LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
CALIFORNIA INSTITUTE OF TECHNOLOGY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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MIT LIGO Group Seismic Survey

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1 ABSTRACT

Ground noise measurements were made at MIT buildings 20, 24, NW13, WW15, and in addition some informal measurements at Lincoln Labs were made. In a later phase, measurements in NW17; these are reported in an addendum (Section 6 at the end of the document). The objective was to determine the suitability of possible relocation sites for the MIT LIGO Laboratory. The measurements and data presentation were performed by Peter Csatorday, Peter Fritschel, Gabriela Gonzalez and David Shoemaker.

2 DISCUSSION

An active program in interferometry is a pre-requisite for participation in the future of LIGO, and gives a focus to the group which is irreplaceable. One could imagine relocating students to the LIGO sites for their theses, for instance, but this is not seen as a workable solution—the LIGO sites do not have support for small-scale prototyping, but more importantly the MIT group would not survive that drastic splintering. A local site that is suitable both for near and far-term prototype R&D work is thus crucial.

There are several measures of the seismic suitability of the sites considered for the MIT LIGO experimental group. The important frequency range to consider for a choice is from ~1-10 Hz; this is because lower frequency motions (less than 1 Hz) are common-mode motions for all of the optical components, and are not bothersome for the short-baseline systems (<100 m) we would consider for lab prototypes. The LIGO GW band is from ~30 Hz to ~3 kHz, but any of the sites considered are less than a factor of 10 above the LIGO site spectra in this frequency range, and so all sites are acceptable by this criterion.

The control systems which hold the interferometers at the correct operating point must deal with the range from 1-10 Hz (10-30 Hz is also relevant, but most of the integral and difficulty is represented by the 1-10 Hz band). If these levels are higher than those in LIGO, then either additional isolation must be introduced, or changes in the dynamic range and slew rate of the controller actuators must be modified from the LIGO design, or we must exclude many interferometer development paths in our lab work at MIT.

Much of the most important work to be performed in the R&D labs in the next 5-10 years is in the domain of seismic isolation and thermal noise. These are experiments which are particularly demanding for these questions of environment. Some optical tests could be performed in noisier environments and still yield results; the present work on the MIT 5m prototype in building 20 falls in this category. However, one pays a high price in the rate of progress: designs for LIGO must be modified to deliver wider bandwidths and larger dynamic ranges to be able to handle the much larger broadband noise in the 1-10 Hz band; when and even-larger (but quite frequent) impulsive seismic event (due to local traffic) occurs, one must wait for the system to settle before recommencing an alignment or measurement process - these events can render a considerable fraction of the daytime useless for making noise measurements on a prototype interferometer.

The velocity of the ground noise is one important measure because it relates directly to electronics requirements for the controller; this is the vertical coordinate chosen for the time-series plots. In addition, one noise source is formed by accidental interference between the suspended components (nominally very quiet in inertial space) and the laser system (which is tied to the ground);

this noise source has a cutoff frequency determined by the velocity of the motion between the ground-mounted system and the suspended components. (Note that with additional effort even the components external to the interferometer could be suspended or made to ‘track’ the suspended components, but this falls in the category of heroic measures needed in a noisy environment and would be best avoided.)

The seismic noise displacement spectrum is also useful when considering the impact on the transfer function of servo-control systems—one can almost read the required gain as a function of frequency from the difference between the noise curve and the allowed deviation from a design curve. The RMS of the displacement is another measure which relates to the dynamic range requirement, and gives a quick figure-of-merit for a site.

Measurements were made during the day and at night were made to understand the sources of noise (it is dominated by human activity in all cases) and to see what advantages would be possible for occasional late-night efforts.

2.1. Evaluation

The present environment, Building 20, is rated Not Acceptable; we would rather not pursue sensitive interferometry than to re-locate to a site with a similar seismic environment to Building 20F. Thus the potential sites in buildings 24 and NW13 are also rated Not Acceptable, as they are similar to 20F.

The Furniture Exchange (WW15) and off-campus (with our informal measurements at Lincoln Lab as an example, labeled here as ‘LL’) are the possibilities which merit serious consideration. Figure 1 (time series for daytime measurements), Figure 3 (displacement power spectra for daytime measurements), and Table 1 (RMS displacements daytime) are the most relevant data.

The RMS motions for all of the sites are dominated by the very low frequency motion (0.1-1 Hz), but due to the similarity at all sites and the common-mode motion in a lab-scale instrument this is not a criterion; thus, we will only consider the 1-10 Hz band in displacement. The velocity time series gives a weighting of one power of frequency to the data which makes this range also the dominant contributor to the time series, and gives the right magnitude of the accidental interferometer problem.

There is an obvious difference in the levels between 20, WW15, and LL. WW15 is about a factor of 3 quieter than 20F which would ease some controller designs but is still orders of magnitude higher than the LIGO spectrum. The lower level at WW15 would mean that solutions exceeding LIGO designs in dynamic range and gain would continue to be necessary but would be easier to implement than in the present 20F environment. The angular motion which has been a primary impediment to progress in 20F is enough smaller in WW15 to make a significant difference in the ease of research.

The LL noise level is a factor of 20 lower than Building 20F, or more significantly about a factor of 7 greater than the LIGO spectrum. While not at the LIGO level, it is comparable; the night measurements at LL are only a factor of 4 above LIGO levels. This would allow LIGO designs to be used, with a smaller margin for the dynamic range (but also certainly reduced requirements for the availability or ‘up-time’ of the interferometer). These informal LL measurements were made on the second floor of a busy lab building, so represent a conservative estimate for the seismic environment there.

There are two options which we recommend be pursued. One is to determine if in fact a site at Lincoln Labs is available and such that a practical extension of the lab could be made there. In addition to the simple question of high-bay space, there are additional criteria such as office space, possibility of off-hours work, and arrangements for non-US citizens to visit and work. The first step is to meet with those responsible at Lincoln for space allocation.

The second option is to pursue the possibility of rendering the WW15 site somewhat more quiet. This requires contact with consultants versed in these techniques to see if a modified isolation system could be produced in a timely and cost-effective way. With an increase in active isolation of a factor of 3 at 1 Hz the WW15 site would be much more attractive, with its additional advantages of physical proximity.

3 INSTRUMENTS

We used a Guralp CMG-40T seismometer, serial number T4157. This is a three-axis velocity sensor, with 3dB points of the response at 30 mHz and 50 Hz in broadband mode. Dynamic range is at least 145 dB. The seismometer was covered with a styrofoam thermal shield during the measurements.

4 MEASUREMENTS

All data were taken with an HP 3562A Dynamic Spectrum Analyzer. Power spectral density measurements were made with 100 Hz bandwidth of all three axes of ground motion and magnetic fields. In addition, 10 Hz spectra were taken of two axes of ground motion. These were taken in the afternoon. We also recorded about 100 minutes of time series data of vertical ground motion starting at 8:00 am and 11:50 pm. These were made with a 10Hz bandwidth.

Signals were fed through Stanford SR560 preamplifiers in all cases, with gain settings of either 1 or 10. The outputs of the seismometer were DC coupled, and no filter was used, and the outputs of the magnetometer were either AC coupled, or a 30mHz 12dB/octave high-pass filter was introduced.

5 RESULTS

The following graphs show the time series data of vertical ground velocity taken at 8:00 am and 11:50 pm, as well as power spectra of the ground displacement calculated from them. (These spectra are composites, the data between 10 Hz and 100 Hz having been taken from the afternoon spectra made directly with the HP3562A.) For purposes of comparison, we calculate the RMS noise values in the range of 0.1 to 10 Hz for the various buildings.

5.1. Daytime

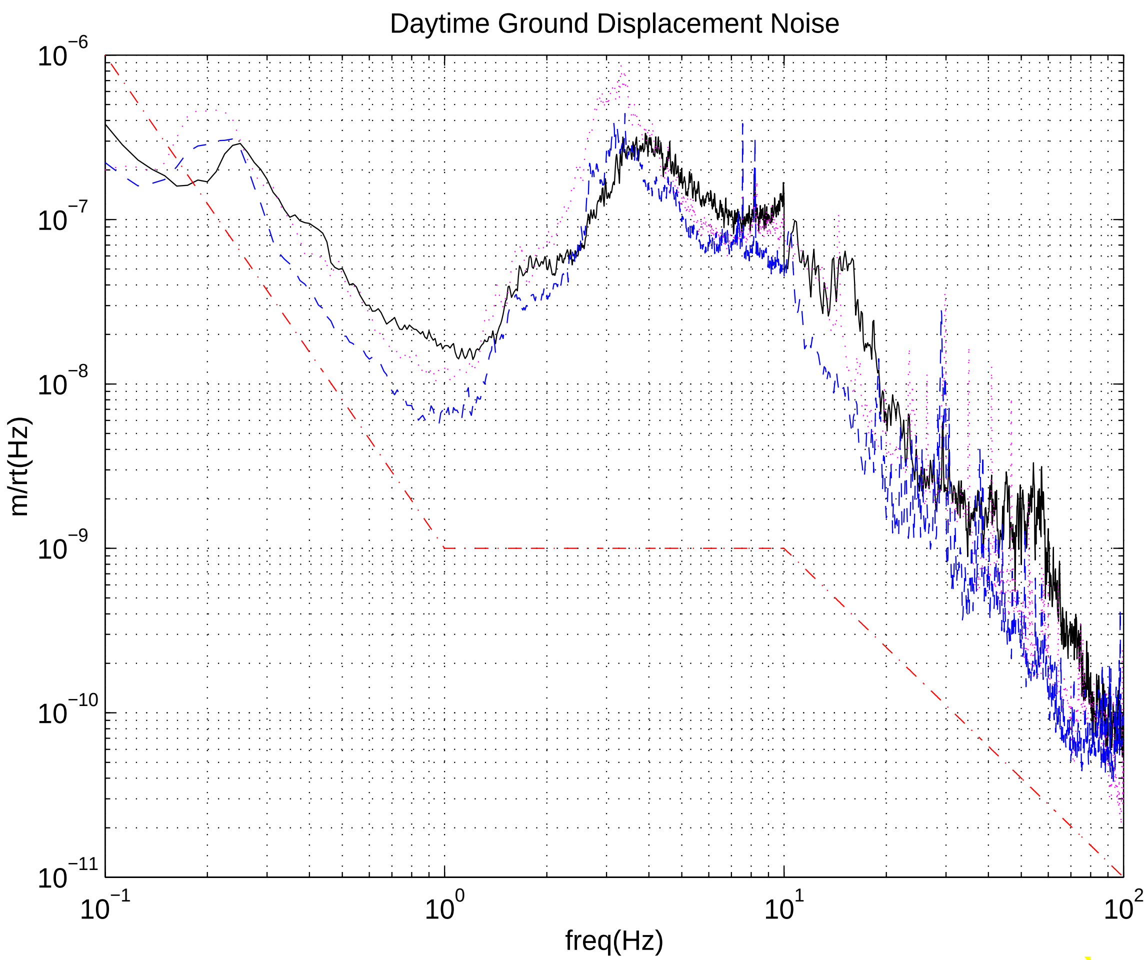

Figure 2: Displacement power spectra calculated from the time series of Figure 1. Building 20 (solid black), 24 (dotted magenta), NW13 (dashed blue) and the LIGO standard (dash-dot red).

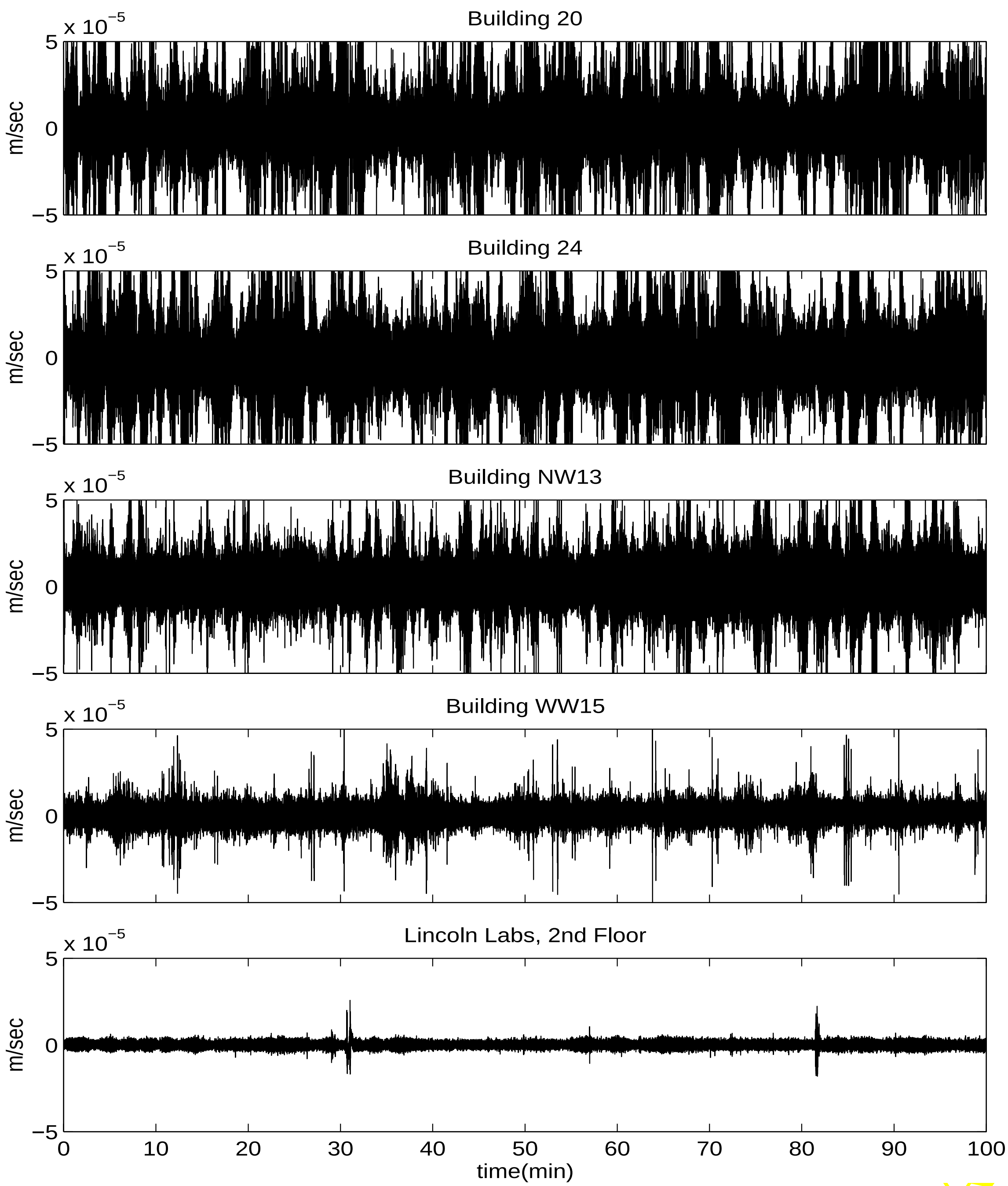

Figure 1: Measured ground velocity at 8:00 am.

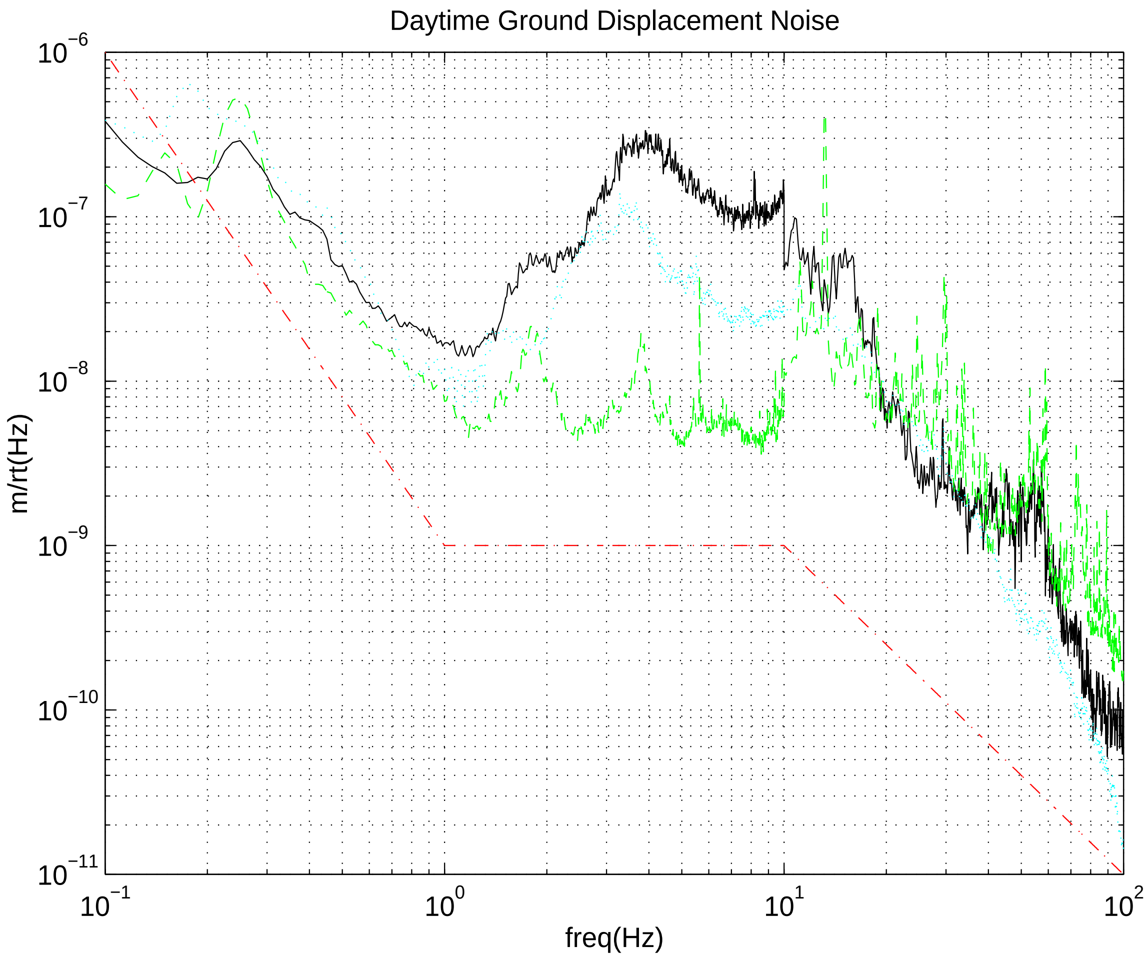

Figure 3: Displacement power spectra calculated from the time series of Figure 1. Building 20 (solid black), WW15 (dotted cyan), Lincoln Labs (dashed green), and the LIGO standard (dash-dot red).

5.2. Nighttime

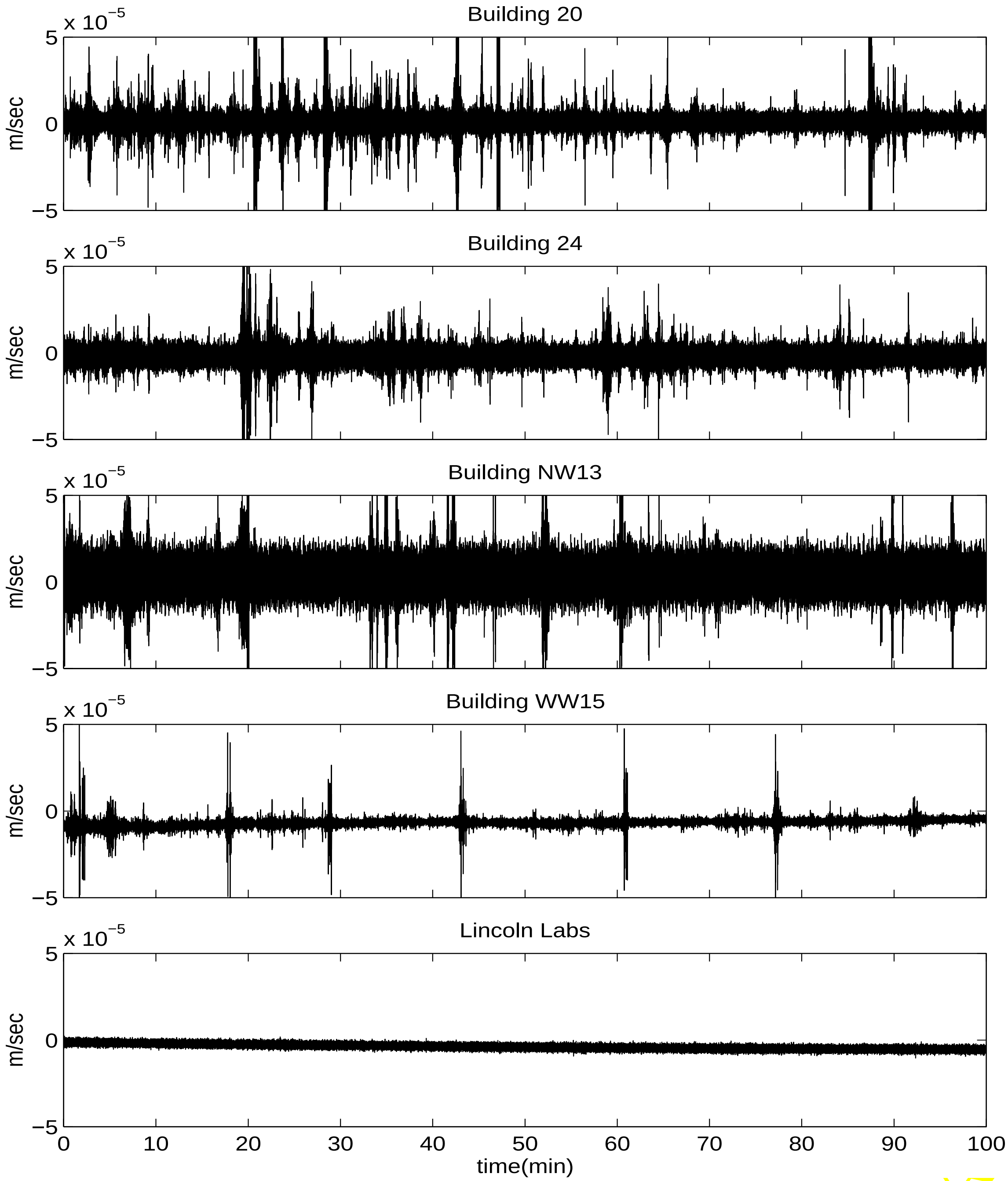

Figure 4: Measured ground velocity at 11:50 pm.

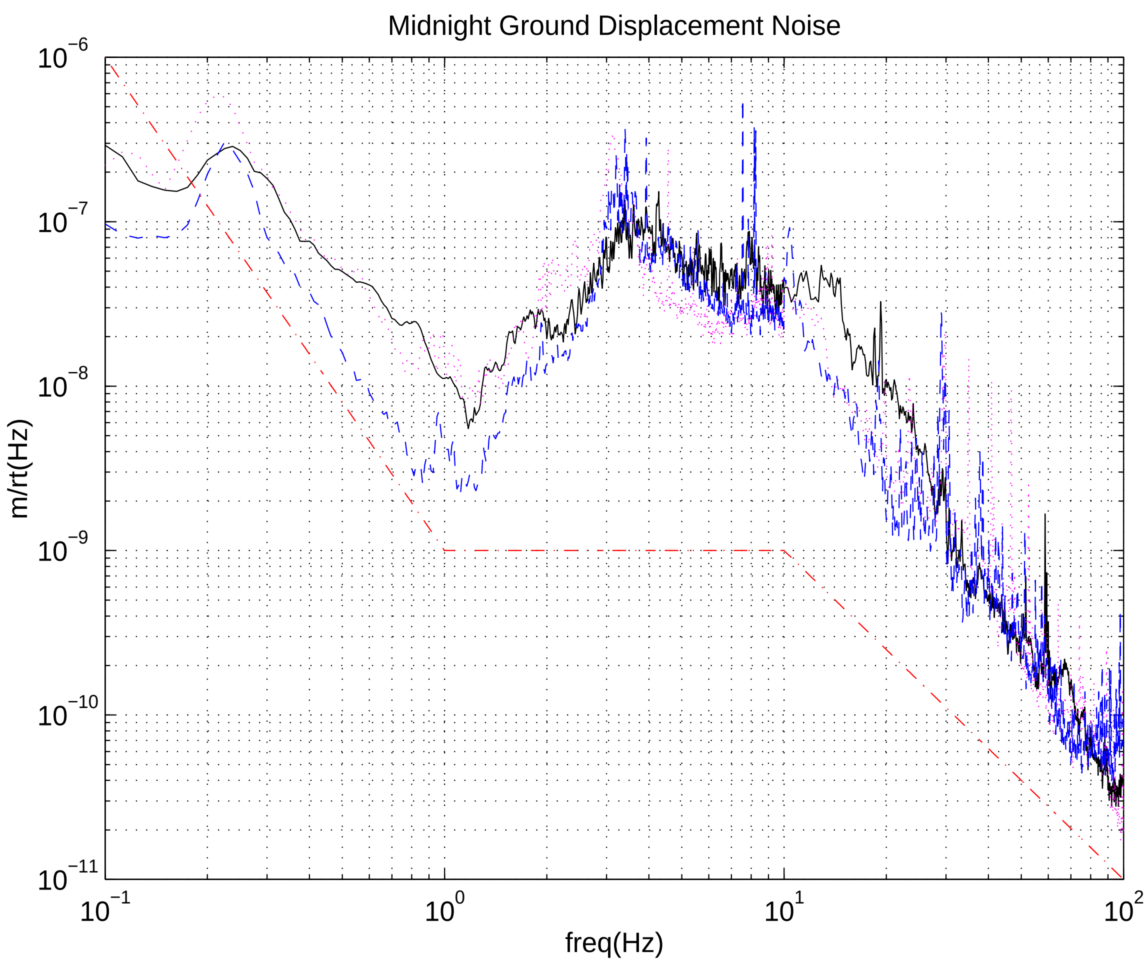

Figure 5: Displacement power spectra calculated from the time series of Figure 4. Building 20 (solid black), 24 (dotted magenta), NW13 (dashed blue) and the LIGO standard (dash-dot red).

Table 1: RMS Displacements Daytime

Building	*.1 - 1.0 Hz*	*1-10 Hz*
LIGO Standard	1.64 e-07 m	0.095 e-07 m
Building 20	1.16	14.2
Building 24	1.52	21.7
Building WW15	1.97	4.56
Building NW13	1.07	11.7
Lincoln Labs	1.37	0.71

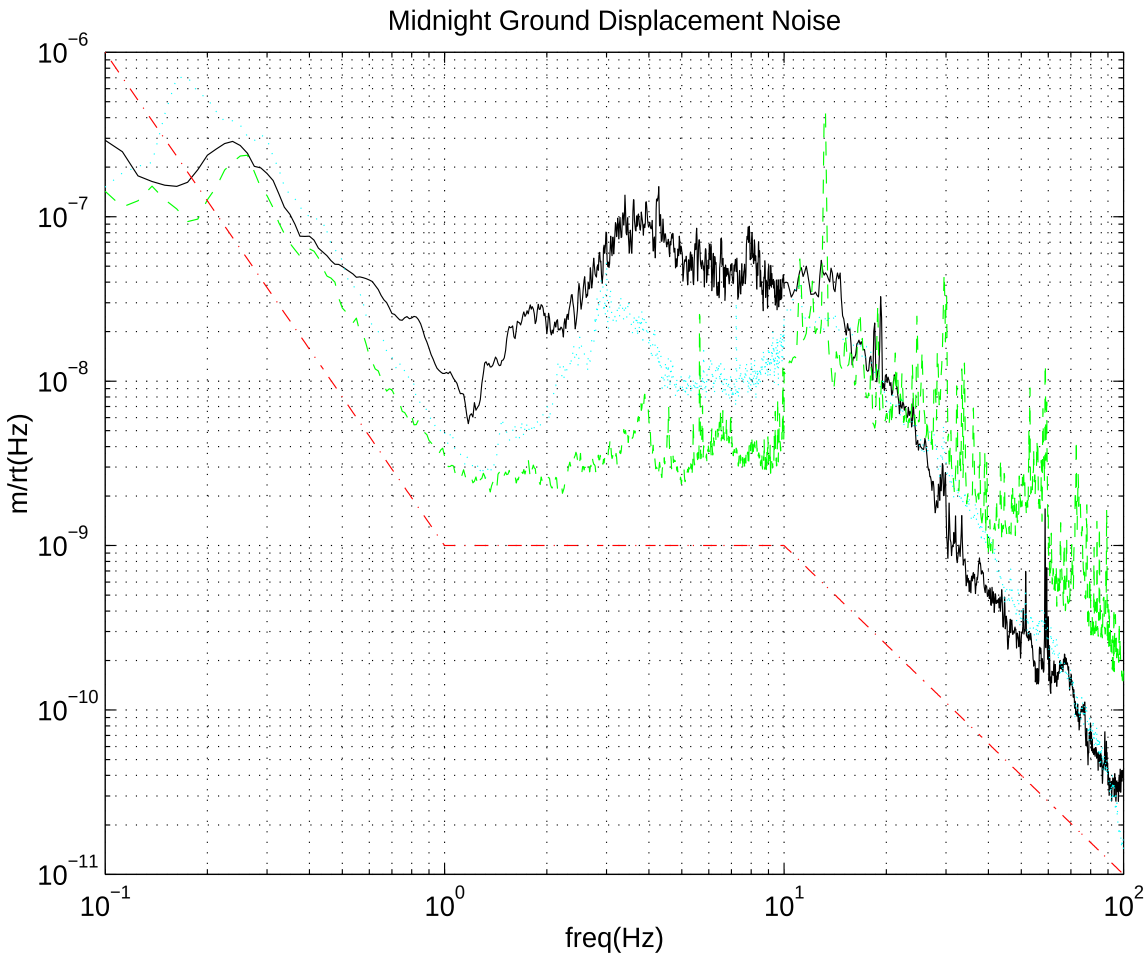

Figure 6: Displacement power spectra calculated from the time series of Figure 4. Building 20 (solid black), WW15 (dotted cyan), Lincoln Labs (dashed green), and the LIGO standard (dash-dot red).

Table 2: RMS Displacements Midnight

Building	*.1 - 1.0 Hz*	*1-10 Hz*
LIGO Standard	1.64 e-07 m	0.095 e-07m
Building 20	1.11	5.31
Building 24	1.70	6.55
Building WW15	1.98	1.38
Building NW13	0.790	6.84
Lincoln Labs	0.787	0.391

6 ADDENDUM: MEASUREMENTS IN NW17

Figure 7 shows the results from measurements made in mid-december in building NW17, close to the freight elevator, on the basement floor. The same instrumentation was used as for the previous measurements, and the measurements were made from 4pm-6pm on December 11. The spectra show a spectrum and an integral roughly the same as that for Building 20, with a peak at 9 Hz which would be quite significant for servo design. All spectra were taken in the afternoon. NW17 does not represent any improvement in the seismic environment over Building 20.

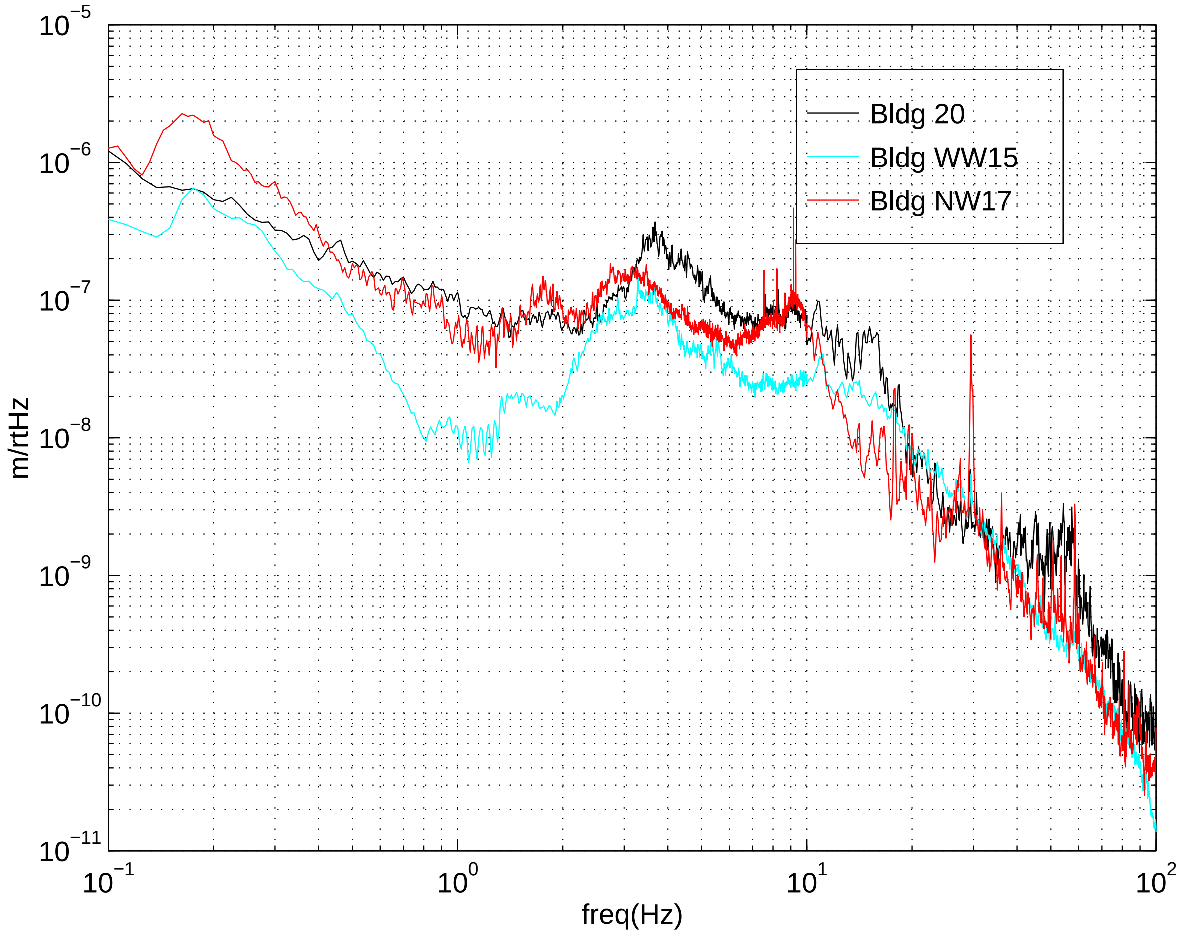

Figure 7: Addendum Displacement power spectra. NW17 is largely overlapping the Building 20 curve; the WW15 curve is at the bottom.