Improving Southern California Seismic Hazard Models With a 45-km Shear Velocity Profile Along the San Gabriel River

External Grant Award Number 03HQGR0068

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NEHRP Element(s): I
Keywords: Site effects, Surficial deposits, Seismic zonation, Engineering seismology

Non-Technical Project Summary

Traditional methods to test how sturdy the ground is can be costly and traffic noise can interfere. We use sounds from the streets to determine how a quake will affect a city. A truck hits a crack in the street and waves radiate from it. If the waves travel slowly, the soil is soft. If the waves travel fast, the soil is hard, and will not shake as much during an earthquake. Knowing the true foundation of a city will help us create better hazard maps. Recent tests show the ground in some big cities is harder than previously thought.

(Abridged from Heineman, K. [producer], 2003, Shaking things up: news short on the San Gabriel River transect in the *Discoveries and Breakthroughs Inside Science* series by NewsProNet Productions, subscribed to by 43 stations nationally, August, 1 min 41 sec. Mailed to grant program managers on VideoCD.)

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Investigations Undertaken

Brief Objectives: Our surveys of shallow ground shear velocity provide information that will assist in mitigating earthquake hazards in the Los Angeles urban area, and in responding to a damaging earthquake. The web site above shows our work in Las Vegas and Reno as well. This work is a reconnaissance, looking for any "hot spots" in the seismic shaking hazard. As shallow shear velocity decreases, shaking hazard increases.

Background: Shallow velocity is traditionally estimated with engineering surveys in boreholes. Such boreholes are costly, with results available from less than 50 sites in Los Angeles. Shaking hazard is best measured by recording damaging earthquakes on strong-motion seismometers, from which data are similarly sparse in both cities. Hazard mitigation and earthquake emergency response planning both need continuous mapping of the shaking hazard. To date these hazard maps have been predicted partly from geologic map units, but our previous results from Reno (shown at www.seismo.unr.edu/hazsurv#reno) show that existing maps may not predict shallow velocities.

Methods: The San Gabriel River transect was completed by UNR students using rolled arrays of IRIS/PASSCAL ``Texan'' single-channel recorders along the river-side bike path, as for the Reno transect. We are indebted to Bob Greschke and the IRIS/PASSCAL Instrument Center for providing the recorders and training in their use; and to the County of Los Angeles and City of Long Beach for their permission to work along the bike path. Data analysis was with Optim's SeisOpt® ReMi™ package, a method developed by Louie (April 2001 *BSSA*), and now widely adopted in western US geotechnical engineering practice (e.g., Fig. 1, a consultant's brochure offering SeisOpt® ReMi™ services). Each team of 3 students placed an array of 30 channels spaced at 20 m for a half-hour recording period. Each channel recorded a 4.5-Hz vertical geophone. Mostly ambient seismic "microtremor" noise was recorded, although some arrays were supplemented with hammer blows for P-wave refraction analysis. Geophones were not buried, but were leveled carefully. With the 12-member crew, the 60-km-long San Gabriel River transect of 99 (600-meter) array placements (Fig. 2) was completed in 4.5 days. Several months of permitting, preparation, and training activities preceded the July 4-16, 2003 field exercises. For each 300-m-long sub-array, SeisOpt® ReMi™ processing produced a velocity-spectral image that we picked for a Rayleigh-wave fundamental-mode phase-velocity dispersion curve. We then modeled each dispersion curve for a shear-velocity vs. depth profile, often getting constraints as deep as 300 m. This transect obtained over 200 separate shear-velocity vs. depth profiles.

Results

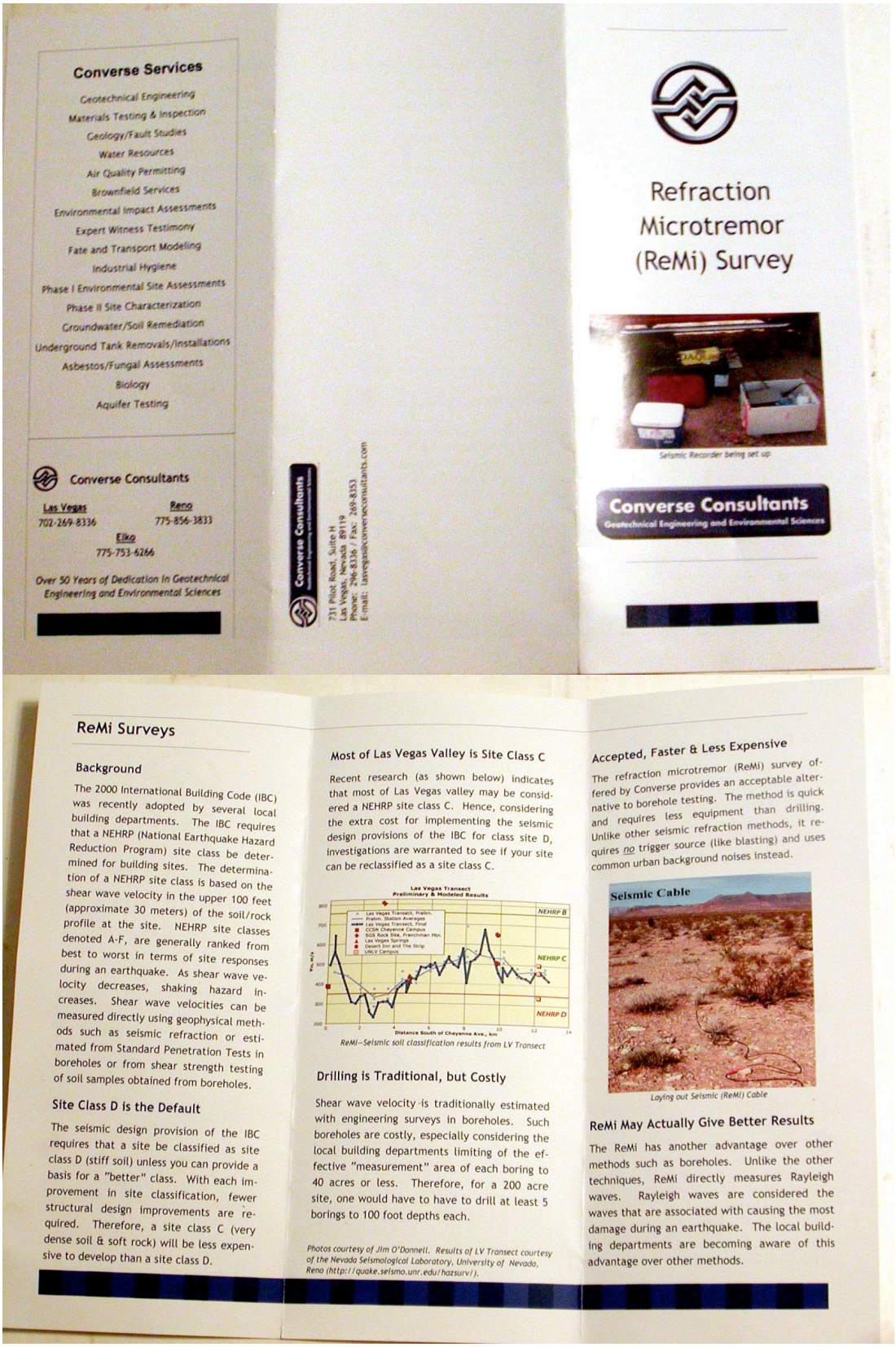
From each of the >200 shear-velocity vs. depth profiles we computed a 30-m depth averaged velocity (averaging by slowness). Fig. 3 plots V_{30} as a function of transect distance south from San Gabriel Canyon in Azusa. The curves are unexpectedly smooth south of Whittier Narrows, at least in comparison to similar transects in Reno and Las Vegas, Nevada.

1. In Los Angeles the lowest V_{30} velocities observed are just below the NEHRP C/D class boundary, showing a minimum of 231 m/s. Several deployments around Alamitos Bay, Long Beach, did not find any very low NEHRP-E class velocities as predicted by Wills et al. (2000; Fig. 2 here), despite being made on artificial fill in a lagoon.
2. The highest V_{30} velocities we observed were in Azusa near the north end of the transect. Velocities within a roadcut into Precambrian granitic gneiss of the San Gabriel Mountains were still below the NEHRP B/C boundary, as the granite of the range is deeply decomposed and thoroughly fractured. These velocities are lower than the NEHRP-B class velocities predicted in the map of Wills et al. (2000) shown in Fig. 2.
3. Along the San Gabriel River, V_{30} velocities stay within NEHRP-C, around 600 m/s, through Azusa and the Santa Fe Dam area as predicted by Wills et al. (2000; Fig. 2 here), despite many kilometers of basin thickness. The bouldery and cobbly nature of the surface there suggests a large average clast size, and a steep hydraulic gradient, may correlate with higher shallow velocities.
4. Some increases in V_{30} velocity, just above the NEHRP C/D boundary, appear near Whittier Narrows Dam. These may correlate with the presence of stiff gravel lenses, or perhaps with the presence of older sediments, uplifted by the Whittier–Elysian Park blind thrust.
5. The lowest V_{30} velocities along the San Gabriel River are at Alamitos Bay. Near Carson Street and Bellflower, the velocities are in the NEHRP-D range as predicted by Wills et al. (2000; Fig. 2 here). We corroborated these velocities along the riverbed against nearby areas with a cross-line extending 2 miles west of the river. Velocities rise slightly at Seal Beach, perhaps due to added littoral sand, or perhaps due to the Holocene uplifts between strands of the Newport-Inglewood fault zone.
6. Along the San Gabriel River, V_{30} shows no correlation with mapped geologic unit (Fig. 4).
7. Along the San Gabriel River, V_{30} also shows no correlation with mapped agricultural soil unit (Fig. 5).
8. Correlation of V_{30} with the classification map by Wills et al. (2000; Fig. 2 here) is good, although our measured V_{30} values do not get as high as NEHRP-B or as low as NEHRP-E, as predicted by the map.

Reports Published

Heineman, K. (producer), 2003, Shaking things up: news short on the San Gabriel River transect in the *Discoveries and Breakthroughs Inside Science* series by NewsProNet Productions, subscribed to by 43 stations nationally, August, 1 min 41 sec. (Mailed to grant program managers on VideoCD.)

Thelen, Weston A., Matthew Clark, Christopher Lopez, Chris Loughner, Hyunmee Park, Jim B. Scott, Shane B. Smith, Bob Greschke, and John N. Louie, 2003, A Transect of 200 shallow shear-velocity profiles across the Los Angeles Basin: to be presented at the Amer. Geophys. Union Fall Meeting, San Francisco, Dec. 11.



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Refraction Microtremor (ReMi) Survey

Seismic Recorder being set up

Converse Consultants
Geotechnical Engineering and Environmental Sciences

ReMi Surveys

Background

The 2000 International Building Code (IBC) was recently adopted by several local building departments. The IBC requires that a NEHRP (National Earthquake Hazard Reduction Program) site class be determined for building sites. The determination of a NEHRP site class is based on the shear wave velocity in the upper 100 feet (approximate 30 meters) of the soil/rock profile at the site. NEHRP site classes denoted A-F, are generally ranked from best to worst in terms of site responses during an earthquake. As shear wave velocity decreases, shaking hazard increases. Shear wave velocities can be measured directly using geophysical methods such as seismic refraction or estimated from Standard Penetration Tests in boreholes or from shear strength testing of soil samples obtained from boreholes.

Site Class D is the Default

The seismic design provision of the IBC requires that a site be classified as site class D (stiff soil) unless you can provide a basis for a "better" class. With each improvement in site classification, fewer structural design improvements are required. Therefore, a site class C (very dense soil & soft rock) will be less expensive to develop than a site class D.

Most of Las Vegas Valley is Site Class C

Recent research (as shown below) indicates that most of Las Vegas valley may be considered a NEHRP site class C. Hence, considering the extra cost for implementing the seismic design provisions of the IBC for class site D, investigations are warranted to see if your site can be reclassified as a site class C.

Las Vegas Transect
Preliminary & Modeled Results
NEHRP B
NEHRP C
NEHRP D
Distance South of Cheyenne Ave., km

ReMi–Seismic soil classification results from LV Transect

Drilling is Traditional, but Costly

Shear wave velocity is traditionally estimated with engineering surveys in boreholes. Such boreholes are costly, especially considering the local building departments limiting of the effective "measurement" area of each boring to 40 acres or less. Therefore, for a 200 acre site, one would have to have to drill at least 5 borings to 100 foot depths each.

Photos courtesy of Jim O'Donnell. Results of LV Transect courtesy of the Nevada Seismological Laboratory, University of Nevada, Reno (http://quake.seismo.unr.edu/hazsurv/).

Accepted, Faster & Less Expensive

The refraction microtremor (ReMi) survey offered by Converse provides an acceptable alternative to borehole testing. The method is quick and requires less equipment than drilling. Unlike other seismic refraction methods, it requires no trigger source (like blasting) and uses common urban background noises instead.

Seismic Cable

Laying out Seismic (ReMi) Cable

ReMi May Actually Give Better Results

The ReMi has another advantage over other methods such as boreholes. Unlike the other techniques, ReMi directly measures Rayleigh waves. Rayleigh waves are considered the waves that are associated with causing the most damage during an earthquake. The local building departments are becoming aware of this advantage over other methods.

Figure 1: New brochure by Converse Consultants, Las Vegas, offering their clients refraction microtremor site-characterization services.

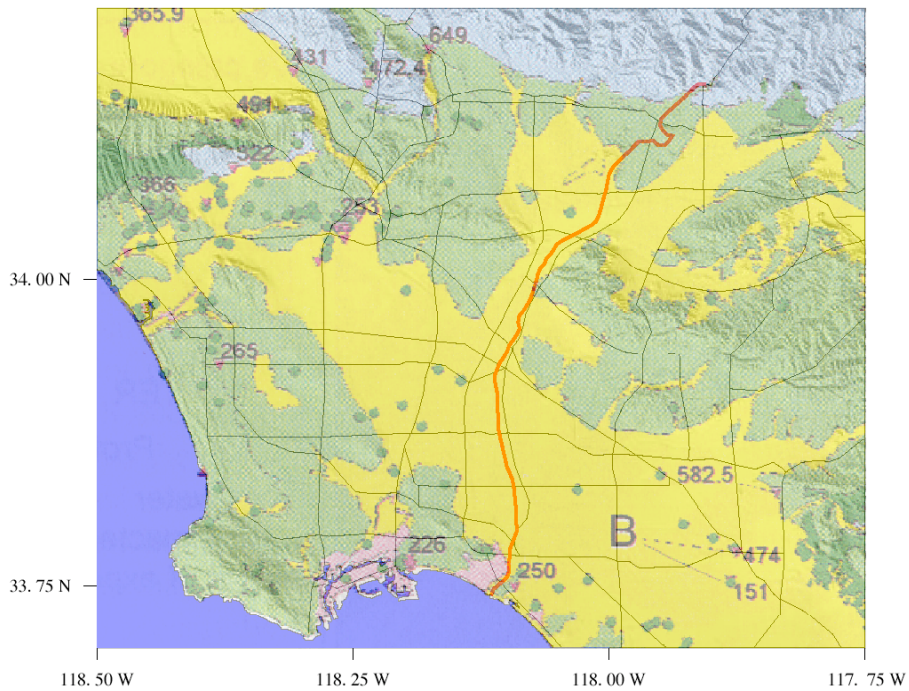

Figure 2: Southern California hazard map of Wills et al. (2000) from the SCEC Phase III Report, with the route of the USGS-funded 60-km shallow shear-velocity transect completed along the San Gabriel River in July 2003, in orange.

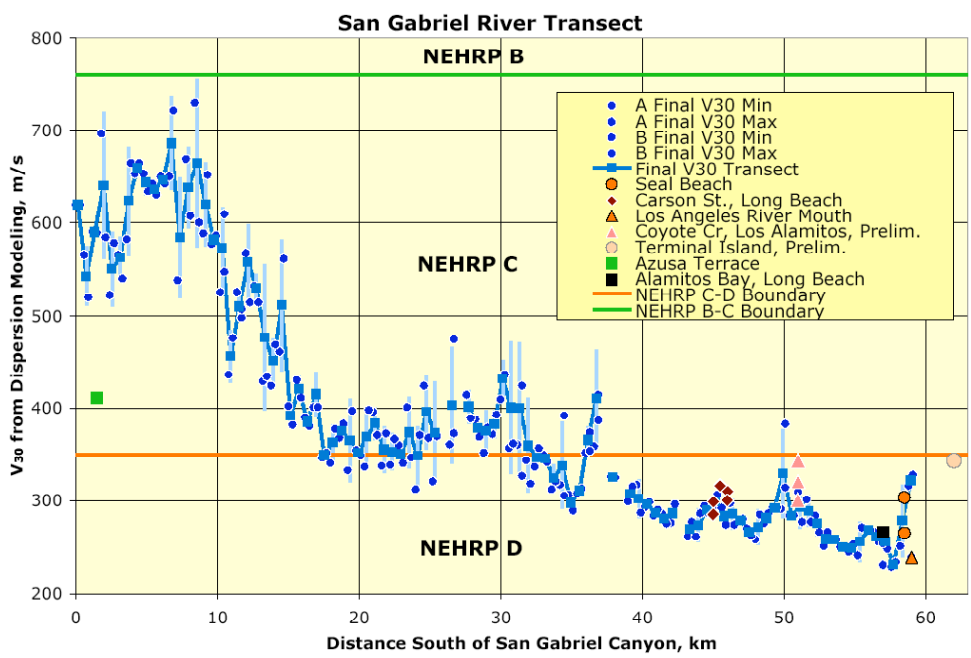

Figure 3: Plot of 200 V_{30} measurements along the July 2003 San Gabriel River transect, along with corroborating measurements made up to 7 km from the transect. V_{30} may correlate with hydraulic gradient, or competence of the River to transport gravel. V_{30} values are slowness-averaged from velocity-depth profiles modeled to fit microtremor dispersion data.

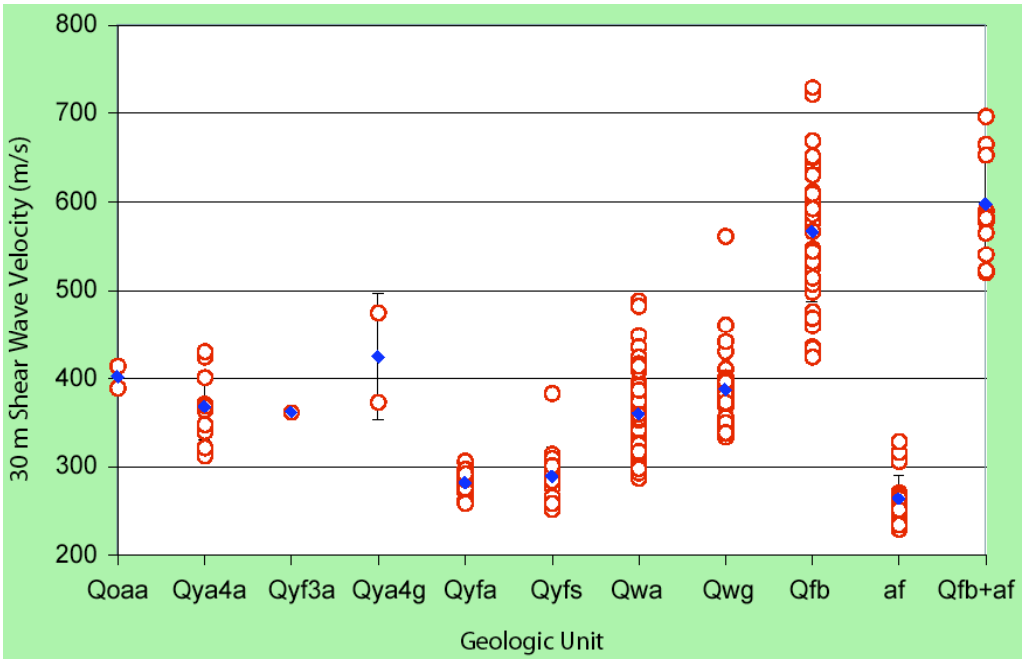

Figure 4: V_{30} measurements collected for each of the 11 geologic-map units crossed by the San Grabriel River transect. Relative geologic age increases toward the left. The V_{30} ranges of most units overlap substantially; further, there is no correlation between V_{30} and active or inactive alluvium, or with overall composition. The only units showing small variance are those on which we made only one or two measurements.

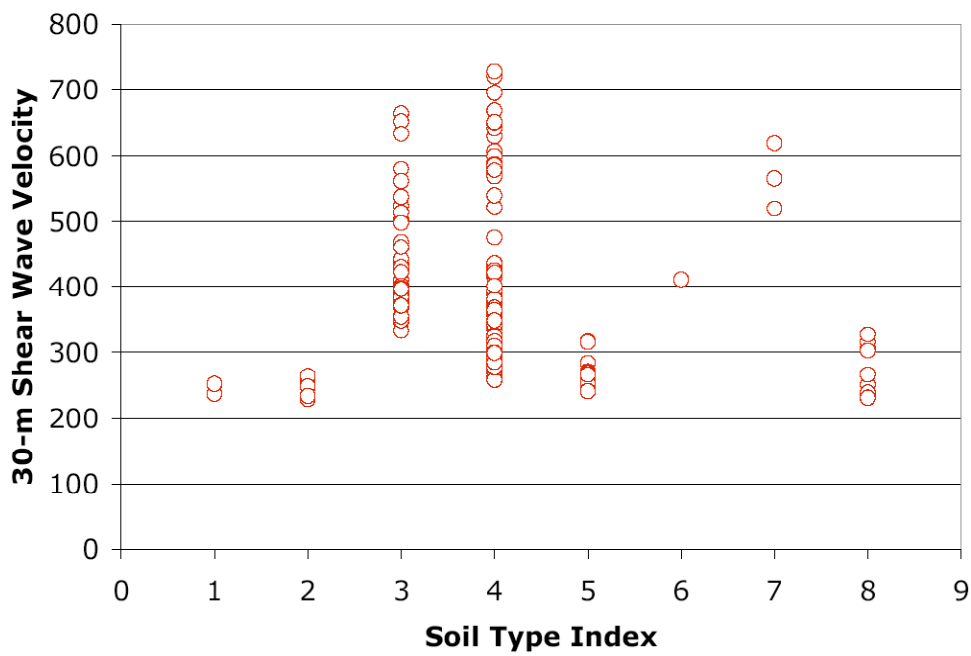

Figure 5: V_{30} measurements collected for each of the 8 agricultural soil-map units crossed by the San Grabriel River transect. Again, the V_{30} ranges of most units overlap substantially. The only units showing small variance are those on which we made only one or two measurements.