ESTABLISHING ACCEPTABLE GROUND MOTION AT THE TDA METROLOGY LABORATORY, AUSTIN, TEXAS

by

Jeffrey G. Paine, Ph.D.
Research Scientist
Bureau of Economic Geology
The University of Texas at Austin

Mail address:
University Station, Box X
Austin, Texas 78713-8924

Street address:
J. J. Pickle Research Campus, Building 130
10100 Burnet Road
Austin, Texas 78758-4445

jeff.paine@beg.utexas.edu

Report prepared for the Texas Department of Agriculture
under contract number UTA01-492

August 2001

INTRODUCTION

In August 2001, researchers at the Bureau of Economic Geology (Bureau) conducted a geophysical investigation for the Texas Department of Agriculture (TDA) to establish vibration characteristics at the Metrology Laboratory (fig. 1) for future comparison with proposed sites. We employed a vibration-monitoring instrument to establish ground-motion characteristics at the laboratory under a representative range of conditions. Tasks included recording ground motion at the laboratory, analyzing recorded data to determine velocities, accelerations, and frequency characteristics in the vertical and horizontal directions, and comparing ground motion recorded inside and outside the laboratory under representative conditions.

METHODS

We purchased a seismograph designed to monitor ground and building vibrations in three orthogonal directions (one vertical axis and two horizontal axes). This instrument, the VMS-200S built by Thomas Instruments Inc. (fig. 2), consists of a triaxial geophone that responds to ground motion in three directions simultaneously and a recording box that measures that ground motion 1,024 times per second. The VMS-200S records ground motion during “events” as long as 10 seconds (s) and can be triggered manually or automatically using threshold sounds or ground motion. It records ground motion in the frequency range of 2 to 250 Hz with magnitudes ranging from 0 to 289 mm/s. Resolution is 0.127 mm/s. The instrument requires calibration once a year through comparison with accelerometers.

The electromagnetic mechanism in the motion-sensing instrument produces a voltage signal that is recorded by the seismograph. The seismograph software converts the recorded voltage for each sensor into a velocity for that direction. The three most critical ground-motion parameters are velocity, acceleration, and frequency, all of which can be calculated from the recorded data. Velocity is directly related to the sensor output. Acceleration is the change in velocity recorded from one sample to the next during an event. Oversimplified, frequency is the number of times

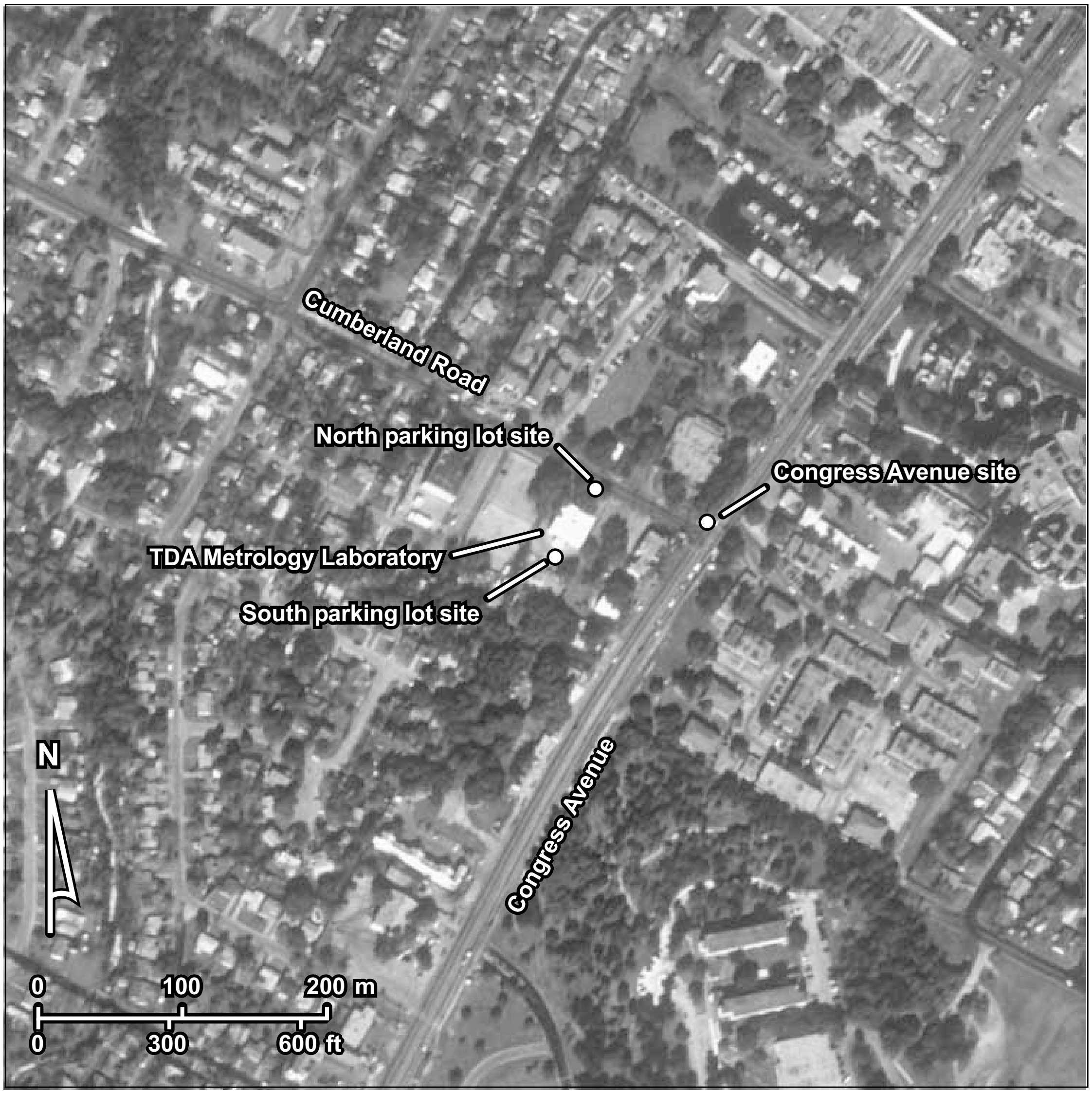

Figure 1. Aerial photographic map of the TDA Metrology Laboratory showing the Congress Avenue, north parking lot, and south parking lot measurement sites. Aerial photograph taken on January 28, 1995 (from Texas Natural Resources Information System).

Figure 2. Photograph of the VMS-200S Vibration Monitoring System manufactured by Thomas Instruments Inc. This instrument was used to measure ground motion inside and outside the Metrology Laboratory. Photograph by David M. Stephens.

per second that an oscillating particle returns to its original position during an event. In general, seismically quiet sites will have low velocities and low accelerations in all three orthogonal directions.

On August 17, 2001, we recorded 25 ground-motion events in and around the Metrology Laboratory. Outdoor measurements were made near the sidewalk adjacent to the north parking lot, on the parking lot south of the laboratory, and adjacent to Congress Avenue north of the Cumberland Road intersection (fig. 1). Indoor measurements were made on the floors of the Large-Mass Laboratory (LML), the Small-Mass Laboratory (SML), and the Volume Laboratory (VL) during normal working hours and representative staff activities. We exported data recorded by the instrument to a portable computer and determined peak velocities and accelerations and dominant frequencies for each ground-motion event using the software WIN200S supplied with the instrument. The software employed Fourier transforms to calculate the contribution of various frequencies to the ground motion recorded in each direction.

RESULTS

We analyzed the calculated velocities, accelerations, and dominant frequencies of ground motion to compare the characteristics of locations inside and outside the Metrology Laboratory. We grouped these measurements by location to illustrate similarities and differences among the sites and recorded events.

Outdoor Sites

The outdoor sites included the north parking lot, the south parking lot, and Congress Avenue (fig. 1). In general, ground motion at these sites during typical daytime activities were at or below the sensitivity of the instrument. The instrument was manually triggered for all events recorded at the north parking lot site because the ground motion was insufficient to automatically trigger the instrument to record. Peak velocities recorded during events 1, 2, and 3 were 0.2 mm/s or less for the vertical and horizontal components (fig. 3 and table 1). Peak accelerations during these same events were also very low, reaching less than 0.04 g (less than 4 percent of the gravitational acceleration) (fig. 4 and table 2).

Velocity and acceleration measurements were similarly low on the south parking lot. Velocity for each component direction was less than 0.2 mm/s and acceleration in each direction was less than 0.04 g. These measurements were made both in the central area of the parking lot (event 8) and near an operating air conditioner (event 9).

Higher noise levels were recorded along Congress Avenue less than 100 m from the laboratory (fig. 1). At this site, noise generated by passing vehicles was sufficient to automatically trigger the instrument. Peak velocities recorded during small-vehicle traffic (event 4) were 0.2 to 0.3 mm/s for each of the component directions and were as high as 0.5 mm/s when all directions

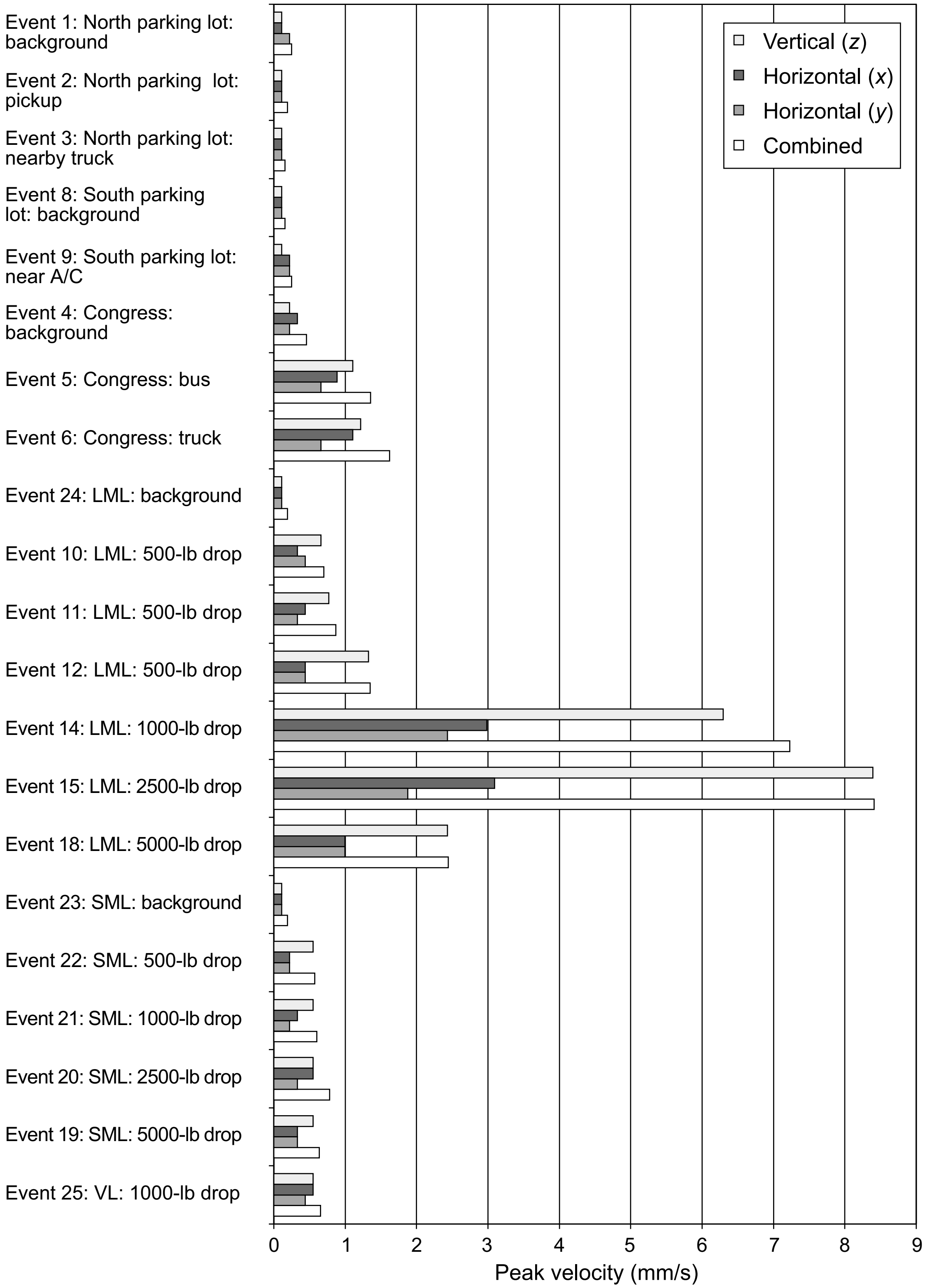

Figure 3. Peak ground velocity recorded in three orthogonal directions during 21 selected events in and near the Metrology Laboratory on August 17, 2001. LML = Large-Mass Laboratory; SML = Small-Mass Laboratory; VL = Volume Laboratory. All weight drops occurred in the LML.

Table 1. Peak velocities for selected events in and near the TDA Metrology Laboratory. Outdoor locations shown on fig. 1. LML = Large-Mass Laboratory; SML = Small-Mass Laboratory; VL = Volume Laboratory.

		Peak velocities (mm/s)			
Event	**Type**	**Vertical**	**Horiz. (*x*)**	**Horiz. (*y*)**	**Combined**
1	North parking lot-background	0.11	0.11	0.22	0.25
2	North parking lot-pickup	0.11	0.11	0.11	0.19
3	North parking lot-nearby truck	0.11	0.11	0.11	0.16
8	South parking lot-ambient	0.11	0.11	0.11	0.16
9	South parking lot-near A/C	0.11	0.22	0.22	0.25
4	Congress-background	0.22	0.33	0.22	0.46
5	Congress-bus	1.10	0.88	0.66	1.35
6	Congress-truck	1.21	1.10	0.66	1.62
24	LML-background	0.11	0.11	0.11	0.19
10	LML-500 lb	0.66	0.33	0.44	0.70
11	LML-500 lb	0.77	0.44	0.33	0.87
12	LML-500 lb	1.33	0.44	0.44	1.35
14	LML-1000 lb	6.29	2.98	2.43	7.23
15	LML-2500 lb	8.39	3.09	1.88	8.41
18	LML-5000 lb	2.43	0.99	0.99	2.44
23	SML-background	0.11	0.11	0.11	0.19
22	SML-500 lb	0.55	0.22	0.22	0.57
21	SML-1000 lb	0.55	0.33	0.22	0.60
20	SML-2500 lb	0.55	0.55	0.33	0.78
19	SML-5000 lb	0.55	0.33	0.33	0.63
25	VL-1000 lb	0.55	0.55	0.44	0.65

were combined (fig. 3 and table 1). Peak accelerations of 0.04 g were similar to those recorded at the laboratory parking lots (fig. 4 and table 2). Noise levels at this site increased with vehicle size; a passing bus (event 5) produced peak velocities of 0.7 to 1.1 mm/s and peak accelerations of 0.03 to 0.06 g, and a passing truck (event 6) increased the peak velocities to 0.7 to 1.2 mm/s with similar peak accelerations. Horizontal velocities and accelerations were nearly as high or higher than the corresponding vertical component.

Examining only the vertical ground-motion component, ground speeds recorded over one second on the north and south parking lots (fig. 5) and along Congress Avenue (fig. 6) show that vehicle traffic on Congress Avenue produces recordable, coherent ground motion whereas

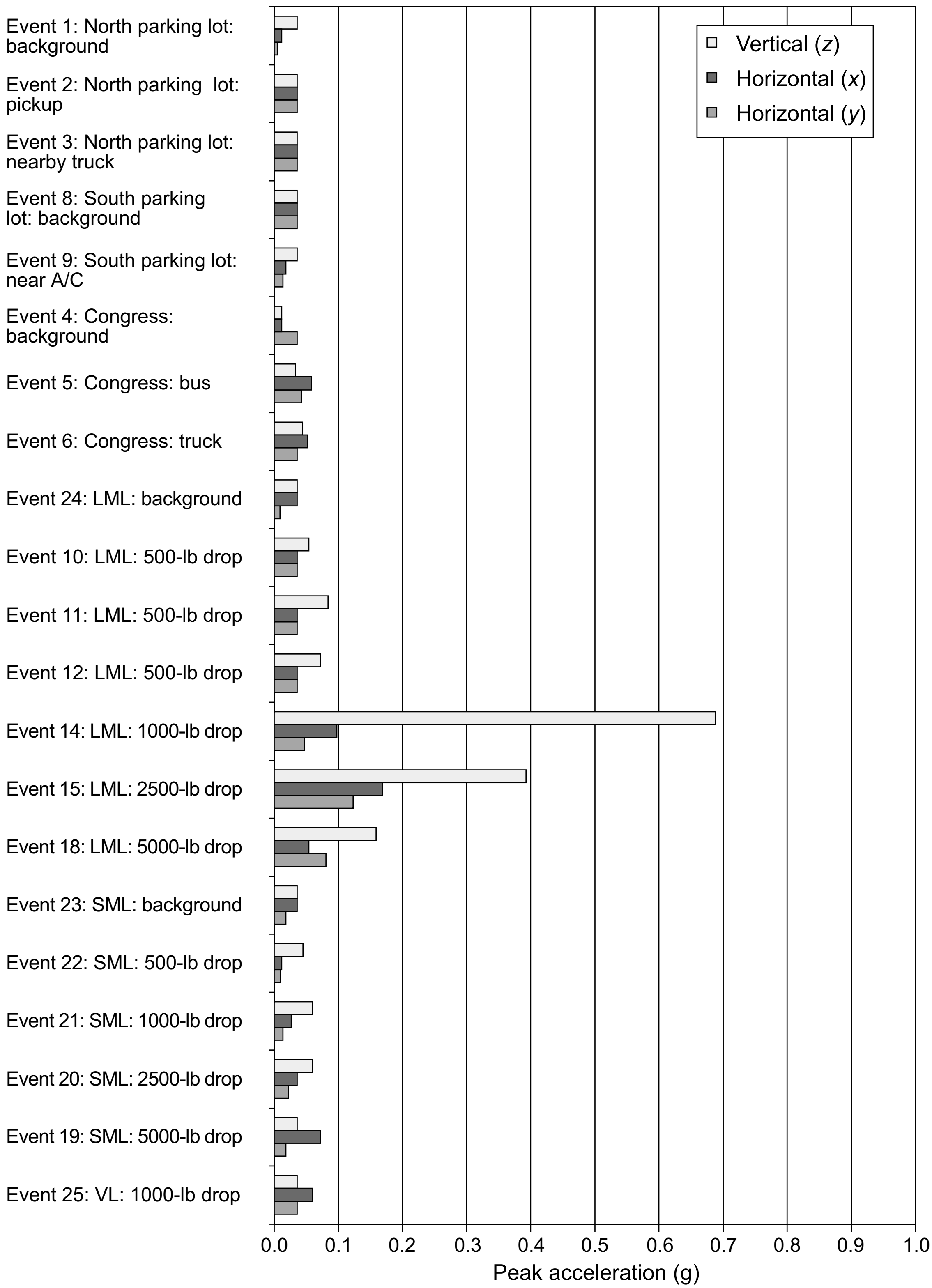

Figure 4. Peak ground acceleration recorded in three orthogonal directions during 21 selected events in and near the Metrology Laboratory on August 17, 2001. LML = Large-Mass Laboratory; SML = Small-Mass Laboratory; VL = Volume Laboratory. All weight drops occurred in the LML.

Table 2. Peak accelerations for selected events in and near the TDA Metrology Laboratory. Outdoor locations shown on fig. 1. LML = Large-Mass Laboratory; SML = Small-Mass Laboratory; VL = Volume Laboratory.

		Peak acceleration (g)		
Event	**Type**	**Vertical**	**Horiz. (*x*)**	**Horiz. (*y*)**
1	North parking lot-background	0.036	0.012	0.005
2	North parking lot-pickup	0.036	0.036	0.036
3	North parking lot-nearby truck	0.036	0.036	0.036
8	South parking lot-ambient	0.036	0.036	0.036
9	South parking lot-near A/C	0.036	0.018	0.014
4	Congress-background	0.012	0.012	0.036
5	Congress-bus	0.033	0.058	0.043
6	Congress-truck	0.044	0.052	0.036
24	LML-background	0.036	0.036	0.009
10	LML-500 lb	0.054	0.036	0.036
11	LML-500 lb	0.084	0.036	0.036
12	LML-500 lb	0.072	0.036	0.036
14	LML-1000 lb	0.688	0.098	0.047
15	LML-2500 lb	0.393	0.169	0.123
18	LML-5000 lb	0.159	0.054	0.081
23	SML-background	0.036	0.036	0.018
22	SML-500 lb	0.045	0.012	0.010
21	SML-1000 lb	0.060	0.027	0.014
20	SML-2500 lb	0.060	0.036	0.022
19	SML-5000 lb	0.036	0.072	0.018
25	VL-1000 lb	0.036	0.060	0.036

background noise around the laboratory is at or below the measurement threshold of the instrument (0.1 mm/s). Light traffic on Congress Avenue generates low amplitude ground oscillation (event 4, fig. 6a). These amplitudes increase with vehicle size; buses and trucks produce ground oscillations at similar frequencies but higher ground speeds (events 5 and 6, fig. 6b and c). The recorded signal is composed of a range of frequencies, but the dominant frequencies of each event are similar (41 Hz for the bus and 35 Hz for the truck).

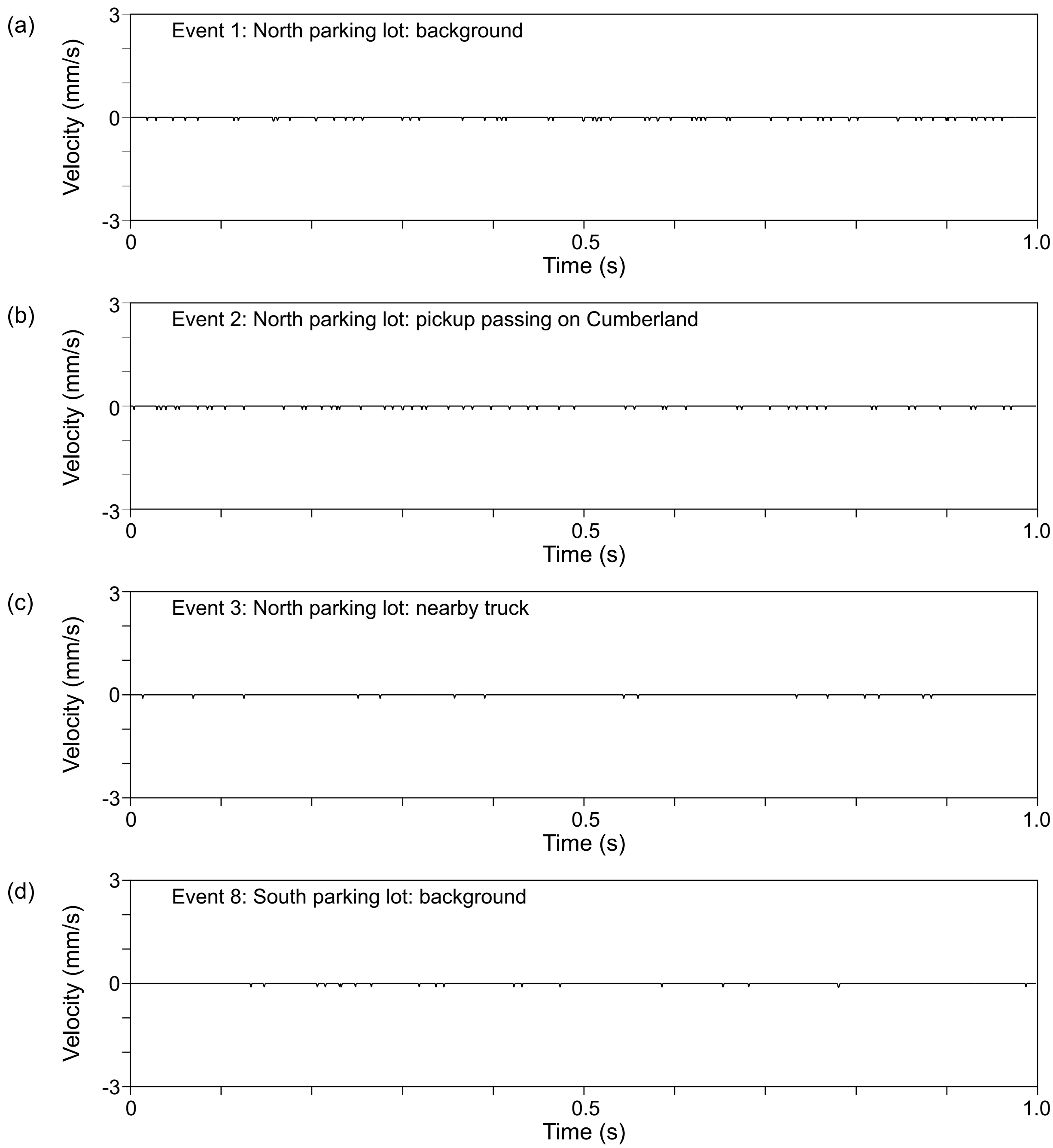

Figure 5. Vertical ground speed recorded over a 1-s interval at the north and south parking lot sites (fig. 1). (a) north parking lot under normal background conditions; (b) north parking lot while a pickup drives by on Cumberland Road; (c) north parking lot during a truck departure from the adjacent business; and (d) south parking lot under normal background conditions.

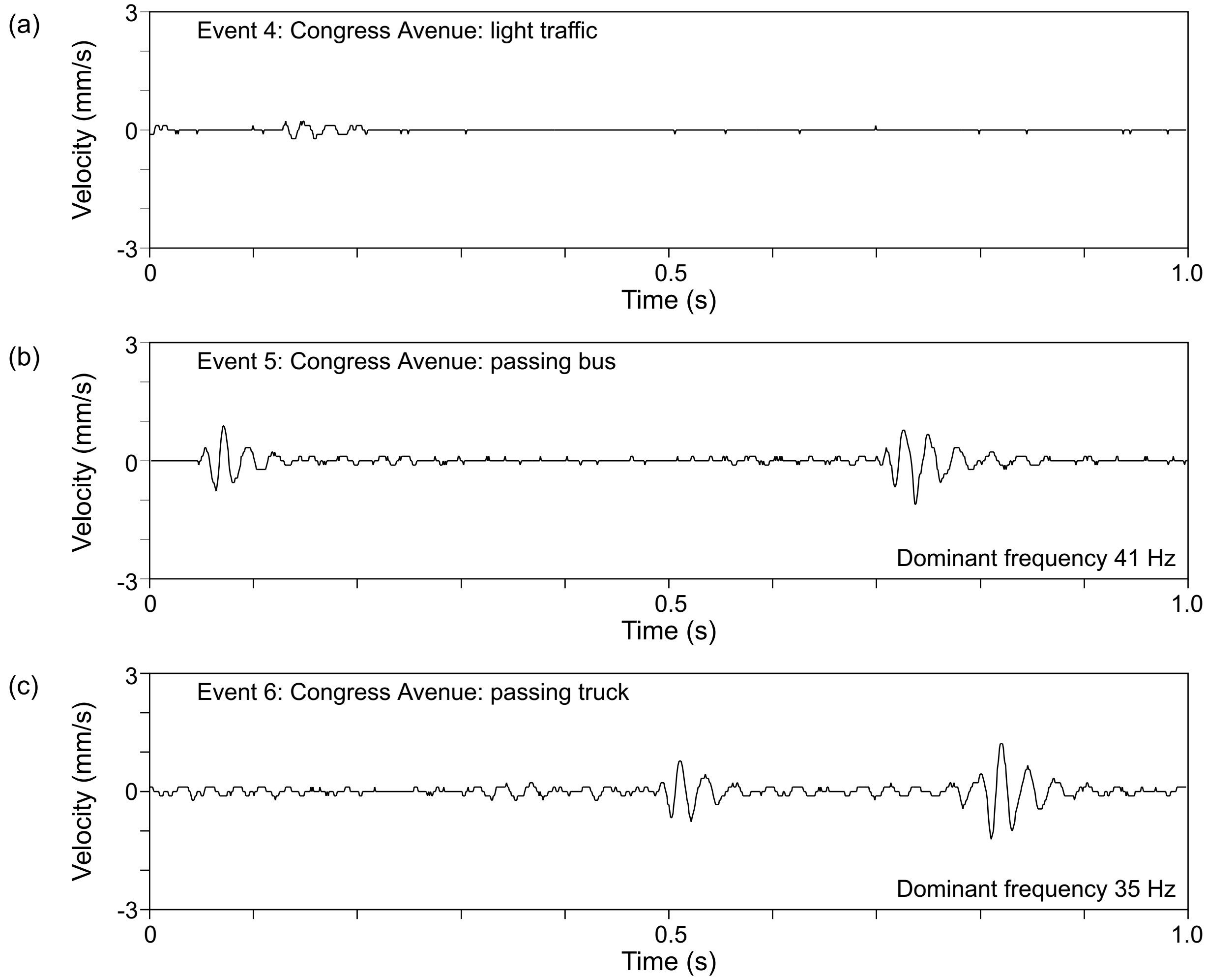

Figure 6. Vertical ground speed recorded over a 1-s interval at the Congress Avenue site (fig. 1) during passage of (a) normal light traffic; (b) a bus; and (c) a truck.

Large-Mass Laboratory

We recorded 7 ground-motion events in the LML during normal background activities without hoist operation and during the lowering of masses (500, 1,000, 2,500, and 5,000 lb) onto the floor of the LML by hoist. Peak velocities during background activities (event 24) were low, not exceeding 0.1 mm/s in the vertical or horizontal directions (table 1 and fig. 3). Peak accelerations were below 0.04 g (table 2 and fig. 4), similar to those recorded on the parking lots. Background ground motion was too low to trigger the instrument to record automatically.

In contrast to the low levels of background noise, ground motion recorded in the LML during the lowering of the large masses was the highest recorded in and near the laboratory. Peak velocities for the series of mass drops ranged from 0.7 to 8.4 mm/s in the vertical direction and 0.3 to 3.1 mm/s in the horizontal directions (table 1 and fig. 3). The 2,500-lb mass (event 15) produced the highest peak velocities in the vertical direction. For each event, vertical velocities were much greater than horizontal velocities, showing that the dominant ground-motion component during mass drops is vertical.

Peak accelerations were also much higher during mass drops than those recorded during events at other indoor and outdoor sites (table 2 and fig. 4). Vertical accelerations ranged from 0.05 to 0.69 g (5 to 69 percent of the gravitational acceleration) and were highest during the 1,000-lb mass drop (event 14). Horizontal accelerations were lower, ranging from 0.04 to 0.17 g.

Continuous displays of vertical velocity during the 1-s interval that includes the mass drop clearly show the difference between ground motion during background activities (event 24, fig. 7a) and ground motion during mass drops (events 12, 14, 15, and 18, fig. 7b through e). For the mass drops, velocities are at background levels until the mass strikes the floor, at which time large oscillations begin and continue for a few tenths of a second. Dominant vibration frequencies recorded during the mass drops were 66 to 84 Hz.

Vertical movement dominates the ground motion generated by the dropped masses. Vertical and horizontal ground speeds recorded during the 2,500-lb mass drop (event 15) show that the shape and duration of the event is similar for all components, but the velocities are higher for the vertical component at all times (fig. 8). Additionally, small reverberations continue for several tenths of a second beyond the end of the main drop event at about 0.7 s.

In comparison with the large events recorded along Congress Avenue, the LML mass drops have higher peak velocities, have ground motion that is more dominantly vertical, and have somewhat higher dominant frequencies.

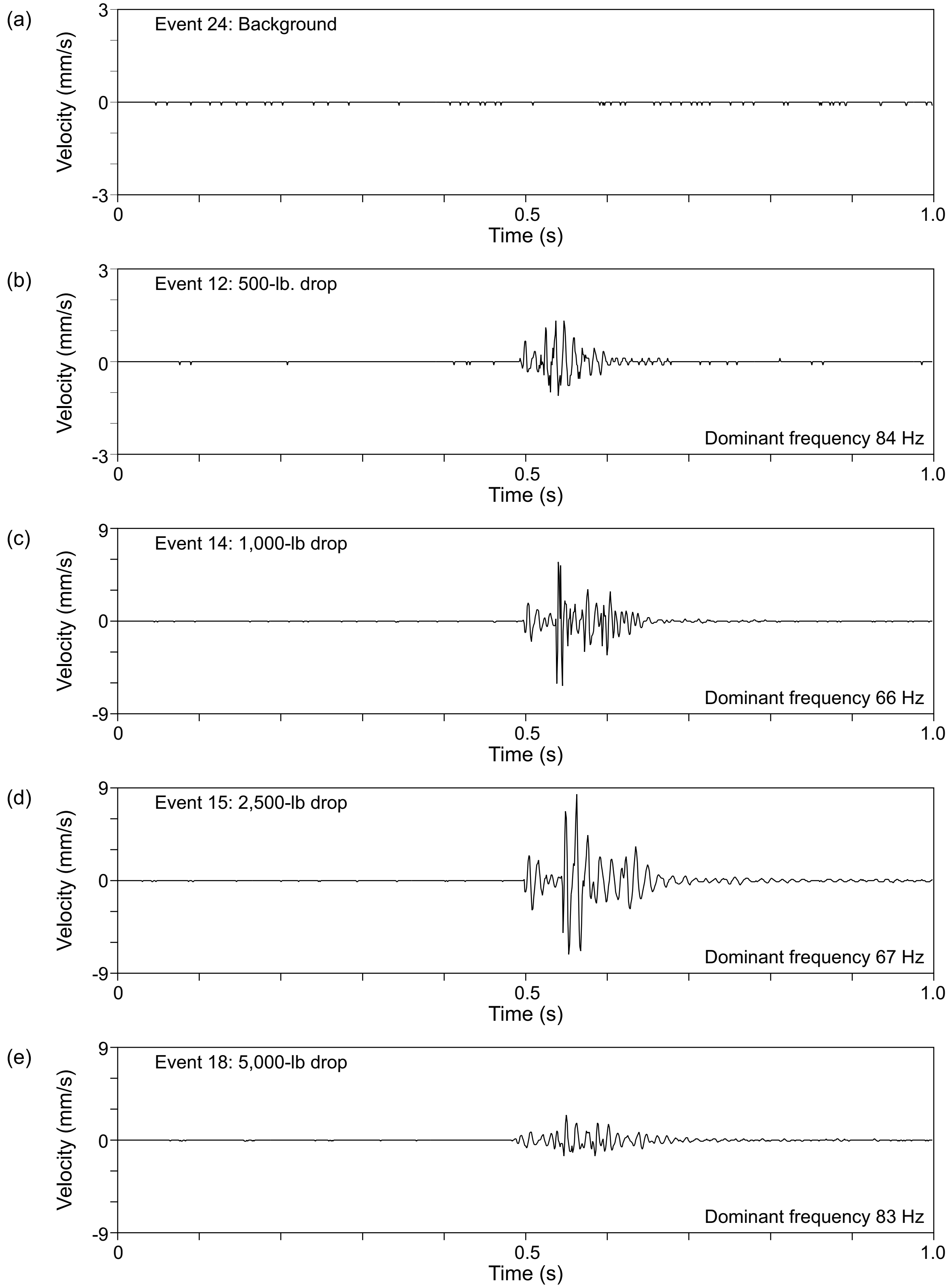

Figure 7. Vertical ground speed recorded over a 1-s interval in the LML (a) during normal laboratory activities but no hoist operation and, (b) through (e), during the lowering of 500-, 1,000-, 2,500-, and 5,000-lb weights onto the floor.

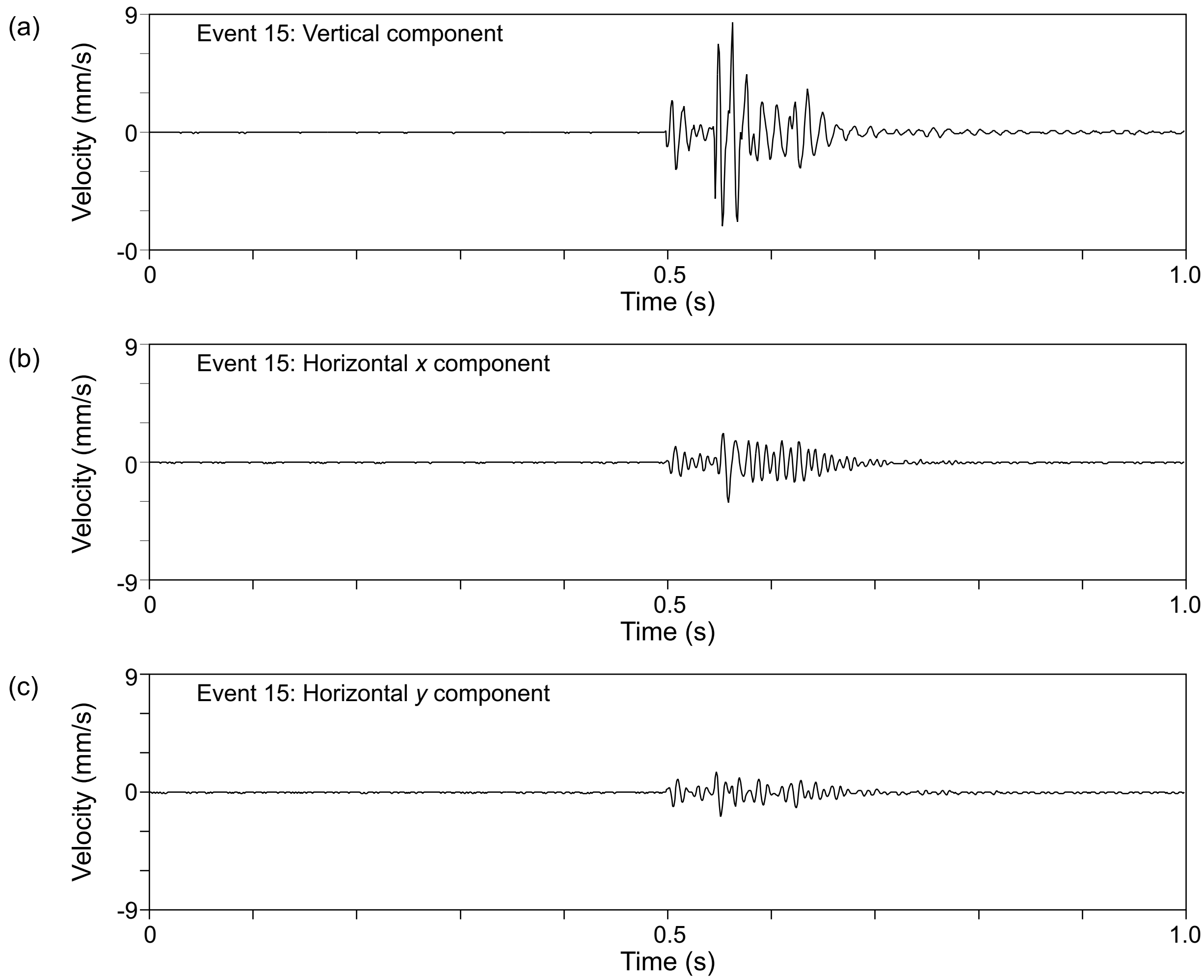

Figure 8. Vertical and horizontal ground speeds recorded over a 1-s interval in the LML during the lowering of a 2,500-lb weight onto the floor.

Small-Mass Laboratory

We recorded 5 events in the SML during normal background activity at the laboratory and during a succession of mass drops in the LML using 500-, 1,000, 2,500-, and 5,000-lb masses. Peak velocities were generally lower than those in the LML and at the Congress Avenue site, but higher than those recorded on the north and south parking lots (table 1 and fig. 3). Peak velocities in the SML during background activity (event 23) were 0.1 mm/s in the vertical and horizontal directions, similar to peak values recorded outside the building. Peak accelerations were less than 0.04 g in the vertical and in one horizontal direction and were less than 0.02 g in the other horizontal direction (table 2 and fig. 4). These peak accelerations are also similar to those recorded under background conditions in the LML and outside on the parking lots. The background noise in the SML was insufficient to automatically trigger the instrument on its most sensitive trigger setting.

Dropping masses onto the floor in the LML produced recordable events in the SML. Ground motion associated with these events was sufficient to trigger the instrument to record, but was not as large as that recorded in the LML during drops of the same mass. Peak vertical velocities in the SML during the mass drops were 0.6 mm/s; peak horizontal velocities were generally lower, ranging from 0.2 to 0.6 mm/s (events 19 through 22, table 1 and fig. 3). Peak vertical acceleration increased from 0.05 to 0.06 g as the dropped mass increased from 500 to 2,500 lb, but the largest mass drop (event 19) produced a peak vertical acceleration of only 0.04 g (table 2 and fig. 4). This mass drop was associated with a relatively large lateral acceleration of 0.07 g, perhaps because the mass was not lowered vertically to the floor. For all other mass-drop measurements in the SML, vertical accelerations were greater than horizontal accelerations.

Vertical velocities recorded over a 1-s window for each of the SML events show that only the dropped weights produced coherent noise (fig. 9). The duration of the recordable event increased with drop mass from about 0.1 s for the 500-lb drop to more than 0.5 s for the 5,000-lb drop, whereas the peak velocities remained nearly the same for all masses. Analysis of the ground motion associated with the 2,500-lb mass indicated a dominant frequency of 65 Hz.

Volume Laboratory

We recorded one event in the VL associated with the lowering of a 1,000-lb mass to the floor in the LML. Peak vertical velocity during this event was 0.6 mm/s (event 25, table 1 and fig. 3), the same as the peak vertical velocity recorded in the SML during a similar mass drop.

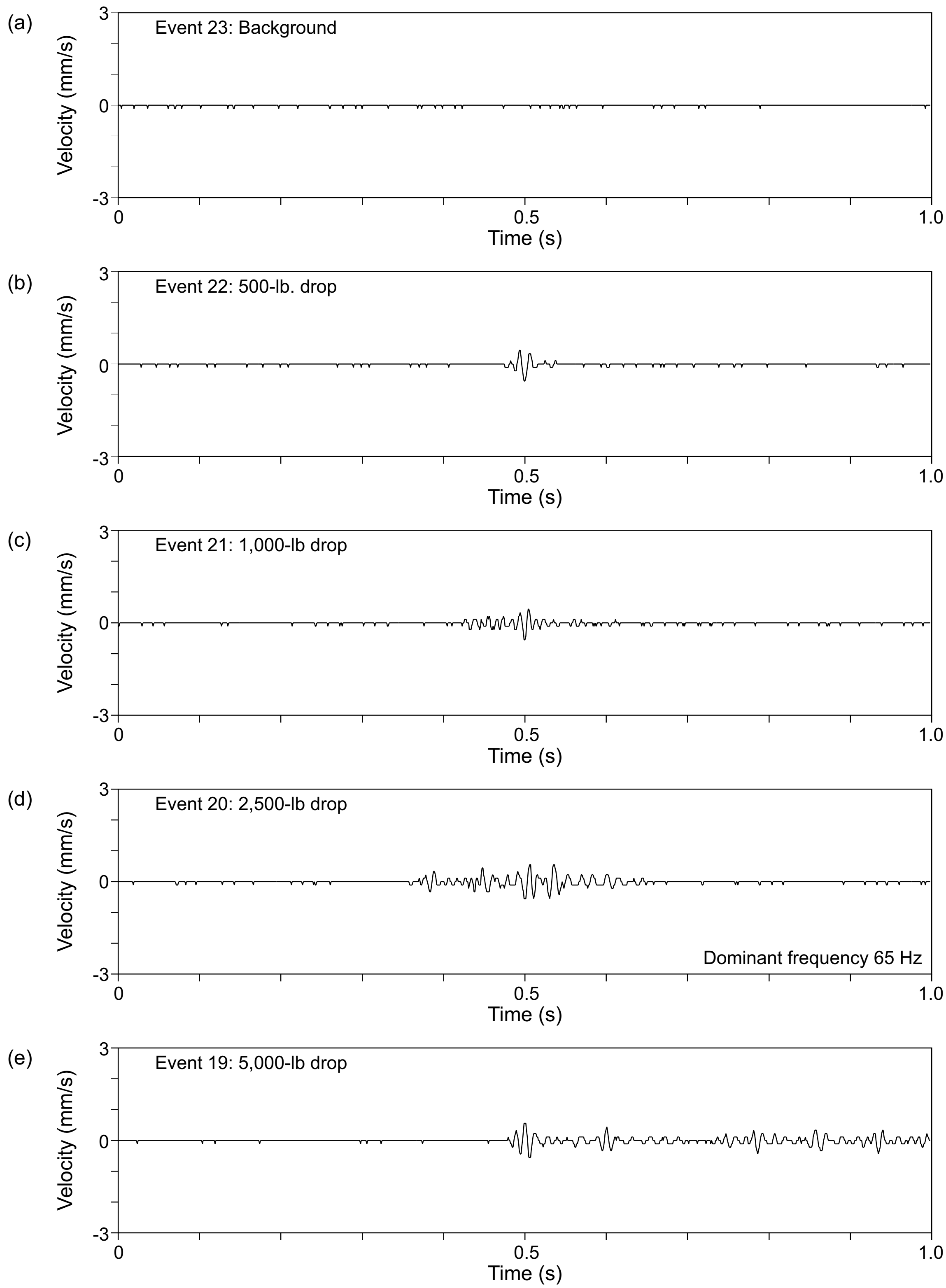

Figure 9. Vertical ground speed recorded over a 1-s interval in the SML (a) during normal laboratory activities but no crane operation and, (b) through (e), during the lowering of 500-, 1,000-, 2,500-, and 5,000-lb weights onto the floor in the LML.

Peak horizontal velocities were 0.4 to 0.6 mm/s, higher than those recorded in the SML at about the same distance from the mass drop. When all velocity components are combined, the peak velocity in the VL was 0.65 mm/s for the 1,000-lb drop compared to 0.6 mm/s in the SML for the same mass. Peak accelerations in the VL were 0.04 g in the vertical direction and 0.04 to 0.06 g in the horizontal directions (table 2 and fig. 4). Vertical velocities recorded during the mass drop are similar in amplitude, frequency, and duration to those recorded in the SML for the same mass (compare figs. 9c and 10).

DISCUSSION AND CONCLUSIONS

Vibration measurements obtained inside and outside the Metrology Laboratory suggest that ambient conditions produce relatively low vertical and horizontal velocities (0.1 mm/s or less) and accelerations (0.04 g or less) at the lab. Much higher velocities and accelerations are produced within the laboratory by activities such as movement of large masses, during which time vertical velocities as high as 8.4 mm/s and accelerations as high as 0.7 g (70 percent gravity) were recorded. Heavy vehicles such as trucks and buses also produce relatively large ground motions along Congress Avenue, but are normally distant enough to not be recordable inside or outside the laboratory. Ground motion generated by heavy vehicles has a dominant frequency of 35 to 41 Hz.

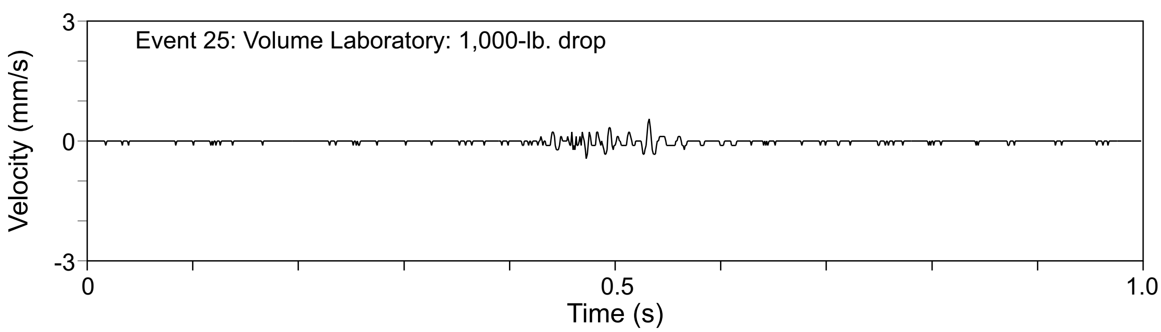

Figure 10. Vertical ground speed recorded over a 1-s interval in the VL during the lowering of a 1,000-lb weight onto the floor in the LML.

Masses dropped in the LML produce high vertical and horizontal velocities in the LML, but much lower velocities in the adjacent SML and VL. Ground motion produced by the mass drops is dominantly vertical, having a dominant frequency within the laboratory of 66 to 84 Hz. Peak vertical velocities are lower (by a factor of 2 to 10) in the SML and VL than they are in the LML for similar mass drops, illustrating the effect of distance from the noise source in the reduction of peak velocities.

Sensitive laboratory devices appear to operate acceptably during normal activities at the laboratory and under most traffic conditions. During these conditions, noise at the site is insufficient to automatically trigger the vibration-monitoring instrument and recorded vibrations are at or below the sensitivity of the instrument (velocities of 0.1 mm/s or less). Larger events, such as those triggered by the mass drops, produce much higher vertical and horizontal velocities that are sufficiently strong to automatically trigger the recording instrument and also to degrade the performance of sensitive laboratory devices. The lowest peak vertical velocity measured during a mass drop was 0.7 mm/s in the LML, 0.6 mm/s in the SML, and 0.6 mm/s in the VL. Threshold vibration velocity above which the laboratory devices are known to be affected is thus 0.6 mm/s, the lowest vertical velocity measured during a mass drop. Lower, unobserved peak vertical velocities may also impact laboratory devices. Background measurements inside and outside the laboratory suggest that the instruments can operate at peak velocities of 0.1 mm/s or lower. Further characterization of the ambient vibration conditions at the laboratory will require a more sensitive recording instrument.

RECOMMENDATIONS

If more information is needed to characterize the vibration characteristics of the laboratory (or other proposed laboratory sites) during “quiet” times, then triaxial accelerometers can be used that operate at a lower acceleration threshold and over a higher range of accelerations. Information collected during this study suggests that the vertical motion threshold is between 0.1

(the peak velocity recorded during quiet times) and 0.6 mm/s (the lowest peak velocity recorded during a mass drop). A more sensitive instrument is required to accurately characterize ground motion below 0.1 mm/s and 0.04 g.

The isolation of the foundation of the SML from the rest of the laboratory may have helped reduce horizontal and vertical velocities observed in the SML, but it is also clear that distance from the noise source is significant. Ground motion in the VL (not isolated from the LML) was similar to that recorded in the SML for the same drop mass. It would be helpful in the next laboratory to place the instruments that are most sensitive to vibration the farthest from potential noise sources such as large-mass hoists, heavy machinery, and large-vehicle traffic.

AVAILABLE RESOURCES

Numerous books, articles, and reports have been written on various aspects of vibration monitoring and control. The books below are useful collections of articles on all types of vibration.

Gazetas, George, and Selig, Ernest T. (editors), 1985, Vibration problems in geotechnical engineering: American Society of Civil Engineers, New York, 303 pp.

Harris, Cyril M., 1996, Shock and vibration handbook: McGraw-Hill, New York, not consecutively paginated.