

## Dave Boore's notes on Poisson's ratio (the relation between $V_p$ and $V_s$ )

### Background

These notes were stimulated by an exchange I had with Ozdogan (Oz) Yilmaz concerning his determinations of near-surface seismic velocities at strong-motion stations in Turkey operated by the Earthquake Research Department of the General Directorate of Disaster Affairs, as part of the project "Compilation of National Strong Ground Motion Database in Accordance with the International Standards" (Prof. Sinan Akkar, Middle East Technical University, project chief). I was reviewing a draft report by Oz in my role as a member of the International Scientific Advisory Board for the project.

In a document title "responses\_to\_oz's\_responses\_of\_19mar07.pdf", emailed to Oz on 19 March 2007, I stated:

*4. The high values of Poisson's ratios for near-surface materials (above the water table) used in your inversions of the surface-wave dispersion are completely inconsistent with values from our surface source-downhole receiver logging (using independent sources for P and S waves). Inserted below is a plot of  $V_p$  vs  $V_s$  from our measurements. Depth is not indicated here, but most values of  $V_p$  less than 1500 m/s are at shallow depths (probably less than 10–20 m, but I need to check on this). As you can see, the relations for Poisson's ratios of 0.45 and 0.48 (the brown and cyan curves; the equations for each curve are given in the legend) are [sic] disagree with the bulk of the measurements for which  $V_p$  is less than 1500 m/s. I suggest that a better near-surface Poisson's ratio for your inversions is 0.3. I note in passing that it is a bit ironic that many people inverting non-intrusive surface wave measurements err in the opposite sense: they use a Poisson's ratio near 0.25 even for depths below the water table.*

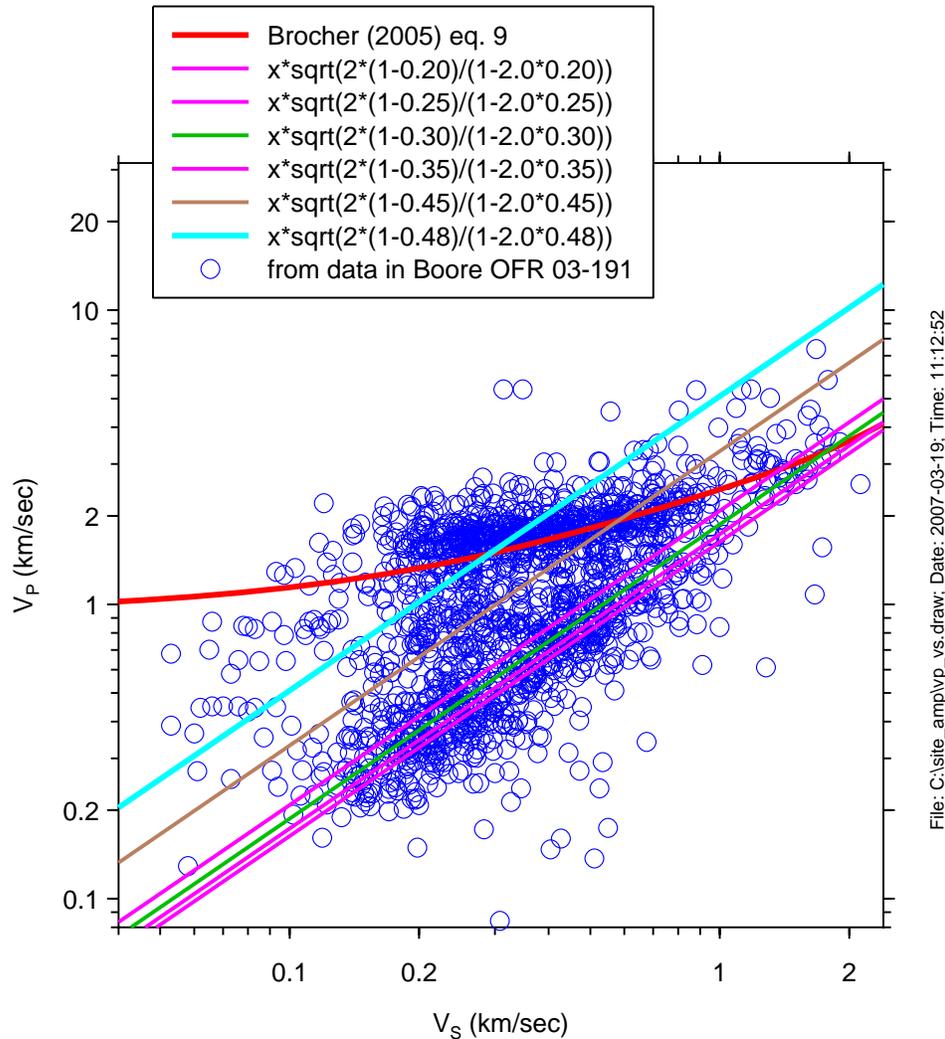


Figure 1.

The comment about the value assumed in inversions of nonintrusive tests is based on my experience from two blind-interpretation exercises (Asten and Boore, 2005, and Cornou et al., 2006).

Here is a portion of the table on which I was commenting, taken from "oz\_reply\_to\_dave\_boore\_comments.doc" (dated 19 March 2007):

Depth (m)	$V_p$ (m/s)	$V_s$ (m/s)	$G$ ( $\text{kg}/\text{cm}^2$ )	$V_p/V_s$	Poisson's Ratio	Depth (m)	SPT N
0	503	216	685	2.3	0.39	1.5	7
1	559	216	703	2.6	0.41	3	2
2	645	117	214	5.5	0.48	4.5	23

3	767	117	223	6.6	0.49	6	50
4	931	200	685	4.7	0.48	7.5	40
5	1141	200	721	5.7	0.48	9	44
6	1387	302	1725	4.6	0.48	10.5	50
7	1633	302	1797	5.4	0.48	12	41
8	1824	325	2140	5.6	0.48	13.5	43
9	1942	325	2174	6.0	0.49	15	50
10	2031	325	2198	6.2	0.49	16.5	50
11	2080	404	3417	5.1	0.48	18	50

Oz's reply to my "responses\_to\_oz's\_responses\_of\_19mar07.pdf" stated in part:

(4) There are contrasting views on this matter. Most users of nonintrusive methods actually use a Poisson's ratio of 0.4 (Xia, personal communication). This makes sense since soil column is more saturated than typical rock formations. Also bear in mind that, after the iterative Rayleigh-wave inversion, the starting value of 0.4 for Poisson's ratio changes to a depth-variable ratio, since  $V_s$  changes with depth. The value of 0.4 is just the initial value to start the inversion. And this is based on hundreds of model tests and real data analyses. Based on your graph, though, we have two different positions on this matter.

(from "oz\_2\_reply\_to\_dave\_boore\_comments.pdf", dated 21 March 2007).

I sent an email to Rob Kayen on 19 March 2007, with an attachment "Ask\_Rob\_Kayen\_about\_Poisson's\_Ratio.pdf" explaining the "controversy" and asking for his opinion on the subject. He responded *we use 0.33 near the surface based on your work with Leo. I have not read of a justification for using 0.4, nor seen Xia et al., 1999* (email, 20 March 2007).

On 22 March 2007, Oz sent this email:

*From: "oz yilmaz" <oz@geotomo.com>  
 To: "David M. Boore" <boore@usgs.gov>  
 Cc: "D. Sinan Akkar" <sakkar@metu.edu.tr>  
 Subject: Poisson's ratio  
 Date: Thursday, March 22, 2007 3:54 AM*

*Dave,*

*You triggered my curiosity to search for some info regarding Poisson's ratio. Attached, is a Poisson's ratio-depth curve derived from PS logging measurements of  $V_p$  and  $V_s$  down the borehole. Note that at shallow depths Poisson's ratio can be fairly large.*

At very very shallow depths above the water table, you think that Poisson's ratio can be as low as 0.25 for dry soil. I have not encountered such cases. I will continue my search.

Oz

His email had a Powerpoint attachment containing this figure:

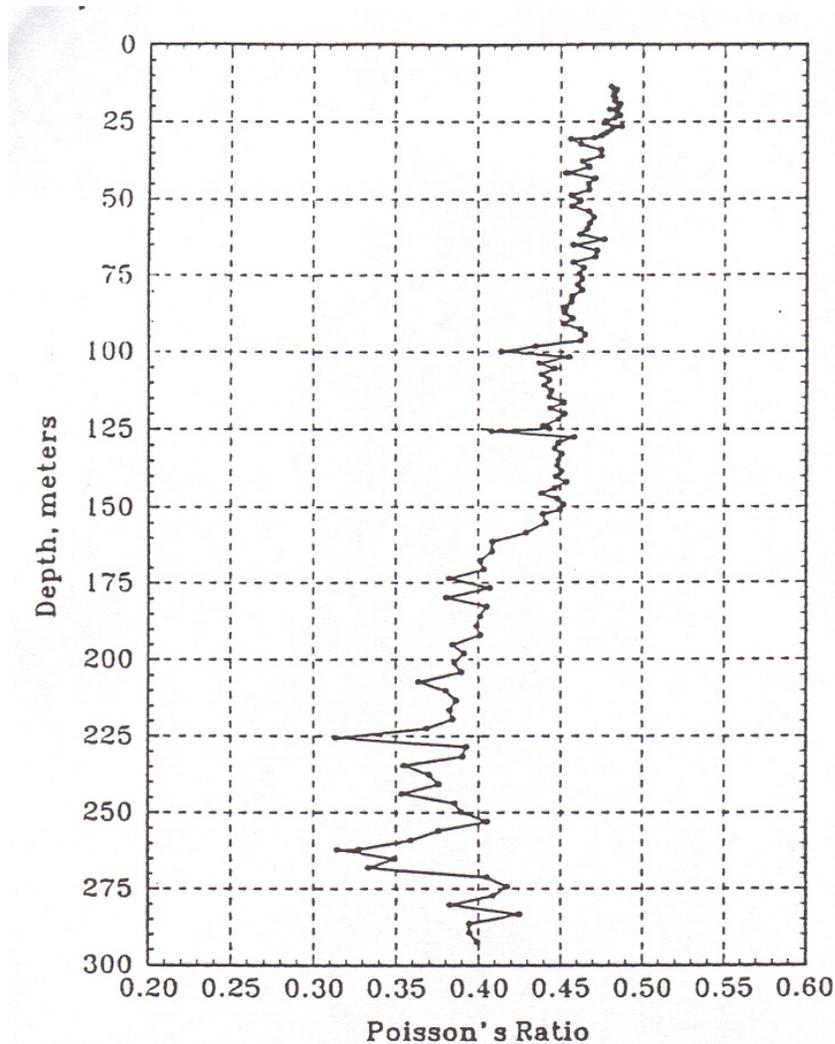


Figure 2. The reference is "(Nigbor and Imai, 1994)". Given Bob Nigbor's close association with P-S suspension logging, I assume that the results in this figure are based on P-S suspension logging.

The figure, however, is not useful in addressing the issue of whether Poisson's ratio for soils above the water table should generally be lower than 0.40, as there is no indication of whether the profile

includes material above the water table. As the curve is not shallower than 15 m, I suspect that it does not extend above the water table.

The exchange above leads to this question:

### What is Poisson's ratio for near-surface sediments?

Using surface-source, downhole-receiver profiles from three USGS Open-File reports, Brown et al (2002) published the following figure:

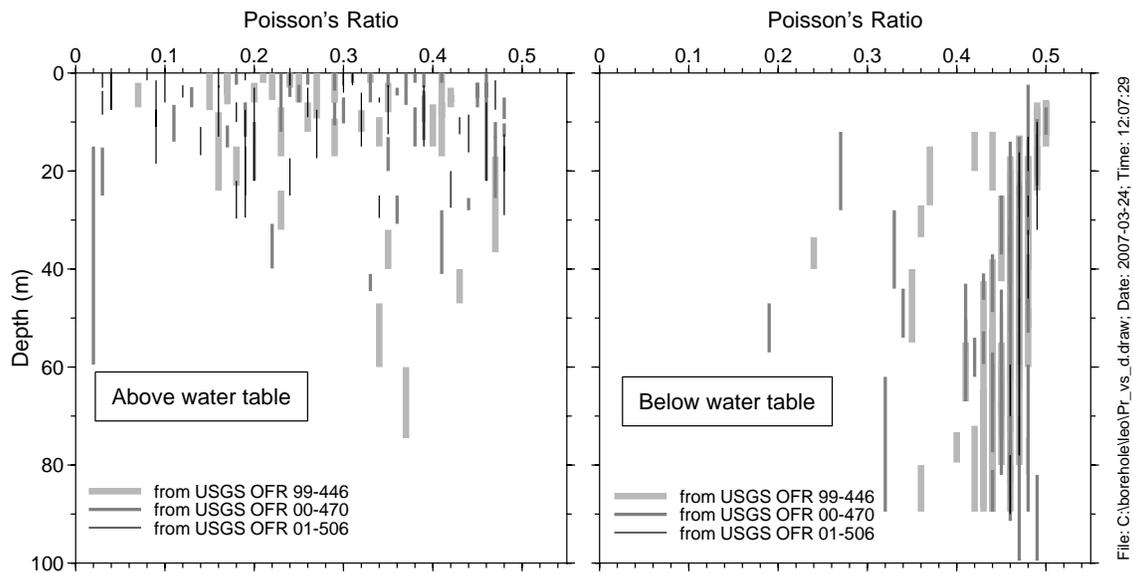


Figure 3. Poisson's ratio versus depth for material above and below the water table, using values from recent measurements of velocities in southern California (Gibbs et al., 1999, 2000, 2001). The length of each vertical line spans the depth range for each particular constant-velocity layer from which Poisson's ratio was determined.

The interpretation of the Poisson's ratio is that there is a wide range for materials above the water table (due in part to partial saturation of the material, changes in lithology, as well as measurement error). Just below the water table, however, the P-wave velocity increases to the velocity of compressional waves in water (about 1500 m/s, depending on salinity content), whereas the S-wave velocity is largely unaffected by the presence of water (with one exception, the low values of Poisson's ratio in the right-hand graph in Figure 3 correspond to high values of  $V_s$ , the exception corresponds to a "dry" layer with low  $V_p$ ). For this reason, the ratio  $V_p/V_s$  is much higher just below the

water table than just above the water table, and the Poisson's ratio, given by

$$\sigma = 0.5 \frac{(V_p/V_s)^2 - 2}{(V_p/V_s)^2 - 1} \quad (1)$$

approaches 0.5. As depth increases, however, the S-wave and P-wave velocities increase due to such things as increased overburden stress, changes in lithology, and cementation. As a result, the Poisson's ratio generally decreases with depth below the water table, eventually reaching values near 0.25.

### **Relation of $V_p$ and $V_s$ from surface-source, downhole receiver surveys.**

The data on which Figure 3 is based is a subset of the data used in plotting Figure 1. In this subsection I discussed in more detail how Figure 1 was produced. For convenience, here is the figure again, but with a few changes:

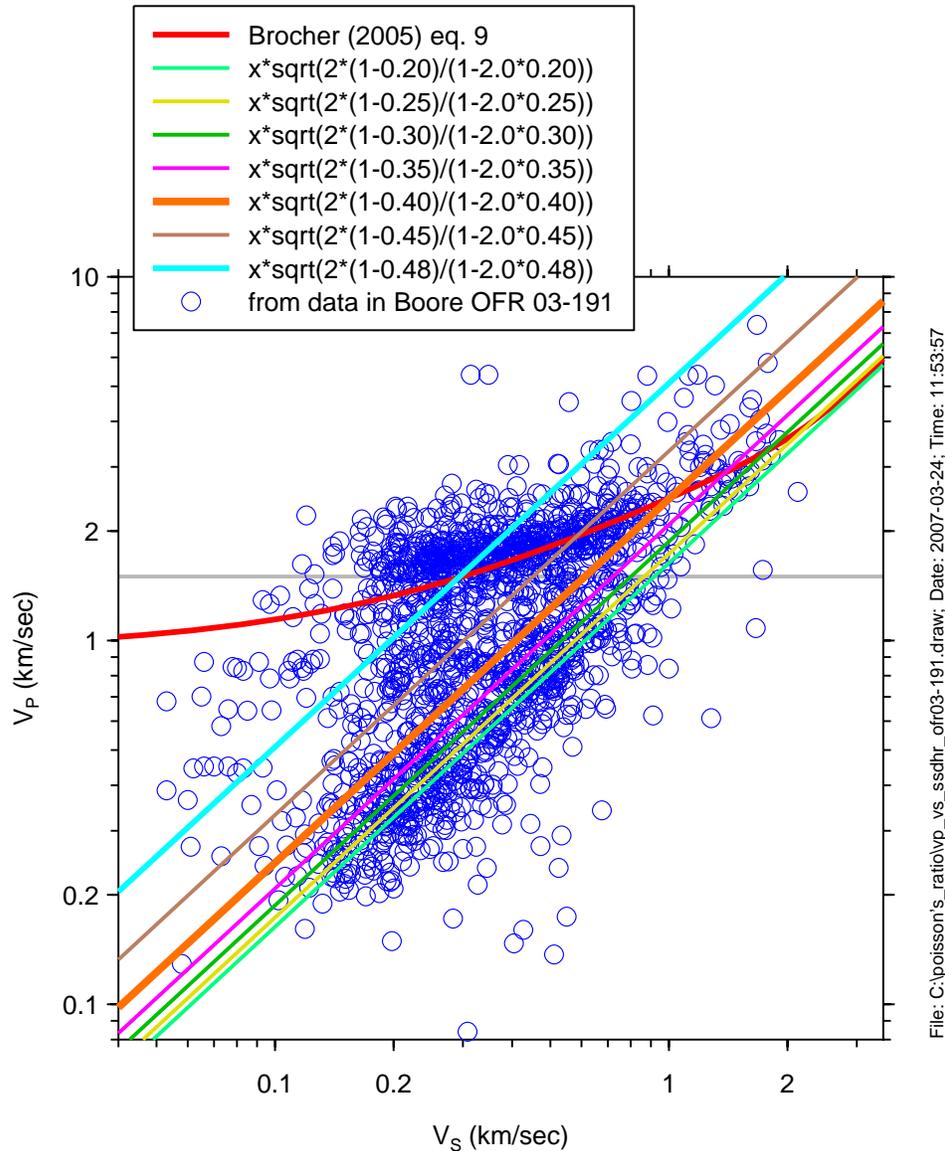


Figure 4. Data from 274 boreholes. The straight lines show the  $V_p, V_s$  relation for Poisson's ratios of 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, and 0.48, as indicated in the equations in the legend (the same as equation (2) below).

The data in the figure were taken from the Poisson's ratio files available from [http://quake.wr.usgs.gov/~boore/data\\_online.htm](http://quake.wr.usgs.gov/~boore/data_online.htm). They represent measurements from 274 boreholes. These files combine separately-determined  $V_p$  and  $V_s$  models composed of a stack of constant-velocity layers. The program that produced the Poisson's ratio files subdivides each separate velocity model, as necessary, so

that both models have the same set of depths to each interface. The Poisson's ratio is then computed for each sublayer. The result is a table giving depth-to-bottom,  $V_p$ ,  $V_s$ , and Poisson's ratio of each layer. I used the Poisson's ratio files rather than the individual  $V_p$  and  $V_s$  files because I was then assured that the  $V_p$  and  $V_s$  values correspond to the same depth range. The straight lines in the figure show  $V_p$ ,  $V_s$  relations for various values of Poisson's ratio, as given by the equation

$$V_p = V_s \sqrt{\frac{2-2\sigma}{1-2\sigma}} \quad (2)$$

where  $\sigma$  is Poisson's ratio. The same dataset can be used to plot Poisson's ratio vs.  $V_p$ . Here is the result:

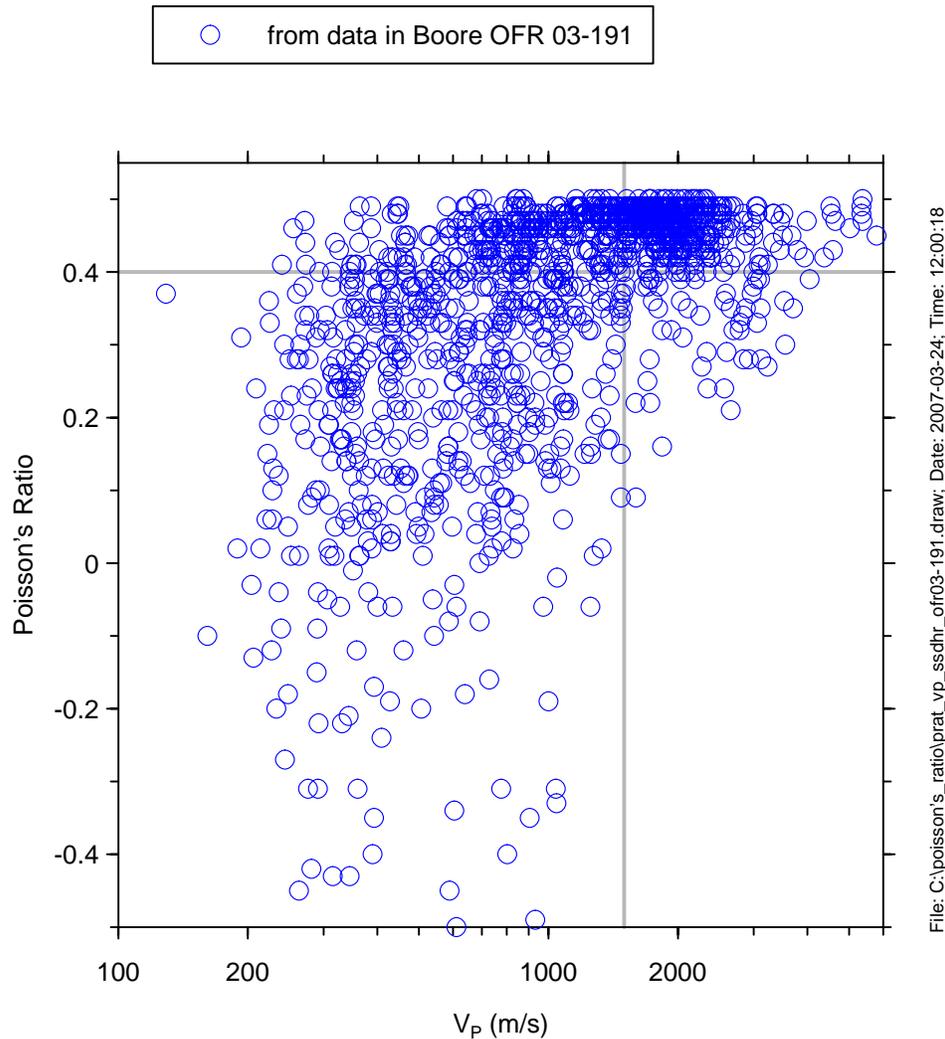


Figure 5. Same data as shown in Figure 4.

Although this is a more direct way of determining Poisson's ratio as a function of  $V_p$ , I like the first graph because it shows more structure (the two-branched nature of the  $V_p$ ,  $V_s$  relation). Poisson's ratio can be determined from Figure 4 from the superimposed lines of constant Poisson's ratio (ranging from 0.2 to 0.48, as indicated in the equations shown in the legend; also shown is Brocher's (2005) relation between  $V_p$  and  $V_s$ ).

### **Relation of $V_p$ and $V_s$ from suspension-log surveys.**

While Figures 4 and 5 show that the bulk of materials above the water table ( $V_p$  less than 1500 m/s) have Poisson's ratios less than 0.45 (with a clear trend in Figure 4 indicating values centered around 0.3), I thought it would be interesting to make the same plot using data from P-S suspension logs ([http://www.geovision.com/PDF/M\\_PS\\_Logging.PDF](http://www.geovision.com/PDF/M_PS_Logging.PDF)). These measurements are available at approximately 1 m increments, and are determined using a completely different method than the surface-source, downhole receiver method. I have data from 53 suspension-log surveys conducted in California, most being done as part of the ROSRINE project (<http://gees.usc.edu/ROSRINE/>). For my own use, I note quickly here how I used the suspension log results in making the graphs below. Each suspension-log survey is reported in a spreadsheet file. I saved each file with a different file name, eliminated unnecessary worksheets, figures, and columns, and inserted a new column in which Poisson's ratio was calculated. The names of the spreadsheet files are given in the table below; some idea of the boreholes logged can be obtained from the file names, but I will replace this table with a table of borehole names if I expand this into a short paper.

ARLETA\_P\_S\_PRAT.XLS  
BALDWIN\_p\_s\_prat.XLS  
bva\_ros\_p\_s\_prat.xls  
ccoc\_steller\_p\_s\_prat.xls  
Corralitos\_p\_s\_prat.xls  
dayton\_metric\_p\_s\_prat.xls  
Desert\_Hot\_Spr\_p\_s\_prat.xls  
Devers\_Hill\_p\_s\_prat.xls  
DOLPHIN\_p\_s\_prat.XLS  
DOWNEY\_p\_s\_prat.XLS  
esc\_ros\_p\_s\_prat.xls  
esc2\_ros\_p\_s\_prat.xls

ETEC\_RD\_7\_metric\_p\_s\_prat.xls  
Gilroy\_6\_p\_s\_prat.xls  
Gilroy3\_p\_s\_prat.xls  
griffith\_metric\_p\_s\_prat.xls  
guadalupe\_river\_steller\_p\_s\_prat.xls  
gvdarr1\_p\_s\_prat.xls  
gvdbrr1\_p\_s\_prat.xls  
HallsValley\_metric\_p\_s\_prat.xls  
IBMAImaden\_p\_s\_prat.xls  
Imperial\_Val\_p\_s\_prat.xls  
JoshuaTree\_p\_s\_prat.xls  
kagelros\_p\_s\_prat.xls  
la00\_ros\_p\_s\_prat.xls  
LABulkMail\_p\_s\_prat.xls  
LACIEN\_p\_s\_prat.XLS  
lakehgh9\_p\_s\_prat.xls  
mcglincy\_steller\_p\_s\_prat.xls  
melo\_ros\_p\_s\_prat.xls  
miracat\_metric\_p\_s\_prat.xls  
N\_Palm\_Springs\_p\_s\_prat.xls  
NEWHALL\_p\_s\_prat.XLS  
obregon\_metric\_p\_s\_prat.xls  
pacoima\_metric\_p\_s\_prat.xls  
Parachute\_p\_s\_prat.xls  
picorros\_p\_s\_prat.xls  
PierFLongBeach\_p\_s\_prat.xls  
pot1\_ros\_p\_s\_prat.xls  
pot2\_ros\_p\_s\_prat.xls  
pot3\_ros\_p\_s\_prat.xls  
rd20\_ros\_p\_s\_prat.xls  
RINALDI2\_p\_s\_prat.XLS  
santana\_park\_steller\_p\_s\_prat.xls  
saratoga\_steller\_p\_s\_prat.xls  
Saturn\_metric\_p\_s\_prat.xls  
Superstition\_p\_s\_prat.xls  
TARZANA\_p\_s\_prat.XLS  
wllwbrk\_metric\_p\_s\_prat.xls  
wndr\_ros\_p\_s\_prat.xls  
wvan\_ros\_p\_s\_prat.xls  
wvas\_ros\_p\_s\_prat.xls  
Yermo\_p\_s\_prat.xls

I then imported each spreadsheet into CoPlot (<http://www.cohort.com/>), appending each spreadsheet to the right of the previous one (using a macro). Each CoPlot datafile contained from 9 to 13 individual suspension log sites. I then made the plots shown

here. I show two plots because there are so many data points that many are obscured if only one plot is made; the data in each plot are based only on the name of the file, not on any physical or geographical basis.

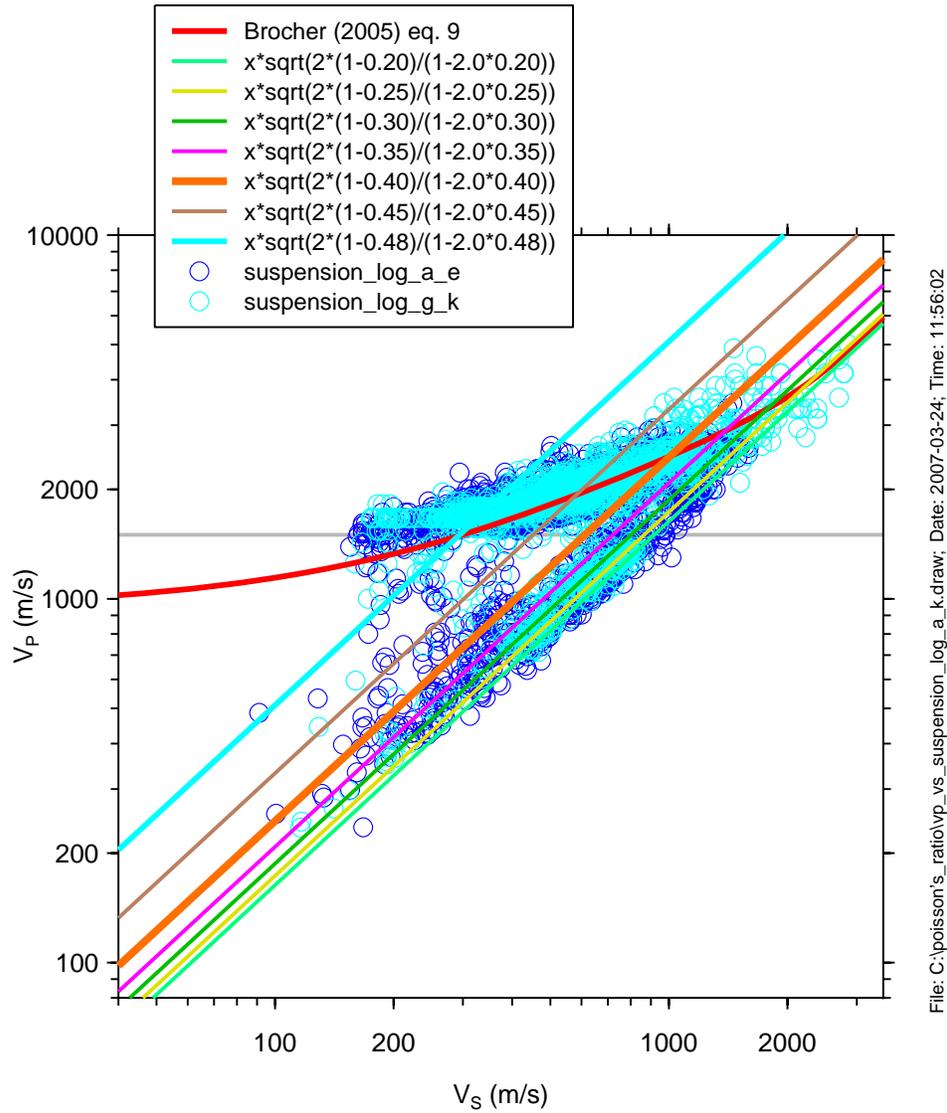


Figure 6. Data from 24 boreholes.

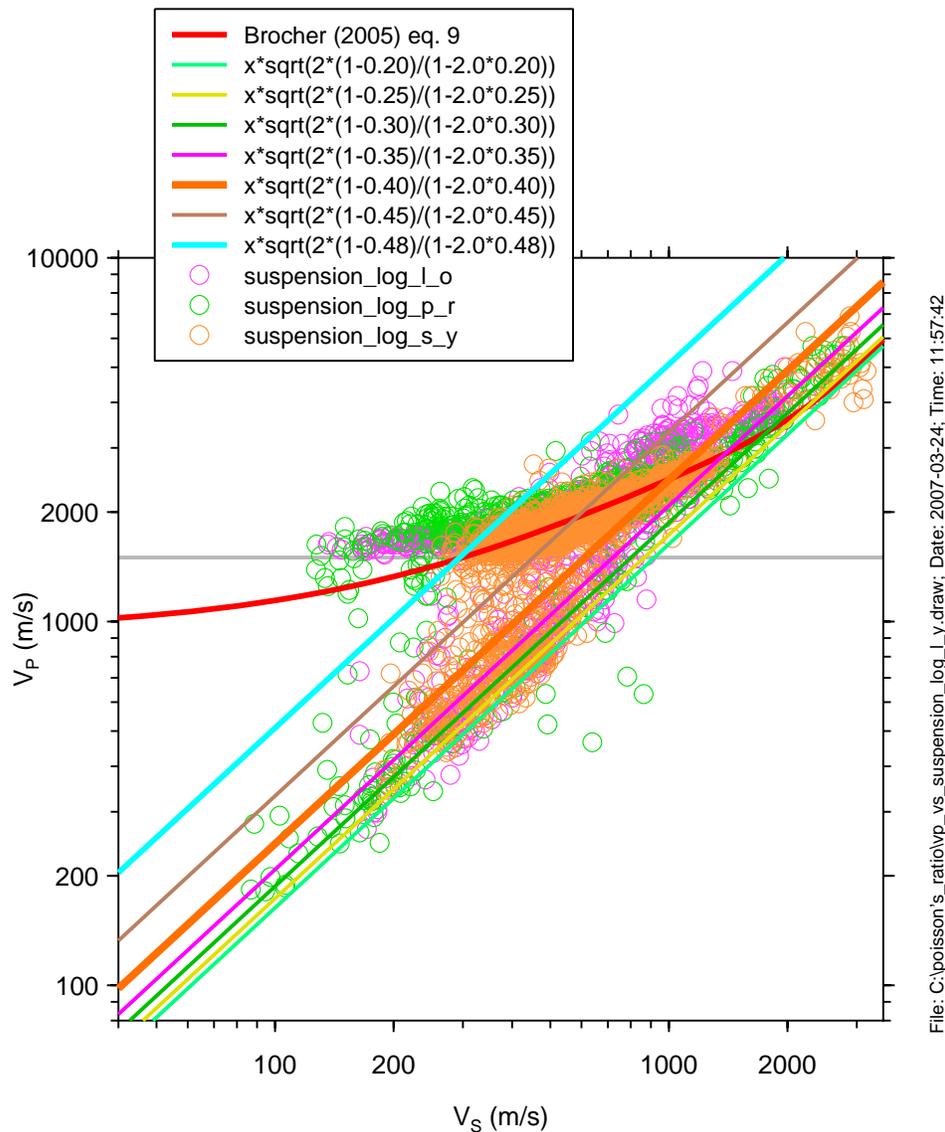


Figure 7. Data from 29 boreholes.

## Discussion

To summarize, the data shown in Figure 4 are from 274 boreholes logged using the surface-source, downhole receiver (ssdhr) method, and those in Figures 6 and 7 are from 53 boreholes logged using P-S suspension logging (some of the boreholes used in the P-S logging are the same as used in the ssdhr logging). Figures 6 and 7 are very similar to Figure 4 (but perhaps with less scatter due to measurement error). They all tell the same story: There seem to be two branches to the relation between  $V_p$  and  $V_s$ , depending on whether  $V_p$  is less than or greater than 1500 m/s (i.e., whether or not the materials are

above or below the water table). For materials above the water table, Poisson's ratio is largely smaller than 0.4. Based on this evidence, I conclude that values of Poisson's ratio greater than 0.4 should not be assumed on average for materials above the water table.

## Acknowledgments

## References

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Boore, D. M. (2003). A compendium of P- and S-wave velocities from surface-to-borehole logging: Summary and reanalysis of previously published data and analysis of unpublished data, *U.S. Geological Survey Open-File Report 03-191*. (available from [http://quake.wr.usgs.gov/~boore/pubs\\_online.php](http://quake.wr.usgs.gov/~boore/pubs_online.php) with accompanying files of results from [http://quake.wr.usgs.gov/~boore/data\\_online.htm](http://quake.wr.usgs.gov/~boore/data_online.htm))

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Cornou, C., M. Ohrnberger, D. M. Boore, K. Kudo, and P.-Y. Bard (2007). Derivation of structural models from ambient vibration array recordings: results from an international blind test, *Third International Symposium on the Effects of Surface Geology on Seismic Motion*, (P.-Y. Bard, E. Chaljub, C. Cornou, F. Cotton, and P. Gueguen, Editors), Grenoble, France, 30 August - 1 September 2006, Laboratoire Central

des Ponts et Chaussées, (in press). (available from [http://quake.wr.usgs.gov/~boore/pubs\\_online.php](http://quake.wr.usgs.gov/~boore/pubs_online.php))

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