COMPARING GROUND MOTION AT THE CURRENT AND PROPOSED SITES OF THE METROLOGY LABORATORY

by

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INTRODUCTION

Researchers at the Bureau of Economic Geology (Bureau) conducted a geophysical investigation for the Texas Department of Agriculture (TDA) to establish ambient vibration characteristics at the current Metrology Laboratory and at a proposed site near Giddings, Texas. We (1) constructed an accelerometer-based instrument capable of measuring low-acceleration (less than 0.001 g) ground motion in three orthogonal directions simultaneously, (2) measured ground motion at Giddings under various conditions, (3) measured low-level ground motion at the current laboratory, and (4) measured ground motion at a representative shallow-bedrock site at the J. J. Pickle Research Campus (PRC) at The University of Texas at Austin. We compared the results of ground-motion tests at the Giddings site (where bedrock depth is greater than 10 m) to those from PRC to investigate the likely influence of bedrock depth on the suitability of the site for laboratory operation.

METHODS

Ground-motion monitoring at the Metrology Laboratory conducted in August 2001 demonstrated that commercial vibration-monitoring instruments such as the Thomas Instruments VMS-200S are adequate for measuring large ground motions caused by common laboratory activities such as moving large masses (Paine, 2001). This instrument proved insufficiently sensitive to accurately record very small ground motion that accompanies other laboratory activities that affect delicate instruments routinely used at the laboratory. To accurately measure and characterize smaller ground motion, we constructed an accelerometer-based sensor that consists of three accelerometers mounted orthogonally (one vertically and two horizontally) on a machined steel block (fig. 1). The accelerometers are connected to amplifiers that enhance the small signal produced by the piezoelectric material within the accelerometers. The signals are passed by cable to a Geometrics Smartseis seismograph, which records the signals from each accelerometer simultaneously and stores them for analysis.

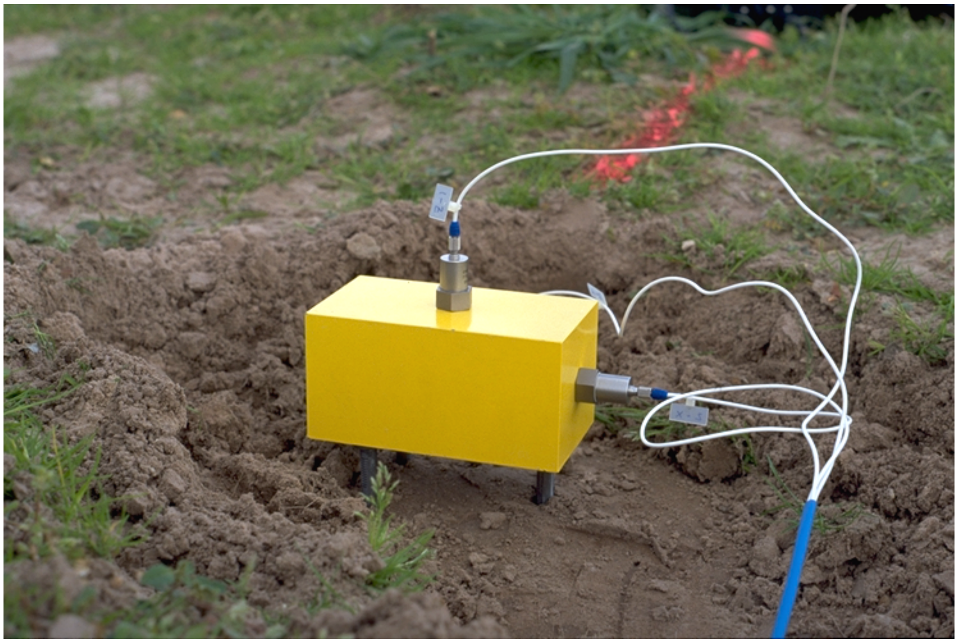

Figure 1. Photograph of vibration-monitoring instrument constructed for this project. Three highly sensitive accelerometers are mounted orthogonally on a machined steel block measuring about 15 cm long, 8 cm high, and 7.5 cm wide. The block is shown resting on 30-cm-long spikes driven into the ground at the Giddings site.

The accelerometers used for this study are model number 7752-1000 manufactured by Endevco. They have factory-calibrated sensitivities ranging from 1,152 to 1,182 millivolts (mV) per g; the accelerometers produce a voltage of 1,152 to 1,182 millivolts when accelerated by the force of gravity. Their voltage output is linearly related to acceleration over a wide range of acceleration values ranging from below 0.0001 to about 5 g. They measure acceleration to within 10 percent of its true magnitude at frequencies ranging from less than 0.1 cycles per second (Hz) to more than 1,000 Hz and are thus well suited for ground-motion studies. We tested the ability of the seismograph to accurately record accelerometer signals by recording a known voltage signal from an electronic pulse generator at the Center for Electromechanics at The University of Texas at Austin.

On November 26, 2001, we recorded 24 ground-motion events at the proposed laboratory site on land owned by the Texas Youth Commission southeast of Giddings, Texas (fig. 2). These events included background measurements as well as measurements taken while plowing around

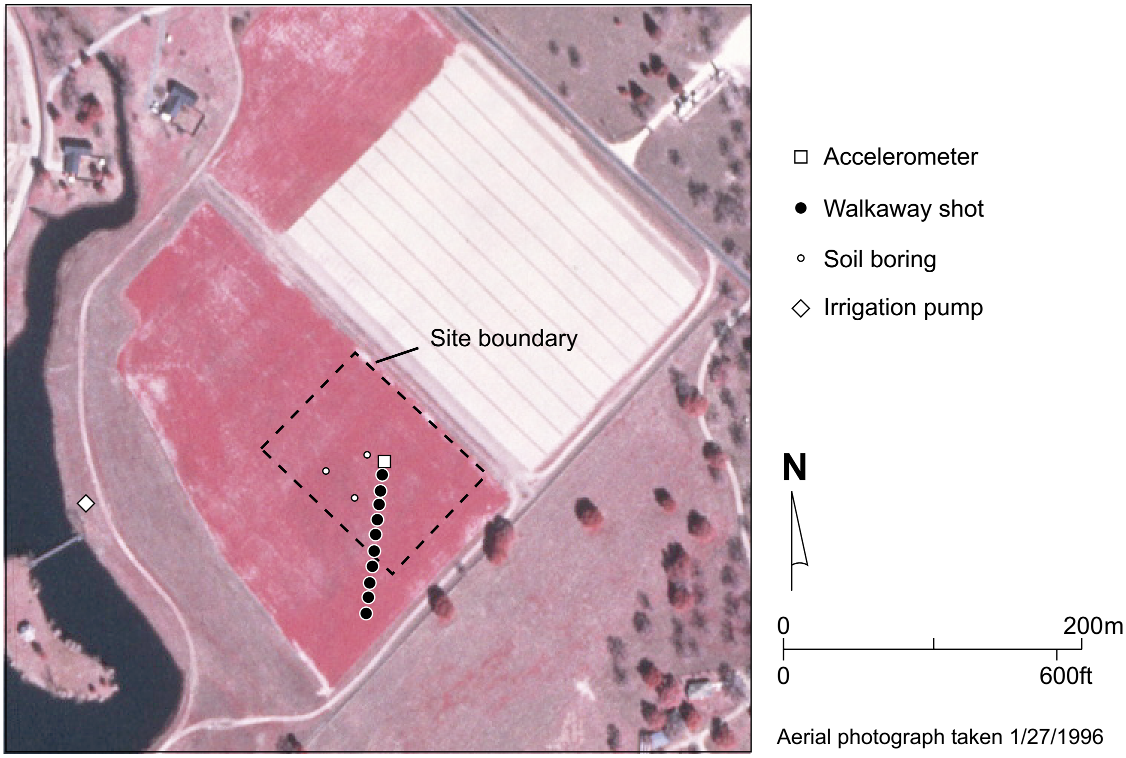

Figure 2. Aerial photographic map of the proposed laboratory site near Giddings, Texas. Aerial photograph taken on January 27, 1996 (from Texas Natural Resources Information System).

the perimeter of the proposed site, while operating an irrigation pump 200 m from the site, and while vehicular traffic passed the site along County Road 226. We also recorded ground motion induced by dropping a 230-kg, trailer-mounted weight at 10-m intervals between a distance of 10 and 100 m from the accelerometers. We used these measurements to compare the vibration characteristics of this site with other sites using a known source.

On November 29, we recorded 11 ground-motion events in the Small-Mass Laboratory (SML) at the current Metrology Laboratory in Austin, Texas. These measurements complemented those made in August 2001 by recording ground motion during smaller events and during background conditions that were below the sensitivity of the VMS-200S. We made measurements while there was no apparent noise source, during passage of a train, and while TDA staff moved a 2,500-lb mass in the Large-Mass Laboratory (LML).

On November 30, we recorded 24 ground-motion events at the PRC in Austin, Texas. These included background measurements and measurements taken using the trailer-mounted weight dropped at the same distances from the accelerometers as those at the Giddings site. Recent soil borings at the PRC have shown it to be a shallow-bedrock site where 9 to 70 inches of soil overlie rigid limestone bedrock (fig. 3).

We analyzed ground motion by downloading the seismograph records to disk, decoding each sample to recorded voltage, converting the voltage to acceleration, integrating the acceleration to velocity and the velocity to displacement for each event, calculating peak and root-mean-square (RMS) values for voltage, acceleration, velocity, and displacement, and exporting the values to a spreadsheet program (Excel) for plotting.

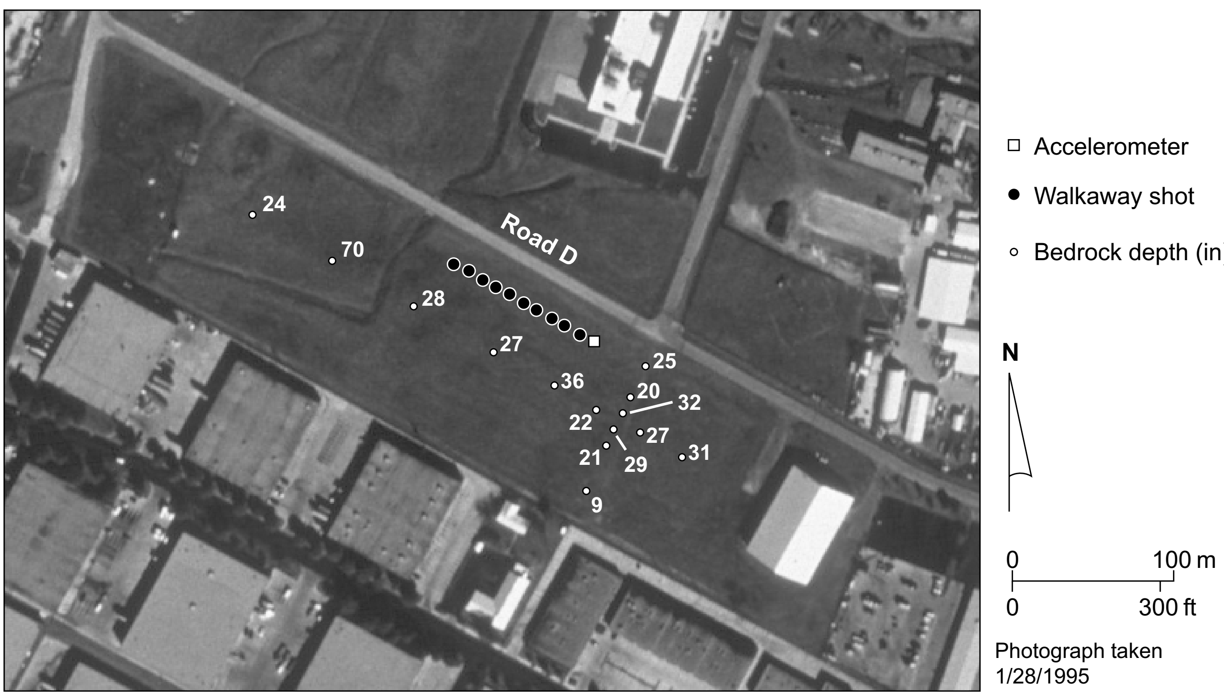

Figure 3. Aerial photographic map of the south end of the PRC site showing locations of soil borings, the accelerometer block, and shot locations for a walkaway noise survey. Aerial photograph taken on January 28, 1995 (from Texas Natural Resources Information System).

RESULTS

The earlier ground-motion study of the Metrology Laboratory using a less sensitive instrument revealed peak accelerations ranging from 0.01 to 0.69 g during various activities (Paine, 2001). These activities commonly disrupt laboratory measurements and are more than 10 times greater than the 0.001 g maximum acceleration recommended in the 1993 NCSL laboratory design manual. Lower accelerations that do not disrupt instrument operation were not measurable at the laboratory using the VMS-200S.

Metrology Laboratory

We returned to the laboratory with the accelerometer instrument to better characterize low-level vibration at that site. Ambient conditions were represented by three records acquired in the SML during working hours, but with no obvious heavy activity occurring. Background measurements, such as the vertical acceleration event depicted in fig. 4a, record peak accelerations of less than 0.004 m/s^2 and RMS accelerations less than 0.0009 m/s^2 in all three directions, well below the 0.001 g (0.0098 m/s^2) NCSL threshold (figs. 5 and 6). During background activities, peak and RMS accelerations are highest in the vertical direction. A train passing through the area several hundred meters west of the laboratory failed to increase peak or RMS accelerations above the values recorded for the three background events (figs. 5 and 6). Particularly later than 0.2 s into the event, the vertical acceleration record during train passage is similar to that recorded while no train was passing (fig. 4).

Much higher peak and RMS accelerations were recorded while the 2,500-lb mass was being moved in the LML (figs. 4, 5, and 6). Peak accelerations observed during the seven events recorded during mass movement ranged from 0.004 to 014 m/s^2 vertically and 0.002 to 0.005 m/s^2 horizontally. Vertical accelerations exceeded the 0.001-g threshold during five of the seven events (fig. 4), corroborating TDA staff reports of the inability to operate SML instru-

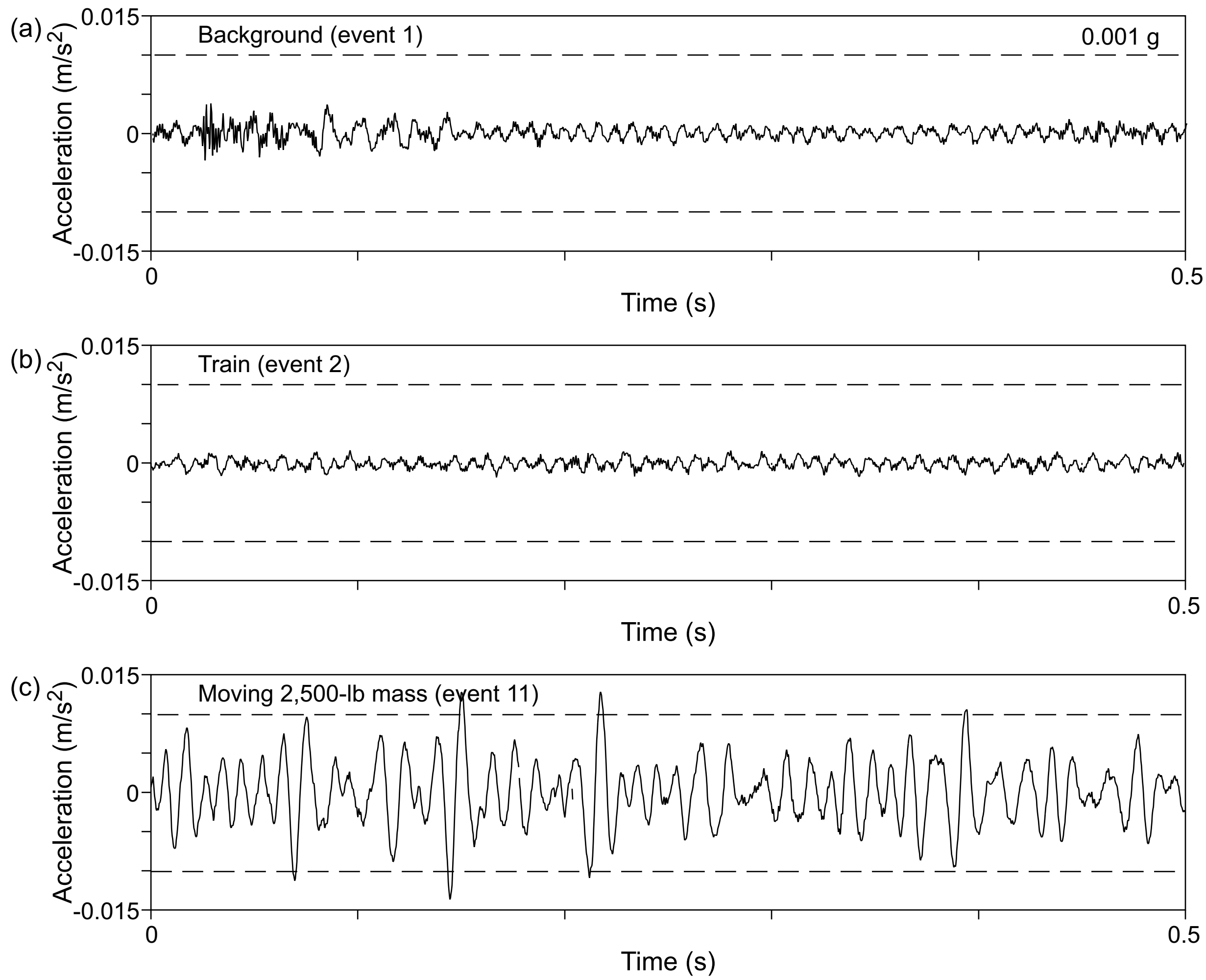

Figure 4. Vertical acceleration recorded over a 0.5-s interval in the SML at the Metrology Laboratory during (a) background activities; (b) passage of a train west of the site; and (c) moving a 2,500-lb mass using the crane in the LML. The dashed line denotes the NCSL guidelines for maximum allowable acceleration.

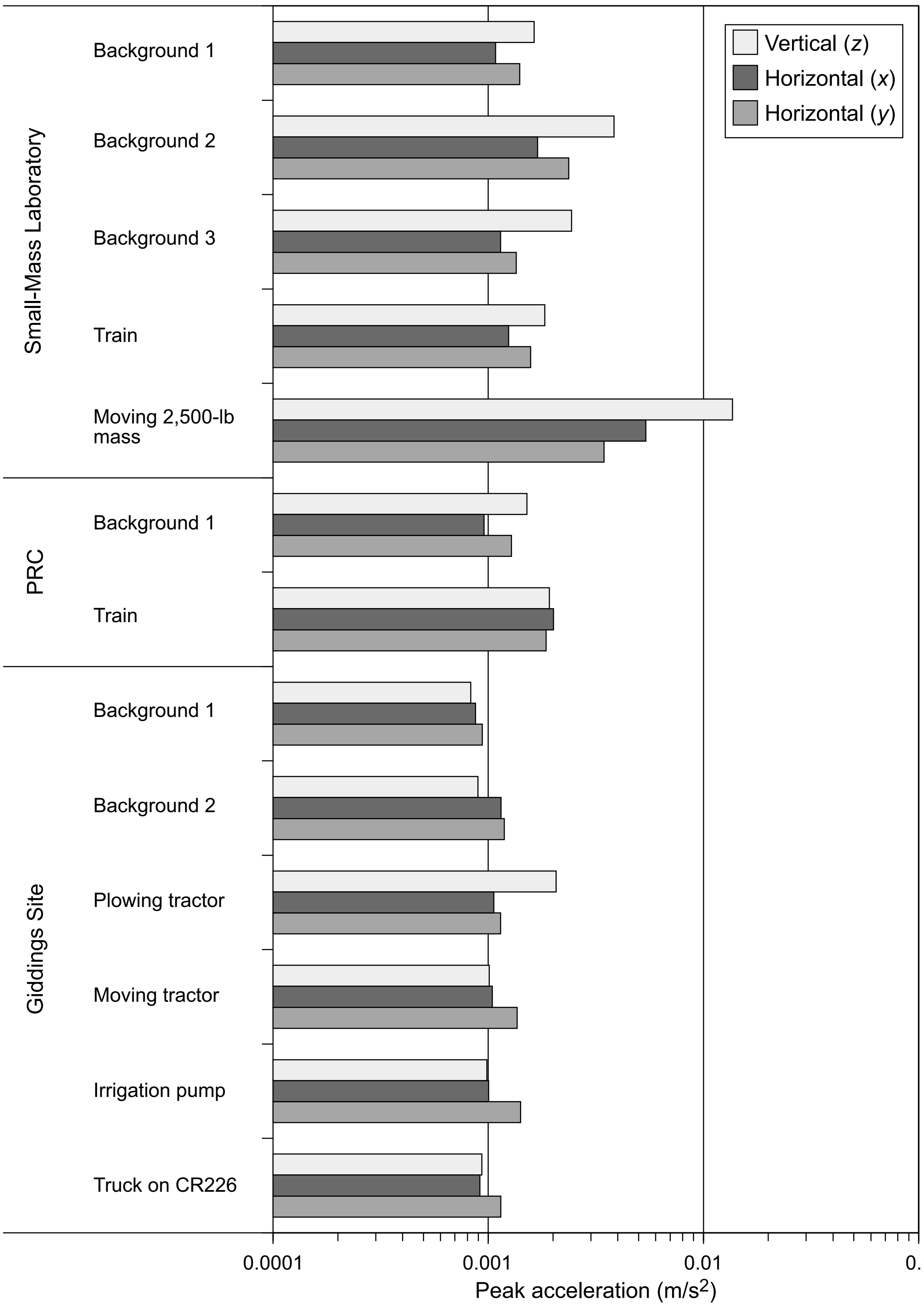

Figure 5. Peak ground acceleration recorded in three orthogonal directions during 13 selected events at the SML, at the PRC, and at the Giddings site in November 2001.

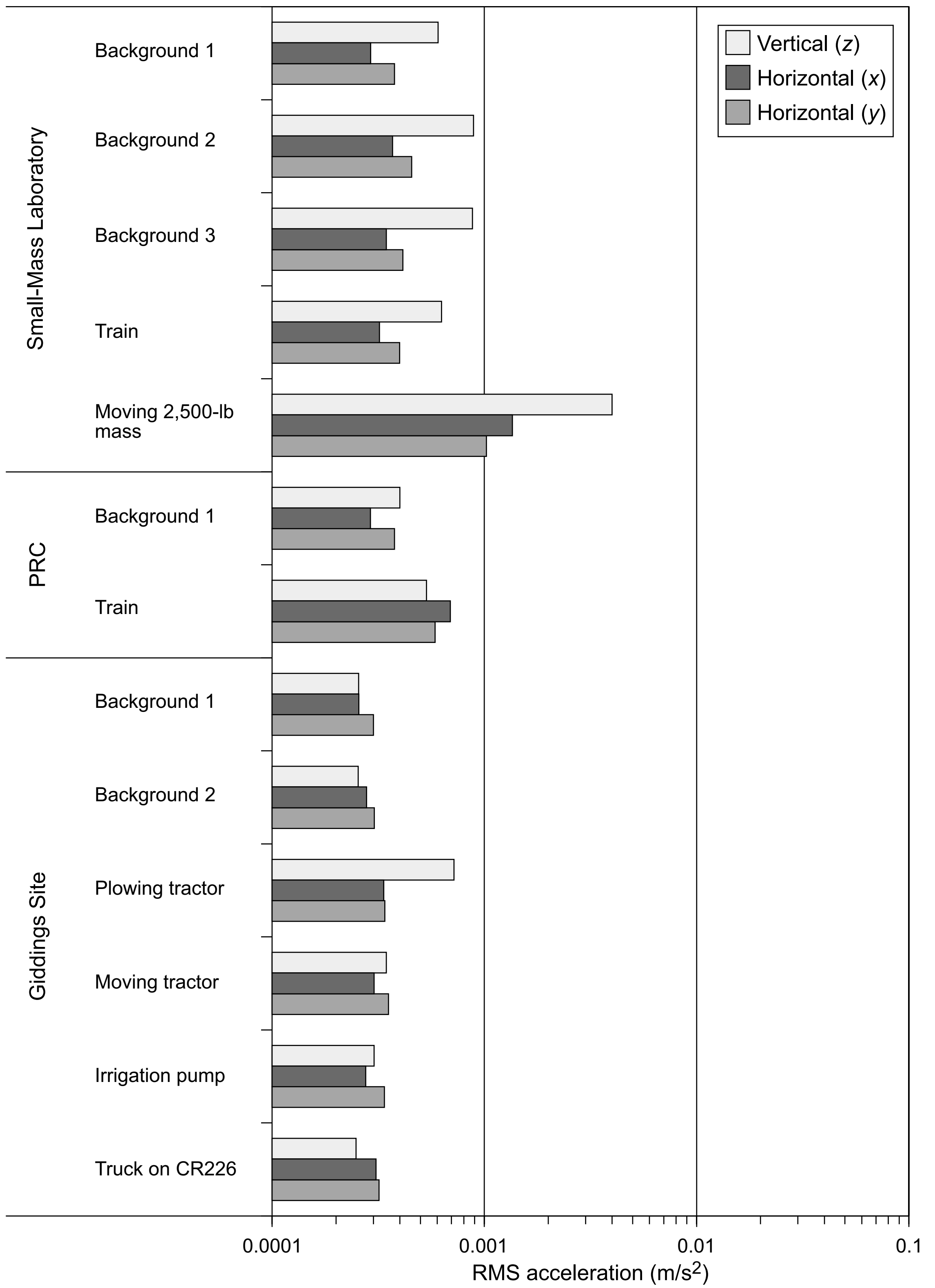

Figure 6. Root-mean-square (RMS) ground acceleration recorded in three orthogonal directions during 13 selected events at the SML, at the PRC, and at the Giddings site in November 2001.

ments during mass movement in the LML (P. Forester, pers. comm., Nov. 2001). Dominant ground-motion frequencies during these events are a few tens of cycles per second.

Giddings Site

Background measurements of ground acceleration at the Giddings site acquired during no obvious activities reveal very little ambient ground motion at the site (figs. 5, 6, and 7). Peak accelerations range from 0.0008 to 0.0009 m/s^2 vertically and 0.0008 to 0.0012 m/s^2 horizontally (fig. 5). These peak values are about an order of magnitude below the NCSL 0.001 g (0.01 m/s^2) threshold. RMS accelerations are 0.0003 m/s^2 or less in all three directions (fig. 6). Records of background acceleration show no significant, coherent noise events (fig. 7).

Nearby activities increased the ground motion at the site (figs. 5, 6, and 7). Operating a trailer-mounted irrigation pump 200 m west of the monitoring site increased ground acceleration slightly over background values (peak accelerations of about 0.001 m/s^2 vertically and horizontally). A tractor plowing in the field around the perimeter of the laboratory footprint further increased the peak accelerations to 0.002 m/s^2 vertically and more than 0.001 m/s^2 horizontally, but these peak values remain well below the NCSL acceleration threshold. Moving the tractor around the perimeter without plowing increased peak accelerations slightly over background values. Relatively light traffic on CR226 more than 200 m north of the site produced peak and RMS ground accelerations that fell within the range recorded during background events (figs. 5 and 6).

Site Comparison

We compared ambient vibration characteristics at the SML, at Giddings, and at the PRC (a representative shallow bedrock site). Ground accelerations recorded during ambient conditions at all three sites are below NCSL threshold accelerations (figs. 5, 6, and 8) for the vertical and two horizontal directions. The two sites in an urban setting (the current laboratory and the PRC)

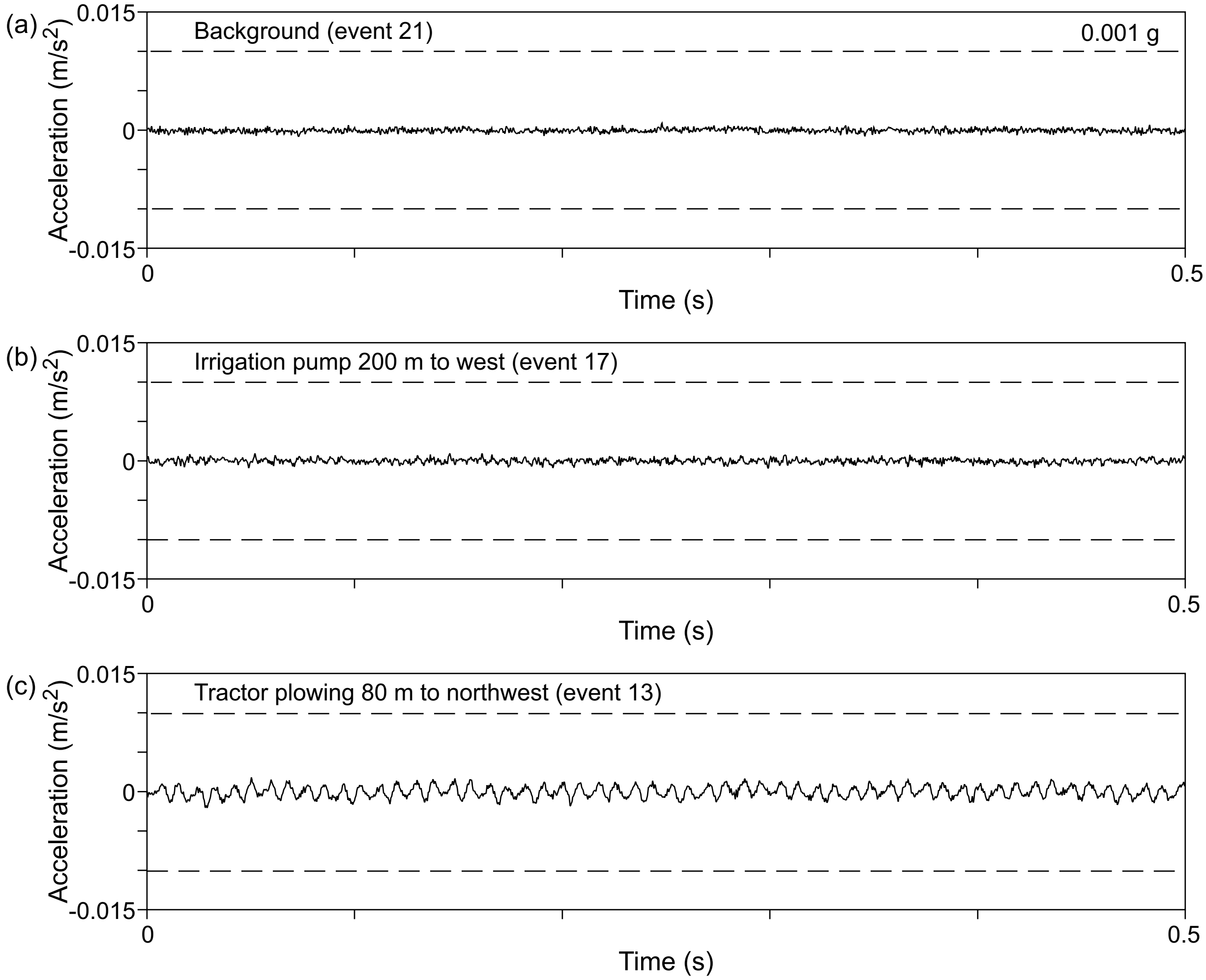

Figure 7. Vertical acceleration recorded over a 0.5-s interval at the Giddings site during (a) background activities; (b) operation of an irrigation pump 200 m west of the monitoring site; and (c) plowing 80 m northwest of the monitoring site. The dashed line denotes the NCSL guidelines for maximum allowable acceleration.

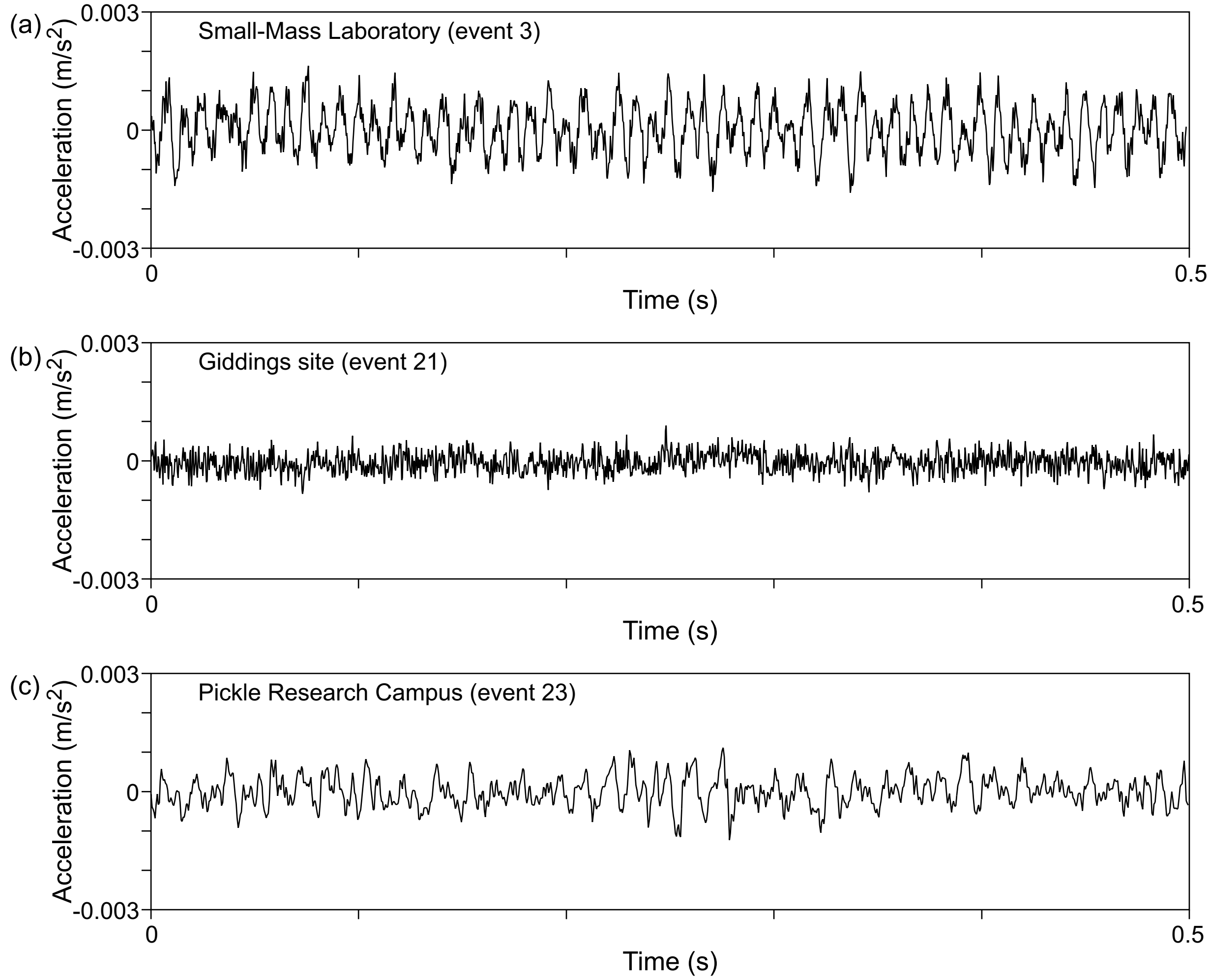

Figure 8. Comparison of background vertical acceleration recorded over a 0.5-s interval at (a) the SML; (b) the Giddings site; and (c) the PRC.

reveal higher ambient ground acceleration than that recorded at Giddings (fig. 8), where no significant nearby noise sources were encountered during monitoring.

Because seismic noise will be generated at the new laboratory that is not present there now, we also conducted controlled, active-source comparisons of the Giddings site (deep bedrock) with a representative shallow-bedrock site (PRC) to examine the relative response of the sites to induced ground motion. This exercise, termed a “walkaway” test, examined ground motion induced by dropping a large weight at a series of fixed distances from the monitoring instrument (fig. 2).

The largest ground motions were recorded when the source was closest to the sensors. At a source–sensor distance of 10 m, peak vertical accelerations reached 0.24 m/s^2 vertically and even higher values of 0.76 and 0.50 m/s^2 horizontally (fig. 9). These accelerations are well above the threshold laboratory values of 0.001 g (0.01 m/s^2). At a source–sensor distance of 50 m, much lower peak accelerations are observed. Vertical acceleration is just below the 0.001-g threshold, whereas the horizontal accelerations continue to exceed the threshold value significantly (fig. 10). Both vertical and horizontal accelerations remain below the 0.001-g threshold at a source–sensor distance of 100 m (fig. 11).

Walkaway test results at the shallow-bedrock site differ considerably from those at Giddings. With the source 10 m from the sensor at PRC, vertical and horizontal accelerations exceed the threshold value, but vertical and inline horizontal accelerations are higher than transverse horizontal accelerations (fig. 12). At 50 m, only the vertical acceleration exceeds the threshold value (fig. 13). At 100 m, ground acceleration in all three directions remains below the 0.001-g threshold (fig. 14).

At the 10-m source distance, peak vertical acceleration is slightly higher at Giddings than at PRC (fig. 15). At source distances beyond 20 m, peak vertical accelerations are higher at PRC than they are at Giddings. Vertical acceleration drops to near the 0.001-g threshold at source distances of about 50 m at Giddings and 80 m at PRC.

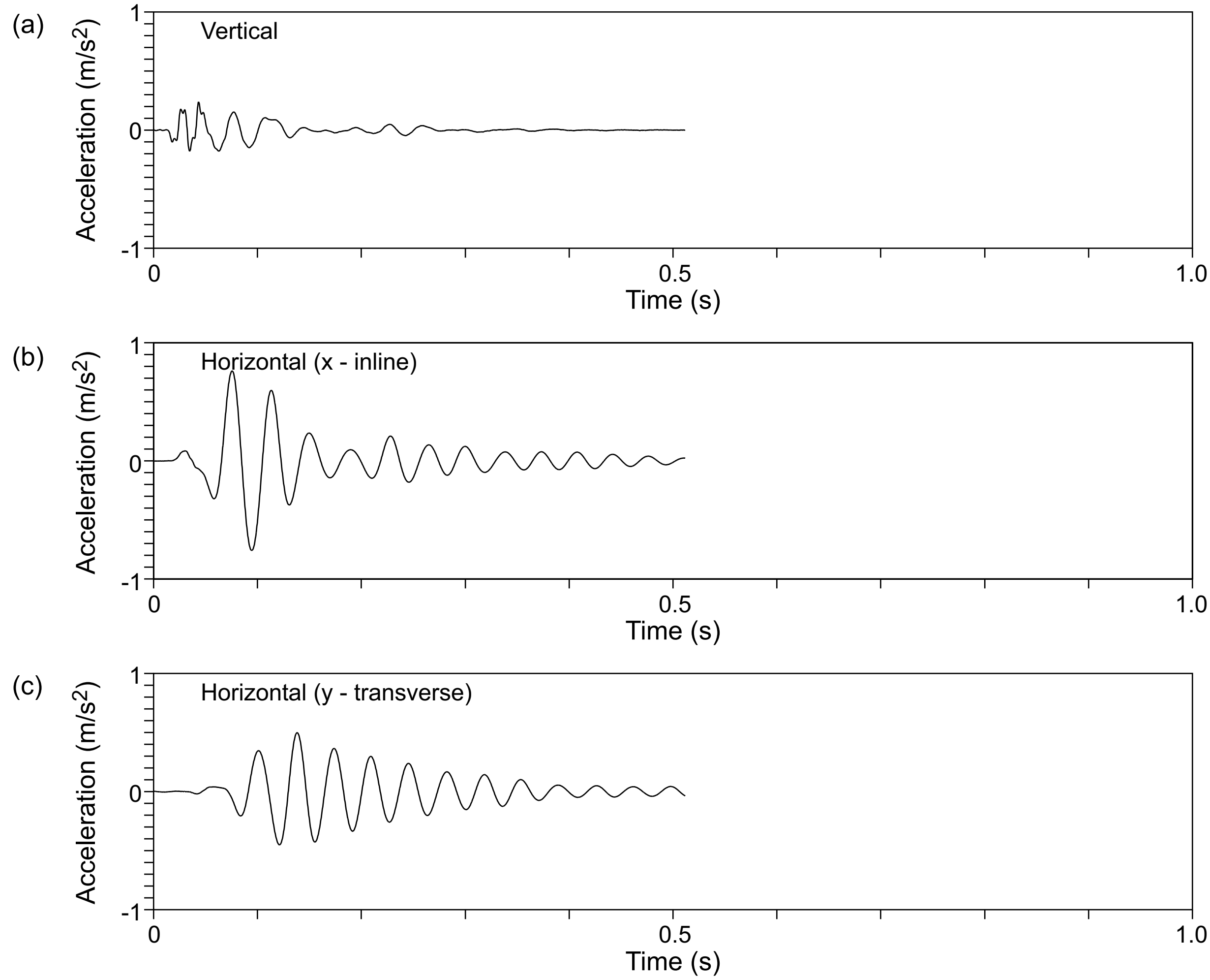

Figure 9. Vertical and horizontal ground acceleration resulting from a controlled drop of a 230-kg mass located 10 m from the accelerometers at the Giddings site.

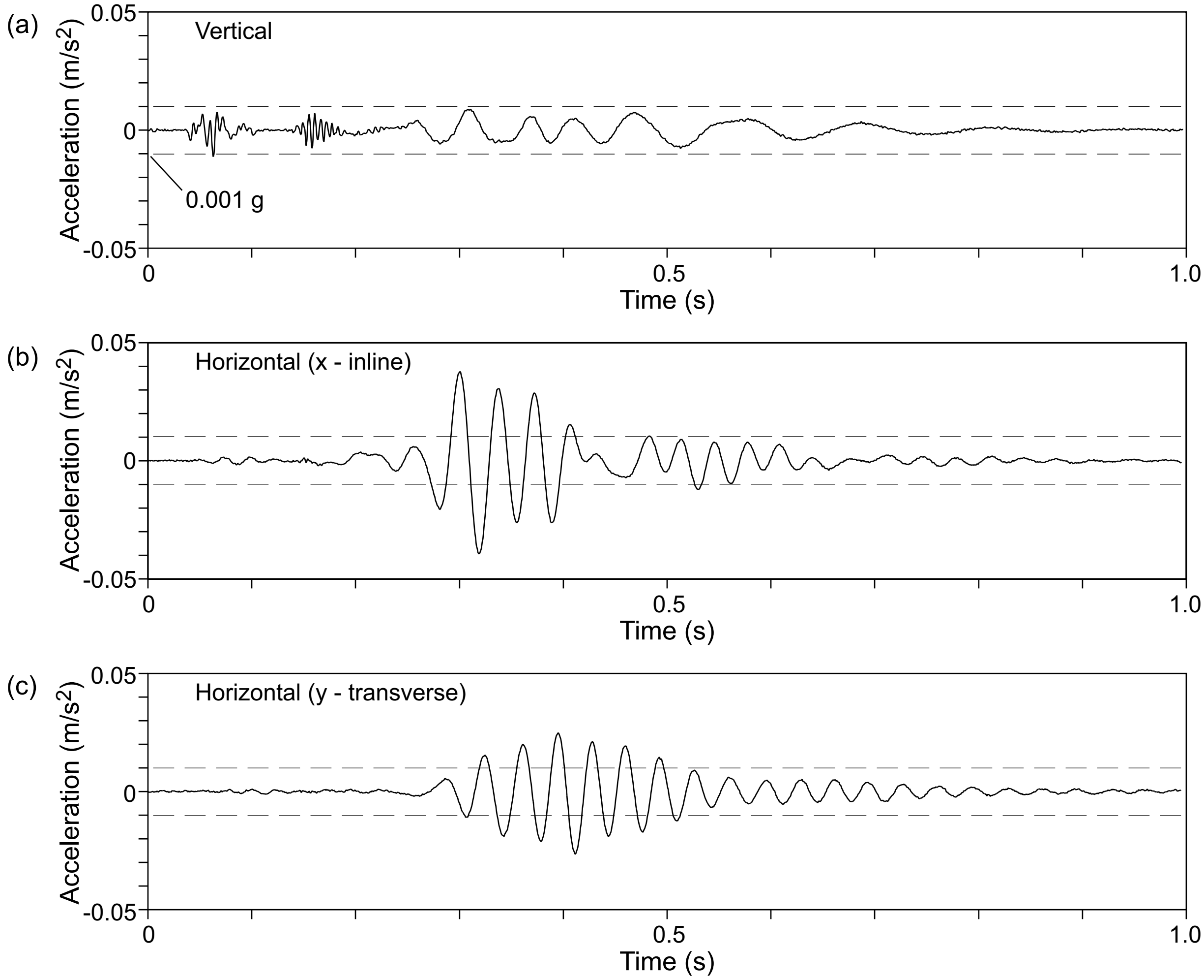

Figure 10. Vertical and horizontal ground acceleration resulting from a controlled drop of a 230-kg mass located 50 m from the accelerometers at the Giddings site.

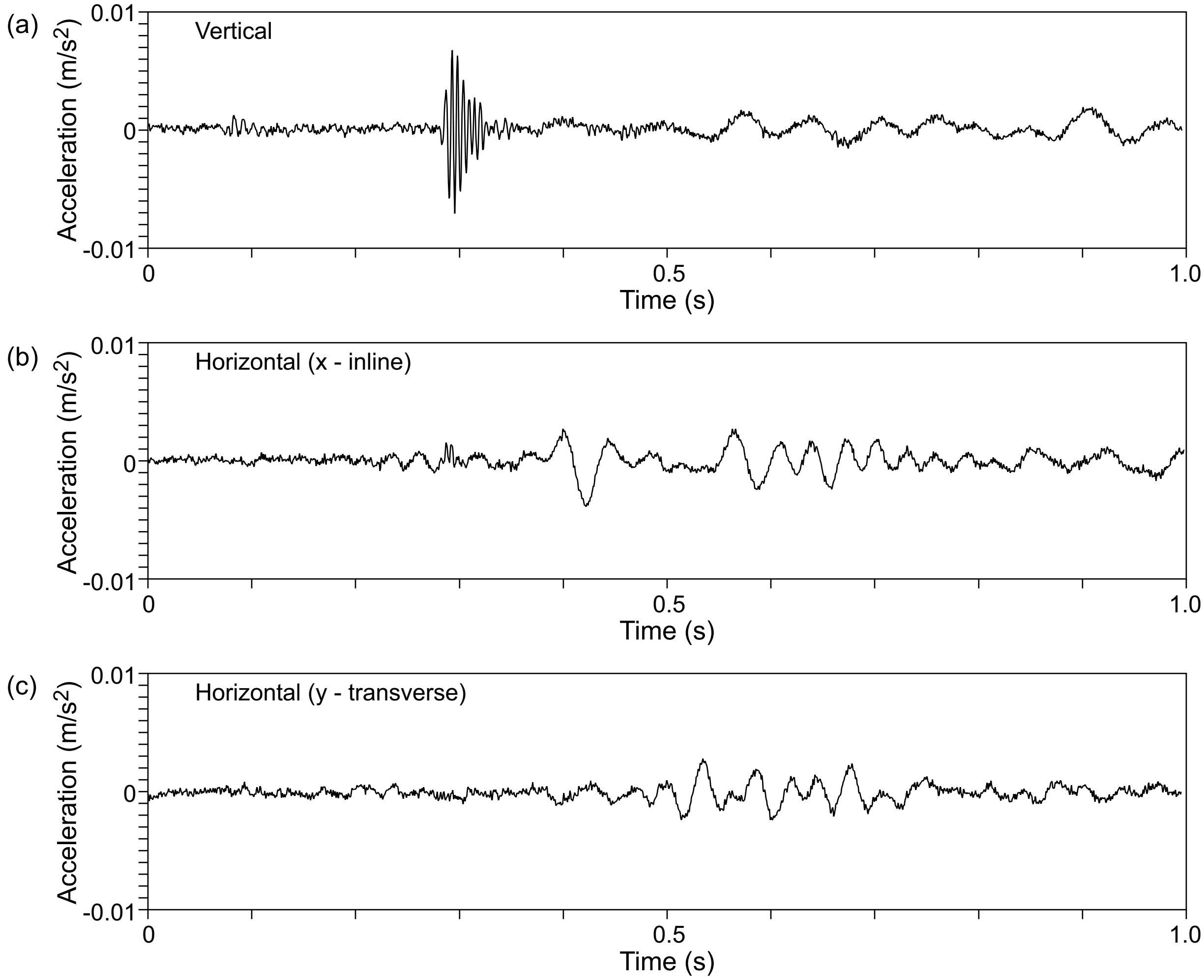

Figure 11. Vertical and horizontal ground acceleration resulting from a controlled drop of a 230-kg mass located 100 m from the accelerometers at the Giddings site.

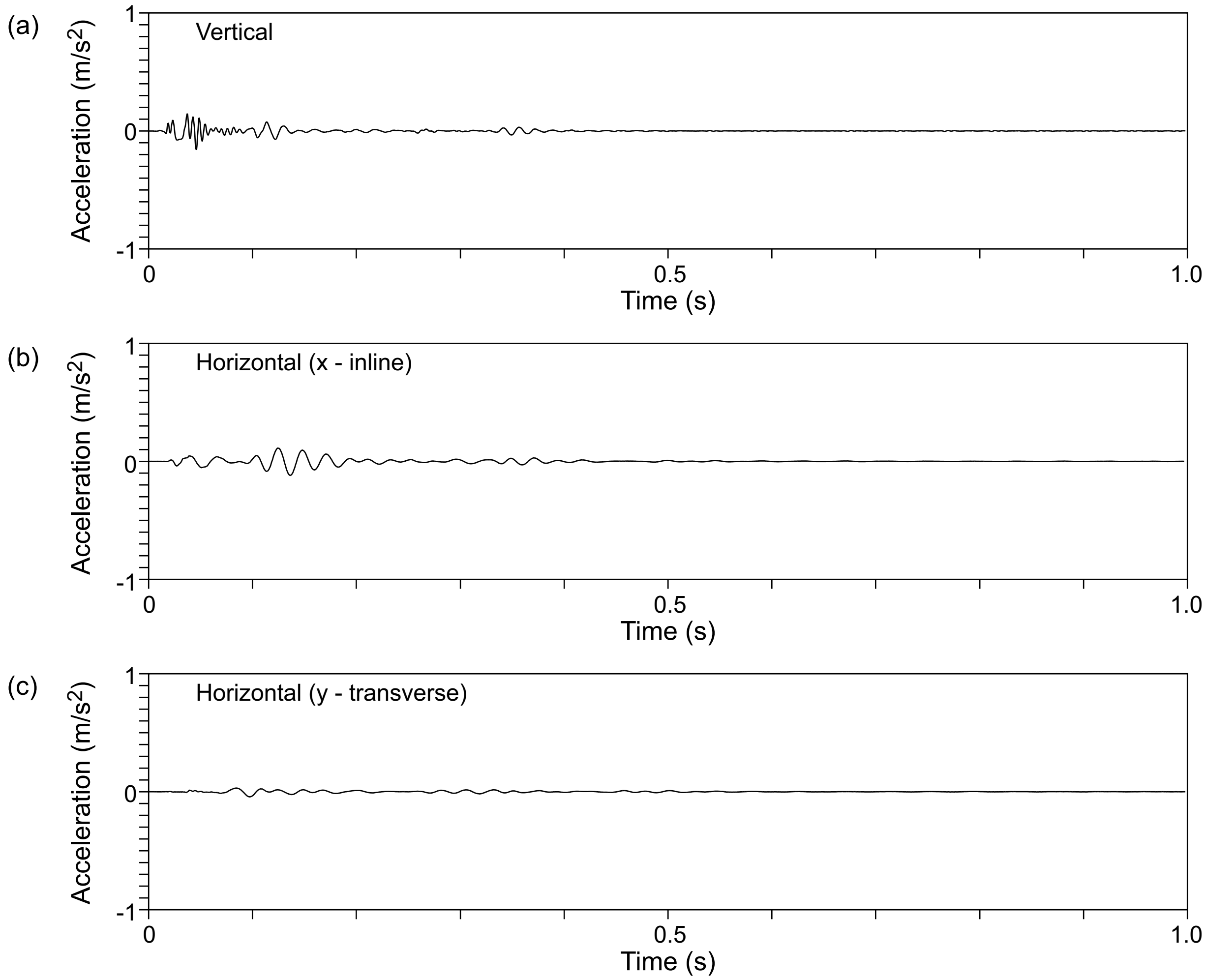

Figure 12. Vertical and horizontal ground acceleration resulting from a controlled drop of a 230-kg mass located 10 m from the accelerometers at the PRC site

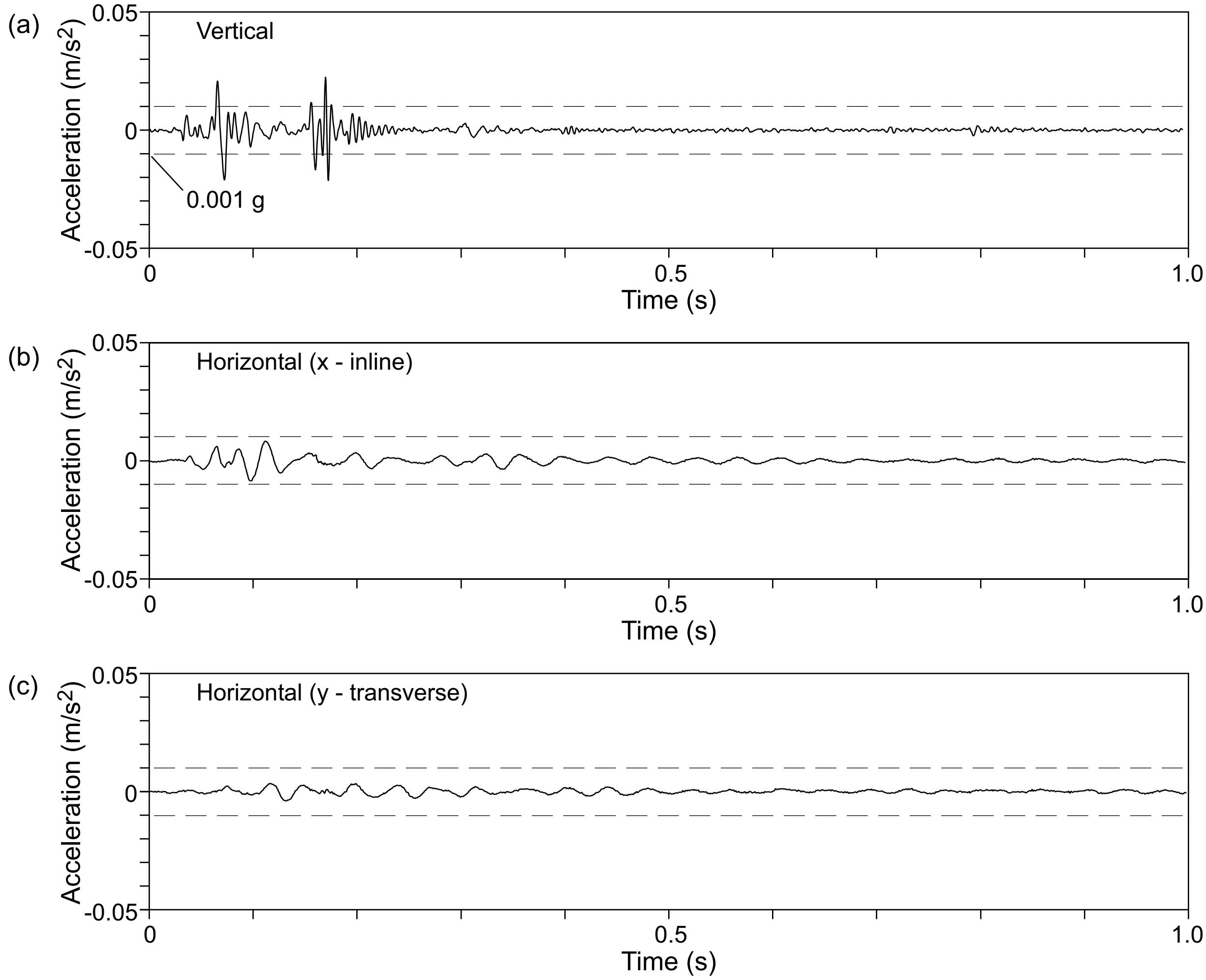

Figure 13. Vertical and horizontal ground acceleration resulting from a controlled drop of a 230-kg mass located 50 m from the accelerometers at the PRC site.

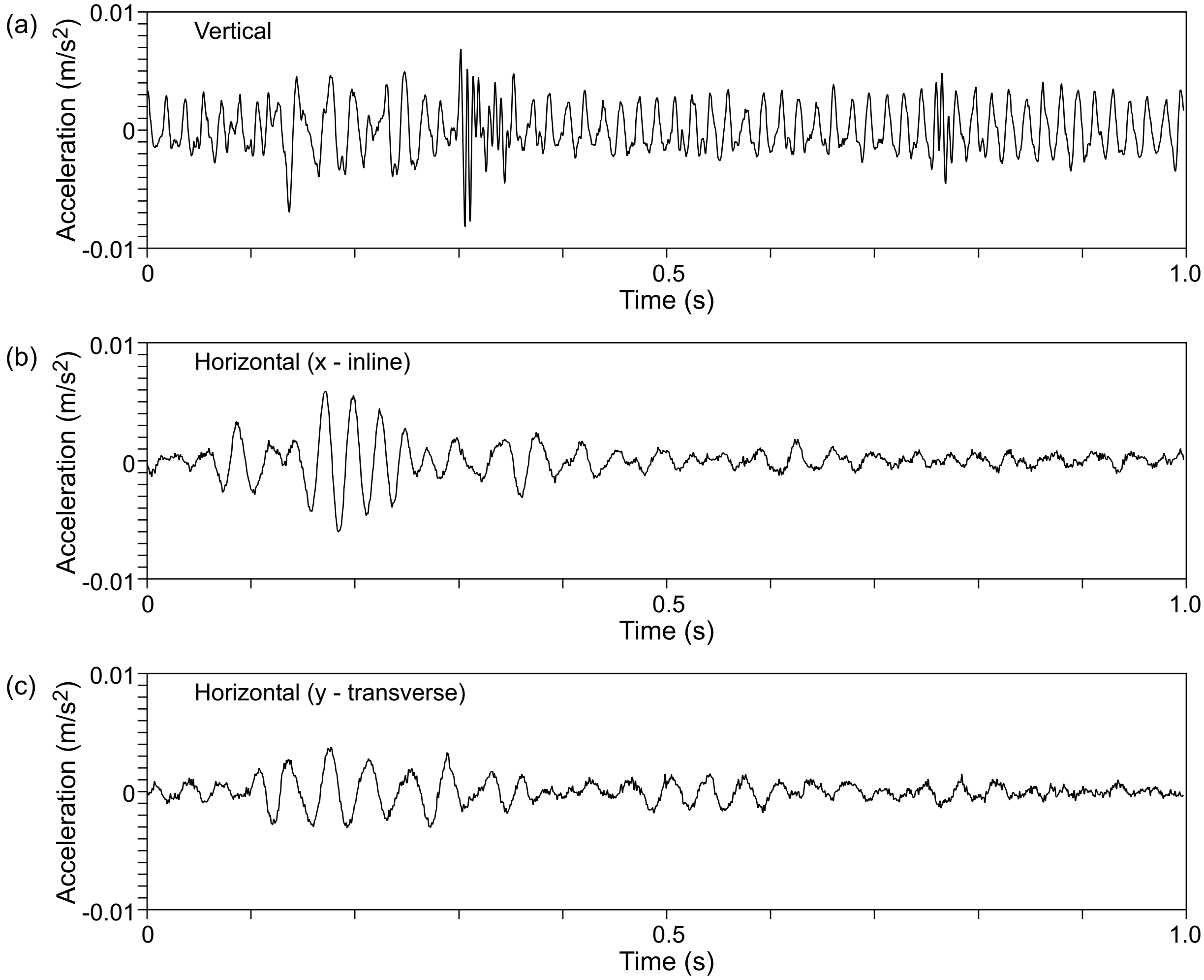

Figure 14. Vertical and horizontal ground acceleration resulting from a controlled drop of a 230-kg mass located 100 m from the accelerometers at the PRC site.

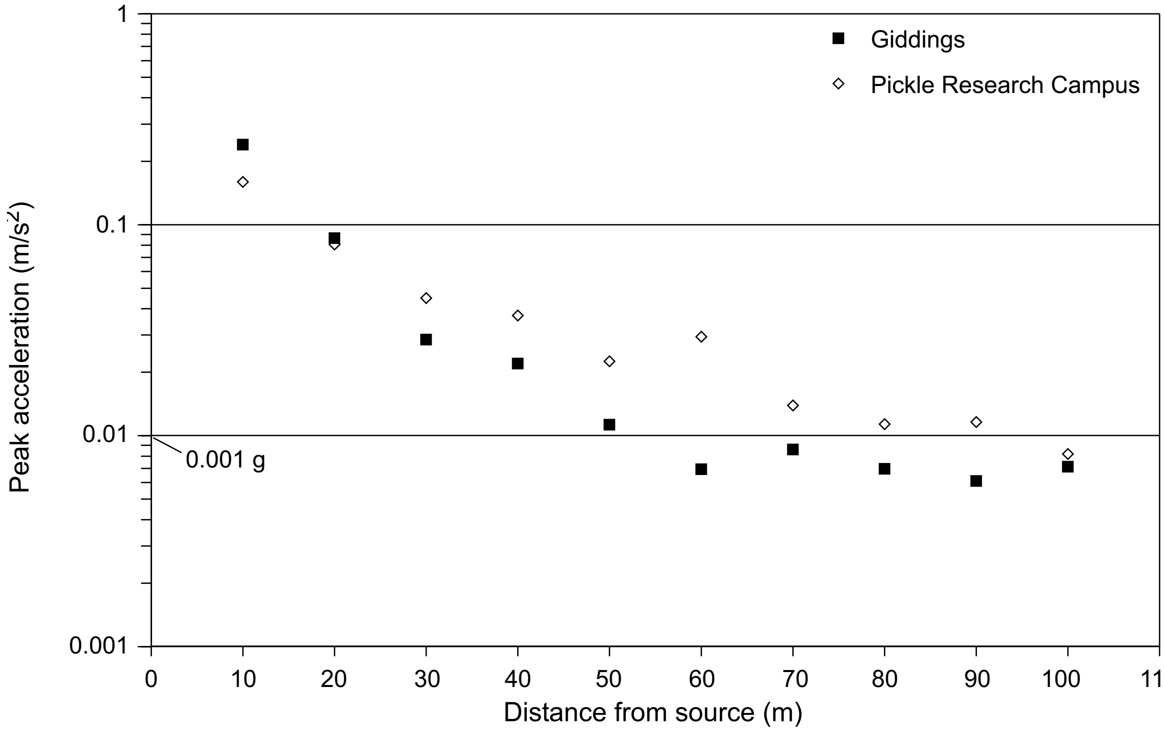

Figure 15. Comparison of peak vertical acceleration induced by mass drops at the Giddings and PRC sites.

In contrast, peak horizontal accelerations are about an order of magnitude higher at Giddings than at PRC for the same distance, a trend that continues to a source distance of more than 70 m in the inline direction and more than 50 m in the transverse direction. Beyond those distances, horizontal accelerations are lower at Giddings than they are at the shallow-bedrock site. Peak inline accelerations drop to near the 0.001-g threshold at source distances of 50 m at PRC compared to more than 70 m at Giddings (fig. 16). In the transverse direction, peak accelerations drop below threshold values by 50 m at PRC and 60 m at Giddings (fig. 17).

Similar seismic inputs create larger ground accelerations at Giddings than at PRC at distances of about 50 m or less, particularly in the horizontal directions. Beyond that distance, ground acceleration in all three directions is as high or higher at PRC than at Giddings.

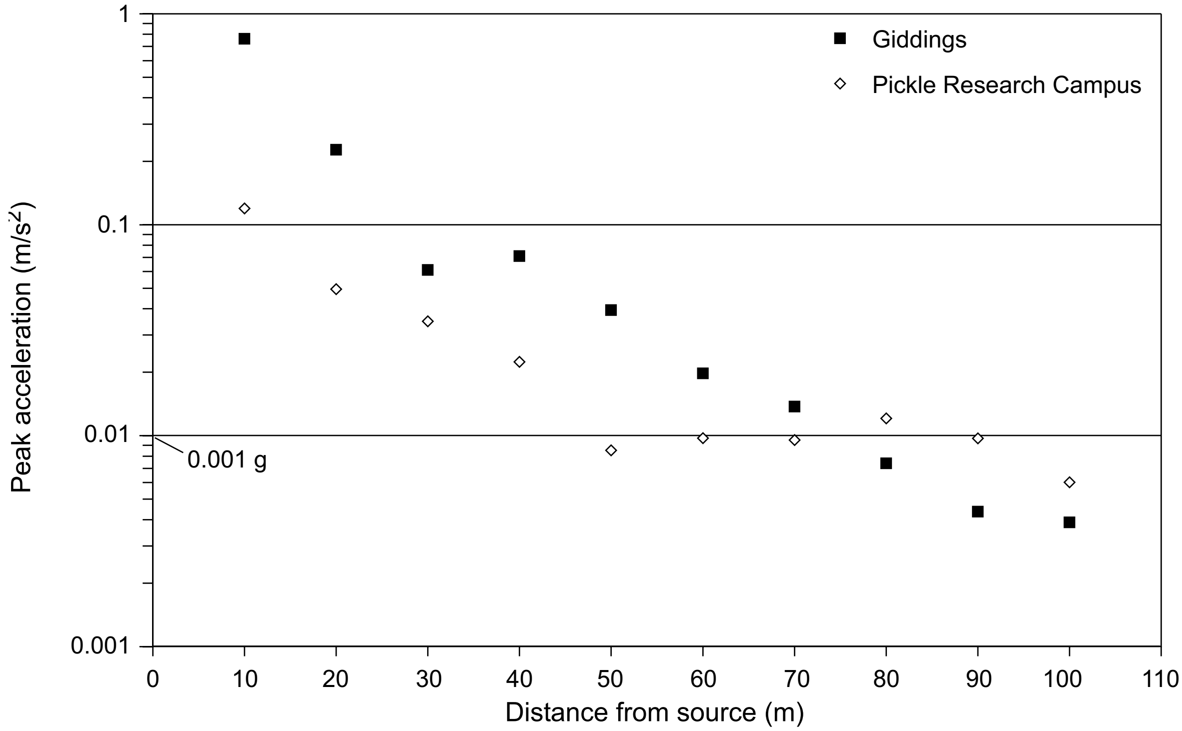

Figure 16. Comparison of peak horizontal acceleration (inline, or x direction) induced by mass drops at the Giddings and PRC sites.

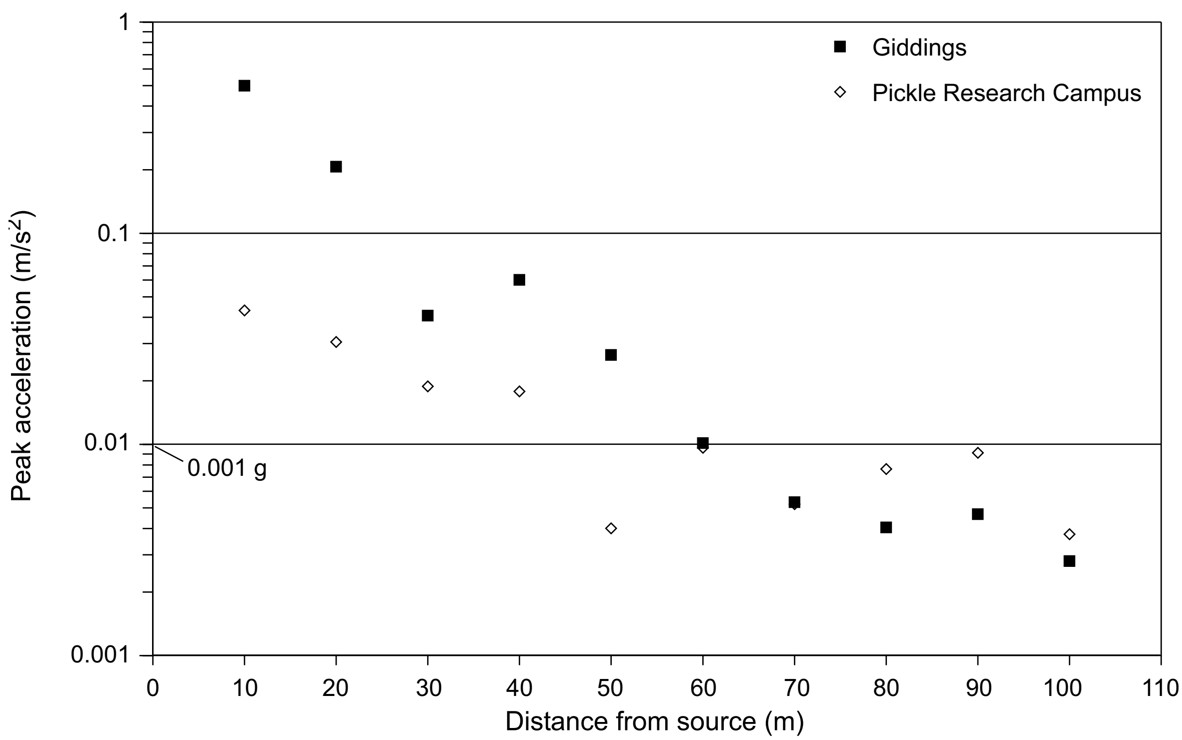

Figure 17. Comparison of peak horizontal acceleration (transverse, or y direction) induced by mass drops at the Giddings and PRC sites.

CONCLUSIONS AND RECOMMENDATIONS

High-sensitivity, triaxial accelerometer measurements at the current Metrology Laboratory demonstrate that ground motion at this urban site exceeds NCSL guidelines during common laboratory activities. Ambient ground motion at the proposed site in Giddings is well below that at the current laboratory and is well below NCSL siting guidelines for acceleration and displacement. Tractor plowing and operating irrigation pumps increase the ground motion at Giddings, but accelerations recorded during these activities remain below the NCSL threshold.

Walkaway tests conducted to compare site response to anticipated additional noise show that accelerations induced at Giddings and at a representative shallow bedrock site exceed NCSL guidelines to distances of 50 to 80 m from the noise source. Extremely large horizontal accelerations are induced close to the source at the Giddings site as opposed to the shallow bedrock site.

Laboratory activities are the largest vibration noise sources measured at the current site and are likely to remain the largest noise sources at any future site. Ambient noise at the Giddings site is very low, but laboratory construction and operation will likely produce vibration levels that are similar to those at the current laboratory. Walkaway tests show that both shallow and deep bedrock sites can experience large ground accelerations from nearby sources of ground motion such as those generated by moving large masses or heavy vehicles. Increasing the distance between sources of ground motion and sensitive instruments at the new laboratory, wherever it is located, should help reduce the impact of the ground motion on the more sensitive laboratory instruments.

REFERENCES AND 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.

Paine, Jeffrey G., 2001, Establishing acceptable ground motion at the TDA Metrology Laboratory, Austin, Texas: Bureau of Economic Geology, The University of Texas at Austin, contract report prepared for the Texas Department of Agriculture under contract no. UTA01-492, 19 p.