A $V_{S30}$-derived Near-surface Seismic Velocity Model

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Introduction

Shallow material properties, S-wave velocity in particular, strongly influence ground motions, so must be accurately characterized for ground-motion simulations. Available near-surface velocity information generally exceeds that which is accommodated by crustal velocity models, such as current versions of the SCEC Community Velocity Model (CVM-S v4.0) or the Harvard model (CVM-H v6.2). The elevation-referenced CVM-H voxel model introduces rasterization artifacts in the near-surface due to course sample spacing, and sample depth dependence on local topographic elevation. To address these issues, we propose a method to supplement crustal velocity models, in the upper few hundred meters, with a model derived from available maps of $V_{S30}$ (the average S-wave velocity down to 30 meters). The method is universally applicable to regions without direct measures of $V_{S30}$ by using $V_{S30}$ estimates from topographic slope (Wald, et al. 2007). In our current implementation for Southern California, the geology-based $V_{S30}$ map of Wills and Clahan (2006) is used within California, and topography-estimated $V_{S30}$ is used outside of California.

Depth dependence

Various formulations for S-wave velocity depth dependence, such as linear spline and polynomial interpolation, were evaluated against the following priorities: (a) capability to represent a wide range of soil and rock velocity profile types; (b) smooth transition to the crustal velocity model; (c) ability to reasonably handle poor spatial correlation of $V_{S30}$ and crustal velocity data; (d) simplicity and minimal parameterization; and (e) computational efficiency. The favored model includes cubic and square-root depth dependence, with the model extending to a transition depth $z_T$. A transition depth of $z_T = 350$ m is used to ensure adequate sampling of CVM-H (shallower depths may be unsampled by the CVM-H near topographic features). S-wave velocity at the surface is derived from $V_{S30}$ by a uniform scaling. $V_P$, and in turn density, are inferred from surface $V_S$ via the scaling laws of Brocher (2005). $V_S$ and $V_P$ are independently interpolated between the surface values and those extracted from the crustal velocity model at the transition depth. Density is derived from interpolated $V_P$ via the Nafe-Drake law of Brocher. Depth dependence for the interpolation is parameterized with

$$z = z'/z_T$$
$$f(z) = z + b(z - z^2)$$
$$g(z) = a - az + c(z^2 + 2\sqrt{z} - 3z)$$
$$V_S(z) = f(z)V_{ST} + g(z)V_{S30}$$
$$V_P(z) = f(z)V_{PT} + g(z)P(V_{S30})$$
$$\rho(z) = R(V_P)$$
where $z'$ is depth, $V_{ST}$ and $V_{PT}$ are S- and P-wave velocities extracted from the crustal velocity model at depth $z_T$, $P()$ is the Brocher P-wave velocity scaling law, and $R()$ is the Nafe-Drake law. The coefficient $a$ controls the ratio of surface velocity to original 30 meter average, $b$ controls overall curvature, and $c$ controls near-surface curvature.

The coefficients $a = 1/2$, $b = 2/3$, and $c = 3/2$ were chosen by trial-and-error fitting Boore and Joyner's (1997) generic rock profile and CVM-S generic soil profiles, as well as to produce smooth and well-behaved profiles when applied to the CVM-H at the selected CyberShake sites.

![Graph showing the generic S-wave velocity profile](image)

Figure 1: Generic S-wave velocity profile for all soil types is a summation of shallow component $g(z)$ scaled by $V_{S30}$ (red), and deep component $f(z)$ scaled by $V_{ST}$ (blue).

**Implementation**

The new near-surface model (known as the geotechnical layer, or GTL) has been implemented as a Python library using CVM-H v6.3 voxet data, and is available as part of the Computational Seismology Tools. In testing, extraction of a 18.5 billion node, 208 Gb mesh, using three processors (one each for $\rho$, $V_P$, and $V_S$) on the NICS Kraken machine, takes 4 hours. The new GTL is also integrated into the SCEC CVM Toolkit by Patrick Small.
Figure 2: Generic $V_S$ profiles (dashed lines) of Boore and Joyner (1997) and Magistrale (2000) with proposed model (solid lines).
Figure 3: CVM-S v4.0 surface S-wave velocity with marked cross-section and vertical profile locations. Color scale is clipped at 400 m/s.
Figure 4: CVM-S v4.0 S-wave velocity cross-section through the Los Angeles basin and San Gabriel Mountains.

Figure 5: CVM-S v4.0 S- and P-wave velocity profiles.
Figure 6: CVM-H v6.2 surface S-wave velocity with marked cross-section and vertical profile locations. White areas indicate locations where the voxel model does not reach the ground surface.
Figure 7: CVM-H v6.2 S-wave velocity cross-section through the Los Angeles basin and San Gabriel Mountains.

Figure 8: CVM-H v6.2 S- and P-wave velocity profiles.
Figure 9: GTL surface S-wave velocity derived from Wills and Clahan (2006) geology based $V_{s30}$ map, supplemented outside of California with Wald et al. (2007) map.
Figure 10: CVM-H v6.3 + GTL S-wave velocity cross-section through the Los Angeles basin and San Gabriel Mountains.

Figure 11: CVM-H v6.3 + GTL S- and P-wave velocity profiles.