A Brief Test of the Tokyo Sokushin VSE–355G3 Strong Motion Velocity Seismometer

By Charles R. Hutt, John R. Evans, and Isamu Yokoi

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A Brief Test of the Tokyo Sokushin VSE–355G3 Strong Motion Velocity Seismometer

By Charles R. Hutt[1], John R. Evans[2], and Isamu Yokoi[3]

1 Introduction

The VSE–355G3 seismometer is a broadband seismometer (called a "servo velocity meter" by Tokyo Sokushin) with a specified clip level of 2 m/s and a flat response to earth velocity from 0.008 Hertz (Hz) to 70 Hz. Mr. Yokoi and Mr. Kurahashi of Tokyo Sokushin shipped one instrument to the U. S. Geological Survey's Albuquerque Seismological Laboratory (ASL) for testing in early September 2007. They gave a presentation on this instrument and some of their other products to the authors and others on September 6, 2007. Testing of the VSE–355G3, Serial Number 70520, commenced on Friday, September 7, 2007.

Figure 1. VSE–355G3 in the ASL temperature test chamber.

[1] U.S. Geological Survey, Albuquerque, NM
[2] U.S. Geological Survey, Menlo Park, CA
[3] Tokyo Sokushin Co, Ltd., Tokyo, Japan

Figure 2. Instrument coated with frost at -30º C.

2 Physical Characteristics

Figure 1 shows Mr. Yokoi with the VSE–355G3 installed in the ASL temperature test chamber. Figure 2 shows the instrument coated with frost at a temperature of -30º C. The horizontal dimensions of the VSE–355G3 are 330 mm by 330 mm. The vertical dimension, not including base plate, is 197.6 mm; including the base plate it is 212.6 mm (see drawing in Appendix). Its weight is approximately 11 kg. Note in Figure 2 that the cable is wired directly into the instrument with no connector at that interface. This design makes replacement of the cable difficult when a bad cable is suspected. On this particular instrument, there are four leveling screws instead of three, which makes it more difficult to level the instrument. The manual (Appendix) shows an instrument with three leveling screws on a mounting plate which has four mounting holes. It is our understanding that this is the standard design, which is a much better arrangement. Also, in Figure 3 (which is oriented with north toward the top of the photo), note that the X axis produces positive signals for north ground motions and the Y axis produces positive signals for east ground motions. This is non–standard compared to some other strong–motion instruments, in which X is east and Y is north.

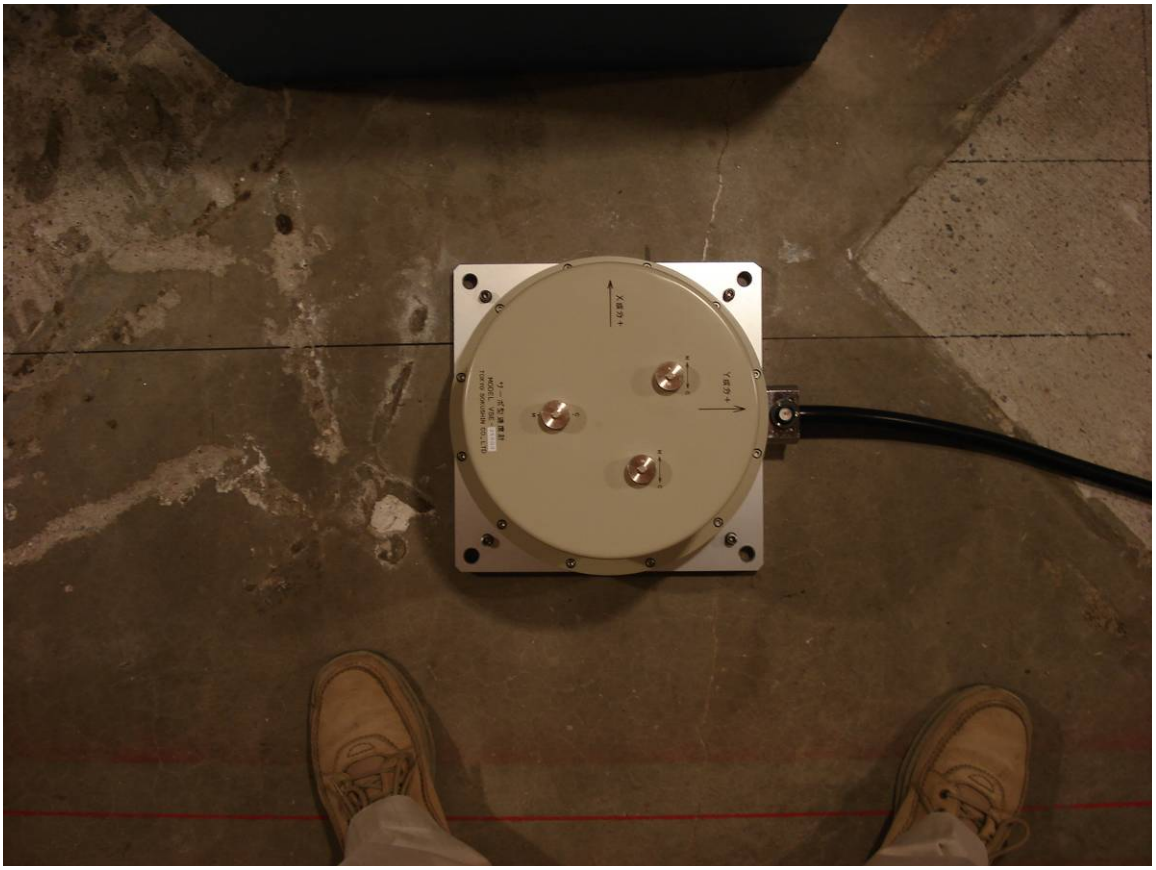


Figure 3. Top view of VSE–355G3.

The mass–lock screws are located under the three caps seen in Figure 3. Each cap has a rubber gasket. It is not known whether these gaskets make the case pressure tight.

3 Tests Performed

The following tests were performed:

3.1. Self-noise level compared to STS–2 in underground tunnel.
3.2. Comparison of signals from earthquakes.
3.3. Shake Table Tests
- Square waves of known displacement amplitude
- Frequency response using sine waves of constant velocity

3.4. Temperature test

A Note About Clipping

It was not possible with existing equipment at ASL to perform a clip level test. However, one of the sine wave tests (16 Hz at 2 mm peak displacement) reached a peak velocity of 193 mm/s, which is almost 10 percent of the specified clip level of 2 m/s. This same test produced a peak acceleration of 19.4 m/s/s (almost at the specified 2 g clipping limit). In addition, the square wave test on the shake table produced a peak velocity of approximately 400 mm/s. No clipping was observed.

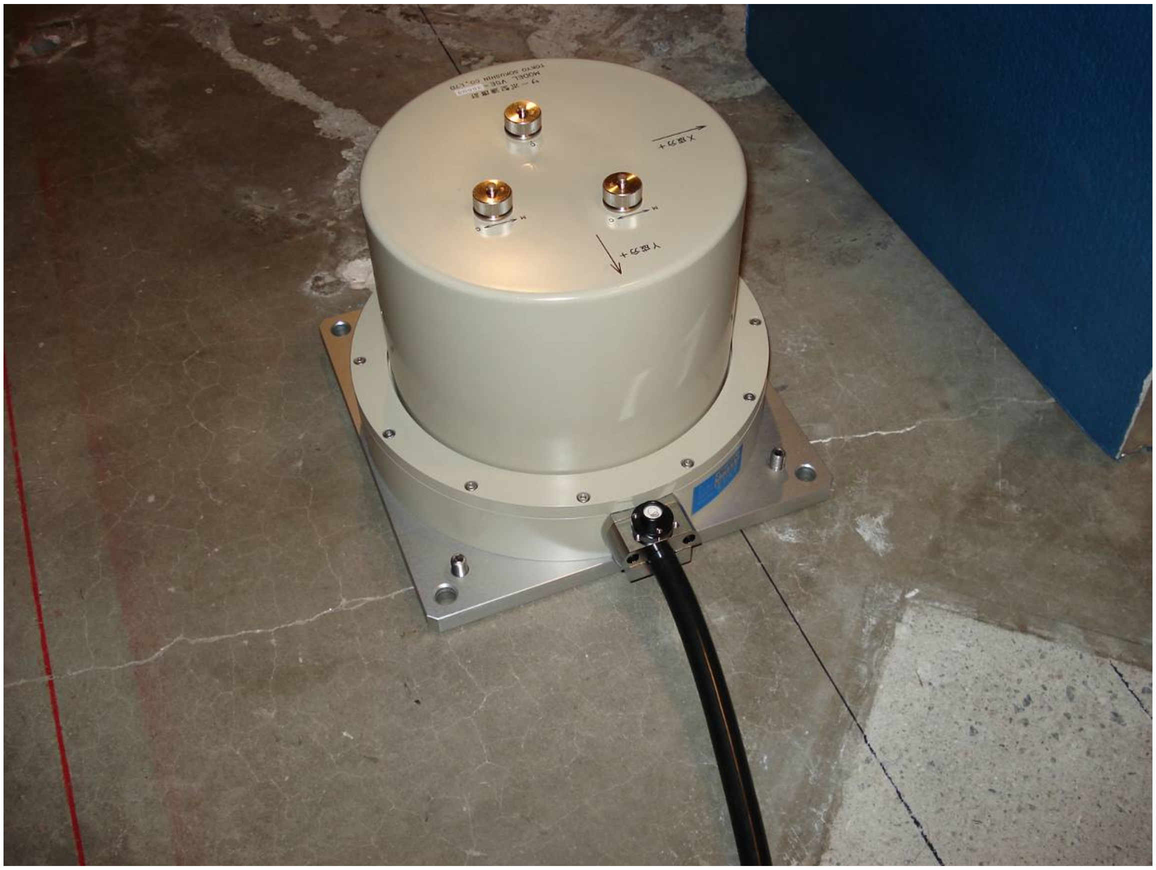


Figure 4. VSE–355G3 installed in ASL tunnel.

Figure 4 shows the VSE–355G3 as installed on the floor of the ASL tunnel adjacent to an STS–2 seismometer, which is installed under the blue Styrofoam box at the upper right. During the noise test, the VSE–355G3 was also protected by a foam cover.

3.1 Noise Level Test

The VSE–355G3 instrument was installed on the floor of the ASL underground tunnel in granite, adjacent to an STS–2 high gain seismometer (Serial Number 50514) having a sensitivity of 20,000 V/m/s (Figure 4).

The VSE–355G3 outputs were connected to channels 1–3 of a Q330HR digitizer/data logger (station code TST1, network code XX) with 26 bits of resolution (2^{25} counts per 20 volts), a preamp gain of 20 for the noise test, and a preamp gain of 1 for the shake table tests. The STS–2 was connected to channels 4–6 of the same digitizer (also with 26 bits of resolution) with a preamp gain of 1. The resulting channel assignments and digital sensitivities were as follows:

Table 1. Channel assignments and sensitivities.

Instrument/Component	Sensitivity (V/m/s)	Digitizer Channel	Preamp Gain	Overall Mid–band sensitivity (counts/m/s)
VSE–355G3 Z	10	EH1	20 or 1	3.355E+08/1.6777E+06
VSE–355G3 Y (East)	10	EH2	20 or 1	3.355E+08/1.6777E+06
VSE–355G3 X (North)	10	EH3	20 or 1	3.355E+08/1.6777E+06
STS–2 Z	20000	EH4	1	6.711E+11
STS–2 Y (North)	20000	EH5	1	6.711E+11
STS–2 X (East)	20000	EH6	1	6.711E+11

For the noise tests, data were recorded on the XX/TST1 data logger at 200 sps. The power spectral densities (PSDs) in Figure 5, Figure 6, and Figure 7 are for a 328–second time segment during a quiet period beginning at 2007,250,17:55:02 UTC (07 September 2007). (Note that the date/time format YYYY,DDD,HH:MM:SS, where YYYY = year, DDD = day number of year, HH = hour, MM = minute, and SS = second, is a format commonly used in describing seismic data. UTC stands for Coordinated Universal Time.) The PSDs shown have been corrected for instrument response. The STS–2 poles and zeros were used for both instruments since both are flat to velocity from 0.01 Hz to 70 Hz. Note that the VSE–355G3 is not resolving the background noise seen by the STS–2, except at the 6–second microseism peak.

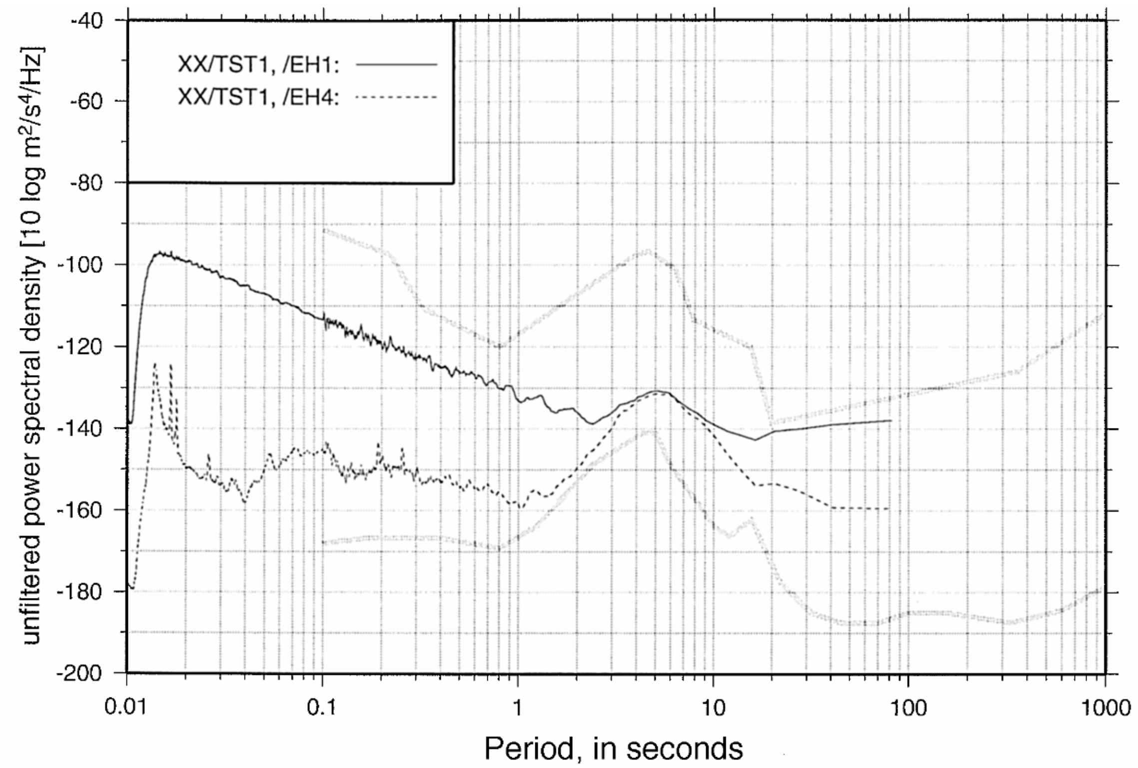


Figure 5. Vertical PSDs during a quiet period.

Figure 5 shows vertical PSDs during a quiet period for VSE–355G3 (Channel EH1 = solid line) and for STS–2 reference instrument (Channel EH4 = dashed line). The lower and upper broad lines are the USGS NLNM (New Low Noise Model) and NHNM (New High Noise Model), respectively (Peterson, 1993).

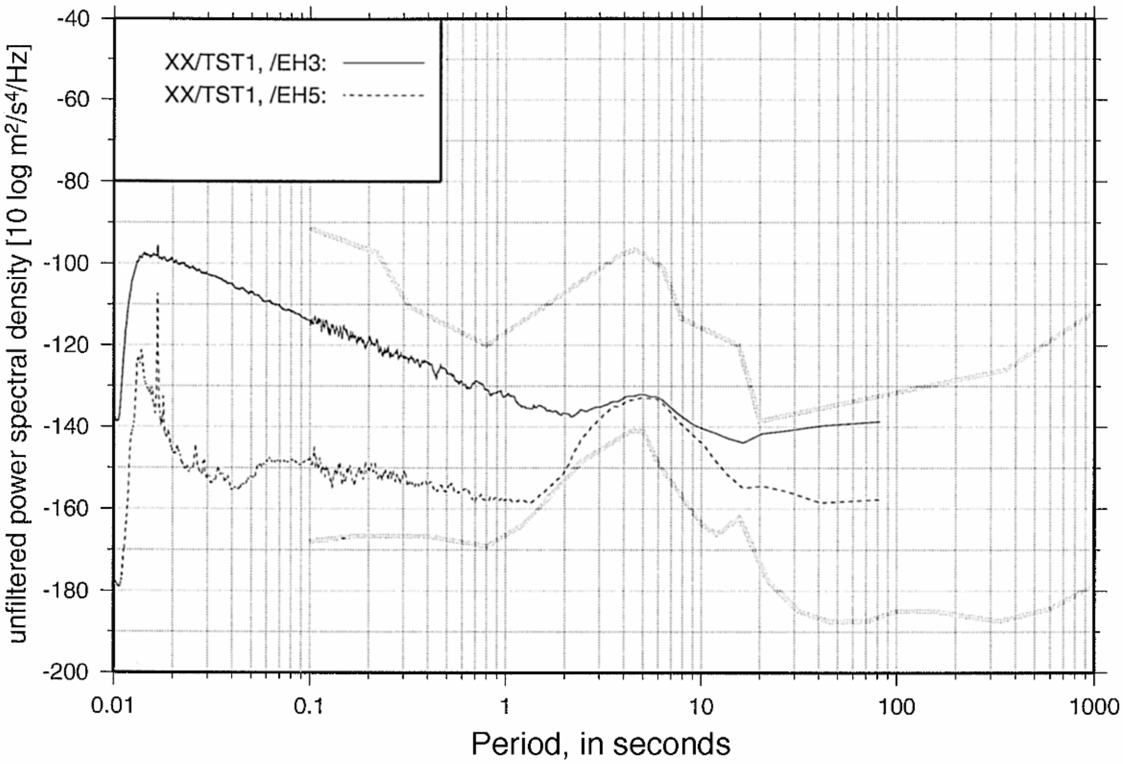


Figure 6. North–South PSDs during a quiet period.

Figure 6 shows North–South PSDs during a quiet period for VSE–355G3 (Channel EH3 = solid line) and for STS–2 reference instrument (Channel EH5 = dashed line). The lower and upper broad lines are the USGS NLNM and NHNM, respectively (Peterson, 1993).

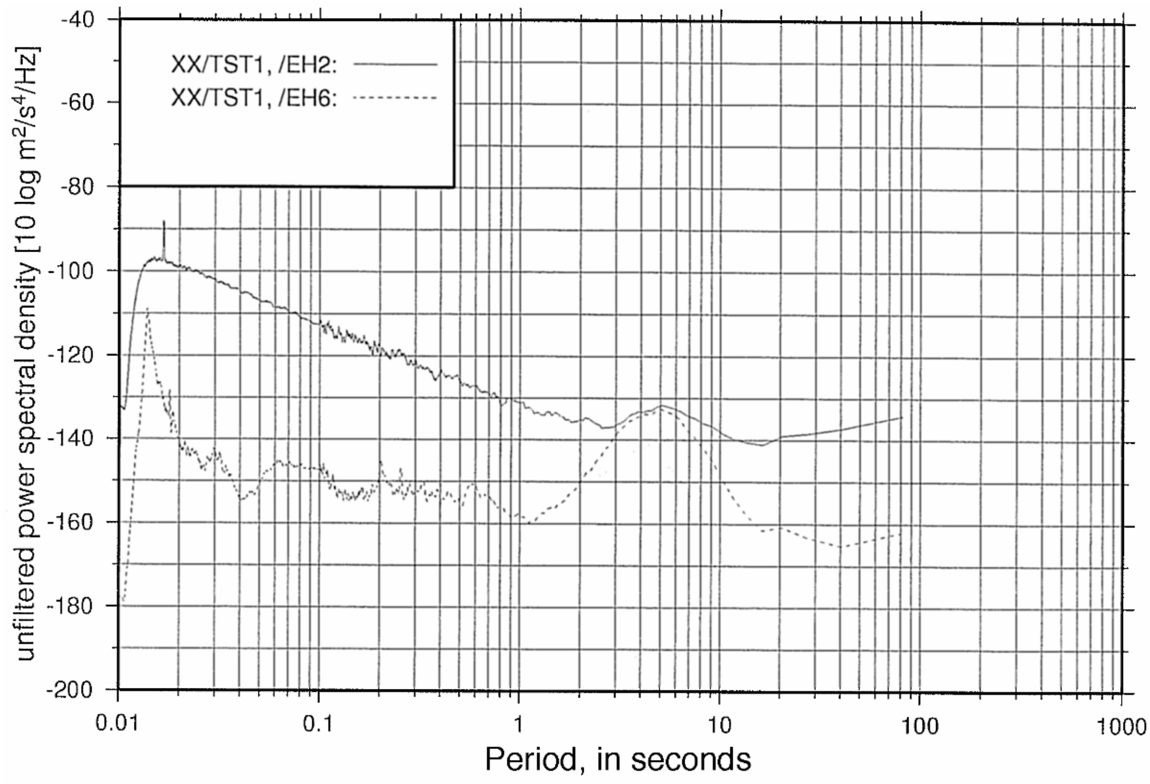


Figure 7. East–West PSDs during a quiet period.

Figure 7 shows East–West PSDs during a quiet period for VSE–355G3 (Channel EH2 = solid line) and for STS–2 reference instrument (Channel EH6 = dashed line).

3.2 Comparison of Earthquake Signals.

Data from the VSE–355G3 and the STS–2 were logged during three different earthquakes:

Table 2. Earthquakes recorded during testing.

Magnitude	UTC Date & Time	Lat (Deg)	Lon (Deg)	Region	Source of information
6.8	2007/09/10 01:49:11 (Day 253)	2.945	–78.069	Near West Coast of Colombia	NEIC
5.4	2007/09/10 00:13:08 (Day 253)	–17.186	–69.277	La Paz, Bolivia	NEIC
Unknown (very small)	2007/09/07 18:17:00 approx (Day 250)	Local	Local	Approx 9 km from ASL	ASL

Figure 8 through Figure 14 are plots of data from these earthquakes, showing the resolving ability of the VSE–355G3 relative to the STS–2.

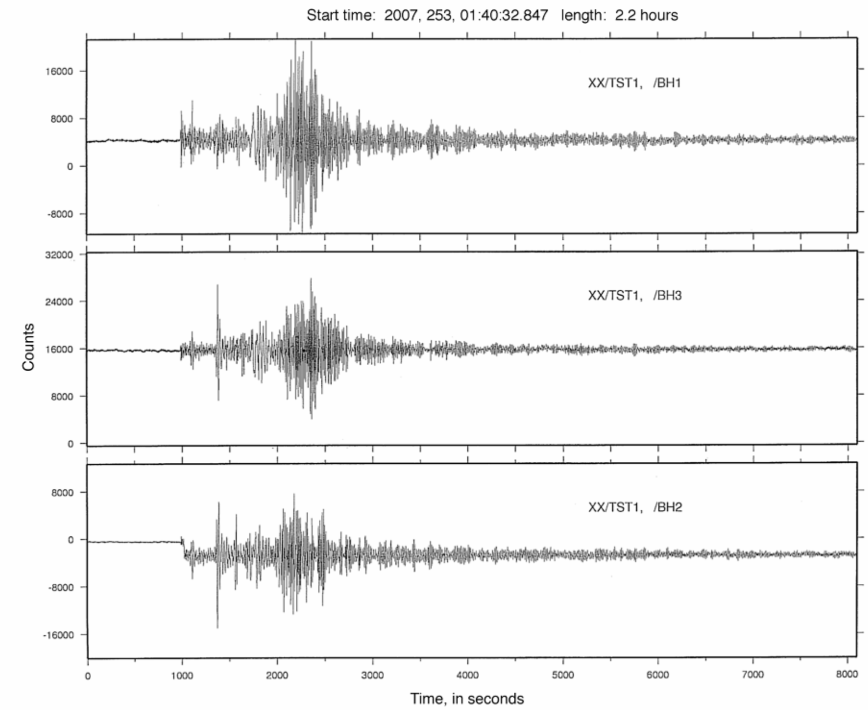


Figure 8. VSE–355G3 recording of magnitude 6.8 Colombia earthquake.

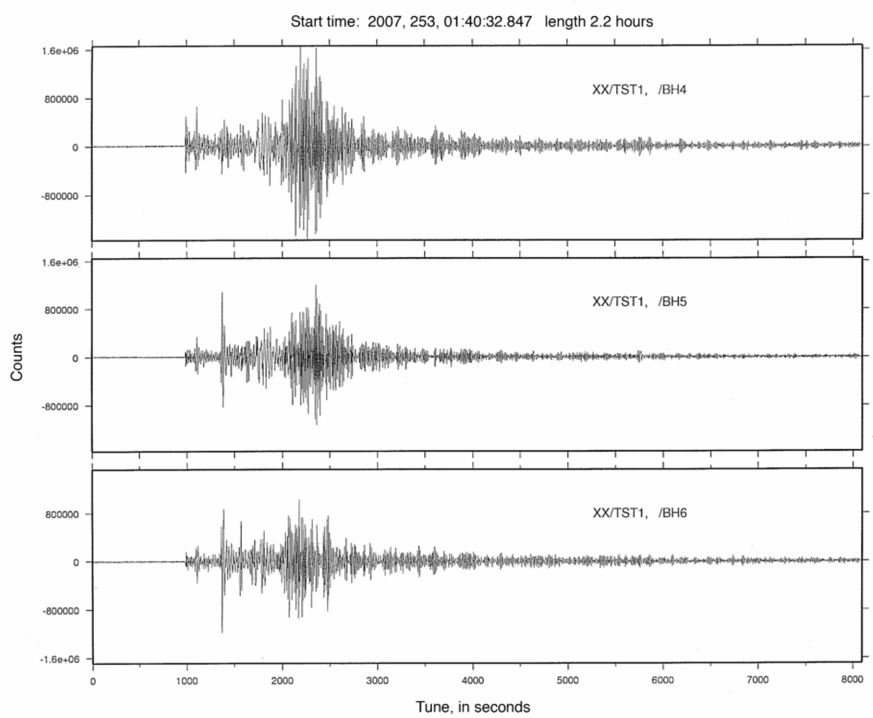


Figure 9. STS–2 recording of magnitude 6.8 Colombia earthquake.

Figure 8 and Figure 9 show unfiltered BH (40 sps) channels for a magnitude 6.8 earthquake near Colombia. Figure 8 shows channels BH1, BH3, and BH2, which are the Z, N, and E directions from the VSE–355G3 instrument. Figure 9 shows channels BH4, BH5, and BH6, which are the Z, N, and E directions from the STS–2. Note the offset in the East component (BH2 channel) of the VSE–355G3 instrument near the beginning of the earthquake signal. Before this offset, the sensitivity of the BH2 channel (VSE–355G3 EW component) was one–half what it should have been, perhaps due to a bad connection (probably external to the instrument) causing half of the balanced output of the instrument to be missing. The PSD plots of this earthquake shown in Figure 10, Figure 11, and Figure 12 are for the time period beginning just after the offset.

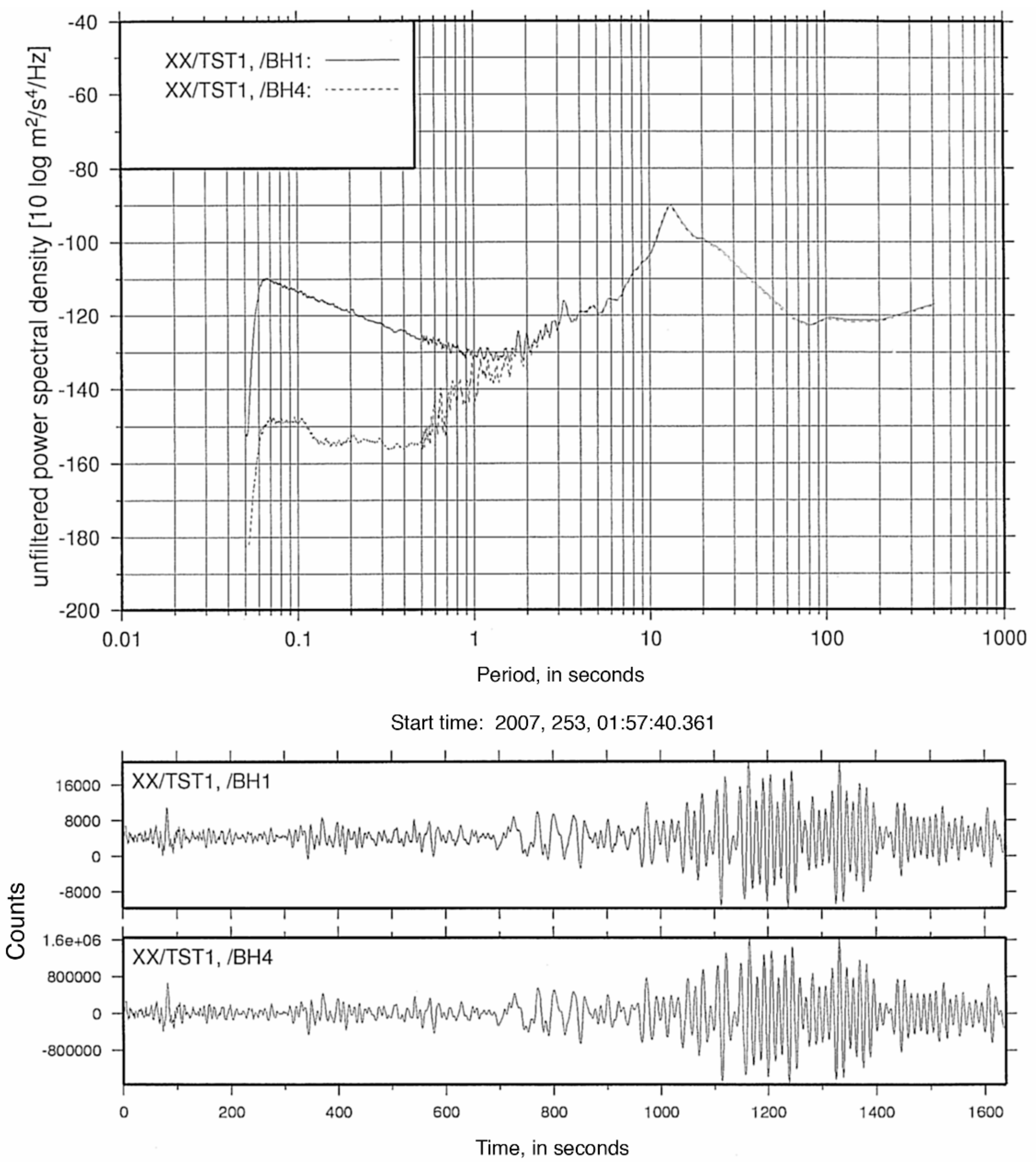


Figure 10. Vertical PSDs and waveforms for magnitude 6.8 Colombia earthquake.

Figure 10 shows vertical PSDs and waveforms for the M6.8 Colombia quake. Channel BH1 (solid line in the PSD plot) is the VSE–355G3, channel BH4 (dashed line in the PSD plot) is the STS–2. PSDs overlay for periods longer than 1 second, indicating that the VSE–355G3 indeed has a flat response to velocity nearly identical to the STS–2 response. The waveforms appear to be identical.

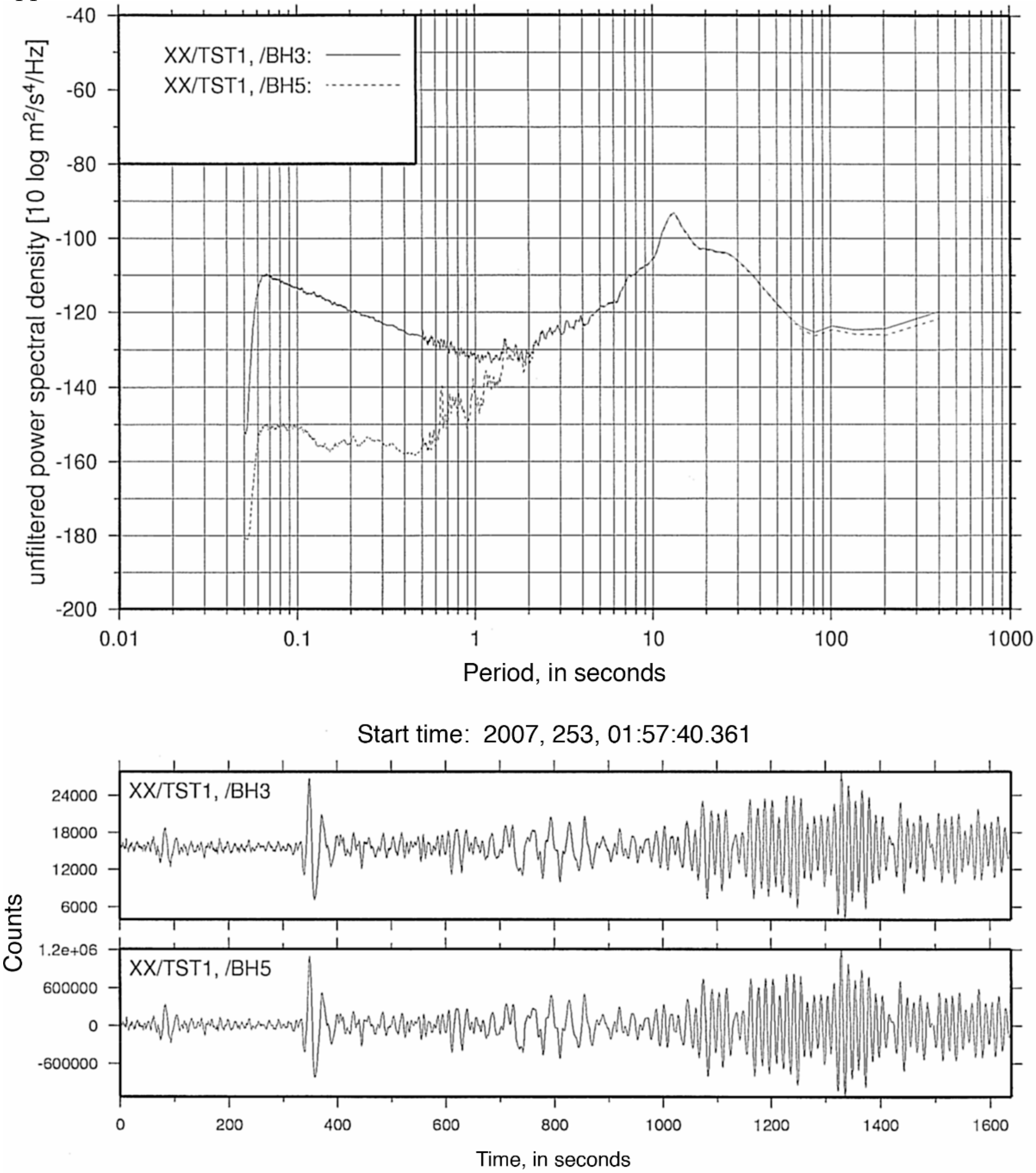


Figure 11. North–South PSDs and waveforms for magnitude 6.8 Colombia earthquake.

Figure 11 shows North–South PSDs and waveforms for the M6.8 Colombia quake. Channel BH3 (solid line in the PSD plot) is the VSE–355G3, channel BH5 (dashed line in the PSD plot) is the STS–2. PSDs overlay for periods longer than about 1.5 seconds, and waveforms appear to be identical.

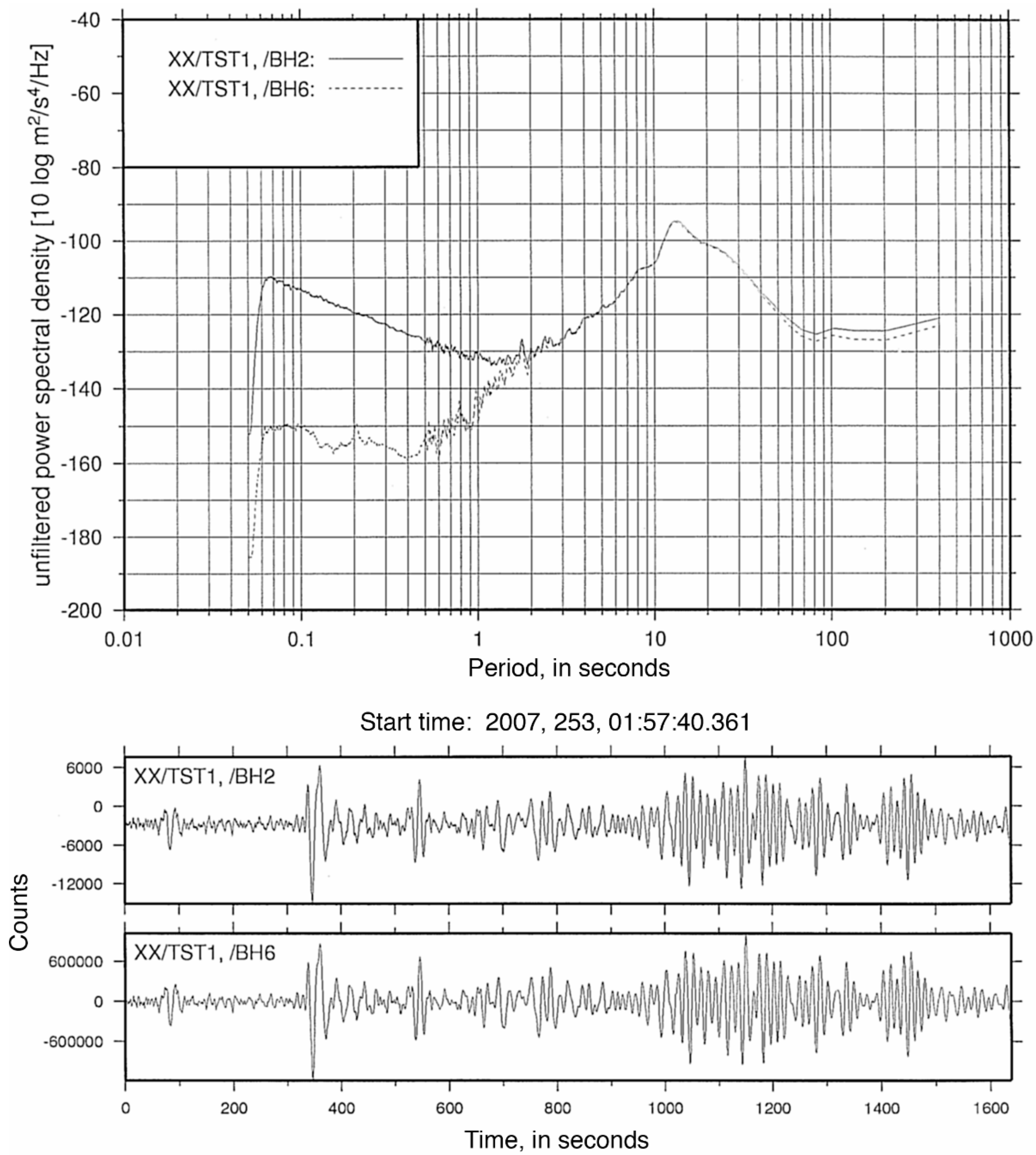


Figure 12. East–West PSDs and waveforms for magnitude 6.8 Colombia earthquake.

Figure 12 shows East–West PSDs and waveforms for the M6.8 Colombia quake. Channel BH2 is the VSE–355G3, channel BH6 is the STS–2. PSDs overlay for periods of about 1.5 to 50 s. Channel BH2 (solid line in the PSD plot) is the VSE–355G3, channel BH6 (dashed line in the PSD plot) is the STS–2. PSDs overlay for periods longer than about 1.5 seconds, and waveforms appear to be identical.

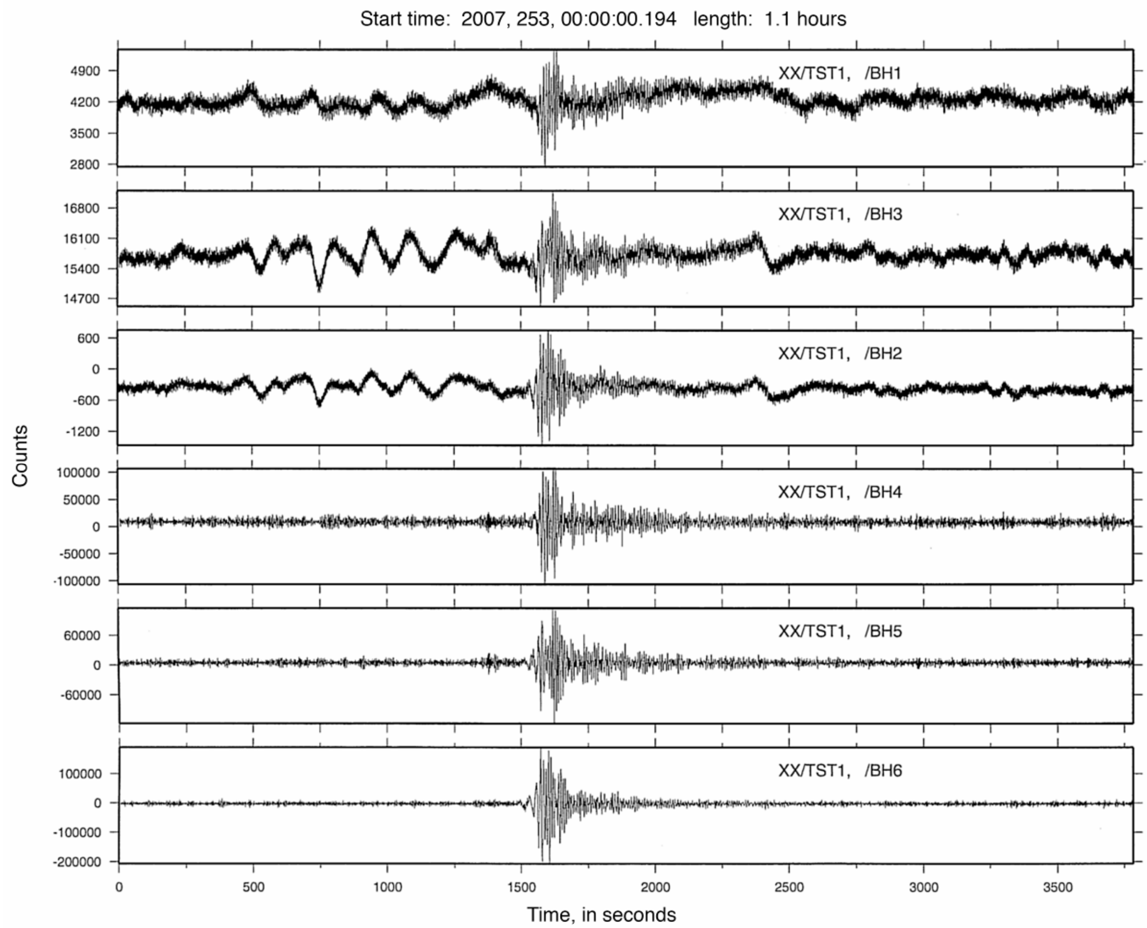


Figure 13. Recordings of magnitude 5.4 Bolivia earthquake.

Figure 13 shows unfiltered BH (40 sps) channels for magnitude 5.4 earthquake near La Paz, Bolivia. Channels BH1, BH3, and BH2 are the Z, N, and E directions from the VSE–355G3 instrument. Channels BH4, BH5, and BH6 are the Z, N, and E directions from the STS–2. The signal from this smaller event is very near the noise level of the VSE–355G3. Each of the six panels in this plot is scaled so that the largest signal is full scale within the panel.

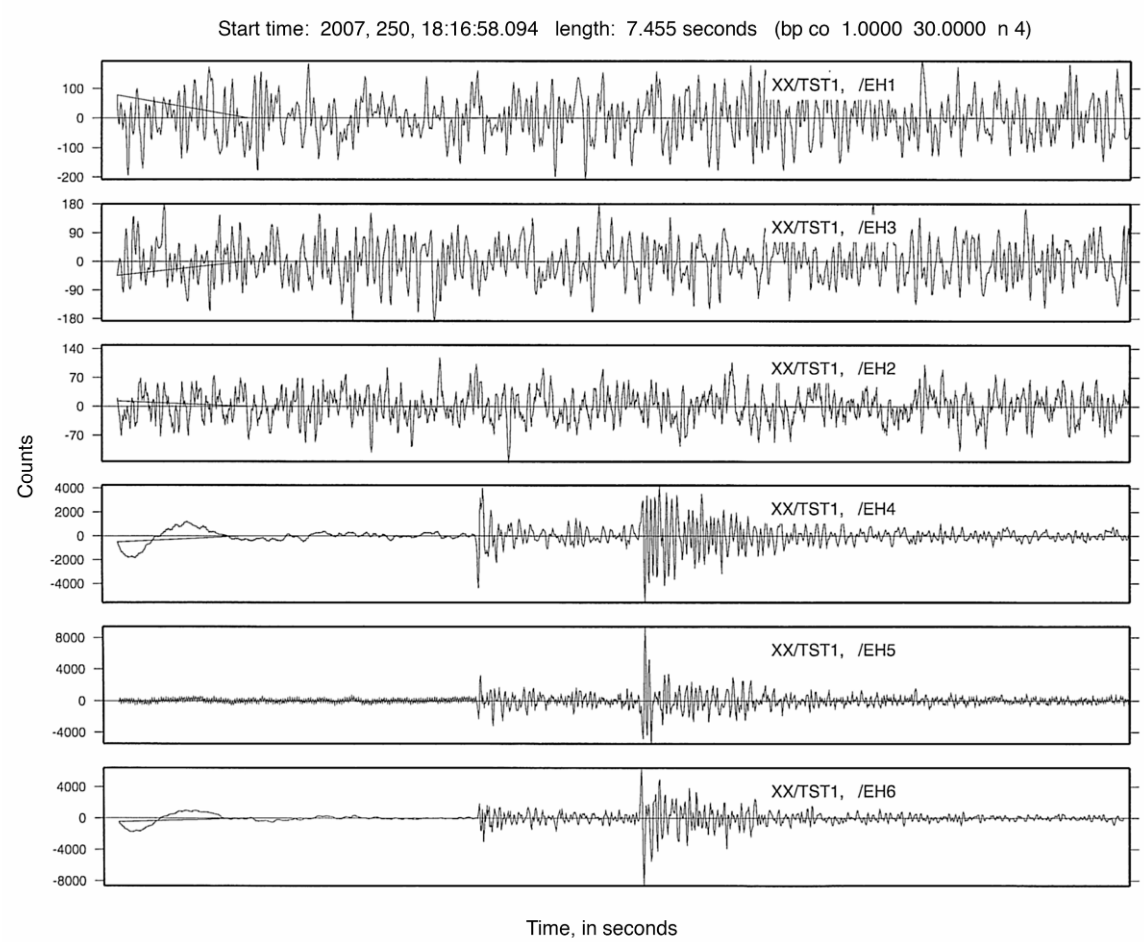


Figure 14. Recordings of very small local earthquake.

Figure 14 shows band–pass filtered (1 Hz to 30 Hz) 200–sps data from a very small local high–frequency event, magnitude unknown. Channels EH1, EH3, and EH2 are the Z, N, and E components of the VSE–355G3. Channels EH4, EH5, and EH6 are the Z, N, and E components of the STS–2. The noise level of the VSE–355G3 is higher than the signal of this local event. The length of the plot is 7.455 seconds. (Background straight–line segments are the result of a plotting program error.) Each of the six panels in this plot is scaled so that the largest signal is full scale within the panel.

3.3 Shake Table Tests

For the shake table tests, data were recorded on the XX/TST3 data logger at 200 sps. For tests on the ASL shake table, which necessarily involve large motions, the preamp gains of the XX/TST3 Q330HR data logger were set to 1× to avoid clipping.

3.3.1 Square Waves of Known Displacement Amplitude

The VSE–355G3 instrument was mounted on a Rockwell/Anorad horizontal positioning stage (horizontal shake table) for step and sine wave testing (Figure 15). It was driven first along its X axis and then its Y axis through accurately known displacement steps of 400 mm of alternating sign. The step drive parameters were set as follows:

Displacement: 400 mm
Maximum Velocity: 400 mm/s
Maximum Acceleration: 20,000 mm/s/s (approximately 2 g)
Maximum Jerk (first time derivative of acceleration): 350,000 mm/s/s/s

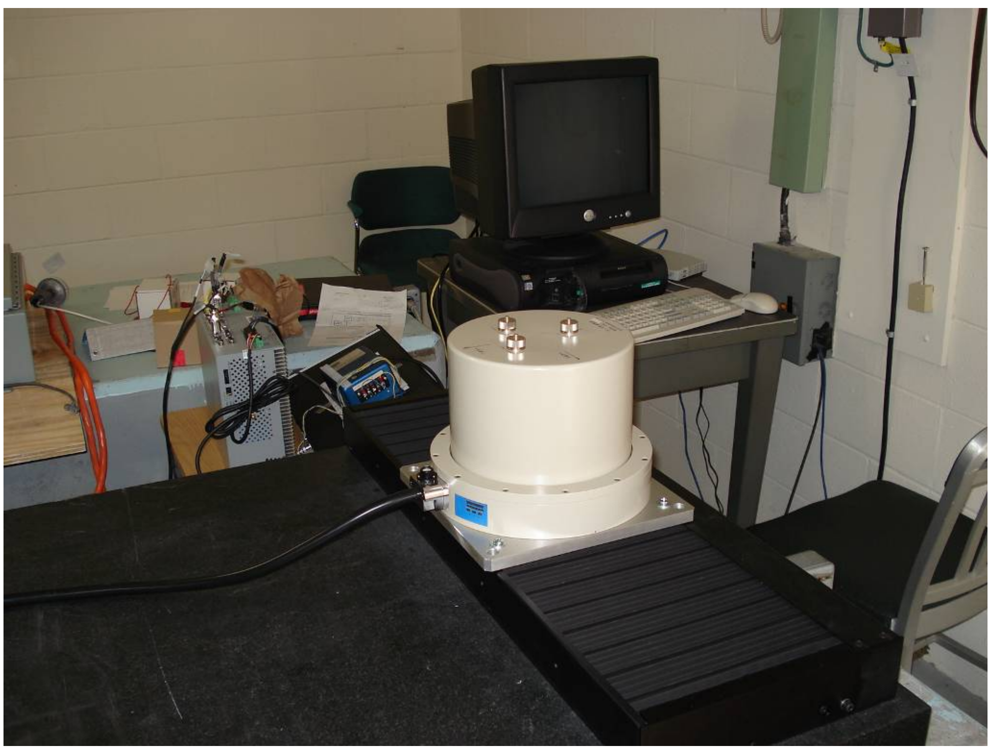


Figure 15. VSE–355G3 mounted on ASL horizontal shake table.

Figure 15 shows the VSE–355G3 mounted on ASL horizontal shake table (Anorad linear positioning stage), with driver electronics and control computer in background.

The resulting waveform for the X–axis output appeared as in Figure 16 and Figure 17.

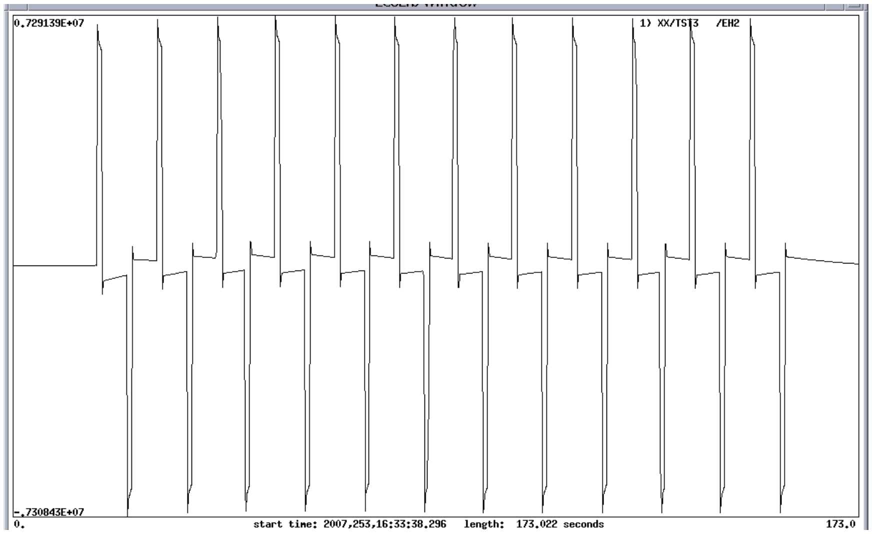


Figure 16. X–axis output from VSE–355G3 on shake table.

Figure 16 shows the X–axis output from the VSE–355G3 when driven along X–axis with 400 mm amplitude steps of alternating direction.

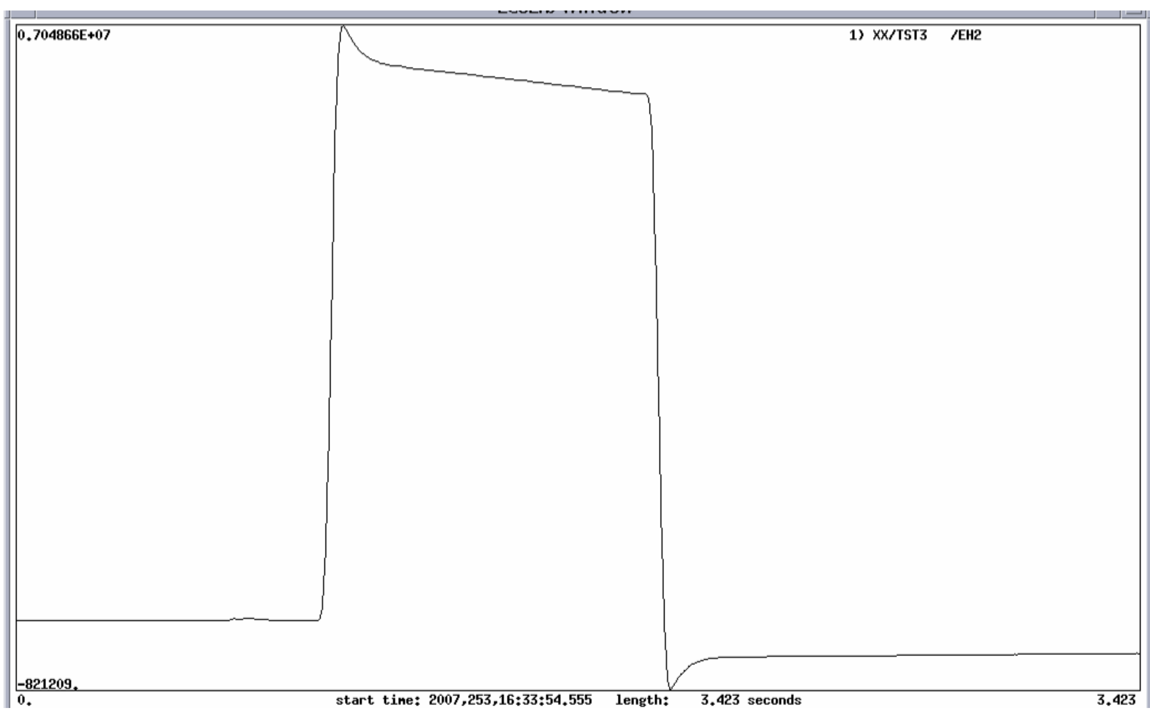


Figure 17. Zoom view of one pulse from Figure 16.

Figure 17 is a zoom view of recorded velocity during one 400 mm step from Figure 16. The rise time of the signal is 74 milliseconds. The time from the peak of the overshoot to the point where it is decaying approximately linearly due to the low–frequency corner of the passband is about 100 milliseconds. The peak input velocity during this step was about 400 mm/s. The peak output seen in this plot corresponds to about 4.2 V, or 21 percent of the advertised clip level.

When these velocity signals are integrated to estimate displacement (without correction for the lower corner at 0.008 Hz), reasonable waveforms are recovered. Nevertheless, the effects of the low–cut filter are readily apparent (Figure 18a,c). Derived displacement amplitudes are about 396 and 397 mm for those two traces. These values are smaller than the true input displacements by about 1.0 and 0.8 percent of full scale. When that lower corner is deconvolved, assuming a corner at about 120 seconds period, the waveforms match the input displacement traces very closely (Figure 18b,d). Derived displacements are now about 396 and 399 mm for the two traces shown in Figure 18b,d, or 1.0 and 0.2 percent of full scale — accuracy surpassing most absolute calibrations. The high fidelity of the displacement trace relative to the known waveform implies a linear response across the excited frequency and amplitude ranges.

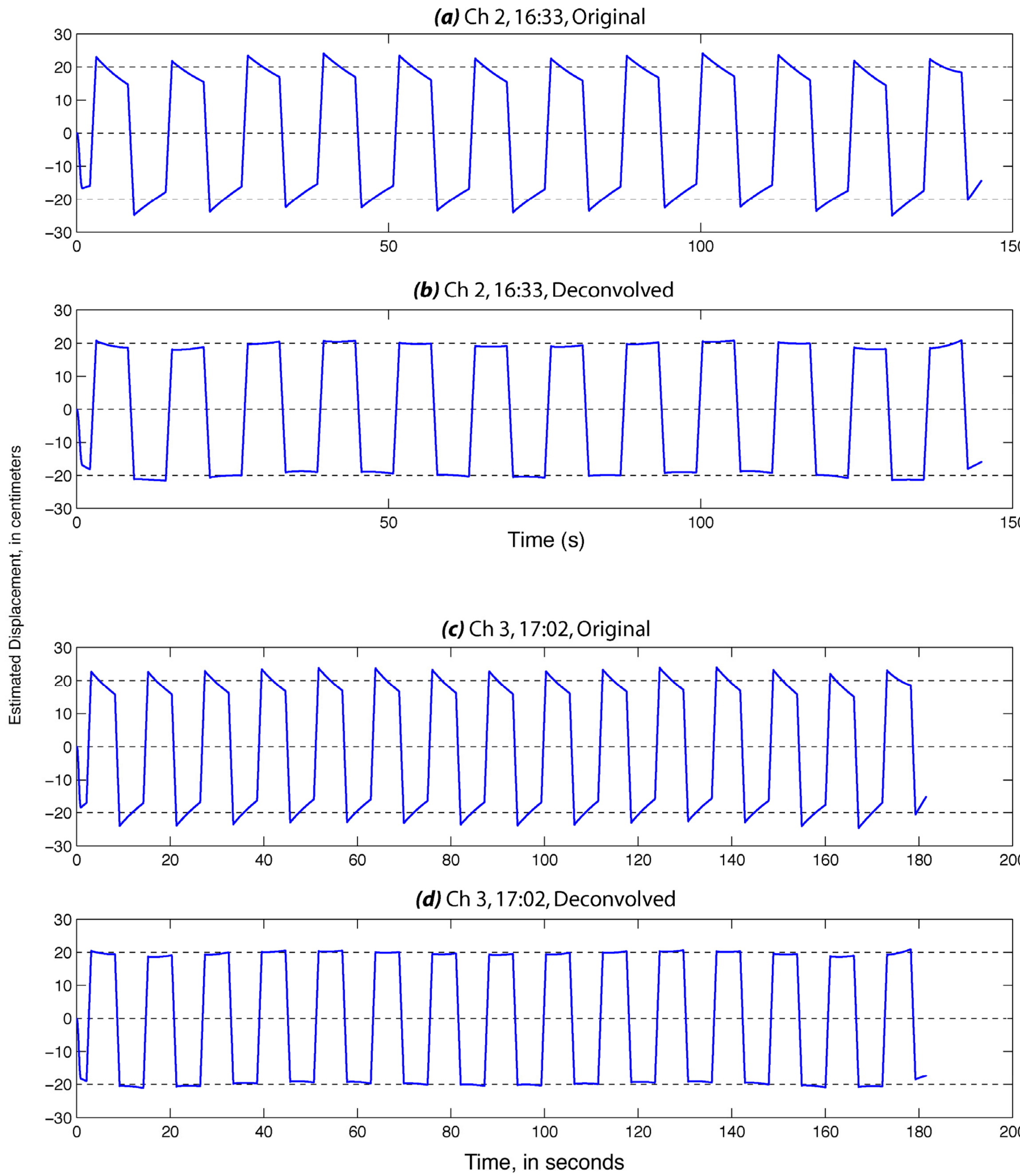


Figure 18. Displacement waveforms recovered by integration.

Figure 18 shows displacement waveforms recovered from horizontal components of the VSE–335G3 excited by a horizontal shake table. The original waveforms were band–limited displacement square waves of 400 mm peak–to–peak amplitude. (a) and (b) are the same record, with (a) not corrected for instrument response and (b) corrected (the 120–second low–cut corner removed). (c) and (d) are a similar pair for the other horizontal axis. Waveforms and amplitudes of the corrected traces, (b) and (d), are accurate renditions of the input displacement waveforms.

3.3.2 Frequency Response Using Sine Waves of Constant Velocity

Both the X–axis and the Y–axis of the VSE–355G3 were driven with sine waves of approximately constant velocity. The resulting responses as a function of frequency are plotted in Figure 19 and Figure 20. The input velocities produced by the horizontal shake table were determined using a display provided with the control software, resulting in an estimated overall accuracy of about ±3%.

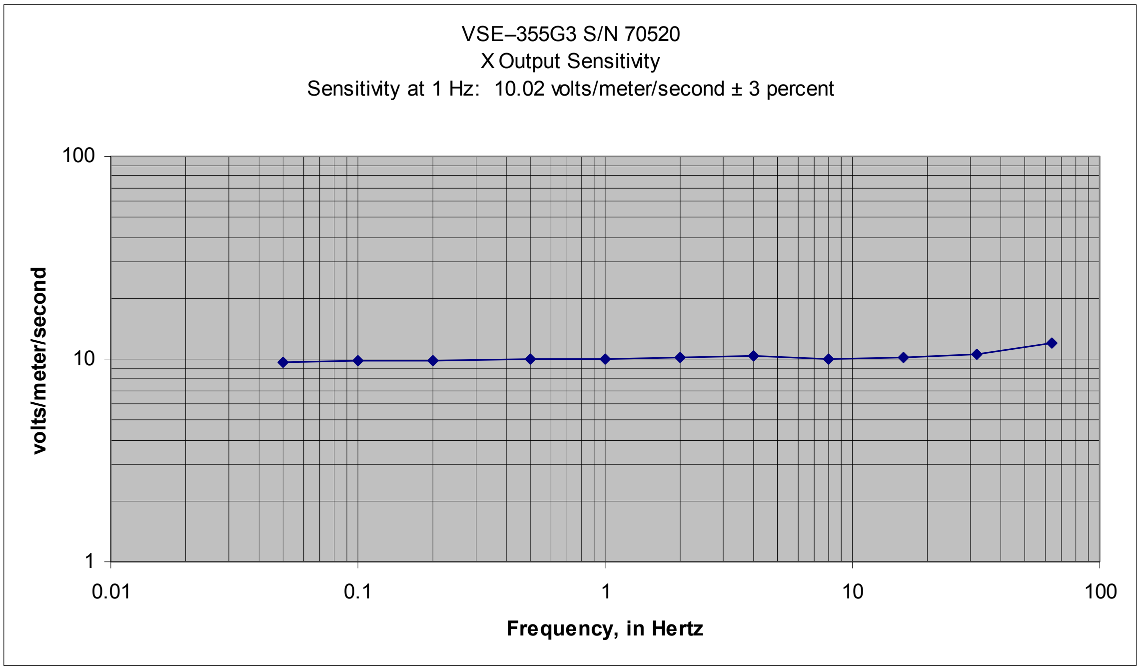


Figure 19. X output sensitivity.

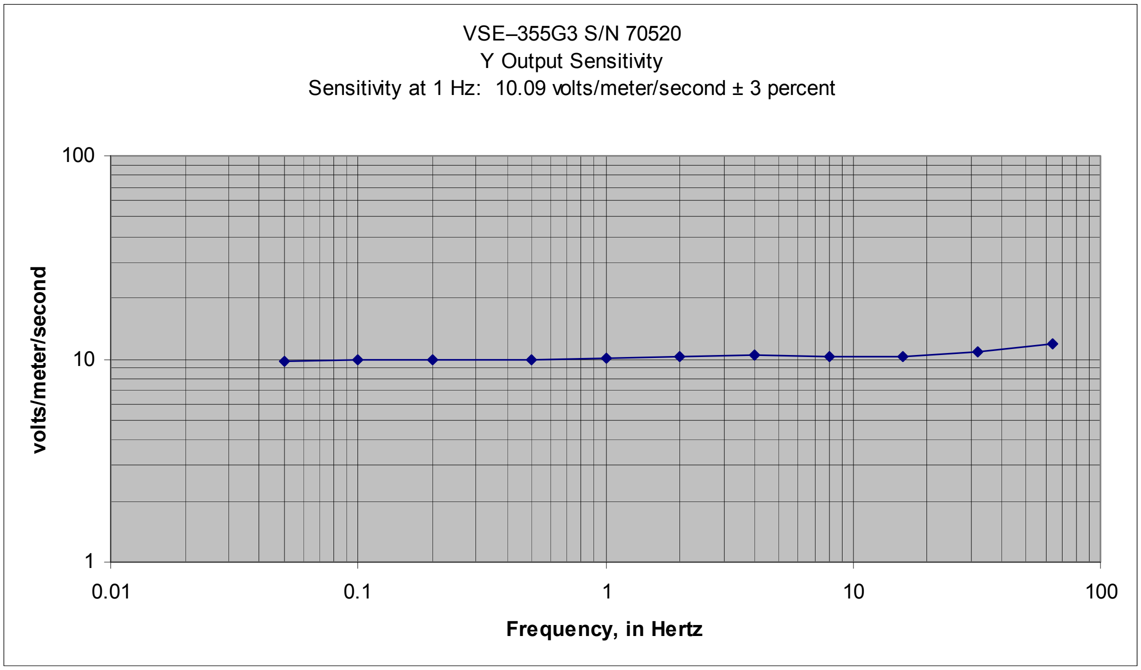


Figure 20. Y output sensitivity.

3.4 Temperature Test

The VSE–355G3 instrument was placed in a thermal test chamber and soaked at three temperatures across its specified operational range. All three velocity outputs and the vertical mass position were monitored during the test (horizontal mass positions were not meaningful due to tilt of the chamber floor during the test). At all test temperatures, the instrument appeared to be operating normally. Although the specifications indicate that the upper temperature limit is +70 °C, the manufacturer advised that it is not a good idea to operate the instrument at +70 °C for extended periods of time. We therefore tested the instrument at -30 °C, +25 °C, and +50 °C. Table 3 lists the vertical mass position as a function of temperature. Note that the room temperature mass position had not been adjusted to zero before the test, and, in fact, had inadvertently been offset from zero due to a misunderstanding on the part of ASL personnel in the use of the vertical mass lock screw when the instrument was removed from the underground tunnel.

Table 3. Vertical mass position as a function of temperature.

Temperature	Vertical Mass Position
-30 °C	+7.6 volts
+25 °C	+7.1 volts
+50 °C	+6.4 volts

4 Summary

The VSE–355G3 strong-motion instrument was subjected to a limited range of tests at the USGS Albuquerque Seismological Laboratory, including:

- Self-noise level compared to STS–2 in underground tunnel.
- Comparison of signals from earthquakes.
- Shake Table Tests:
    - Square waves of known displacement amplitude
    - Frequency response using sine waves of constant velocity
- Temperature test

The instrument met all of the published specifications that correspond to these tests. In addition, the square wave input test resulted in driving the instrument to about 21 percent of its advertised clip level of 2 m/s. It responded in an apparently linear fashion to this large input. Overall, the instrument was easy to use and performed well.

On the test instrument, the cable is wired directly into the instrument with no connector at that interface, making replacement of the cable difficult. We understand that the manufacturer intends to change this design in favor of a removable cable with connector. Also, on the test instrument, there are four leveling screws instead of three, which makes it more difficult to level the instrument than it would be with three leveling screws. It is our understanding that the standard design for production units is three leveling screws, which we believe is a much better arrangement.

5 Strong Motion Velocity Meter vs. Accelerometer

Recent studies have considered the tradeoffs between measuring strong motion velocity versus acceleration. For example, John Clinton states in his PhD thesis (2004):

“A velocity meter has the advantage of increased sensitivity at low frequencies, so more teleseismic and regional events can be recorded – this is especially useful if the station is operated in continuous mode, as these motions would fail to trigger a triggered setup. Transient displacement estimates are more stable as only a single integration is required to obtain displacement with frequencies above 0.0125 Hz. Accelerometers, however, have the advantages of being cheaper, smaller, lighter and easier to calibrate.”

Although it is usually better to integrate only once (velocity to displacement) instead of twice (acceleration to displacement), the quality of the result ultimately depends on the linearity of the seismometer. That is, integrating the output of a non–linear velocity seismometer may not be better than integrating the output of a high quality accelerometer twice (T. Heaton, written personal communication). That being said, however, the results in Figure 18 seem to indicate that the VSE–355G3 velocity sensor is very linear. Probably the most common source of instability in deriving displacement data from horizontal seismic data is unknown tilts (T. Heaton and J. Clinton, written personal communication).

References:

Clinton, J. F., 2004, Modern digital seismology—instrumentation, and small amplitude studies in the engineering world, http://resolver.caltech.edu/CaltechETD:etd–05202004–225044, accessed June 2008.

Peterson, Jon, 1993, Observations and modeling of seismic background noise: USGS Open–File Report 93–322.

6 Appendix:

Operation Manual for the VSE–355G3 Servo Velocity Meter

Servo Velocity Meter

(VSE-355G3)

Operation Manual

TOKYO SOKUSHIN CO., LTD.

OFFICE: 3-14-34, OUGI, ADACHI-KU,
TOKYO, 123−0873 JAPAN

PHONE:03-3855-5911 FAX:03-3855-5921

Contents

[1] Outline

This is high precision velocity meter developed on the basis of servo technology. In addition to the direct detection of velocity, it also detects acceleration at the same time. The velocity meter has a built-in calibration coil, which is used for the calibration of sensitivity and other characteristics of the system (sensor and recorder).

[2] Specifications

Model	VSE-355G3 (Ground surface type)
Frequency range	0.008～70Hz
Mode of operation	Tri-axial
Max. measuring range	±2m/s、±2000gal
Sensitivity	5 V／m/s×2
Output resistance	Less than 510 Ohm
Max. Output voltage	±20V (Balanced output)
Linearity	0.03% of Full scale
Resolution	10^{-6}gal
Damping ratio	h =approximately 10000%
Calibration coil	・Sensitivity : 15μA／gal ・Coil resistance : 700Ω (±20%)
Power requirements	±15VDC ±3%
Current consumption	Approximately ±90mA
Linearity	Less than 0.03%
Cross axis sensitivity	0.03G／G
Sensitivity of temperature coefficient	0.01%／℃
Temperature coefficient of zero-shift	0.05%／℃
Arrester	Voltage 30V、Current 5KV、100A
Temperature range	−30℃～70℃
Connect cable	Shielded 10 pair twist cable
Allowable shock	30G (less than 0.1Sec)

Dimension	ground surface type 330×330 [mm]
Case	watertight 1kg／c ㎡ (ground surface type)
Extension Cable	5.47 yards (5m)

[3] Operation

3-1) Connection

This velocity meter needs the external power of ±15V DC (±3%).
The cable assignment is as follows:

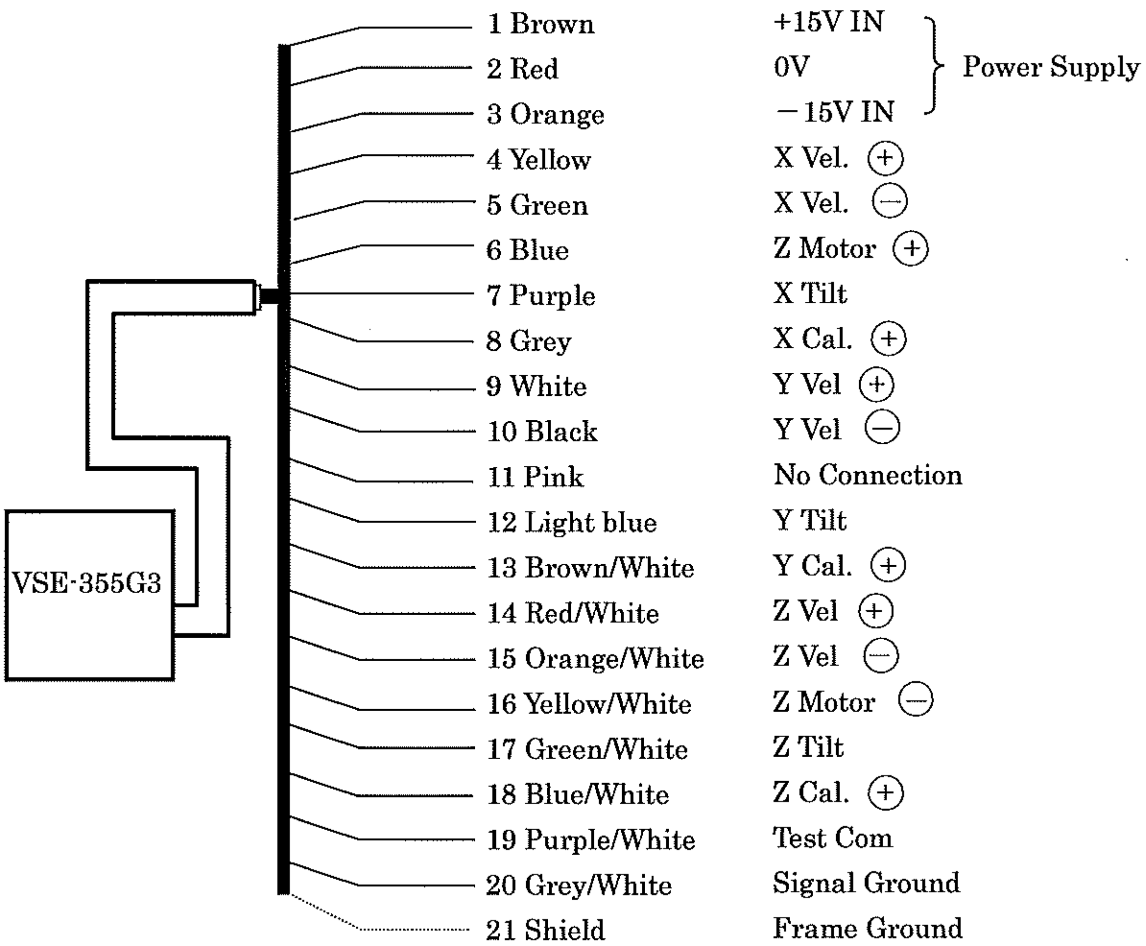


Figure 1. Cable assignment

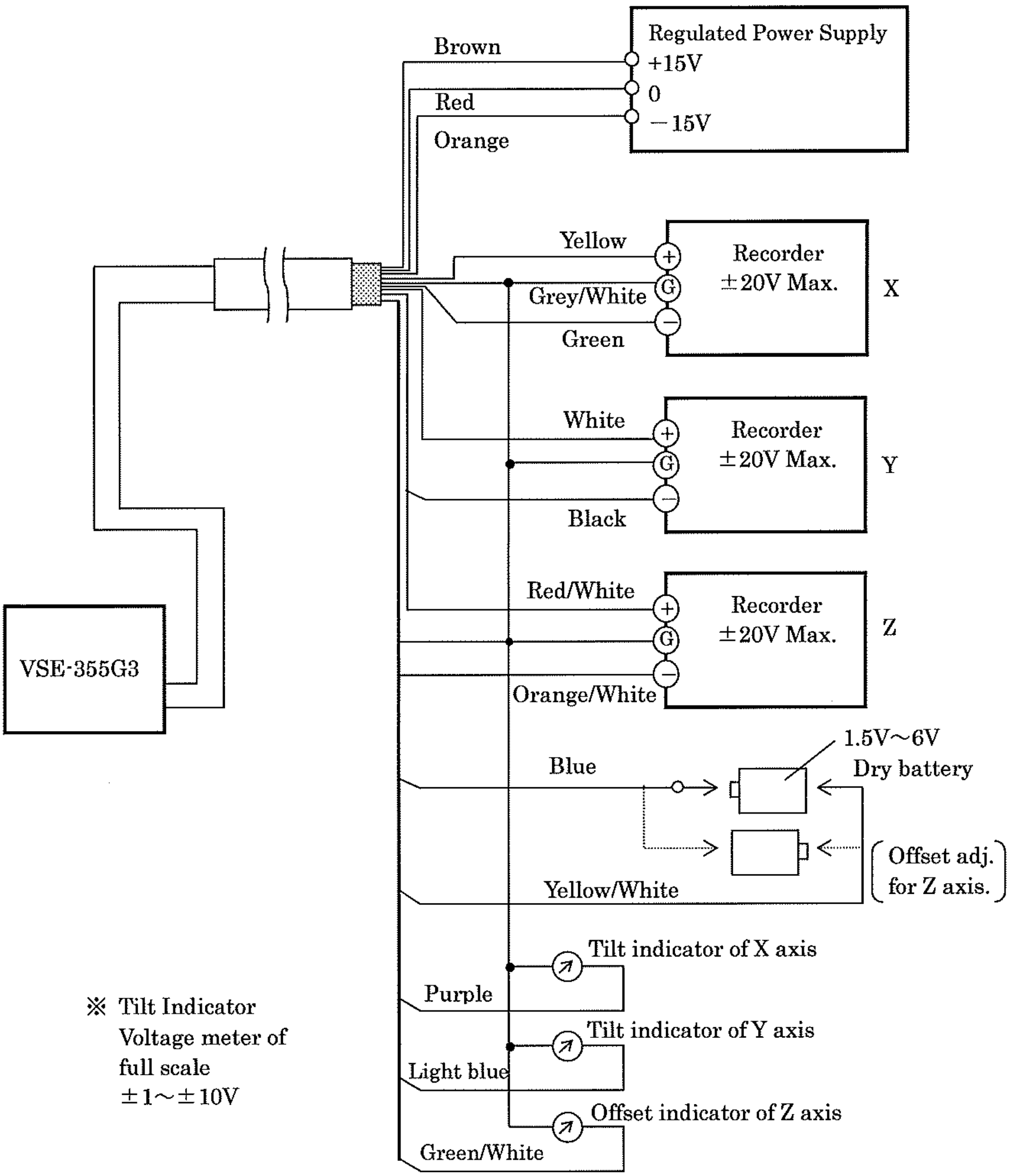


Figure 2 Wiring Diagram

※Stability of external power should be less than ±3%.
Current consumption is approximately 90mA.
※Input impedance of the recorder must be 100KΩ minimum.

3-2) Leveling and Polarity

The velocity meter is to set to keep the horizontal and the direction as specified.
The arrow in Figure 3 shows the polarity of the sensor.

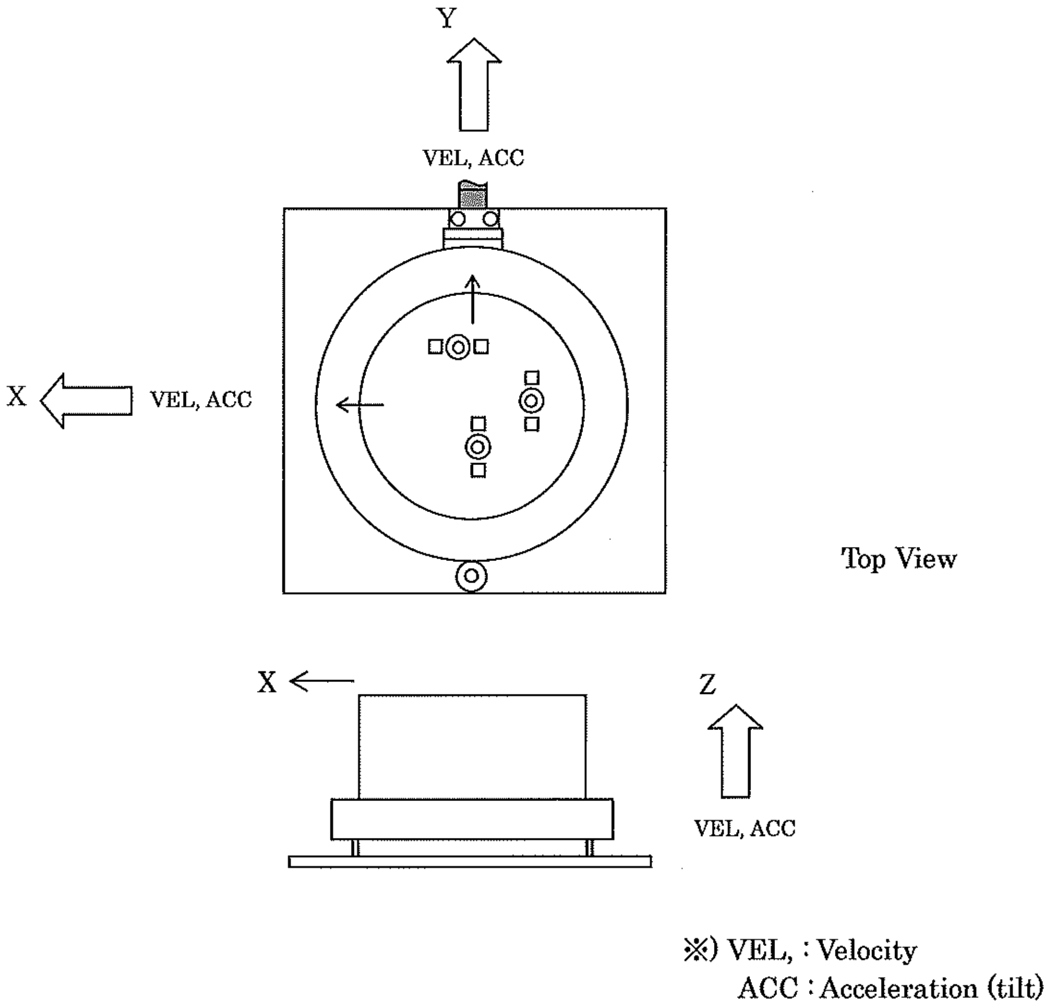


Figure 3 Polarity

Level adjustment

※If X axis tilt indicator shows(+) in the offset voltage, put X(+)position down slowly to indicate offset voltage is zero. (Same as Y axis)

※If Z axis tilt indicator shows(+) in the offset voltage, contact the dry battery (1.5～6V) of (+)to Z motor (−) (Yellow/White), and Z motor(+) (Blue) is connected to (−) of dry battery.

3-3) Installation

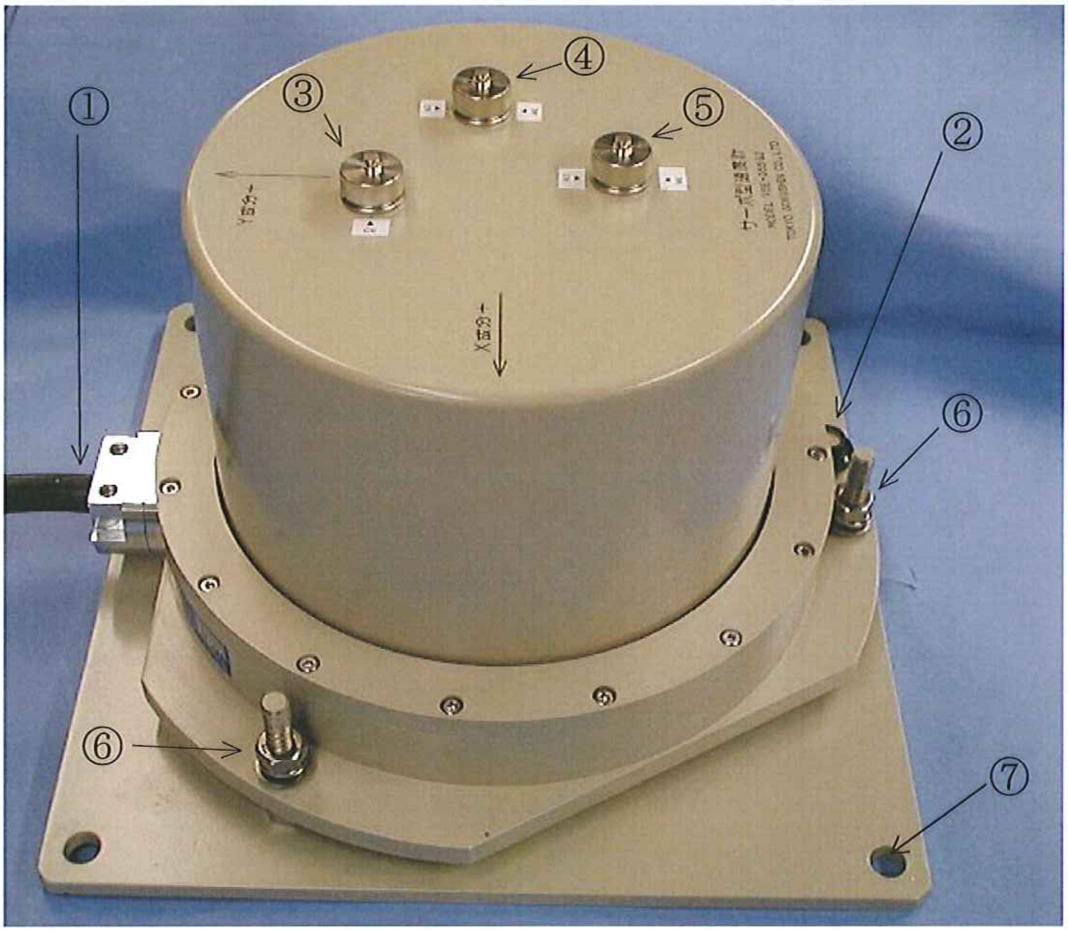


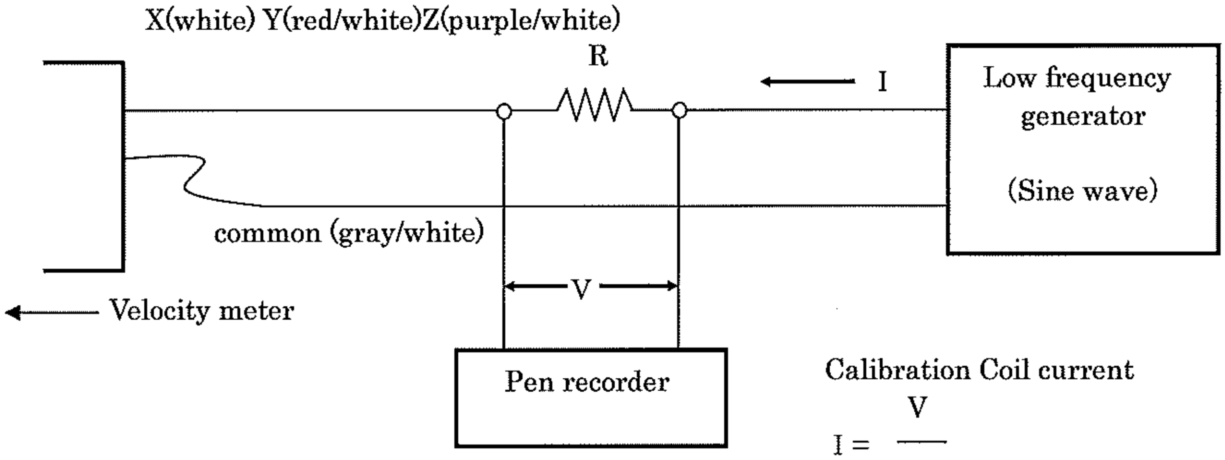
Figure 4　Outside view

①Output Cable	Refer to Cable assignment table.
②Eyehole for level	Indicate the horizontal level of sensor.
③X cramp ④Y cramp ⑤Z cramp	Remove the each cap of X, Y, Z components. Adjust the each nob to "measure" from "cramp" in time of measure, and tighten each cap as before.
⑥Level screw	Adjust the horizontal level of the sensor.
⑦Set screw hole	Fix this sensor on the concrete base with M10(ϕ 10mm) hole-in-anchores.

3-4) Calibration Coil

You can check the sensitivity and frequency characteristics of this device by running a constant level of current (not voltage) through the calibration coil.
15 μA current run in the calibration coil is equivalent to 1gal vibration, which generates a signal output. Connection is shown in Figure 5.

Other signal lines are same as Figure 2.



Calibration Coil current

$$I = \frac{V}{R}$$

Usually, R is resistance of 1KΩ～10KΩ

Figure 5 Calibration Coil

To obtain current I in the calibratin coil, voltage V across the ends of resistance R is measured with a pen recorder, and calculated by equation I= V/R. (Use a precision resistance with maximum error 0.5%.) To obtain sensitivity at each frequency, vary the frequency of the low frequency generator in the 0.05Hz to 100Hz range.
It should be noted that the velocity output will fluctuate even if the current in the calibration coil is constant, when the input frequency varies.

$$\text{Velocity output} = \frac{\text{Calibration coil current}}{2\pi f}$$

f=generator frequency (Hz)

For this reason, you must read exactly the generator frequency.

[4] Caution for Handling

4-1) Stabilization Time

When you move the unit or switch on the power, signal output may fluctuate significantly and it may take approximately 1 minute before the unit functions normally. This is because the sensor part of this device is affected by the acceleration of the gravity, especially by the vertical direction of vibration, so it takes time to be stable. To minimize the noise level, it sometime takes 1 week for horizontal component, and 2 weeks for vertical component.

4-2) Do Not Give a Shock or Disassemble

All internal components are precision parts, which may be damaged by the shocks. Handle the unit carefully. The capacitor type detector built in the unit has an airtight structure, and the constants may be changed or malfunction may occur when the detector is disassembled.
Caution: Our warranty may not apply when the device is disassembled by the costomer.

4-3) Be Careful of Polarity and Voltage Level When Connecting the Unit to Power Supply.

Inverse connection of polarity (⊕, ⊖) and application of excessive voltage above ±18V will damage the unit. Check to be sure that the supply voltage is ±15V(±3%).

[5] Sensitivity and Other Characteristic

5-1) Sensitivity

Velocity : 5.0V/m/s×2
Acceleration : 50V/m/s^2 (8.55V/degree)

It has the following frequency characteristics.

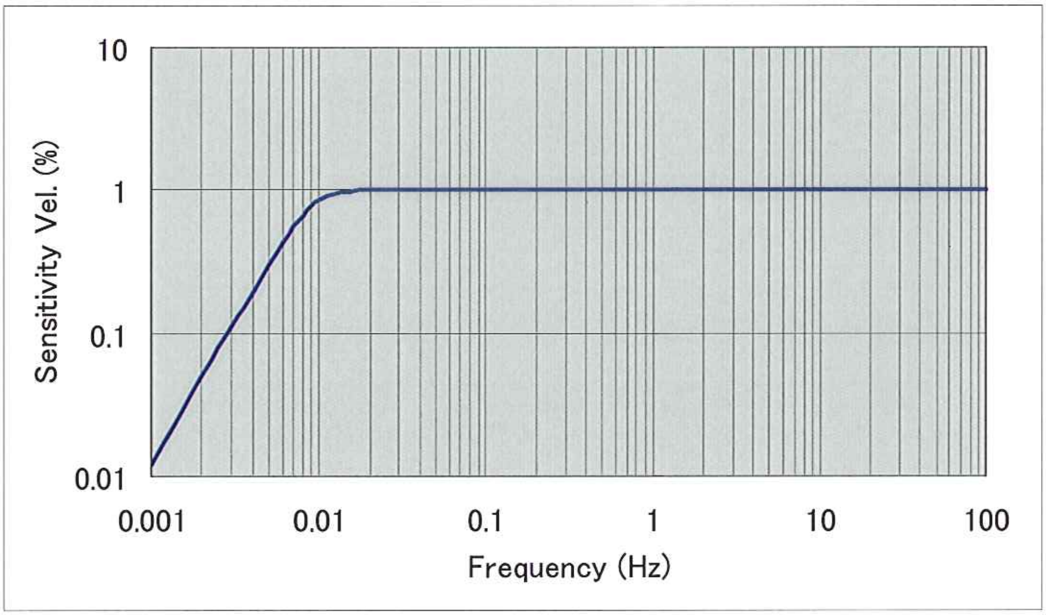


Figure 6 Frequency response of Velocity

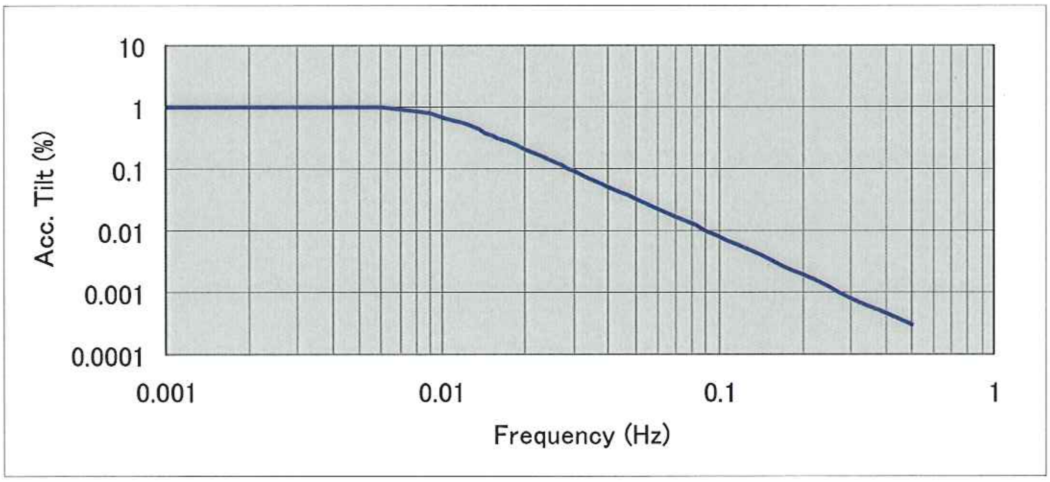


Figure 7 Frequency response of Acceleration (Tilt)

Where,

m	:	mass of pendulum
Ra・Rf	:	precision fixed resistance
Cf	:	precision capacitor
G	:	generated constant of electro-magnetic circuit

All of them are stable material constants that are hardly affected by temperature change, and scale factor (α) of the displacement transducer, as well as gain of amplifier (A), are totally irrelevent of sensor sensitivity.

Acc (Tilt)

$$Acc = \frac{Ev}{s \cdot y} \cdot \frac{1}{s} \cdot \frac{1}{s \cdot D \cdot C} \quad [V/gal]$$

$= 50\ [V/m/s^2] = 0.5\ [V/gal]$

$= 8.55\ [V/degree]$

[6] Transfer function of VSE-355G3

$$\frac{Ev}{s\cdot y}\,[m/s] = \frac{-a\cdot A\cdot s^2}{s^3+\left(\frac{G}{m}\cdot\frac{B\cdot K}{L}\cdot a\cdot A\right)s^2+\left(P+\frac{G}{m}\cdot\frac{K}{E\cdot L}\cdot a\cdot A\right)s+\frac{g}{m}\cdot\frac{1}{C\cdot D}\cdot\frac{1}{F}\cdot a\cdot A}\,[V/m/s] \cdots\cdots (1)\ \text{Velocity}$$

$$\frac{Av}{s^2\cdot y} = \frac{Ev}{s\cdot y}\cdot\frac{1}{s}\cdot\frac{1}{s\cdot D\cdot C}\ [V/m/s^2] \cdots\cdots\cdots\cdots (2)\ \text{Acc \& Tilt}$$

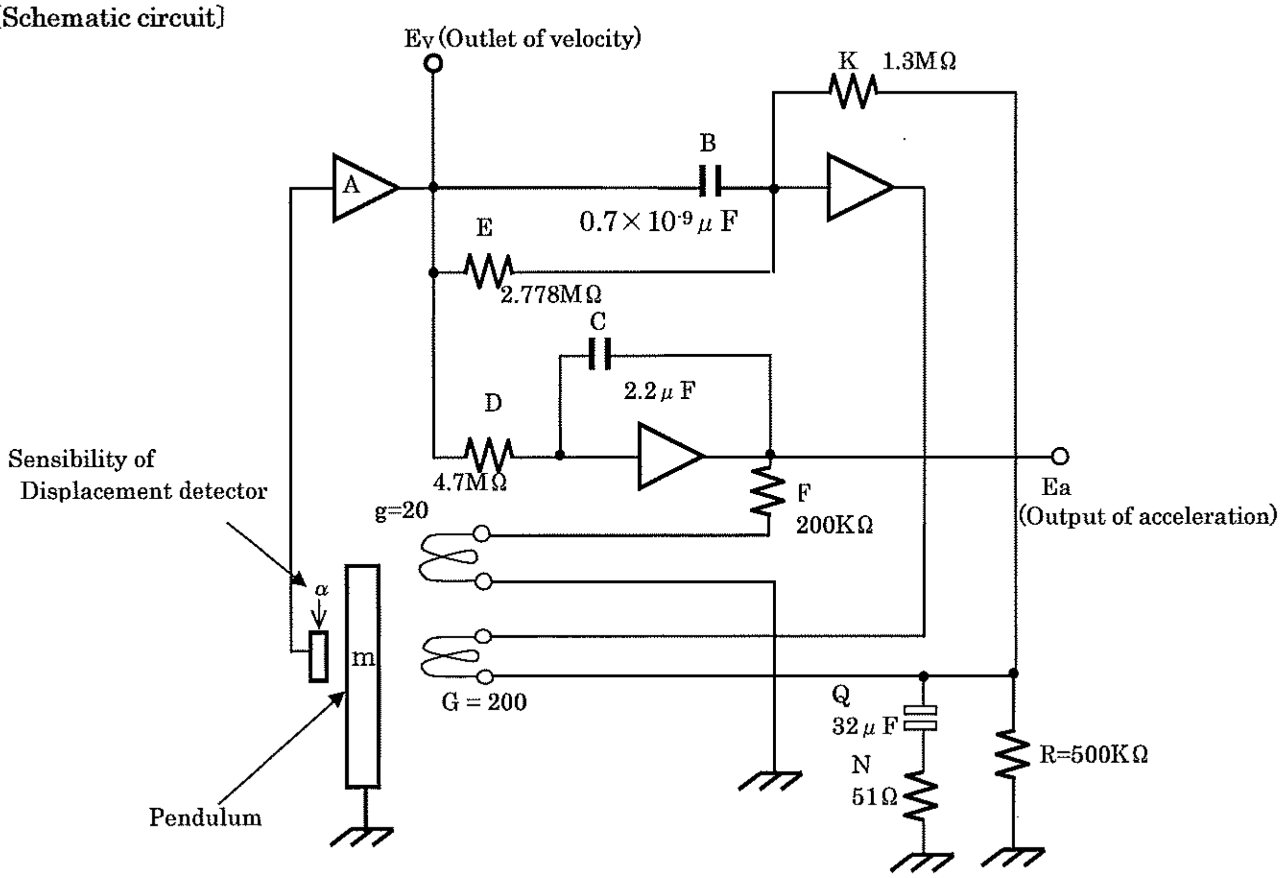
Where

$$L = \frac{R+s\cdot Q\cdot R\cdot N}{1+s\cdot Q\cdot(R+N)}$$

all constant value as follows, $s = j\cdot\omega = j\cdot 2\pi\cdot f$

$a\cdot A = 500\times10^3$ V/m	D = 4.7MΩ	m = 0.03kg
B = 0.7×10^{-3} μF	F = 200KΩ	$P = \omega^2 = 355$
C = 2.2μF	K = 1.3MΩ	G = 200
E = 2.778MΩ	N = 51Ω	g = 20

〔Schematic circuit〕



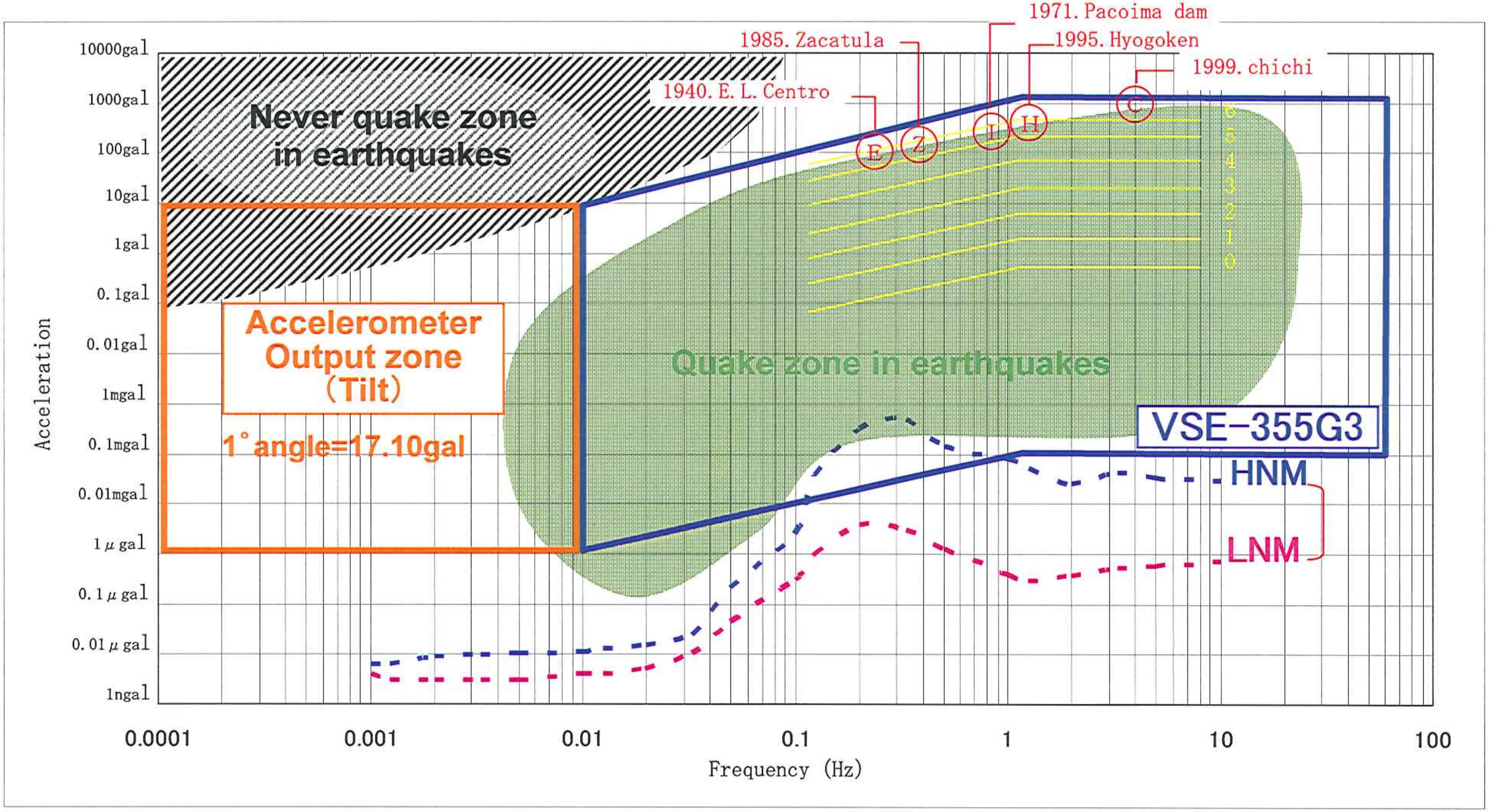
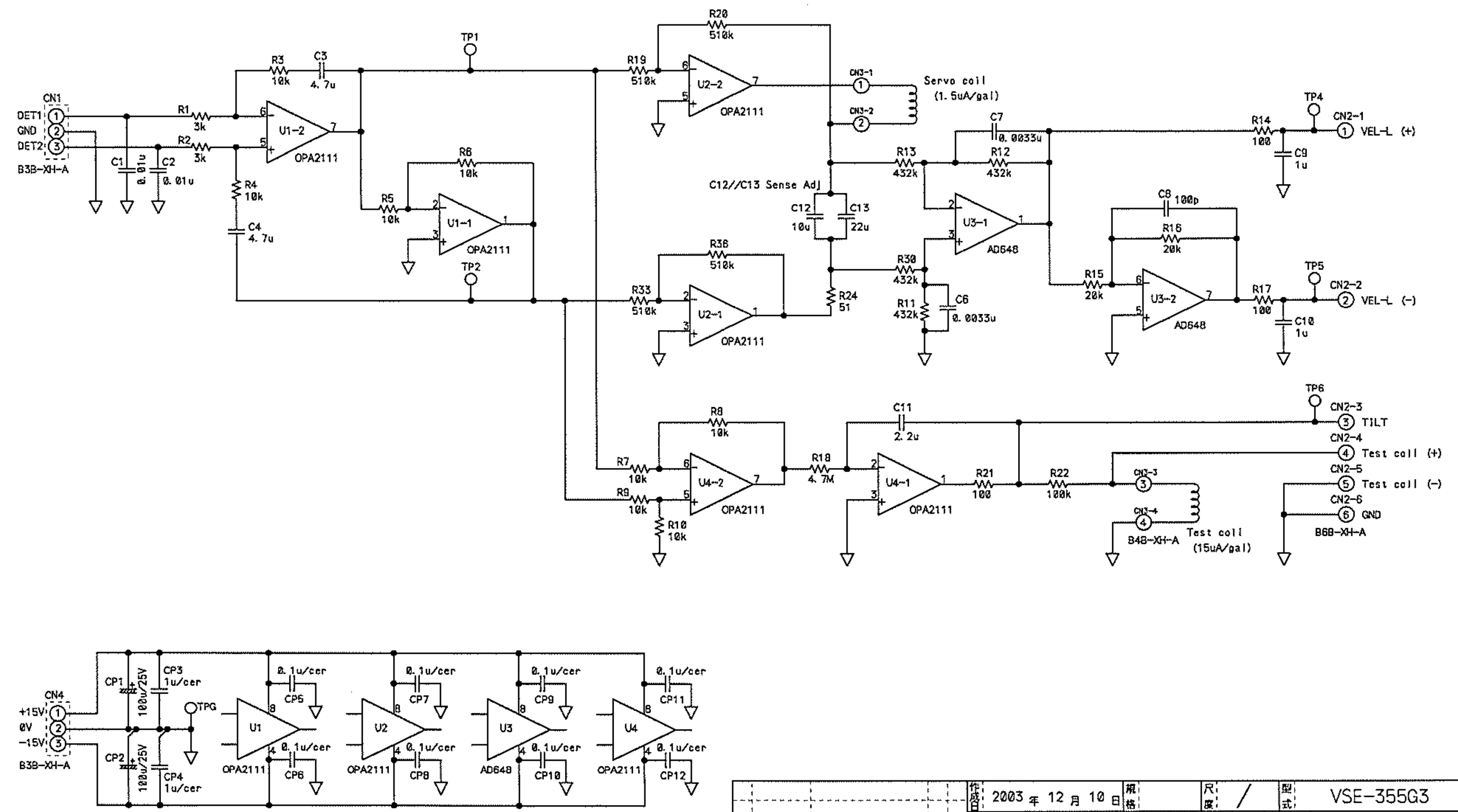
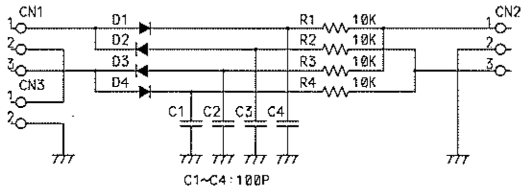


Figure 8 VSE-355G3 covers the almost all of earthquake zone and works as accelerometer in DC ～ 0.01Hz range



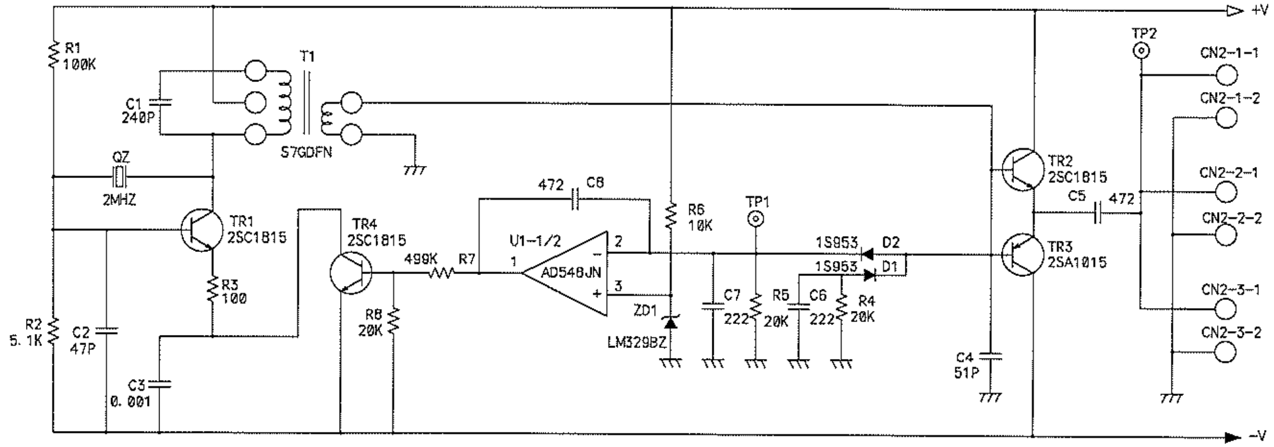
作成日	2003年 12月 10日	規格	尺度 /	型式	VSE-355G3
承認	検図	設計	製図	Ass'y No.	A1−
				図番	32−
名称	Servo Velocity Meter	図名	Servo Controller	株式会社東京測振	頁 1/1

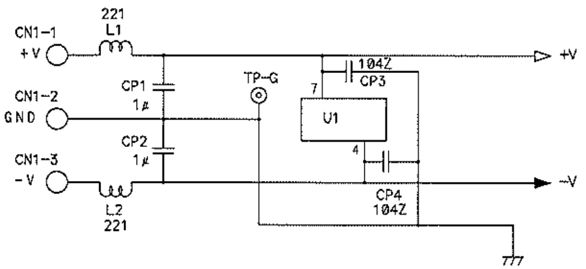
符号 年 月 日 改 訂 記 事 担当 承認



No.291 VSE-355G-3/3

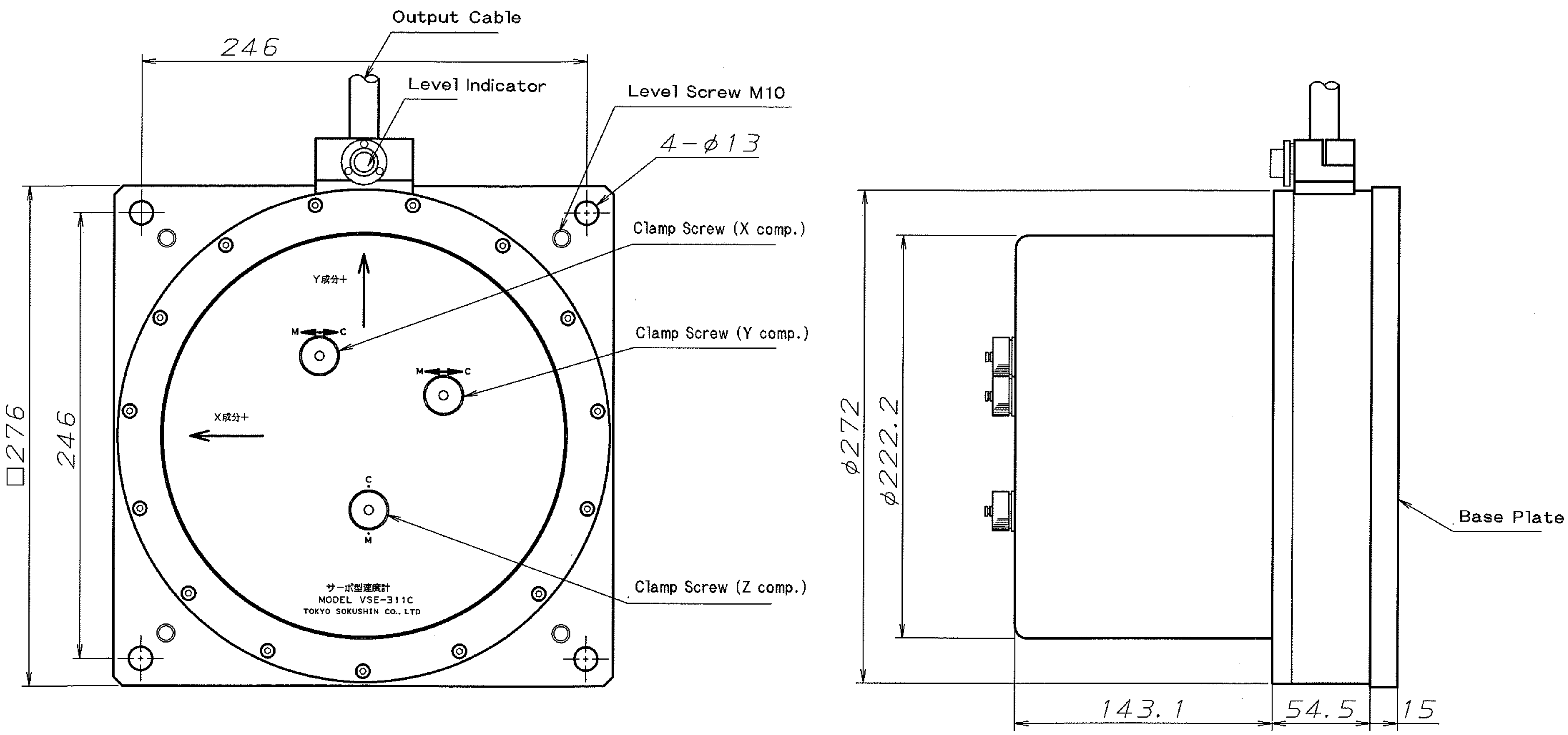
作成日	2000 年 4 月 11 日	規格		尺度	**/***
型式	VSE-355G				
Ass'y No.	A1-5334200				
承認		検図	設計	製図	
図番	31-211046				
符号	年 月 日	改 訂 記 事	担当	承認	
名称	Servo Velocity Meter	図名	Carrier Detector	株式会社東京測振	1/1





No. 290 VSE-355G-2/3

符号 年 月 日 改 訂 記 事 担当 承認	作成日 2000 年 4 月 11 日	規格	尺度 **/***	型式 VSE-355G
	承認 検図	設計	製図	Ass'y No. A1-534100
				図番 31-211045
名称 Servo Velocity Meter	図名 Carrier Oscillator		株式会社東京測振	頁 1/1



UNIT mm

作成日 2003年10月2日	規格	尺度 2/5	型式 VSE-355G3	
承認	検図	設計	製図	Ass'y No.
符号 年月日 改訂記事 担当 承認			図番 32-041467	
Strong Motion Velocity Seismometer	図名 Outside View		株式会社東京測振	頁 1/1