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Guide for Using Data from the LNN Seismic Monitoring Network

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Introduction

The four quiet seismic sites that comprise the Lawrence Livermore National Laboratory-Nevada Test Site Regional Seismic Network (LNN) are located in Nevada, Utah, and California (see Fig. 1). LLNL deployed the first seismic equipment at these sites in the late 1960s and has upgraded these stations over the years to reflect advances in seismographic equipment. Originally, each station had three broadband seismometers that provided continuous seismic data recorded on FM analog tapes.

Figure 1. LNN seismic stations are deployed at regional distances from the Nevada Test Site (NTS). The stations are located in mines near Mina, Nevada; Elko, Nevada; Kanab, Utah; and Landers, California.

In 1979, we installed a digital recording system at each station and named the network the Digital Seismic System (DSS). The digital data were transmitted on leased phone lines to our central recording station at LLNL.

In 1988, we upgraded the DSS collection and transmission hardware by adding a high frequency capability, and we renamed the network the LNN. Figures 2 and 3 show the LNN equipment setup at the remote sites. We have installed Teledyne Geotech GS-13 high-frequency seismometers to gather data in the frequency range of 1 to 30 Hz. The signals from the modems are buffered in a programmable communication board that transfers the data to an inexpensive, readily available workstation. This continuous stream of data is available to researchers using workstations on our local area network.

The GS-13 sensors, along with the existing broadband (0.07 to 5 Hz) Sprengnether S-5100 seismometer, provide a seismic monitoring capability equivalent to proposed in-country monitoring stations. Figure 4 and Table 2 indicate the response curves for the current LNN system. Table 3 lists the changes in the LNN recording methods, data channels, and frequency bands employed over the years.

Figure 2. The equipment setup at each remote LNN seismic monitoring site.

Figure 3. Configuration of the LNN station hardware, data telemetry, and central station hardware.

Table 2. Instrument response parameters for DSS and LNN at different times.

Dates	Channel names	Sensor	Sample rate (samples/s)	Free period (s)	Corner (Hz)	No. of anti-alias poles	Type
7/79 to 5/83	v, r, t	S-5100	~42	30	10	6	Bessel
5/83 to 11/87	z, n, e	S-5100	40	30	10	6	Bessel
11/87 to 11/88	bbz, bbn, bbe	S-5100	40	15	16	6	Butterworth
11/88 to present	h _{fz} , h _{fn} , h _{fe}	S-13	40	1	16	6	Butterworth
	bbz, bbn, bbe	S-5100	25	15	6	6	Butterworth
	h _{fz} , h _{fn} , h _{fe}	GS-13	125	1	32	6	Butterworth

Figure 4. The response curves of the LNN high-frequency (GS-13) and broadband (S-5100) data channels indicate a range of 0.06 to 30 Hz. DSS is the 1979–87 response, and BB and HF correspond to the present broadband and high-frequency LNN response.

Table 3. Changes in LNN recording methods, data channels, and frequency bands over the years.

Year deployed	Recording method	Data channels	Frequency band
1967–69	FM tapes; continuous record of all data	One broadband component (vertical)	20 s to 10 Hz
1976		Three broadband components	
DSS			
1979	Digital telemetry, event detection only		30 s to 10 Hz
1980	Continuous digital record of all data		
LNN			
1988		Six components (three broadband, 25 samples/s; three high frequency, 125 samples/s)	15 s to 30 Hz

Format for LNN and DSS Data

LNN

Each LNN station has two sets of 3-component seismometers; the high frequency (hf) channels have GS-13 sensors sampled at 125 samples/s, and the broadband (bb) channels have Sprengnether S-5100 sensors sampled at 25 samples/s. Figure 4 and Table 2 show the system response for both sets of sensors. The hf channels are flat to velocity from 1 to 32 Hz. The bb channels are flat to velocity from 15 s to 6 Hz.

All channels are digitized at a fixed gain of 16 bits, which results in a dynamic range of 96 dB. The absolute time, which is derived from satellite signals received at LLNL, is sent to each station periodically. As a result, the timing of the data is correct to within 15 ms.

The continuous data from all four LNN stations is archived by a SUN workstation on 8-mm video tapes. When access to a specific time segment of LNN data is desired, a sequence of programs must be executed to extract the data from the archive tape and convert it to the format described below.

Procedure for Extracting and Formatting Data from Archive Tapes

- Once an event window is identified, read the raw data, correct errors that are correctable, remove gain factors, and create Seismic Analysis Code (SAC) files. The program `rt2sac` is used for this operation. Usually, regional event lengths are 600 s, with 120 s before the origin time and 420 s after. In some cases, a different window is used, such as for events at teleseismic distances
- Convert from volts to nanometers/second (nm/s) by multiplying each channel by its velocity sensitivity. This velocity sensitivity has been determined for each channel from calibration signals and is accurate to within 5%.
- Remove the mean and apply a 1% cosine taper to the ends of the data window.
- If necessary, use linear interpolation from adjacent samples to remove one sample-point "glitches" in the seismic data caused by communication errors.
- Add header information [see the SAC manuals listed on the next page of this document for a more detailed explanation of this header information].

SAC Header Information

1. KSTNM- `elk, knb, lac, mnv`
2. STALAT, STALON,
(station latitude and longitude)
3. CMPAZ CMPINC
 `z 0. 0.`
 `n 0. 90.`
 `e 90. 90.`
4. KCMPNM
 `hfz, hfn, hfe (GS-13)`
 `bbz, bbn, bbe (S-5100)`
5. IDEP = IVEL
(units are velocity in nm/s)
6. KNETWK = LNN
7. RESP1 = high pass corner
(0.0 if not used).
 RESP2 = anti-alias corner
 RESP3 = seismometer free period
 RESP4 = damping factor
 RESP5 = velocity sensitivity in volts/(m/s)
 that was used to correct the data
 RESP6 = LSB in nm/s (least-significant bit)
 RESP7 = saturation amplitude (nm/s)
8. Event information
(Optional: will be entered if known)
 `EVLA, EVLO, EVDP, IEVTYP, KEVNM,`
 origin time
(if origin time is entered, set 0 time to origin time)

Instrument Correction

The instrument response parameters listed in Table 2 are nominal values. The seismometer free period, damping, and velocity sensitivity vary slightly for each instrument. We have used the measured values for the velocity sensitivity to scale the data, and we have entered the free-period and damping in the SAC header. The velocity sensitivity that we used to scale the data is also in the header so that, if necessary, it can be changed to another value if the user wishes to use something different than the gains that we use.

SAC has a command called `transfer` that can be used to remove the instrument response from DSS and

LNN data. The option DSS is used for DSS, and the LNN option has two subtypes, BB and HF. For both the DSS and LNN options in transfer, the nominal values (after 11/88 for LNN) for free-period, damping, and corner frequency are used.

To remove the instrument response from an LNN data file when the instrument constants are not the nominal values (such as before 11/88 or when other information is available) use the reftek option in transfer:

```
transfer from reftek freep &1, resp3
damp &1, resp4 corner &1, resp2 highpass
&1, resp1 to....
```

Transfer does not adjust the gain or multiplicative factor of the data values for either the LNN or reftek options.

Deviations from Current Configuration

We developed and installed the LNN system between September 1987 and March 1989; as a result, the data from this period may be different than data from the current configuration. The system configuration for any specific date can be deduced from the header values.

September 1987 to October 1988. During this period, the sample rates were 40 samples/s for both the hf and bb channels, the anti-alias corner frequency was 16.0 Hz, and the hf sensors were S-13s.

October 1988 to March 1989. During this period, in order to increase the effective dynamic range of the system, the hf channels may have had a 1-pole high-pass filter with a corner frequency at 10 Hz applied before digitization. The SAC header value resp1 indicates whether the high pass was used. The use of this filter was discontinued after March 1989 because we found that it could cause the pre-amp to distort at a voltage less than the saturation voltage.

For data collected during this time period, the user must remove the high pass using the transfer command in SAC (discussed above). If this has already been done, it will be indicated by setting resp1 to -10.0.

DSS

DSS was in operation from July 1979 through September 1987. The response of the DSS system is plotted in Fig. 4 and tabulated in Table 2. The 12-bit, gain-ranged digital seismic data produced by DSS had a dynamic range of 120 dB and was recorded at LLNL on 1600-bpi magnetic tape.

DSS SAC files are scaled in units of nm/s, and the station location, component azimuth, and event origin time are included in the header.

From 1979 to 1983, the DSS horizontal components were oriented radial and tangential relative to NTS. The file names have suffixes *v*, *r*, and *t*, and the SAC headers have the appropriate orientations entered in CMPAZ and CMPINC.

SAC Manuals

Joseph E. Tull, *SAC User's Manual Revision 2*, Lawrence Livermore National Laboratory, Livermore, CA (April 1989).

Joseph E. Tull, *SAC Command Reference Manual Revision 10.4c*, Lawrence Livermore National Laboratory, Livermore, CA (April 1989).

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