Constructing equivalent constant-velocity layered models

David M. Boore

The need sometimes arises to construct a velocity-depth profile made up of constant-velocity layers that is equivalent to a model defined by a series of line segments, potentially with offsets between the line segments. For example, the full-resonance program *nrattle* uses a velocity model made up of a stack of constant-velocity layers. "Equivalent" means that the travel time from the surface down to any layer boundary in the layered model equals the travel time to that depth in the original velocity-depth profile. A convenient way to do this is to use programs in the *SiteAmp* suite of programs (*http://daveboore.com/software_online.html*). The main program (*site_amp_batch*) computes amplifications using the square-root-impedance method (Boore, 2013) for a velocity profile made up of any set of constant velocity layers and segments with linear dependence of velocity with depth. As will be seen, sometimes several programs need to be run to obtain the equivalent models. Although the computations are very rapid, the person-time inefficiencies can be annoying and also can be avoided if I combined several programs into a separate program. I have not had time to do that yet.

The constant velocity layered models cannot be used directly in making a plot of velocity vs depth; the models need to be converted to "stair-step" models, with interfaces represented by consecutive rows with the same depth to the interface but with the velocities of the layers above and below the interface. The program layr2plt can be used to do the conversion, but the conversion can also be done by running *site_amp_batch* on the constant-velocity model, as *site_amp_batch* reformats the input model into a stairstep model as part of the output file prepared by the program.

The SiteAmp programs that create equivalent constant-velocity layered models are:

- *pwr2lyr*
- *site_amp_batch*
- *vel2cvl_model*

A brief description of when and how to use these programs is discussed next.

pwr2lyr

This produces a stair-step model from velocity model defined by power-law with depth. I have not used the program for many years and is only included here for completeness. The input information is obtained from the screen, rather than a control file as with more recent programs.

site_amp_batch

The program's primary output are frequencies and amplifications for a series of layers, where the frequencies correspond to the depths corresponding to a quarter wavelength given by the average travel time above a given depth. The velocities and densities of each layer are part of the output, so this is how *site_amp_batch* can be used to obtain an equivalent layered model. The depths to the bottom of each layer are specified in one of two ways, depending on the specification of nfreqs in *site_amp_batch*.ctl:

- nfreqs = 0: use the depths of the original model (with the frequencies of the amplification corresponding to these depths).
- nfreqs > 0: compute the depth corresponding to each frequency. Note that if the requested frequency is smaller than the frequency corresponding to the bottom of the input velocity model, the output constant-velocity model will include layers into the halfspace below the input model. A way of avoiding this is to run *site_amp_batch* twice: the first time to obtain the frequency corresponding to the bottom of the input model (this is an output of the program), and then with that frequency as the lowest frequency to be used in the calculations.

vel2cvl_model

This program was written to provide more control over the depths to the bottom of the layers in the stack of constant-velocity layers than is possible using *site_amp_batch*. A list of depths is provided as input, and the equivalent constant-velocity model is written as output. The list of depth can be provided in several ways: 1) a sequence of log-spaced depths from a minimum to a maximum depth, 2) a sequence of linearly-spaced depths from a minimum to a maximum depth, 3) a set of individual depths, 4) depths for equal travel times. The sequences in Options 1 and 2 are specified by giving the number of depths and the starting and stopping depths. Option 4 divides the total thickness of the model into a sequence of constant velocity layers with equal travel times in each layer; it requires only the number of depths. The output file can be used as input to *site_amp_batch*, and the output from that program can be used by *f4nrattle* to make the control file for *nrattle*. The *vel2cvl_model* output can also be used with a spreadsheet program to create the control file for *nrattle*.

code_to_compute_depths_for_tt_increments.R

An additional program that might be useful is *code_to_compute_depths_for_tt_increments.R*. This program was written to provide the depths used in *vel2constant_velocity_model*, but that program now includes the option to compute depths corresponding to equal increments of travel time. But for completeness I discuss the R code anyway. *code_to_compute_depths_for_tt_increments.R* obtains d2layer_bot and tt2lyrbot from *site_amp_batch* output and then computes depths corresponding to subdivisions of tt2lyrbot. The program was initially developed to find the set of depth corresponding to the total travel time from the surface to the model bottom divided into nlayers equal travel-time increments.

These depths were then used in the control file for *vel2cvl_model*. This use of the R program has now been included in *vel2cvl_model.*

Example of equivalent models

The programs discussed above were used to construct a number of equivalent constant-velocity models. The results are shown in Figure 1.

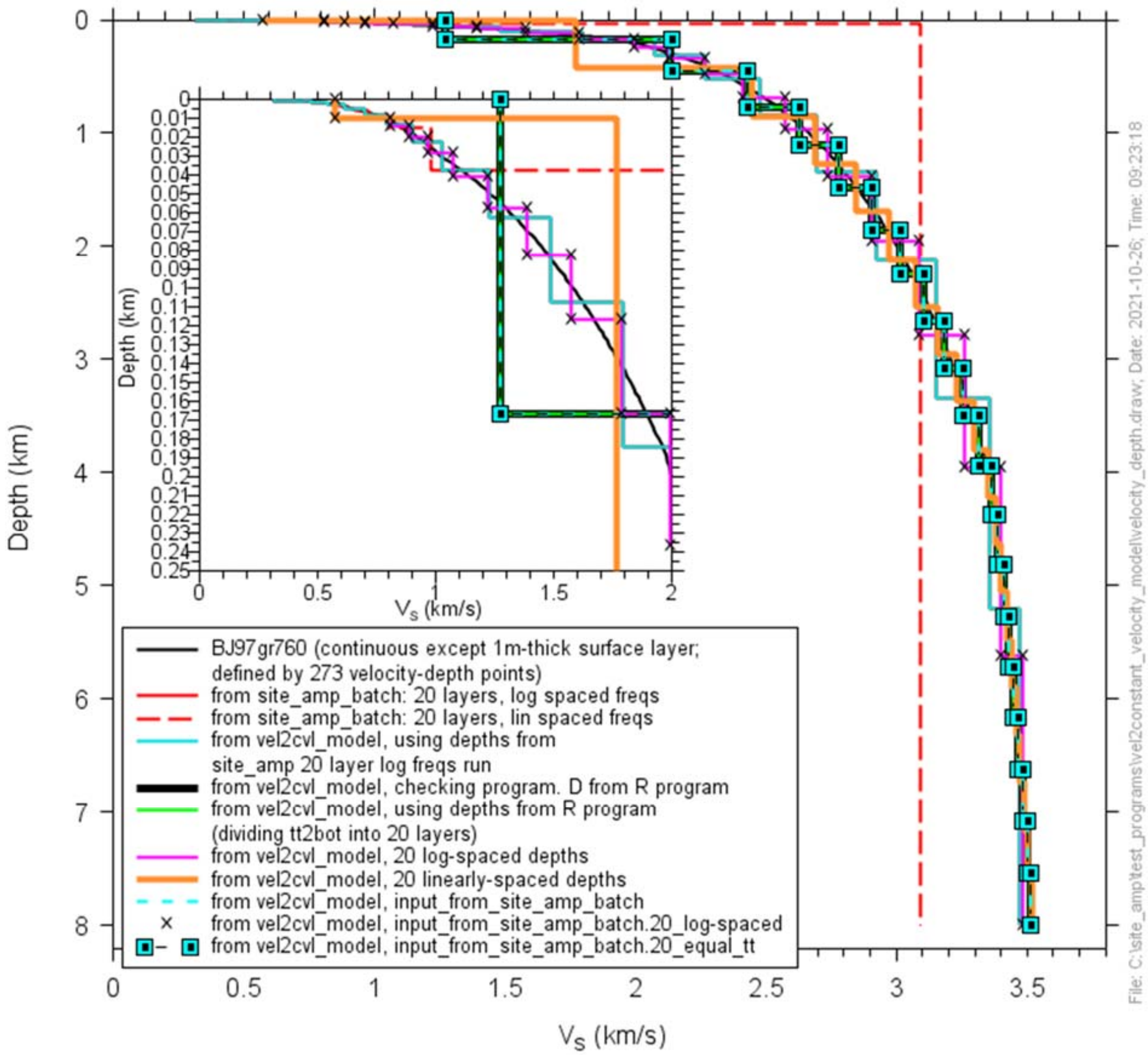

Figure 1.

All of the models have the same travel time to 8 km (the bottom of the bj97gr760 model of Boore, 2016), including the dashed line model from *site_amp_batch* using 20 linearly-spaced frequencies. Most of the frequencies for this model correspond to depths so shallow that they do not show up well even in the inset graph (half of the depths are less than 1.7 m). Except for a very special need involving very shallow depths, this would generally be a poor choice as an equivalent model, even though it satisfies the two constraints for equivalent models.

Data and Resources

The programs can be obtained under the *SiteAmp* heading on the online software page of *www.daveboore.com*.

References

Boore, D.M. (2013). The uses and limitations of the square-root impedance method for computing site amplification, *Bull. Seismol. Soc. Am.* **103**, 2356–2368.

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