VS30 MAPPING USING MRVBF IN THE WESTERN UNITED STATES

T. D. Ancheta\textsuperscript{1} and D. Mitra\textsuperscript{1}

ABSTRACT

Estimating site response over a large domain using Vs30 is improved by utilizing a new geostatistical spatial prediction model. The new method uses a combination of surface geology and multiple resolution of valley bottom flatness, MRVBF, for unconsolidated geology units. The new geostatistical model is tested for basins in the Western United States. Improvements in the spatial prediction of Vs30 using the new trend can see a reduction in the residual standard deviation between 15 and 40\% for Holocene geologic units. The new trend model for unconsolidated units can distinguish areas where a thin surficial unit may overly another geologic unit from areas where the surficial unit may compose a significant portion of the upper 30 meters.

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Estimating site response over a large domain using Vs30 is improved by utilizing a new geostatistical spatial prediction model. The new method uses a combination of surface geology and multiple resolution of valley bottom flatness, MRVBF, for unconsolidated geology units. The new geostatistical model is tested for basins in the Western United States. Improvements in the spatial prediction of Vs30 using the new trend can see a reduction in the residual standard deviation between 15 to 40\% for Holocene geologic units. Additional, the new trend model for unconsolidated units can distinguish areas where a thin surficial unit may overly another geologic unit from areas where the surficial unit may compose a significant portion of the upper 30 meters.

Introduction

A reliable prediction of the site response during a future earthquake has a number of potential benefits including improved building practices over a region, cost effective and resilient city planning, and quantifying the risk of earthquake damage to the existing buildings, to name a few. While the site response, or the modification of earthquake ground motions as it travels from the source to site, has been correlated to a number of site factors this paper proposes a new geostatistical methodology for mapping one of these parameters over a large domain. The parameter Vs30, the time-averaged shear wave velocity of the upper 30 meters, has been used to predict spatial variations in the high to moderate frequency ground motions.

This paper focuses on a spatial prediction relying more on the geostatistical trend model rather than kriging. Mathematically, the trend model is an equation that quantifies the median variation of Vs30 in space as a function of secondary parameters. Secondary parameters are parameters that have a strong correlation to the spatial variation of Vs30 and are available continuously over the prediction domain. It is proposed that the trend model represents the physical process responsible for causing spatial variation in the primary variable. The physical process can be solely driven by natural processes or a combination of natural and man-made processes. In this paper, we are investigating the spatial variability of Vs30. Therefore, the we assume that the spatial variation of shear wave velocity is driven by natural processes while the simplification into Vs30 is a man-made process. The stochastic component is therefore, the random spatial variation from the trend, or the residual defined as the difference between the measurement and the median prediction at the measurement location. This paper does not model the stochastic component. We propose when a sufficient trend model is developed, the stochastic

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component may be excluded altogether without significant loss in the prediction uncertainty. More importantly, this philosophy focuses on improving the prediction uncertainty over the much larger domain of the unsampled locations rather than within or near the measurement locations.

Using the spatial prediction philosophy discussed above, we first model the geology only trend and then compare against a geology and MrVBF trend. Through exploratory data analysis we have found that creating a trend with geology first separates areas of similar shear wave velocity profiles. Additionally, we have found that MrVBF is more correlated to spatial variability of Vs30 within Holocene geologic units than slope.

**Description of Data**

Developing a geostatistical trend model requires collection of primary and secondary data. Primary data is a measurement of the parameter of interest usually at point locations. Secondary data is a measurement of a parameter that is correlated to the primary data usually easy to measure continuously in space or on a grid of locations. The primary data in this study is shear wave velocity measurements with depth and the secondary data includes surficial geology and MrVBF collected in the Western United States. This section details the collection and processing methodology used for both the primary and secondary data.

**Shear Wave Velocity Data**

Shear wave velocity profiles or velocity measured at various depths can be directly or indirectly measured. The shear wave velocity profile is used to calculate Vs30. There will be distinct spatial variations in Vs30 created by this averaging step. The sections describing the secondary data will focus on these variations trend modeling sections will describe how they affect the spatial variation in the prediction uncertainty. The 1060 measurement locations collected for this study were estimated by MASW, SASW, downhole, and various other methods and shown in Fig. 1.

![Figure 1](image)  
Figure 1. Vs30 measurement locations, sub groups of data, and the larger basins used.
The shear wave velocity data has been collected from [1,2, 3 and 4] and filtered to only use profiles with depths greater than 20 m.

Surficial Geology

Surficial geology has been known to correlate with Vs30 variations on the surface of the Earth. Raw geologic information includes map name, unit symbol, description, geologic age, geologic map scale, and geology map intent. Surficial geology at each measurement location is grouped into geology categories or a smaller subset of the geologic units that have similar spatial variation in Vs30. The selection of the smaller categories which group similar geologic units has a number of benefits including reducing the set of unique geologic units inflated due to differences in the naming conventions across different geologic maps and increases in the number of measurements for the final geologic categories, usually smaller than the original set. The final selected geologic categories strike a balance between spatial coverage of the constrained categories and the spatial resolution in the median variation.

Geologic units may be grouped subjectively by their similarities in their geology type and age or objectively between similar groups if their median and standard deviations are not statistically unique. Unfortunately, both methods will be inconsistently applied due to inconsistent sampling across the possible categories and space. Given the inherent limitations in either method we propose a set of 4 subjective geologic categories shown in Fig. 2 following age only categories similar to [5]. The geologic map in Fig. 2 was compiled from numerous smaller geologic maps obtained from [6].

Figure 2. Compilation surficial geology map binned into 4 age categories.

MrVBF Estimation

Above a geologic age only model, we propose to use MrVBF, defined as the Multiresolution
Valley Bottom Flatness. It identifies valley bottom using a slope classification constrained to convergent areas. The classification algorithm is applied at multiple scales by progressive generalization of the DEM combined with progressive reduction of the slope class threshold. The results obtained at different scales are then combined into one single index.

The MRVBF algorithm identifies the transition of the valley bottom from the steep areas. It uses the following assumptions: (1) Valley bottoms are low and flat relative to their surroundings. (2) Valley bottoms occur at a range of scales. (3) Large valley bottoms are flatter than smaller ones [7].

For calculating the index values, it utilizes the flatness and lowness characteristics of the valley bottoms. Flatness is measured as the inverse of slope while lowness is measured by the ranking of elevation with respect to a circumference area. These two measures are both normalized to a range 0 to 1, and compounded together as member functions of fuzzy sets [8]. The resultant MrVBF map for the study area is illustrated in Fig. 3.

![MrVBF map](image)

**Figure 3.** MrVBF derived from elevation data.

**Geostatistical Trend**

Previous studies have used surface geology, average/maximum ground slope, terrain classification, or a combination of surface geology and slope to create a trend model. This study utilizes surface geology with MrVBF for unconsolidated geologic. We employ a step-wise model building process involves defining median variations between a select set of geology bins and testing further Vs30 dependencies with the remaining secondary variables.

**Geology Trend**
Pairing the selected geology bins with a set of Vs30 measurements is performed with a spatial join between the geology polygons and point measurements. The sample count, median, and standard deviation is reported in Table 1. Scatter in the correlation with geology is due to the lack of spatial variability of soil thickness information within the geologic boundary. We have split the database into different basins determined by the zones illustrated in Fig. 1. These basins have been shown to have different geology and geology plus MrVBF models as presented in the following sections.

Table 1. Geology based median Vs30 values along with the geology and geology plus MrVBF standard deviation of the residuals.

<table>
<thead>
<tr>
<th>Region</th>
<th>AGE</th>
<th>No of Points</th>
<th>Median Vs30</th>
<th>Standard Deviation (Ln)</th>
<th>Standard Deviation using MrVBF (Ln)</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Francisco Bay</td>
<td>Holocene</td>
<td>165</td>
<td>235</td>
<td>0.335</td>
<td>0.204</td>
</tr>
<tr>
<td></td>
<td>Pleistocene</td>
<td>41</td>
<td>378</td>
<td>0.319</td>
<td>0.268</td>
</tr>
<tr>
<td></td>
<td>Rock</td>
<td>56</td>
<td>535</td>
<td>0.347</td>
<td>0.347</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>Holocene</td>
<td>164</td>
<td>313</td>
<td>0.266</td>
<td>0.19</td>
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<tr>
<td></td>
<td>Pleistocene</td>
<td>68</td>
<td>368</td>
<td>0.266</td>
<td>0.243</td>
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<tr>
<td></td>
<td>Rock</td>
<td>83</td>
<td>512</td>
<td>0.353</td>
<td>0.353</td>
</tr>
<tr>
<td>Las Vegas</td>
<td>Holocene</td>
<td>74</td>
<td>741</td>
<td>0.394</td>
<td>0.318</td>
</tr>
<tr>
<td></td>
<td>Pleistocene</td>
<td>58</td>
<td>813</td>
<td>0.431</td>
<td>0.431</td>
</tr>
<tr>
<td></td>
<td>Rock</td>
<td>6</td>
<td>1007</td>
<td>0.157</td>
<td>0.157</td>
</tr>
<tr>
<td>Mojave Desert</td>
<td>Holocene</td>
<td>23</td>
<td>466</td>
<td>0.382</td>
<td>0.322</td>
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<tr>
<td></td>
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<td>485</td>
<td>0.31</td>
<td>0.232</td>
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<tr>
<td></td>
<td>Rock</td>
<td>15</td>
<td>801</td>
<td>0.401</td>
<td>0.362</td>
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<tr>
<td>Salt Lake City</td>
<td>Holocene</td>
<td>69</td>
<td>233</td>
<td>0.275</td>
<td>0.21</td>
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<tr>
<td></td>
<td>Pleistocene</td>
<td>112</td>
<td>256</td>
<td>0.318</td>
<td>0.254</td>
</tr>
</tbody>
</table>

Geology and MrVBF Trend

The individual geology bins shown in Table 1 are then used to separate the Vs30 measurements and evaluate if MrVBF can reduced the standard deviation of the model residuals. The different geology plus MrVBF models are shown in Fig. 4, 5, and 6. The Holocene models shown in Fig. 4 show the strongest dependence with respect to MrVBF. It is also apparent that some models are driven by either a single geologic environment or multiple environments. The data points are labeled for the three main environments sampled including alluvium, lacustrine, and marine sediments. It is noted that the Holocene models tend to display lacustrine environments at larger MrVBF values or in areas of the flatter portions of the valleys. The Holocene and Pleistocene trends exhibit a flat trend with MrVBF less than 1 and a decreasing Vs30 as MrVBF is greater than 1. This can be interpreted as areas on the map where the geologic unit mapped at the surface is thin (MrVBF less than 1) and thick (MrVBF greater than 1) relative to a 30 meter profile depth. If the unit is thin, then most of the profile is composed of geologic units not mapped at the ground surface.
Figure 4. Individual Holocene geology bin regression fits along with the Vs30 measurements. The solid line is the model, while the dashed lines are a plus and minus standard deviation line. The colored circles are the Vs30 measurements used.

Figure 5. Individual Pleistocene geology bin regression fits along with the Vs30 measurements. The solid line is the model, while the dashed lines are a plus and minus standard deviation line. The colored circles are the Vs30 measurements used.
Conclusions

Prediction uncertainty is a function of the selected secondary data, quality of the raw secondary data (e.g. resolution and measurement error), and data processing of the secondary data. In the case of the trend only models presented above we see a reduction of the Holocene geology model prediction error but not in the Pleistocene geology models. The reduction is likely due to the fact that the ground surface for older geologic units has been significantly altered since the deposition of the near surface soils. One example is an older alluvium dissected by younger alluvium. We interpreted the larger reduction in the Holocene geology model prediction as evidence that MrVBF is correlated to the spatial variation in the average grain size in the upper 30 meters. Larger grain size will correspond to faster velocities and spatially will occur near the base of hills. Smaller grain size will correspond to slower velocities and spatially will occur near the middle of valleys.

References


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