Poster Session Abstract
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REDUCING HORIZONTAL LONG PERIOD NOISE IN BOREHOLES WITH SAND

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During the past 23 years, installations of KS-36000 and KS-54000 sensors have been plagued by the presence of excessive horizontal long period noise at many sites. The source of this noise has proven to be elusive and it has been impossible to eliminate in many cases. Over the past three years, various experimental investigations conducted at ASL have established that installing KS instruments in sand at the bottom of the borehole is an effective method for eliminating most of the excessive horizontal noise. Two stations in the IRIS/ASL network have been successfully converted to sand installations (ANMO and SNZO) and one new IRIS/ASL site has been installed in sand (COLA). Sand installed horizontal long period noise levels at all three of these sites are very near the vertical noise level at each individual site. The conversion of SNZO from a conventional air installation to a sand installation reduced both horizontal noise levels at SNZO about 15.3 db. Improvements in long period noise levels exceeding 15 db can reasonably be expected if three existing sites (CHTO, RAR, and TATO) are converted to sand installations. ASL plans to install all future KS sensors in sand and to retrofit some of the noisier existing sites as resources permit.

CONTROLLING TILT NOISE IN BOREHOLES WITH SAND

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Horizontal long period seismic sensors are normally considerably noisier than vertical long period sensors at periods above 20 seconds if they are installed on the surface of the earth. The primary source of this noise arises because horizontal sensors are very sensitive to tilt and tilt at the earth's surface is generated by processes in the atmosphere. Theoretical and experimental studies conducted during the 60's and 70's revealed that the level of tilt noise decays quite rapidly if the sensor is installed at depth below the earth's surface. This result led to the installation of long period sensor systems in deep underground mines when possible and to the development of borehole deployable long period sensors for use where mines were not accessible.

Installation at depth significantly reduces the tilt noise generated by the atmosphere but tilt arising from sources near the instrument remains. Installation techniques devised to reduce air motion near the instruments both in mines and in boreholes have been quite successful in most cases; despite these precautions, the horizontal data from even the best borehole installations has always been measurably noisier than the vertical data from the same borehole.

There is no known reason that true horizontal background earth motion should be larger than the vertical background earth motion at the same site. Therefore, the excess horizontal noise in boreholes must be due to an instrumentation problem of some type. For many years personnel at Teledyne Geotech and the Albuquerque Seismological Laboratory (ASL) have believed that this noise arises from the action of air moving about within the borehole in the vicinity of the borehole sensor system thereby generating tilt in the sensor package. The simplest method for eliminating potential air motion is to fill up the volume in which the air might move with a barrier of some type.

During the past three years, ASL has conducted a series of experiments to evaluate the effectiveness of using sand to suppress air motion generated tilt in borehole installations. This effort has led to a very simple method for installing KS-36000 and KS-54000 sensors in sand at the bottom of the borehole, which reduces the horizontal noise levels to nearly the same levels as the vertical noise levels.

Briefly, a sand installation eliminates the need for the hole lock, the stabilizer assembly, the pilot probe, the foam wrapping of the sensor system, and the foam plugs in the borehole. A flat bottomed "sand foot" is screwed to the lower end of the sensor package where the pilot attached previously. About one foot of sand is poured on the bottom of the borehole and the sensor package is lowered into the hole to rest on the sand. A volume of ordinary playground sand calculated to fill the annular volume between the sensor package and the borehole wall to a depth not to exceed the height of the sensor package is then poured into the hole. That is it!

The power spectral density (PSD) data presented on this poster are daily median PSD estimates calculated as follows. First, a given day of 1 sample per second time domain data from a given channel was divided into 2048 second segments with a 50% overlap between segments. The FFT of each segment was then converted to PSD and the FFT bin wise median of these 84 PSD segments was evaluated. This yielded the "daily median" PSD estimate for that channel and day; these spectra are plotted between 30 and 2048 seconds in the PSD surface figures on this poster and between 2 and 2048 seconds in the daily median plots.

Four operational IRIS/ASL KS sites are now installed in sand. The first operational sand installation was made at ANMO (Albuquerque, New Mexico) over two years ago in March of 1995. There were several reasons for converting ANMO to sand. First of all, the vertical component had been slowly getting noisier over the years at periods greater than 20 seconds; the vertical noise level was approaching that of the horizontals so it needed to be changed. Second, we wanted to determine if sand would reduce the horizontal noise levels even though they were already among the quietest horizontals at any site. Finally, ANMO would serve as a demonstration of sand installation technology in a deep borehole. Figure ANMO1 contains a typical median spectral density of all three components before ANMO was converted to a sand installation and Figure ANM02 is typical of the performance after conversion. Note that the vertical component is significantly quieter after sand than before; this improvement is believed to be due to the use of a new sensor, not sand. The horizontals are also quieter at periods between 90 and 1000 seconds after the sand installation; this improvement is believed to be due to the sand installation.

The second sand installation was at COLA (College, Alaska); this was a new KS-54000 borehole installation which was installed in June, 1996. Examples of typical sand installation noise levels at COLA are shown in Figure COLA1. Horizontal noise levels above 20 seconds at COLA are usually slightly above the vertical noise level and sometimes slightly below that level. Essentially, the COLA long period horizontal noise levels are approximately equal to the vertical noise level which is as low as one could reasonably expect them to be.

The existing installation at SNZO (South Karori, New Zealand) was converted from a conventional to a sand installation in February of 1997 to demonstrate the effectiveness of sand at a site which had had noisy horizontals for many years. Figures SNZO 1, SNZ02, and SNZ03 contain PSD daily median surfaces for the vertical, north, and east components at SNZO for time periods both before and after the sand installation. There was no detectable change in the character or level of the noise for the vertical component (Figure SNZO1). However, note the decrease in the north and east horizontal PSD levels between 30 and 600 seconds produced by the sand installation (Figures SNZ02, and SNZ03 respectively). Also note that the horizontal long period PSD levels before the sand installation were very constant and smooth whereas the horizontal PSD levels after the sand installation show some variation and roughness with time. The constant PSD levels before the sand installation were probably due to steady state air convection generated tilt noise within the borehole in the vicinity of the sensor. The variation of the PSD level after the sand installation is probably arises from tilt sources external to the borehole system; the chief source of this variation is quite probably due to changes in the state of the sea which is only about 4 kilometers from the site.

Another method of quantifying noise levels is to simply calculate the root mean square (RMS) value of the signal over a specified time period (we chose time periods 1/2 an hour in length) within the band of interest (we chose the 20 to 600 second band). Calculating RMS signal levels for all the half hour long data segments in a day with a 50% overlap between segments yields 48 RMS noise levels per day. Averaging the 25% smallest RMS values yields a number indicative of the average lowest levels of the RMS noise. This number is the “25% minimum averaged RMS noise level” for a given day. Figures SNZ04, SNZO5, and SNZ06 depict the daily time behavior of the 25% minimum RMS noise level for the SNZO vertical, north and east respectively. Note that the minimum RMS noise levels within the band for the SNZO vertical are essentially identical before and after conversion to a sand installation. However, the noise levels for both horizontals dropped about 15 db after the sensor was installed in sand.

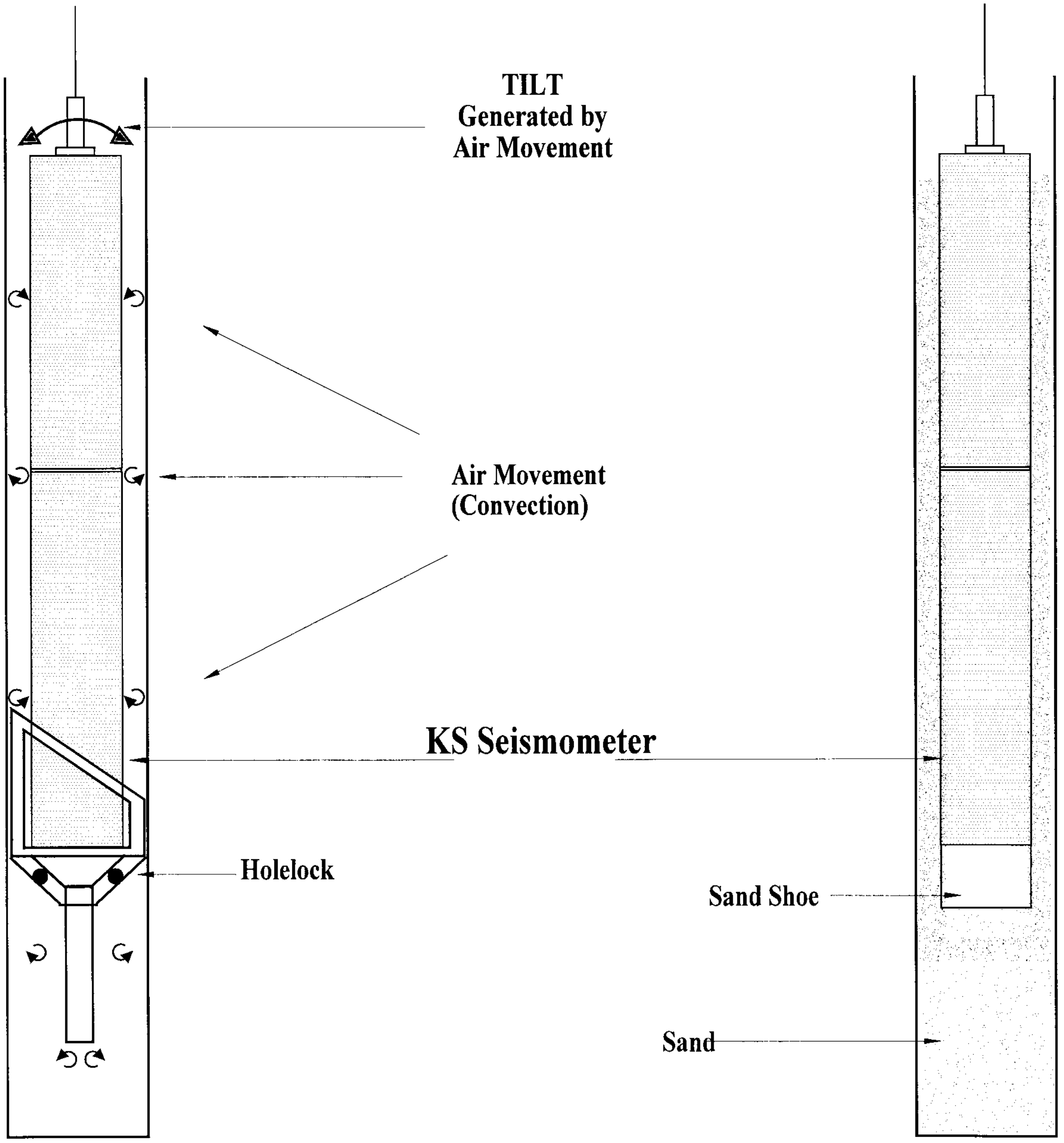
Finally, a new installation with sand was just completed (May, 1977) at WAKE (Wake Island). This station is too new to produce meaningful results yet.

Several existing borehole installations have noisy horizontal channels which could probably be improved by reinstalling the sensors in sand. Figure STATION RMS illustrates the relative levels of the horizontal noise to the vertical noise at several stations; the horizontal noise levels at CHTO, RAR, TATO, VNDA, and CPUP could probably be reduced to much lower levels with sand.

This new method of installing KS borehole instruments has been proven to significantly reduce horizontal noise levels at three operating IRIS/ASL stations. Similar improvements should be expected at future new installations and at existing sites as they are retrofitted. The method is simple, reliable, and quite literally dirt cheap!

A.
Borehole using a Holelock Installation

B.
Borehole using a Sand Installation



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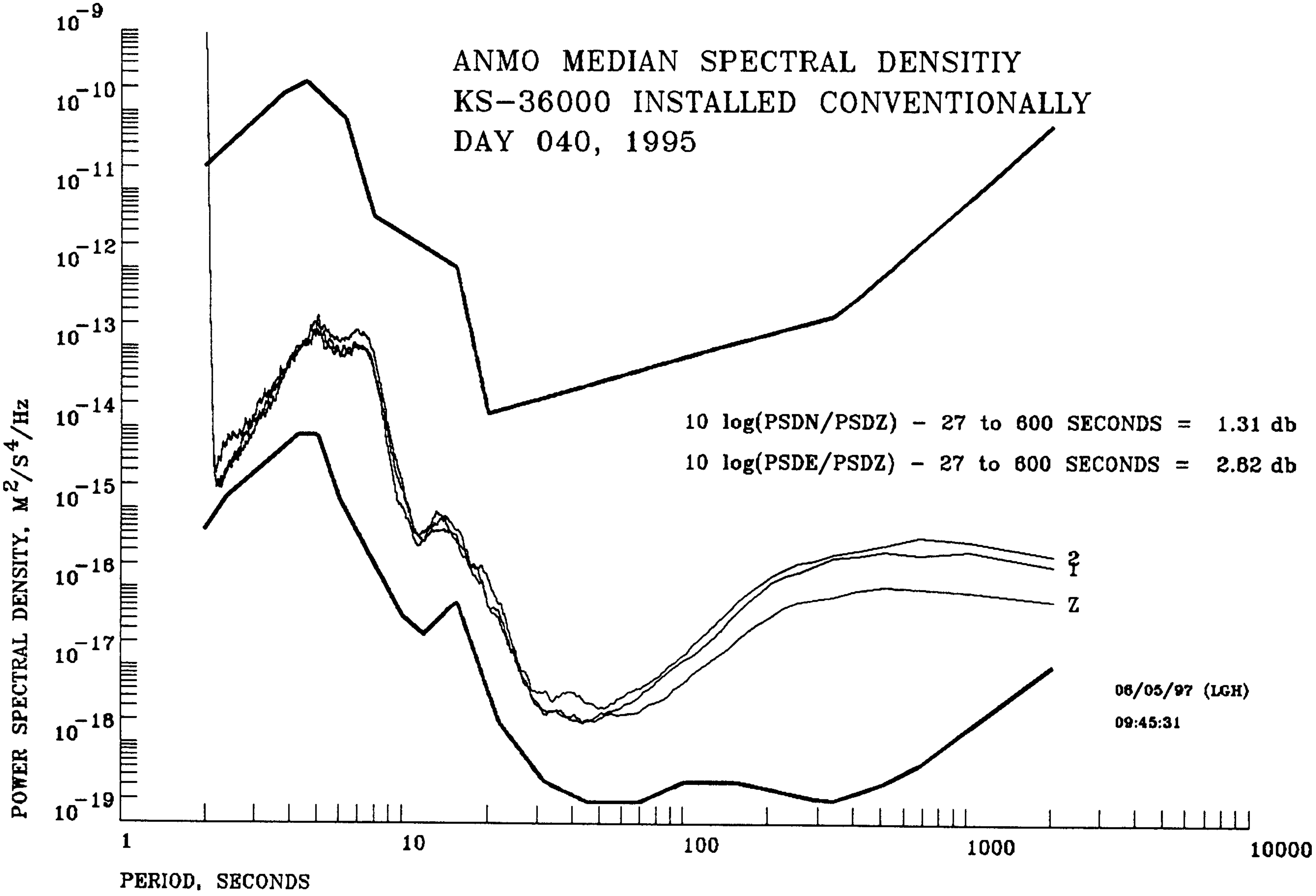

Figure ANMO1. Typical daily median noise levels for all three components at ANMO before conversion to a sand installation.

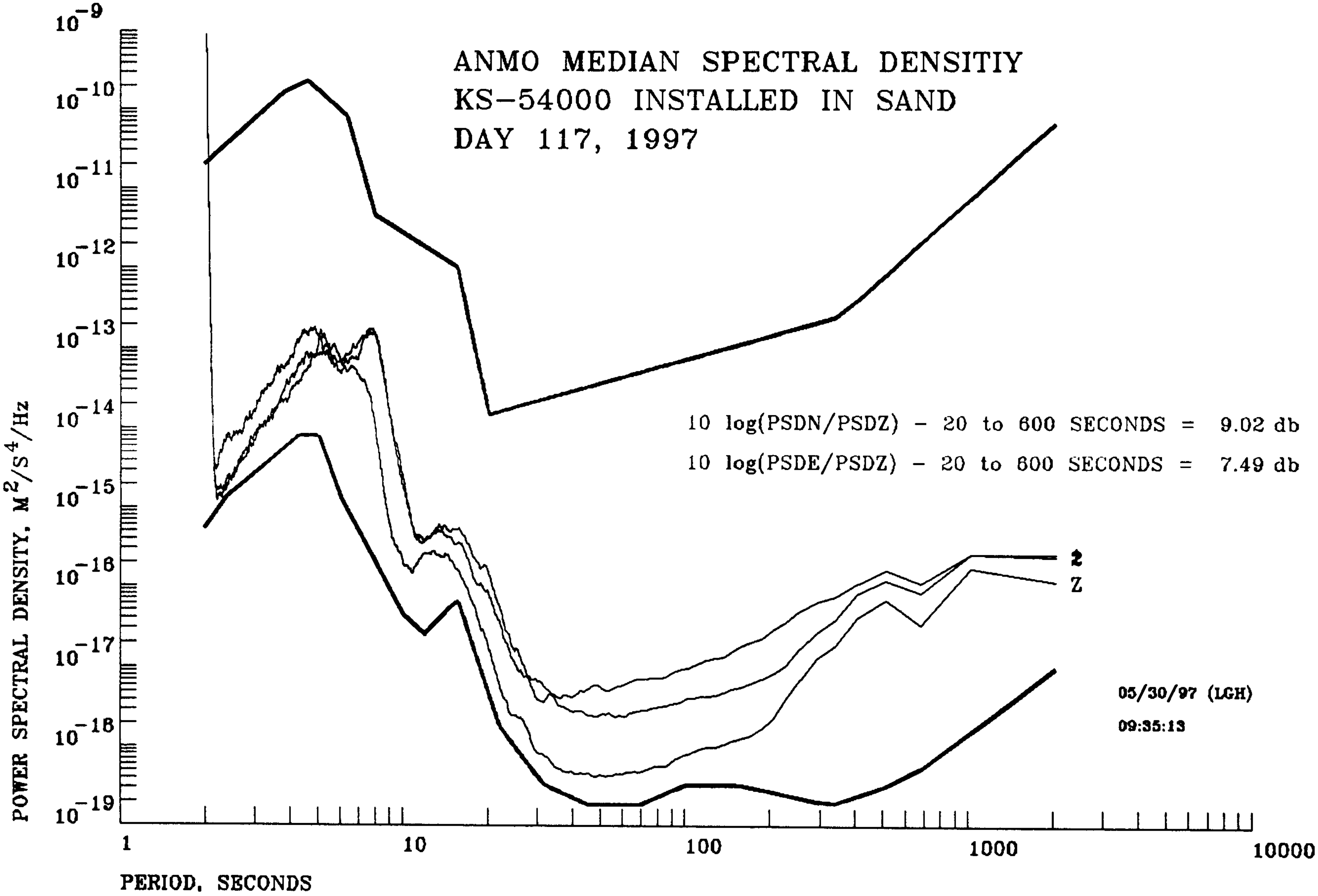

Figure ANMO2. Typical daily median noise levels for all three components at ANMO after conversion to a sand installation.

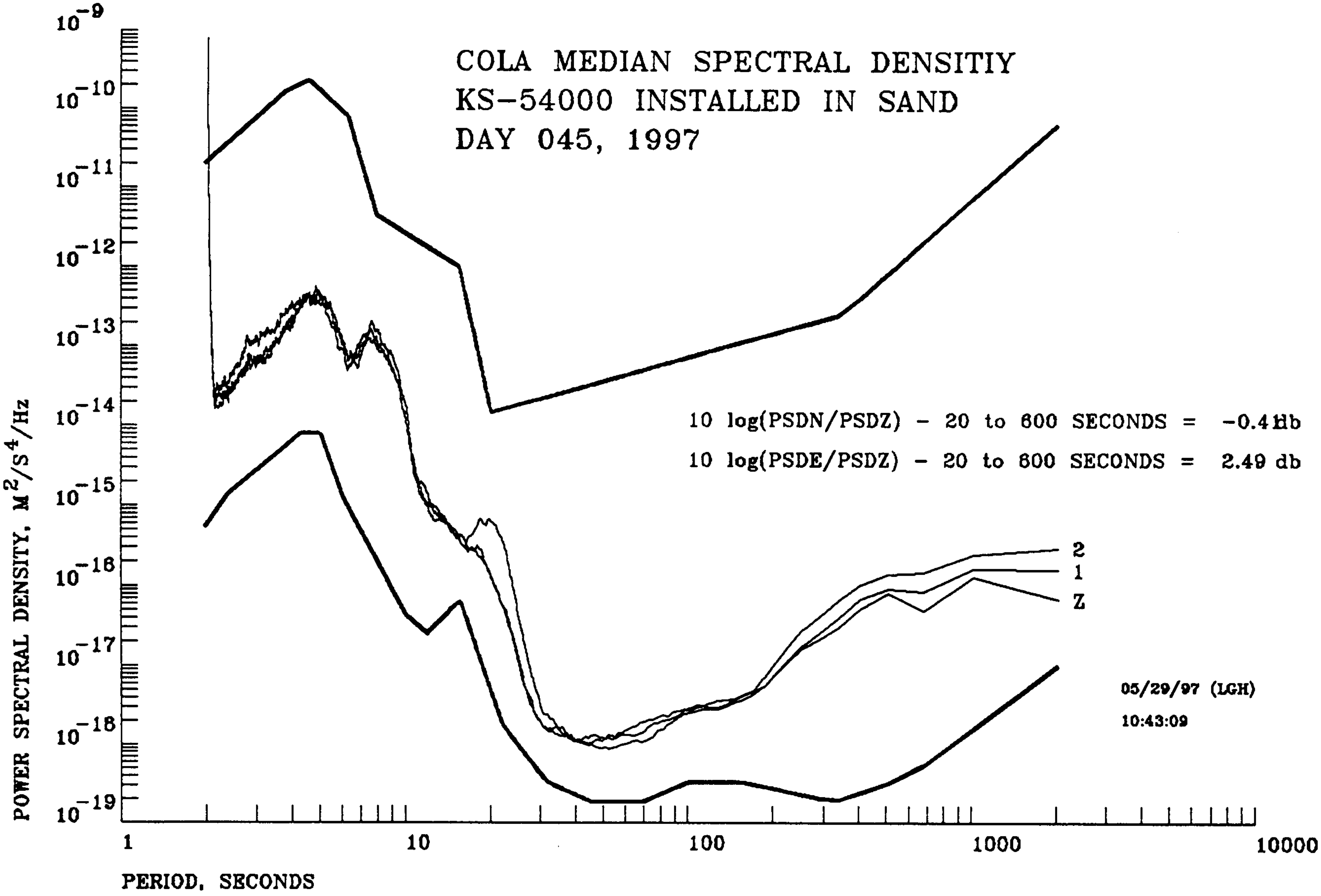

Figure COLA1. Typical daily median noise levels for all three components at COLA.

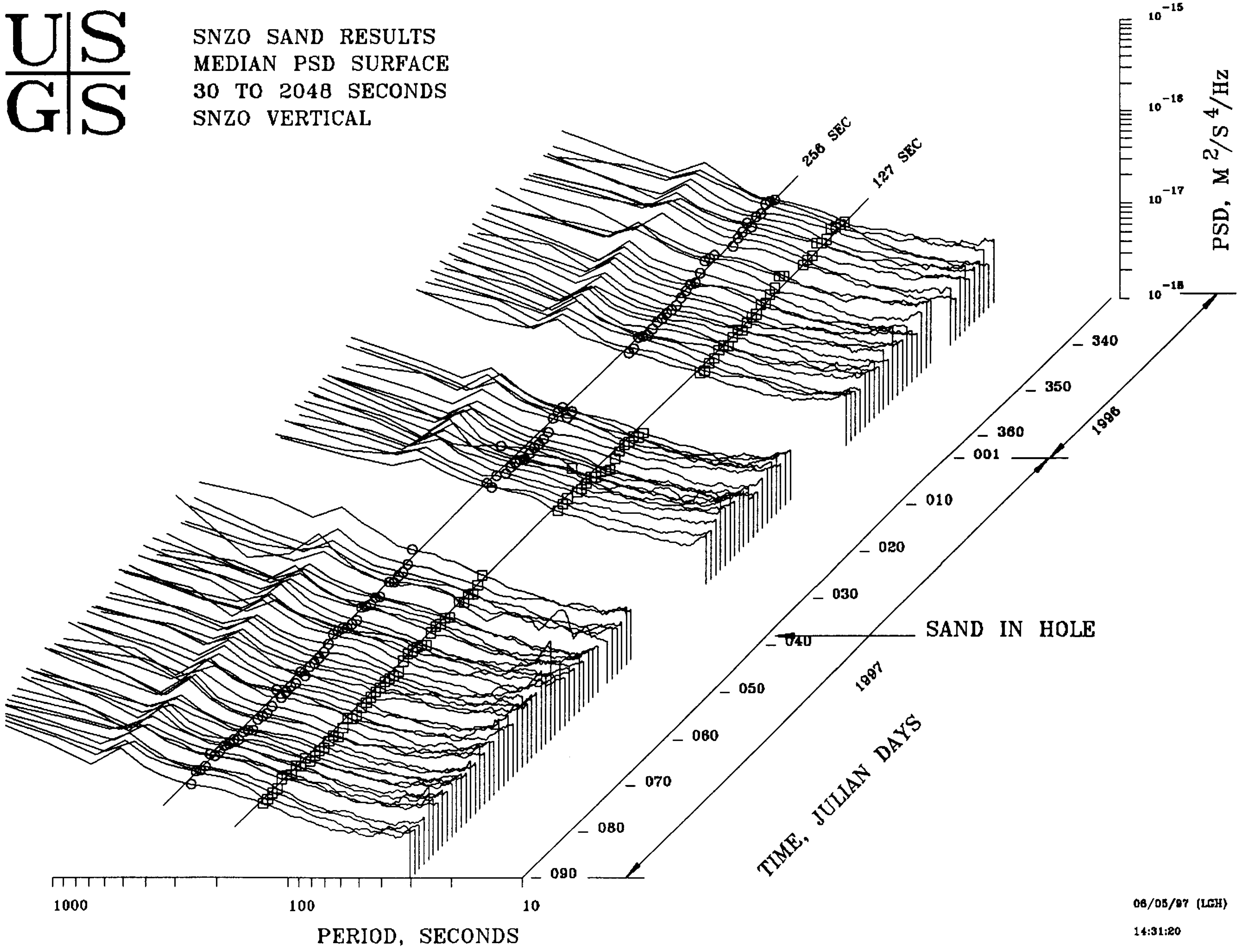

Figure SNZO1. Daily median PSD surface history of the vertical long period noise level at SNZO both before and after conversion to a sand installation.

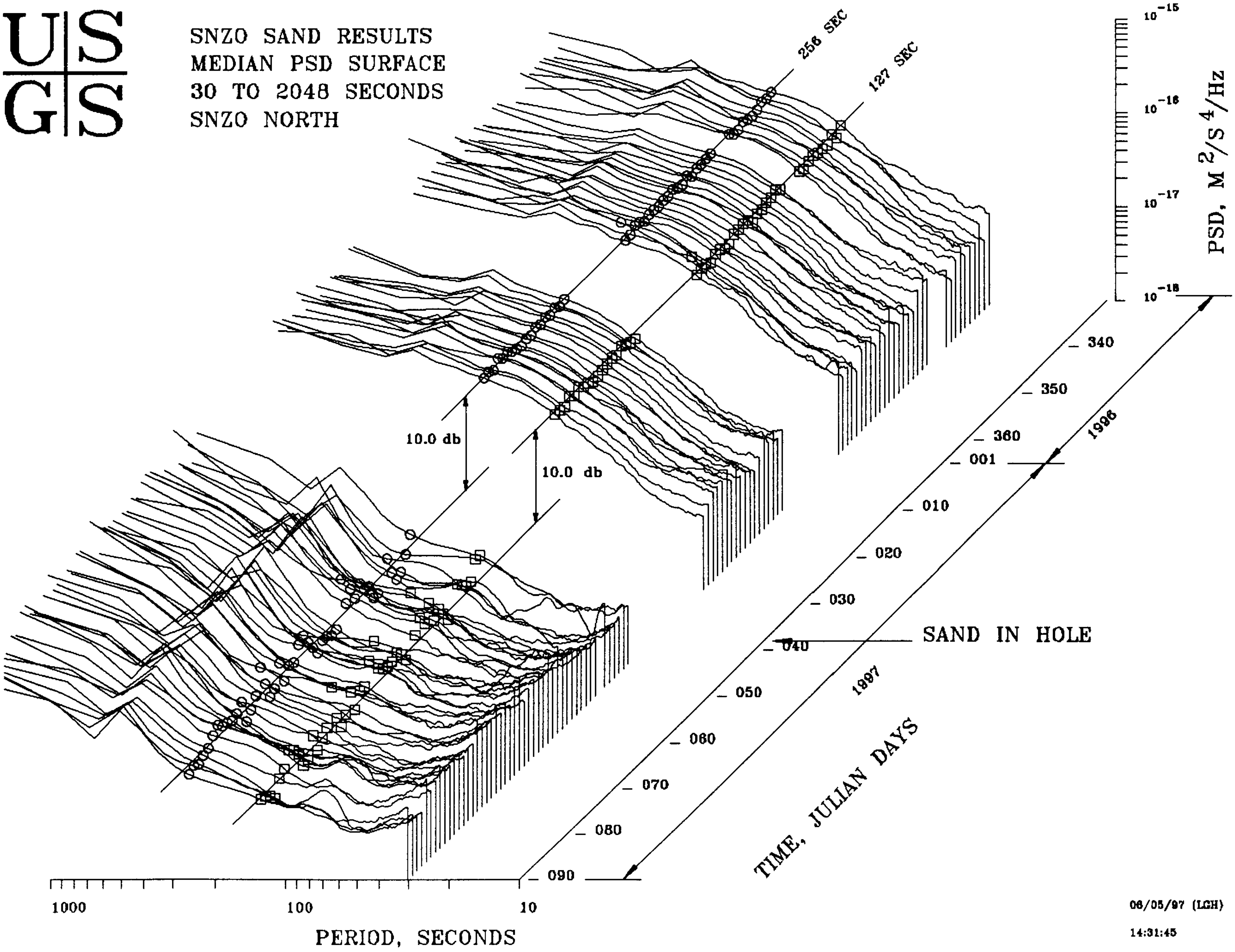

Figure SNZO2. Daily median PSD surface history of the north long period noise level at SNZO both before and after conversion to a sand installation.

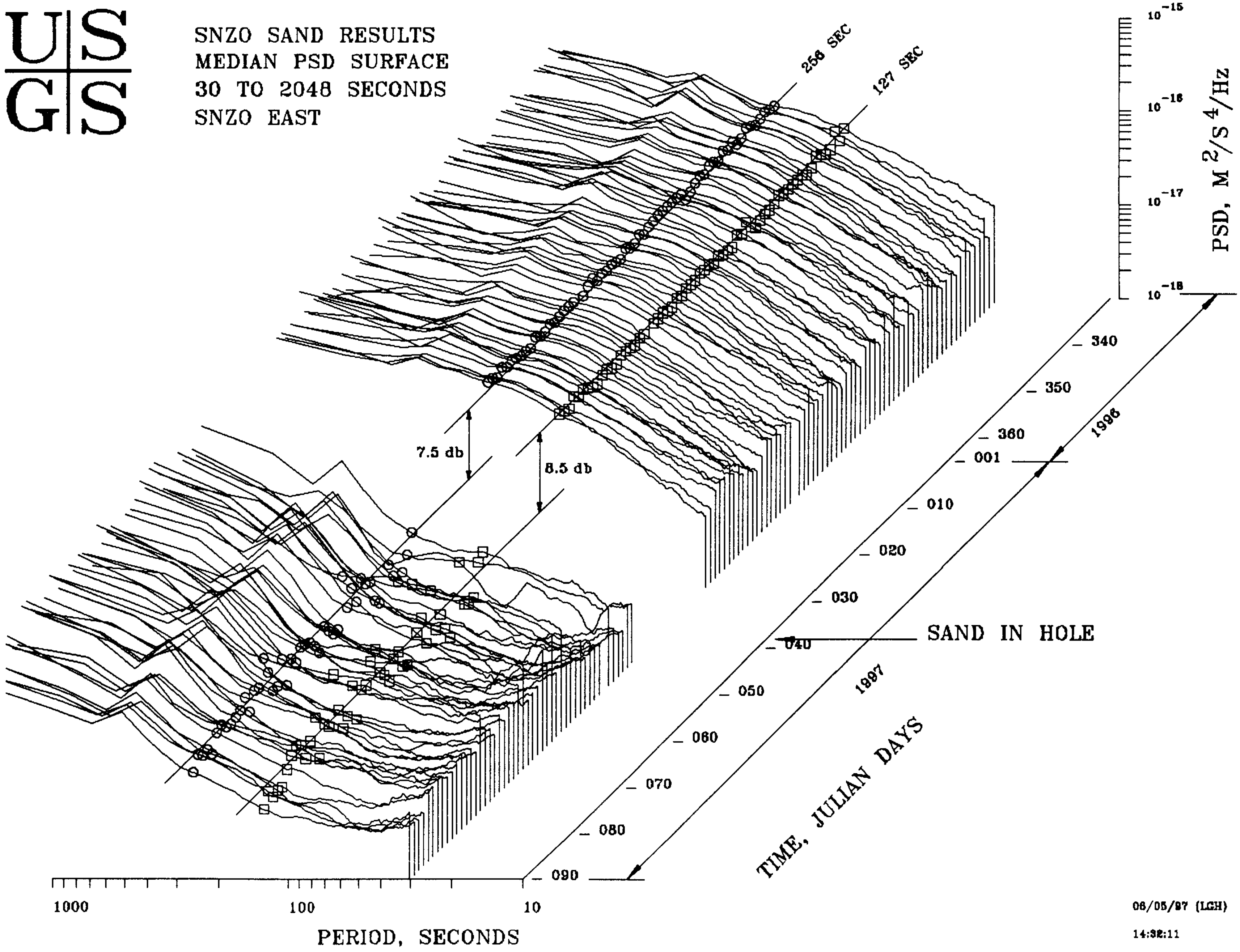

Figure SNZO3. Daily median PSD surface history of the east long period noise level at SNZO both before and after conversion to a sand installation.

SAND INSTALLATION RESULTS
25% MINIMUM AVERAGED RMS NOISE LEVEL
SNZO VERTICAL

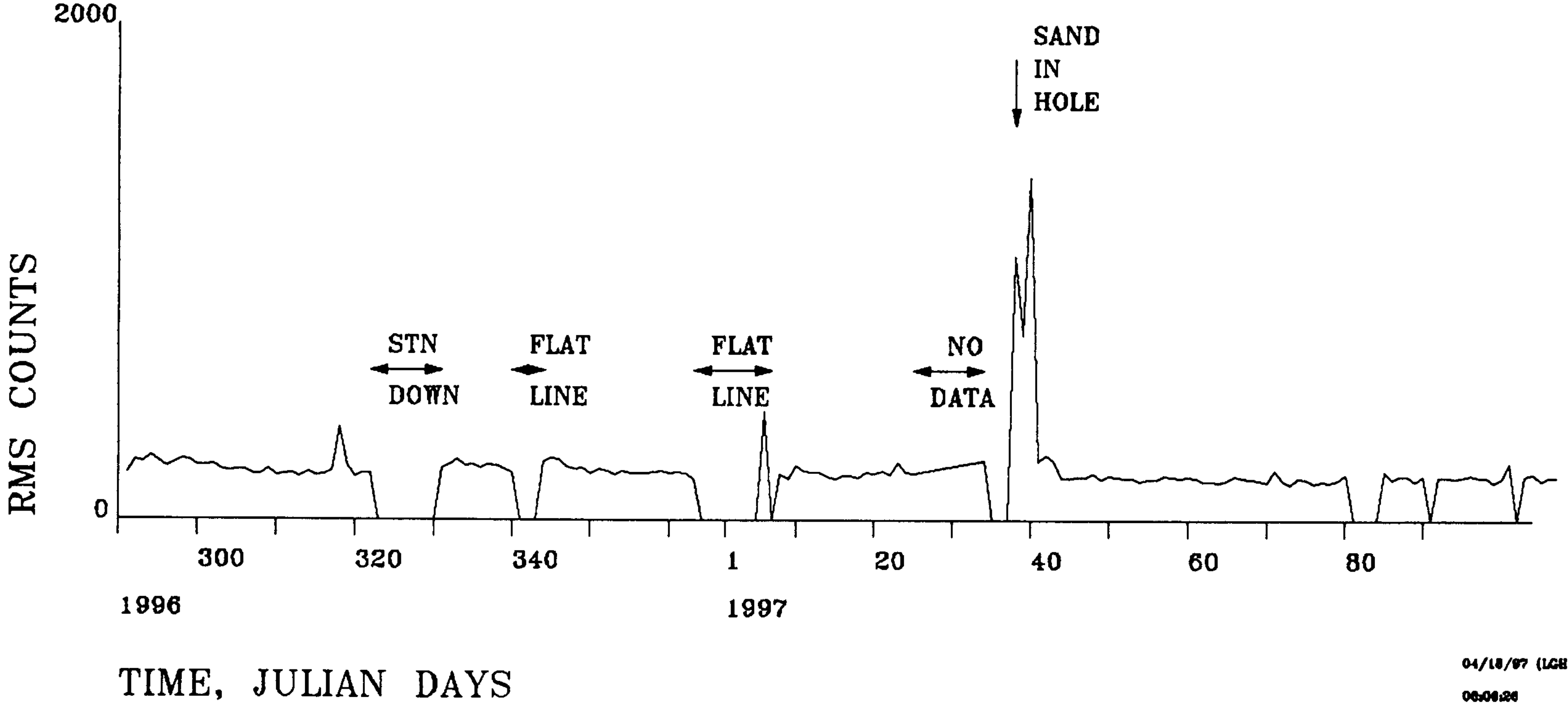

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Figure SNZO4. The minimum averaged RMS noise level for the SNZO vertical for the time period surrounding the conversion of SNZO to a sand installation.

SAND INSTALLATION RESULTS
25% MINIMUM AVERAGED RMS NOISE LEVEL
SNZO NORTH

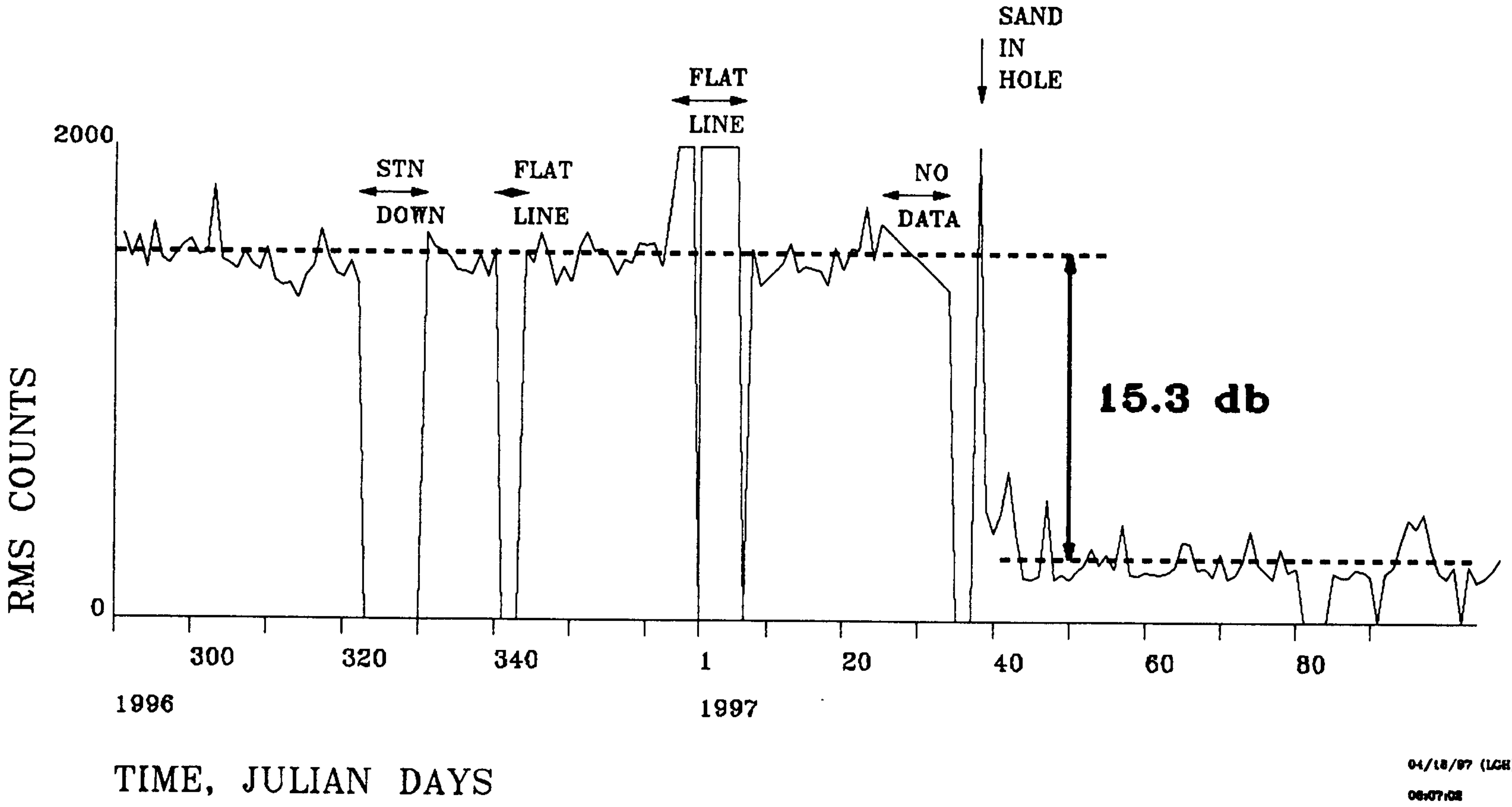

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Figure SNZO5. The minimum averaged RMS noise level for the SNZO north for the time period surrounding the conversion of SNZO to a sand installation.

SAND INSTALLATION RESULTS
25% MINIMUM AVERAGED RMS NOISE LEVEL
SNZO EAST

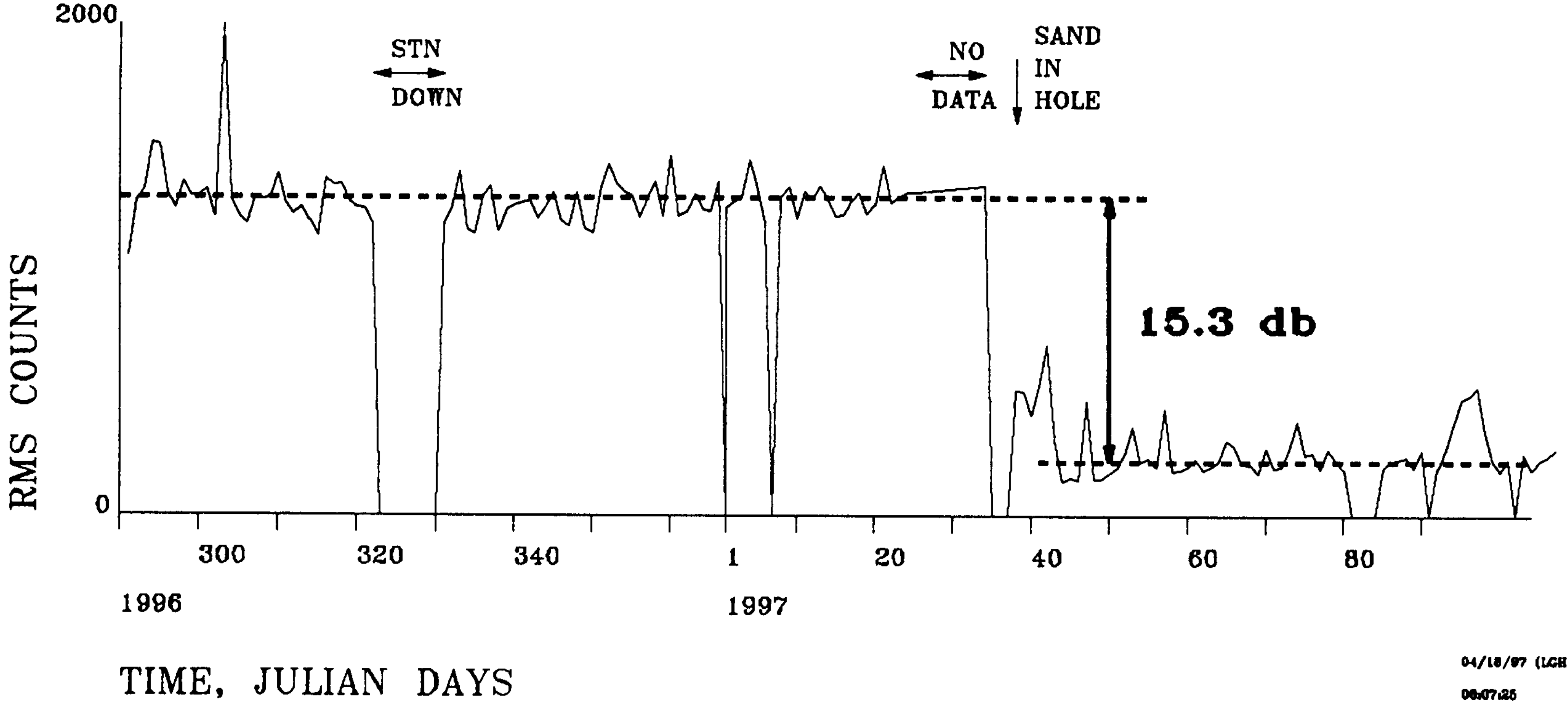

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Figure SNZ06. The minimum averaged RMS noise level for the SNZO east for the time period surrounding the conversion of SNZO to a sand installation.

THREE COMPONENT STATION NOISE
25% MINIMUM AVERAGED RMS SIGNAL LEVELS

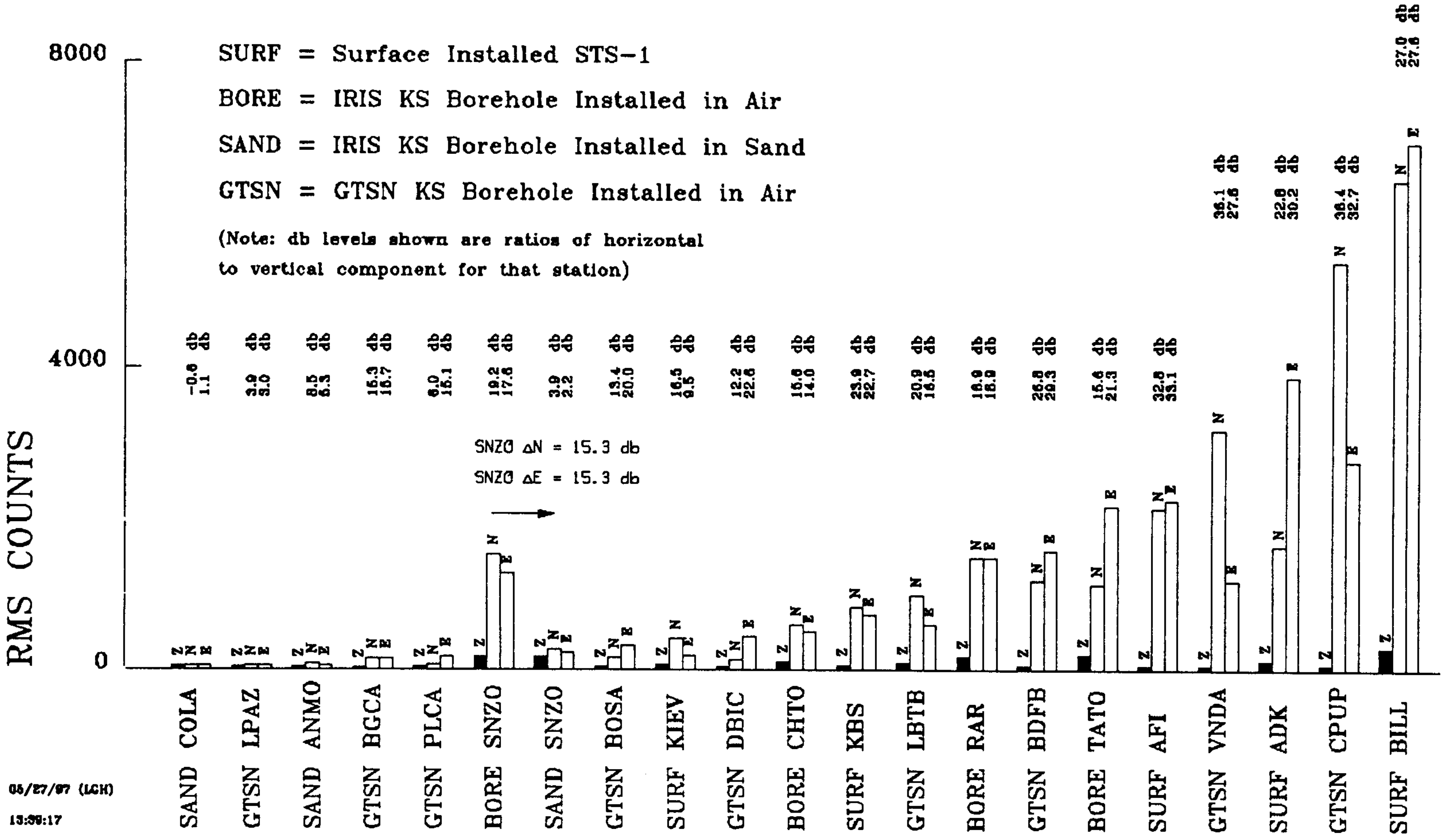
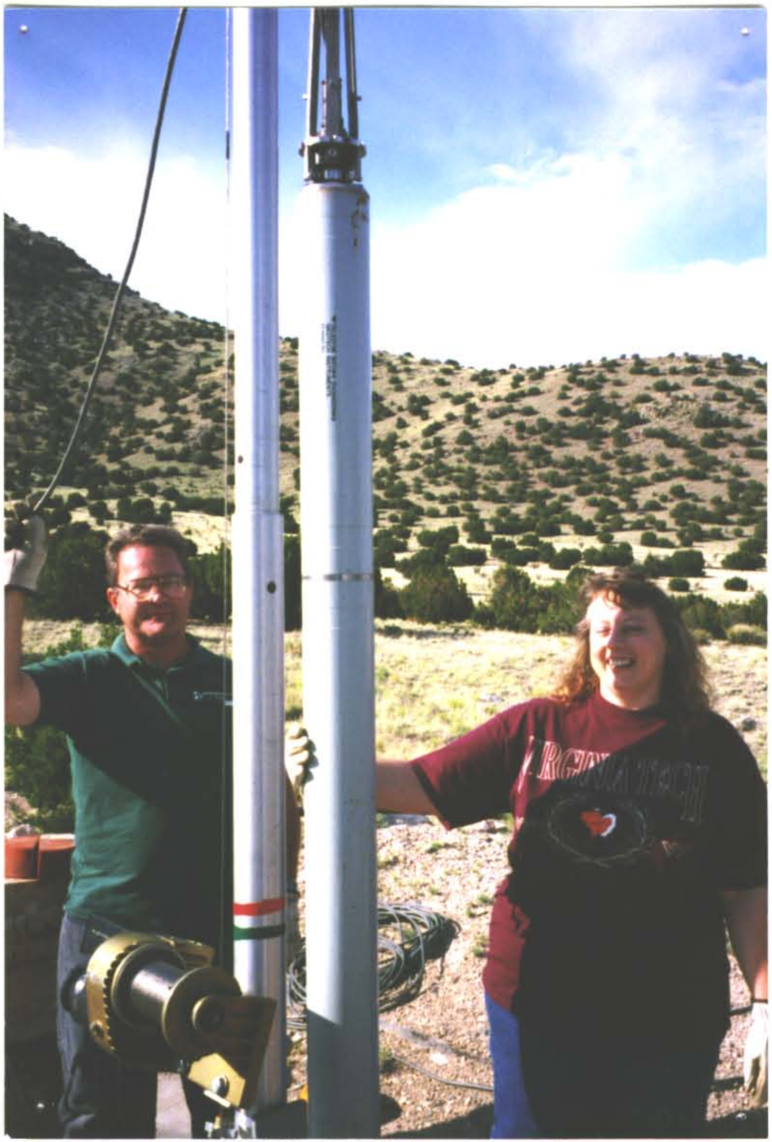


Figure STATION RMS. Relative 25% minimum RMS averaged signal levels at several stations illustrating the high levels of noise in several of the horizontal channels relative to the vertical channel at the same site.

Entire KS-54000 assembly ready to be installed in sand in the borehole. Note the "sand foot" on the bottom of the sensor and the plastic borehole tube standing on the right.



Upper end of KS-54000 assembly. Note that the three stabilizer springs have been removed; the three stabilizer feet have also been restrained with a tie wrap. Field engineers: Dawn Schock and Neil Ziegelman.

Bottom end of KS-54000 assembly with the "sand foot" installed".

Pouring sand into a 6.5" ID transparent plastic borehole with a KS-54000 installed in the tube.

Sand accumulating at the bottom of the plastic borehole around the "sand foot".

Sand accumulating in the annulus between the KS-54000 and the inner wall of the plastic borehole.