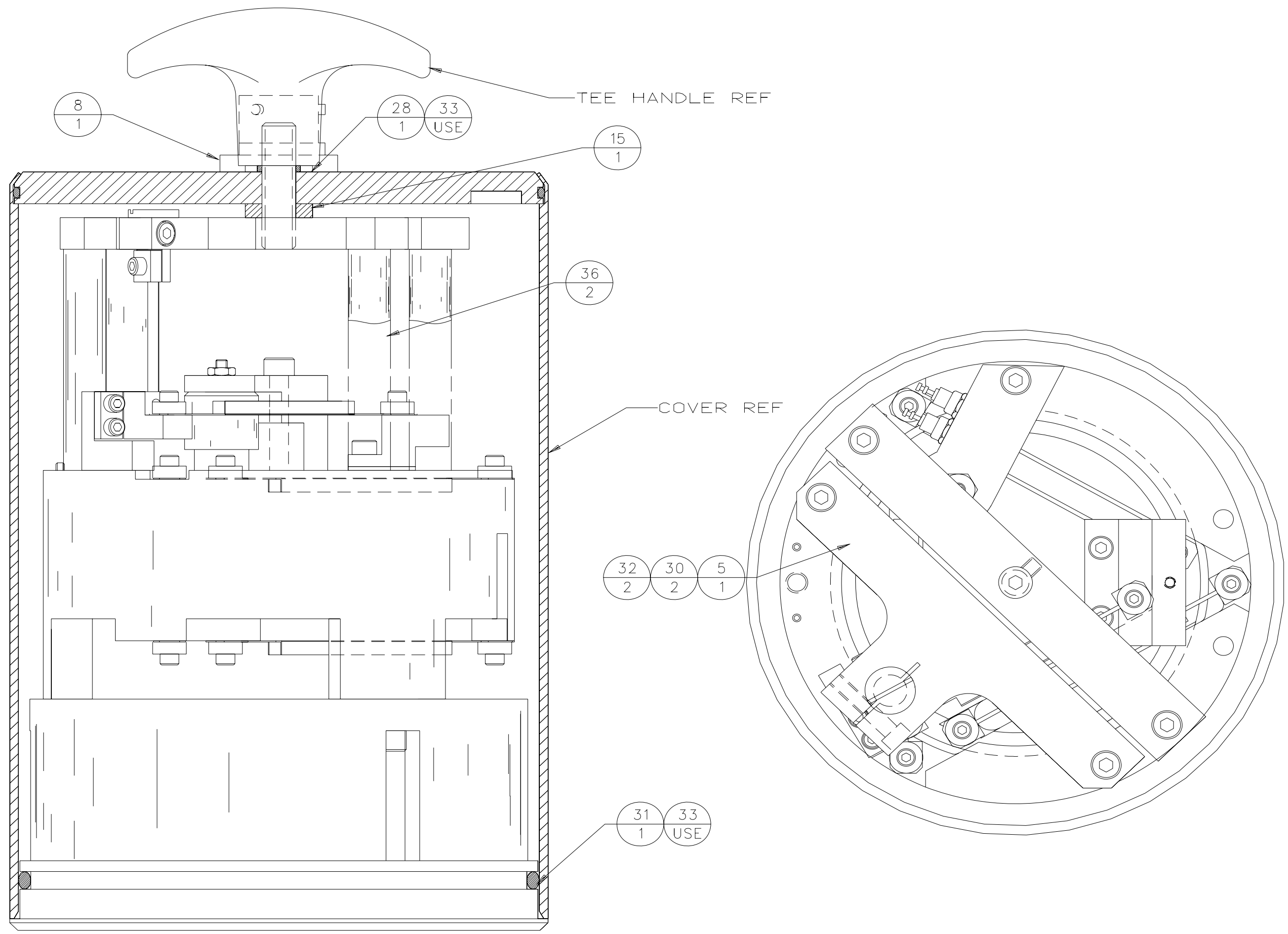

Figure 5-6 - S-13JH Short-Period Seismometer, Assembly (Sheet 2 of 2)

5.14 Cable Assembly - 990-60337-0101

Table 5-4 - Cable, Assembly - Parts List

Item	NO	Qty	U/M	Description
007361704050	1	1	EA	RCPT, JAM NUT, 6 PIN MALE
046311221012	2	3	IN	TUBING, INS, HEAT SHRINK, .125 MIN. / .062 REC ID
064062400150	3	8	IN	WIRE, ELECTRICAL, STRANDED, INSULATED, TEFLON(TP E),24 AWG, WHT
064062400250	4	8	IN	WIRE, ELECTRICAL, STRANDED, INSULATED, TEFLON(TP E),24 AWG, BLK
064062400450	5	8	IN	WIRE, ELECTRICAL, STRANDED, INSULATED, TEFLON(TP E),24 AWG, GRN
064062401350	6	8	IN	WIRE, ELECTRICAL, STRANDED, INSULATED TEFLON (TP E),24 GA, WHT/GRN
064062400950	7	8	IN	WIRE, ELECTRICAL, STRANDED, INSULATED, TEFLON(TP E),24 AWG, GRY
308201410100	8	1	EA	LUG, SOLDER SOURCE CONTROL DRAWING

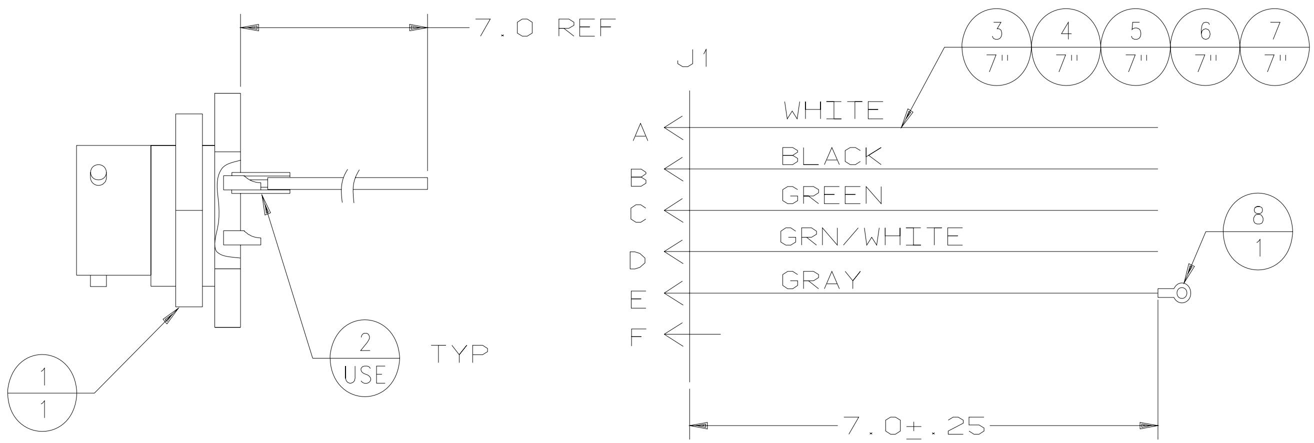

Figure 5-7 - Cable, Assembly and Schematic

On request, a damping resistor corresponding to 0.7 of critical damping is soldered internally between pins A and F.
In this case, the cable connector should have a short between pins B and F.
Open circuit can still be tested between pins A and B.

5.15 Lower Assembly - 990-60326-0101

Table 5-5 - Lower Assembly - PartsList

Component	Item	Qty	U/m	Description
990600870101	1	1	EA	PLUNGER, LOCK
990603270101	2	1	EA	GUIDE ASSEMBLY,PLUNGER REFERENCE DRAWINGS- A 990-60327-1101 SLBOM
990603280101	3	1	EA	MAGNET ASSEMBLY REFERENCE DRAWINGS- A 990-60328-1101 SLBOM
990600590102	4	1	EA	CLAMP,
990600890102	5	1	EA	BASE
990600880102	6	1	EA	SCREW,LOCK
990600960101	7	1	EA	RETAINER,LOCK SCREW
042612121902	8	1	EA	RING,SNAP
035010212400	9	3	EA	SCREW,MACH(CAP),SOCKET HEAD, 18-8 SST,8-32 x 1.5 LG
035170130400	10	3	EA	SCREW,MACH,FLAT HD(82),CROSS REC,18-8 SST,4-40 X 1/4 LG
035010130800	11	2	EA	SCREW,MACH(CAP),SOCKET HEAD,18-8 SST,4-40 X 1/2 LG
042110126747	12	2	EA	O-RING,3/8 ID X 1/16 W
070040005500	13	0	EA	GREASE,SILICONE (5.3 OZ TUBE) DOW CORNING #55

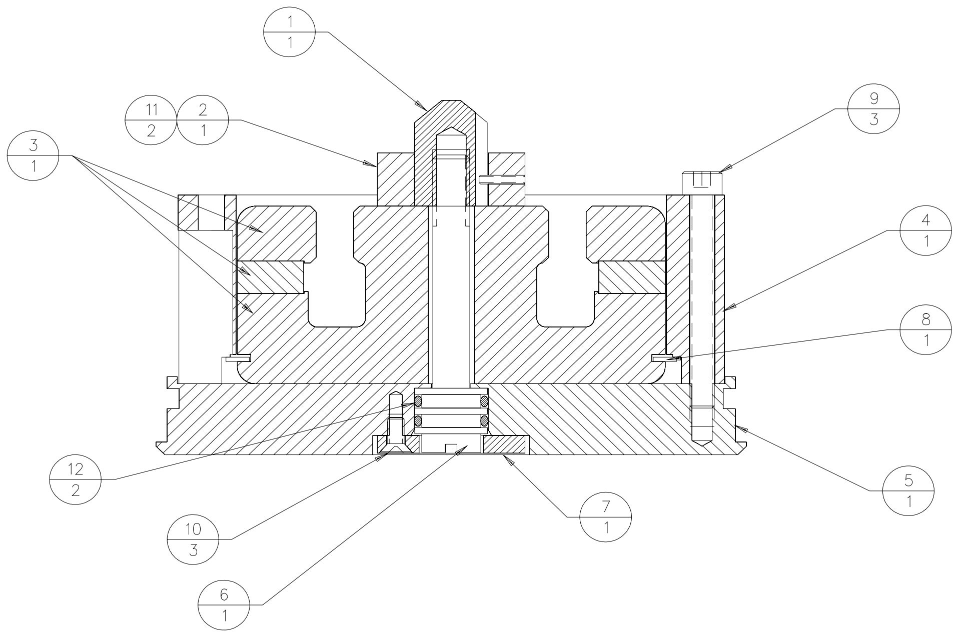

Figure 5-8 - Lower Assembly

5.16 Lever Assembly - 990-60329-0101

Table 5-6 - Lever Assembly - Parts List

Item	No.	Qty	U/M	Description
990600610102	1	1	EA	LEVER
990199650101	2	1	EA	CLAMP, FLEXURE
990600750103	3	1	EA	STUD PIN, FLEXURE
990600630101	4	1	EA	FLEXURE CONNECTOR, LEVER/SPRING
990199700101	5	1	EA	PIN, FLEXURE
990600570103	6	1	EA	SUPPORT, LEVER
035070131000	7	1	EA	SCREW, TRIMMED SLOTTED HEX HEAD, MACH, 18-8 SST, 4-40 X 5/8 LG
035470070200	8	5	EA	SETSCREW, SOCKET, CUP PT, 18-8 SST, 2-56 X 1/8 LG
035010070600	9	1	EA	SCREW, MACH(CAP),SOCKET HD, 18-SST, 2-56 X 3/8
038500060000	10	1	EA	WASHER, FLAT, 18-8 SST, NO. 2, 1/4 0D X 3/32 ID X .022 THK
038520060000	11	1	EA	WASHER, LOCK, SPLIT(SPRING),18-8 SST, NO. 2
038020070000	12	1	EA	NUT, PLAIN, HEXAGON, 2-56 UNC-2B, 300 SER SST
080864650000	13	0	EA	ADHESIVE, (1/3 OZ BOTTLE)
031224750088	14	2	EA	PIVOT, FREE FLEX, .250
038020130000	15	1	EA	NUT, PLAIN, HEXAGON, 4-40 UNC-2B 300 SER SST

2. ASSEMBLE PER 990-60329-1001.
3. ALIGN CROSS HOLE VERTICAL PER ASSEMBLY INSTRUCTIONS.

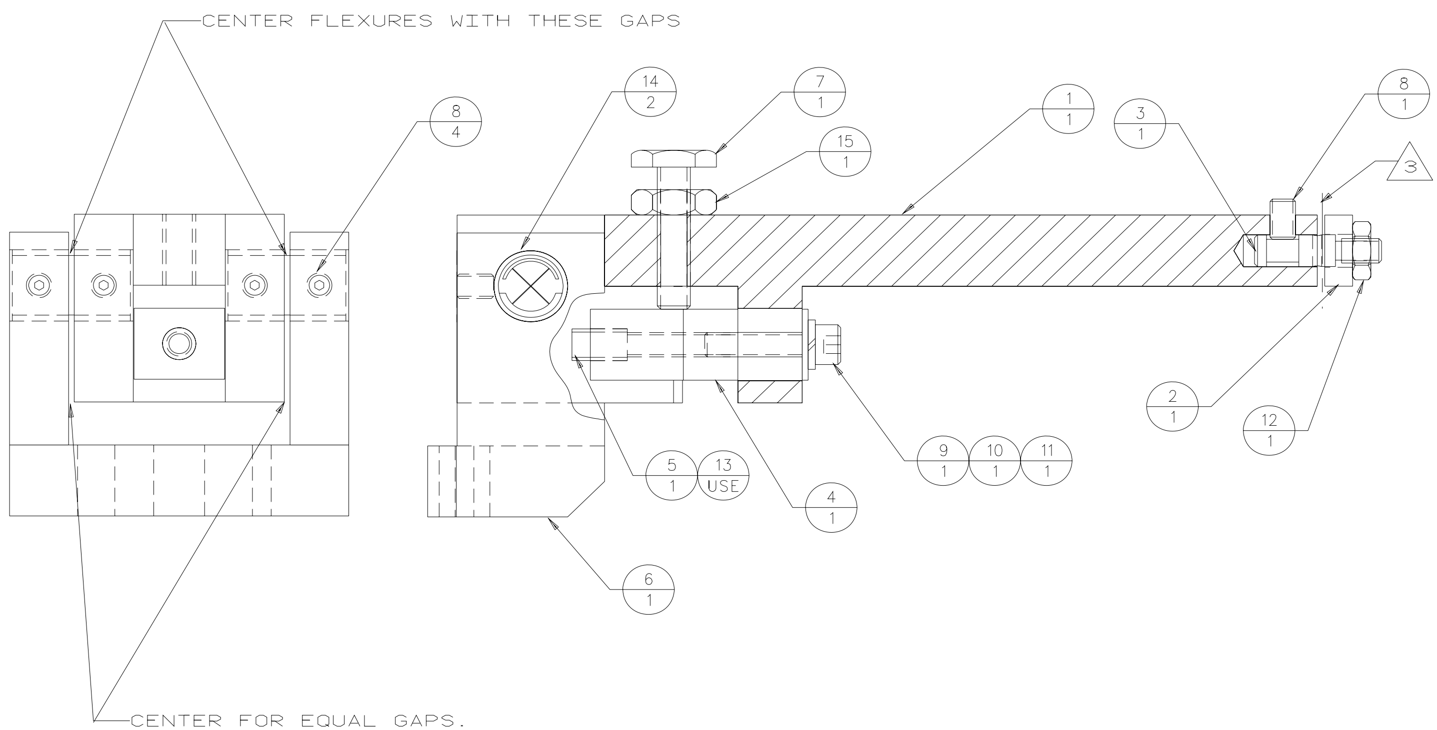

Figure 5-9 - Lever Assembly

5.17 Flexure Connector Assembly, Mass to Lever - 990-60334-0101

Table 5-7 - Flexure Connector Assembly, Mass to Lever - Parts List

Item	No.	Qty	U/M	Description
990600670103	1	1	EA	FLEXURE CONN, MASS TO LEVER
990600750103	2	1	EA	STUD PIN, FLEXURE
990199650101	3	1	EA	CLAMP, FLEXURE
038020070000	4	1	EA	NUT, PLAIN, HEXAGON, 2-56 UNC-2B, 300 SER SST
035474070200	5	1	EA	SETSCREW, SOCKET, CUP PT, HARDENED STEEL, 2-56 X 1/8 LG

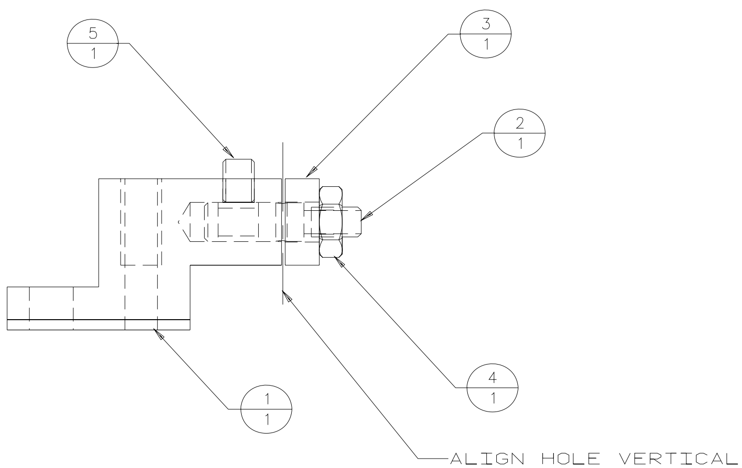

Figure 5-10 - Flexure Connector Assembly, Mass to Lever

5.18 Spring Assembly - 990-60335-0101

Table 5-8 - Spring Assembly – Parts List

Item	No.	Qty	U/M	Description
990600420101	1	1	EA	SPRING, TRIANGULAR
990600970101	2	1	EA	FLEXURE, SPRING CONNECTOR
990600740101	3	1	EA	NUT PLATE, SPRING END
990600730102	4	1	EA	CLAMP, SPRING END
035010130400	5	2	EA	SCREW, MACH(CAP),SOCKET HEAD, 18 -8 SST, 4-40 X 1/4 LG

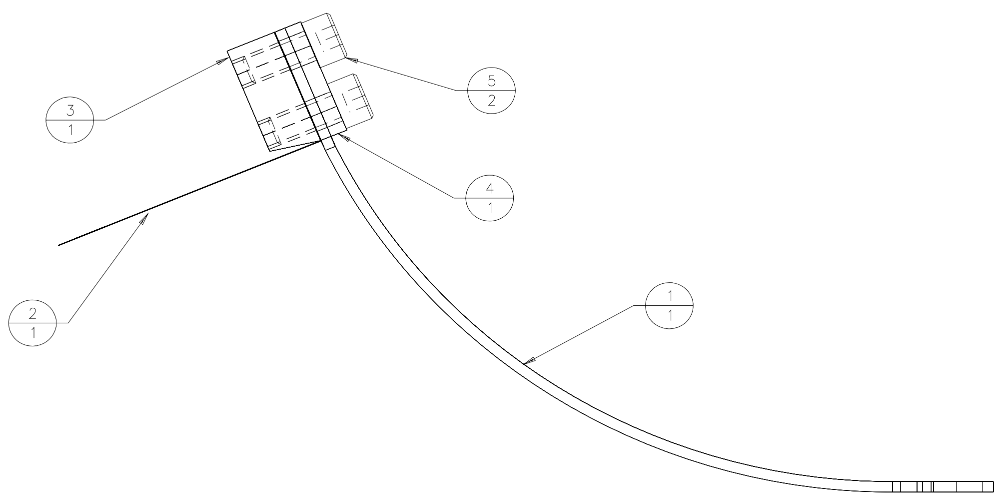

Figure 5-11 - Spring Assembly

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5.19 Mass Assembly - 990-60333-0101

Table 5-9 - Mass Assembly – Parts List

Item	NO	Qty	U/M	Description
990600640101	1	1	EA	MASS
990600660102	2	1	EA	FRAME, DELTA ROD
990600650102	3	6	EA	DELTA ROD
990600580104	4	12	EA	CLAMP, DELTA ROD
990600930101	5	1	EA	MAIN COIL ASSEMBLY
035010070600	6	12	EA	SCREW, MACH(CAP),SOCKET HD, 18-8 SST, 2-56 X 3/8 LG
035010130400	7	3	EA	SCREW, MACH(CAP),SOCKET HEAD, 18-8 SST, 4-40 X 1/4 LG
008220148037	8	2	EA	TERMINAL, 4-40 THD
990600980101	9	2	EA	PIGTAIL, LEAD
039020040600	10	2	EA	PIN, SPRING (ROLL), SST, 1/16 DIA. X 5/16 LG (Mc MASTER CARR #92383A100)
990199700101	11	12	EA	PIN, FLEXURE
080864650000	12	0	EA	ADHESIVE, (1/3 OZ BOTTLE)

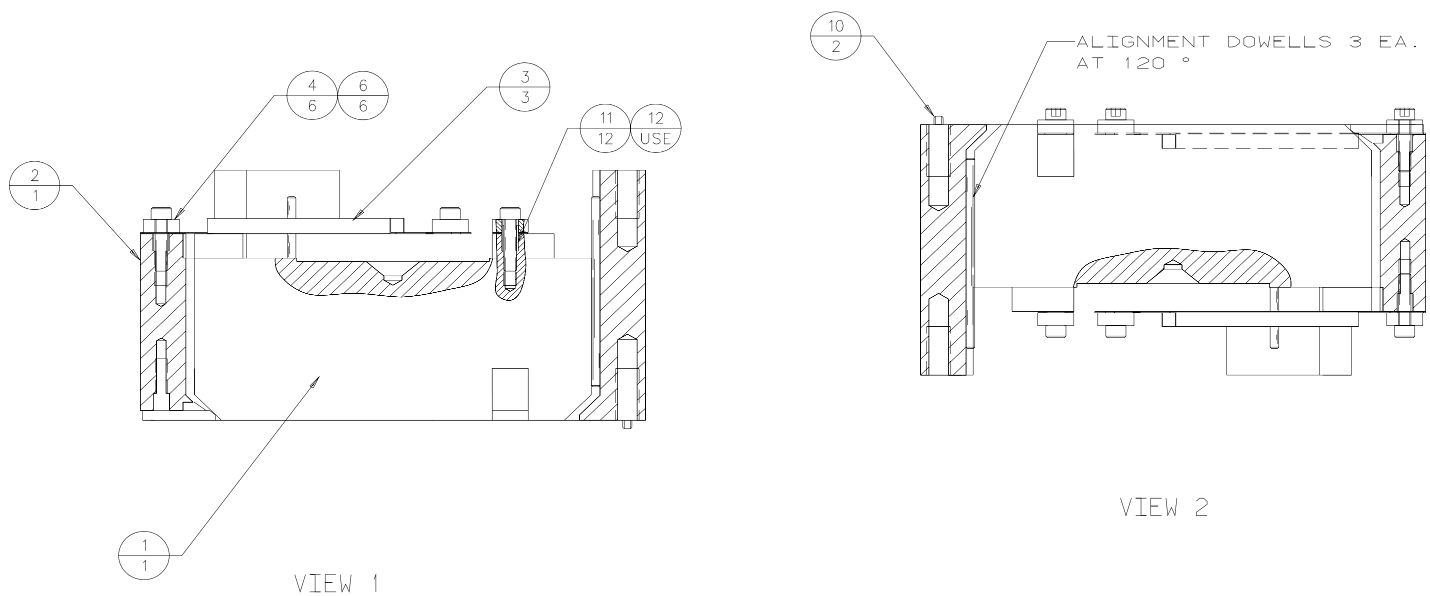

Figure 5-12 - Mass Assembly (Sheet 1 of 2)

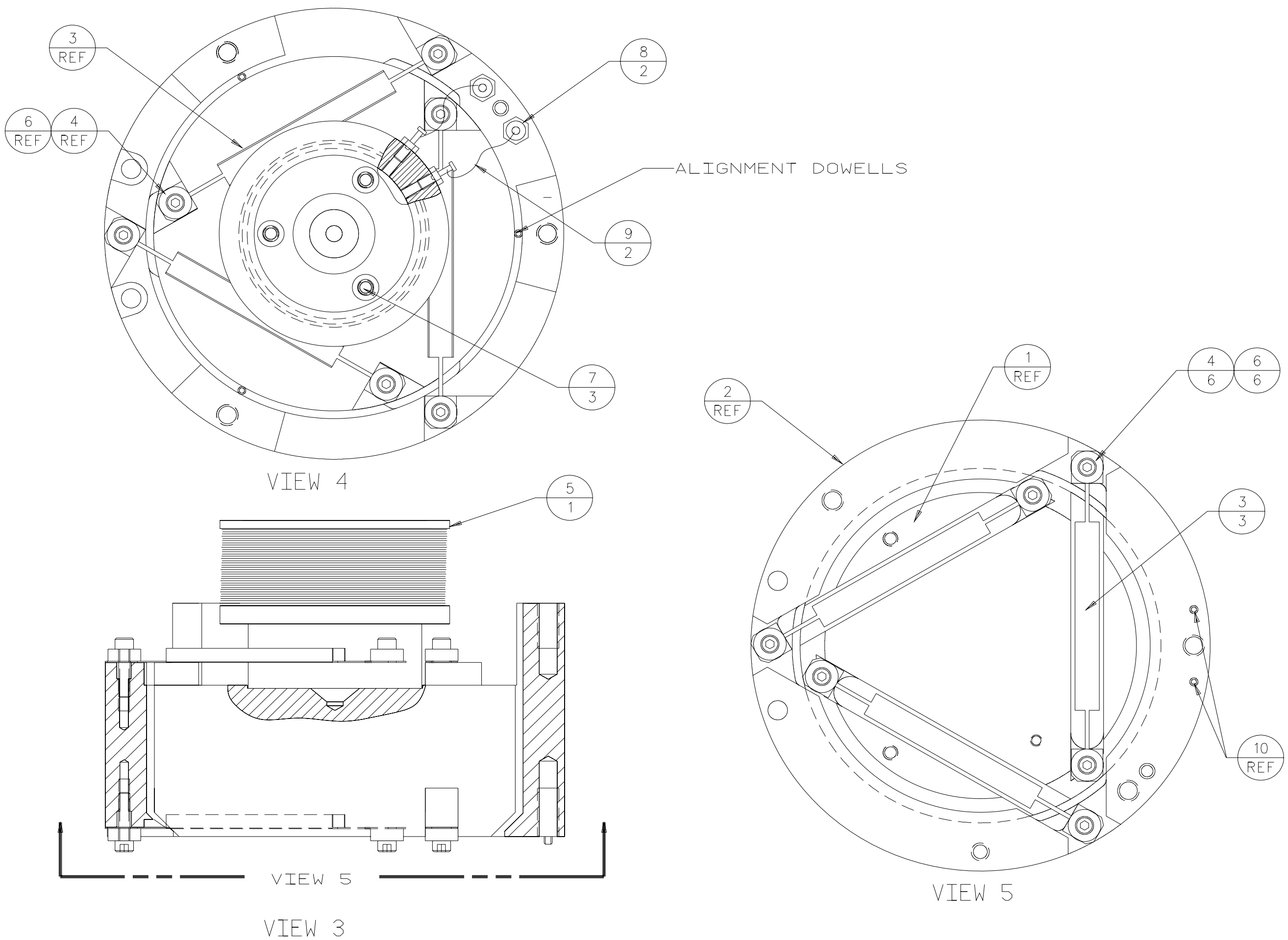

Figure 5-13- Mass Assembly (Sheet 2 of 2)

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6 INSTRUMENT CHARACTERISTICS

6.1 General

Typical instrument characteristics of the Model S-13J Short-Period Seismometer are shown in Figure 6-1 through Figure 6-3.

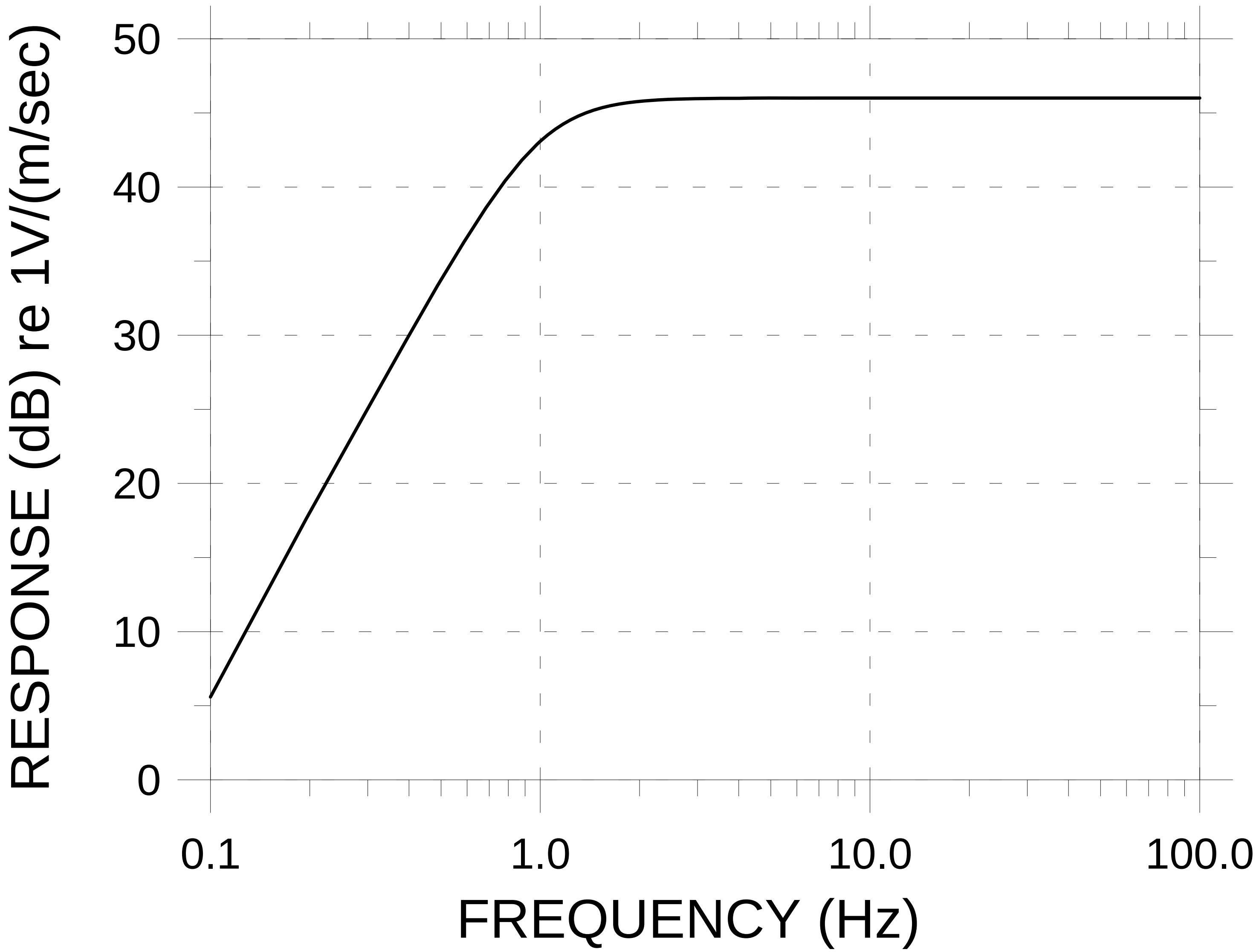

Figure 6-1 - Relative Terminal Voltage As A Function Of Frequency, Natural Frequency 1.0 Hz, Damping 0.7

(The response remains flat up to about 400 Hz)

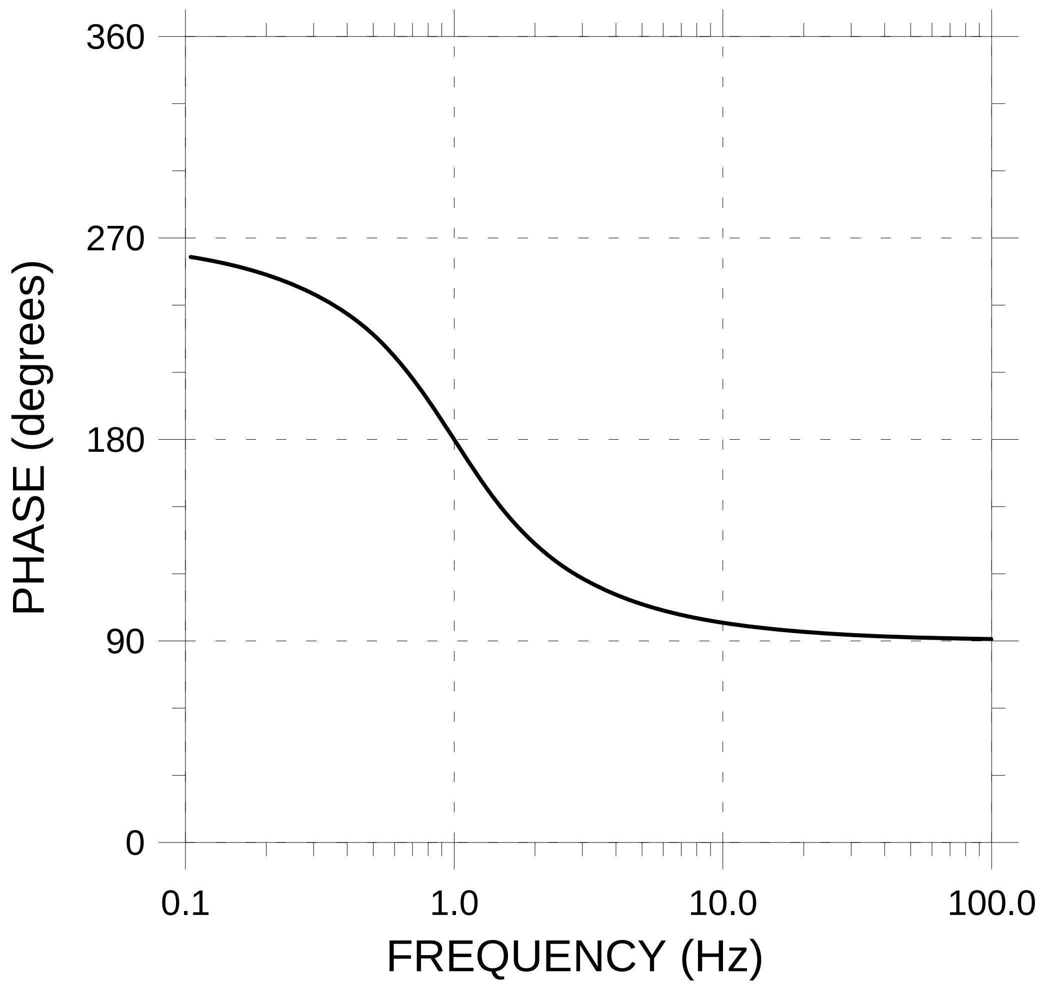

Figure 6-2 - Phase Shift Between Terminal Voltage And Ground Motion As A Function Of Frequency, Natural Frequency 1.0 Hz, Damping 0.7

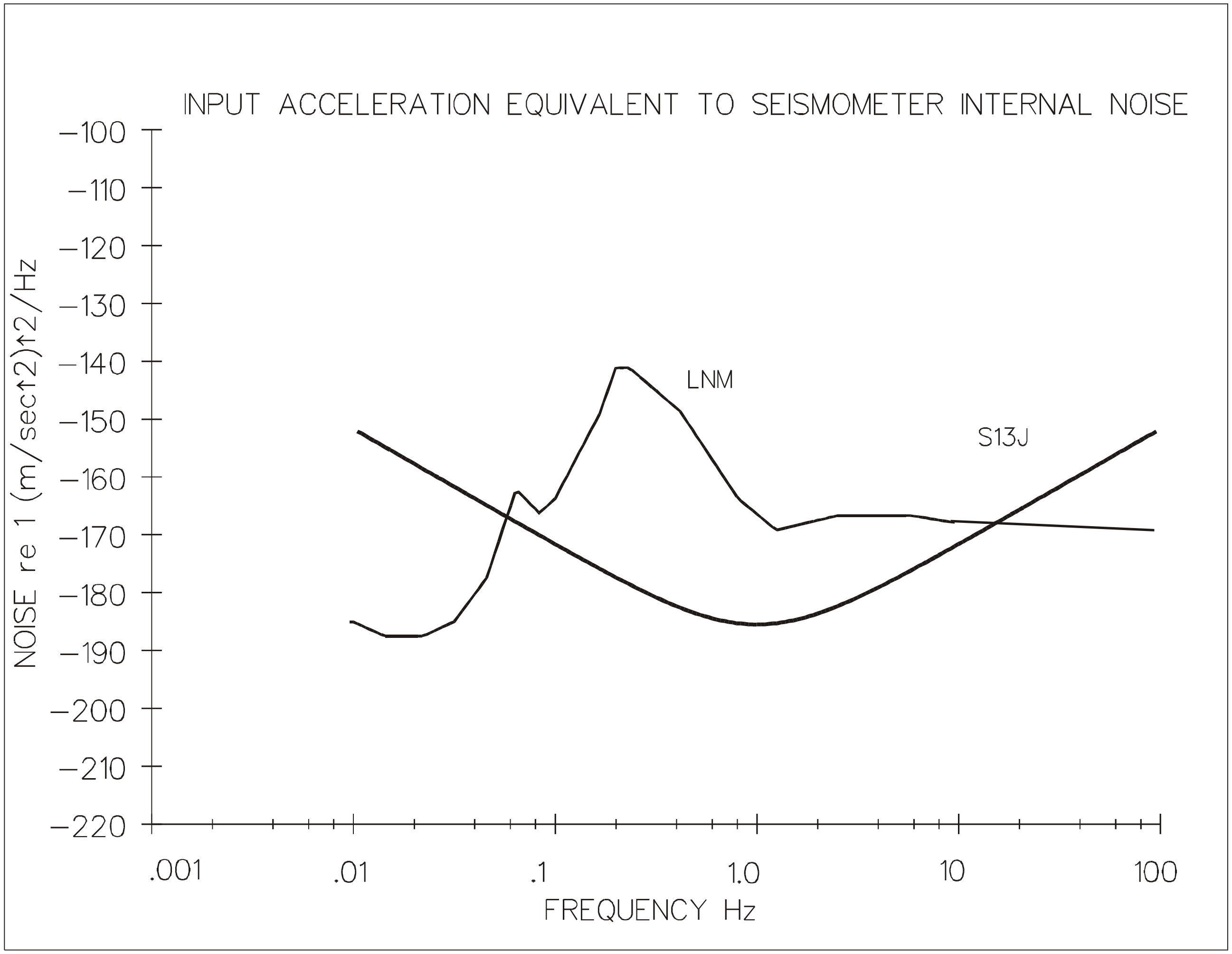

Figure 6-3 - Self Noise of S13J Seismometer, Together With The Low Noise Model

7 SYMBOLS

7.1 Definition Of Symbols

R_{CDR}	In a Seismometer having negligible internal losses and negligible inductance, this is the critical damping resistance (R_{CDRX} + Data Coil resistance).
G_c	The Data Coil generator/motor constant of an instrument, that is emf per unit velocity or mechanical force per unit current.
λ_o	Fraction of critical damping, or ratio to critical damping, of the Seismometer due to the circuit resistance as seen by the Seismometer (includes Data Coil resistance of the Seismometer).
λ_x	Fraction of critical damping, or ratio to critical damping of a Seismometer due to losses within the instrument tending to reduce the velocity of the inertial mass such as residual eddy currents, air damping, and so forth. Presumed proportional to velocity.
R_c	Resistance of the Data Coil of the Seismometer.
R_d	Decade or adjustable resistance, in ohms.
R_a	Amplifier input impedance, in ohms.
R_{CDRX}	External resistance that is added to R_c to equal R_{CDR}
f_o	Undamped natural frequency of a Seismometer.
X_4, X_5	Amplitudes of consecutive half cycles (in the same direction) of an instrument free period decay signal.
R_t	The series loop resistance of a Seismometer Data Coil and damping resistor.
R_o	The load resistor across the Data Coil of a Seismometer.
$\wedge_o$	Total Seismometer ratio to critical damping, where $\wedge_o = \lambda_o + \lambda_x$
m_w	Weight lifted, in grams.
X_m	Trace amplitude caused by weight lifted, in millimeters (zero-to-peak).
$Wt_{(eq)}$	Weight-lift equivalent of electromagnetic calibrator output in grams.
i_p	Electromagnetic Calibrator input current, in Amperes (zero-to-peak).
M_m	Mass of the inertial mass of a Seismometer, in kilograms.
E_t	Voltage developed across the load resistor, R_o, of a Seismometer.
y_e	Earth displacement parallel to the motional axis of the instrument. For vertical instrument, y_e is taken positive upward.7
f_l	Driving frequency of a shake table or other device for calibrating a Seismometer.
f_l	Shunt resistance equivalent of the mechanical losses in the Seismometer.
ω_o	Natural angular frequency of Seismometer in rad/sec $= 2\pi f_o$.
I_T	Current required to force Seismometer mass to top stop.
I_L	Current required to force Seismometer mass to bottom stop.
k_{eff}	Effective spring rate in Newton/meter.
X_1	Zero-to-peak amplitude; in millimeters, of system record caused by weight lift.
Hz	Cycles per second.

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8 INDEX

8.1 Symbols Index

8.2 General Index

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